2001
Outfall monitoring overview

Massachusetts Water Resources Authority

Environmental Quality Department
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Outfall Monitoring Overview

submitted to

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Summary

During this first full year of discharge from the Massachusetts Bay outfall, the Deer Island treatment plant operated as designed, and the health of Massachusetts and Cape Cod bays remained good. Total loads of many parameters measured within the effluent, including solids and metals, declined to historic lows. The treatment plant earned the Association of Metropolitan Sewerage Agencies Silver Award for facilities that had five or fewer permit violations during the year.

Conditions within the bays did not change from baseline conditions. For example, concentrations of chlorophyll in the water column remained at levels close to the baseline mean for much of the year, rising in December during a late fall phytoplankton bloom. Concentrations of dissolved oxygen and percent saturation were also close to the baseline mean. Conditions on the sea floor were also unchanged from the baseline, and winter flounder health remained good. Tumors were absent, and at the outfall, levels of precancerous conditions were the lowest measured for the program. Concentrations of contaminants in fish and shellfish remained well below levels of concern for human health.

There were five contingency plan exceedances during the year (Table 1). Three exceedances occurred during effluent monitoring—one exceedance of the warning level for fecal coliform bacteria and two exceedances of warning levels for toxicity tests. Two caution level exceedances occurred for caged mussels deployed near the outfall.

The exceedance of a fecal coliform bacteria threshold resulted from one sample taken during a rainstorm. Perhaps due to the storm, chlorine residual dropped suddenly and bacteria levels rose. Staff increased the chlorine dosing rate and levels returned to normal. The toxicity test exceedances included one failure of a sea urchin fertilization test and one failure of a fish chronic survival test. For the sea urchin test, the results can be attributed to sub-optimal condition of the test organisms rather than to toxicity. The fish test failure appeared to be a statistical anomaly in the calculation of results.

Thresholds for PAH and chlordane were exceeded in mussels deployed in cages near the outfall. MWRA has reviewed the exceedances and determined that they do not indicate cause for environmental concern. Concentrations of PAHs and chlordane in the effluent met water quality standards, and concentrations of contaminants in the mussels were not at levels that would pose toxicological risks to the mussels or public health concerns to humans. Rather, it appears that the simple formulation of a threshold set as the doubling of levels found during the baseline period was not a realistic threshold for mussels that are caged within the effluent plume.

Table 1. Summary of contingency plan thresholds and exceedances for 2001. (NA = not applicable, ✔ = no exceedance, C = caution level exceedance, W = warning level exceedance)

Location/ Parameter Type	Parameter	2000	2001
Effluent			
	pH	W	✔
	Fecal coliform bacteria, monthly	✔	✔
	Fecal coliform bacteria, weekly	✔	✔
	Fecal coliform bacteria, daily	✔	W
	Fecal coliform bacteria, 3 consecutive days	✔	✔
	Chlorine residual, daily	W	✔
	Chlorine residual, monthly	✔	✔
	Total suspended solids	✔	✔
	cBOD, weekly	✔	✔
	cBOD, monthly	✔	✔
	Acute toxicity, mysid shrimp	✔	✔
	Acute toxicity, fish	✔	✔
	Chronic toxicity, fish	✔	W
	Chronic toxicity, sea urchin	✔	W
	PCBs	✔	✔
	Plant performance	✔	✔
	Flow	NA	✔
	Total nitrogen load	NA	✔
	Floatables	NA	NA
	Oil and grease	✔	✔
Water Column			
Nearfield bottom water	Dissolved oxygen concentration	C	✔
	Dissolved oxygen percent saturation	C	✔
Stellwagen Basin bottom water	Dissolved oxygen concentration	✔	✔
	Dissolved oxygen percent saturation	✔	✔
Nearfield bottom water	Dissolved oxygen depletion rate (June-October)	NA	✔
Nearfield chlorophyll	Annual	NA	✔
	Winter/spring	NA	✔
	Summer	NA	✔
	Autumn	C	✔
Nearfield nuisance algae *Phaeocystis pouchetii*	Winter/spring	NA	✔
	Summer	NA	✔
	Autumn	✔	✔
Nearfield nuisance algae *Pseudonitzchia*	Winter/spring	NA	✔
	Summer	NA	✔
	Autumn	✔	✔
Nearfield nuisance algae *Alexandrium tamarense*	Any sample	✔	✔

Location/ Parameter Type	Parameter	2000	2001
Farfield shellfish	PSP toxin extent	✔	✔
Plume	Initial dilution	NA	✔
Sea Floor			
Nearfield sediment, toxic contaminants	Acenaphthene	NA	✔
	Acenaphylene	NA	✔
	Anthracene	NA	✔
	Benz(a)pyrene	NA	✔
	Benzo(a)pyrene	NA	✔
	Cadmium	NA	✔
	Chromium	NA	✔
	Chrysene	NA	✔
	Copper	NA	✔
	Dibenzo(a,h)anthracene	NA	✔
	Fluoranthene	NA	✔
	Fluorene	NA	✔
	Lead	NA	✔
	Mercury	NA	✔
	Naphthalene	NA	✔
	Nickel	NA	✔
	p,p'-DDE	NA	✔
	Phenanthrene	NA	✔
	Pyrene	NA	✔
	Silver	NA	✔
	Total DDTs	NA	✔
	Total HMW PAH	NA	✔
	Total LMW PAH	NA	✔
	Total PAH	NA	✔
	Total PCBs	NA	✔
	Zinc	NA	✔
Nearfield sediment	RPD depth	NA	✔
Nearfield benthic diversity	Species per sample	NA	✔
	Fisher's log-series alpha	NA	✔
	Shannon diversity	NA	✔
	Pielou's evenness	NA	✔
Nearfield species composition	Percent opportunists	NA	✔
Fish and Shellfish			
Nearfield flounder tissue	Total PCBs	NA	✔
	Mercury	NA	✔
	Chlordane	NA	✔
	Dieldrin	NA	✔
	Total DDTs	NA	✔
Nearfield flounder	Liver disease (CHV)	NA	✔
Nearfield lobster tissue	Total PCBs	NA	✔
	Mercury	NA	✔

Location/ Parameter Type	Parameter	2000	2001
	Chlordane	NA	✔
	Dieldrin	NA	✔
	Total DDTs	NA	✔

Location/ Parameter Type	Parameter	2000	2001
Nearfield mussel tissue	Total PCBs	NA	✔
	Lead	NA	✔
	Mercury	NA	✔
	Chlordane	NA	C
	Dieldrin	NA	✔
	Total DDTs	NA	✔
	Total PAHs	NA	C

As required by the permit, during 2001, field tests confirmed that the outfall's minimum dilution is equal to the minimum dilution that had been predicted when it was designed. This confirmation was achieved by comparing field results to model predictions. The "minimum" dilution (1:70) described in the permit is that dilution predicted by the model for a selected set of combined worst-case conditions. Since those conditions do not exist in the field, the actual field results were compared to model predictions made under corresponding conditions. The field measurements made under stratified conditions in July found an initial dilution of about 1:100, and the model gave similar results. EPA and MADEP approved the certification of the outfall in October 2002.

MWRA also measured dramatic water quality improvements in Boston Harbor during 2001. Significant decreases in nitrogen and phosphorus were found throughout the harbor. Chlorophyll concentrations were the lowest that MWRA has measured since monitoring of the harbor began in 1995. Improvements in water clarity and bacterial indicator levels were also observed.

No effects of the outfall on the Stellwagen Bank National Marine Sanctuary were detected. Plume tracking, water column, and sea floor studies suggested that no effects of the outfall on the sanctuary are likely.

1. Introduction

Background

On September 6, 2000, the Massachusetts Water Resources Authority (MWRA) ceased discharge of sewage effluent into Boston Harbor and began operation of a new outfall in Massachusetts Bay. Commissioning the outfall was the last major step towards ending long-standing violations of the Clean Water Act, which had resulted from discharge of sewage sludge and primary-treated effluent into Boston Harbor.

Since its creation in 1985, MWRA has worked to end these violations. Sludge discharges ended in 1991, and MWRA has taken steps to minimize effects of wastewater discharge. These steps have included source reduction to prevent pollutants from entering the waste stream, improved treatment before discharge, and better dilution once the effluent enters the marine environment.

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

Improved treatment began in 1995, when a new primary treatment plant at Deer Island was brought on line, and disinfection facilities were completed. The first and second batteries of secondary treatment began in 1997 and 1998. Also during 1998, discharge from the Nut Island Treatment Plant into Quincy Bay ended, and all wastewater was conveyed to Deer Island for treatment. A final battery of secondary treatment became operational in 2001.

Better dilution has been achieved by diverting the effluent discharge from Boston Harbor to the new outfall and diffuser system, located 9.5 miles offshore in Massachusetts Bay (Figure 1-1). The outfall location was selected because it had a water depth and current patterns that would promote effective dilution, it was the least likely to affect sensitive resources, and it was feasible to construct an outfall tunnel to the location.

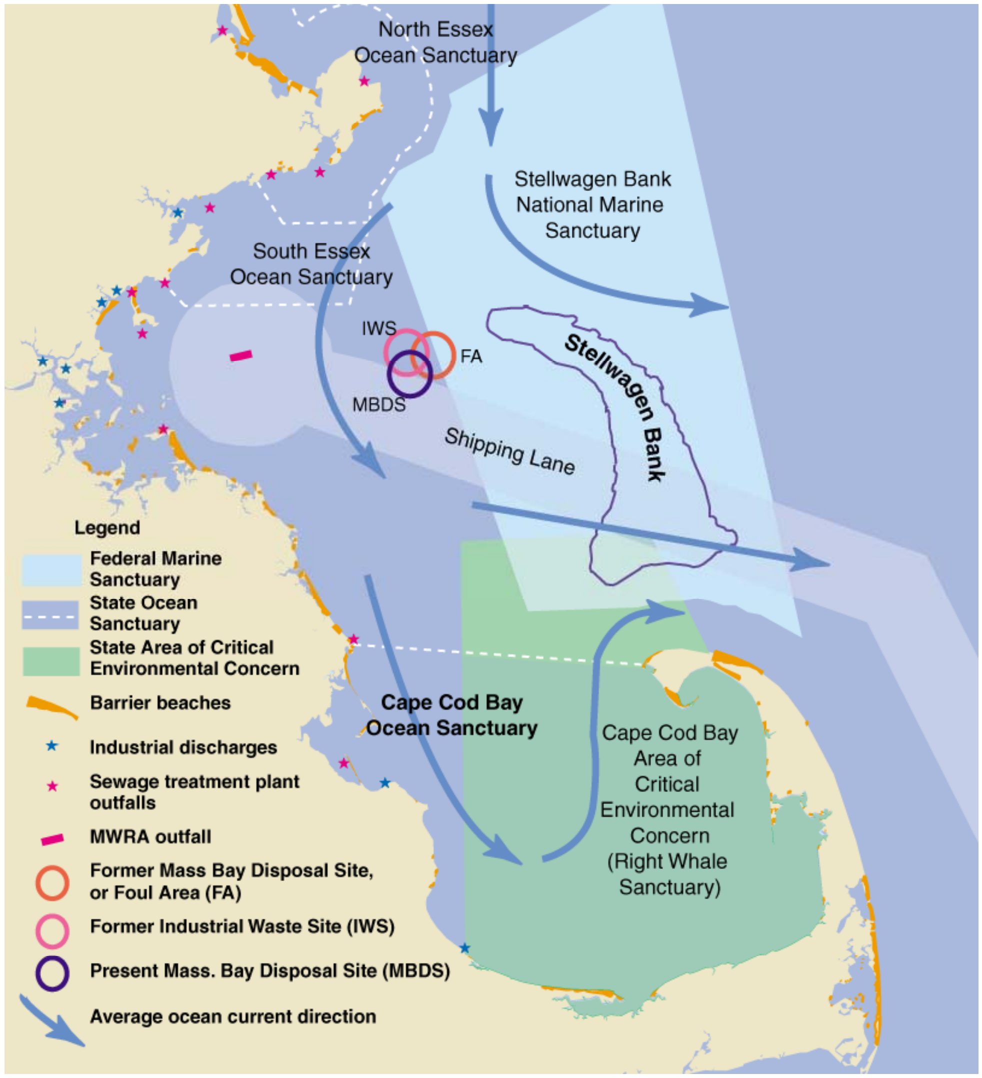


Figure 1-1. Map of Massachusetts and Cape Cod bays

The outfall tunnel is bored through bedrock. It 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 (MWRA 1997a). Initial dilution at the outfall is about 5 times that of the Boston Harbor outfall, which was shallower, in 50 feet of water. The offshore location of the new outfall diffuser ensures that effluent will not reach beaches or shellfish beds within a tidal cycle, even if currents are shoreward.

MWRA's goals are to make it safe to swim in the harbor, safe to eat fish caught there, to protect marine resources, and to ensure that the harbor becomes and remains a resource that people can aesthetically enjoy, without degrading the offshore environment. For many of the components of MWRA's work, there has been little or no argument that the project benefits the marine environment and the people of the region. One aspect of the project, moving the effluent outfall from the harbor to Massachusetts Bay, raised some concerns. The concerns have been recognized by MWRA and by the joint permit for the outfall issued by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MADEP).

Outfall Permit

A permit issued by EPA and MADEP under the National Pollutant Discharge Elimination System (NPDES) regulates discharges from the new outfall. The permit, which became effective on August 9, 2000, limits discharges of pollutants and requires reporting on the treatment plant operation and maintenance. It requires MWRA to continue an ongoing pollution prevention program that encompasses industrial, commercial, and residential users of the system and to employ best management practices aimed at preventing accidental discharge of pollutants to the sewer system.

The permit requires MWRA to monitor the effluent and the ambient receiving waters for compliance with permit limits and in accordance with the monitoring plan (MWRA 1991, 1997a) developed in response to the EPA Supplemental Environmental Impact Statement (SEIS, EPA 1988). The permit requires MWRA to update, maintain, and run the three-dimensional Bays Eutrophication Model, and to measure the dilution at the discharge. MWRA must implement a contingency plan (MWRA 1997b, 2001), which identifies relevant environmental quality parameters and thresholds, which, if exceeded, would require a response.

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

OMSAP may form specialized focus groups when specific technical issues require expanded depth or breadth of expertise. Two standing sub-committees also advise OMSAP. The Public Interest Advisory Committee (PIAC) represents local, non-governmental organizations and environmental groups and advises OMSAP on values and uses of the harbor and the bays. The Inter-agency Advisory Committee (IAAC) represents state and federal agencies and provides OMSAP with advice concerning environmental regulations.

Table 1-1. Roster of panel and committee members

<table>
<tr><td colspan="2">OMSAP as of December 2001

Andrew Solow, Woods Hole Oceanographic Institution (chair)
Robert Beardsley, Woods Hole Oceanographic Institution
Norbert Jaworski, retired
Robert Kenney, University of Rhode Island
Scott Nixon, University of Rhode Island
Judy Pederson, MIT Sea Grant
Michael Shiaris, University of Massachusetts, Boston
James Shine, Harvard School of Public Health
Juanita Urban-Rich, University of Massachusetts, Boston

Catherine Coniaris, MA Department of Environmental Protection (OMSAP staff)</td></tr>
<tr><td>IAAC as of December 2001

Salvatore Testaverde (chair, representative of National Marine Fisheries Service)
MA Coastal Zone Management
Christian Krahforst
Jan Smith (alternate)
MA Department of Environmental Protection
Russell Isaac
Steven Lipman (alternate)
MA Division of Marine Fisheries
Jack Schwartz
James Fair (alternate)
National Marine Fisheries Service
David Dow (alternate)
Stellwagen Bank National Marine Sanctuary
Ben Haskell
US Army Corps of Engineers
Thomas Fredette
US Environmental Protection Agency
Matthew Liebman
David Tomey (alternate)
US Geological Survey
Michael Bothner</td>
<td>PIAC as of December 2001

Patty Foley (chair, representative of Save the Harbor/Save the Bay)
Association for the Preservation of Cape Cod
Maggie Geist
Bays Legal Fund
Wayne Bergeron
The Boston Harbor Association
Vivian Li
Joan LeBlanc (alternate)
Cape Cod Commission
John Lipman
Steve Tucker (alternate)
Center for Coastal Studies
Peter Borrelli
Conservation Law Foundation
Anthony Chatwin
New England Aquarium
Marianne Farrington
Massachusetts Audubon Society
Robert Buchsbaum
MWRA Advisory Board
Joseph Favaloro
Safer Waters in Massachusetts
Salvatore Genovese
Polly Bradley (alternate)
Save the Harbor/Save the Bay
Bruce Berman (alternate)
Wastewater Advisory Committee
Edward Bretschneider</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. Some studies began during 1989-1991, in anticipation of these requirements. A broader baseline-monitoring program began in 1992. During the intervening years, both baseline and discharge monitoring plans have been developed and refined (MWRA 1991, 1997a). These plans were developed by MWRA, under the direction of an Outfall Monitoring Task Force (OMTF), made up of scientists, regulators, and environmental advocacy groups. The OMTF was disbanded upon creation of OMSAP in 1998.

The outfall-monitoring program focuses on critical constituents in treatment plant effluent, such as nutrients, organic material, toxic contaminants, pathogens, and solids (Table 1-2). Presence and potential effects of these constituents are evaluated within the context of four environmental measurement areas: effluent, water column, sea floor, and fish and shellfish. This basic program is augmented by special studies that are conducted in response to specific permit requirements, scientific questions, and environmental concerns. The monitoring program is designed to compare environmental quality of the Massachusetts Bay system, including Boston Harbor and Cape Cod Bay, before and after the outfall location moved from the harbor to the bay.

Baseline monitoring was initially planned to last for a minimum of three years, as the outfall was originally planned for completion in 1995. Delays in outfall construction allowed a relatively long period for baseline studies. Consequently, MWRA was able to document greater natural variability and develop a better understanding of the system than would have been possible in a briefer baseline period. MWRA was also able to evaluate the response in Boston Harbor to other parts of the Boston Harbor project (Leo *et al.* 1995, Pawlowski *et al.* 1996, Rex and Connor 1997, Rex 2000). The extended period also meant that the discharge to Massachusetts Bay, when it did begin, had the benefit of nearly complete implementation of secondary treatment.

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

Contingency Plan

The MWRA contingency plan (MWRA 1997b, 2001 and available at www.mwra.com) 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 the 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 1-3). The plan provides a process for evaluating parameters that exceed thresholds and formulating appropriate responses.

Table 1-2. Summary of the monitoring program

Task	Objective	Sampling Locations And Schedule	Analyses
Effluent			
Effluent sampling	Characterize wastewater discharge from Deer Island Treatment Plant	Monthly	Toxicity
		Weekly	Nutrients
		Daily	Organic material (cBOD)
		Several times monthly	Toxic contaminants
		3x/day	Bacterial indicators, total chlorine residual
		Daily	Solids
Water Column			
Nearfield surveys	Collect water quality data near outfall location	17 surveys/year 21 stations	Temperature Salinity Dissolved oxygen Nutrients Solids Chlorophyll Water clarity Photosynthesis Respiration Plankton Marine mammal observations
Farfield surveys	Collect water quality data throughout Massachusetts and Cape Cod bays	6 surveys/year 26 stations	
Plume-track surveys	Track locations and characteristics of discharge plume, measure dilution of discharge	2 surveys in 2001	Rhodamine dye Salinity Temperature Currents Nutrients Solids Selected metals Bacterial indicators
Moorings (GoMOOS and USGS)	GoMOOS near Cape Ann and USGS near outfall provide continuous oceanographic data near outfall location	Continuous monitoring GoMOOS at one location USGS at two locations 3 depths	Currents Temperature Salinity Water clarity Chlorophyll
Remote sensing	Provides oceanographic data on a regional scale through satellite imagery	Available daily (cloud-cover permitting)	Surface temperature Chlorophyll
Sea Floor			
Soft-bottom studies	Evaluate sediment quality and benthos in Boston Harbor and Massachusetts Bay	1 survey/year 20 nearfield stations 11 farfield stations	Sediment chemistry Sediment profile imagery Community composition
Hard-bottom studies	Characterize marine benthic communities in rock and cobble areas	1 survey/year 21 stations on 6 transects	Topography Substrate Community composition
Fish and Shellfish			
Winter flounder	Determine contaminant body burden and population health	1 survey/year 5 locations	Tissue contaminant concentrations Physical abnormalities, including liver histopathology
American lobster	Determine contaminant body burden	1 survey/year 3 locations	Tissue contaminant concentrations Physical abnormalities
Blue mussel	Evaluate biological condition and potential contaminant bioaccumulation	1 survey/year 4 locations	Tissue contaminant concentrations

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, most parameters have "caution" as well as "warning" thresholds. Exceeding caution or warning thresholds could indicate a need for increased attention or study. If a threshold is exceeded, MWRA, with guidance from OMSAP and the regulatory agencies, may expand the monitoring to track effluent quality and environmental conditions. The data are examined to determine whether it is likely that an unacceptable effect resulting from the outfall has occurred.

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

Table 1-3. Summary of contingency plan threshold parameters

Monitoring Area	Parameter
Effluent	pH Fecal coliform bacteria Residual chlorine Total suspended solids Biological oxygen demand Toxicity PCBs Plant performance Total nitrogen load Floatables
Water Column	Dissolved oxygen concentration Dissolved oxygen percent saturation Dissolved oxygen depletion rate Chlorophyll Nuisance and noxious algae Effluent dilution
Sea Floor	Benthic community structure Sediment oxygen Sediment toxic metal and organic chemicals
Fish and Shellfish	Mercury, PCBs, and lipid-normalized toxic compounds in mussels and flounder and lobster meat Lead in mussels Liver disease in flounder

As for the monitoring plan, every effort is made to incorporate new scientific information and improved understanding resulting from the monitoring program into appropriate thresholds. A process for modifying the contingency plan is set forth in MWRA's NPDES permit. Revision 1 to the contingency plan was approved during 2001. The revision included several minor corrections and some substantial changes (Table 1-4).

Table 1-4. Substantial revisions to the contingency plan.

Item	2001 Revision
Effluent floatables	Changed warning level threshold from 5 gallons/day to "threshold under development." Sampling protocol to be developed.
Benthic opportunists	Added caution level of 10% and warning level of 25% opportunists.
Nearfield and Stellwagen Basin dissolved oxygen.	Added phrase "unless background conditions are lower" to thresholds.
Nuisance algae cell count, *Alexandrium*	Added caution level of 100 cells/liter.
Zooplankton	Deleted caution threshold, "shift towards inshore community." Instead, MWRA to prepare a report on zooplankton populations and evaluate whether a scientifically valid threshold can be developed.

Data Management

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

As discharge and 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 any caution or warning levels are exceeded.

Reporting

MWRA's NPDES permit requires regular reports on effluent quality and extensive reporting on the monitoring program, including a variety of reports submitted to OMSAP for review (Table 1-5). Changes to the monitoring program or 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 within 90 days of each sampling event.

Reports are posted on MWRA's web site (www.mwra.com), with copies placed in repository libraries in Boston and on Cape Cod. OMSAP also holds public workshops where outfall-monitoring results are presented.

Table 1-5. List of monitoring reports submitted to OMSAP

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

Outfall Monitoring Overview

Among the many reports that MWRA completes, this report, the outfall monitoring overview, is prepared for each year of the monitoring program (Gayla *et al.*1996, 1997a, 1997b, Werme and Hunt 2000a, 2000b, 2001). The report includes a scientific summary of each year of monitoring. Overviews for 1995-1999 included only baseline information. With the outfall operational, subsequent reports include information relevant to the contingency plan, such as data that exceed thresholds, responses, and corrective activities. When data suggest that monitoring activities, parameters, or thresholds should be changed, the report summarizes those recommendations.

This year's outfall monitoring overview presents monitoring program results for effluent and field data for 2001, the first full year of discharge monitoring. It compares all results to contingency plan thresholds. The overview also includes a special section on initial dilution of the outfall and a section on data relevant to the Stellwagen Bank National Marine Sanctuary.

2. Effluent

Background

Pollution Prevention and Wastewater Treatment

Reducing inputs of pollutants to the system and effective treatment before discharge are the most important aspects of MWRA's strategy to improve the environmental quality of Boston Harbor without degrading Massachusetts and Cape Cod bays. The MWRA Toxic Reduction and Control Program sets and enforces limits on the types and amounts of pollutants that industries can discharge into the sewer system. Secondary treatment further reduces the concentrations of most contaminants of concern.

To mitigate accidental discharge of pollutants to the system, MWRA has implemented best management practice plans for the Deer Island plant, its headworks facilities, the combined sewer overflow facilities, and the sludge pelletizing plant. The plans include inspections, which are conducted at least once a year by non-facility staff.

Environmental Concerns

Sewage effluent contains a variety of wastes that can, at too high levels, affect the marine environment, public health, and aesthetics. The constituents of greatest concern include pathogens, toxic contaminants, organic material, solid material, nutrients, oil and grease, and "floatables," that is, plastic and other debris. The MWRA permit also sets limits for chlorine and pH.

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

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

Organic material, a major constituent of sewage effluent, 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 sea floor communities.

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 pose aesthetic concerns. Plastic debris can also be harmful to marine life, as plastic bags are sometimes mistaken for food and clog the digestive systems of turtles and marine mammals. Plastic and other debris can also entangle animals and cause them to drown.

Sewage effluent is disinfected by addition of a form of chlorine, sodium hypochlorite, which is the active ingredient in bleach. Unfortunately, while sodium hypochlorite is effective in destroying pathogens, at high enough concentrations, it is also harmful to marine life.

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

Monitoring Design

The main purpose of effluent monitoring is to measure the concentrations and variability of constituents of the effluent (Table 2-1). Effluent monitoring is designed to assess compliance with NPDES permit limits, which are based on state and federal water quality standards and criteria, ambient conditions, and the dilution at the outfall. Effluent monitoring also provides accurate mass loads of effluent constituents, so that fate, transport, and risk of contaminants can be assessed.

Table 2-1. Reporting requirements of the outfall permit

Parameter	Sample Type	Frequency
Flow	Flow meter	Continuous
Flow dry day	Flow meter	Continuous
cBOD	24-hr composite	1/day
TSS	24-hr composite	1/day
pH	Grab	1/day
Fecal coliform bacteria	Grab	3/day
Total chlorine residual	Grab	3/day
PCB, Aroclors	24-hr composite	1/month
LC50	24-hr composite	2/month
C-NOEC	24-hr composite	2/month
Settleable solids	Grab	1/day
Chlorides (influent only)	Grab	1/day
Mercury	24-hr composite	1/month
Chlordane	24-hr composite	1/month
4,4' – DDT	24-hr composite	1/month
Dieldrin	24-hr composite	1/month
Heptachlor	24-hr composite	1/month
Ammonia-nitrogen	24-hr composite	1/month
Total Kjeldahl nitrogen	24-hr composite	1/month
Total nitrate	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

The permit includes numeric limits 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 of any of those limits. The permit also prohibits discharge of nutrients in amounts that would cause eutrophication. The permit requires MWRA to test the toxicity of the effluent as a whole on sensitive organisms and establishes limits based on the tests. Allowable concentrations of contaminants were based on the predicted dilution at the new outfall. Actual dilution was measured in 2001, and the results, presented in Section 3, indicate that dilution is as had been predicted.

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 Kjeldahl nitrogen, ammonia, nitrate, and nitrite. Organic material is monitored by measuring the cBOD. Monitoring for toxic contaminants includes analyses for heavy metals of concern, chlorinated pesticides, PCBs, volatile organic compounds, polycyclic aromatic hydrocarbons (PAHs), total residual chlorine, and cyanide. Toxicity is tested using whole effluent samples. Tests for acute toxicity include 48-hour survival of mysid shrimp (*Americamysis bahia*, formerly known as *Mysidopsis bahia*) and inland silverside fish (*Menidia beryllina*). Chronic toxicity is assessed through inland silverside growth-and-survival and sea urchin (*Arbacia punctulata*) one-hour-fertilization tests. Pathogen monitoring consists of enumeration of fecal coliform bacteria. Total suspended solids (TSS) and settleable solids are also measured. Methods for measuring floatables remain under development.

