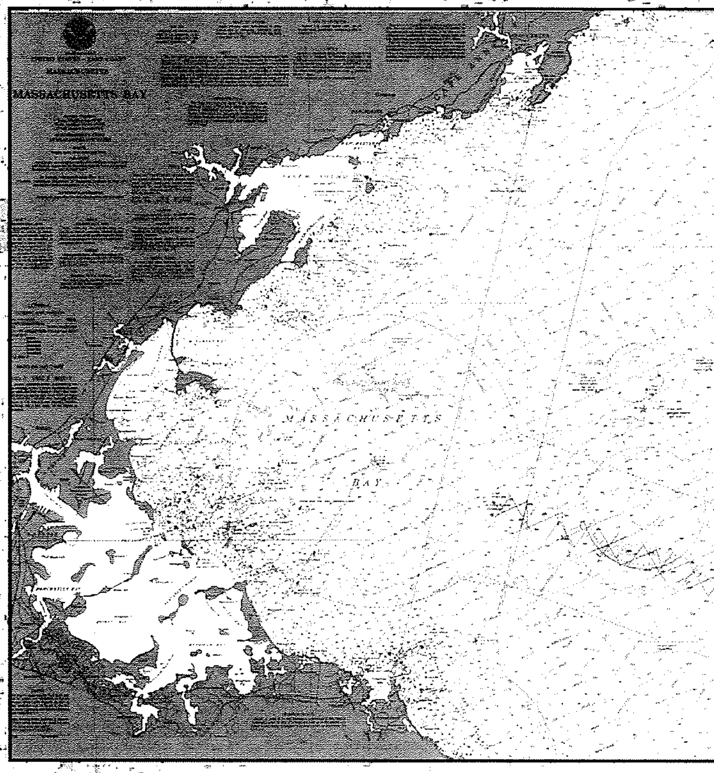

Massachusetts Water Resources Authority

MWRA Environmental Quality Department Technical Report Series 96-4

Outfall Monitoring Overview Report: 1994

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Executive Summary

The people of the metropolitan Boston area, through the MWRA, are in the midst of an ambitious program to upgrade their sewage treatment facilities and improve the quality of Boston Harbor. This program includes the elimination of sludge discharges into the harbor, construction of new primary and secondary sewage treatment plants, and relocation of the current Boston Harbor effluent discharge point to a new location in Massachusetts Bay. The new Deer Island primary treatment facility went on-line in January 1995, successive phases of the secondary treatment facilities will begin operating in late 1996, and the new effluent discharge outfall is expected to be operational in 1998.

A number of concerns have been raised regarding potential environmental impacts associated with the relocation of the wastewater discharge to Massachusetts Bay. An Outfall Monitoring Program was developed in order to assure that these concerns are addressed. This program consists of two main phases. Baseline Studies which commenced in 1992 are currently underway to document conditions before outfall relocation. Post-Discharge Monitoring will commence in 1998; these studies will evaluate conditions after the new outfall is operational. This report describes the baseline monitoring program, summarizes and discusses the program results through 1994, and summarizes Post-Discharge Monitoring warning and action levels.

Both phases of monitoring evaluate six categories of wastewater constituents: Nutrients, Organic Material, Toxic Contaminants, Pathogens, Solids, and Floatables. These six parameters were evaluated in four different environmental measurement areas: Effluent, Water Column, Benthic Environments, and Fish and Shellfish. The overall monitoring program is summarized on Table ES-1.

Wastewater Effluent Monitoring

Wastewater Effluent from the treatment plant is routinely evaluated to ensure that discharged effluent meets required standards.

The Baseline effluent monitoring program has included monitoring of nutrients, organic material, toxic contaminants, pathogens, solids, and oil and grease. Effluent monitoring has demonstrated that improvements made to the MWRA system during the last few years have generally resulted in substantial improvements in wastewater effluent quality. As the MWRA upgrades to secondary treatment of sewage, continued improvement of effluent quality will result in compliance with federal secondary treatment standards and Massachusetts water quality standards.

Water Column Monitoring Program

The Water Column monitoring program is designed to measure water quality in Massachusetts and Cape Cod Bays. Based on extensive predictive modeling studies, changes in water quality due to outfall relocation are expected to be minimal in Massachusetts and Cape Cod Bays. Detectable changes in water quality are expected to occur only in the immediate vicinity of the outfall. The water column monitoring program provides a basis for detecting changes in water quality and plankton resulting from the relo-

TABLE ES-1

Summary of MWRA Monitoring Program

Task	Objective	Sampling Locations and Schedule	Analyses
EFFLUENT MONITORING			
Effluent Sampling	Characterize wastewater discharged from Deer Island Treatment Plant	• Monthly • Daily • Monthly • 3 Times/Day • Daily • Weekly • Weekly	• Nutrients • cBOD • Toxic contaminants • Pathogens • Solids • Oil & Grease • Floatables
WATER COLUMN MONITORING			
Nearfield Surveys	Collect water quality data near outfall location	• 17 surveys/year • 21 locations (See Figure 2-4)	• Temperature • Salinity • Dissolved oxygen • Chlorophyll • Nutrients • Total Suspended Solids • Plankton
Farfield Surveys	Collect water quality data throughout Massachusetts and Cape Cod Bays	• 6 surveys/year • 26 locations (See Figure 2-4)	• Temperature • Dissolved oxygen • Chlorophyll • Total suspended solids • Salinity • Nutrients • Plankton
Plume Track Surveys	Track location and characteristics of discharge plume	• 3-4 surveys/year	• Salinity • Temperature • Dissolved oxygen • Chlorophyll • Total suspended solids
Continuous Monitoring	Provides continuous water quality data near outfall	• Continuous monitoring • Single station • 3 depths	• Temperature • Salinity • Optical beam transmittance
Remote Sensing	Evaluate outfall impacts on a regional scale through satellite imagery	• Approximately 1/month	• Temperature • Chlorophyll
BENTHIC MONITORING			
Nutrient Flux Surveys	Evaluate nutrient interactions between the sediment and water column	• 5 surveys/year • 7 locations (See Figure 8-2)	• Oxygen demand • Nutrient flux • Porewater nutrients
Soft Bottom Surveys	Evaluate sediment quality in Boston Harbor and Massachusetts Bay	• 8 Boston Harbor stations (See Figure 8-3) • 20 nearfield stations (See Figure 8-4) • 11 farfield stations (See Figure 8-4)	• Sediment chemistry • Benthic community composition
Hard Bottom Surveys	Characterize marine communities in rock and cobble areas	• 1 survey/year • 6 transects (See Figure 8-5)	• Topography • Substrate • Benthic community composition
FISH AND SHELLFISH MONITORING			
Flounder Studies	Determine contaminant body burden and population health	• 1 survey/year • 5 locations (See Figure 4-2)	• Tissue contaminant concentrations • Physical abnormalities (including histopathology)
Lobster Studies	Determine contaminant body burden	• 1 survey/year • 3 locations (See Figure 4-2)	• Tissue contaminant concentrations • Physical abnormalities
Mussel Studies	Evaluate biological condition and short-term contaminant bioaccumulation	• 1 survey/year • 3 locations (See Figure 4-2)	• Tissue contaminant concentrations • Physical abnormalities

cation of the effluent outfall. It also provides a basis for monitoring potential food chain effects on endangered species, such as humpback and right whales.

A number of different parameters are evaluated in the baseline water column monitoring program. Studies are underway to gather baseline information on nutrient levels, temperature, salinity, and dissolved oxygen in the marine system. Other water column studies evaluate the presence of sensitive biological indicators such as algae. The baseline water column monitoring program has demonstrated that the Massachusetts and Cape Cod Bay system is dynamic, with considerable spatial and temporal variability. Nutrient and chlorophyll (representing algae density) concentrations are highest in coastal waters near Boston Harbor and decrease with increasing distance offshore. Seasonal algal bloom trends are significantly different between Massachusetts and Cape Cod Bays, indicating that these ecological systems behave somewhat independently. Dissolved oxygen values vary seasonally, with the highest values measured during the winter, and the lowest occurring in bottom waters in the summer. In 1994, several dissolved oxygen measurements in bottom waters in the area of the future outfall were below state water quality standards. The influence of seasonal cycles and differing ecological environments must be considered when evaluating the potential influence of the MWRA upgrades within this marine system.

Benthic Studies

Benthic Studies are designed to evaluate the sea floor environment in Boston Harbor and Massachusetts and Cape Cod Bay. Benthic studies provide a means to document recovery of Boston Harbor following improvements to the MWRA system. These studies are also designed to assess potential impacts to the Massachusetts and Cape Cod Bay sea floor resulting from relocation of the outfall.

The ongoing baseline benthic monitoring program has provided valuable information on the current status of the benthic environment in the system. Studies are underway to evaluate benthic ecological communities and sediment quality. The complex physical environment in Massachusetts Bay, especially near the future outfall, makes the assessment of the benthic environment particularly challenging. In general, the benthic sedimentary environment, or habitat, in the area of the future outfall is highly diverse, with large variability in sediment type over relatively short distances. Benthic biological communities appear to demonstrate similar variability, reflecting a strong influence of sediment type on the benthic community characteristics. In addition, the benthic environment in the vicinity of the future outfall is highly changeable, with dramatic shifts in both sediment type and benthic organisms occurring after storm events.

Fish and Shellfish Monitoring Program

The Fish and Shellfish monitoring program focuses on key natural resources in the marine environment. This program evaluates potential risks to human health and the environment from contamination in fish and shellfish. Fish and shellfish studies provide a basis for evaluating recovery of natural systems following MWRA upgrades.

The baseline fish and shellfish monitoring program has included studies of mussels, flounder, and lobster. In general, contaminant concentrations are higher in fish and shellfish from Boston Harbor than from the future outfall site. Contaminant concentrations in fish and shellfish from a site in Cape Cod Bay are consistently lower than at the other sites. Fish and shellfish contaminant concentrations have generally decreased in Boston Harbor over the past years. In contrast, at the future outfall site, concentrations of several contaminants in fish and shellfish increased in 1994 compared to previous years. Nevertheless, contaminant concentrations in fish and shellfish at all sites have consistently been well below levels that might cause any concern because of human consumption. The contaminant levels have apparently caused tumors and other physical abnormalities in flounder, as the data indicate that the prevalence of tumors increases with increasing contaminant concentration. As secondary treatment is phased in, and as effluent and water quality continues to improve in Boston Harbor and the Bays, it is anticipated that the health of the fish and shellfish populations will continue to improve.

The MWRA's Baseline Outfall Monitoring Program has gathered considerable information documenting the existing conditions in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. Scientific data collected during the last few years reflect current levels of sewage treatment. As improvements are made to the MWRA sewage treatment process, the extensive economic, aesthetic, and ecological resources of this unique marine system are expected to benefit.

1.0 INTRODUCTION

1.1 Background

In 1986 the Massachusetts Water Resources Authority (MWRA) initiated a program to end longstanding violations of the Clean Water Act associated with the discharge of sewage sludge and effluent in Boston Harbor. This program included the elimination of sludge discharges into the harbor, construction of new primary and secondary treatment plants, and the relocation of the treated effluent discharge point. The new effluent discharge location is 9.5 miles offshore in Massachusetts Bay (Figure 1-1). The new outfall should be operational in 1998.

The U.S. Environmental Protection Agency (EPA) assessed the potential impacts associated with the discharge of MWRA's wastewater effluent into Massachusetts Bay. This study is discussed in the 1988 project Supplemental Environmental Impact Statement (SEIS). EPA performed a water quality modeling study to evaluate pollutant transport in the bays and potential water quality changes due to the wastewater discharge. The magnitude and location of the potential water quality impacts were predicted and evaluated. In addition, biological impacts on endangered species, such as the North Atlantic Right Whale, and other threatened marine species were assessed in the EPA's Biological Assessment and the National Marine Fisheries Service's Biological Opinion. It was determined that there would not be significant water quality or biological impacts associated with the project.

1.2 Reasons for Monitoring

Even though the SEIS projected minimal impacts from the relocated, cleaner discharge, concerns remained with respect to the potential environmental effects associated with the relocation of the wastewater discharge to Massachusetts Bay. In the SEIS Record of Decision, the EPA required the development of a monitoring program to establish baseline conditions of the Massachusetts and Cape Cod Bay ecosystem and measure any future impacts on the system due to outfall relocation. The Certificate issued by the Massachusetts Executive Office of Environmental Affairs (EOEA) on the Secondary Treatment Facilities Plan/Final Environmental Impact Report (STFP/FEIR) in 1988 contained a similar requirement.

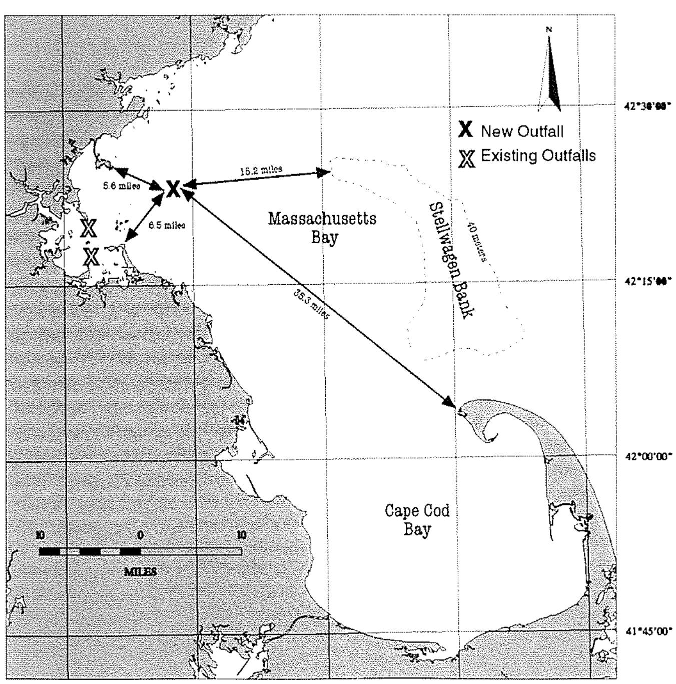


FIGURE 1-1
Distances of the new outfall from selected sensitive areas in Massachusetts and Cape Cod Bays.

- The MWRA sewer system serves more than 2 million Massachusetts residents in 43 communities in eastern Massachusetts. On the average day, 370 million gallons of sewage flows to one of two MWRA sewage treatment facilities located on the shores of Boston Harbor. The MWRA is currently in the middle of an ambitious program to upgrade and consolidate the sewage treatment facilities serving the region.

- After nearly a decade of planning, design, and construction, the MWRA started-up the new Deer Island primary treatment plant in January, 1995. The primary treatment process involves removing solids from sewage and chlorinating effluent prior to discharge. A new secondary treatment facility is currently under construction. Secondary treatment combines a bacterial process to decompose sewage with a physical settling process. Secondary sewage treatment results in removal of more than 75% of the organic matter and toxic pollutants prior to effluent discharge.

- Following treatment at the MWRA's primary treatment facilities, treated wastewater or effluent flows into Boston Harbor. The MWRA is currently constructing a 9.5-mile long, 24-foot diameter outfall tunnel. This tunnel will discharge effluent from the new secondary treatment facility to Massachusetts Bay. Discharge will occur through 55 diffusers located at a depth of approximately 100 feet.

- Water quality legislation in the United States has a long history, dating to 1899. The modern era of water quality legislation began in 1972 with the federal Clean Water Act, that established the National Pollutant Discharge Elimination System (NPDES) program. The NPDES program requires all wastewater dischargers, including the MWRA, to obtain a NPDES permit. Through the NPDES permit, regulatory agencies impose effluent limitations on the amount of pollutants discharged and other requirements. Effluent limits are based on state and federal water quality criteria and standards which are designed to protect the water quality and aquatic life in receiving water bodies.

During the preparation of the Secondary Treatment Facilities Plan, the Citizens Advisory Committee identified the following general areas of concern with respect to Massachusetts and Cape Cod Bays:

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

An Outfall Monitoring Program was developed to meet agency requirements and address citizens' concerns.

1.3 Monitoring Program History/Status

Numerous scientific studies were carried out in 1986 and 1987 as part of the outfall siting process. These studies and preliminary water column monitoring carried out in 1989 and 1990 formed a basis of information for monitoring plan development. At the direction of the Massachusetts EOEA, an Outfall Monitoring Task Force (OMTF) was formed to provide the MWRA with guidance and recommendations on the development of a monitoring plan. The OMTF is composed of academic scientists, as well as representatives from federal and state regulatory agencies and non-profit organizations.

MWRA and the OMTF initially developed an Outfall Monitoring Program in 1991. Baseline studies, dedicated to determining background conditions in the Bays, began in 1992 (except for flounder studies which began in 1991) and will continue until the new outfall becomes operational in 1998. Then, similar post-discharge studies, dedicated to determining the effects of the discharge, will begin.

The OMTF and MWRA review the monitoring results on an ongoing basis and work to implement cost-effective modifications that better address public and technical concerns.

1.4 Monitoring Program Objectives

The Outfall Monitoring Program was developed and has evolved with continuous attention to a number of specific goals and objectives. The Outfall Monitoring Program is intended to:

- Develop baseline data from which future changes can be evaluated
- Test whether the impact of the discharge is within the bounds predicted in the SEIS;
- Evaluate compliance with threshold values for trigger parameters (as defined below); and
- Measure and evaluate potential impacts to Massachusetts and Cape Cod Bays associated with outfall relocation.

Since 1992, baseline data have been collected to achieve the first objective. Additional data are required to achieve this objective. The baseline data have demonstrated considerable natural year-to-year variability in the water quality and biological characteristics of the Bay system. These results indicate that the Massachusetts and Cape Cod Bay system is complex and cannot be completely described with the information collected to date. Without a more complete understanding of the inherent behavior and natural variability of the Bay system prior to the introduction of MWRA wastewater discharge, it may be difficult to determine if wastewater has adversely affected water quality once the discharge into Massachusetts Bay begins.

There have been several changes in both the system under study and in the monitoring program during the past few years. Sludge disposal into the harbor was terminated in December 1991, and the new primary treatment system became operational in 1995. Ongoing monitoring is helping to assess the response of Boston Harbor and the bays to these changes in pollutant discharges.

In addition to the outfall monitoring program, a related monitoring program for Boston Harbor is currently being conducted by MWRA. This program assesses the water quality and ecosystem recovery in Boston Harbor following treatment system improvements and outfall relocation. Together, the Outfall and Boston Harbor monitoring programs will provide information essential to evaluating the costs and benefits, as well as the potential impacts of the treatment system and outfall modifications.

1.5 Wastewater Constituents of Environmental Concern

The National Research Council has recommended consideration of the following six wastewater constituents in determining the environmental impact of coastal discharges of treated sewage:

- Nutrients
- Organic Material
- Toxic Contaminants
- Pathogens
- Solids
- Floatables

The Outfall Monitoring Program was designed to obtain data that would allow an assessment of the water quality and ecological impacts of these constituents. These six parameters were evaluated within the context of four different environmental measurement areas, or matrices: effluent, water column, benthic environment, and fish and shellfish.

The MWRA evaluates these program areas based on specific monitoring indicators, called trigger parameters. Each trigger parameter has a quantitative, or in some cases a qualitative, threshold that indicates the potential for impacts. Once discharge begins, the exceedance of trigger parameter threshold values will automatically trigger MWRA action. There are two types of thresholds under development that will be used to alert the MWRA to different degrees of environmental risk. Warning levels indicate the potential for increased risk of environmental impact, triggering an evaluation of potential impacts and the need for more intensive study. Action levels trigger the need for a response to avoid an environmental impact.

1.6 Report Objectives and Organization

The objectives of this Outfall Monitoring Overview Report are to describe the monitoring program goals, component elements, and results of the ongoing monitoring program. The focus of this report is the Massachusetts and Cape Cod Bays system; pertinent information on Boston Harbor has also been included.

A number of related reports have been produced by the MWRA. Although some of these reports contain information similar to this overview, they provide substantially more detailed information in specific areas. "The Effluent Outfall Monitoring Plan, Phase I: Baseline Studies" (November 1991) and "Phase II: Post Discharge Monitoring" (draft November 1995) describe the goals, strategy, and design of the Outfall Monitoring Program in detail. The "Contingency Plan" (draft March 1995) provides a detailed discussion of the development of trigger parameter values and MWRA's planned contingency measures. The "State of Boston Harbor" reports focus on the Boston Harbor system, with less information provided on Massachusetts and Cape Cod Bays.

The material presented in this report represents data collected through the 1994 field season, and therefore reflects the levels of sewage treatment current at that time. These data are synthesized in a series of technical reports prepared annually for every project area (more frequently for some). Synthesis reports for 1995 data are currently (Spring 1996) in development and are expected to add to the understanding of the Harbor and Bay system. A current listing of the technical reports can be found on the World Wide Web at http://world.std.com/~enquad. Raw data from all studies are available in electronic form through MWRA's Environmental Management and Mapping system.

This report is organized into three primary areas: (1) this introduction that discusses the reasons for and objectives of the monitoring program; (2) six sections that discuss each of the wastewater constituents of concern, water quality and biological issues associated with each constituent, monitoring program elements, and recent monitoring program results; and (3) a summary of the Outfall Monitoring Program.

2.0 NUTRIENTS

2.1 Water Quality/Biological Issues

Nutrients are essential for the growth of algae and other aquatic plants. Algae form the base of the aquatic food chain, and are critical to the maintenance of the aquatic ecosystem. For marine and coastal environments, such as the Massachusetts and Cape Cod Bays system, nitrogen is the most important nutrient. Sources of nutrient loading into the Bay system include the MWRA discharge, discharges from several other municipal wastewater treatment plants, Combined Sewer Overflow (CSO) inflows, nonpoint source rainfall runoff, river and tributary discharges, and atmospheric deposition. As secondary treatment is phased in, nutrient removal from the MWRA effluent will improve somewhat, and the relative nutrient contribution to the Bay system from the MWRA discharge will decrease.

The primary concerns associated with the discharge of nitrogen and other nutrients into the coastal environment are related to effects on (1) dissolved oxygen (DO) concentrations and (2) the algal community structure.

What are algae?

- **Aquatic algae may be suspended and drift in the water column (planktonic) or attached to the ocean bottom. The MWRA primarily monitors planktonic algae, which under certain conditions undergo periods of intensive growth known as blooms. Phytoplankton are planktonic algae and are the basis of the marine food chain.**

2.1.1 Dissolved Oxygen Effects

Algal blooms are periods of intense algal growth that are often part of the natural aquatic ecosystem. Excess nutrients, such as nitrogen, may lead to excessive algal blooms and overabundant algal growth, a condition known as eutrophication. As algae die and decompose, DO is consumed due to the oxidation of carbon in algal biomass. During eutrophication, DO consumption may lead to DO depletion and low DO concentrations. This condition, known as hypoxia, may have serious effects on fish and other marine animals which need DO to breathe. The various processes that consume and otherwise influence DO concentrations are shown and discussed on Figure 2-1.

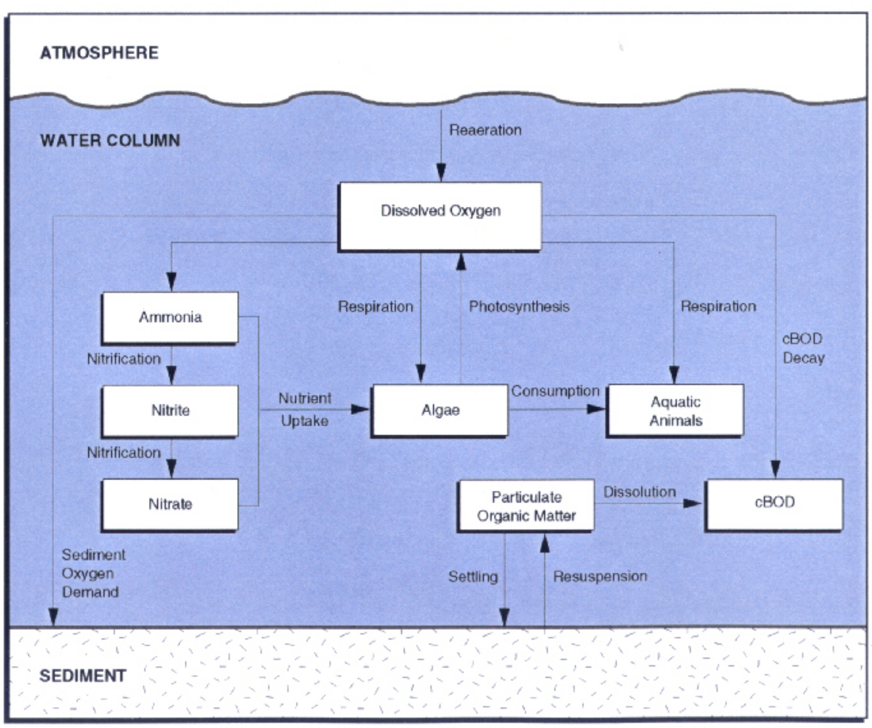
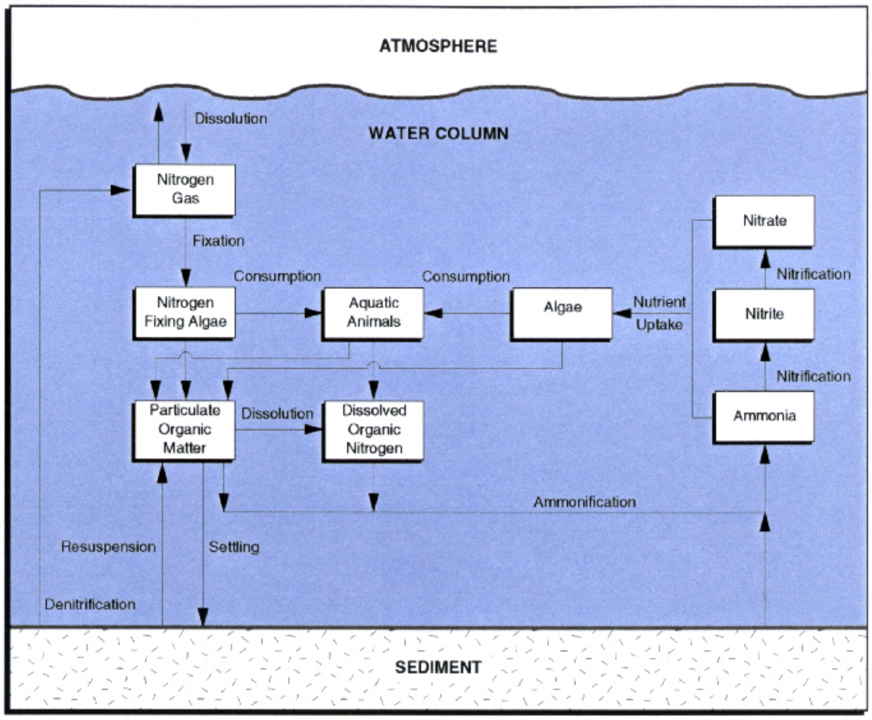


FIGURE 2-1
Dissolved oxygen processes and reactions

- For higher organisms, oxygen in the environment is a requisite for life. Dissloved oxygen (DO) in marine waters is critical for the survival of fish and other aquatic life forms. An understanding of the dynamics of DO in marine waters is essential to understanding the distribution, growth, and behavior of aquatic organisms..
- DO saturation in marine waters is a function of several factors, including temperature and salinity. Colder waters hold more DO than warmer waters. Fresh water holds more oxygen than salt water.
- Water is said to be DO-saturated when it holds the maximum possible amount of DO. For instance, water at 4°C can hold up to 13 mg/L DO before it is considered saturated.
- Typically, cooler, well-mixed winter waters have the highest DO concentrations. Stratification of water occurs in the summer months, while mixed conditions predominate in winter months.
- Atmospheric aeration and algal photosynthesis are two primary sources of DO in marine waters.
- A combination of processes, including nitrification and respiration by aquatic life, consume marine DO. Nitrification is the process whereby ammonia is oxidized to nitrates and nitrites.
- Death and decay of algal blooms result in reduced concentrations of DO in water. If sufficient algae decay occurs, DO concentrations may drop dangerously low and a condition known as hypoxia may occur. Sensitive marine animals may suffocate during periods of hypoxia.
- Considerable spatial variability exists relative to DO concentrations in Boston Harbor and Massachusetts Bay. DO concentrations vary both vertically and horizontally, and marine currents serve to transport DO in and out of marine habitats. Diffusive transport in sediments also occurs when DO moves from areas of high to low DO concentrations.



NITROGEN CYCLE:

- Nitrogen behavior in the aquatic environment is complex. In natural water bodies, nitrogen can occur as dissolved nitrogen gas; dissolved nitrate, nitrite, and ammonia species; and as part of organic matter and aquatic organisms. The collective processes involved with the behavior and transformation of nitrogen and its species is known as the nitrogen cycle.
- Nitrogen gas can enter and dissolve in the water column from the atmosphere. This process is reversible.
- Dissolved nitrate, nitrite, and ammonia, collectively known as dissolved inorganic nitrogen (DIN) are important nutrients for the growth of aquatic plants, such as algae.
- Nitrification is a process involving a reaction with dissolved oxygen to change ammonia to nitrite and nitrite to nitrate.
- Denitrification involves the reduction of nitrate to nitrite or dissolved nitrogen gas, a process that occurs under anaerobic or oxygen depleted conditions.
- Nitrogen gas is generally not available to aquatic plants, but under certain conditions blue green algae can use nitrogen gas as a nutrient source of nitrogen in a process known as nitrogen fixation.
- The decay of organic matter releases nitrogen species into the water column. The decay of organic matter resulting in the release of ammonia is called ammonification.

FIGURE 2-2
Nitrogen Cycle

In addition to potential eutrophication effects on DO, nitrogen can make a minor contribution to the loss of DO by reactions in which nitrogen species combine with and consume DO. Nitrogen exists in a number of forms in the aquatic environment. The behavior and interaction of the different forms of nitrogen in the environment is known as the nitrogen cycle, and is described in Figure 2-2.

Algae Communities

- The composition of the algal community, or the relative numbers of various algae species, is known as the community assemblage. Approximately 30 to 50 algae species typically are observed in the community assemblage monitored by MWRA. These include species commonly known as diatoms, blue-green algae, and flagellates. (Figure 2-3). Flagellates are planktonic algae that have limited self-propelled mobility. Red tides are a specific kind of dinoflagellate bloom that may produce toxic chemicals. Some red tides can result in mortality of fish and other marine organisms and toxicity of seafood.

2.1.2 Algal Community Effects

Wastewater discharges to the marine environment can change the existing or natural nutrient concentrations and concentration ratios in surface waters. In this changed environment, undesirable algae may grow faster than desirable algae. Undesirable algae include nuisance algae, such as brown tides which affect the appearance of the water, and noxious algae, such as red tides which are toxic to some organisms. In addition, there is a concern that changes in the algal community could result in food chain impacts that affect endangered species, such as humpback and right whales.

Numerous factors affect algae community composition and the potential for algal blooms. These factors include a number of natural phenomena, such as nutrient availability, temperature, light, time of year, salinity, and grazing by herbivores such as zooplankton.

2.2 Trigger Parameters and Thresholds

A number of trigger parameters have been established to evaluate the impacts of nutrients on the Massachusetts and Cape Cod Bay system. These trigger parameters have been established to monitor and measure nutrient concentrations in MWRA effluent and the bays, eutrophication and hypoxia events, DO concentration in water and sediments, DO depletion rate, algal biomass trends, and the growth of undesirable algae. A compilation of trigger parameters and threshold values, with their bases, is provided in Table 2-1.

Flagellated Unicellular Organisms

Flagellated organisms are characterized by the presence of one or more long, whiplike structures called flagella which are used for locomotion. Flagellated organisms may be either naked with no cell wall or armored with a cell wall, such as some dinoflagellates with spiny cell walls.

Diatoms

Diatoms are a group of algae characterized by cell walls made of silica. Two major groups of diatoms are pennate diatoms, which have bilateral symmetry, and centric diatoms which have radial symmetry.

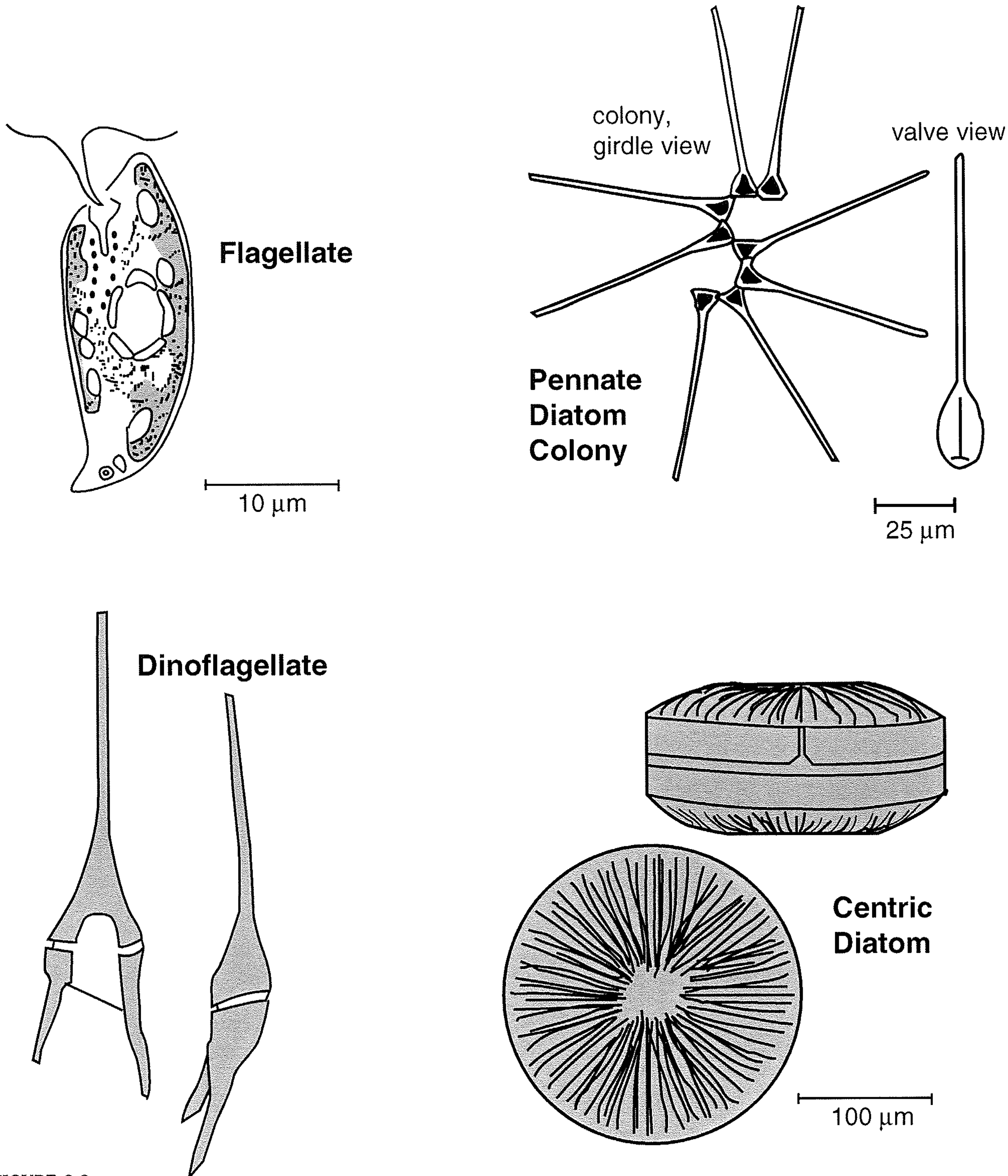


FIGURE 2-3
Typical Marine Algae
Source: Linneaus Protist™ and Linneaus Toolkit™

TABLE 2-1

Trigger Parameters and Threshold Values for Nutrients

Trigger Parameter	Threshold Values	Basis for Trigger Parameter and Threshold Values
Nitrogen Effluent Loading	**Warning Level:** – Annual effluent nitrogen load more than 12,500 metric tons. **Action Level:** – Annual Effluent nitrogen load more than 14,000 metric tons.	– Measures mass of nitrogen discharged – Thresholds based on effluent nitrogen loads used in water quality modeling and SEIS
Water Column DO Concentration	**Warning Level:** – Monthly mean nearfield bottom DO less than 6.5 ppm (or 80% of saturation) during the summer (June-October). – Monthly mean Stellwagen Basin bottom DO less than 6.5 ppm (or 80% of saturation) during the summer. **Action Levels:** – Monthly mean nearfield bottom DO less than 6 ppm (or 75% of saturation) during the summer. – Monthly mean Stellwagen Basin bottom DO less than 6 ppm (or 75% of saturation) during the summer.	– Measures potential for hypoxia, or low DO impacts – Action levels based on Massachusetts Water Quality Standards
Water Column DO Trends	**Warning Levels:** – Nearfield annual mean bottom DO concentration below baseline by more than one standard deviation for 3 consecutive years.	– Measures long-term trends in DO levels – Warning levels based on water quality modeling prediction of DO changes due to effluent discharge
DO Depletion Rate	**Warning Levels:** – Nearfield mean bottom oxygen depletion rate greater than 2 times the baseline rate during summer. – Stellwagen Basin mean bottom summertime oxygen depletion rate greater than 2 times the baseline rate.	- Measures short-term and long-term rate of DO depletion and potential for future hypoxia – Thresholds based on prediction in SEIS that might indicate the potential for hypoxia.
DO Concentration and Depth in Sediments	**Warning Level:** – Decrease in baseline mean redox potential discontinuity (RPD) depth at muddy nearfield stations by 50%. – Decrease in mean RPD depth by 20% per year for 3 consecutive years.	– Measures potential for low DO impacts on animals that live in bottom sediments – Thresholds based on evaluation of DO penetration into sediments

TABLE 2-1 (cont'd)
Trigger Parameters and Threshold Values for Nutrients

Trigger Parameter	Threshold Values	Basis for Trigger Parameter and Threshold Values
Chlorophyll-a Concentration	**Warning Levels:** – Chlorophyll-a concentration annual mean nearfield or farfield variability greater than 2 times the baseline level, for 3 consecutive years. – Increase by factor of two relative to baseline level in annual mean nearfield or farfield chlorophyll-a concentration, for 3 consecutive years. – Annual mean nearfield or farfield chlorophyll-a concentration greater than 12 ppb. – Increase in annual mean nearfield chlorophyll-a concentration by 20% per year for 3 years. – Change in seasonal nearfield or farfield chlorophyll-a, or nearfield or farfield euphotic zone chlorophyll-a pattern. **Action Level:** – Annual mean nearfield or farfield chlorophyll-a concentration greater than 15 ppb.	– Measures algal biomass and provides indication of eutrophication state. – Thresholds based on long-term statistical increases in algal biomass and National Oceanic and Atmospheric Administration (NOAA) recommended level for indication of excessive algal bloom activity.
Nuisance/Noxious Algae Concentration	**Warning Levels:** – Nuisance or noxious algae concentration in nearfield or farfield greater than 10 times baseline conditions for 3 years. – Nuisance or algae frequency of occurrence in nearfield or farfield greater than baseline conditions. – Nuisance algae dominate the nearfield or farfield algal community.	– Measures and evaluates increases in undesirable algae concentrations and associated environmental impacts. – Warning levels based on predictions in SEIS that discharge will not increase undesirable algae concentrations. Action levels based on qualitative indications of undesirable algae impacts.