Results

Average daily flow of effluent from the Deer Island treatment plant in 2001 was slightly less than 2000 and about the same as 1999, which had been a year of drought (Figure 2-1). Approximately 93% of the flow received secondary treatment, the greatest percentage ever.

For many parameters, total loads decreased (Figure 2-2). Total solids discharged in the effluent remained low, decreasing slightly to 30.4 tons per day. Solids removal has steadily increased over the past 10 years. Nitrogen loads, while decreasing with the implementation of secondary treatment, have increased since 1998, but have remained below threshold values. About 80% of the total nitrogen is dissolved inorganic nitrogen, mostly ammonia. Loads of selected metals decreased in 2001. Monthly average TSS and cBOD remained low in 2001, reflecting the increased levels of secondary treatment (Figure 2-3).

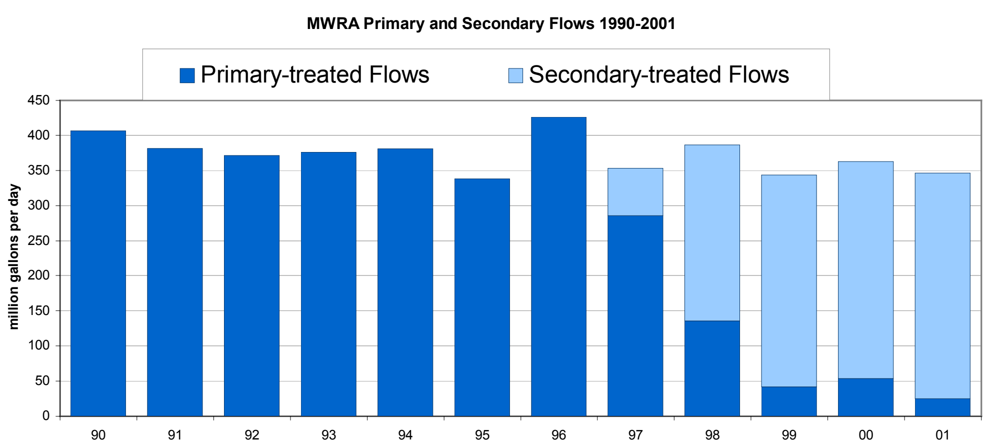


Figure 2-1. Annual effluent flow

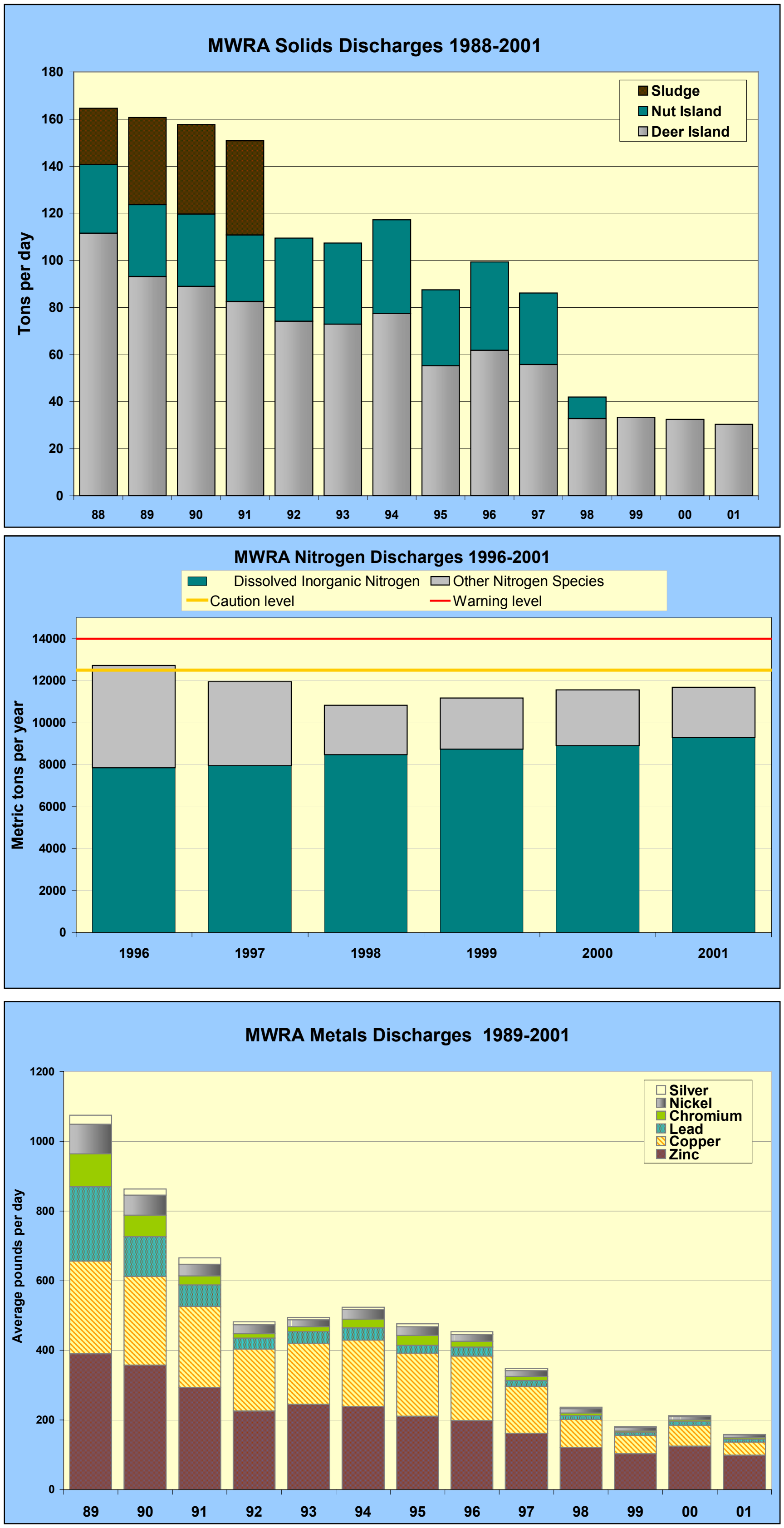
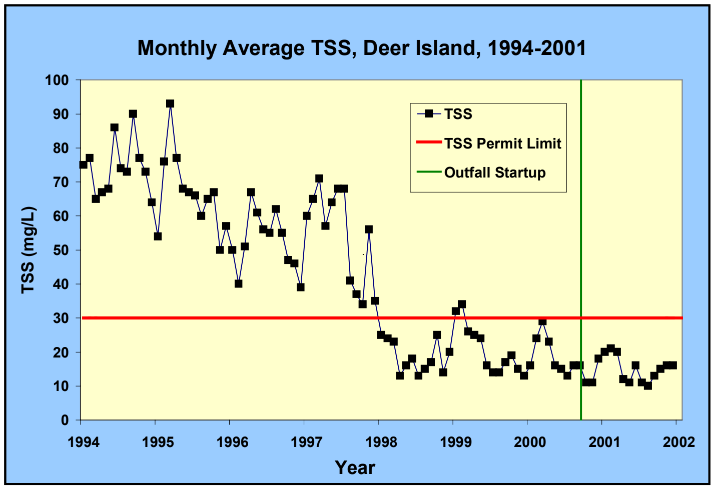


Figure 2-2. Annual solids, nitrogen, and metals discharges



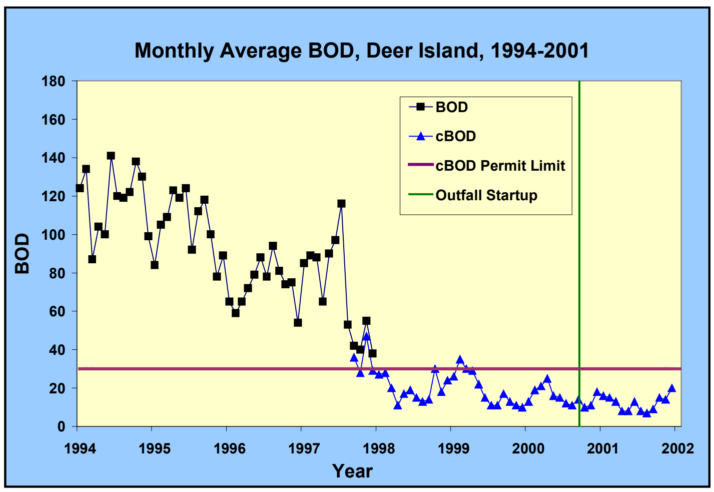


Figure 2-3. Monthly average TSS and monthly BOD (measured as cBOD since 1997) from 1994-2001

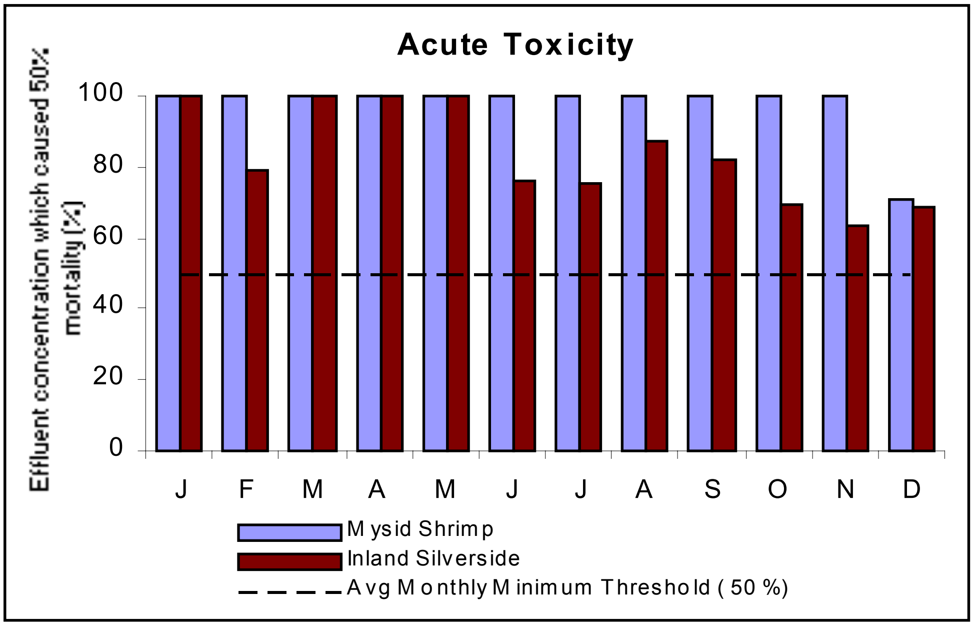
Contingency Plan Thresholds

The Deer Island Treatment Plant had few permit violations during 2001 (Table 2-2), earning it the Association of Metropolitan Sewerage Agencies Silver Award for facilities that have had five or fewer violations during the year. Two monthly and one daily contingency plan thresholds were exceeded in 2001. In January, the sea urchin fertilization test failed, and in April, the chronic fish growth test failed. On December 18, the daily limit for fecal coliform bacteria was exceeded.

Table 2-2. Contingency plan threshold values and 2001 results for effluent monitoring

Parameter	Caution Level	Warning Level	2001 Results
pH	None	<6 or >8	Not exceeded
Fecal coliform bacteria	None	14,000 fecal coliforms/100 ml (monthly 90th percentile, weekly geometric mean, maximum daily geometric mean, and minimum of 3 consecutive samples)	One exceedance of daily geometric mean level
Chlorine, residual	None	631 ug/l daily, 456 ug/l monthly	Not exceeded
Total suspended solids	None	45 mg/l weekly 30 mg/l monthly	Not exceeded
cBOD	None	40 mg/l weekly, 25 mg/l monthly	Not exceeded
Toxicity	None	Acute: effluent LC50<50% for shrimp and fish Chronic: effluent NOEC for fish survival and growth and sea urchin fertilization <1.5% effluent	One exceedance of chronic fish growth and one exceedance of sea urchin fertilization
PCBs	Aroclor=0.045 ng/l		Not exceeded
Plant performance	5 violations/year	Noncompliance >5% of the time,	Not exceeded
Flow	None	Flow >436 for annual average of dry days	Not exceeded
Total nitrogen load	12,500 mtons/year	14,000 mtons/year	Not exceeded
Floatables			Threshold revision pending
Oil and grease	None	15 mg/l weekly	Not exceeded

Effluent used in the January toxicity tests met requirements for all the acute toxicity tests and for the chronic fish test, but the chronic sea urchin test failed (Figure 2-4). All other requirements of the permit were met on January 9-10, the days that the sample used in the toxicity tests was collected, and there were no operational upsets that would have caused the sample to violate any parameters. The test organisms were in sub-optimal condition, which may have contributed to this failure. More details are available at www.mwra.com/harbor/html/exceed.htm.



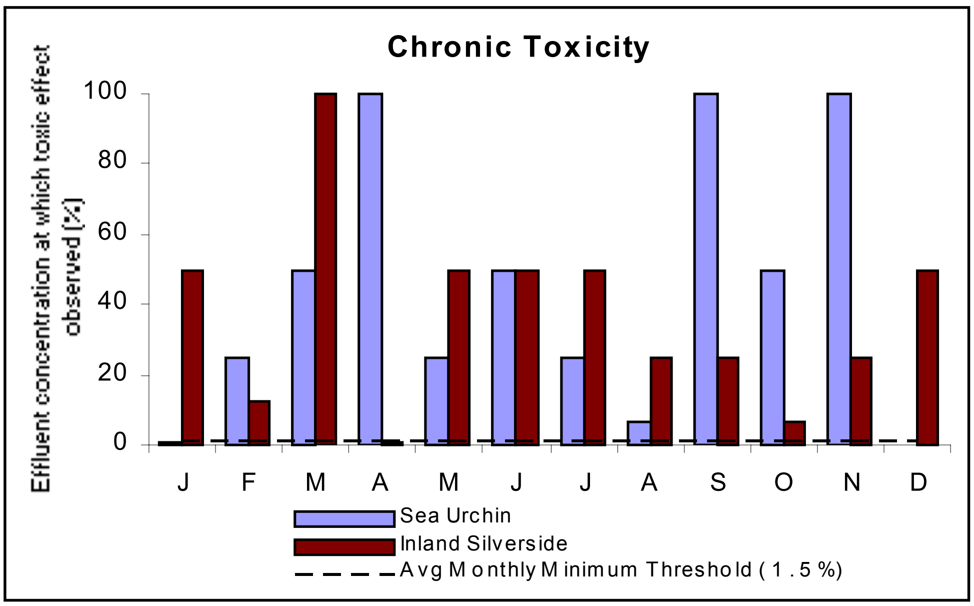


Figure 2-4. Acute and chronic toxicity test results for 2001(No sea urchin data available for December)

In April, even 100% effluent had no effect on mysid tests and the sea urchin chronic test. The fish chronic growth test, which did not pass, compares final weights of juvenile inland silversides grown in six dilutions of effluent. In the April tests, the final weights of fish grown in 1.5%, 6.25%, 25%, and 100% effluent were statistically less than the control fish. However, fish grown in 12.5% and 50% effluent did not differ from the control. In fact, fish grew more in 50% than in 1.5%

effluent. MWRA believes that these results are more likely due to natural variability in the fish rather than to a toxic effect. More details are available at www.mwra.com/harbor/html/exceed.htm.

For fecal coliform bacteria measurements, the December 18, 2001 geometric mean of three samples was 15,597 colonies/100 ml, slightly higher than the permit limit of 14,000 colonies/100 ml (Figure 2-5). This result reflected an elevated count found in one sample that was collected during a 70-minute drop in chlorine residual in the disinfection basin. The other two samples were below the threshold. The drop in chlorine residual occurred when flow was elevated due to a rainstorm. Apparently, chlorine demand in the wastewater increased suddenly, perhaps related to the storm. Staff reacted to the event by increasing the sodium hypochlorite dosing rate, and the chlorine residual returned to normal.

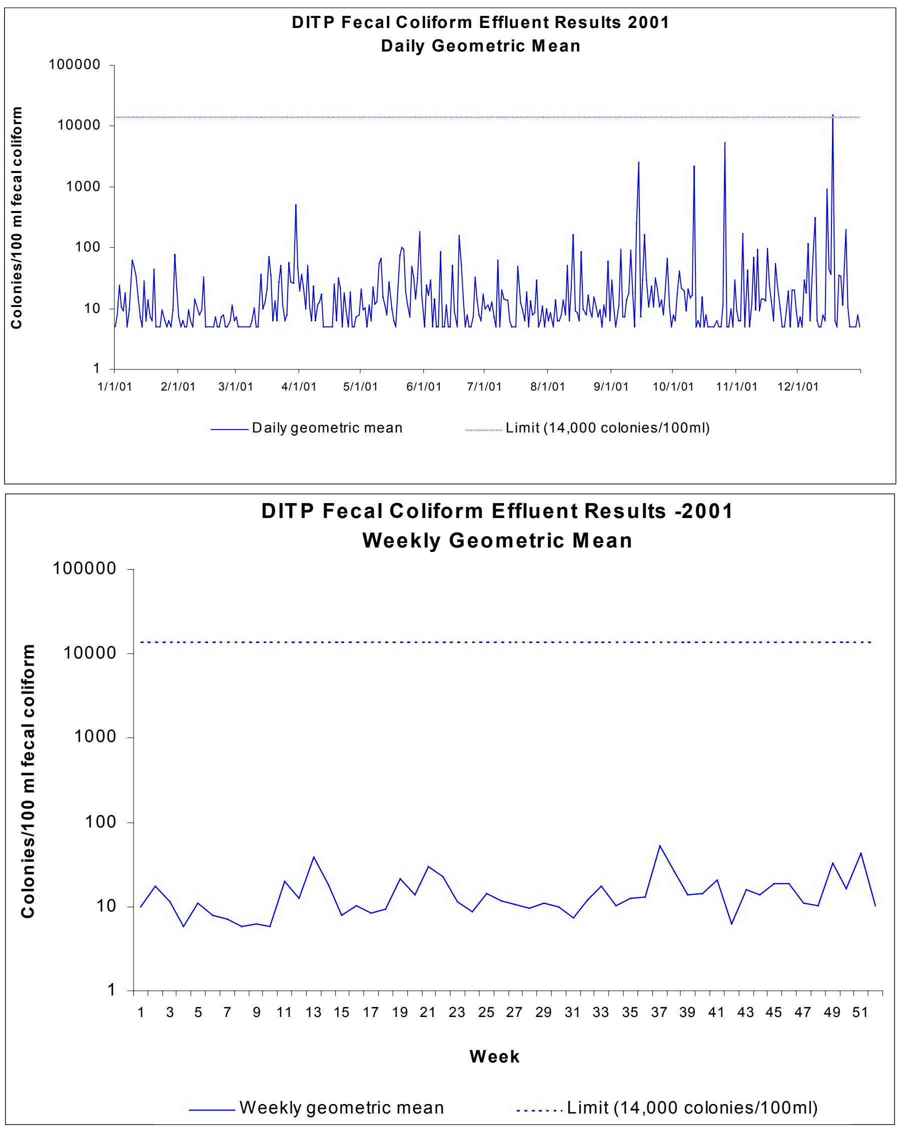


Figure 2-5. Daily and weekly geometric mean fecal coliform counts

3. Certification of the Outfall

Background

Along with effective treatment of the effluent, achieving high dilution is a key to ensuring that all other permit conditions are met and that the outfall causes no harm to the environment. One important condition of the discharge permit is that MWRA “field test and certify whether the outfall’s minimum dilution is equal to, or greater than, the predicted minimum dilution” that had been specified by a physical or scale model used during design of the outfall (hydraulic studies by Roberts and Snyder 1993a, 1993b).

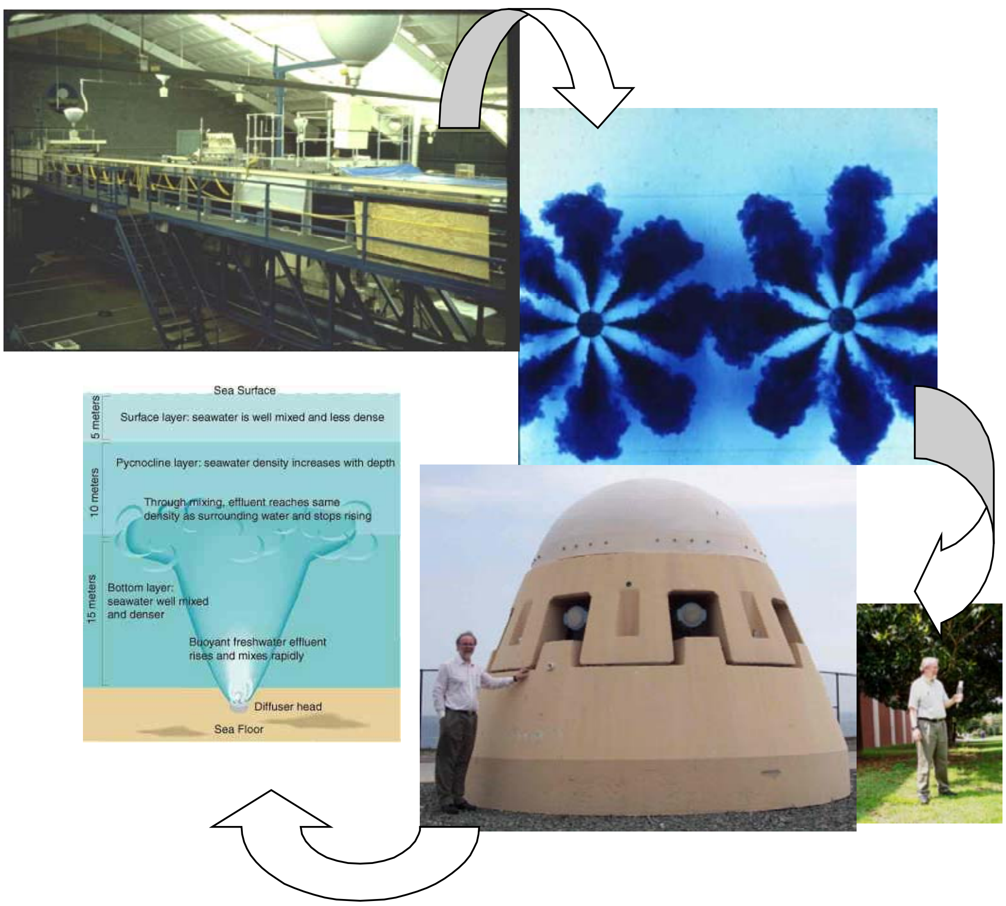


Figure 3-1. A scale model was used to optimize the design of the MWRA diffuser, which is made up of a series of 8-port risers. (Panels, clockwise from upper left: EPA Fluid Modeling Facility at Research Triangle Park, North Carolina; flow of dye from two miniature 8-port riser caps in the facility; Dr. Phil Roberts of Georgia Institute of Technology, holding a miniature and next to a full-size riser cap; conceptual panel showing rapid dilution and depth-trapped plume as means for reducing effects on surface waters)

The scale model studies were carried out in a large density-stratified tank (Figure 3-1). The studies used flows that would be equivalent to 390, 620, and 1,270 million gallons per day (MGD) and current speeds of 0, 12, and 25 cm/s. Most tests were conducted assuming currents that were perpendicular to the diffuser line. Some tests were carried out with currents parallel to the line.

The studies set a predicted minimum dilution of approximately 1:70 at edge of the hydraulic mixing zone, that is, the transition point between the area where dilution is a result of turbulence generated by the outfall and the area in which dilution is the result of oceanographic processes. In the summer, the distance from the outfall to the edge of the hydraulic mixing zone can be less than 20 meters.

Monitoring Design

Certification of the outfall required measurement of dilution during the stratified portion of the year, that is, during the summer months. To meet the permit requirements and to further evaluate plume behavior, MWRA conducted a "shakedown" survey during April 2001, before the water column was well stratified, and a certification survey in July, under stratified conditions (Hunt *et al.* 2002a, 2002b).

Dilution was determined by adding a solution of the dye Rhodamine WT to the effluent at the treatment plant and measuring dye concentrations at the treatment plant and the outfall site. Naturally occurring plume tracers were also measured, including salinity, total suspended solids, ammonia, phosphate, silver, copper, and sewage tracer bacteria. The dye can be measured rapidly, at concentrations less than one part per billion, providing a means of tracking the plume for kilometers, long after the other tracers would be diluted into their background ranges.

Within the treatment plant, *in situ* and discrete samples were used to measure the overall concentration of dye in the effluent and to determine how evenly the dye was mixed within the treatment plant's two disinfection basins. The offshore part of the program included four components: (1) a background survey to establish background fluorescence in the environment prior to dye release, (2) exploratory surveys to determine the hydrographic gradients and current directions and velocities near the diffuser, (3) hydraulic mixing zone surveys to measure plume dilution within and immediately outside the hydraulic mixing zone, and (4) plume-tracking exercises to determine plume structure and behavior outside the area of initial dilution and up to the point at which the plume reached dilutions of 1:1000.

The scale model, which was used to set the permit condition, tested effluent dilution under a limited number of physical conditions (current speed and direction, effluent flow rate, and degree of stratification of the water column). The actual field conditions could not exactly match the model conditions. Consequently, modelers used results from the scale model to develop a mathematical model to predict outfall dilution over a much wider range of conditions (Roberts *et al.* 1989). MWRA then used this model, known as RSB, to confirm that effluent dilutions measured in the field were consistent with those predicted during outfall design.

Results

Outfall Certification

Dye was introduced to the effluent stream on July 16 and 17, 2001 (Hunt *et al.* 2002b). Flow rates varied from a high of about 370 MGD a few hours after dye addition began to a low of 254 MGD at the end of the dye addition. Horizontal and vertical profiles of dye concentrations at the treatment plant indicated that the dye was well mixed through the effluent.

During the certification study, there was moderate stratification of the water column, as is typical of the early summer. Temperature was the major influence on the pycnocline. The ebb tide had just begun, and currents were to the east, essentially parallel to the diffuser line, as the dye emerged. Consequently, the three hydraulic mixing zone surveys were conducted at three locations along and just to the east of the diffuser line, following the dye progress along the diffuser.

The first hydraulic mixing zone survey included transects at the western end of and perpendicular to the diffuser line. The core of the plume was found between 15 and 20 meters depth, with dilutions of 1:90-100 (Figure 3-2, top).

The second survey, conducted near the center of the diffuser line, found a plume that was more than four times wider than the first and with variable dye concentrations (Figure 3-2, bottom). The minimum dilution, about 1:50, was measured just above a diffuser head and appeared to be located within the hydraulic mixing zone.

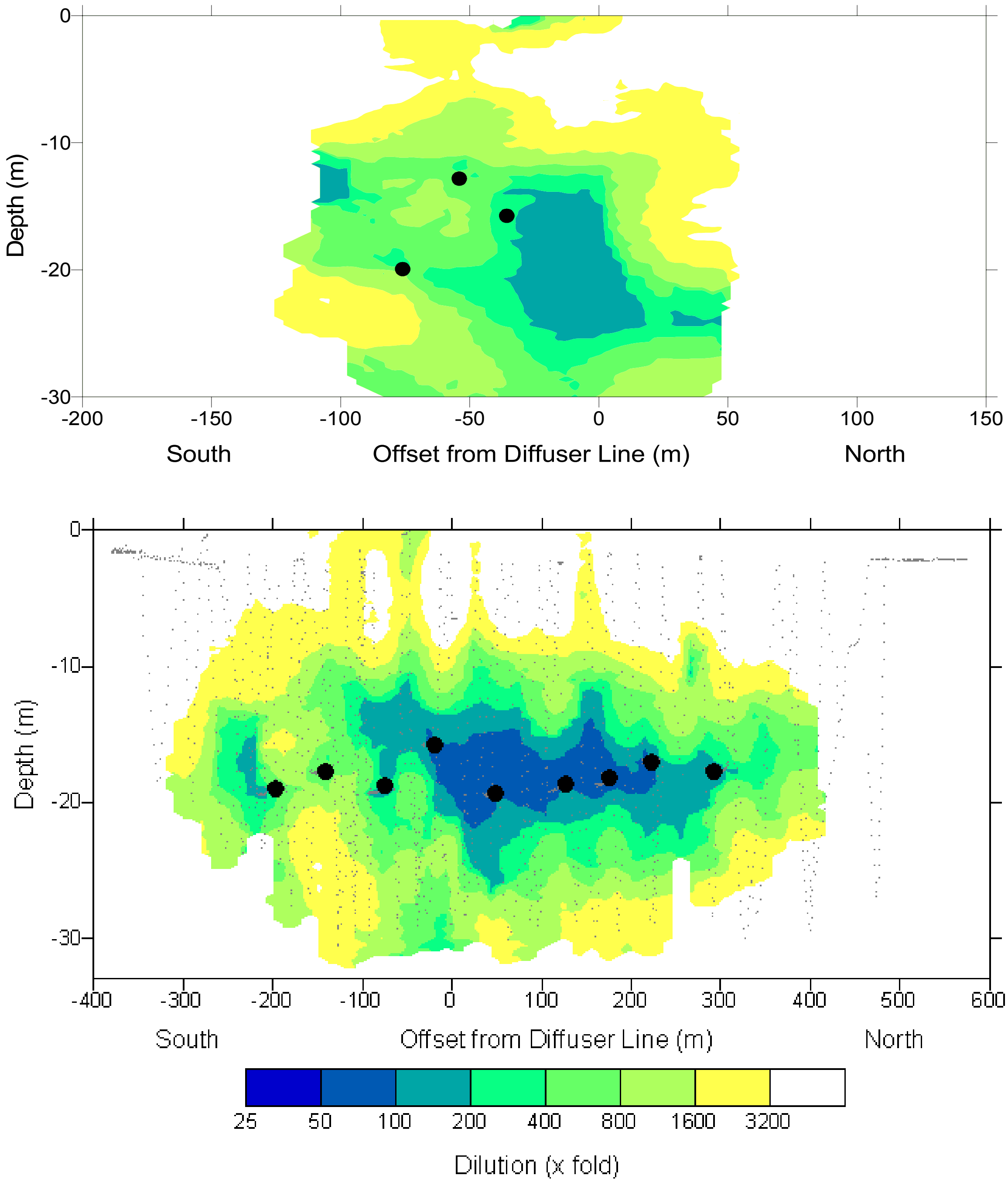


Figure 3-2. Cross-section view of dilution measured during the first (top) and second (bottom) hydraulic mixing surveys. The large dots show the locations where discrete samples were taken. The small dots on the bottom figure show the track of the remote sampling transects.

The last hydraulic mixing survey took place off the east end of the diffuser line after the tide had turned. As would be predicted (Roberts *et al.* 1989), the plume was wider during this last survey, more than twice the width at the midpoint of the diffuser line and ten times wider than at the western end (Figure 3-3). The core of the plume, with dilutions of 1:85-100 was centered on the diffuser axis, at a depth between 12 and 18 m.

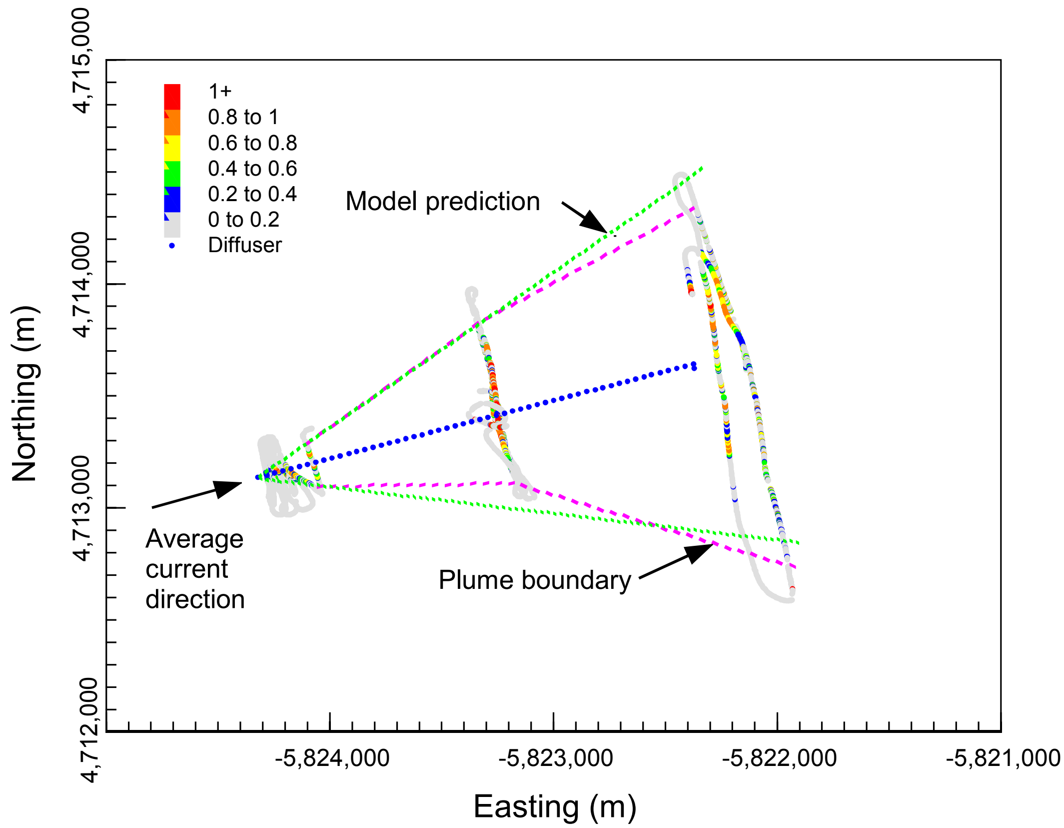


Figure 3-3. Vessel track lines and dye concentrations (ppb) measured during the three hydraulic mixing surveys. Actual lateral spreading of the plume agreed with mathematical predictions.

MWRA's instantaneous field measurements provided data at different temporal and spatial scales than were used by modelers to predict dilution. Consequently, the MWRA data detected the patchiness that occurred during hydraulic mixing. To be able to compare the field data with the time-averaged values used by the modelers, data were filtered to remove high-frequency fluctuations (Figure 3-4).

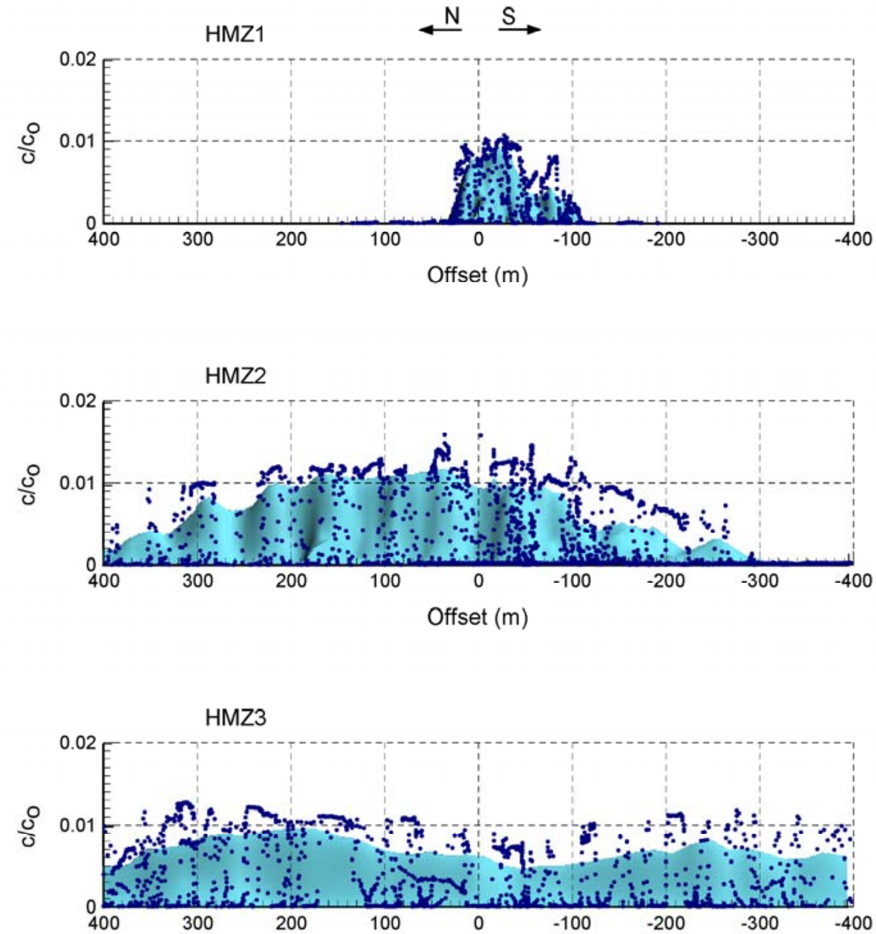


Figure 3-4. Instantaneous (dots) and low-pass-filtered (shading) dilution (expressed as c/c_o dye concentration in the field divided by dye concentration in the effluent) in each of three hydraulic mixing zone surveys

The comparison indicated that there is good agreement between the model and field results (Table 3-1) and that the outfall met the minimum dilution assumed by the permit. Dilution, thickness of the wastefield, height to the top of the wastefield, and height of minimum dilution matched well. Water quality in the plume after initial mixing met all state and federal marine water quality criteria. EPA and MADEP approved the certification of the outfall in October 2002.

Table 3-1. Comparison of model predictions and plume measurements (HMZ3 data shown) for the summer certification survey

	Model predictions	Field results
Dilution	104	102
Thickness of wastefield (m)	18.8	20
Height to top of wastefield	24.8	28
Height of minimum dilution	16.6	18

Plume Structure and Transport

Results from the plume-tracking surveys carried out beyond the hydraulic mixing zone provided additional assurance that the effluent plume behaved as predicted. The dye plume was tracked for two days (Figure 3-5). During those two days, the plume was transported to the southeast. Consistent with modeling studies, dilution increased to approximately 1:200-400 within one day after discharge. The spread and dilution was mostly horizontal, with plume thickness remaining relatively constant.

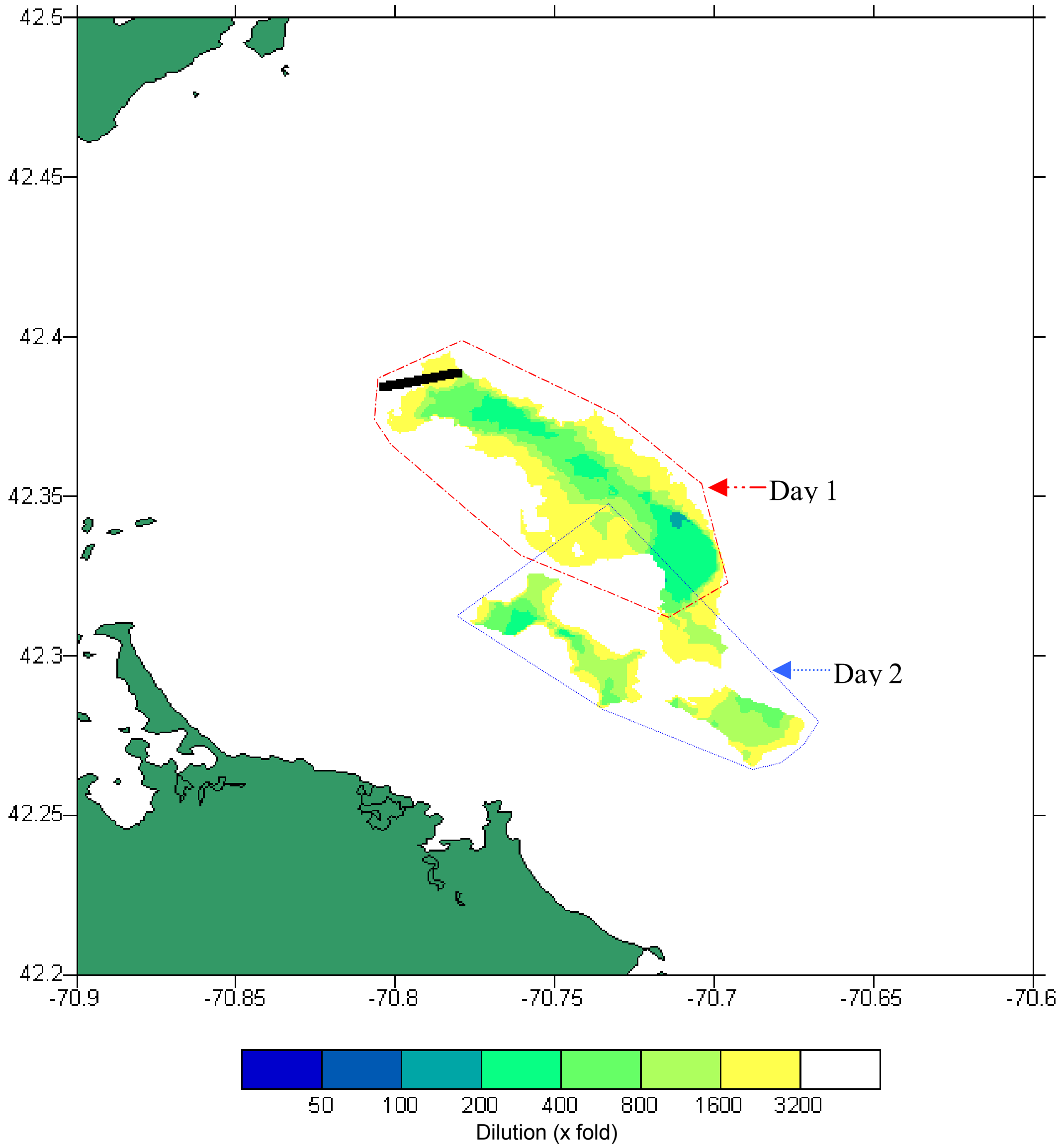


Figure 3-5. Transport of the plume over two survey days. (Note that the boundaries for each day represent the total area occupied by the plume throughout the day rather than the area at a given moment.)

4. Water Column

Background

Circulation and Water Properties

Circulation, water properties, and consequently, the biology of Massachusetts and Cape Cod bays are mainly driven by the larger pattern of water flow in the Gulf of Maine (Figure 4-1). A general coastal current flows southwestward and may enter the bays by Cape Ann to the north of Boston. Water flows back out of the bays to the north of Race Point at the tip of Cape Cod. During much of the year, a weak counterclockwise circulation persists within eastern Massachusetts Bay and Cape Cod Bay.

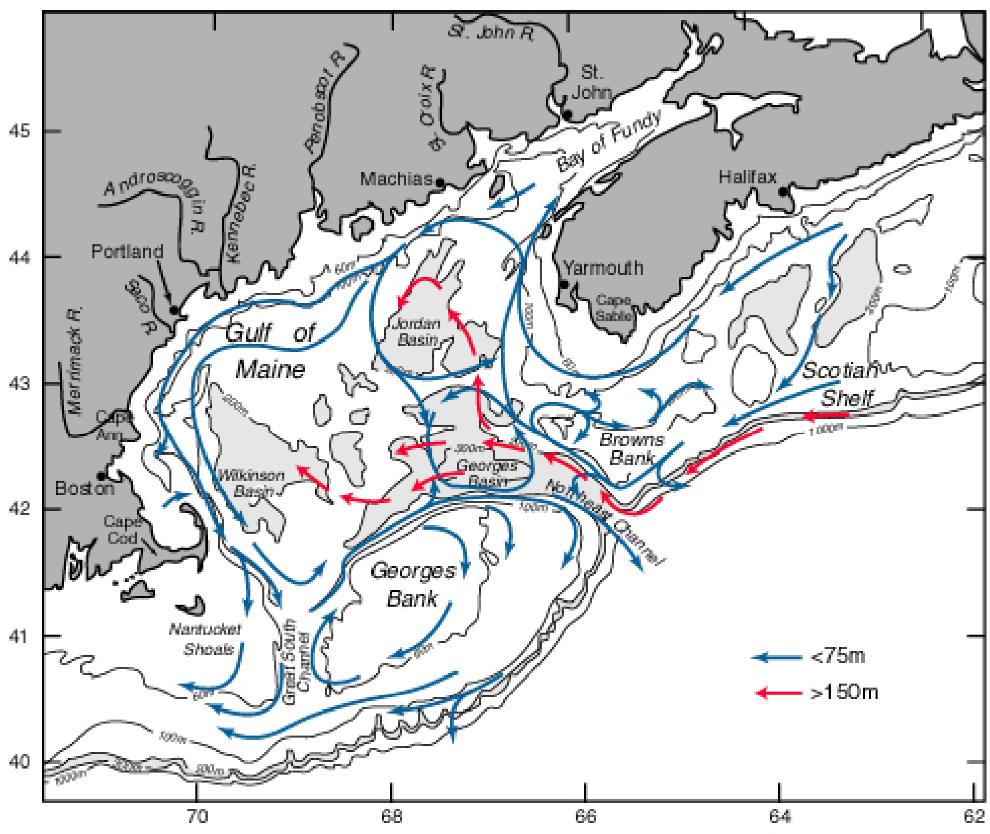


Figure 4-1. General circulation on Georges Bank and in the Gulf of Maine during the summer, stratified season (from Beardsley et al. *1997)*

When the MWRA monitoring program began, scientists assumed that the water quality and biology of the bays followed a rigid annual cycle, typical for coastal waters. In fact, monitoring has shown that wind, regional conditions, and other factors greatly influence the pattern. According to the typical coastal cycle, waters are well mixed, and nutrient levels are high during November through April. As light levels increase in the early spring, phytoplankton begin the period of rapid growth known as a spring bloom. Monitoring has shown that spring blooms may also occur earlier than April or not at all. During the years in which there are spring blooms, they begin in the shallowest waters of Cape Cod Bay. Blooms in deeper waters begin two to three weeks later. Spring phytoplankton blooms are typically followed by an increase in zooplankton abundance. These zooplankton populations are food for many animals, including the endangered right whale.

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 of oxygen to the bottom. Phytoplankton in the surface waters deplete the available nutrients and then undergo senescence, sinking to the bottom. Oxygen levels remain high in the surface waters throughout the year, but oxygen levels decrease in the bottom waters. Bottom-dwelling animals respire, and bacteria use up oxygen as they decompose the phytoplankton, so bottom-water oxygen levels are typically lowest during August through October.

In the fall, cooling surface waters and strong winds 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. Typically, fall blooms end in the early winter, when declining light levels limit photosynthesis. Plankton die and decay, replenishing nutrients in the water column.

Surface water temperatures show nearly the same pattern each year. Bottom water temperatures are more variable and are affected by wind patterns. If strong southerly or southwesterly winds, that is, winds from the south or southwest, persist during the summer, then upwelling occurs. Upwelling leads to colder inshore bottom-water temperatures and also higher concentrations of dissolved oxygen. Weaker southerly winds result in less upwelling, with warmer inshore bottom-water temperatures and lower levels of dissolved oxygen.

Environmental Concerns

The MWRA monitoring program focuses on concerns that the outfall will introduce effects from organic material, nutrients, and toxic contaminants in the effluent. Because organic material and toxic contaminants are effectively removed by secondary treatment, but nutrients are not, nutrient issues cause the greatest concern.

The concern is that excess nutrients, particularly nitrogen, could promote algal blooms followed by low levels of dissolved oxygen when the phytoplankton die, sink, and decompose. Another concern is that changes in the relative levels of nutrients could stimulate growth of undesirable algae. Three nuisance or noxious species are of particular concern: the dinoflagellate *Alexandrium tamarense*, the diatom *Pseudo-nitzschia multiseries*, and the colonial flagellate *Phaeocystis pouchetii*. *Alexandrium tamarense* typically blooms during April to June and can cause paralytic shellfish poisoning, known as PSP or red tide. Its toxin, when sufficiently concentrated, can be fatal to marine mammals, fish, and humans. Paralytic shellfish poisoning toxin has been periodically found in Massachusetts since the 1970s. *Pseudo-nitzschia multiseries* blooms can occur at any time of the year. It is one of a group of species that at high concentrations, more than 1 million cells per liter, may produce sufficient quantities of domoic acid to cause a condition known as amnesic shellfish poisoning. Toxin-forming species occur with and appear identical to non-toxin forming species. *Phaeocystis pouchetii* blooms usually occur during the late winter and spring. The species is not toxic, but individual cells can aggregate in gelatinous colonies that are poor food for zooplankton.

Although it is effectively removed by secondary treatment, potential effects of organic material from the wastewater effluent remain a focus of study. Decomposition of organic matter consumes oxygen necessary for survival of marine life. Because of the concern that low levels of dissolved oxygen could affect animals in the vicinity of the outfall, it was important during the baseline-monitoring period to develop an understanding of the natural fluctuations of oxygen levels within the system. Modeling and measurements showed that the periods of low oxygen that are typical in bottom waters appear to correlate with saltier bottom waters.

Due to source reduction and treatment, toxic contaminants discharged in the MWRA effluent are present at extremely low concentrations. Therefore, most monitoring for the effects of toxic contaminants is focused not on the water column, but on the sediments, which are known to be contaminant sinks, and on fish and shellfish, which could accumulate organic compounds or metals.

Monitoring Design

Water column monitoring includes assessments of water quality, phytoplankton, and zooplankton in Massachusetts and Cape Cod bays. Baseline monitoring includes four major components: nearfield surveys, farfield surveys, continuous recording, and remote sensing.

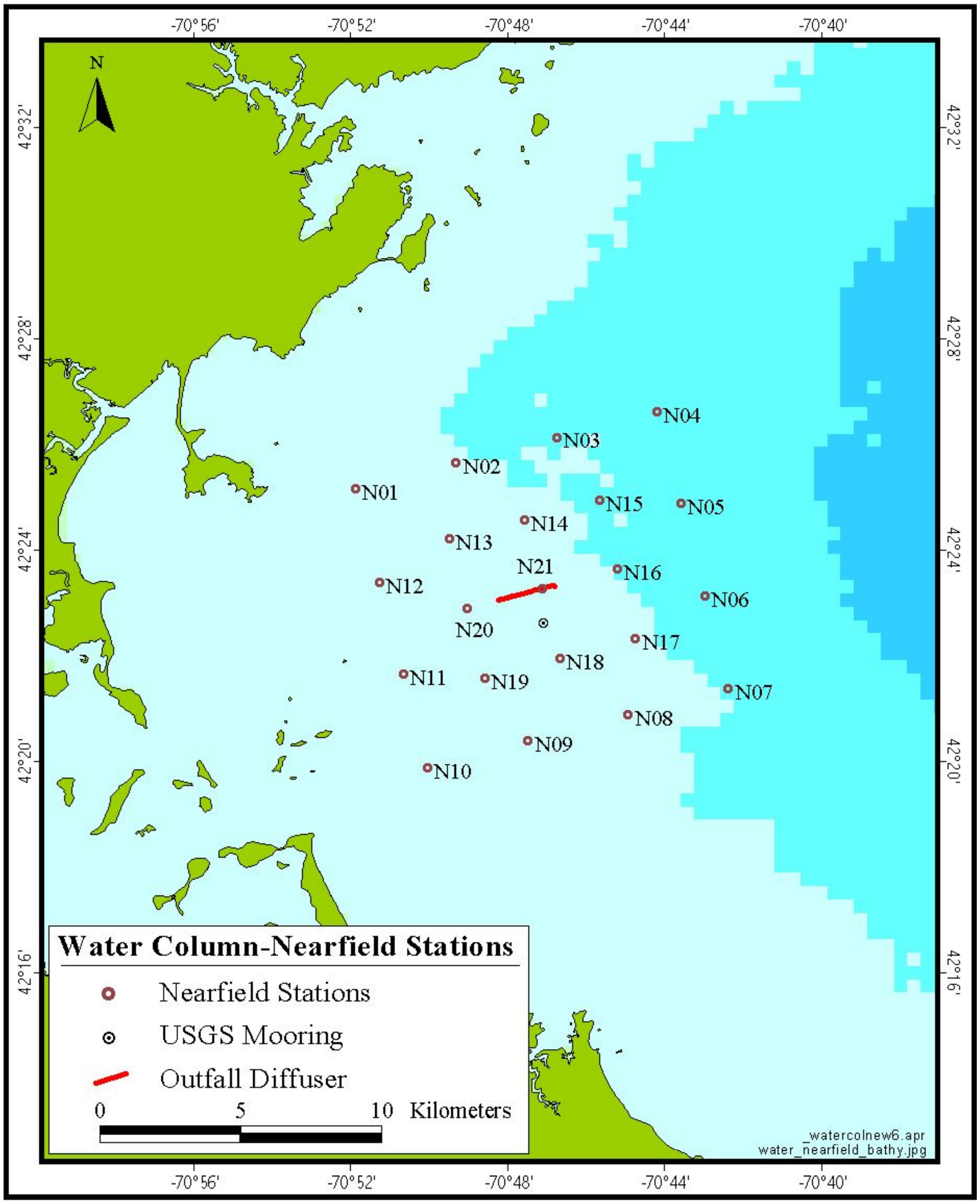


Figure 4-2. Nearfield sampling stations

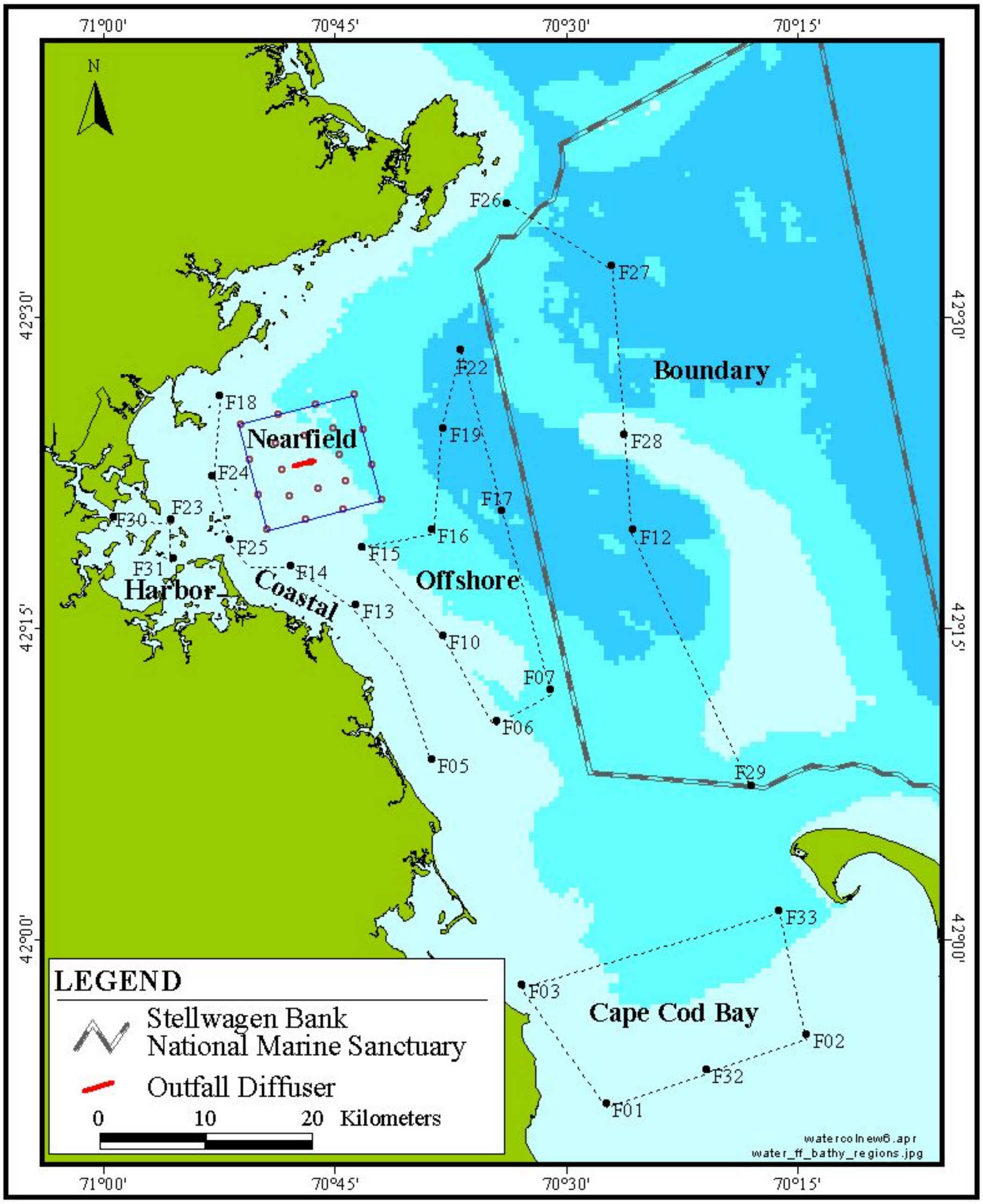


Figure 4-3. Farfield geographic regions and sampling stations

Nearfield surveys provide vertical and horizontal profiles of physical, chemical, and biological characteristics of the water column in the area around the outfall where some effects of the effluent are expected (Figure 4-2). Farfield surveys assess differences across the bays and seasonal changes over a large area (Figure 4-3). Five of the farfield stations mark the boundary of the monitoring area and are in or near the Stellwagen Bank National Marine Sanctuary. Other stations are in Boston Harbor, "coastal" and "offshore" regions, and in Cape Cod Bay. During 2001, 17 surveys of the nearfield and 6 surveys of the farfield were conducted.