2.3 Monitoring Program Components Designed to Address Issues

MWRA has conducted extensive water quality modeling studies to evaluate the potential effects of outfall relocation. The results of the modeling studies indicate that outfall relocation will significantly reduce nutrient and chlorophyll concentrations, while increasing DO concentrations, in Boston Harbor. The study results also show that detectable changes in nutrient levels, chlorophyll, or DO will not occur in Massachusetts or Cape Cod Bay, except in the immediate vicinity of the new outfall. The modeling study was used to assist in the design of the water column monitoring program, which will be used to verify the modeling study results.

■ Chlorophyll is the green pigment in plants that supports photosynthesis. Chlorophyll is used as a measure of the algal biomass, the total amount of algae in the water. The type of chlorophyll most commonly measured is chlorophyll-a.

To establish baseline conditions in the bays, the MWRA is monitoring nutrients through a number of different analytical techniques. Some analyses focus on measurement of concentration of nutrients in MWRA effluent, while other studies evaluate ongoing nutrient and other water quality trends in the receiving waters. Nutrient sampling is occurring at stations in the nearfield (within about 5 km of the site of the future outfall) and in the farfield

- MWRA will perform statistical tests to determine if significant changes in the environment have occurred as a result of the effluent discharge. The tests will employ common statistical methods and have a 20% chance of identifying no change when there has been a change and a 5% chance of identifying a change when there has not been a change.

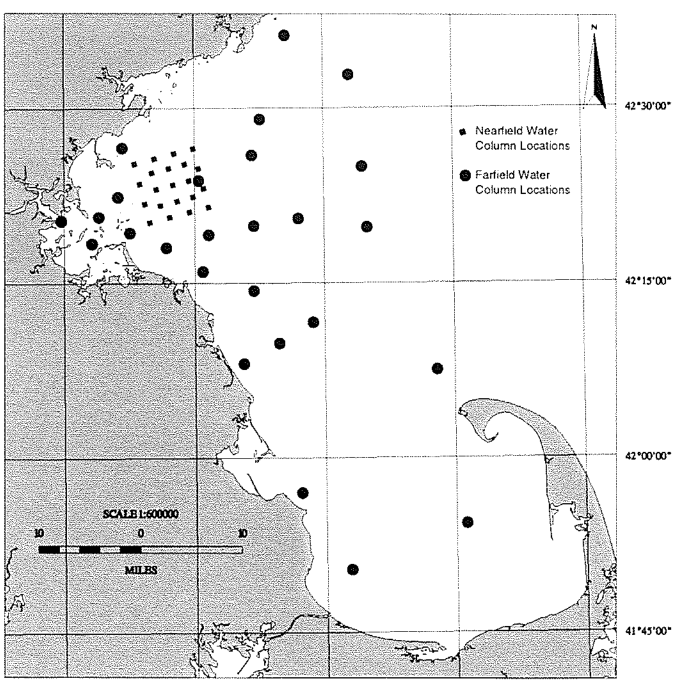
(throughout Massachusetts and Cape Cod Bays) (Figure 2-4). Monitoring program components associated with nutrients are as follows.

- The total nitrogen concentration and load are directly monitored in MWRA effluent, prior to discharge to the bays.
- Dissolved oxygen (DO) and nutrients are routinely monitored at numerous stations in the nearfield and farfield. Analysis of long-term DO monitoring data allows the MWRA to track trends in DO conditions, and anticipate future hypoxic conditions.
- The depth of oxygen penetration in soft sediments is monitored to provide a measure of environmental health with respect to sediment oxygen supply and demand.
- In order to monitor long-term changes in algal biomass, chlorophyll-a concentrations are monitored in the nearfield and farfield.
- Nuisance or noxious algae are annually present in small numbers in Massachusetts and Cape Cod Bays. To evaluate changes in the frequency or abundance of these organisms, ongoing monitoring of nuisance and noxious algae populations is underway.

2.4 Monitoring Program Results

Moving the location where effluent is discharged to the marine environment has the potential to change the relative levels of nutrients in water. MWRA has conducted a comprehensive nutrient sampling program in Massachusetts and Cape Cod Bays since 1992. In addition to monitoring nutrients directly, the monitoring program also measures parameters that nutrients could impact (e.g., algae populations, DO concentrations). This monitoring program provides MWRA scientists with sound baseline water quality data.

FIGURE 2-4
Nearfield and Farfield water column sampling locations



Effluent

In the 1994 sampling program, total nitrogen (the sum of particulate and total dissolved nitrogen) in the primary effluent samples ranged from 740 to 1,740 µM (10.4 to 24.4 ppm) (Figure 2-5). The 1994 annual load of total nitrogen was estimated at 8,220 metric tons. This value is well below the annual nitrogen loading threshold warning level of 12,500 metric tons (the action level is 14,000 metric tons). Seventy to ninety percent of the nitrogen in the effluent was present as ammonia. Significant seasonal variability was observed in total nitrogen levels. This is not unusual, given the variability in daily flows into and out of the treatment facility. Average winter and spring (December-May) concentrations of total nitrogen were considerably lower than the average concentrations observed in the summer and fall. This trend corresponds inversely with, and may reflect, the effluent flow conditions during the sampling period. Lower flows occurred in summer months, while flows tended to be higher in the winter and spring.

Water Column Nitrogen

Monitoring dissolved inorganic nitrogen (DIN) in the water column provides a measure of the effects associated with nitrogen loading to the Massachusetts Bay and Cape Cod Bay systems. MWRA began monitoring of DIN in Massachusetts Bay and Cape Cod Bay waters in 1992. The DIN measurements from 1994 indicated similar patterns to those in previous years. Spatially, DIN concentrations are generally highest in Boston Harbor and decrease with increasing distance offshore (Figure 2-6). Annually, the highest DIN values in Massachusetts Bay surface waters occur before April and after October. Surface DIN concentrations generally decrease as nitrogen is consumed by algal growth during the spring, summer, and early fall.

Water Column Chlorophyll

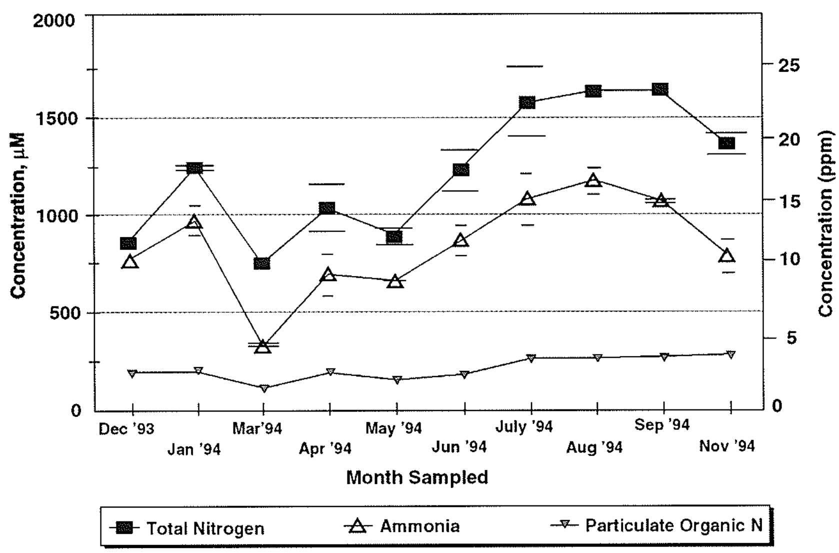


FIGURE 2-5

Nitrogen, ammonia, and particulate organic nitrogen in Deer Island effluent. Symbol represents mean concentration, horizontal lines show concentration range. Source: Hunt et al., 1995

Spatial and temporal patterns of chlorophyll concentration are related to those of DIN. The average chlorophyll concentrations in Massachusetts Bay surface waters in 1994 were generally higher in the nearshore coastal region with decreasing values offshore. The highest chlorophyll measurements were located along the shore to the southeast of Boston Harbor. The seasonal trends for chlorophyll in nearshore and offshore Massachusetts Bay in 1994 included: (1) relatively low concentrations in the winter, (2) a rapid increase in the spring associated with a springtime algal bloom, (3) generally increasing values during the summer, and (4) peak concentrations in October associated with a fall algal bloom. These trends are similar to those seen during the 1992 and 1993 measurement periods.

Chlorophyll in Cape Cod Bay followed a significantly different seasonal pattern than in Massachusetts Bay. In Cape Cod Bay, very high chlorophyll measurements, higher than any of the peak measurements in Massachusetts Bay, were obtained during late winter-early spring. Low chlorophyll values were measured during the late spring and summer, followed by a relatively low peak in the fall. This indicates that the Massachusetts Bay and Cape Cod Bay ecological systems behave somewhat independently, at least with respect to chlorophyll.

Chlorophyll concentrations in the water column provide a valid measure of algal blooms and eutrophication. Concentrations of chlorophyll in Massachusetts Bay are generally low. Average nearfield chlorophyll levels for the period 1992-1994 were relatively consistent in the Bay systems (2.0, 2.4, and 2.0 ppb, respectively). Figure 2-7 shows surface layer chlorophyll concentrations (depth averaged 0-20m) in the nearfield portions of the system in 1992, 1993, and 1994. A comparison of these results with the chlorophyll threshold values indicates that current levels of chlorophyll at the nearfield stations are less than either

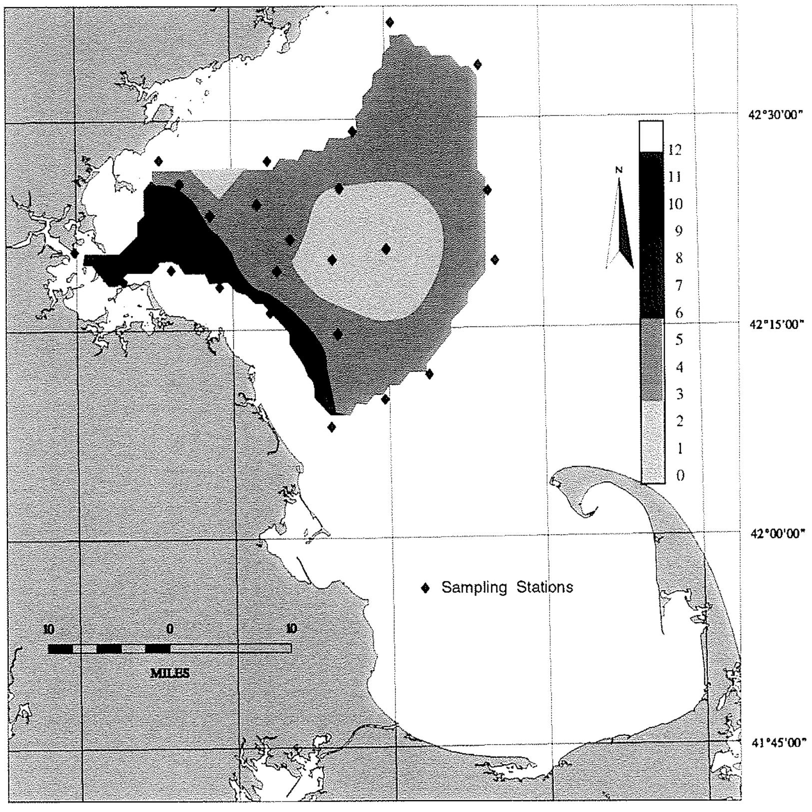


FIGURE 2-6
Spatial pattern of annual mean surface DIN concentration (μM) in Massachusetts Bay in 1994. (Kelly and Turner, 1995)

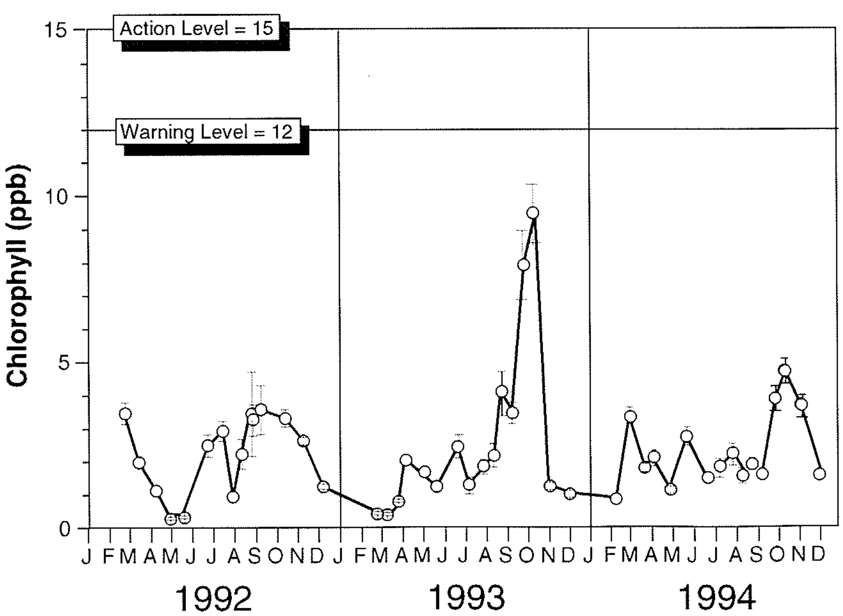
the warning or action levels (12 and 15 ppb, respectively). These results indicate that, under current conditions, algal biomass in the nearfield does not present a major water quality problem.

Overall, the monitoring results demonstrate that the monitoring program is sensitive enough to measure spatial gradients and seasonal variability. This provides a high degree of confidence that the program will be adequate to detect any changes in algal concentrations that might result from outfall relocation.

Dissolved Oxygen

DO concentrations in marine waters vary according to season and location. (Figure 2-1 summarizes the many processes that affect DO concentrations.) Thermal stratification of the water column is one of the most significant factors influencing seasonal DO variability in the Massachusetts and Cape Cod Bay system. From late fall through early spring, the water column is well mixed with little vertical variation in temperature, DO or other water quality parameters. Thermal stratification of the water column in the Bays occurs during the summer as surface heating causes surface waters to become warmer than bottom waters. Because warm water is lighter, or less dense, than cold water, the warm surface water and cold bottom water tend to form separate, stratified layers. Because of DO production from algal activity and atmospheric reaeration, DO levels in the surface layer are generally high. In contrast, DO in the bottom layer typically declines due to DO consumption from respiration and decay of organic matter, and the lack of atmospheric reaeration.

FIGURE 2-7
Surface (0–20 meters) chlorophyll concentrations in the nearfield. (Bars represent 2 standard errors on the mean of data.)



Comprehensive DO and temperature data have been collected in Massachusetts and Cape Cod Bays since 1992. Figure 2-8 shows surface and bottom layer temperature measurements throughout the year for 1992 - 1994. Surface and bottom measurements are indistinguishable from late fall through early spring, indicating well-mixed conditions. Starting in the early spring each year, the surface layer temperature increases much more rapidly than the bottom layer temperature resulting in stratified conditions by late spring. In 1994, the stratification began earlier and bottom layer temperatures in the summer and fall were higher than in previous years. Figure 2-9 shows a comparison of bottom water DO concentrations in the nearfield of the future outfall site between 1992-1994. Nearfield bottom water DO concentrations declined after the early summer months in all three years because of stratification and the other processes described above. Early spring DO concentrations were lower and the DO decline began earlier in 1994 than in previous years. By October 1994, the DO concentrations of several individual bottom samples were below the 6.0 ppm action level for nearfield locations. The lowest DO concentration observed in October 1994 was 4.8 ppm, substantially below the 1993 minimum concentration. The low 1994 DO concentrations may be a result of low initial DO values, the early onset of stratification, and high bottom water temperatures in summer and fall. The high water temperatures would have caused higher DO consumption due to higher respiration and organic material decay rates, and a lower capacity to hold oxygen.

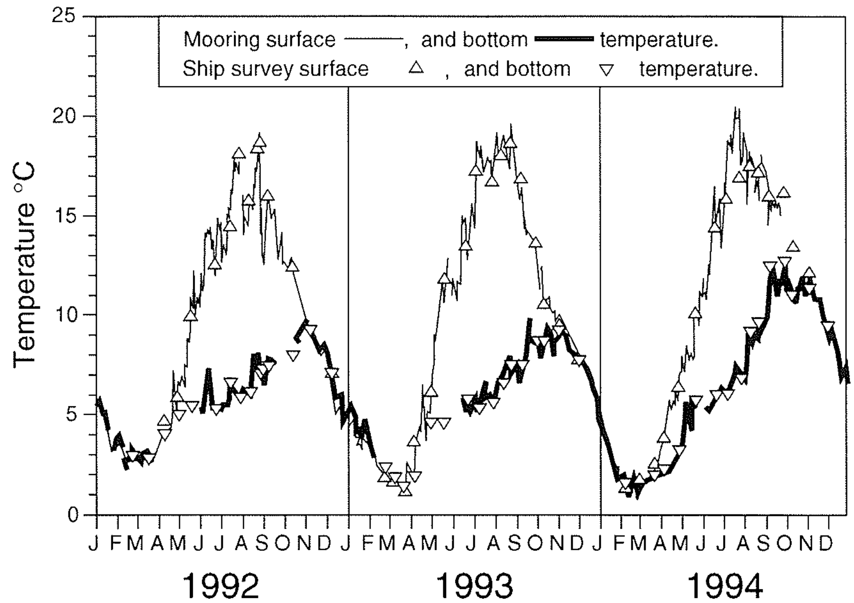
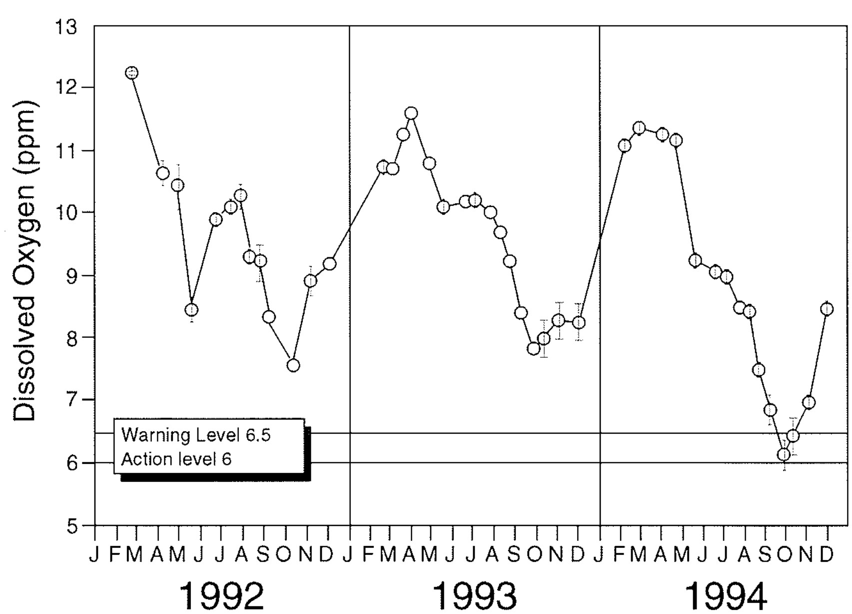


FIGURE 2-8
Surface and bottom layer temperatures in the outfall nearfield.