Parameters measured in water column monitoring include dissolved inorganic and organic nutrients, particulate forms of nutrients, chlorophyll, total suspended solids, dissolved oxygen, productivity, respiration, phytoplankton abundance and species composition, and zooplankton abundance and species composition. Nutrient measurements include the major forms of nitrogen, phosphorus and silica. The measurements focus on the dissolved inorganic forms, which are readily used by phytoplankton.

The continuous recording components of the program, the USGS and Gulf of Maine Ocean Observation System moorings, capture temporal variations in water quality between nearfield water quality surveys. Remote sensing by satellite captures spatial variations in water quality on a regional scale.

Results

Physical Conditions

The year 2001 was dry, indicated by low river flow (Figure 4-4) during the first months of the year, normal flow during the spring and summer, and the driest fall of the monitoring program (Libby *et al.* 2002). Wind stresses during early 2001 were more northerly (from the north) than usual, resulting in stronger than average downwelling, a condition that tends to increase transport of Gulf of Maine waters through Massachusetts Bay. Downwelling conditions persisted during the spring. The upwelling conditions typical during the summer were average, and downwelling conditions in October were weaker than usual. Average wind speeds were typical, and there were no extreme wind-stress events.

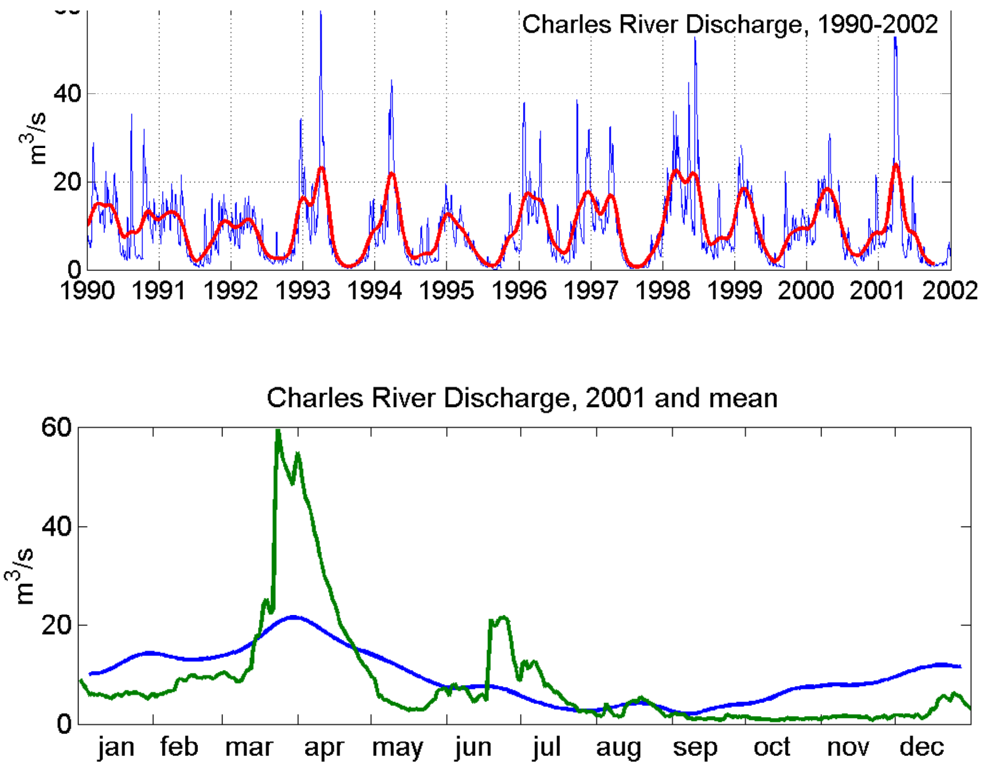


Figure 4-4. Above: Charles River discharge, 1990-2001 (recorded data from a gauge at Waltham and 3-month moving average); Below: 2001 discharge compared to the12-year historic mean

Water temperatures followed a typical pattern in the surface and at the bottom until the fall (Figure 4-5). The fall of 2001 was warm, and surface water temperatures were the warmest recorded for that time period during the monitoring program. Salinity measurements showed a normal seasonal progression, unaffected by the fall drought. Stratified conditions were first observed in early April, and by June, there was a strong density gradient throughout most of Massachusetts and Cape Cod bays. Despite one mixing event in September, stratified conditions continued late into the fall, lingering until early December.

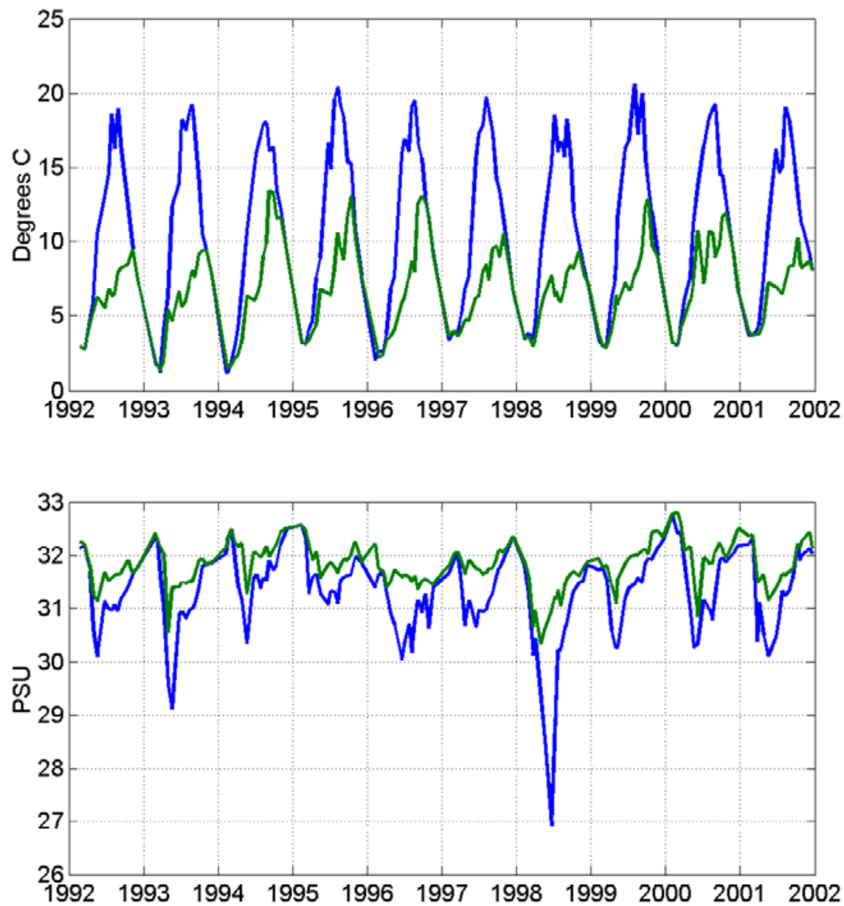


Figure 4-5. Nearfield surface and bottom water temperature and salinity, 1992-2001 (Surface measurements are the upper line for temperature and the lower line for salinity.)

Water Quality

Water quality measurements during the first full year of discharge confirmed predictions that it would be possible to detect localized effects of the discharge for some parameters, but that there would be no adverse effects on the farfield (Libby *et al.* 2002). Measurements of nutrients, chlorophyll, and dissolved oxygen indicated that, even in the nearfield, there were few measurable effects of the outfall during 2001.

Elevated concentrations of ammonia, the form of nitrogen most readily taken up by phytoplankton, were observed in the nearfield over much of the year (Figure 4-6, top). These elevated levels were anticipated, because a large portion of the dissolved inorganic nitrogen in treated effluent is ammonia, and ammonia has proven to be a good short-term tracer of the effluent plume. Concentrations of ammonia were particularly higher than the baseline during the summer months. During this period, however, the nutrient inputs from the outfall were trapped below the pycnocline and not available to phytoplankton. Averaged over the entire year, the increase in ammonia concentrations in the vicinity of the outfall was small in comparison to the large decrease in ammonia concentrations in the harbor (Figure 4-6, bottom). There were no increases in annual ammonia concentrations in the farfield.

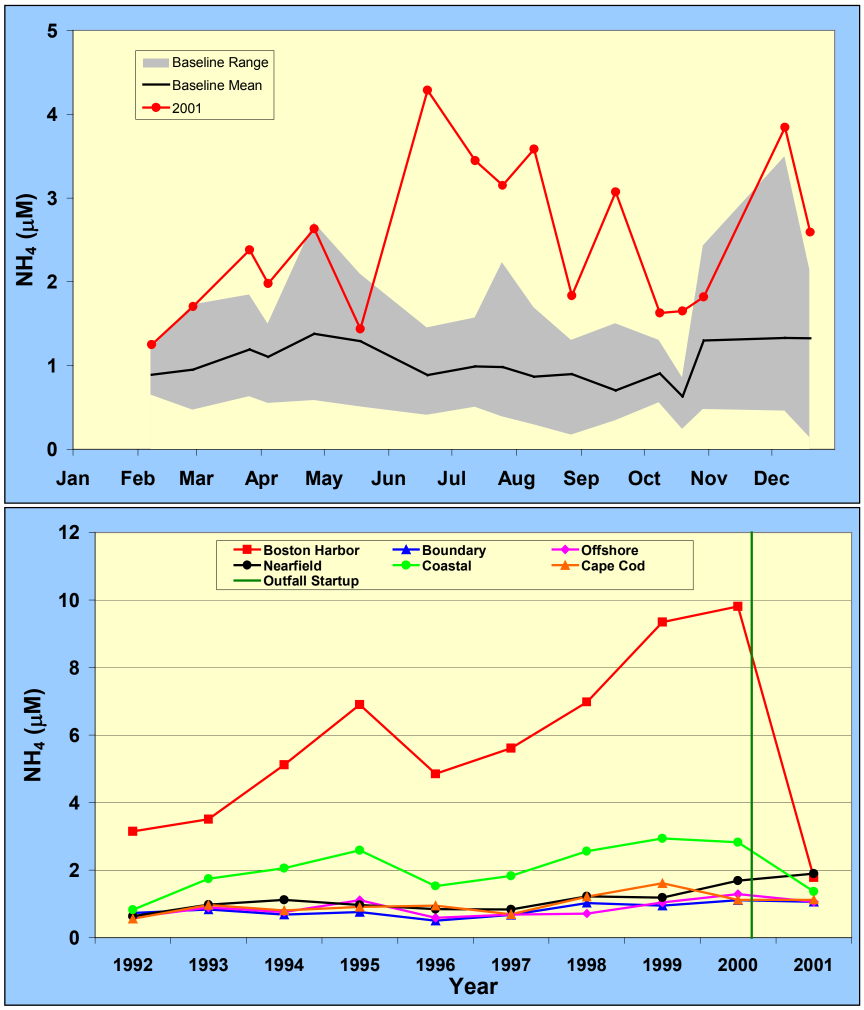


Figure 4-6. Above: 2001 nearfield ammonia concentrations compared to baseline range and mean; Below: annual mean ammonia concentrations in Massachusetts Bay regions

Concentrations of nitrate, another form of nitrogen readily used by phytoplankton and present in the effluent, generally fell into the range and showed the same seasonal pattern that had been established during baseline monitoring (Figure 4-7, top). These results were anticipated, because under most circumstances, nitrate concentrations in the effluent only about 10 times of the ambient bottom water. Just as during the baseline period, maximum nitrate concentrations were observed during the early part of the year. Seasonal stratification led to typical, persistent nutrient depletion in the surface waters, with no evidence of inputs from the outfall. Because the fall bloom occurred later than usual, late October nitrate concentrations were higher than had been measured during comparable surveys during the baseline period, and December nitrate concentrations fell below the baseline range. The increased concentrations observed in late October were small and a result of the delayed bloom rather than a measure of inputs from the outfall. The annual average for 2001 showed little increase in nitrate concentrations in the nearfield (Figure 4-7, bottom). There were no measurable effects on the farfield, with annual concentrations of nitrate falling within the baseline range for the boundary stations and in Cape Cod Bay. The typical pattern persisted, with highest concentrations at the boundary, lowest in Cape Cod Bay, and intermediate levels in the nearfield.

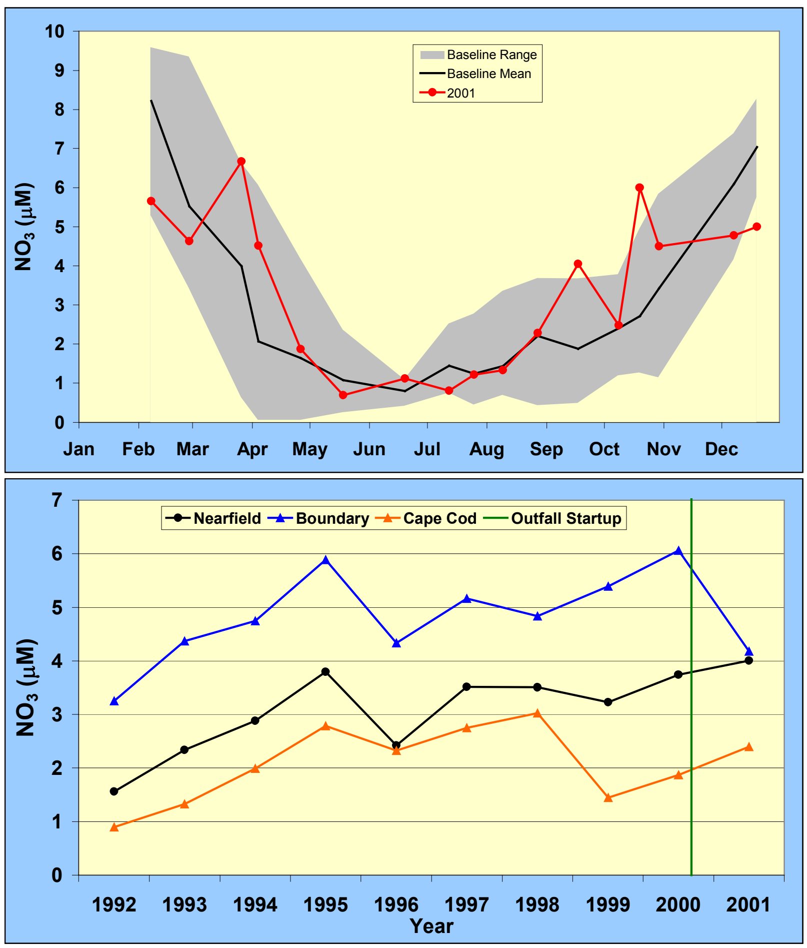


Figure 4-7. Above: 2001 nearfield nitrate concentrations compared to baseline range and mean; Below: annual mean nitrate concentrations in Massachusetts Bay regions

Concentrations of another nutrient, phosphate, were slightly elevated above the baseline mean during most surveys and above the baseline range in the nearfield during two of the seventeen surveys (Figure 4-8). Overall, the annual average concentration was not elevated in the nearfield, while concentrations decreased in the harbor (not shown).

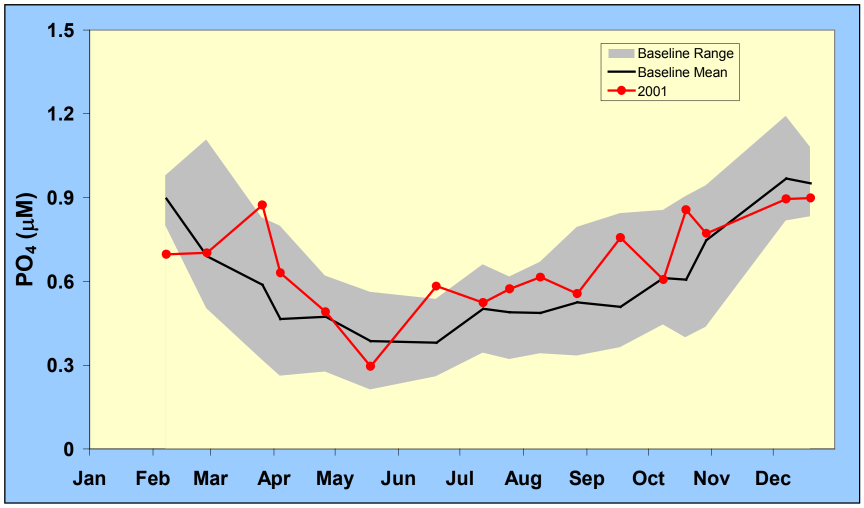


Figure 4-8. 2001 nearfield phosphate compared to baseline range and mean

Concentrations of chlorophyll, a measure of phytoplankton biomass, showed no response to nutrient enrichment of the outfall, even in the nearfield (Figure 4-9, top). During most nearfield surveys, concentrations of chlorophyll were at or below the baseline mean. Chlorophyll concentrations were higher than the baseline range during the first surveys in February and December. These increases resulted from the deviations in the timing of the spring and fall blooms, with the spring bloom earlier and the fall bloom later than in past years. The magnitudes of the peak measurements were within ranges of spring and fall blooms of the baseline period. The annual (Figure 4-9, bottom) and seasonal (not shown) chlorophyll concentrations showed no response to the outfall in the nearfield or any region of the farfield. Overall, annual average concentrations of chlorophyll were much lower in 2001 than in 2000, with similar decreases observed in the nearfield and in Cape Cod Bay.

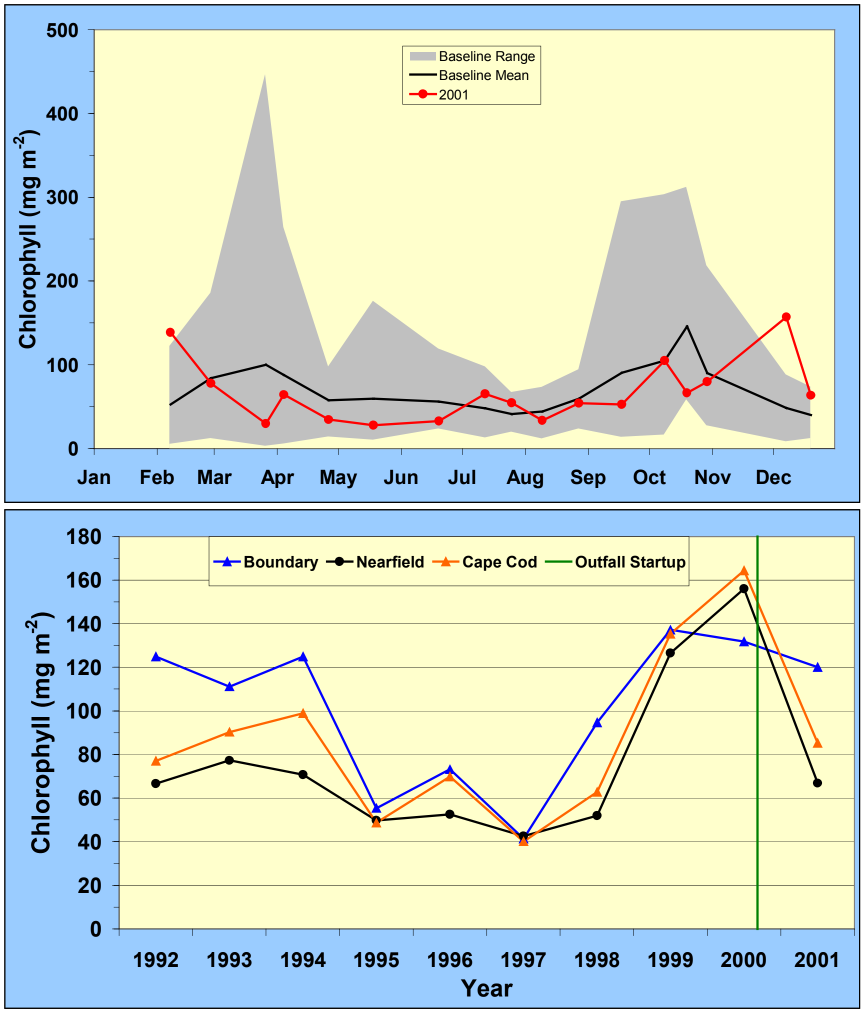


Figure 4-9. Above: 2001 nearfield chlorophyll concentrations compared to baseline range and mean; Below: annual mean chlorophyll concentrations in Massachusetts Bay regions

Measurements of concentrations (Figure 4-10) and percent saturation (not shown) of dissolved oxygen in 2001 showed no response to nutrient enrichment or addition of organic matter from the outfall. Survey mean concentrations and percent saturation of dissolved oxygen in bottom waters of the nearfield and Stellwagen Basin were unchanged from the baseline period. Measurements of both parameters remained close to the baseline mean throughout the year. Minimum concentrations and percent saturation were found in October, as is typical.

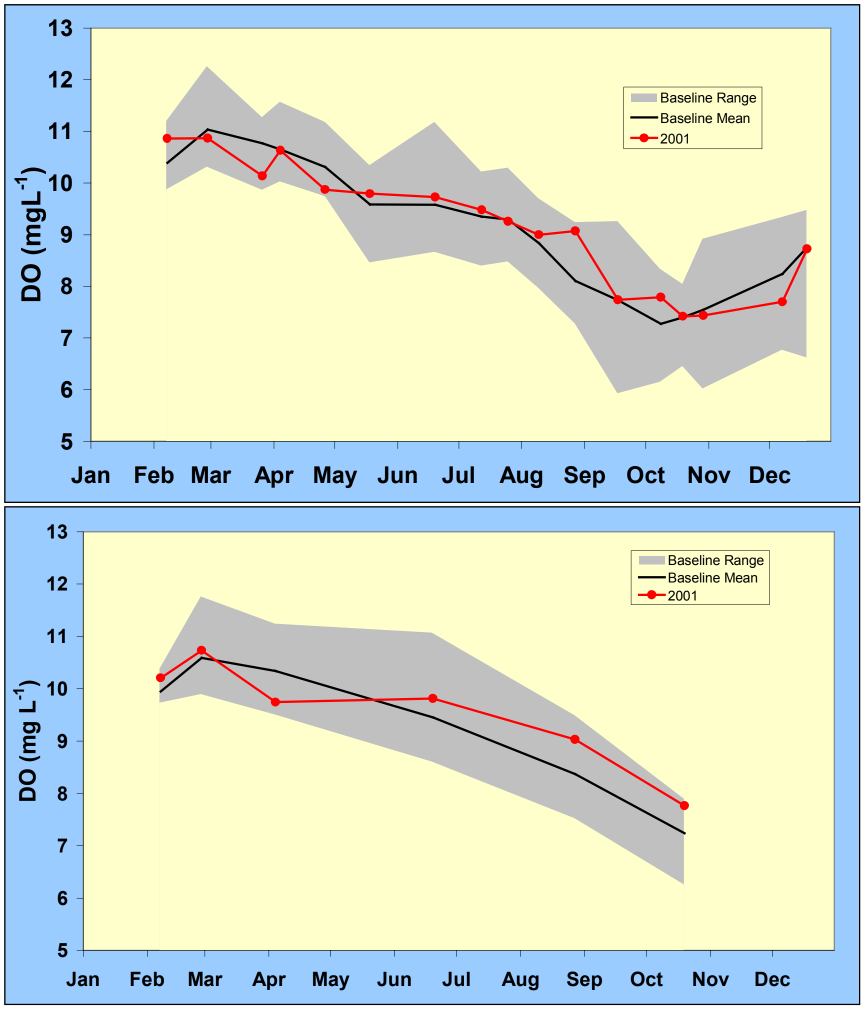


Figure 4-10. Above: 2001 nearfield dissolved oxygen concentrations compared to baseline range and mean; Below: Stellwagen Basin dissolved oxygen concentrations compared to baseline range and mean

Phytoplankton Communities

Abundance of phytoplankton during 2001 was within the baseline range (Libby *et al.* 2002, Figure 4-11). Counts did not reach peaks seen in some years, such as 1993, 1995, or 1997, but they were similar to 1996, 1998, and 1999. The seasonal pattern was similar to that to the baseline. Although sampling in 2001 missed the peak of the winter-spring bloom, similar conditions existed in 1996, 1998, and 1999. Cell counts during the fall were not higher than those during the baseline period, although they remained elevated for longer into the early winter.

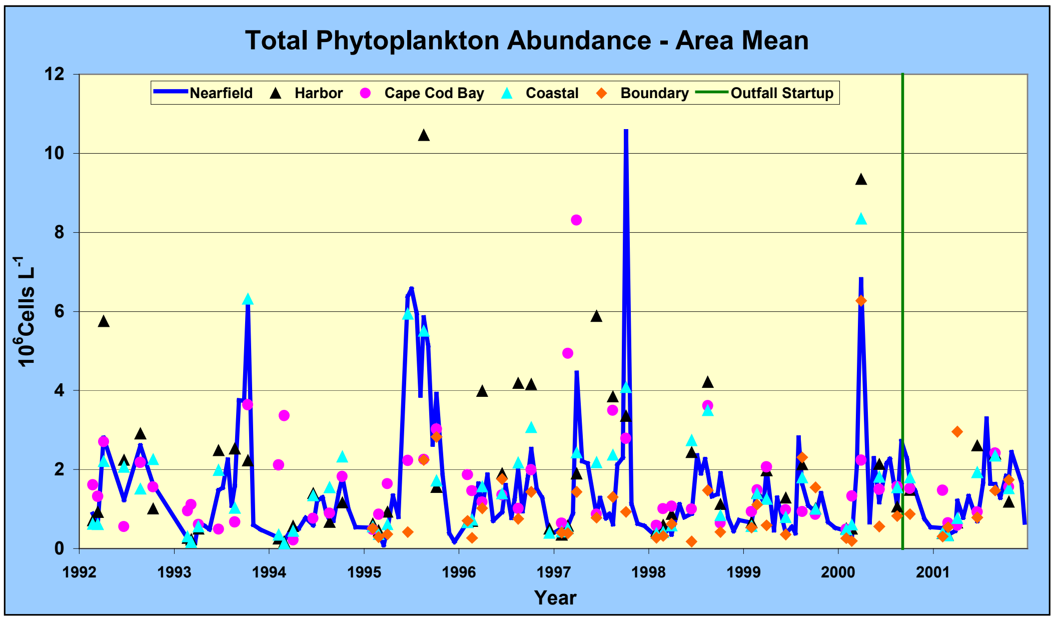


Figure 4-11. Total phytoplankton abundance by area, 1992-2001

Community composition and abundance patterns were similar in the nearfield and the farfield, and both regions showed similar patterns as the baseline period. As in previous years, the assemblages were dominated by microflagellates, with brief diatom peaks.