FIGURE 2-9
Concentrations in outfall near field (bars represent two standard errors on the mean of data).

Sediment

A number of processes, including respiration of bottom dwelling organisms and decay of organic material in sediments, act to consume and reduce oxygen levels in sediments. As a result, sediments generally undergo a transition with depth from oxygenated (aerobic) to anaerobic (having no oxygen). The redox potential discontinuity (RPD) depth is the depth at which this transition occurs. The RPD is dependent on several factors, including inputs of organic carbon and water temperature. Measurement of sediment RPD provides a sensitive indicator of change in sediment; more deeply oxygenated sediment supports a higher quality benthic community, whereas less oxygenated sediment often supports only a degraded community.



The average RPDs in nearfield and farfield sediments during the August baseline study are relatively consistent (Figure 2-10). RPDs were generally 5 to 7 cm, and were lowest in the

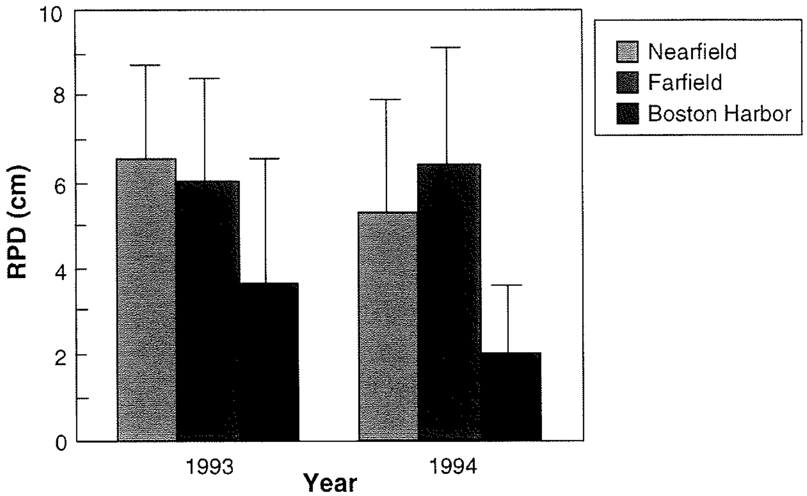


FIGURE 2-10
Measured RPD (redox potential discontinuity depth) in Massachusetts Bay sediments. (lines represent one standard deviation.)

organic-rich sediments of Boston Harbor. It is anticipated that, as effluent water quality improves, the Boston Harbor RPDs will increase. An advantage of measuring sediment RPD is that this parameter responds rapidly to changes in organic matter loading. Continued observation of sediment RPDs in Massachusetts and Cape Cod Bays will allow the MWRA to evaluate benthic impacts associated with the new secondary treatment plant and outfall tunnel.

Nuisance and Noxious Algae

The MWRA monitors a number of species of nuisance and noxious algae in Boston Harbor and the bays. To date, the MWRA monitoring program has shown that undesirable algae are present at acceptably low levels within the Massachusetts and Cape Cod Bay system. A separate study of toxic red tides (D. Anderson, pers. comm.) concluded that these algae most often occur in shallow embayments to the north of Massachusetts Bay, and that wind and rainfall play a significant role in red tide blooms. The algae were less influenced by nutrient loading because they are able to swim down to deeper nutrient-rich water.

3.0 Organic Material

3.1 Water Quality Issues

Organic material occurs naturally in water bodies and may also be introduced by wastewater effluents. The decay or decomposition of organic material in waterbodies consumes DO and in excessive amounts may contribute to DO depletion and hypoxia. Figure 2-1 describes the interaction between DO and organic material, as well as the other processes that control DO concentrations.

The amount of DO consumed by decomposing material in effluent is the biochemical oxygen demand (BOD) which consists of the nitrogenous biochemical demand (nBOD) and the carbonaceous biochemical oxygen demand (cBOD). The best parameter to provide a measure of the DO consumption by organic material is the cBOD. This is because the exertion of nBOD, caused by ammonia oxidation, is a much slower process in the environment. Oxidation of ammonia can be significant when ammonia levels are relatively high, as is the case in effluent and nearfield receiving waters.

3.2 Trigger Parameters and Thresholds

Many of the environmental measurement parameters (for example, bottom water DO, sediment RPD) that might be associated with organic material can also be related to nutrient levels. The cBOD concentration in the wastewater effluent is the trigger parameter for organic material. Threshold values specific for organic material were developed based on anticipated NPDES permit values. These values are shown on Table 3-1.

In addition, the DO and sediment trigger parameters and thresholds discussed in the nutrients section above also apply to organic material.

3.3 Monitoring Program Components Designed to Address Issues

In addition to the water quality and nutrient monitoring programs, the MWRA evaluates the cBOD in the wastewater effluent on a daily basis. The effluent cBOD is monitored to

TABLE 3-1

Trigger Parameters and Threshold Values for Organic Material

Trigger Parameter	Threshold Value	Basis for Trigger Parameter and Threshold Value
cBOD Concentration in Effluent	**Warning Levels:** - Weekly mean cBOD greater than 36 ppm. - Monthly mean cBOD greater than 22.5 ppm. **Action Levels:** - Weekly mean cBOD greater than 40 ppm. - Monthly mean cBODF greater than 25 ppm.	- Provides measure of organic loading to bay. - Warning levels based on 90% of expected NPDES permit limits. - Action levels based on expected NPDES permit limits.

ensure that treatment is adequately removing organic matter. In addition to effluent monitoring, potential impacts from organic matter on receiving waters are also evaluated through evaluation of levels of particulate organic carbon in the water column.

3.4 Monitoring Program Results

In 1994, monthly cBOD levels in Deer Island effluent ranged from 90 to 140 ppm; seasonally, cBOD tended to be lower in the spring and highest in the summer months. The cBOD in Deer Island effluent averaged approximately 100 ppm during 1994. This value was above the established warning and action thresholds (22.5-40 ppm). This is to be expected, as much of the organic matter in MWRA's system is dissolved, and not efficiently removed by primary treatment.

In January 1995, MWRA began the startup period of the new primary treatment plant on Deer Island. Although total suspended solids (TSS) concentrations in effluent appeared slightly lower than in 1994, the preliminary data suggest that the cBOD concentrations did not significantly drop. The MWRA anticipates that full completion of the new primary and secondary treatment facilities will improve the effluent quality, and that TSS and cBOD levels will drop substantially once these plants are on-line. Expected cBOD values from the primary treatment system are in the range of 80-100 ppm. After startup of the secondary treatment system, it is anticipated that cBOD levels will drop to 10-15 ppm.

4.0 Toxic Contaminants

4.1 Water Quality Issues

Toxic contaminants can cause direct harmful effects to organisms from short-term exposure and/or can cause disease, such as cancer, from long-term exposure. Toxic contaminants include heavy metals (such as lead, mercury, chromium, and cadmium); volatile organic compounds (such as benzene, toluene, and chlorinated solvents); semi-volatile organic compounds (including polychlorinated biphenyls [PCBs], polyaromatic hydrocarbons [PAHs], and pesticides such as DDT); ammonia; and chlorine. Many toxic contaminants of concern, particularly heavy metals and semi-volatile compounds, tend to preferentially adhere or partition to suspended particulate matter in the water column and settle out onto the seafloor.

Because many toxic contaminants adhere to particles, toxic impacts on marine animals are likely to primarily affect bottom-dwelling organisms and the animals that feed on them, such as flounder and lobster. Shellfish, such as mussels and clams, that feed by filtering suspended matter from large quantities of water are also potentially vulnerable to toxic contaminants. Exposure of flounder to toxic contaminants may result in fin rot, liver tumors, and other diseases. Consumption of contaminated organisms results in exposure of predators through the food chain. Human exposure to toxic contaminants in sea water may be direct, from swimming or wading, or through consumption of contaminated fish and shellfish.

4.2 Trigger Parameters and Thresholds

Trigger parameters and thresholds for toxic contaminants have been established to identify potential toxic problems by measuring and evaluating toxic loading in the discharge effluent, the dilution achieved by the diffuser, toxic contaminant concentrations in water and sediments, and toxic concentrations in and effects on marine life. Specific trigger parameters and thresholds are provided in Table 4-1.

4.3 Monitoring Program Components Designed to Address Issues

The MWRA is monitoring potentially toxic contaminants through the use of a number of different studies.

- Contaminant concentrations of numerous chemicals are directly monitored in effluent prior to discharge to the bays.
- Bioassay tests, which measure the response of indicator species to treated effluent, are being used to evaluate toxicity to various life stages of marine organisms, such as shrimp, finfish, and sea urchins.
- Sediment in the vicinity of the outfall and throughout the bays is monitored for toxic contaminants. A bacterium, *Clostridium perfringens*, is also measured in sediments, providing a sensitive indicator of sewage discharge effects on bottom sediments.

- **Effluent bioassay testing is used to measure the potential toxicity of wastewater to aquatic organisms. Aquatic toxicity measurement parameters include the No Observed Effect Concentration (NOEC) and LC50, or effluent concentration that is lethal to 50% of the test organisms.**

TABLE 4-1

Trigger Parameters and Threshold Values for Toxic Contaminants

Trigger Parameter	Threshold Values	Basis for Trigger Parameter and Threshold Values
Effluent Toxic Parameter Analysis	**Warning Level:** – Toxic contaminant concentrations and effluent toxicity greater than 90% of the expected NPDES permit limits. **Action Levels:** – Effluent LC50 less than 50% for shrimp (*Mysidopsis bahia*). – Effluent NOEC for fish (*Menidia beryllina*) growth less than effluent concentration at the edge of the mixing zone. – Effluent NOEC for sea urchin (*Arbacia punctulata*) fertilization less than effluent concentration at the edge of the mixing zone. – Toxic contaminant concentrations and effluent toxicity greater than limits set by the expected NPDES permit.	– Measures discharge of toxic parameters. – Thresholds based on expected NPDES permit limits.
Diffuser Dilution	**Warning Level:** – Effluent dilution less than predicted in the expected NPDES permit.	– Measures dilution achieved by diffuser compared to dilution needed to protect the nearfield from toxic impacts. – Thresholds based on expected NPDES permit limits.
Sediment Toxic Concentrations	**Warning Level:** – Toxic contaminant concentration in sediment at mid-field (2-7 km from outfall) stations greater than 90% of the EPA sediment criteria or NOAA ER-M values. **Action Level:** – Toxic contaminant concentrations in nearfield sediment greater than EPA sediment criteria.	– Measures potential for toxic effects on benthic marine life in sediments. – Thresholds based on national sediment quality criteria.
Toxic Accumulation and Effects on Marine Life	**Warning Levels:** – Annual mean mercury concentration in flounder, lobster, and caged mussel edible tissue greater than 0.5 ppm wet weight. – Increase in annual mean contaminant concentration in flounder, lobster, and caged mussel edible tissue by a factor of two, for 3 consecutive years. – Annual mean PCB concentration in flounder, lobster, and caged mussel edible tissue greater than 1 ppm wet weight. – Annual mean lead concentration in caged mussel edible tissue greater than 2 ppm wet weight. – Increase in annual mean lead concentration in caged mussel edible tissue by 20% per year relative to baseline conditions, for 3 consecutive years. – Centrotubular hydropic vacuolation prevalence in flounder liver at future outfall site equal to average baseline prevalence in Harbor flounder. **Action Levels:** – Annual mean mercury concentration in flounder, lobster, and caged mussel edible tissue greater than 0.8 ppm wet weight. – Annual mean PCB concentration in flounder, lobster, and caged mussel edible tissue greater than 1.6 ppm wet weight. – Annual mean lead concentration in caged mussel edible tissue greater than 3 ppm wet weight.	– Measures contaminant body burden and incidence of disease in marine organisms to evaluate contaminant exposure and identify unanticipated effects on marine life. – Thresholds are based on U.S. Food and Drug Administration Action Levels.

- Tissue analyses, which measure concentrations of toxic chemicals in animal tissue, are being used to evaluate bioaccumulation of certain contaminants in flounder, lobster, and mussels.
- Abnormalities, such as diseased livers and fin rot in flounder and diseased gills in lobster, are being monitored to evaluate adverse effects associated with exposure to contaminants.

- Water quality criteria are maximum pollutant concentration values, or minimum concentrations of desirable parameters (such as DO), that were established to support a specific water body use, such as protection of aquatic life. Acute criteria values were developed to be protective of relatively short-term (less than 96 hours) exposure to pollutants. Chronic criteria are values that provide protection from relatively long-term pollutant exposure.

4.4 Monitoring Program Results

Exposure to toxic contaminants in sewage may result in risks to human health and the environment. Humans may be exposed to contaminants through ingestion of accumulated contaminants in seafood. Marine organisms such as finfish and shellfish may be harmed by chronic exposure to toxic contaminants. Filter feeders such as mussels, and bottom feeders such as flounder, are particularly at risk from exposure to toxic contaminants in the bays. When humans or other predators eat fish and shellfish that have accumulated toxic contaminants, exposure to these chemicals may occur through the food chain.

4.4.1 Effluent

- Effluent sampling provides the MWRA with the ability to monitor several nutrients, trace metals, and anthropogenic organic compounds prior to discharge. As the level of treatment increases, effluent quality is expected to improve substantially.

To evaluate levels of trace metals and organic contaminants in the effluent, the MWRA collects and analyzes samples from the effluent wastestream at the Deer Island plant. Bimonthly twenty-four hour composite samples are collected two days apart. The effluent monitoring program uses clean sampling and laboratory analysis methods in order to detect very low levels of contaminants. This is necessary because toxic contaminant levels in MWRA effluent are so low that normal NPDES methods, developed by the EPA, would not be able to detect or quantify effluent contaminants. These low detection methods provide a sensitive measure of the toxic pollutant loading associated with the MWRA discharge. In addition, *Clostridium perfringens*, which is measured in both effluent and sediments, forms stable spores which provide a tracer of sewage solids in Boston Harbor and the bays.

In general, monitoring data indicates significant reductions in toxic contaminant levels over the past few years due in part to the efforts of MWRA's Toxic Reduction and Control (TRAC) Department to reduce the amount of toxic pollutants discharged into the MWRA system. The 1994 results were obtained before start up of the new primary treatment system. Initial data since then indicates that the new primary treatment system is resulting in a small further reduction of toxics in effluent. Effluent quality is expected to improve further as the reduction in toxic discharges to the system continues, as the primary treatment process continues to improve, and as secondary treatment is phased in.

Average effluent analyte concentrations for the Deer Island Treatment Plant from June 1993 to November 1994 are presented in Table 4-2 (organics) and Table 4-3 (inorganics). These tables also include acute and chronic marine water quality criteria, and expected concentrations within the nearfield mixing zone of the new diffuser. (It should be noted that those concentrations conservatively assume no reduction in toxics in effluent before outfall relocation). None of the mean concentrations of organic analytes exceed acute water quality criteria. Average concentrations of three pesticides (4,4-DDT, dieldrin, and endrin) in the undiluted effluent were, however, higher than chronic criteria. With respect to metals, undiluted effluent silver, mercury, lead, and zinc levels exceeded chronic criteria for the protection of aquatic life, while copper and silver concentrations exceeded acute criteria. However, nearfield dilution predictions (assuming a 100:1 initial dilution) indicate that organic and metal concentrations in Massachusetts Bay (shown in Tables 4-2 and 4-3) would meet acute and chronic criteria values within a few meters of the new outfall diffuser.

The potential for secondary treatment to improve effluent water quality was evaluated through a pilot treatment plant study. Relatively little pilot treatment plant data are current-

TABLE 4-2

Organic Contaminant Concentrations (ppb) in Undiluted Effluent and in Future Outfall Mixing Zone Compared to EPA Aquatic Life Criteria

Parameter	Marine Acute Water Quality Criteria	Marine Chronic Water Quality Criteria	Mean Effluent Concentration[1]	Mean Predicted Concentration in Mixing Zone[2]
Pesticides				
Aldrin	1.3	NC	.0007	0.000007
4, 4'-DDT	0.130	0.001	.0099	0.0001
Dieldrin	0.710	0.0019	.0024	0.00002
Endrin	0.037	0.0023	.0026	0.0003
Heptachlor	0.053	0.0036	.0007	0.000007
Heptachlor Epoxide	0.053	0.0036	.0013	0.00001
Lindane	0.160	NC	.014	0.0001
PAH				
Acenaphthene	0.970[3]	0.710[3]	0.163	0.0016
Fluoranthene	40[3]	16[3]	0.194	0.0019
Naphthalene	2,350[3]	NC	1.350	0.0135
ΣPAH	300[3]	NC	20.761	0.207

[1]Average concentration in samples in which contaminant was detected.
[2]Estimate based on discharge mixing zone dilution of 100:1.
[3]Value presented is a lowest observed adverse effects concentration (LOAEC); insufficient data are available for EPA to develop aquatic life criteria. NC = No established criterion.
Source: Hunt et al., 1995

TABLE 4-3

Mean Concentration (ppb) of Metals in Undiluted Effluent and in Future Outfall Mixing Zone Compared to EPA Aquatic Life Criteria

Parameter	Marine Acute Water Quality Criteria	Marine Chronic Water Quality Criteria	Mean Effluent Concentration	Mean Concentration in Mixing Zone[1]
Silver	2.3	0.92[2]	4.9	NA
Cadmium	43	9.3	0.7	0.04
Chromium (UI)	1100	50	4.0	0.2
Copper	2.9	NC	74.7	1.0
Mercury	2.1	0.025	0.15	0.004
Nickel	75	8.3	6.3	1.6
Lead	220	8.5	11.8	0.3
Zinc	95	86	87.0	1.5

[1] Conservative estimate based on 100:1 dilution of effluent with seawater containing the maximum Massachusetts Bay concentration in Table 4-4.
[2] Proposed criterion. NC = No established criterion. NA = Not analyzed.
Source: Hunt et al., 1995.

TABLE 4-4

Comparison of Metal Concentrations (ppb) in the Pilot Treatment Plant Effluent, Deer Island Effluent, Ambient Values in Massachusetts Bay, and EPA Chronic Water Quality Criteria

Parameter	1994 Effluent[1] Concentration	Pilot Plant Effluent Concentration[2]		Ambient water Concentrations in Massachusetts Bay[3]	EPA Chronic Water Quality Criteria
		Primary	Secondary		
Silver	4.9	3	0.6	NA	0.92[4]
Cadmium	0.7	.5	0.03	0.02 - 0.03	9.3
Chromium	4.0	7	2.7	0.10 - 0.18	50
Copper	74.7	57	8	0.1 - 0.3	2.9[4]
Mercury	0.15	0.1	0.02	0.0005 - 0.003	0.025
Nickel	6.3	9	5	0.26 - 1.6	8.3
Lead	11.8	20	1.4	0.03 - 0.2	8.5
Zinc	87.00	88	30	0.08 - 0.6	86

[1]Average value from June 1993 through November 1994.