Presence of *Phaeocystis pouchetii*, a nuisance species, did not reach the levels of the 2000 bloom. Its presence for a second year did, however, challenge the prevailing thought that blooms occurred about once every few years. Previous blooms had occurred in 1992, 1994, and 1997. Other nuisance species were also present during 2001, but in low numbers. The dinoflagellate *Alexandrium tamarense* was recorded sporadically. Diatoms in the genus *Pseudo-nitzschia* were present in the spring and fall, but they were never abundant.

Zooplankton Communities

Zooplankton abundance and community structure in 2001 were similar to those of the baseline period, although maximum abundance was lower than in most years, particularly 1999 and 2000 (Libby *et al.*2002, Figure 4-12). The most abundant taxa were, as in previous years, various copepod nauplii and adults and copepodites of the small copepod *Oithona similis*. *Pseudocalanus* spp. copepodites and meroplankters, animals that are part of the plankton for part of their lives, were also common. The larger copepods *Calanus* spp. and *Centropages* spp. were present, although in lower numbers than the smaller species. As in other years, copepods in the genus *Acartia* were confined to Boston Harbor. In 2001, high densities of ctenophores were observed again in Boston Harbor, as they were in 2000, but not in the nearfield.

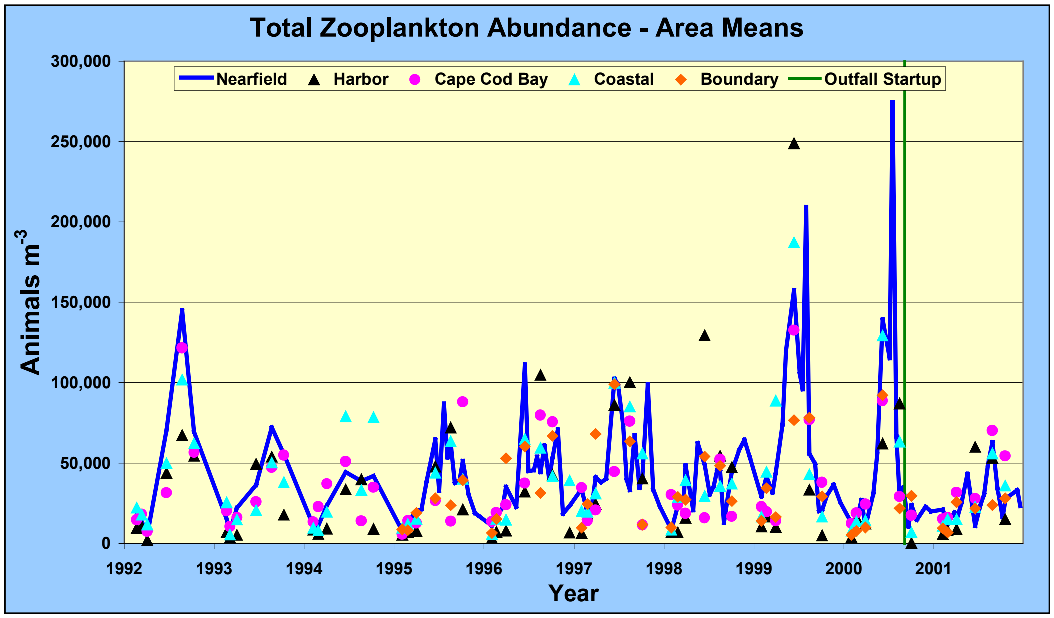


Figure 4-12. Zooplankton abundance by area, 1992-2001

Contingency Plan Thresholds

Threshold parameters for water-column monitoring include minimum dissolved oxygen concentrations and percent saturation in nearfield and Stellwagen Bank bottom waters, dissolved oxygen depletion rate in nearfield bottom waters, chlorophyll levels, abundance of nuisance algal species, geographic extent of PSP toxin, and initial dilution. There was no repeat of the high chlorophyll levels measured in the fall of 2000, and no contingency plan thresholds were exceeded during 2001 (Table 4-1).

Table 4-1. Contingency plan threshold values for water column monitoring

Location/ Parameter	Specific Parameter	Baseline	Caution Level	Warning Level	2001 Results
Bottom water nearfield	Lowest survey dissolved oxygen concentration	Background 5th percentile 5.75 mg/l	Lower than 6.5 mg/l for any survey (June-October) unless background conditions are lower	Lower than 6.0 mg/l for any survey (June-October) unless background conditions are lower	Lowest survey, October, 7.4 mg/l
	Lowest survey dissolved oxygen percent saturation	Background 5th percentile 64.3%	Lower than 80% for any survey (June-October) unless background conditions are lower	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey, October, 77%
Bottom water Stellwagen Basin	Lowest survey dissolved oxygen concentration	Background 5th percentile 6.2 mg/l	6.5 mg/l for any survey (June-October) unless background conditions lower	Lower than 6.0 mg/l for any survey (June-October) unless background conditions are lower	Lowest survey, October, 7.8 mg/l
	Lowest survey dissolved oxygen percent saturation	Background 5th percentile 66.3%	Lower than 80% for any survey (June-October) unless background conditions	Lower than 75% for any survey (June-October) unless background conditions are lower	Lowest survey, October, 79%
Bottom water nearfield	DO depletion rate (June-October)	0.0244 mg/l/d	0.037 mg/l/d	0.049 mg/l/d	0.020 mg/l/d
Chlorophyll nearfield	Annual	71 mg/m^2	107 mg/m^2	143 mg/m^2	67 mg/m^2
	Winter/spring	81 mgml^2	182 mg/m^2	None	69 mg/m^2
	Summer	51 mg/m^2	80 mg/m^2	None	45 mg/m^2
	Autumn	90 mg/m^2	161 mg/m^2	None	87 mg/m^2
Nuisance algae nearfield *Phaeocystis pouchetii*	Winter/spring	470,000 cells/l	2,020,000 cells/l	None	186,400 cells/l
	Summer	72 cells/l	334 cells/l	None	0 cells/l
	Autumn	300 cells/l	2,370 cells/l	None	0 cells/l
Nuisance algae nearfield *Pseudo-nitzschia*	Winter/spring	6,200 cells/l	21,000 cells/l	None	5,700 cells/l
	Summer	13,000 cells/l	38,000 cells/l	None	100 cells/l
	Autumn	9,700 cells/l	24,600 cells/l	None	5,900 cells/l
Nuisance algae nearfield *Alexandrium tamarense*	Any nearfield sample	Baseline maximum = 163 cells/l	100 cells/l	None	35 cells/l maximum
Farfield	PSP toxin extent	Not applicable	New incidence	None	No toxicity or shellfish closures
Water column	Initial dilution of the outfall	Not applicable	None	Effluent dilution predicted by EPA as basis for NPDES permit	Dilution consistent with prediction

Several changes to the water-column thresholds in the contingency plan were approved in 2001. The phrase "unless background conditions are lower" was added to the descriptions of both dissolved oxygen concentration and dissolved oxygen saturation, bringing the thresholds into closer conformity with state standards. Previously, more rigid contingency plan thresholds were at levels that frequently could not be met even during baseline monitoring. The background conditions have been calculated as follows: 5.75 mg/l dissolved oxygen in the nearfield. 6.2 mg/l dissolved oxygen in Stellwagen Basin, 64.3% saturation in the nearfield, and 66.3% saturation in Stellwagen Basin.

Also in 2001, EPA and MADEP established a threshold of 100 cells/liter in any sample for *Alexandrium tamarense,* noting that the maximum count prior to the outfall startup was 163 cells/l. Further study of appropriate thresholds for paralytic shellfish poisoning toxin are underway. Paralytic shellfish poisoning toxin is not generally observed in shellfish until cell counts reach more than 300 cells/l. MWRA also uses data from a Massachusetts Department of Marine Fisheries (DMF) monitoring program, which addresses extent of paralytic shellfish poison toxicity in the area. The program traditionally has been conducted from early April through November and has involved sampling of shellfish, primarily blue mussels, from 16 primary stations and, if significant toxin is measured at the primary sites, 47 secondary stations. PSP toxin was not detected in bay waters in 2001.

MWRA is also evaluating whether a scientifically valid zooplankton community threshold can be developed. By the end of 2001, no appreciable changes to the zooplankton community were detected by the monitoring program.

5. 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 (USGS 1997a, 1998).

Sediment transport in the region occurs primarily during storms. 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, where they are likely to remain. Cape Cod Bay is partially sheltered from large waves by the arm of Cape Cod, and storm waves are rarely large enough to resuspend sediments in Stellwagen Basin, which is the deepest feature in the region.

Environmental Concerns

Within Boston Harbor, studies of the sediments have documented recovery following the cessation of sludge discharge, improvements to CSO systems, and improved sewage effluent treatment. Conversely, relocating the outfall has introduced concerns about potential effects on the offshore sea floor. Concern is focused on three issues: eutrophication and related low levels of dissolved oxygen, accumulation of toxic contaminants in depositional areas, and smothering of animals by particulate matter.

If transfer of the nutrient loads to offshore were to cause eutrophication, depressed levels of dissolved oxygen could profoundly affect bottom communities. Increasing the amount of particles and organic matter to the bottom could disrupt normal benthic community structure in the vicinity of the discharge. Although source control and treatment plant performance are designed to keep effluent contaminant concentrations too low to affect the sediments, the location of the outfall in an area of considerable sediment transport causes concern about accumulation of toxic contaminants in Cape Cod Bay and Stellwagen Basin. Similarly, concentrations of particulate matter are expected to be low, but there remains some concern that bottom communities near the outfall could be affected by deposition.

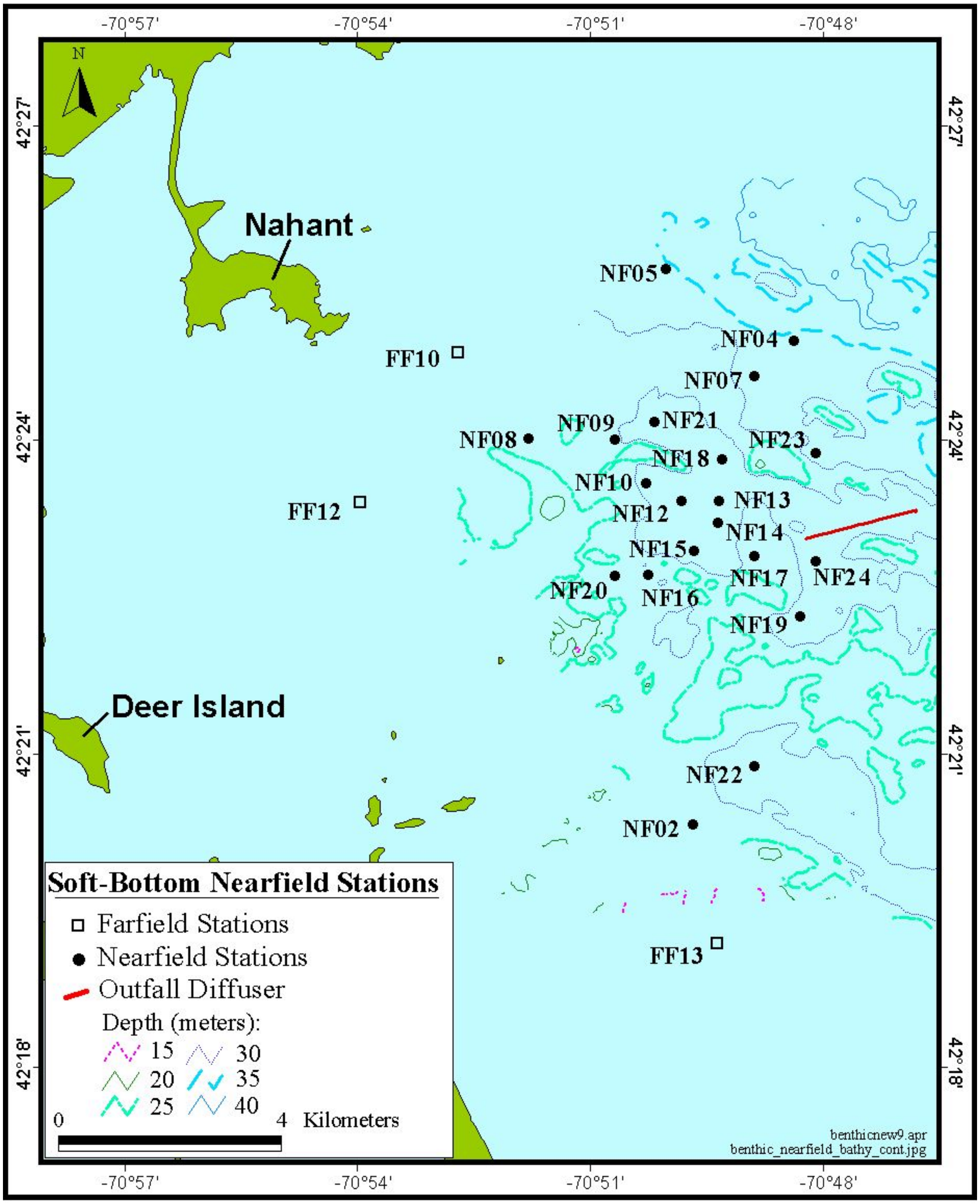


Figure 5-1. Locations of nearfield soft-bottom stations (NF12 and NF17 are also sampled by USGS)

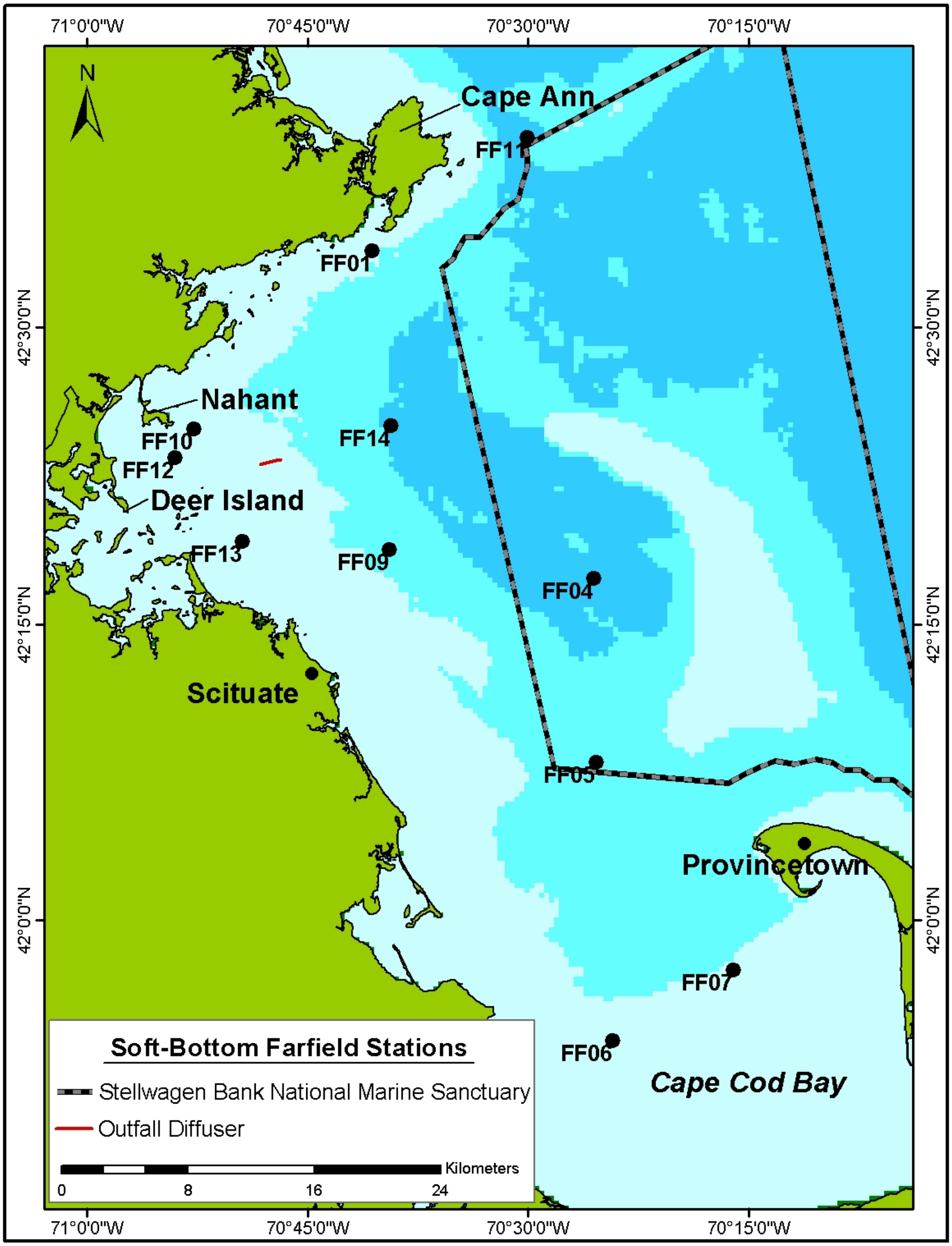


Figure 5-2. Locations of farfield soft-bottom stations

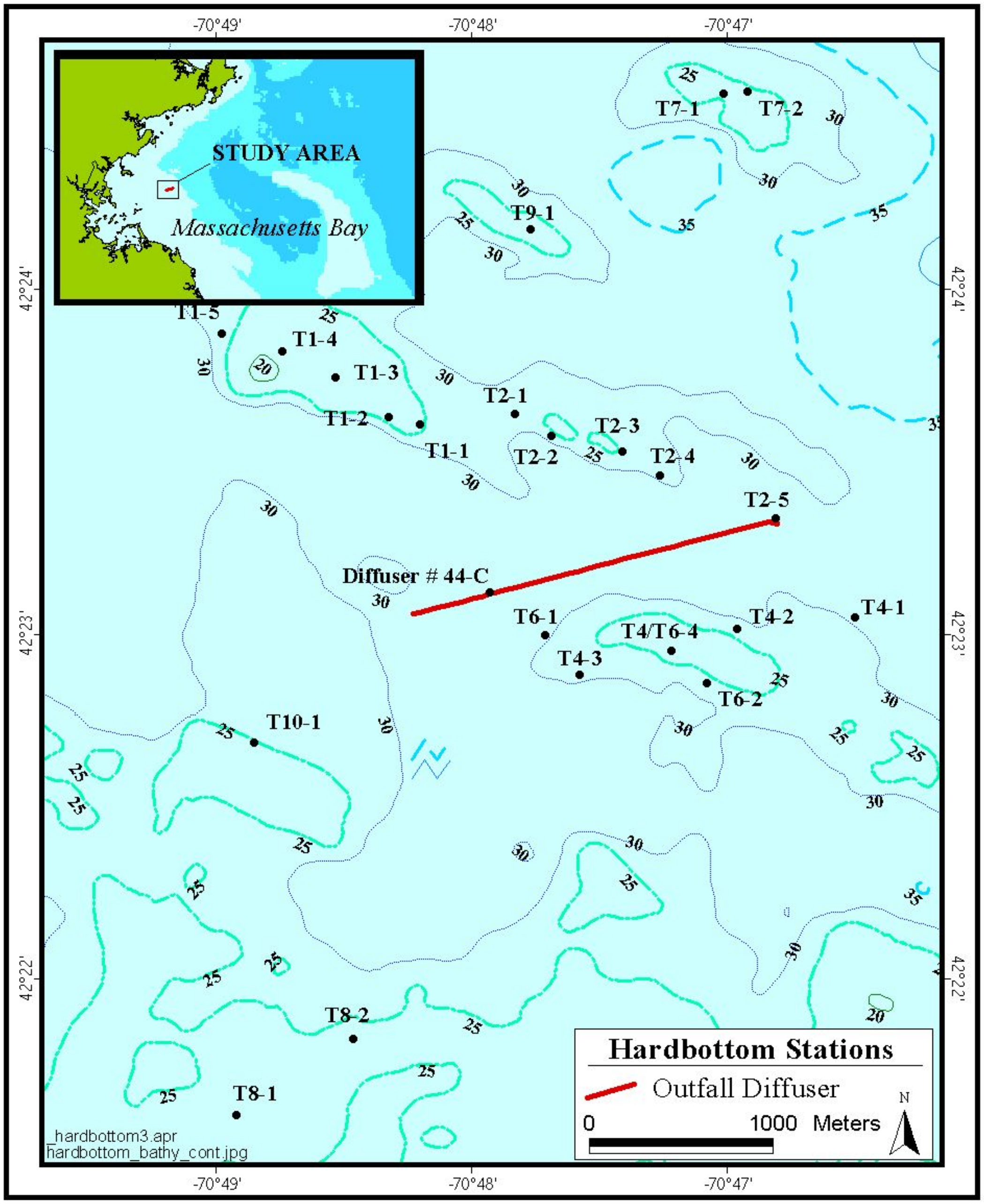


Figure 5-3. Locations of hard-bottom stations

Monitoring Design

Sea floor monitoring includes several components: measurements of contaminant concentrations and other chemistry parameters in sediments, sediment-profile imaging to provide a rapid assessment of potential effects on benthic communities and sediment quality, studies of nearfield and farfield soft-bottom communities (sampling sites in Figures 5-1 and 5-2), and study of hard-bottom communities (sampling sites in Figure 5-3).

In addition to MWRA's outfall monitoring, long-term studies of sediment transport and contaminant levels in Boston Harbor, Massachusetts Bay, and Cape Cod Bay are conducted by USGS. Since 1977, USGS has periodically sampled four stations within Boston Harbor, and since 1989 they have taken sediment cores three times a year from two stations, one sandy and one muddy, near the Massachusetts Bay outfall (USGS 1997b; Figure 5-1).

Because contaminant concentrations were consistently low, the MWRA baseline sediment-contaminant studies were considered adequate after three years of sampling in 1995. Then, until the outfall began operation, sampling for contaminant measurements occurred intermittently. All stations were sampled in 2001.

Beginning in 1998, a subset of four stations was designated for special study. The stations were selected because they have a high percentage of fine-grained material, with those percentages remaining stable during the baseline-monitoring period. They have high concentrations of total organic carbon (TOC) and are located in the zone of effluent particle deposition predicted by the Bays Eutrophication Model. The data from these stations are intended to provide early indications of rapid contaminant build-up, should it occur.

Prior to the startup of the outfall, the special-study stations were sampled once per year, in August. Since late 2000 when the outfall began operation, the stations have been sampled three times per year, in February or March, August, and October. Samples are analyzed for spores of the sewage indicator bacterium *Clostridium perfringens*, sediment grain size, TOC, and contaminants.

Sediment-profile image surveys are conducted in August of each year at 20 nearfield and three farfield, western Massachusetts Bay, stations to give an area-wide assessment of sediment quality and benthic community status. They provide a more rapid assessment of benthic habitat conditions than is possible from traditional faunal analyses. A system called "Quick Look," which uses digital video cameras along with film, provides an even faster assessment. A real-time narration of the videotape describes the substrate and estimates depth to which oxygen penetrates, known as the oxidation-reduction potential discontinuity (RPD). Later, complete analyses of films provide information on prism penetration, surface relief, apparent color RPD depth, sediment grain size, sediment layering, fauna and structures, and successional stage of the soft-bottom animal communities.

Nearfield and farfield soft-bottom surveys are also conducted in August. Sampling of 23 nearfield and western Massachusetts Bay stations is designed to provide spatial coverage and local detail about the fauna in depositional areas located within eight kilometers of the diffuser. Farfield sampling of eight additional stations in Massachusetts and Cape Cod bays contributes regional data on soft-bottom habitats. Samples are analyzed for community parameters, *Clostridium perfringens* spores, sediment grain size, TOC content, and contaminant concentrations.

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 5-3). Video and still photographs are taken at 21 stations or waypoints, which include diffuser head #44 of the outfall (which will not be opened), and at diffuser head #2. These surveys are conducted annually in June. Photographs are examined for substrate type (top or flank of the drumlin, with relief defined by presence of boulders and cobbles), amount of sediment drape (the degree to which there is a layer of fine material on the hard surface), and biota (taxa identified to species or species groups).

Results

The August 2001 sampling marked the beginning of sediment sampling for the discharge period. The first discharge monitoring of hard-bottom areas was conducted in June 2001. The data represent the response of the sea floor to the first full year of discharge.

Sediment Contaminants

Baseline sampling at nearfield stations indicated that the area around the outfall was composed of heterogeneous sediments that had received historic inputs of contaminants from Boston Harbor. Data from 2001 were not substantially different from the baseline. Most parameters measured in 2001 were within the baseline range. However, concentrations of lead were greater than the baseline at several stations, and at one station, well away from the diffuser, concentrations of total PAHs, lead, mercury, nickel, silver, and zinc concentrations were all greater than the baseline range. Another station (NF21, located about 4 kilometers to the northwest of the outfall) had an unusually high concentration of total DDT. This result passed the program's quality assurance tests, which included re-analysis, and may be real. Stations nearer the outfall did not show elevated DDT concentrations, and the result is so unusual that an analytical interference (false positive) remains a possibility. Draft data from the 2002 sampling indicate no anomalously high DDT values from any station. Statistical analyses using principle components indicated a general decrease in levels of anthropogenic compounds in the nearfield.

For stations located within 2 km of the outfall, when the data accounted for the percent of fine particles in the samples, there were increased concentrations of *Clostridium perfringens* spores, a tracer of effluent particles. These results indicate that the sediments in the immediate vicinity of the discharge are responding as expected, that is, there is a localized increase in effluent tracers near the outfall.

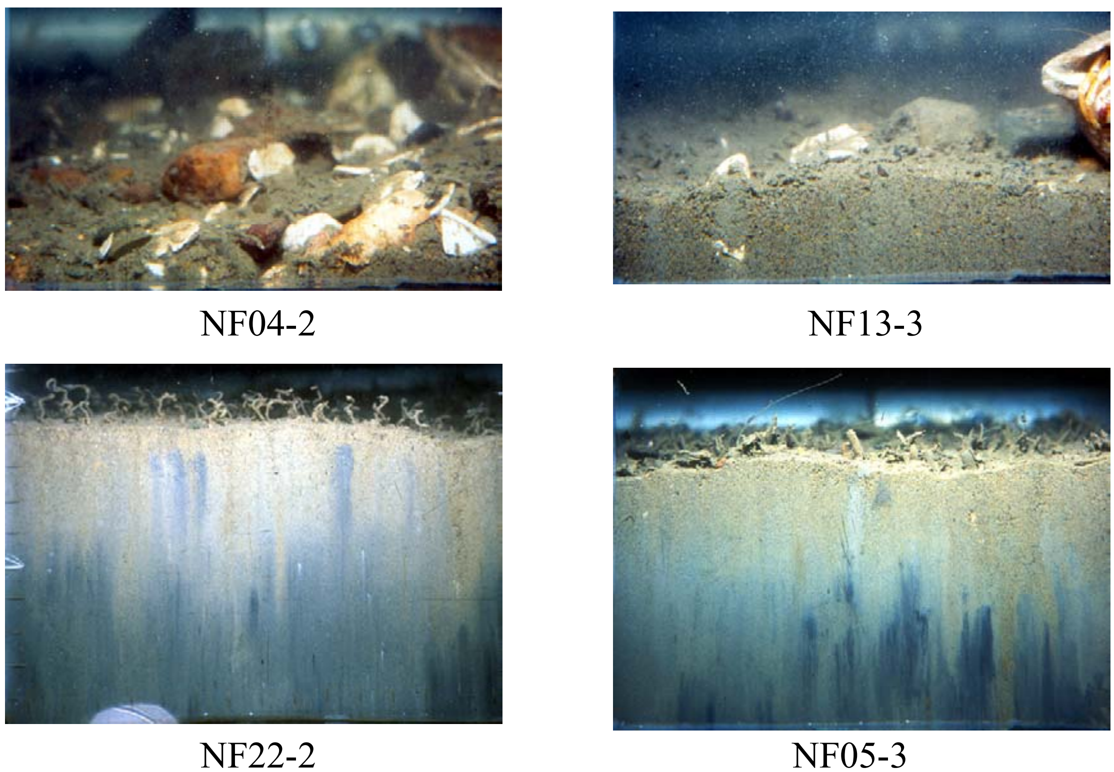


Figure 5-4. Representative sediment profile images from 2001. NF04 had very hard, gravelly sediments that the prism could not penetrate, NF13 had a combination of sand and gravel, while NF05 and NF22 contained primarily muddy sediments.

Sediment Profile Imaging

Benthic habitat conditions in 2001 were similar to those of the recent baseline period (Kropp *et al.* 2002, Figure 5-4). The nearfield stations were dominated by biogenic structures and organism activity. Sediments at some stations were heterogeneous, composed of particles ranging from silts and clays to cobbles. Other stations were composed of homogeneous, fine-grained material. Most stations with fine sediments had high densities of polychaete tubes. Stations with coarser sediments were covered with a thin drape of sediments, most of which had been incorporated into biogenic tubes.

The depth of the apparent RPD continued to reflect the dominance of biological processes, and the grand average RPD layer for all stations was essentially the same in 2001 as in 2000 (Figure 5-5). This average was within the annual range of the baseline period. Overall, it appeared that biological processes predominated in shaping surface sediments, although there were also signs of physical processes.

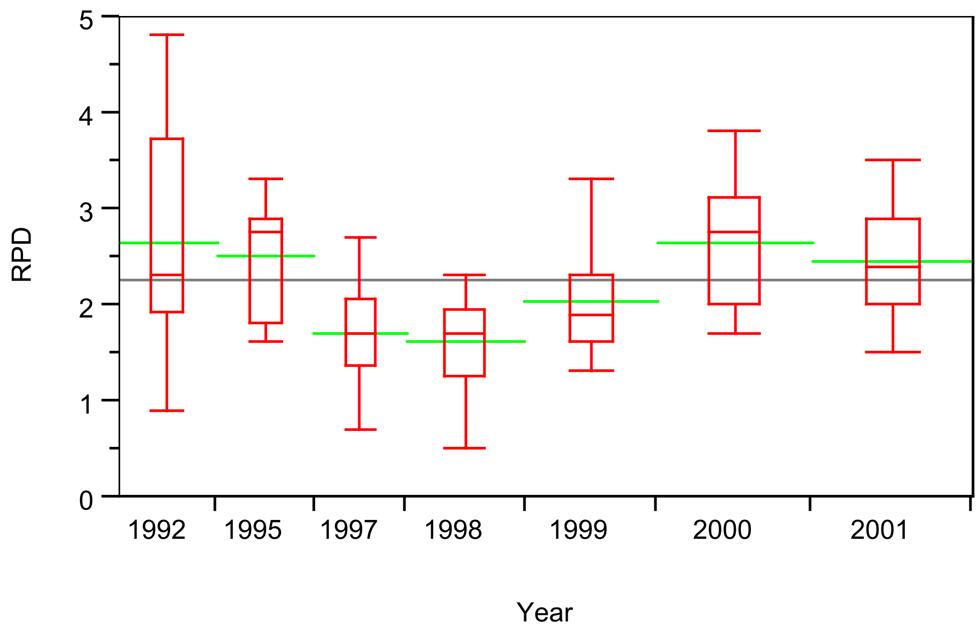


Figure 5-5. Apparent color RPD depth (cm) for all data from nearfield stations. Box is interquartile range, short bar is median, wide bar is mean, and whiskers are ranges. Horizontal line is grand mean for all years. (The caution threshold is 1.18 cm.)

Soft-bottom Communities

Soft-bottom sediments in the nearfield support typical New England coastal benthic communities. Stations with fine sediments have communities dominated by polychaetes worms, such as *Prionospio steenstrupi, Spio limicola, Mediomastus californiensis,* and A*ricidea catherinae.* Sandier stations are inhabited by polychaetes *Polygordius* sp. and *Exogone* spp. and by the amphipods *Crassicorophium crassicorne* and *Unciola* spp. The nearfield stations are sometimes affected by winter storms that resuspend sediments.

Farfield stations occupy a broader geographic and depth range. While communities found at farfield stations share many species with those found in the nearfield, they also support a wider variety of species characteristic of New England coastal habitats. Polychaete worms, including *Euchone incolor*, *Aricidea quadrilobata*, and *Levinsenia gracilis,* predominate at most stations.

During the nine years of baseline monitoring, annual measurements of community parameters showed somewhat similar temporal patterns in the nearfield and farfield. In the nearfield, there was a large reduction in overall abundance and number of species between 1992 and 1993. This decline has been attributed to a severe winter storm in 1992. The effects of the storm were evident in the two community parameters that are measured directly, total abundance of organisms and total number of species, and in one of the calculated indices, log-series alpha. Two other indices, Shannon diversity, and Pielou's evenness, did not detect any change from the storm. The effects of the storm were not apparent in the farfield.

In 2001, measurements of community parameters were within the range measured for the baseline period (for example, Figure 5-6). Infaunal abundance, numbers of species, Shannon diversity, evenness, and log-series alpha were within the historic ranges for both nearfield and farfield stations.

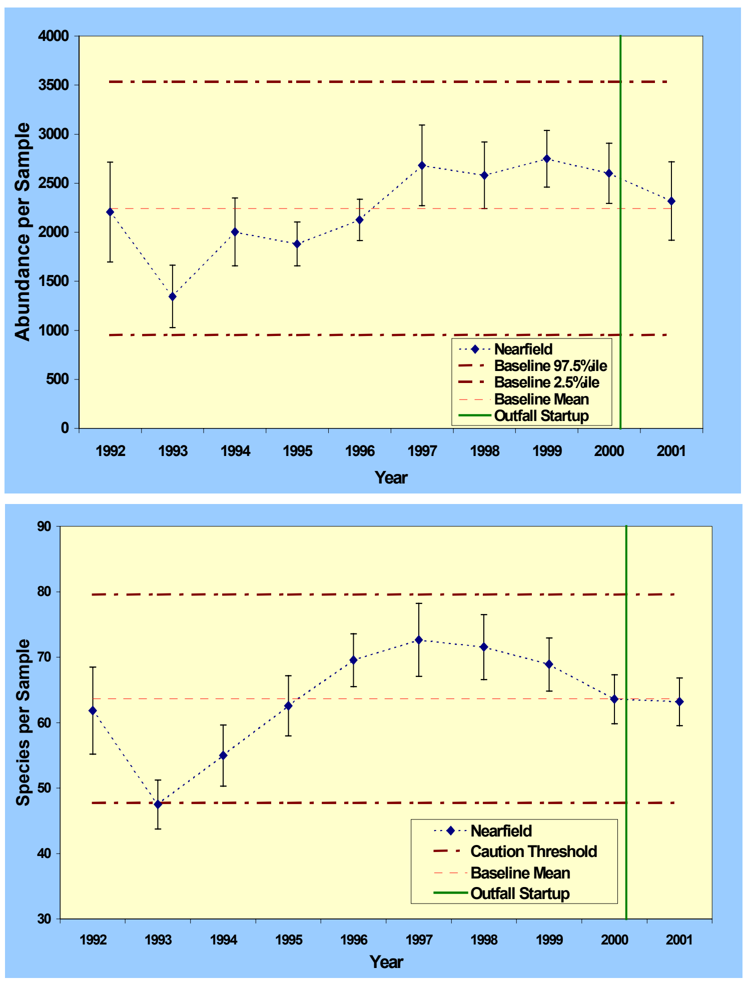


Figure 5-6. Abundance of species and total species per soft-bottom sample, nearfield,1992-2001

Opportunistic species of concern were present in low numbers at all nearfield stations and did not show any response to the first full year of discharge. Relative abundance of opportunists was at the low end of the baseline range.

Hard-bottom Communities

Rocky environments in the vicinity of MWRA's outfall support communities of algae and invertebrates similar to those found throughout northern New England. Near the outfall, these environments and the communities they support are stable from year to year, but vary over relatively short distances, on the scale of tens of meters, ranging from large boulders to cobbles to gravel pavements (Figure 5-7, Kropp *et al.* 2002). These patterns persisted in 2001, with no changes in response to operation of the outfall.

Typically, approximately half the organisms seen can be identified to species. Other organisms are grouped into taxa that could be described by general characteristics, such as "orange-tan encrusting." In 2001, eighty-five species and grouped taxa were identified. The most abundant taxon was, as in previous years, coralline algae, species whose colonies form thin, pinkish-purple crusts on rock surfaces. Coralline algae were seen at 20 of the 23 waypoints or stations. Other common algae included dulse *Rhodymenia palmata* and a red, filamentous alga *Ptilota serrata*. Shotgun kelp *Agarum cribosum* was very abundant at one waypoint, where, similar to 2000, it was typically overgrown by a lacy bryozoan.

As in previous years, the most abundant invertebrate was the northern seastar, *Asterias vulgaris*. Other common invertebrates included the frilled anemone *Metridium senile,* the horse mussel *Modiolus modiolus*, the sea pork tunicate *Aplidium* sp., an unidentified white sponge, the brachiopod *Terebratulina septentrionalis*, and an unidentified orange or tan sponge. Anemones were especially abundant on the smooth surface of the outfall diffuser that is included in the monitoring. The most common fish was the cunner *Tautogolabrus adspersus*.

As in previous years, algae usually dominated the tops of drumlins, while encrusting or attached invertebrates were increasingly dominant on the flanks. Abundance of encrusting coralline algae has been inversely correlated with sediment drape throughout the baseline-monitoring program, percent cover being greatest in areas with the least sediment.

At the end of the baseline period, it appeared that coralline algae could be good indicators of outfall effects. Change could occur either through smothering or by changes in light penetration or water clarity. After the outfall began operating in 2001, slight decreases in percent cover by coralline algae were noted at three stations on the drumlin immediately to the north of the outfall. However, similar decreases were found at the two most northern reference stations, so the changes could not be attributed solely to the outfall.

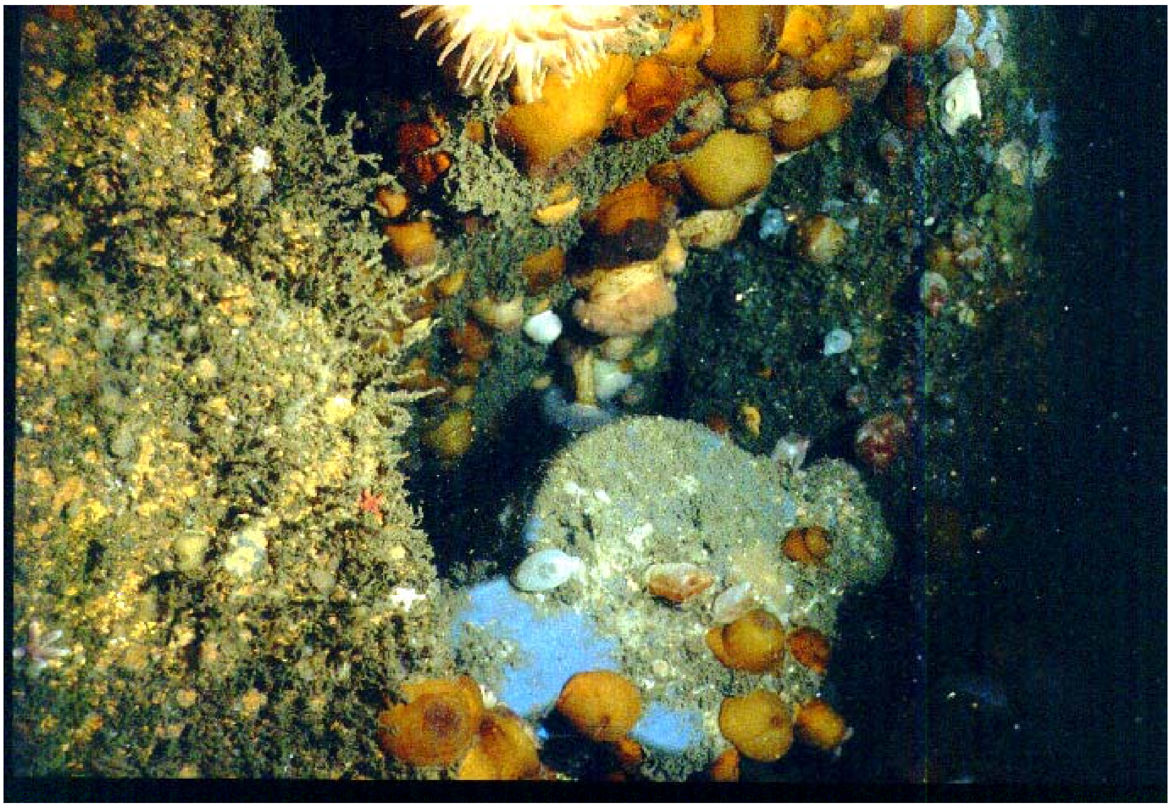


Figure 5-7. Hard-bottom survey photograph of an inactive port on Diffuser Head #2

Contingency Plan Thresholds

No contingency plan threshold parameters for sea floor monitoring were exceeded in 2001. Those parameters include contaminant concentrations, RPD depth, and benthic diversity and species composition in soft-bottom communities (Table 5-1).

Table 5-1. No contingency plan baseline and threshold values for sea floor monitoring were exceeded in 2001.

Location	Parameter	Caution Level	Warning Level	2001 Results
Sediment toxic contaminants, nearfield	Acenaphthene	None	500 ppb dry	35 ppb dry
	Acenaphylene	None	640 ppb dry	48 ppb dry
	Anthracene	None	1100 ppb dry	167 ppb dry
	Benz(a)pyrene	None	1600 ppb dry	277 ppb dry
	Benzo(a)pyrene	None	1600 ppb dry	285 ppb dry
	Cadmium	None	9.6 ppm dry	0.1 ppm dry
	Chromium	None	370 ppm dry	75.1 ppm dry
	Chrysene	None	2800 ppb dry	278 ppb dry
	Copper	None	270 ppm dry	24.3 ppm dry
	Dibenzo(a,h)anthracene	None	260 ppb dry	47 ppb dry
	Fluoranthene	None	5100 ppb dry	569 ppb dry
	Fluorene	None	540 ppb dry	52 ppb dry
	Lead	None	218 ppm dry	46 ppm dry
	Mercury	None	0.71 ppm dry	0.27 ppm dry
	Naphthalene	None	2100 ppb dry	83 ppb dry
	Nickel	None	51.6 ppb dry	18 ppb dry
	p,p'-DDE	None	27 ppm dry	0.5 ppm dry
	Phenanthrene	None	1500 ppb dry	421 ppb dry
	Pyrene	None	2600 ppb dry	528 ppb dry
	Silver	None	3.7 ppm dry	0.5 ppm dry
	Total DDTs	None	46.1 ppb dry	5 ppb dry
	Total HMWPAH	None	9600 ppb dry	3625 ppb dry
	Total LMWPAH	None	3160 ppb dry	1669 ppb dry
	Total PAH	None	44792 ppb dry	5293 ppb dry
	Total PCBs	None	180 ppb dry	13 ppb dry
	Zinc	None	410 ppm dry	60 ppm dry
Sediments, nearfield	RPD depth	1.18 cm	None	2.4 cm
Benthic diversity, nearfield	Species per sample	<47.97 or >81.09	None	63.1
	Fisher's log-series alpha	<10.13 or >15.58	None	13.1
	Shannon diversity	<3.32 or >4.02	None	3.8
	Pielou's evenness	<0.56 or >0.67	None	0.64
Species composition, nearfield	Percent opportunists	10%	25%	0.34%

6. Fish and Shellfish

Background

MWRA monitors fish and shellfish because of concerns for public health and because some fish and shellfish species are good indicators of effects of pollutants on overall marine health. This section presents the results of fish and shellfish monitoring for the year 2001, the first samples collected following start up of the outfall.

The fish and shellfish industry is an important part of the regional identity and economy of Massachusetts. One concern about relocating sewage effluent offshore, into relatively clean waters, is that contaminants could adversely affect resource species, either through direct damage to the fishery stocks or by contamination of the fish, lobster, and other shellfish, rendering them unfit for human consumption. Because many toxic contaminants adhere to particles, animals that live on the bottom, in contact with sediments, and animals that eat bottom-dwelling organisms are most likely to be affected. Exposure to contaminated sediments could result in fin erosion, black gill 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. These shellfish are themselves resource species and are prey to other fisheries species. Consumption of these animals by predators could result in transferring contaminants up the food chain and ultimately to humans.

Monitoring Design

The monitoring program focuses on three indicator species: winter flounder, lobster, and blue mussel (Figure 6-1). Winter flounder and lobster are important resource species in the region. The blue mussel is also a fishery species and, when deployed in caged arrays, is a common biomonitoring organism.

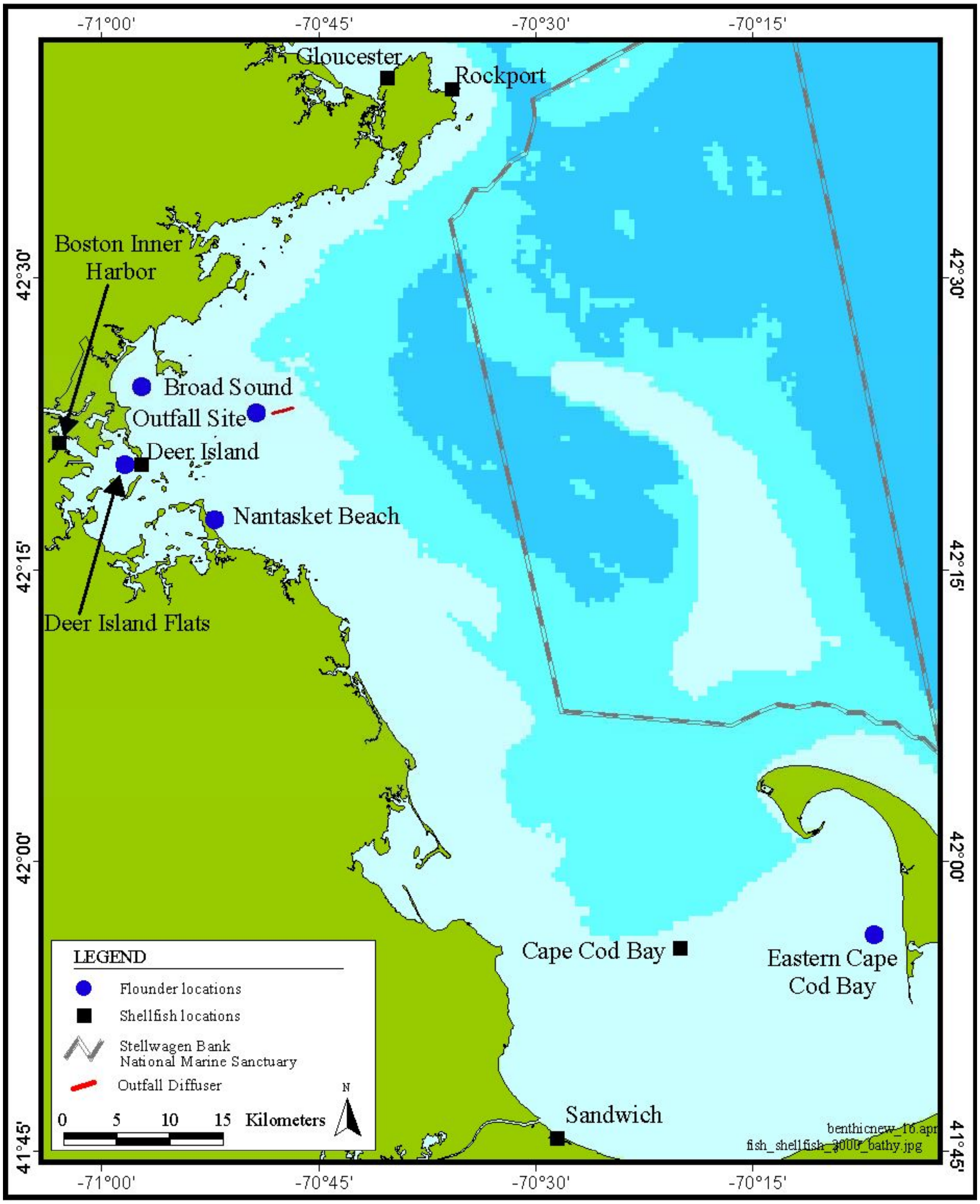


Figure 6-1. Sampling areas for fish and shellfish monitoring. (See text for sample locations of individual species.)

Like all flatfish, winter flounder live on and eat food from the bottom, often lying with all but their eyes buried in the sediments. Consequently, flounder can be exposed to contaminants directly, through contact with the sediments, or indirectly, by ingesting contaminated prey. Flounder are collected from five locations to obtain specimens for age determination, gross examination of health, and liver histology: Deer Island Flats, Broad Sound, off Nantasket Beach, the outfall site, and eastern Cape Cod Bay. Livers are examined to quantify three types of vacuolation (centrotubular, tubular, and focal, representing increasing severity), microphage aggregation, biliary duct proliferation, and neoplasia or tumors. Neoplasia and vacuolation have been associated with chronic exposure to contaminants.

Chemical analyses of winter flounder tissues from Deer Island Flats, the outfall site, and Cape Cod Bay are also made to determine tissue burden and to evaluate whether contaminant burdens approach human health consumption limits. Chemical analyses of composite samples of fillets and livers include PCBs, pesticides, mercury, and lipids. Liver samples are also analyzed for PAHs, lead, silver, cadmium, copper, nickel, and zinc.

Lobsters live on a variety of surfaces within the region, including mud, sand, gravel, and rock outcrops. Commercial lobstermen collect lobsters for the monitoring program, with on-board scientists verifying the sampling locations. Lobsters are taken from Deer Island Flats, the area near the new outfall, and eastern Cape Cod Bay to determine specimen health and tissue contaminant burden. 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.

Like other filter feeders, blue mussels process large volumes of water and can concentrate toxic metals and organic compounds in their tissues. Mussels can be readily maintained in fixed cages, so they are convenient monitoring tools. Until 2000, mussels were collected from reference sites in Gloucester and Sandwich. Gloucester mussels provided a reference for organic contaminant analyses, and Sandwich mussels provided a reference for inorganic contaminants. Beginning in 2000, a new reference area, with low levels of both organic and inorganic contaminants, was identified in Rockport.

Mussels are deployed in replicate arrays at as many as four sites, including Boston Inner Harbor, Deer Island, the outfall site, and Cape Cod Bay. 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.

Results

Winter Flounder

Fifty sexually mature (at least three years old) winter flounder were taken from each of five sampling sites in April 2001 (Lefkovitz *et al.* 2002). Each of the fish was examined for physical characteristics. Fifteen fish from Deer Island Flats, the outfall site, and eastern Cape Cod Bay were designated for chemical analyses. All fish were used for histological and age analyses.

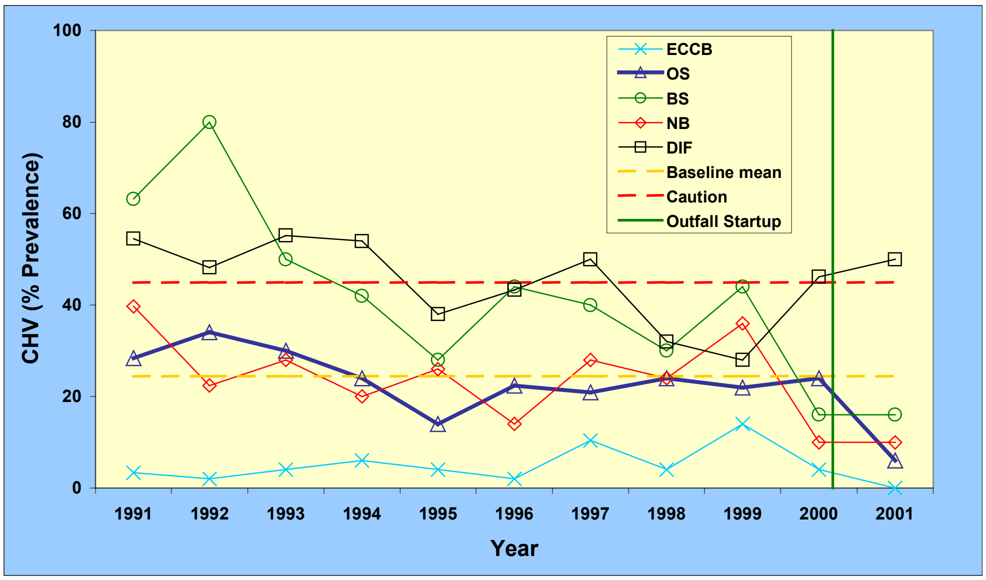


Figure 6-2. Prevalence of centrotubular hydropic vacuolation (CHV) (ECCB = Eastern Cape Cod Bay, OS = Outfall Site, BS = Broad Sound, NB = Nantasket Beach, and DIF = Deer Island Flats)

Overall, the fish appeared healthy, and no response to the outfall was detected. Tumors were absent and incidence of fin erosion was low. As in previous years, the milder centrotubular hydropic vacuolation (CHV) was the most common form of vacuolation.

For the second year in a row, CHV prevalence at Deer Island Flats was higher than the year before (Figure 6-2). Conversely, CHV prevalence dropped at the outfall site and Broad Sound. In 2001, there was some suggestion that the increase in CHV at Deer Island could be related to the increasingly older fish collected since 1999.

Overall, body burdens of organic contaminants in edible tissues were similar to burdens in previous years. Mercury concentrations were similar to 1999 and 2000. Concentrations of organic contaminants in flounder livers were also comparable to concentrations measured in prior years. Over all the years of sampling, concentrations of organic compounds have tended to be highest in liver tissue of fish from Deer Island Flats and lowest in those from eastern Cape Cod Bay. However, metals concentrations have been highest in fish from the outfall site and lowest in those from eastern Cape Cod Bay. In 2001, concentrations of lead and cadmium were at the upper end of the historical range at the outfall site, similar to 1999 and 2000. In eastern Cape Cod Bay, concentrations of mercury were the lowest measured during the program.

Lobster

Fifteen lobsters were taken from each of the three sampling locations during July through September (Lefkovitz *et al.* 2002). The lobsters were approximately the same weight and size at all sites. Mostly males were found at eastern Cape Cod Bay and Deer Island Flats. Females predominated at the outfall site. No gross abnormalities or other deleterious conditions were noted in any of the lobsters collected during the survey.

As in previous years, contaminant concentrations in lobster meat were low. The highest concentrations of most organic contaminants in tail and claw meat were found in lobsters taken from Deer Island Flats, and the lowest concentrations were found in lobsters taken from eastern Cape Cod Bay. Following a different pattern, mercury concentrations were highest in samples taken at the outfall site and lowest in those from Cape Cod Bay. This pattern was also consistent throughout the baseline-monitoring period. Concentrations of mercury in the claw and tail meat were in the middle of the historical range.

The inter-regional pattern of organic contaminant burdens in lobster hepatopancreas was the same as in prior years, with the highest concentrations in lobsters from Deer Island Flats. Concentrations of organic contaminants tended to be similar to or lower than in previous years at all three locations.

Historically, concentrations of metals in lobster hepatopancreas have been more variable than concentrations of organic contaminants, with concentrations often as high or higher in animals from the outfall site and eastern Cape Cod Bay as in those from Deer Island Flats. In 2001, concentrations were within the historic range.