[2]Pilot plant results are generally the highest concentrations measured in tests conducted in July 1994.

[3]Massachusetts Bay data concentrations near future outfall site. NA = Not analyzed.

[4]Proposed criterion.

Source: Hunt et al., 1995.

ly available, and the results must be considered preliminary. However, as shown in Table 4-4, with the exception of copper, metals concentrations in undiluted effluent from the pilot treatment plant study were well below any federal water quality criteria. When one considers the expected 100-fold effluent dilution within meters of the outfall diffuser, it appears doubtful that any exceedances of toxic parameter water quality thresholds will occur once the future outfall and secondary treatment system are both operating.

4.4.2 Sediment

Toxic contaminants, including metals and semi-volatile organics such as PCBs and 4,41-DDT, tend to concentrate in bottom sediments. Sediment contaminant testing is necessary to verify model predictions of toxic contaminant buildup in sediments in the nearfield region of the future outfall site. These conservative calculations, which are intentionally designed to overpredict possible contaminant build-up, indicate that after outfall relocation it will take years before measurable increases of toxics in sediments could possibly be reached and decades before levels could potentially reach those that might cause biological effects.

The MWRA has conducted annual sediment sampling since 1992 at 20 locations in the nearfield, and at 11 stations throughout the remainder of Massachusetts and Cape Cod Bays. Analytical parameters include metals, PCBs, PAHs, pesticides, total organic carbon, grain size, and sewage tracers. In general, contaminant levels in nearfield sediments and in the bays have been considerably below draft criteria established by EPA for several PAHs and pesticides. Concentrations of these parameters in the bays are typically less than in Boston Harbor sediments. Representative concentrations of metals evaluated in 1994 are shown in Table 4-5. Contaminant concentrations can be generally characterized as low, with substantial variability between sampling stations. Concentrations of a few contaminants exceed the

Sediment Quality Guidelines

- Sediment quality guidelines are useful screening tools to evaluate potential impacts to sediment-dwelling organisms. The National Oceanographic and Atmospheric Administration (NOAA) has developed effects-based guidelines based on a weight of evidence from many studies. Chemical concentrations below the NOAA "Effects Range-Low" (ER-L) values are rarely associated with toxic effects, whereas chemical concentrations above the NOAA "Effects Range Median" (ER-M) values often are associated with toxic effects.

TABLE 4-5

Comparison of 1994 Mean Concentrations, Levels of Detectable (Significant) Increase, and the NOAA ER-L Values for Sediments within 2 km of the Diffuser. (Metals in ppm; organics in ppb)

Contaminant	Mean Sediment Concentration	Detectable Change[1] (Within 2 km of diffuser)	NOAA ER-L Value	Representative Boston Harbor Concentrations[2]
Silver	0.16	0.35	1	2.8 (0.14 to 7.9)
Cadmium	0.05	0.1	1.2	1.0 (0.04 to 3.9)
Chromium	50	71	81	142 (32 to 385)
Copper	15	24	34	98 (11 to 219)
Mercury	0.12	0.22	0.15	0.8 (0.039 to 3.75)
Nickel	12	20	21	26 (7.4 to 43)
Lead	41	53	47	146 (25 to 419)
Zinc	39	53	150	184 (31 to 407)
Total DDT	0.8	2.3	1.6	59 (1.1 to 207)
Total PCB	7.9	14.5	22.7	193 (7 to 855)
Chlordane	0.05	0.16	0.5	Not measured
Total PAH	2061	4395	4022	30,717 (380 to 156,200)

[1]The lowest hypothetical concentration that would be interpreted as a significant increase over 1994 concentrations based on statistical analysis.

[2]Values from Durell (1995) are presented as: average (min to max).

Source: Hunt et al., 1995

NOAA ER-L screening values presented in Table 4-5; all were well below NOAA ER-M levels. The third column of the table indicates that the monitoring program is appropriately designed to measure variations of contaminant levels in sediments and that it will be sufficiently sensitive to detect changes that could cause exceedance of action or warning levels.

In addition to its sediment sampling program, the MWRA and the U.S. Geological Survey are engaged in a joint study of contaminant transport in the vicinity of the future outfall. Metals such as silver, whose major current source to the bays is the existing MWRA effluent discharge, are tracked in this joint effort. Consistently stable levels of silver have been observed by the USGS between 1989 and 1992 (Figure 4-1). In general, silver concentrations during this period averaged between 0.5 and 0.7 mg/kg; however, in February 1993, a significant increase in silver concentrations was seen. This increase in silver may be related to sediment transport and accumulation of fine material following the major northeast storm of December 11-16, 1992. This finding demonstrates the importance of sediment transport processes in determining the concentration and distribution of toxic materials in sediments.

- MWRA has conducted modeling studies to evaluate future contaminant loads in the bays. These models have demonstrated that within the estimated 50 year lifetime of the treatment plant, the addition of metals through the outfall will result in minimal increases in the overall concentrations of metals in bottom sediments.

Analytical Chemistry

- Data in this report are presented as both wet weight and dry weight. Fish and shellfish tissue data are reported as wet weight, where as sediment data are presented on a dry weight basis.

4.4.3 Tissue Analyses

Flounder & Lobster Studies

Between 1992-1994, the MWRA conducted annual sampling of winter flounder and lobster in Massachusetts Bay. The primary goals of this monitoring program are: (1) to evaluate the health of these marine resources in terms of disease (Section 4.4.4) and (2) to evaluate organic and inorganic contaminant concentrations in the organs and edible tissues of these organisms.

Winter flounder were collected from five sites in Boston Harbor and the bays: Deer Island Flats, Broad Sound, Nantasket Beach, the Future Outfall Site, and a reference site in eastern Cape Cod Bay (Figure 4-2). Lobster were collected from the Deer Island, Future Outfall, and eastern Cape Cod Bay sites.

In 1994, contaminant concentrations were measured in 15 flounder muscle samples, 15 flounder liver samples, eight lobster muscle samples, and eight lobster hepatopancreas samples at each site. All samples were analyzed for PCBs, chlorinated pesticides, and mercury. The liver and hepatopancreas samples were also analyzed for a number of other organic and inorganic contaminants.

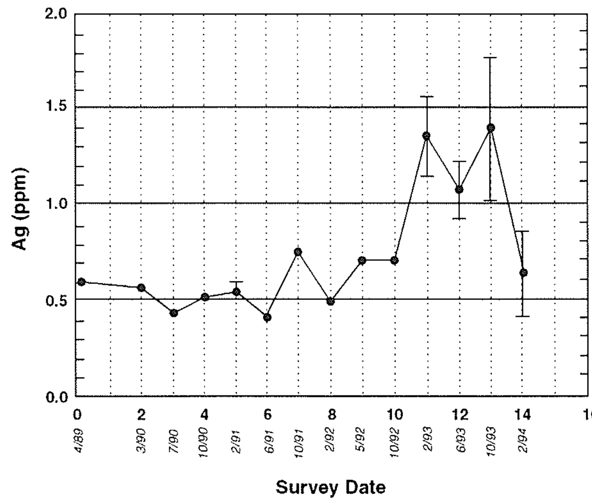


FIGURE 4-1
Concentrations of silver in the surface sediment layer near the future outfall in Massachusetts Bay: 1989-1994. Bars represent one standard deviation on mean of data. (Source: Bothner, et al., 1993)

The monitoring results indicate that contaminant concentrations in flounder and lobster are generally higher in Boston Harbor near the existing Deer Island outfall and at the future outfall site than at the Cape Cod Bay site. Contaminant concentrations at the future outfall site are generally intermediate between values at Deer Island and the Cape Cod Bay site. However, the data were highly variable and PCB and mercury concentrations in lobster and mercury in flounder were higher at the future outfall site than at Deer Island in 1994 (see Figure 4-3).

Long term monitoring data indicate that over the past decade there has been a general decline in contaminant concentrations in fish and shellfish in Boston Harbor. Mercury concentrations in flounder tissue from the MWRA studies and an earlier study were compiled for the Deer Island sampling station (Figure 4-4). These data suggest that tissue concentrations of mercury decreased by approximately a factor of two between 1987 and 1994.

Over the past few years, temporal variations in the concentrations of various contaminants in flounder and lobster have been mixed, with some increases and some decreases. For example, at the Deer Island site PCB concentrations in flounder increased by over a factor of two between 1993 and 1994, while mercury in flounder decreased during the same period. At the future outfall site, most contaminants increased between 1993 and 1994. During this period, PCBs and chlordane in lobster increased by approximately a factor of three and DDT increased by a factor of two. These variations are likely due to a number of complex factors, including analytical variability, migration of animals, the transport and mobility of contaminated sediments and the effects of exposure of fish and shellfish to contaminants in sediments and resuspended sediments. In general, it is expected that outfall relocation will result in decreased contaminant levels in harbor fish and shellfish, without any significant increases at the future outfall site.

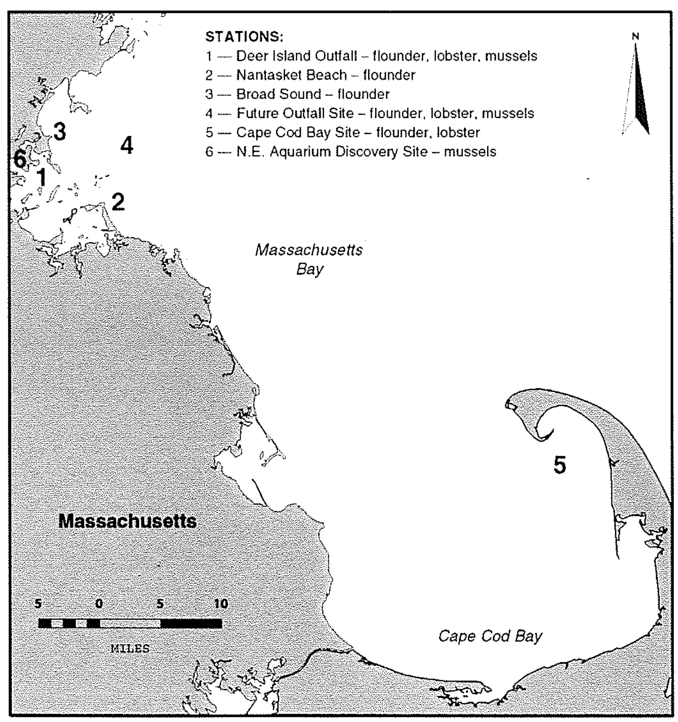


FIGURE 4-2
Sampling stations for winter flounder, lobster and mussels during 1994.

- When contaminants are stored in fish and shellfish tissues, they are said to bioaccumulate. Tissue analysis to determine the contaminant body burden provides useful information for evaluating risks to human health and the environment from food chain exposure. However, many organisms are known to bioaccumulate toxic chemicals without exhibiting adverse health effects.

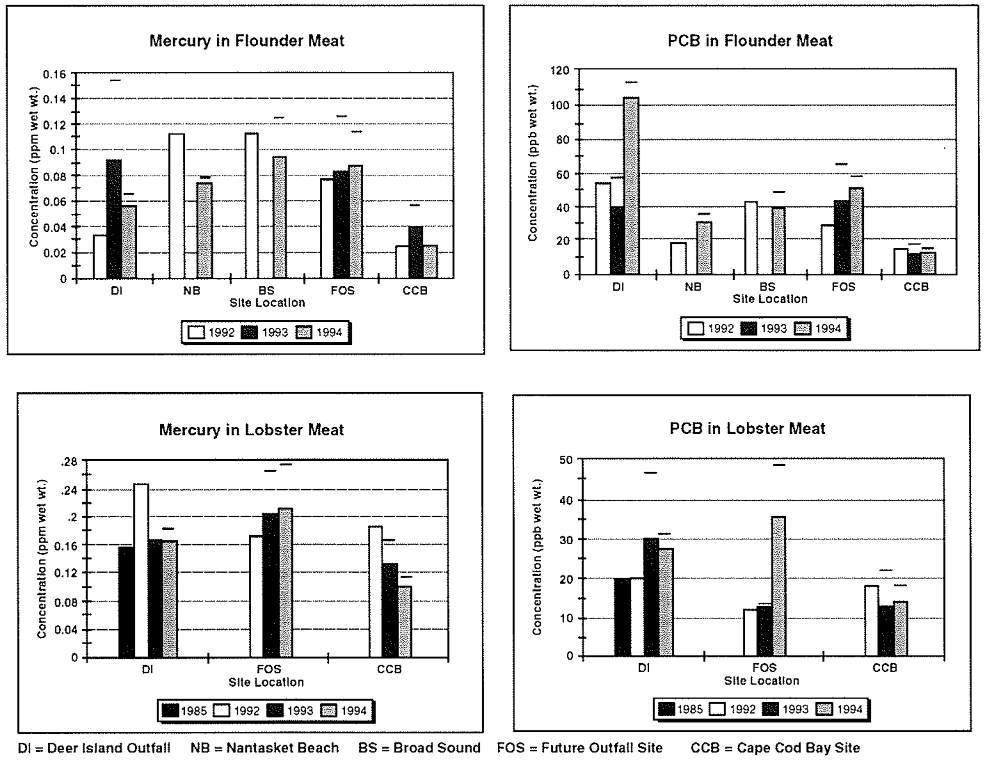


FIGURE 4-3
PCB and mercury concentrations in flounder muscle and lobster meat, 1992 to 1994. (Lines represent range of data). Source: Hillman and Peven, 1995.

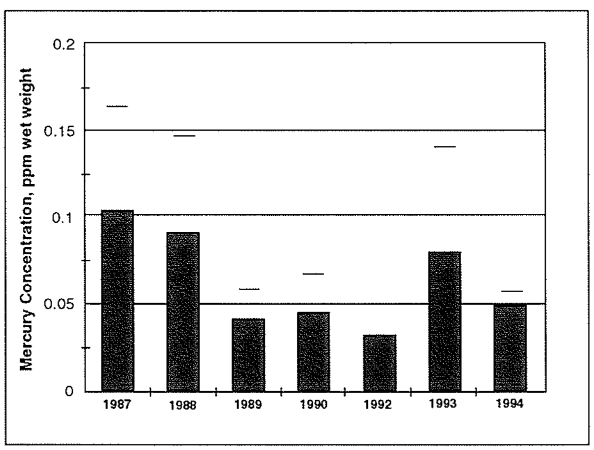


FIGURE 4-4
Mercury concentrations in flounder meat from Deer Island, 1987 to 1994. (Lines represent one standard deviation). Source: Hillman and Peven, 1995.

Historical monitoring data have demonstrated that contaminant levels in tissues of lobster and flounder are well below applicable action levels in Massachusetts Bay. The MWRA's baseline monitoring data support this finding even with the recent increase in tissue contaminants at the future outfall site and Deer Island. A comparison of PCB and mercury concentrations in various tissues with the U.S Food and Drug Administration Action (FDA) Levels for these contaminants in edible tissue (thresholds for toxic contaminants in tissue are based on these action levels) indicates that the detected concentrations were at least four times lower than the FDA action level. PCB concentrations in lobster hepatopancreas were the closest to the action levels, ranging from 4 times lower at the future outfall site to 15 times lower in the Cape Cod Bay site.

Bioaccumulation in Mussels

A series of mussel bioaccumulation studies have been conducted since 1987 to determine whether selected contaminants (PCBs, pesticides, PAHs, and metals) bioaccumulate in shellfish. This study was also used to obtain background data offshore in the vicinity of the future outfall site. Mussels were collected from a relatively clean location in Gloucester, MA and deployed in cages at three locations (Figure 4-2): near the present Deer Island outfall; at the future outfall site; and in the inner harbor (the New England Aquarium Discovery barge). After 60 days, mussels were harvested for biological and chemical analyses. Overall, study contaminant levels at the Boston Harbor stations (Deer Island and Discovery) have decreased since 1987. For example, as shown in Figure 4-5, PCB levels near the Deer Island outfall decreased by approximately a factor of three between 1986 and 1994.

In 1994, contaminant concentrations were generally lowest at the future outfall site and highest at the Deer Island and Discovery stations. For example, in 1994 the average total PAH concentration in control mussels from the Discovery Station (2255 ppb) was significantly higher than in all other mussel deployment groups. Likewise, in 1994 the average concentration of total PAH in Deer Island mussels (848 ppb) was significantly greater than the average total PAH concentration in mussels from the future outfall site (122 ppb).

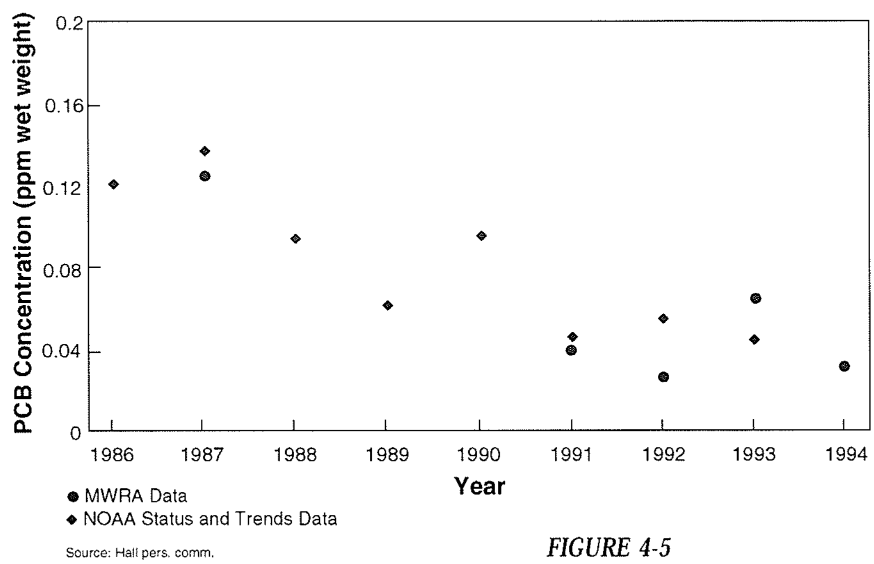


FIGURE 4-5
Total PCB Bioaccumulation in mussels near Deer Island discharge, 1986-1994

Total PCB body burdens in mussels at all stations were generally lower in 1994 than in the previous year (Table 4-6). None of the stations had PCB concentrations that exceeded the action levels. The Discovery mussels typically had the highest observed PCB concentrations, while the mussels deployed at the future outfall location had the lowest concentrations of PCBs. Mussels caged at the future outfall site in 1993 and 1994 contained contaminant levels equal to or less than levels at the Gloucester predeployment location. This demonstrates that no bioaccumulation of PCBs is currently occurring at the future outfall site (Table 4-6).

4.4.4 Abnormalities in Marine Life

Some winter flounder from all sampling sites, including the future outfall site, had fin erosion or a number of different histopathological liver lesions. One sensitive indicator of contaminant exposure is the prevalence of a liver lesion known as centrotubular hydropic vacuolation (CHV) in fish livers.