Blue Mussel

Full mussel arrays were recovered after 40 and 60 days (Lefkovitz *et al.* 2002). Survival was high, ranging from 98 to 100% for both 40- and 60-day deployments.

Table 6-1 summarizes the results of the 2001 bioaccumulation data for contingency plan constituents at the four test locations and the control site.

Historically, the Boston Inner Harbor and Deer Island sites have shown the highest concentrations of contaminants, and the Cape Cod Bay and outfall sites were the lowest. Overall, the inner harbor site still shows the greatest degree of bioaccumulation.

Table 6-1. 2001 mussel bioaccumulation results

Parameter	Outfall Site	Cape Cod Bay	Boston Harbor Deer Island	Boston Inner Harbor	Rockport (Control)
PCB (ppm wet weight)	0.0096	0.0131	0.0302	0.0383	0.0017
Lead (ppm wet weight)	.024	0.32	0.48	0.97	0.17
Mercury (ppm wet weight)	0.018	0.018	0.017	0.020	0.013
Chlordane (ppb lipid)	250	63	122	233	52
Dieldrin (ppb lipid)	25	17	22	56	11
DDT (ppb lipid)	205	203	356	907	122
PAH (ppb lipid)	3,024	1,116	3,485	26,488	1,134

In this first bioacculation test since the outfall came on-line, some contaminants, such as lead, mercury, PCBs, and DDT, remained at low levels at both the outfall site and in Cape Cod Bay. The test detected an increase in other contaminants (chlordane, dieldrin, and PAHs) at the outfall site only, indicating that the effluent is the probable source. For chlordane and PAHs, concentrations exceeded the contingency plan caution levels.

Contingency Plan Thresholds

Threshold parameters for fish and shellfish include levels of toxic contaminants in flounder, lobster, and mussels and liver disease in flounder (Table 6-2). Some thresholds are based on U.S. Food and Drug Administration (FDA) limits for maximum concentrations of specific contaminants in edible portions of food. Others are based on the baseline monitoring.

Table 6-2. Contingency plan baseline, threshold, and 2001 values for fish and shellfish monitoring

Parameter Type/ Location	Parameter	Baseline	Caution Level	Warning Level	2001 Results
Flounder tissue nearfield	PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.027 ppm
	Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.08 ppm
	Chlordane	242 ppb/g lipid	484 ppb/g lipid	None	144 ppb/g lipid
	Dieldrin	63.7 ppb/g lipid	127 ppb/g lipid	None	68.1 ppb/g lipid
	DDT	775.9 ppb/g lipid	1552 ppb/g lipid	None	596 ppb/g lipid
Flounder nearfield	Liver disease (CHV)	24.4%	44.9%	None	6%
Lobster tissue nearfield	PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0097 ppm
	Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.15 ppm
	Chlordane	75 ppb/g lipid	150 ppb/g lipid	None	49.5 ppb/g lipid
	Dieldrin	161 ppb/g lipid	322 ppb/g lipid	None	172 ppb/g lipid
	DDT	341.3 ppb/g lipid	683 ppb/g lipid	None	305 ppb/g lipid
Mussel tissue nearfield	PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0096 ppm
	Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.24 ppm
	Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.02 ppm
	Chlordane	102.3 ppb/g lipid	205 ppb/g lipid	None	250 ppb/g lipid, caution level exceedance
	Dieldrin	25 ppb/g lipid	50 ppb/g lipid	None	25.2 ppb/g lipid
	DDT	241.7 ppb/g lipid	483 ppb/g lipid	None	205 ppb/g lipid
	PAH	1080 ppb/g lipid	2160 ppb/g lipid	None	3020 ppb/g lipid, caution level exceedance

During 2001, the caution thresholds for PAHs and chlordane were exceeded in mussels, prompting evaluation of treatment plant operations, the mussel deployments, and the chemical analyses. The review found that the treatment plant was functioning well during the period of mussel deployment, achieving near-optimal removal levels of contaminants. Almost all of the flow received secondary treatment during the mussel-deployment period. Even in the undiluted effluent, concentrations of chlordane were at most, near the water quality criteria for marine receiving waters.

There were three deployments near the outfall site, located 15 m, 60 m, and 1000 m from the outfall diffuser (Figure 6-3). Deployments at these three locations allowed MRWA to examine contaminant concentrations data on a fine geographic scale (Hunt *et al*. 2002c).

Concentrations of PAHs and chlordane were highest in mussels deployed 15 meters from the outfall, intermediate in those deployed 60 meters from the outfall, and lowest in those deployed 1000 m from the outfall. (Mussels from all three of these locations had greater concentrations of PAHs and chlordane than those deployed at Deer Island or in Cape Cod Bay.)

MWRA compared data from these three deployments with estimates of predicted contaminant concentrations. The predictions were based on concentrations of the contaminants in the effluent, dilution as measured during the July dye study, and calculated bioconcentration factors. Although there is considerable uncertainty in the factors used to make the predictions, the results indicated a reasonable match between the predicted and actual measurements. Further, the measured data, while exceeding the caution thresholds, were not at levels that pose a toxicological risk to mussels or a public health risk to humans.

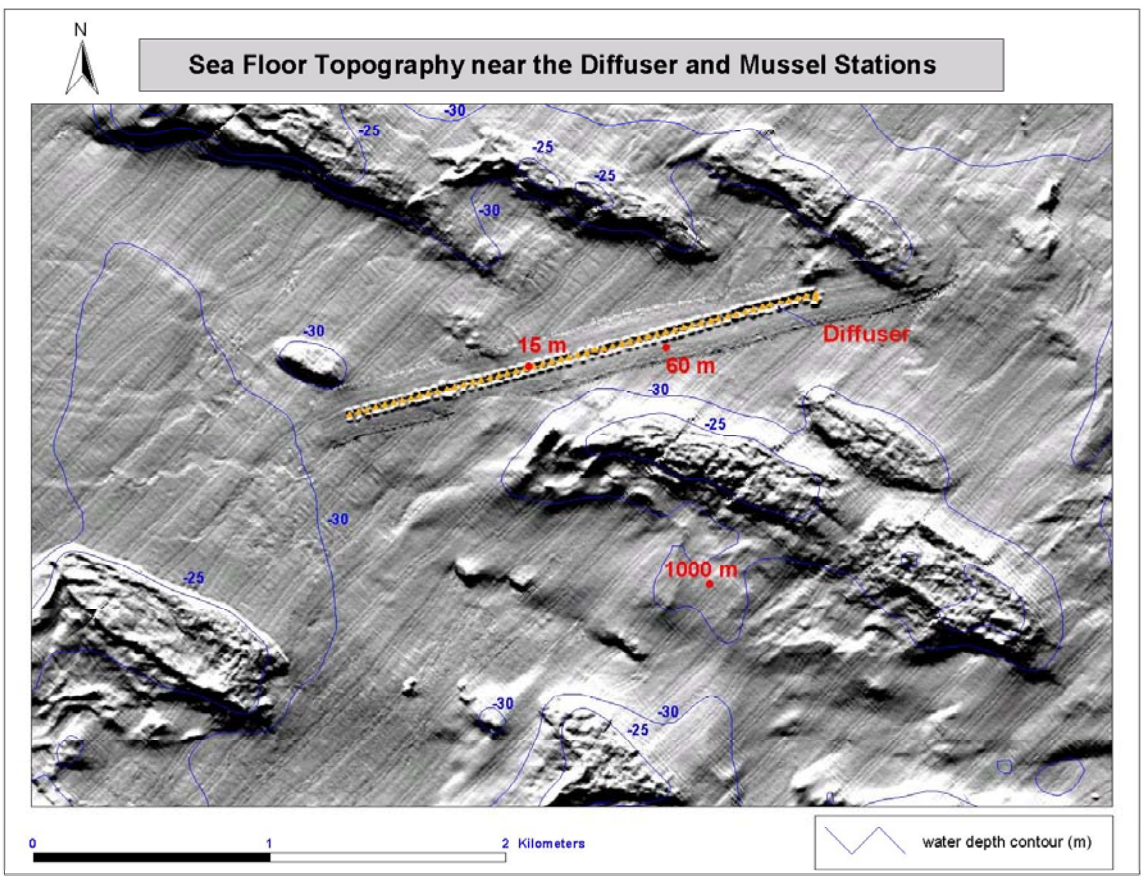


Figure 6-3. Locations of mussel deployments in the vicinity of the outfall site

Consequently, the findings prompted a review of the methods used to develop the thresholds. The review found that at the time that the thresholds were developed, MWRA did not anticipate any appreciable change in concentrations of contaminants in animals that naturally occur near the outfall. Thus thresholds were set as a simple “doubling” of the baseline concentrations. This approach was reasonable for mobile animals, which would not be expected to show any changes in contaminant concentrations. However, it should have been anticipated that concentrations of contaminants in caged animals located within the effluent plume would increase over the low baseline levels. MWRA will obtain more detailed estimates of PAH and chlordane in the effluent discharges during the summer of 2002 and may suggest that threshold values for PAH and chlordane in mussels are overly conservative and should be changed.

7. Special Studies

Background

Besides monitoring the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay and the surrounding area, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. For example, MWRA has a program to monitor Boston Harbor, which in 2001, documented dramatic improvements in water quality following diversion of the effluent from the harbor to Massachusetts Bay. MWRA also monitors nutrient cycling in the harbor and the bay and makes observations of marine mammals during water column and other surveys. On the recommendations of an OMSAP committee, the Bays Eutrophication Model Evaluation Group (BEMEG), MWRA has been working to improve the Bays Eutrophication Model. Also, MWRA monitoring is augmented by USGS studies of sediments and sediment trap samples near the outfall.

Improved Water Quality in Boston Harbor

Since the beginnings of the Boston Harbor Project, MWRA has been documenting improvements to the harbor. Each aspect of the project, including ending of sludge discharges in 1991, transfer of all wastewater to Deer Island Treatment Plant for secondary treatment in 1998, continued controls on CSO discharges, and the ending of effluent discharges to the harbor in 2000, has been a benefit to the harbor.

The improvements to water quality in the harbor following the ending of effluent discharges were immediate and striking (Figure 7-1, Table 7-1; Taylor 2002), and the magnitude of change seen in 2001 is not expected to continue in the future. Twelve months after the transfer of effluent to the offshore outfall, there were large decreases in nitrogen, phosphorus, and chlorophyll concentrations over most of the harbor. Average total nitrogen concentrations declined by 31%, largely due to an 83% decrease in ammonia concentrations. Significant decreases in total nitrogen were found at all harbor stations, including the south harbor. Decreases in phosphorus concentrations followed a similar pattern. Summer chlorophyll concentrations were the lowest measured since monitoring began in 1995, declining by 50%. These results were consistent with those predicted by the Bays Eutrophication Model.

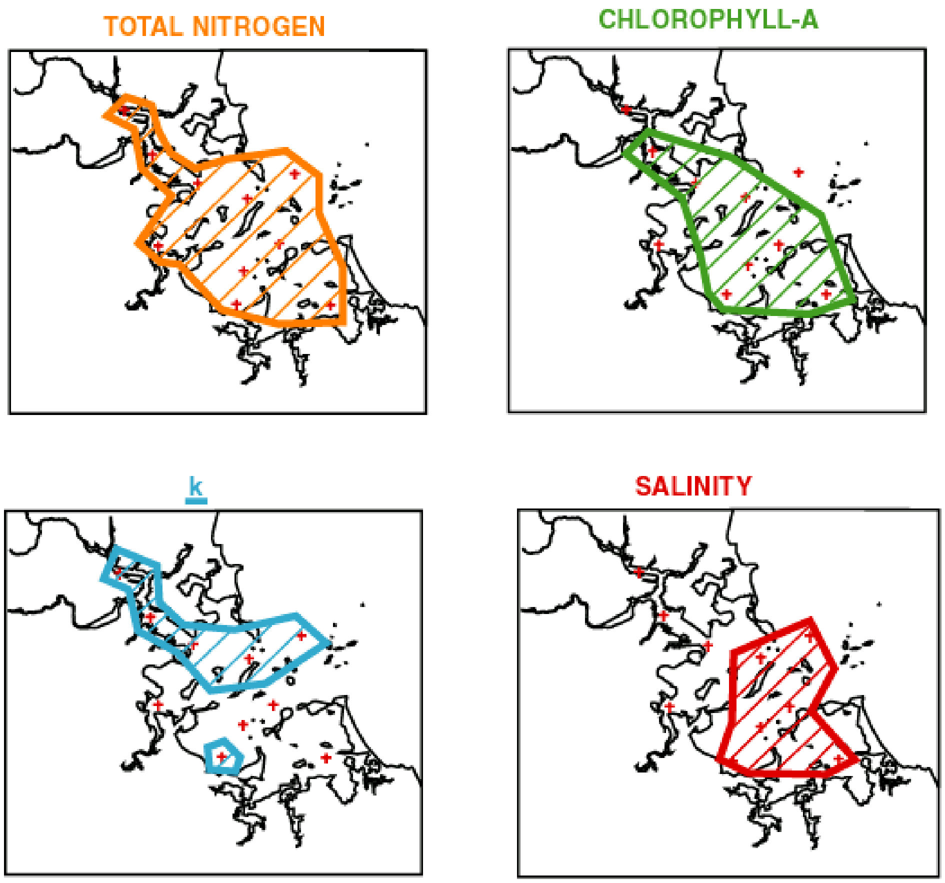


Figure 7-1. Spatial patterns of nitrogen, chlorophyll, water clarity (k), and salinity changes in Boston Harbor. Shaded areas enclose the sampling stations where significant changes were observed.

There were also smaller, more localized increases in water clarity, decreases in counts of sewage-indicator bacteria, and very localized increases in concentrations of dissolved oxygen in bottom waters. Water clarity, measured by beam attenuation k, increased significantly in the northern and inner portions of the harbor and in Hingham Bay.

Salinity also increased throughout the harbor. The increase was less than 1 part per thousand and mostly in the southern harbor. The small increase was consistent with predictions made by the USGS (R.Signell, USGS Wood Hole, unpublished data).

Table 7-1. Summary of the improvements in water quality in Boston Harbor following transfer of effluent discharge to the bay. Solid arrows indicate changes that were statistically significant for the harbor as a whole. Open arrows indicate changes that were significant at some stations.

WATER QUALITY INDICATOR	BEFORE	AFTER	CHANGE
TOTAL NITROGEN (µMOL L^{-1})	30.6	21.0	↓ 31% (solid)
TOTAL PHOSPHORUS (µMOL L^{-1})	1.8	1.6	↓ 11% (solid)
CHLOROPHYLL-A (µG L^{-1})	4.5	2.3	↓ 49% (solid)
WATER CLARITY (k) (M^{-1})	0.53	0.45	↑ 15% (solid)
DISSOLVED OXYGEN (MG L^{-1})	8.65	8.70	↑ 3 - 7% (open)
SEWERAGE-INDICATOR BACTERIA (*Enterococcus*) (CFU 100 ML^{-1})	21	7	↓ 67% (solid)
SALINITY (ppt.)	30.4	31.0	↑ 2 - 4% (open)

Nutrient Flux

MWRA has conducted studies of benthic nutrient cycling within Boston Harbor and in Massachusetts Bay since 1992. In 2001, studies were conducted at four sites in the harbor, three sites in the nearfield, and one site in Stellwagen Basin. No results showed any consistent response to relocation of the outfall (Tucker *et al.* 2002).

Sediment respiration rates in the bay were not especially high in 2001, less than those recorded in 1999 and 2000, possibly because phytoplankton biomass was lower. Nitrogen, phosphorus, and silica flux rates were not unusual. There were also no obvious changes in sediment carbon or pigment concentrations.

One concern that has motivated conducting these studies has been that organic matter, toxic contaminants, or nutrients from the relocated outfall could affect the sediment biogeochemistry of the bay. Stations monitored in the bay are located within the depositional areas that would be most likely to exhibit an effect. The processes studied, however, are not expected to show any immediate response to change, but rather to provide a measurement of long-term changes.

Marine Mammal Observations

Several endangered or threatened species of whales and turtles regularly visit Massachusetts and Cape Cod bays, including the right, humpback, finback, sei, and blue whales. Marine mammals that are not endangered or threatened also occur, including the minke whale, harbor porpoise, gray seal, harbor seal, and several species of dolphins.

Since 1995, MWRA has included endangered species observers on monitoring surveys. In 2001, observers were included on 29 surveys (McLeod 2002). Besides providing observational data, presence of trained marine mammal observers addresses a request by NMFS that MWRA take active steps to minimize the chances of a collision of one of its survey vessels with a right whale.

During the 2001 surveys, 20 individual whales, 30 harbor porpoise, and more than 100 Atlantic white-sided dolphins were sighted by the trained observers and other members of the monitoring team (McLeod 2002). Whale sightings included 7 right whales, 4 humpback whales, 4 minke whales, and 5 animals that could not be identified to species (Figure 7-2). The whale sightings were concentrated in Cape Cod Bay, but were also made throughout the bay, including the nearfield and Stellwagen Bank National Marine Sanctuary.

More right whales were sighted than in previous years. However, fewer total numbers of whales were seen in 2001 compared to 1999 and 2000, possibly because fewer sampling routes led through Stellwagen Bank, where many sightings had been made in previous years. Interpretation of the sightings data is difficult, because observations are made opportunistically, that is, on surveys devoted to other purposes, rather than by following systematic transects.

Observations of Stellwagen Bank made by the Whale Center of New England throughout 2001 indicated that humpback and fin whales occurred in low numbers during May and June. Humpback whales were abundant along the southern portion of the bank from July through November. Fin and minke whales were sighted throughout the region.

Systematic surveys of Cape Cod Bay, which have been conducted by the Center for Coastal Studies, found the number and seasonal occurrence of whales in 2001 was similar to previous years. For the first time since 1997, whale calves were present.

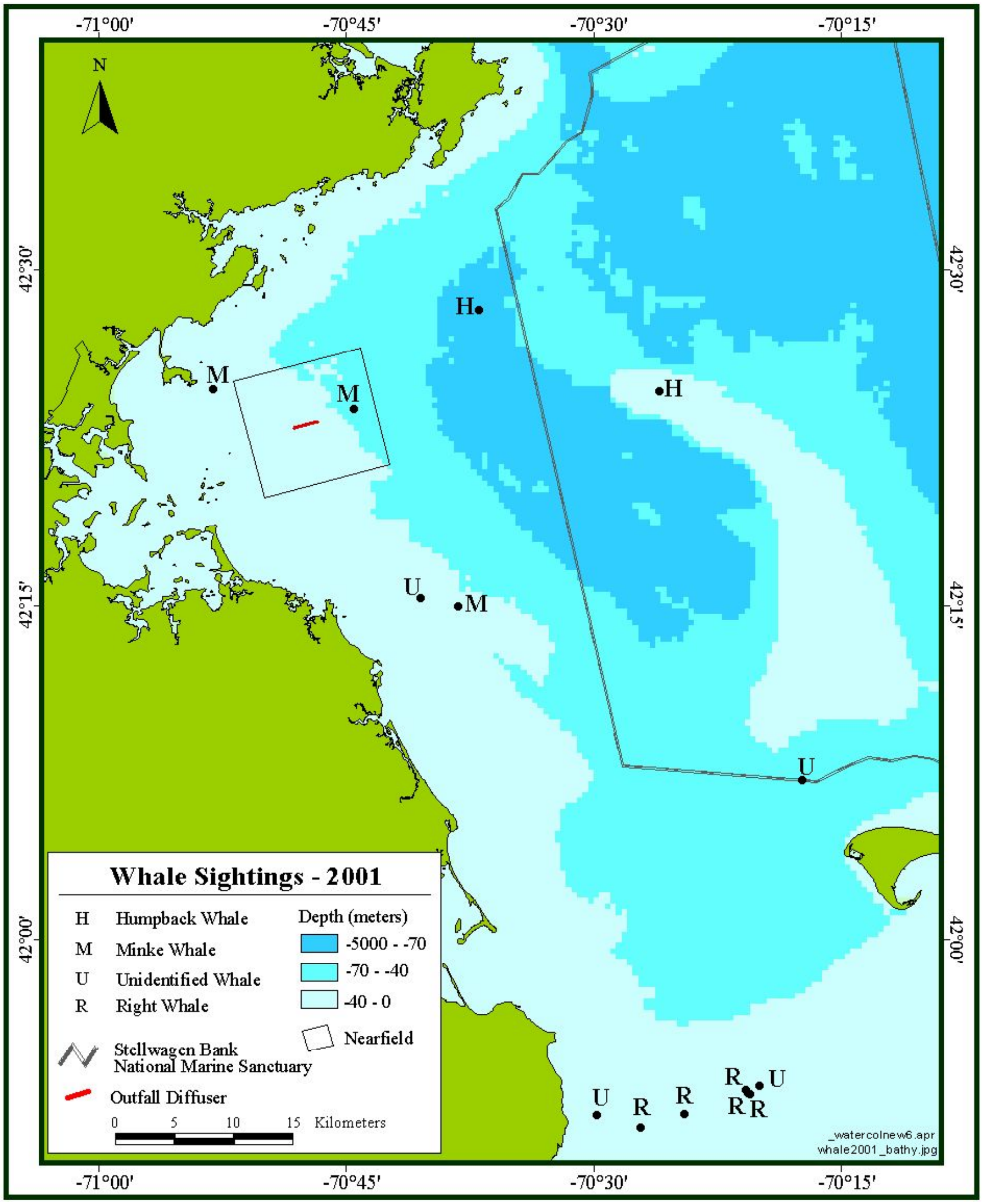


Figure 7-2. MWRA whale sightings during 2001

Modeling

In 1992, MWRA established a Model Evaluation Group (MEG) to advise MWRA, USGS, and HydroQual, Inc. on the development of predictive circulation and water-quality models. That group oversaw development and calibration of the Bays Eutrophication Model. OMSAP later established a successor committee, the Bays Eutrophication Model Evaluation Group (BEMEG) to review and recommend any changes to the model or the monitoring program that would improve the capabilities of models to predict circulation and water quality. BEMEG's reviews have covered model calibration, sensitivity of the predicted concentrations of dissolved oxygen and dissolved inorganic nitrogen near the outfall to changes in variables at the boundary stations, and attempts to improve predictions of the fall phytoplankton bloom.

BEMEG has made several recommendations for further work. For example, at an April 2002 meeting, BEMEG recommended additional model runs to determine whether the model captures changes resulting from closing the Nut Island plant and implementing secondary treatment. The group also recognized the importance of conditions in the western Gulf of Maine on Massachusetts Bay and recommended continued and improved sampling of water properties along the upstream boundary, which MWRA has been obtaining from the Gulf of Maine Ocean Observation System mooring.

USGS Sediment Studies

The USGS has been independently studying suspended and bottom sediments near the outfall since 1989, and in 2001, USGS scientists published the first results on concentrations of metals and bacteria spores before and after discharge began (Bothner *et al.* in press). USGS samples two nearfield stations (MWRA Stations NF12 and NF17, see Section 5, Sea Floor) and has deployed a time-series sediment trap 1.3 km south of the outfall and 4.2 meters above the bottom at a water depth of about 30 meters.

USGS has found that silver, which is used in film processing, is a good sewage tracer in sediments. Since 1989, concentrations of silver and the bacterial tracer *Clostridium perfringens* spores in surface sediments have followed similar patterns (Figure 7-3). Concentrations of both tracers increased dramatically in 1992, following a December storm when waves reached 8 meters in height. Presumably, the storm resulted in resuspension and transport of fine sediments and contaminants from inshore to offshore, depositional areas. By 1994, concentrations of sewage tracers in surficial sediments had returned to the levels they had been before the storm. USGS has not detected any effect of the outfall on concentrations of sewage tracers in the sediments. In 2001, concentrations of silver and the bacterial tracer were within the range of natural variability for the baseline period.

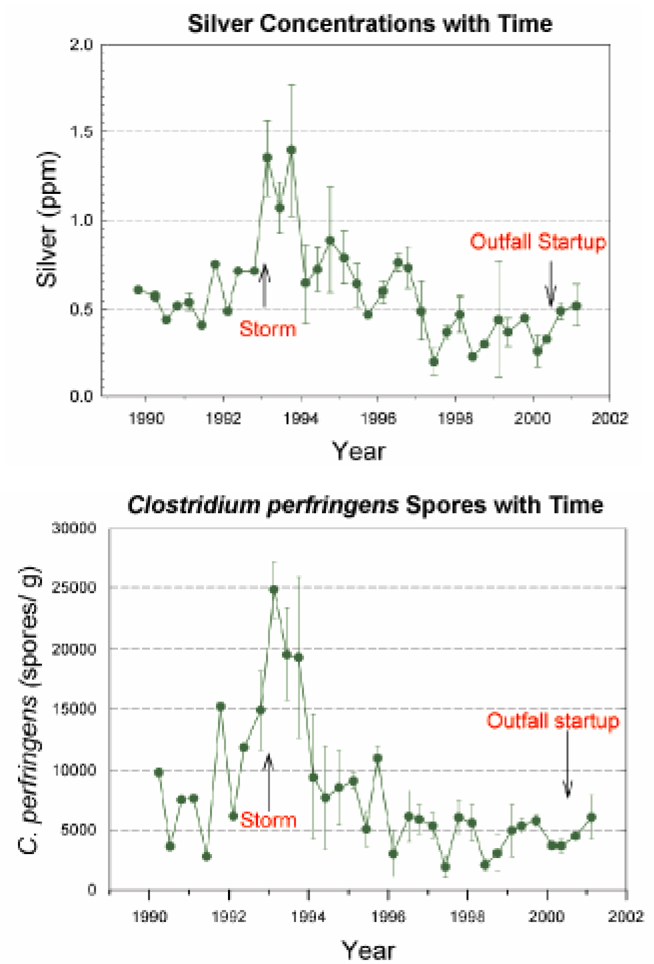


Figure 7-3. Silver and Clostridium perfringens *spores in surface sediments (from Bothner et al. in press)*

Analyzing contaminant concentrations in sediment traps has been a more sensitive measure of the effects of the outfall. Except during storms, when there is considerable resuspension, sediment traps isolate particles from older sediments, which may be mixed by bioturbation. USGS found no changes in concentrations of chromium, zinc, or copper in sediment trap samples before and after outfall start-up (Figure 7-4). Silver concentrations did increase slightly, and concentrations of *C. perfringens* spores doubled. A general correspondence between concentrations of the two tracers indicates a common source, that is, the outfall. The levels, although elevated, are within the range that USGS found in 1996 and 1997, when the sewage outfall was in Boston Harbor but secondary treatment had not been implemented.

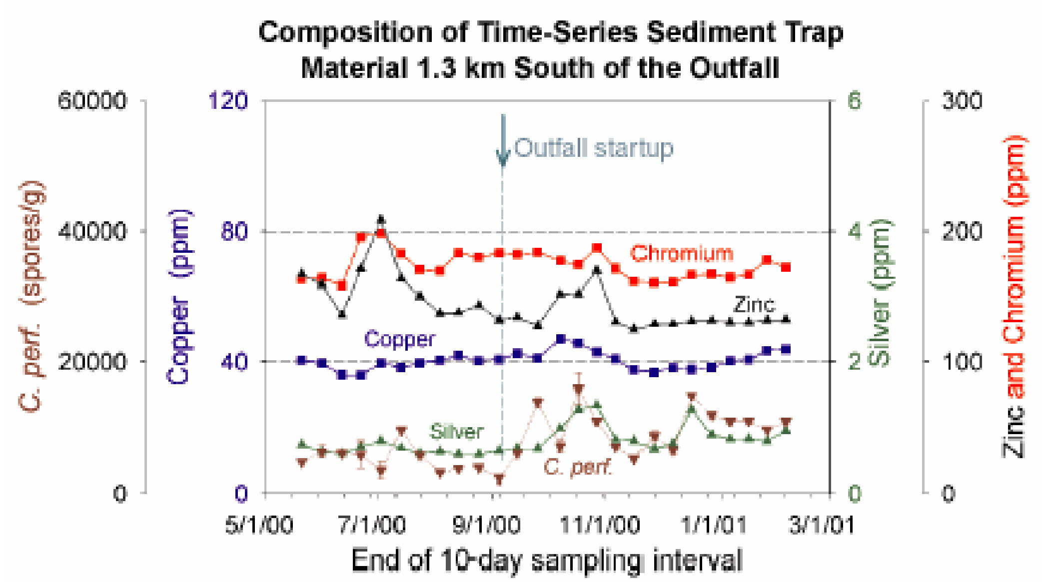


Figure 7-4. Average concentrations of metals and bacteria spores in sediment trap samples before and after outfall start-up (from Bothner et al. *in press)*

8. Stellwagen Bank National Marine Sanctuary

Background

The Gerry E. Studds Stellwagen Bank National Marine Sanctuary comprises 842 square miles located at the boundary of Massachusetts Bay and the Gulf of Maine. It extends to approximately 25 miles east of Boston, three miles north of Provincetown, and three miles south of Gloucester. Stellwagen Basin, which is partially within the sanctuary, is the deepest part of Massachusetts Bay and thus is a long-term sink for fine-grained sediments. Rising 165 feet to its east is Stellwagen Bank, a sand-and-gravel plateau, with water depths of about 65 feet. Currents from the Gulf of Maine and the basin create a rich habitat for marine life on Stellwagen Bank.

The sanctuary is currently revising its 1993 management plan. Ongoing scoping meetings have listed five issues of concern (Table 8-1).

Table 8-1. Issues of concern for the Stellwagen Bank National Marine Sanctuary

Management Plan Issues
▪ Alteration of seafloor habitat and ecosystem protection ▪ Impacts of human activities on marine mammals ▪ Condition of water quality ▪ Lack of public awareness ▪ Effective enforcement

The MWRA permit recognizes the concerns about possible effects of the outfall on the sanctuary and requires an annual assessment of those possible effects.

Monitoring Design

MWRA's regular water-column and sea-floor monitoring programs include stations within and near the sanctuary. Five water-column stations, including four within the sanctuary and one just outside the northern border are considered "boundary" stations, that is, they mark the boundary between Massachusetts Bay and the rest of the Gulf of Maine. These stations are important to MWRA, not just because of their location within a marine sanctuary, but also because water column processes within Massachusetts Bay are largely driven by the regional processes in the Gulf of Maine. Eight water-column stations located just inshore from the sanctuary are considered "offshore" stations by the MWRA program.

Figure 8-1 shows also shows for reference four non-MWRA stations, which were sampled by Battelle for the Sanctuary management in August and October 2001. The results are described in a SBNMS report (Hunt *et al.* 2002d) and compared to MWRA stations. Taken together, the data showed that the water quality in the sanctuary is excellent, even though physical attributes of salinity and temperature in the northern region of the sanctuary are spatially quite variable.

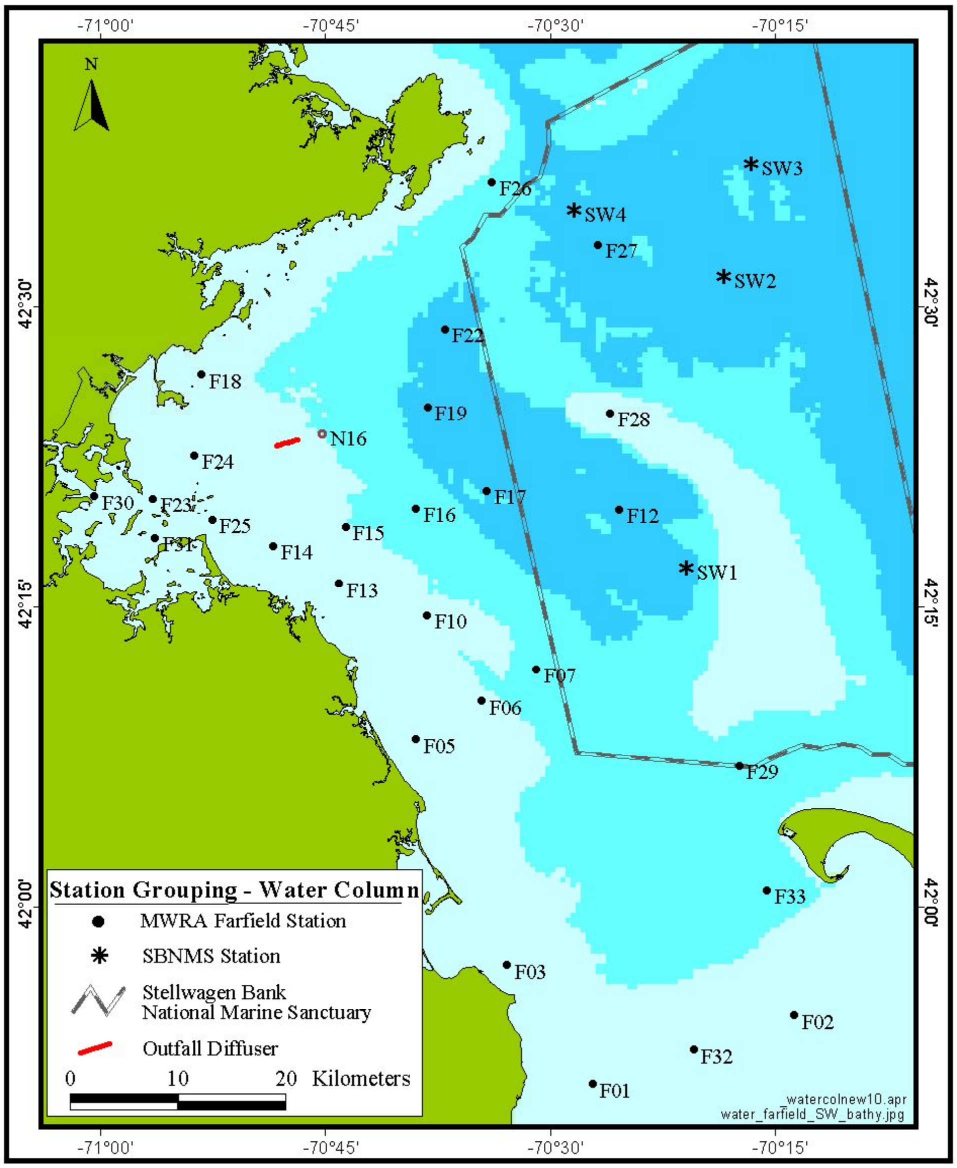


Figure 8-1. Water column stations, including the additional Stellwagen Bank National Marine Sanctuary (SBNMS) stations sampled in August and October 2001

Two MWRA sea-floor stations are within the sanctuary, one at the southern boundary and one within Stellwagen Basin. A third sea-floor station is just north of the sanctuary boundary and a fourth station is located outside the sanctuary, but within Stellwagen Basin. These four stations are the deepest of those included in the monitoring program and have similar properties, with muddy sediments and moderate total organic carbon concentrations. The station north of the sanctuary and the one within Stellwagen Basin are east or northeast of the outfall, outside the circulation pattern that transports diluted effluent south and southeastward in Massachusetts Bay. These stations are sampled annually in August.

Results

Water Column

Overall, water quality within the sanctuary was excellent during 2001. There were no elevated levels of ammonia, which if present could have indicated that the plume was being transported to sanctuary waters.

Mean concentrations of dissolved oxygen in bottom waters of Stellwagen Basin were somewhat higher than those found in the nearfield, typical of the pattern observed throughout baseline monitoring. The survey minimum concentration measured in Stellwagen Basin in 2001 was 7.8 mg/l, well above the 6.2 mg/l contingency plan background (Figure 8-2).

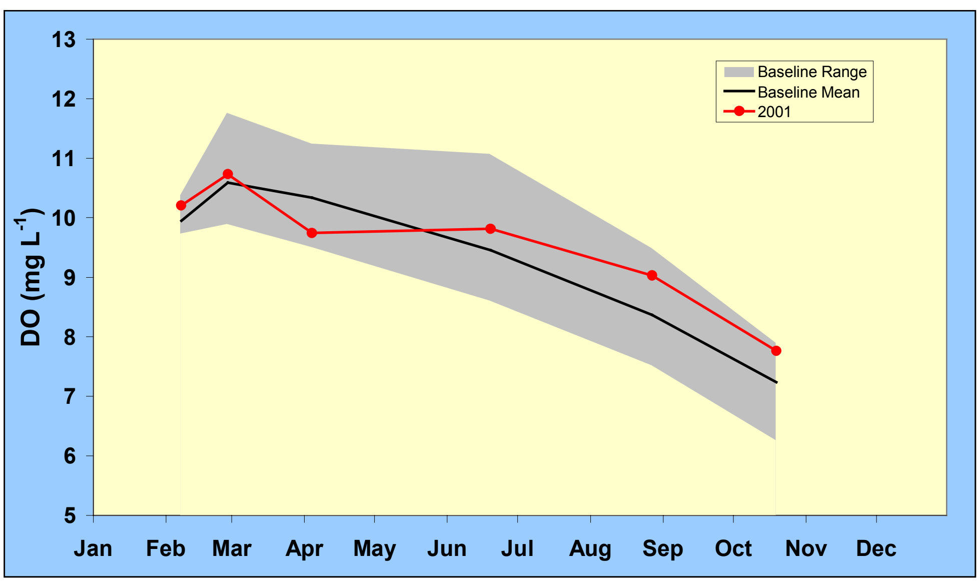


Figure 8-2. Survey mean dissolved oxygen concentrations in Stellwagen Basin, 1992-2001

As in previous years, levels of nutrients and chlorophyll within the sanctuary were at the upper end but in the same range as levels at other monitoring stations and no changes could be attributed to the outfall (Figure 8-3).

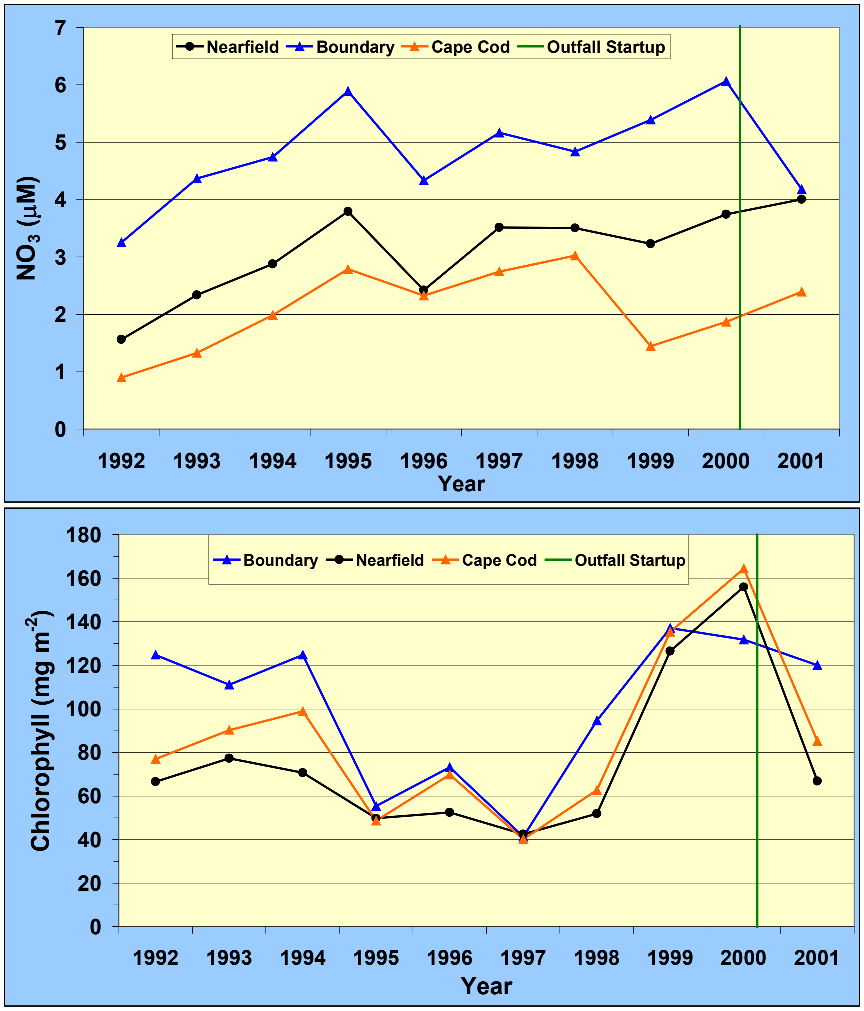


Figure 8-3. Survey mean nitrate and chlorophyll in and near the Stellwagen Bank National Marine Sanctuary (boundary) and other regions of Massachusetts and Cape Cod bays

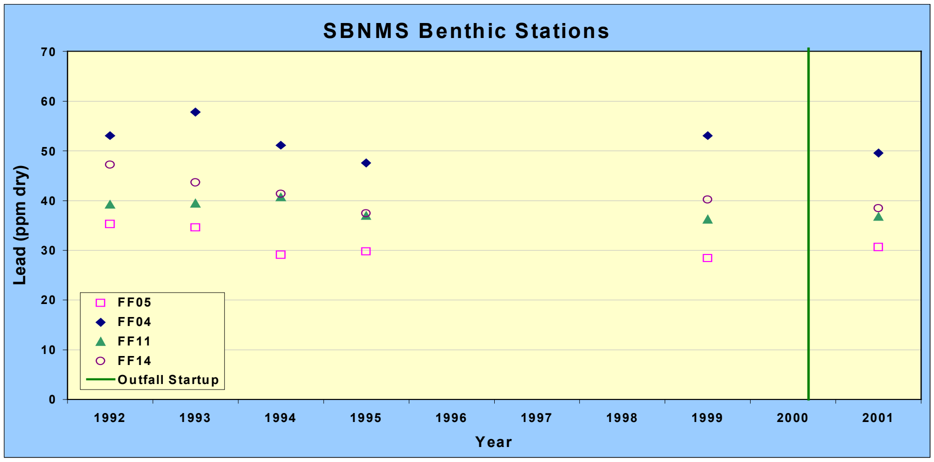
Hydrodynamic modeling suggests that effluent will not enter the sanctuary until after the plume has reached dilutions of about 1000:1 or greater. The summer plume-tracking studies supported the model predictions, with dilutions of hundreds to one being reached while the plume was several days of transport and mixing away from the sanctuary boundary (Hunt *et al.* 2002b).

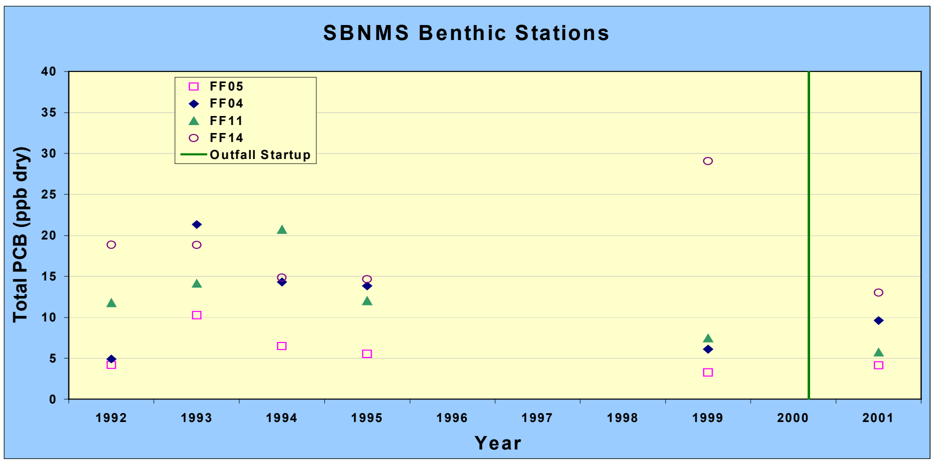
Sea Floor

No changes in concentrations of sewage tracers or contaminants in sediments or in benthic community parameters were observed at stations within the sanctuary in 2001. Grain size and TOC concentrations in the sediments sampled within and near the sanctuary were unchanged from the baseline period. Contaminant concentrations remained consistently low (Figure 8-4, top). At each of the stations, lead concentrations decreased slightly during the 1990s and did not increase when the offshore outfall began operation. These results are consistent with results from the nearfield, which indicated that only a slight increase in lead could be detected within 2 km of the diffuser.

Likewise, PCB concentrations in the sediments in 2001 were similar to or lower than concentrations measured in 1995 (Figure 8-4, middle). Concentrations of other contaminants (not shown) and numbers of sewage tracer *Clostridium perfringens* spores further indicated that there was no substantive influence of the outfall on the sediments (Figure 8-4, bottom). Concentrations of *Clostridium perfringens* spores peaked in the mid 1990s, and in 2001 they were at or below levels measured in the early 1990s. This trend was especially apparent at Station FF04, which is located within Stellwagen Basin. That station is characterized by fine-grained sediments and high TOC concentrations.

Multivariate community-composition analyses are designed to measure similarity in the benthic communities found at individual stations. In 2001, as in all baseline years, these analyses indicated that all four deepwater stations, including the two stations within the sanctuary, had similar benthic community compositions (Figure 8-5). Theses four stations form a station group whose communities are more similar to each other than to the communities of other farfield stations. For example, the four stations shared six to nine of their most abundant (dominant) species, whereas they shared only three to five dominant species with stations located within Cape Cod Bay.





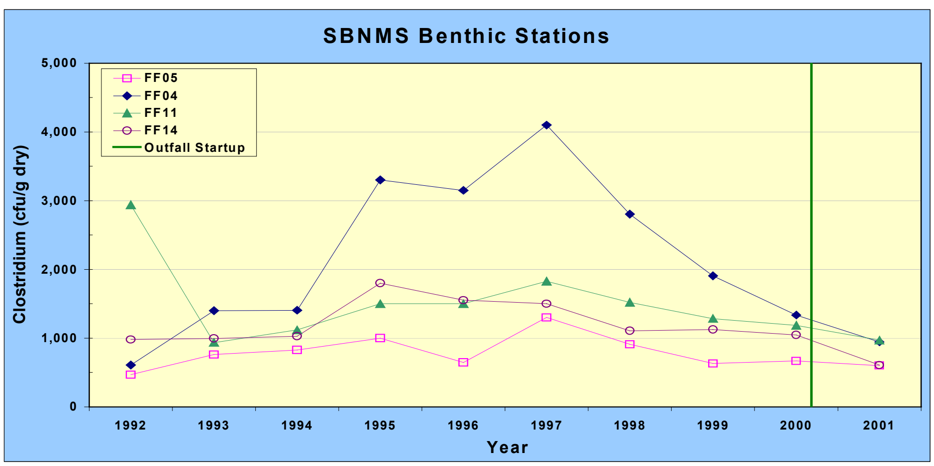


Figure 8-4. Representative contaminant data from stations in and near the Stellwagen Bank National Marine Sanctuary (Refer to Figure 8-5 for station locations.)

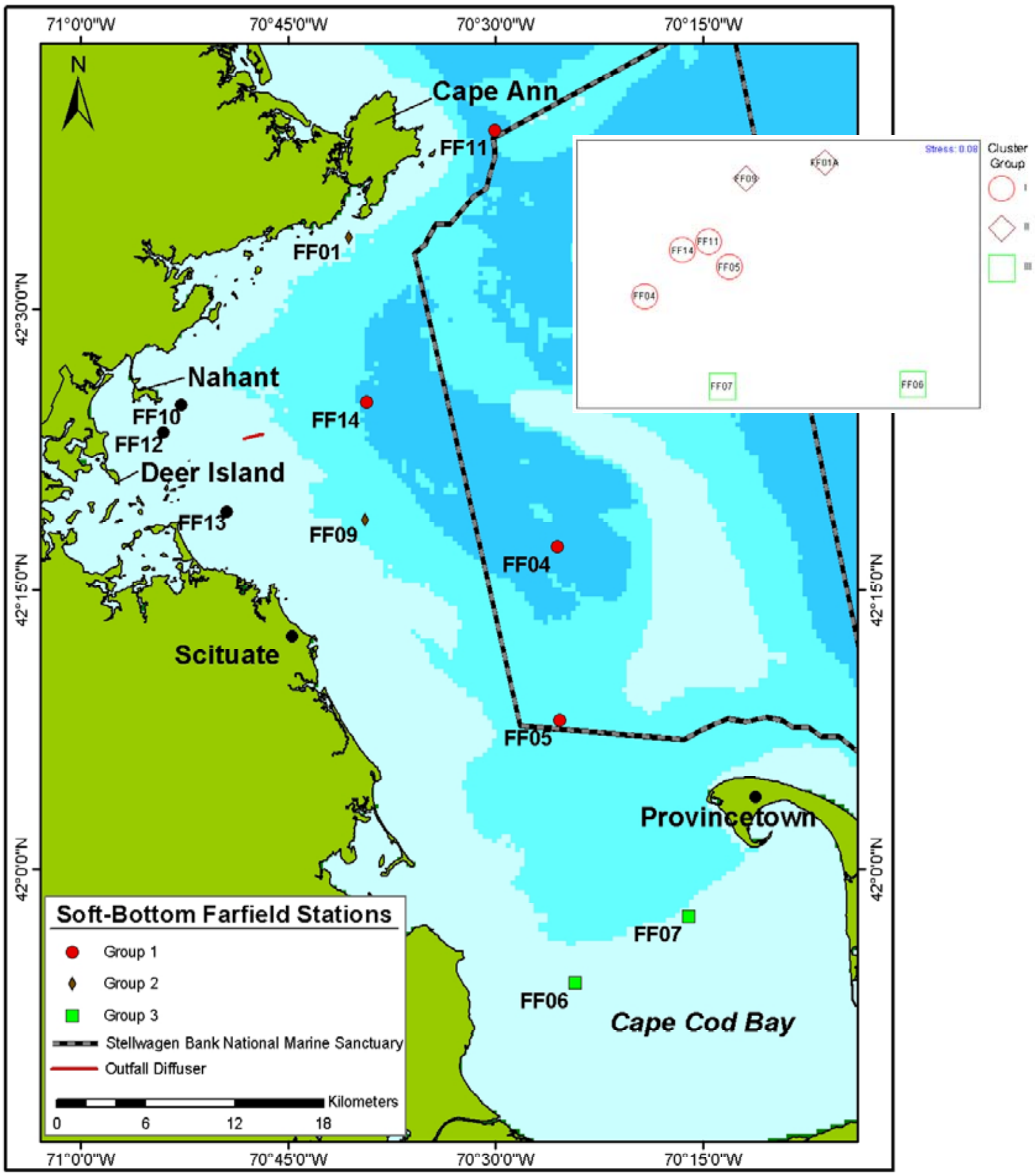
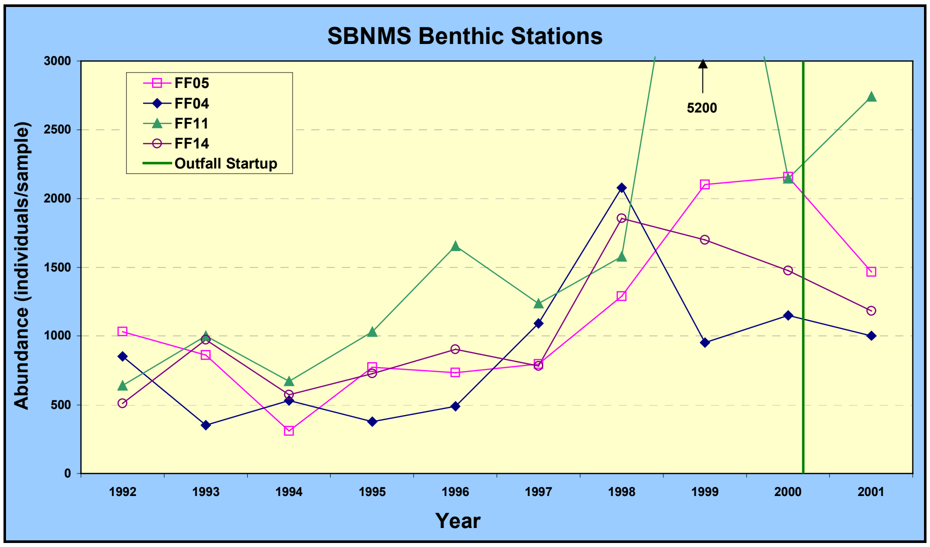


Figure 8-5. Multidimensional scaling analyses of similarities in benthic infaunal communities in 2001

Individual benthic community parameters showed no change following start-up of the outfall in 2000 (Figure 8-6). Infaunal abundance at the four stations was within the historic range. The number of species per sample increased during 1995-1998, paralleling results from throughout Massachusetts Bay.



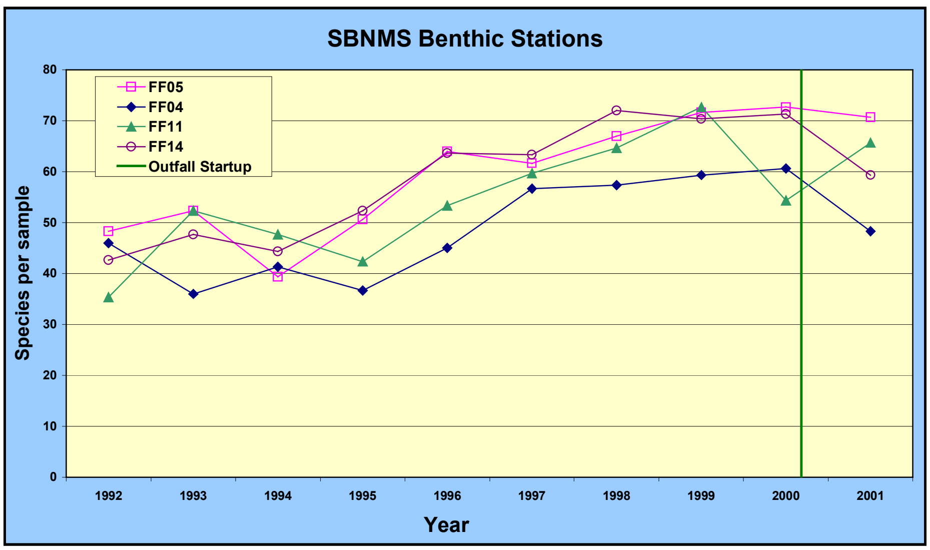


Figure 8-6. Benthic community measurements from stations in and near the Stellwagen Bank National Marine Sanctuary

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List of Acronyms

BEM	Bays Eutrophication Model
BEMEG	Bays Eutrophication Model Evaluation Group
BIH	Boston Inner Harbor
BOD	Biochemical oxygen demand
BS	Broad Sound
cBOD	Carbonaceous biochemical oxygen demand
CCB	Cape Cod Bay
CHV	Centrotubular hydropic vacuolation
C-NOEC	Chronic test, no observable effect concentration
CSO	Combined sewer overflow
DI	Deer Island
DIF	Deer Island Flats
DITP	Deer Island Treatment Plant
DMF	Massachusetts Division of Marine Fisheries
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
GoMOOS	Gulf of Maine Ocean Observation System
IAAC	Inter-agency Advisory Committee
LC50	50% mortality concentration
MADEP	Massachusetts Department of Environmental Protection
MEG	Model Evaluation Group
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NASA	National Air and Space Administration
NB	Nantasket Beach
NMFS	National Marine Fisheries Service
NOEC	No observable effect concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OMTF	Outfall Monitoring Task Force
OS	Outfall site
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
RPD	Redox potential discontinuity
PSP	Paralytic shellfish poisoning
SBNMS	Stellwagen Bank National Marine Sanctuary
SEIS	Supplemental Environmental Impact Statement
USGS	U.S. Geological Survey
TCR	Total chlorine residual
TOC	Total organic carbon
TSS	Total suspended solids

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