The National Marine Fisheries Service and researchers from Woods Hole Oceanographic Institute have monitored tumors in flounder since the late 1980's. Since 1991, the MWRA has monitored the presence of CHV and other tumors in flounder from Boston Harbor and the bays. These studies have consisted of annual sampling of 50 winter flounder from five different locations. Sampling results to date indicate that the incidence of CHV in winter flounder from the vicinity of the future outfall site has been relatively constant since 1991 (Figure 4-6). In contrast, tumors in Boston Harbor flounder decreased significantly in the late 1980s.

CHV has been present in about 30% of the fish population from the future outfall site, significantly less than the approximately 50% incidence in flounder in Boston Harbor. The lowest prevalence (<10% in 1994) of CHV occurs at the eastern Cape Cod Bay reference site.

Comparison of CHV occurrence with contaminant levels indicates that the prevalence of this disorder increases with increasing contaminant concentration. Figure 4-7 shows this trend for PCB concentrations, indicating that CHV occurrence in flounder is correlated with PCB levels. The causes of CHU, however, are not known at present.

Fish and Shellfish Action Levels

- The U.S. Food and Drug Administration (FDA) has established action levels for toxic or deleterious substances in human food and animal feed. Action levels represent limits at or above which FDA may take action to remove products from the market. For example, the FDA legal limit for contaminants in fish and shellfish is 2.0 ppm for total PCBs and 1.0 ppm for mercury.
- The presence of physical abnormalities in fish and shellfish can be a sensitive indicator of contaminant exposure. Tumors, lesions, finrot, and gross deformities are physical abnormalities that may be attributable to pollution. Certain physical abnormalities such as liver lesions may only be detected through histopathology, the study of adverse changes in tissue structures.

TABLE 4-6
Comparison of Average Body Burdens of Deployed Mussels
for Select Organic Compounds and Metals

Parameters	1993				1994			
	Predeployment Gloucester	Future Outfall Site	Deer Island	Discovery	Predeployment Gloucester	Future Outfall Site	Deer Island	Discovery Average
PAH (ppb wet weight)								
LMW PAH	13.2	13.2	33.8	22	21.2	12.2	43.4	15.8
HMW PAH	24.4	20.2	99.2	242	31.6	12.2	126	435
Total PAH	37.6	33.2	133	264	52.8	24.4	170	451
Pesticides (ppb wet wt)								
Total Chlordane	3.2	2.2	4.8	5.2	2	1.8	5.4	5.8
Total DDT	16.4	6	12.6	26	5.4	3.8	10	17.2
Polychlorinated Biphenyls (ppb wet weight)								
Total PCB	47.8	22	64.2	119	21.4	17.8	32.2	100
Metals (ppb wet wt)								
Mercury	0.078	.02	.036		.036	0.026	0.042	.032
Lead	1.024	.742	1.176		1.72	.96	1.8	1.33

Source: Downey et al., 1995.

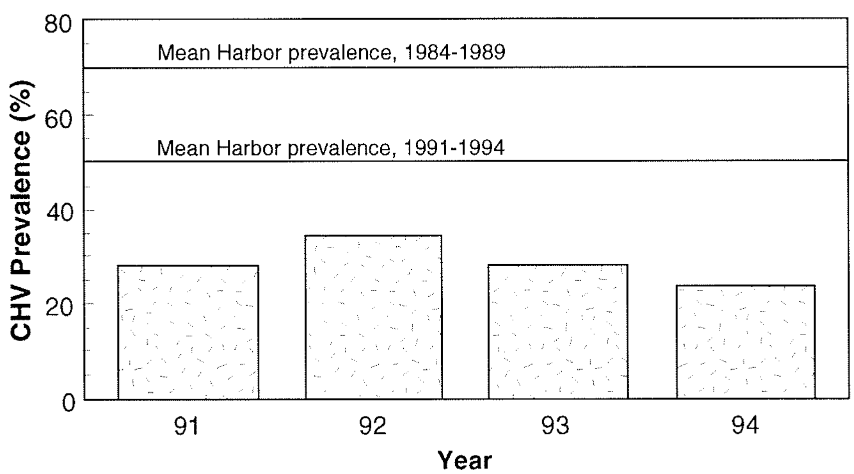


FIGURE 4-6
Prevalence of CHV near the future outfall site: 1991-1994. CHV=Centrotubular Hydropic Vacuolation. Source: Hillman and Peven, 1995.

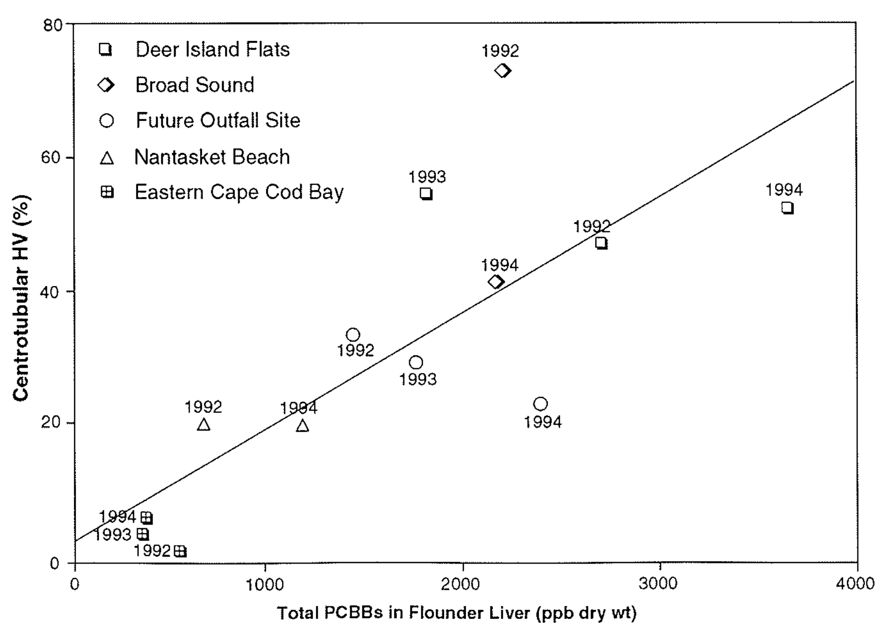


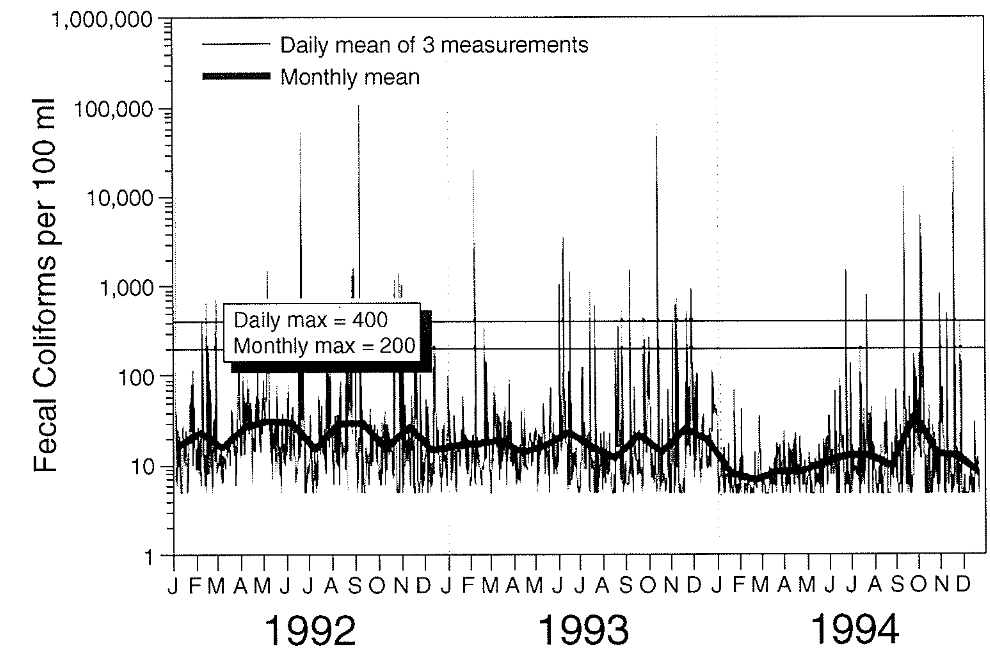
FIGURE 4-7
Total PCBs in Flounder Liver Tissue vs. CHV Prevalence. Source: Moore & Stegeman 1993; Shea 1993; Hillman et al. 1994; Hillman & Peven 1995

5.0 Human Pathogens

5.1 Water Quality/Health Issues

Human pathogens in effluent are bacteria and viruses from human and animal waste that cause disease in humans. Although human pathogens are not known to harm marine life, they may concentrate in filter feeding shellfish, such as mussels and clams. Human exposure to pathogens may occur primarily from the consumption of contaminated shellfish and from incidental ingestion of water while swimming. Fecal coliform bacteria are often used as an indicator of the presence of human pathogens.

FIGURE 5-1
Measurements of Fecal Coliform in Effluent



Pathogens in wastewater are commonly controlled by disinfection, generally by chlorination. Also, pathogens die off very quickly in sea water and the effect of pathogens discharged in marine waters are typically very localized near an outfall. MWRA's new outfall location is far from beaches and shellfishing areas, which will minimize the potential for human exposure. Computer modeling studies have indicated that, even in the unlikely circumstance of a complete failure of the disinfection system, discharges from the new outfall location would result in insignificant pathogen levels at the nearest beaches, Nahant and Nantasket Beach.

5.2 Trigger Parameters and Thresholds

Trigger parameters and thresholds for bacterial indicators of the presence of human pathogens were based on state water quality standards and designed to measure the discharge of pathogens that might lead to unacceptable exposure to humans. Established action levels are:

- Daily mean greater than 400 fecal coliform/100 ml in effluent.
- Monthly mean greater than 200 fecal coliform/100 ml in effluent.

5.3 Monitoring Program Components Designed to Address Issues

Because the effluent will be diluted at the new outfall, it is unlikely that any bacterial water quality standards would be exceeded if undiluted effluent bacteria concentrations were less than the action levels. In order to ensure that pathogen levels are below action levels, the

MWRA monitors fecal coliform levels in the effluent three times each day. Long-term monitoring for pathogen indicators in the Massachusetts Bay receiving waters is not necessary, as long as the diffuser design dilution is met and effluent monitoring indicates that effluent quality is within the permitted limit.

5.4 Monitoring Program Results

Fecal coliform levels in Deer Island effluent vary widely (Figure 5-1). Although these results show that on occasion the fecal coliform levels in 1991 and 1992 exceeded daily threshold values, the monthly averages during this time period were below effluent standards. This level of performance is expected to be further improved when the new treatment plant is on-line. The new treatment plant will have a longer chlorine contact time, resulting in increased pathogen destruction.

6.0 Solids

6.1 Water Quality Issues

Suspended solids are small particles of matter, such as mud, sand, or organic debris, suspended in the water column. Solids have an important influence on the behavior of toxic contaminants and other water quality parameters. However, the primary concern associated with solids is deposition and the resulting potential for smothering of bottom habitat and benthic (bottom dwelling) organisms. Another issue of some concern is the aesthetic effect of loss of clarity of waters with high suspended solids levels.

■ Benthic Community Diversity is often used to evaluate environmental change. Examples of changes in community diversity include changes in the relative abundance of various species, or changes in the numbers and kinds of species that live in a particular habitat.

6.2 Trigger Parameters and Thresholds

Trigger parameters and thresholds for solids for the effluent were developed based on expected NPDES permit limits, which should protect the receiving water body from solids discharges. Other threshold values provide a measure of impacts on the benthic biological community. Established threshold values for solids are shown on Table 6-1.

Thresholds for carbonaceous BOD and depth of sediment DO discussed above are also relevant for identifying the impact of solids.

6.3 Monitoring Program Components Designed to Address Issues

The MWRA monitors the environmental impact from solids in the following ways:

- Concentrations of total suspended solids are measured daily in the effluent.
- In cooperation with the USGS, the MWRA monitors suspended solids at the future outfall site and sediment depositional patterns and trends throughout Massachusetts Bay.

TABLE 6-1

Trigger Parameters and Threshold Values for Solids

Trigger Parameter	Threshold Values	Basis for Trigger Parameter and Threshold Values
Effluent TSS Concentrations	**Warning Levels:** – Weekly mean effluent total suspended solids (TSS) greater than 40.5 mg/L. – Monthly mean effluent TSS greater than 27 mg/L. **Action Levels:** – Weekly mean effluent TSS greater than 45 mg/L. – Monthly mean effluent TSS greater than 30 mg/L.	– Provides measure of total suspended solids loading to bay. – Warning levels for effluent based on 90% of expected NPDES permit limit. – Action levels for effluent based on expected NPDES permit limit.
Benthic Community	**Warning Levels:** – Mean benthic community diversity at nearfield muddy or sandy stations decrease by 50%. – Significant downward trend in mid-field benthic diversity for 3 post-discharge years. – Change in mid-field soft bottom community to typical degraded benthic community. – Significant difference in species composition and relative abundance at stable mid-field soft bottom sites relative to baseline.	– Provides measure of benthic community health. – Thresholds based on community diversity.

What is a Benthic Community?

- A marine benthic community is composed of organisms such as worms or crustaceans dwelling on or in the sea floor (see Figure 6-1). Benthic communities in Massachusetts Bay include numerous marine invertebrate and fish species.

Why Evaluate the Benthic Community?

- Benthic communities reflect the overall ecological quality of an area. Surveys of communities can provide sensitive measures of effects from physical and chemical stressors such as sewage effluent toxicants and organic matter. Benthic invertebrates are useful indicators of potential impacts associated with stressors because:
  - Some benthic organisms are commercially important species.
  - Benthic organisms are a primary food source for many recreationally and commercially important fish species.
  - Many species have limited mobility, so they cannot move away from stressful conditions.
  - Sensitive life stages exist for most species.
  - Sampling is relatively routine and cost-effective.
  - There is a large literature database available to assess impacts.
  - Degraded conditions can be readily detected using modern automated methods.

- Sediment sampling and video inspection of the sediments in the immediate vicinity of the outfall are conducted.
- TSS, turbidity and light penetration are measured as part of water column monitoring.
- Benthic communities can serve as sensitive indicators of environmental perturbations. For this reason, the MWRA monitors numbers and types of benthic organisms in Boston Harbor, in the vicinity of the future outfall site, and throughout the rest of Massachusetts and Cape Cod Bays.

In addition, other parameters such as the depth of oxygenated sediment are used to monitor environmental impacts from solids. This information is presented in Section 2.0 of this report.

6.4 Monitoring Program Results

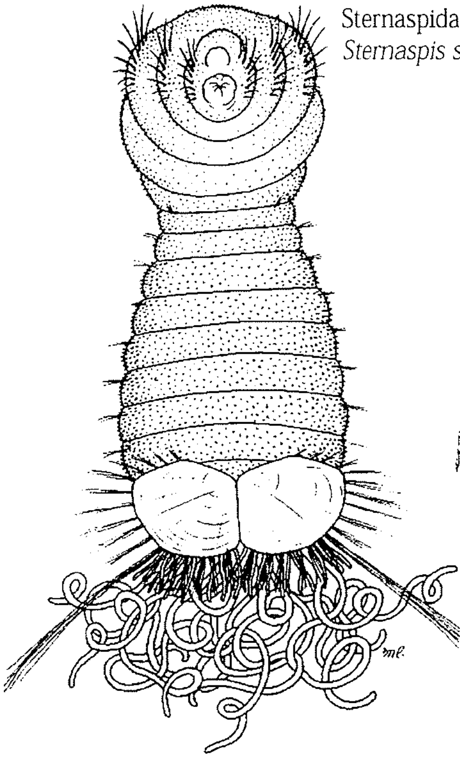
Effluent

Average monthly TSS concentrations in the effluent from the Deer Island Treatment Plant in 1994 ranged from 65 to 90 mg/L. On average, of 44% of the solids entering in the influent to the Deer Island facility were removed following primary treatment. In January 1995, the MWRA began monitoring effluent TSS from the new Deer Island Primary Treatment Plant. Preliminary 1995 data suggest that total solids levels in the effluent are slightly lower than in 1994 (55 to 65 mg/L in the first third of 1995). Although the TSS appears to be lower in the new plant effluent, these values are still substantially higher than the established threshold values. The MWRA anticipates that completion of the new secondary treatment facility will further improve effluent water quality, and that TSS levels will drop substantially once secondary treatment commences. The TSS level for the secondary treatment plant is expected to be approximately 15 mg/L.

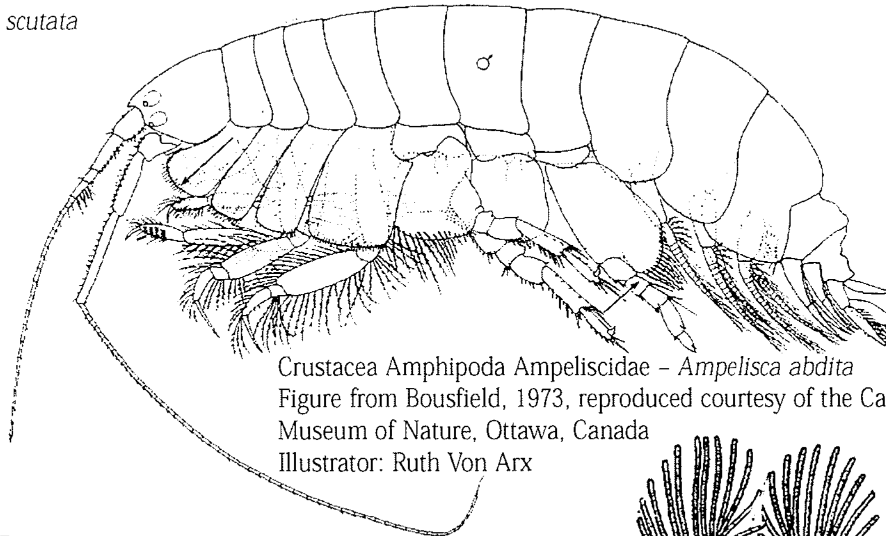
Benthic Habitat/Community Monitoring

The assessment of benthic community changes in response to effluent quality requires a thorough understanding of the benthic habitat, as well as the existing community structure, function, stability, and variability. Numerous factors other than effluent discharge have the potential to affect benthic community composition. The complex and variable habitat and environment in Massachusetts Bay — especially in the vicinity of the future outfall diffuser — are important considerations in the assessment of benthic communities. Western Massachusetts Bay, including the nearfield future outfall site area, is a region of highly variable bottom habitat types. Erosional (representing hard bottom, cobbles, rock and/or gravel), depositional (representing soft bottom mud and fine-grain sand), and mixed environments are widely interspersed (see Figure 6-2). Typical habitat patch sizes are on the order of hundreds of meters. There is strong evidence that some of these sediments are highly dynamic, showing dramatic changes after major storm events. In contrast, Cape Cod Bay has a relatively homogeneous, stable bottom environment.

Between 1992 and 1994, 170 benthic samples were collected. The database from these samples lists 244,040 organisms representing 322 species. The data indicate that the benthic community is strongly influenced by bottom habitat type. Therefore, communities in western Massachusetts Bay show strong shifts over relatively small distances. However, widely separated stations with similar sediment types often show very similar benthic com-

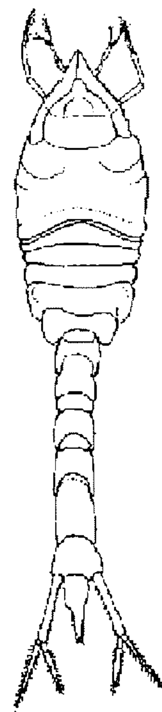


Annelida Polychaeta
Sternaspidae –
Sternaspis scutata

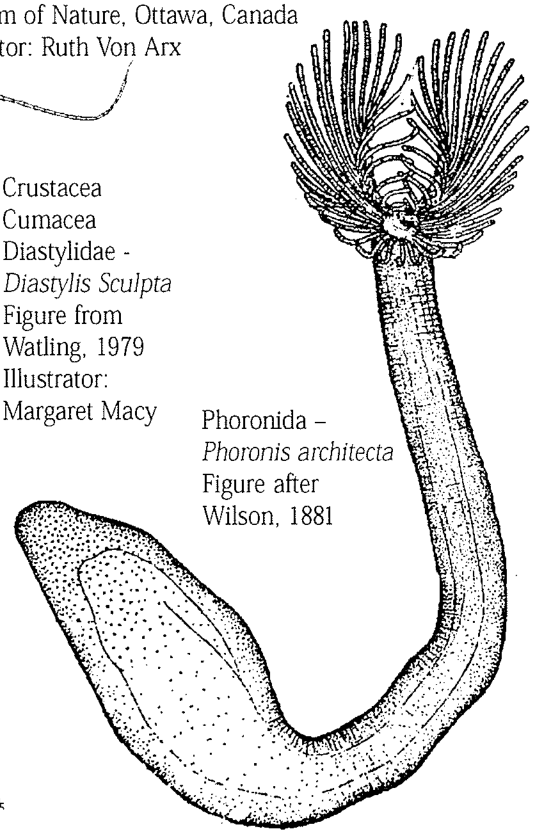


Crustacea Amphipoda Ampeliscidae – *Ampelisca abdita*
Figure from Bousfield, 1973, reproduced courtesy of the Canadian Museum of Nature, Ottawa, Canada
Illustrator: Ruth Von Arx

Annelida
Polychaeta
Capitellidae –
Heteromastus filiformis,
anterior portion

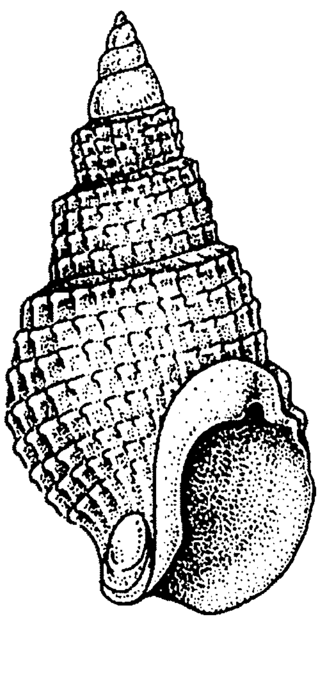


Crustacea
Cumacea
Diastylidae -
Diastylis Sculpta
Figure from Watling, 1979
Illustrator: Margaret Macy



Phoronida –
Phoronis architecta
Figure after Wilson, 1881

Gastropoda Nassariidae –
Ilyanassa trivittata
Figure from R. I. Smith, 1964
Illustrator: Ruth Von Arx



Mollusca Bivalvia Arcticae –
Arctica islandica
Figure from Weiss, 1995
Illustrator: Lauren Churchill

Echinodermata Asteroidea –
Ctenodiscus crispatus
Figure from Weiss, 1995
Illustrator: Lauren Churchill

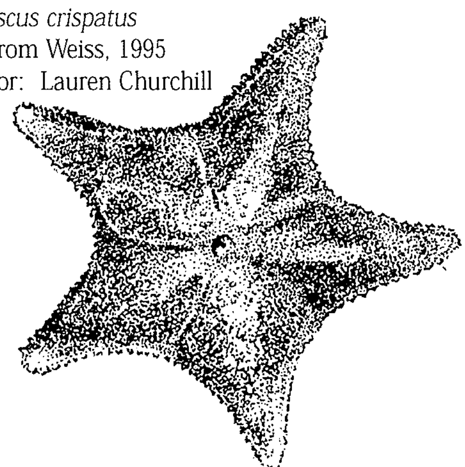


FIGURE 6-1
Benthic organisms collected in Massachusetts Bay

Soft Bottom and Hard Bottom Benthic Communities Differ

■ The benthic community inhabiting the soft silty sands that characterize soft bottom regions of Massachusetts Bay differs vastly from the community dwelling on the rocks and cobbles that make up the hard bottom. Soft bottom or infaunal organisms include various worm and invertebrate species that tunnel into the silty sediments, whereas hard bottom or epifaunal species include animals such as shellfish, crabs, and anemones that dwell on the surface of the rocky ocean floor. Different techniques are used to evaluate the benthic community in these two differing habitats. Figure 6-2 shows the varied sea floor environments of Boston Harbor and Massachusetts Bays.

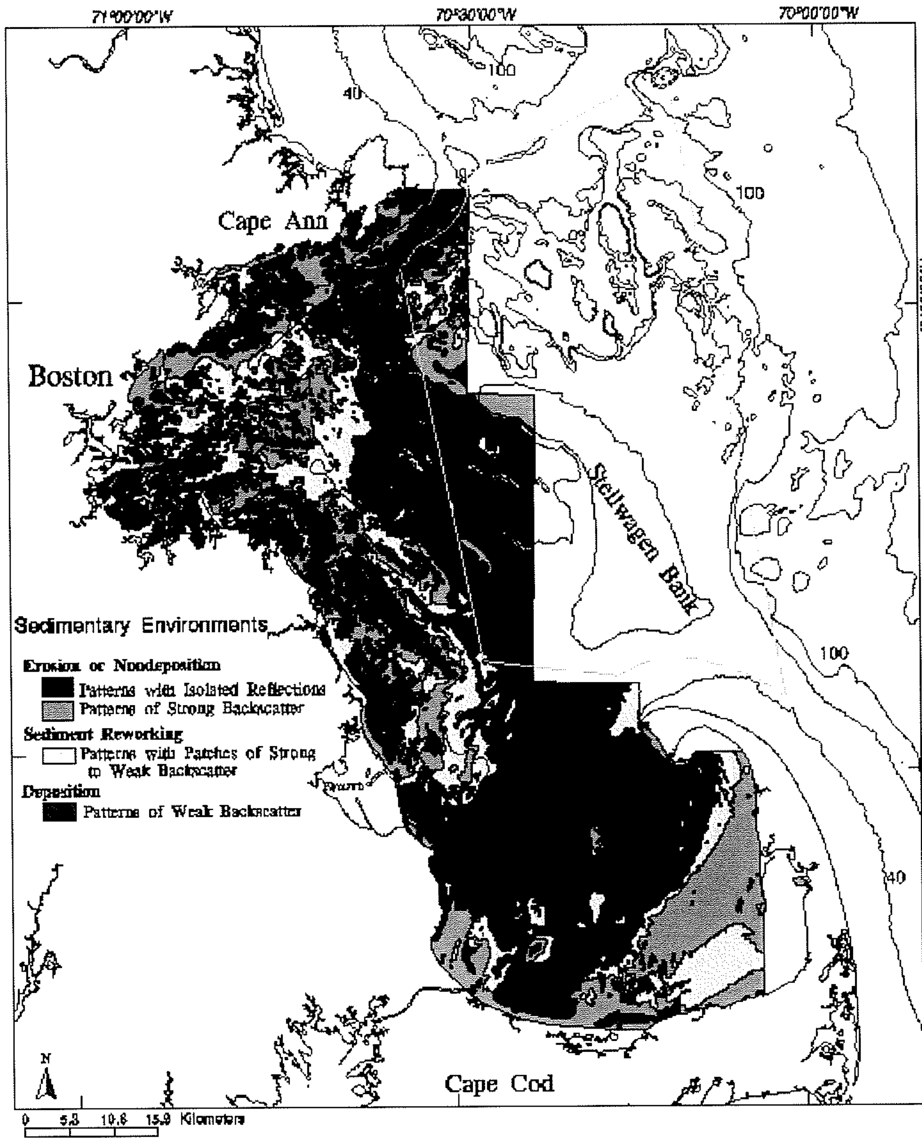


FIGURE 6-2
Sea Floor Environments Within the Boston Harbor – Massachusetts Bay Sedimentary System
USGS Web Site: http:\\vineyard.er.usgs.gov\arc\data\seafloor.gif

munities. Generally, year to year benthic community changes in the near field during baseline monitoring correspond to changes in sediment characteristics. Stations where little sediment change has occurred since 1992 show relatively small changes in the number and type of organisms found, while stations in areas with major changes in sediment type show equally dramatic changes in the benthic community. For example, one site changed from 70% mud to 95% sand between 1992 and 1993. Correspondingly, the benthic community changed from one characterized by numerous species of polychaetes (small marine worms) to one overwhelmingly dominated by a single bivalve mollusc species.

Statistical analyses will be used to evaluate any changes in the benthic community resulting from effluent discharge through the new outfall. MWRA is currently evaluating promising statistical methods that will allow differentiation between naturally occurring spatial and temporal variability such as that measured during baseline monitoring, and meaningful changes or impacts from sewage effluent after outfall relocation.

7.0 Floatables

7.1 Water Quality Issues

Floatables are pollutants, such as plastic materials, oil, and grease, that float on the surface of the water. Floatables are primarily an aesthetic problem, but may cause harm to marine life. In addition, oil and grease can affect the taste and odor of seafood.

7.2 Trigger Parameters and Thresholds

Thresholds have been established to measure whether floatables are removed as expected and whether the oil and grease discharge is within NPDES limits. Action levels are:

- Greater than 5 gallons per day of floatables collected in a series of floatables collection devices.
- Maximum petroleum oil and grease concentration in effluent greater than 15 ppm.

7.3 Monitoring Program Components Designed to Address Issues

The MWRA has already made significant reductions in floatable discharge. Scum and sludge discharge has ceased, dramatically reducing the volume of floatable material discharged. In addition, the new Deer Island Treatment Plant includes state-of-the-art mechanisms for removing floatables. To evaluate floatables before discharge, the MWRA makes regular observations of wastewater during treatment to ensure that floatables are removed as expected, and that oil and grease discharges are within the NPDES permit limitations. If the MWRA detects floatables in the effluent, it will review the treatment plant operations and take steps to remedy the problem.

7.4 Monitoring Program Results

Current sewage treatment operation includes routine and efficient removal of floatable materials early in the treatment process. As a result, substantial levels of floatables have not been detected in the effluent.

8.0 Summary of Monitoring Program

The baseline monitoring program has focused on the following six wastewater constituents for determining the environmental impact of coastal discharges of treated sewage:

- Nutrients
- Organic Material
- Toxic Contaminants
- Pathogens
- Solids
- Floatables

For organizational purposes, these six parameters were divided into four major monitoring areas: effluent, water column, benthic, and fish and shellfish. Twenty baseline measurement parameters were defined as key monitoring parameters for the monitoring program (Figure 8-1). A summary of the monitoring program is presented in Table 8-1.

8.1 Effluent Monitoring

The primary objective of the effluent monitoring program is to characterize waters discharged from the Deer Island treatment plant. Concentrations and variability of chemical and biological constituents in the treatment plant effluent are measured. These data will be compared to NPDES permit limitations and evaluated to determine loadings and potential impacts on Massachusetts Bay.

Water samples are collected at the Deer Island treatment facility and analyzed for nutrients, priority pollutant organics and metals, pathogens, and oil and grease.

To date, with only primary treatment in operation, the effluent monitoring program has demonstrated that certain metals and organic compounds in undiluted effluent exceed marine water quality criteria. However, the MWRA anticipates that approximately a 100 fold dilution of the effluent will occur within a few tens to hundreds of meters of the diffuser. This dilution will ensure that the chemicals in effluent water will pose a minimal risk to aquatic life. In addition, as the MWRA upgrades to secondary treatment of sewage, further reductions in organic content and toxic compounds in the effluent are anticipated.

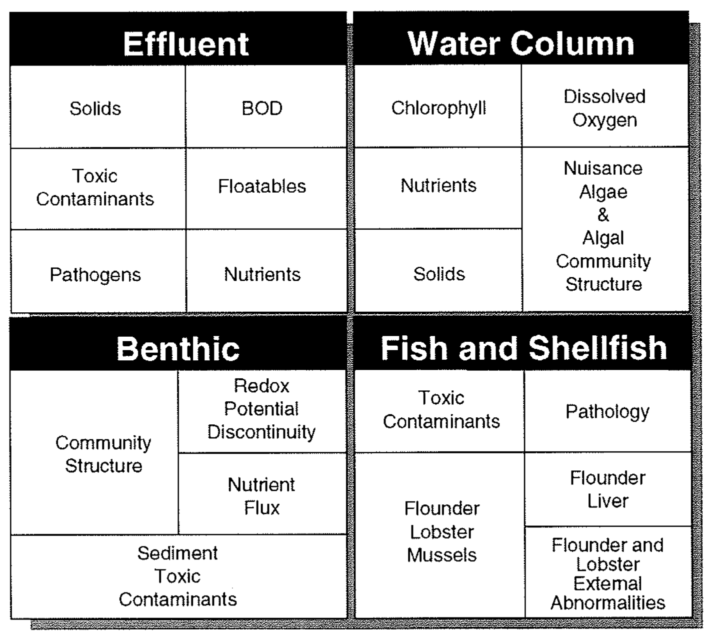


FIGURE 8-1
MWRA monitoring plan: Monitoring areas and endpoint parameters

8.2 Water Column Monitoring

The water column monitoring program is designed to provide measurement of water quality and plankton data in Massachusetts Bay and Cape Cod Bays. Water column monitoring program data will help detect changes in the water column of Massachusetts and Cape Cod Bays resulting from the relocation of the effluent outfall. Water quality and plankton data

TABLE 8-1

Summary of MWRA Monitoring Program

Task	Objective	Sampling Locations and Schedule	Analyses
EFFLUENT MONITORING			
Effluent Sampling	Characterize wastewater discharged from Deer Island Treatment Plant	• Monthly • Daily • Monthly • 3 Times/Day • Daily • Weekly • Weekly	• Nutrients • cBOD • Toxic contaminants • Pathogens • Solids • Oil & Grease • Floatables
WATER COLUMN MONITORING			
Nearfield Surveys	Collect water quality data near outfall location	• 17 surveys/year • 21 locations (See Figure 2-4)	• Temperature • Salinity • Dissolved oxygen • Chlorophyll • Nutrients • Total Suspended Solids • Plankton
Farfield Surveys	Collect water quality data throughout Massachusetts and Cape Cod Bays	• 6 surveys/year • 26 locations (See Figure 2-4)	• Temperature • Dissolved oxygen • Chlorophyll • Total suspended solids • Salinity • Nutrients • Plankton
Plume Track Surveys	Track location and characteristics of discharge plume	• 3-4 surveys/year	• Salinity • Temperature • Dissolved oxygen • Chlorophyll • Total suspended solids
Continuous Monitoring	Provides continuous water quality data near outfall	• Continuous monitoring • Single station • 3 depths	• Temperature • Salinity • Optical beam transmittance
Remote Sensing	Evaluate outfall impacts on a regional scale through satellite imagery	• Approximately 1/month	• Temperature • Chlorophyll
BENTHIC MONITORING			
Nutrient Flux Surveys	Evaluate nutrient interactions between the sediment and water column	• 5 surveys/year • 7 locations (See Figure 8-2)	• Oxygen demand • Nutrient flux • Porewater nutrients
Soft Bottom Surveys	Evaluate sediment quality in Boston Harbor and Massachusetts Bay	• 8 Boston Harbor stations (See Figure 8-3) • 20 nearfield stations (See Figure 8-4) • 11 farfield stations (See Figure 8-4)	• Sediment chemistry • Benthic community composition
Hard Bottom Surveys	Characterize marine communities in rock and cobble areas	• 1 survey/year • 6 transects (See Figure 8-5)	• Topography • Substrate • Benthic community composition
FISH AND SHELLFISH MONITORING			
Flounder Studies	Determine contaminant body burden and population health	• 1 survey/year • 5 locations (See Figure 4-2)	• Tissue contaminant concentrations • Physical abnormalities (including histopathology)
Lobster Studies	Determine contaminant body burden	• 1 survey/year • 3 locations (See Figure 4-2)	• Tissue contaminant concentrations • Physical abnormalities
Mussel Studies	Evaluate biological condition and short-term contaminant bioaccumulation	• 1 survey/year • 3 locations (See Figure 4-2)	• Tissue contaminant concentrations • Physical abnormalities

are being collected in Massachusetts Bay and Cape Cod Bay in order to characterize water column conditions before completion of the outfall. Once the outfall is on-line, water column monitoring data will be compared to background data and any impacts to Massachusetts and Cape Cod Bay will be assessed.

To date, the water column monitoring program has demonstrated that the Massachusetts and Cape Cod Bay system is dynamic, with considerable spatial and temporal variability. The influence of seasonal cycles and differing ecological environments must be considered when evaluating the potential influence of the MWRA upgrades within this marine system.

The five major components of the water column monitoring program, nearfield surveys, farfield surveys, plume track surveys, continuous recording, and synoptic overview, are outlined below. These components are designed to provide comprehensive coverage of water quality conditions in Massachusetts and Cape Cod Bays.

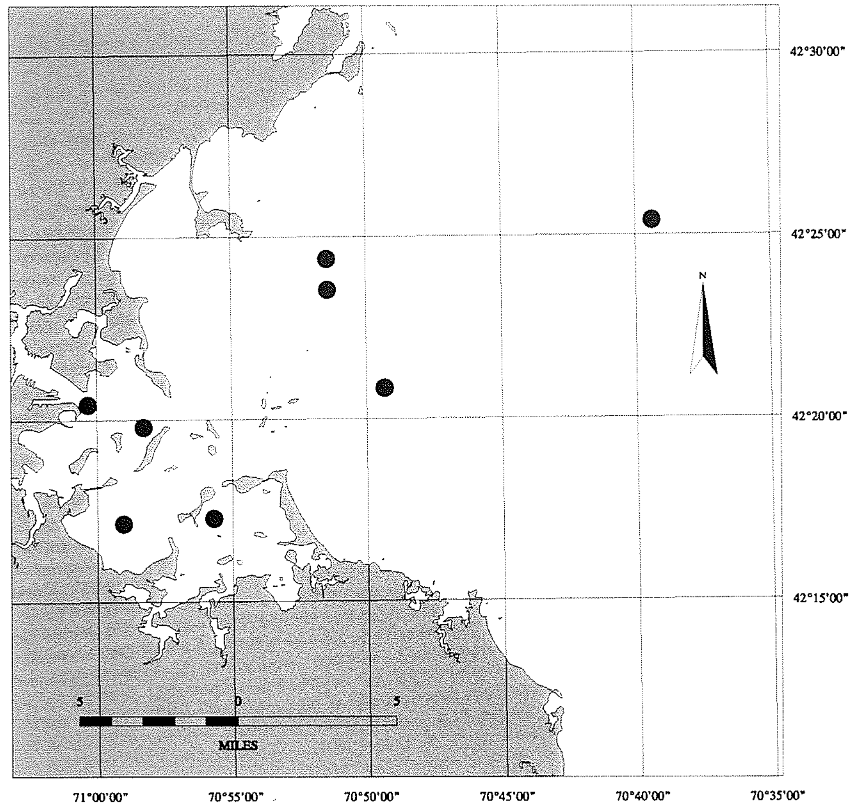


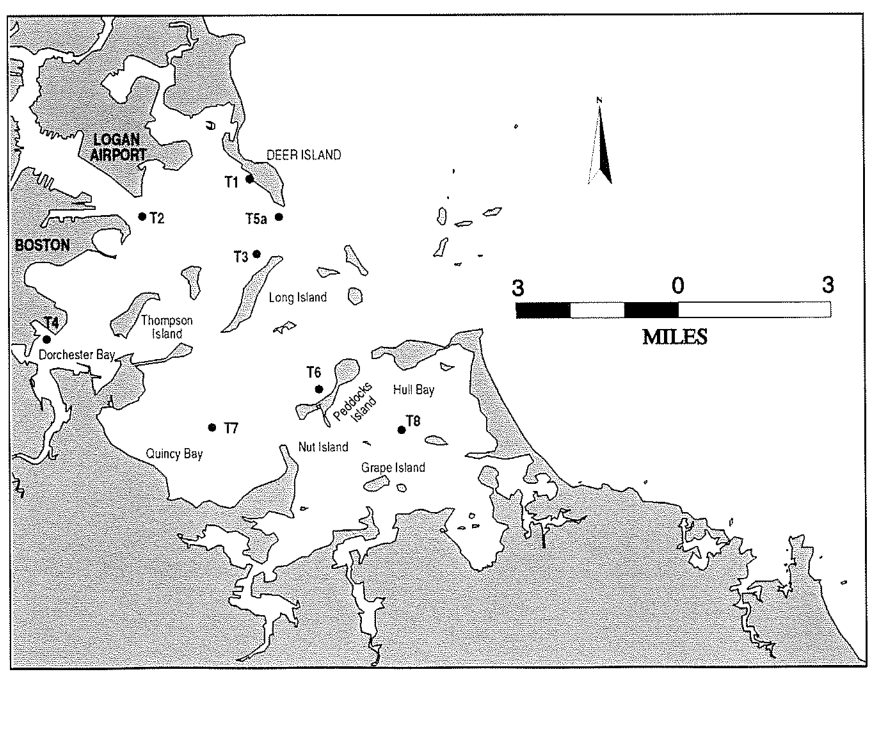
FIGURE 8-2
Benthic Nutrient Flux Sampling Locations

Nearfield Surveys

Nearfield water column surveys are designed to collect frequent, intensive sets of water quality and plankton data near the outfall location. Data are collected at 21 locations (Figure 2-4) in 17 annual surveys. These surveys provide vertical profiles of physical, chemical, and biological water column characteristics throughout each year, identifying seasonal cycles and events of interest (e.g. algal blooms).

During each nearfield survey, temperature, salinity, dissolved oxygen, chlorophyll fluorescence, light transmission, and photosynthetically available light are measured *in situ* throughout the water column. Water samples are collected throughout the water column for laboratory analysis of constituents including nutrients, chlorophyll, TSS, DO, phytoplankton, and zooplankton.

FIGURE 8-3
Boston Harbor Soft Bottom Benthic Stations



Farfield Surveys

Farfield water quality surveys are designed to collect intensive sets of water quality, plankton and primary productivity data

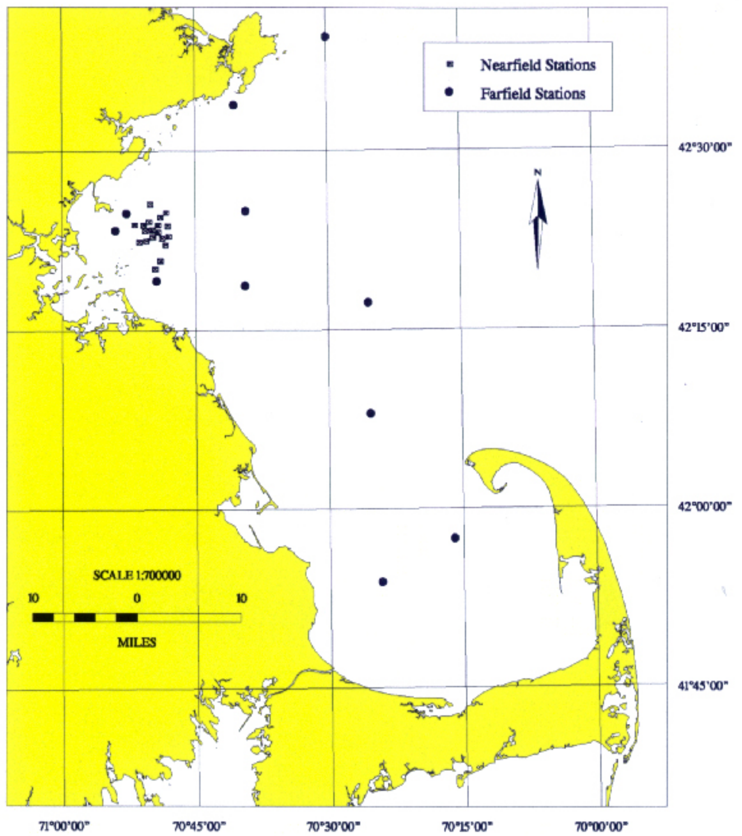


FIGURE 8-4
Locations of Soft Bottom Benthic Stations

over a broad spatial scale, including Massachusetts and Cape Cod Bays. The purpose of the farfield surveys is to determine differences across the bays and assess seasonal changes over a large area, (e.g. relating trends observed in the nearfield area to the surrounding region).

Six farfield surveys are conducted each year collecting water quality, plankton and primary productivity data at 26 stations throughout Massachusetts and Cape Cod Bays (Figure 2-4). *In situ* measurement and water sampling performed during farfield surveys is comparable to the nearfield sampling described above.

Plume Tracking Surveys

Plume tracking surveys are performed to determine the location and chemical and biological characteristics of the effluent discharge plume leaving the outfall and mixing with ambient waters. Once the outfall is on-line, several surveys per year will be performed near the outfall location. These data will be helpful in understanding the migration of the discharge effluent. Sampling will include measurement of salinity, temperature, DO, chlorophyll, and total suspended solids. Some preliminary plume tracking studies of an exploratory nature have been performed.

Continuous Monitoring

The continuous monitoring component of the program is designed to provide continuous water quality data. The purpose of continuous monitoring is to capture temporal (i.e., time-dependent) variations in water quality in between nearfield water quality surveys. Continuous monitoring data includes measurement of temperature, salinity, and optical beam transmittance at three depths at a single mooring station in Massachusetts Bay near the future outfall location.

Remote Sensing

Remote sensing is designed to capture spatial variations in water quality on a regional scale. Remote sensing via satellite provides a snap shot of water quality data, such as Massachusetts Bay and Boston Harbor sea surface temperature and chlorophyll. This component creates a spatial link among survey sample locations.

8.3 Benthic Studies

The benthic studies program is designed to provide measurement of the benthic environment in Boston Harbor and Massachusetts Bay. The goals of the benthic program are two-fold. The first objective is to document the recovery of benthic conditions in Boston Harbor following the cessation of sludge discharge and improvements in CSO treatment and discharge. These data will provide valuable information on bottom sediment response and benthic ecosystem recovery.

The second objective is to collect background data on the physical, chemical, and biological processes in the benthic environment near the outfall location in Massachusetts Bay. These data are essential to assessing potential impacts of effluent discharged near the outfall on the surrounding benthic ecosystem.

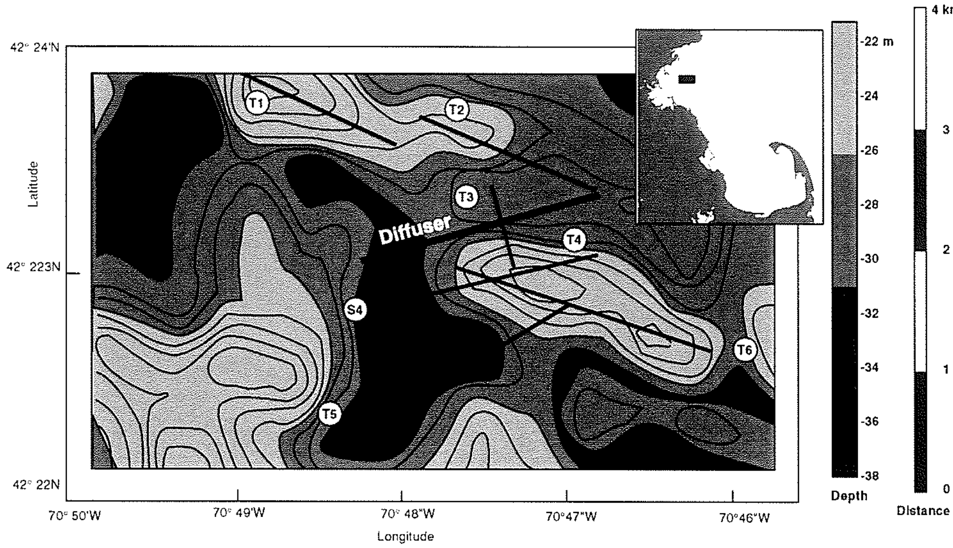


FIGURE 8-5
Location of nearfield hard bottom benthic survey transects. Inset shows the study-area locations within Massachusetts Bay.

To date, the benthic monitoring program has provided valuable baseline information on the status of the benthic environment in the system. The complex physical environment in Massachusetts Bay, especially near the diffuser, makes the assessment of the benthic environment particularly difficult. In general, the benthic environment in the area appears healthy; sediments are well-oxygenated and benthic communities are diverse.

Three types of benthic surveys are performed: benthic nutrient flux surveys, soft-bottom surveys, and hard-bottom video surveys. Each of the three survey types is described below.

Nutrient Flux Surveys

Nutrient flux surveys are designed to measure nutrient interactions between sediments and the water column in Boston Harbor and Massachusetts Bay. The nutrient flux surveys are performed five times per year at seven sampling locations (Figure 8-2). Using a sediment coring technique, vertical columns of sediment are removed and brought to the surface intact. Each sediment core is analyzed for a set of parameters including sediment oxygen demand, sediment nutrient flux, and sediment pore water (water contained between sediment particles) nutrients. Analysis of nutrient flux data provides information required to assess the nutrient loading to the water column from marine sediments.

Soft Bottom Benthic Surveys

Soft bottom benthic surveys are designed to assess sediment quality and the status of the benthic communities of Boston Harbor and Massachusetts Bay. During soft-bottom surveys, grab samples of sediments are collected at specified locations and analyzed for apparent redox-potential discontinuity depth, benthic infauna, and physical and chemical sediment parameters. Three soft-bottom benthic surveys (harbor benthic, outfall nearfield benthic, and outfall farfield benthic surveys) comprise the soft-bottom benthic studies program.

The harbor soft-bottom surveys are performed twice annually at eight stations in Boston Harbor (Figure 8-3). These surveys are designed to measure long-term recovery in benthic communities and sedimentary conditions at a variety of locations in Boston Harbor. Outfall nearfield soft-bottom surveys provide baseline data on the sedimentary environment, contaminant concentrations, and benthic infaunal communities that can be used as a benchmark to evaluate the effects of sewage disposal from the future outfall when it becomes operational. Nearfield benthic surveys are performed once per year with sampling at 20 stations near the outfall site (Figure 8-4).

Farfield soft-bottom surveys provide benthic sampling data from locations throughout Massachusetts and Cape Cod Bays (Figure 8-4). This survey provides a farfield baseline that may be used as reference for the nearfield stations and as true monitoring stations in the unlikely event that the effects of the sewage discharge extend further than expected.

Hard-Bottom Surveys

A nearfield hard-bottom video survey is performed annually to supplement the nearfield soft-bottom surveys. The hard-bottom survey provides visual information on benthic habitat and organisms in rock and cobble areas near the future outfall where use of soft-bottom survey methods is impractical. This survey is performed using a remotely operated vehicle (ROV) equipped with a color video camera and a 35-mm camera. These surveys permit assessment of types of topography and substrate present, populations of marine organisms, and other evidence of biological activity. Each survey is performed along pre-specified transects, allowing for detection of year-to-year alterations (Figure 8-5).

8.4 Fish and Shellfish Monitoring Program

The fish and shellfish monitoring program addresses potential risks to human health and the environment arising from contamination of ecologically significant and economically important fish and shellfish stocks. Bioaccumulation data are collected from flounder, lobster, and mussel populations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. Comparison of the data between stations and to pre-discharge data will allow evaluation of spatial and temporal trends in the fisheries. The three biomonitoring surveys are outlined below.

The flounder survey is designed to collect sufficient mature winter flounder to perform general and histopathological examinations and determine bioaccumulation of priority pollutant organics, metals, and other constituents. This survey is performed annually at five locations: the Deer Island outfall, future outfall site, Cape Cod Bay site, Broad Sound and Nantasket Beach (Figure 4-2). All fish are collected using an otter trawl deployed by a commercial dragger.

The lobster survey is designed to collect sufficient mature lobster specimens to provide data on gross abnormalities and provide sufficient tissue samples for determination of physiological condition and body burden of contaminants. Once annually, lobster are collected in 25 to 30 commercial lobster traps deployed at each of three locations: the Deer Island outfall, future outfall site, and Cape Cod Bay site (Figure 4-2).

The mussel bioaccumulation survey obtains, deploys, and recovers blue mussels for determination of biological condition and short-term accumulation of contaminants in tissues. Each year, mussels are deployed in replicate arrays in waters near Deer Island and in

Massachusetts Bay near the outfall location. Mussel arrays are deployed using a subsurface and surface buoy system.

In general, the lobster and flounder populations in Boston Harbor and Massachusetts Bay appear healthy. Although lesions were observed on flounder in the system, tissue levels of contaminants are well below action levels. The flounder, lobster, and mussel data provide the MWRA with valuable baseline information. As secondary treatment is phased in, and as effluent and water quality continues to improve in Boston Harbor and the bays, it is anticipated that the health of fish and shellfish populations will continue to improve.

8.5 Monitoring Program Database

Since the beginning of the Outfall Monitoring Program in 1992, over 200 million pieces of data have been generated and compiled. As the program continues, the amount of compiled data will grow even larger. In order to meaningfully use this large mass of data, a coupled computerized database system and Geographical Information System (GIS) has been developed. The coupled database/GIS system allows MWRA to store, retrieve, analyze, and display data from the monitoring program. Arc/Info is used as the GIS platform. The database system consists of an Oracle 7 server networked to PC workstations running MS Access. This system allows monitoring data to be entered, analyzed, and viewed simultaneously by several researchers working at their own computers. The database is the source of the multi-year data analyzed by researchers in the preparation of synthesis reports.

For the goals of the program to be met, all of the data must be of known, high quality. Data quality is maintained through the program-wide use of rigorous Quality Assurance/Quality Control procedures. Data from field surveys and laboratory analyses are exhaustively checked and validated to ensure that field equipment was working properly during surveys and that the analyses met the program's Quality Control objectives. Only validated data are loaded onto the centralized database.

8.6 Conclusion

Studies conducted through the MWRA Harbor and Outfall monitoring program are providing scientists with exceptional baseline scientific data. Scientific data collected during the last few years reflect current levels of sewage treatment. As the MWRA begins discharge through the new outfall to Massachusetts Bay and upgrades to secondary treatment of sewage, these baseline studies will provide a sound basis for monitoring improvements in Boston Harbor and potential changes in Massachusetts and Cape Cod Bays. As improvements are made to the MWRA sewage treatment process, the extensive economic, aesthetic, and ecological resources of this unique marine system are expected to benefit.

References

Bothner, M.H., M. Buchholtz ten Brink, C.M. Parmenter, W.M. d'Angelo, and M.W. Doughten. 1993. **The distribution of silver and other metals in sediments from Massachusetts and Cape Cod Bays—an interim compilation.** Open File Report 93-725, United States Geological Survey, Woods Hole, MA. 33 pp.

Bousfield, E.L., 1973. **Shallow-water Gammaridean Amphipoda of New England.** Cornell University Press, Ithaca and London. 312 pp.

Downey, P.C., B.D. Moffat, and G.R. Lescarbeau. 1995. **Bioaccumulation of selected organic compounds and metals in mussels deployed near Deer Island discharge and in Massachusetts Bay, 1994.** 60 pp (Tech Rep #95-9).

Durrell, G.S. 1995. **Concentrations of contaminants in Dorchester Bay and Boston Harbor sediments collected in the vicinity of CSO discharges and comparison to 1990 data.** Massachusetts Water Resources Authority, Environmental Qualtiy Department, Technical Report Series No. 95-14, Boston, MA. 128 pp.

Hillman, R.E., M.J. Moore, C.S. Peven, D.A. Lewis, L. Hansen, C.D. Hunt, and J. Stegerman. 1994. **1993 annual fish and shellfish report.** 195 pp.

Hillman, R.E. and C.S. Peven. 1995. **1994 annual fish and shellfish report.** MWRA Enviro. Quality Dept. Tech. Rpt. Series No. 95-5. Massachusetts Water Resources Authority, Boston, MA. 82 pp.

Hunt, C.D., D.E. West, and C.S. Peven. 1995. **Deer Island effluent characterization and pilot treatment plant studies: June 1993 - November 1994.** MWRA Enviro. Quality Dept. Tech. Rpt. Series No. 95-7. Massachusetts Water Resources Authority, Boston, MA. 140 pp.

Hyman, L.H. 1959. **The Invertebrates: smaller coelomate groups. (Vol V).** McGraw-Hill Book Co., Inc., New York, London, Toronto. 783 pp.

Kelly, J.R. and J. Turner. 1995. **Water column monitoring in Massachusetts and Cape Cod Bays: annual report for 1994.** MWRA Enviro. Quality Dept. Tech. Rpt. Series No. 95-17. Massachusetts Water Resources Authority, Boston, MA. 163 pp.

Linneaus Protist™ and the Linneaus Toolkit™. 1991. K. W. Estep and F. Rey. Institute of Marine Research, Bergen, Norway and UNESCO (PROMAR) UNESCO MARINF/84a, Paris, November 1991.

MacDonald, D.B., J.F. Fitzgerald, and M.S. Connor. **Draft Contingency Plan.** Massachusetts Water Resources Authority. 74 pp.

Moore, M.J. and J.J. Stegeman. 1993. **Liver pathology of winter flounder: Boston Harbor, Massachusetts Bay, and Cape Cod Bay—1993.** 45 pp.

References (cont'd)

MWRA. 1991. **Massachusetts Water Resources Authority effluent outfall monitoring Plan phase I: baseline studies.** MWRA Enviro. Quality Dept. Misc. Rpt. No. ms-2. Massachusetts Water Resources Authority, Boston, MA. 95 pp.

MWRA. 1995. **Massachusetts Water Resources Authority - Effluent Outfall Monitoring Plan: Phase II Post Discharge Monitoring (Draft).** MWRA Enviro. Quality Dept. Massachusetts Water Resources Authority, Boston, MA.

Shea, D. 1993. **Annual review of toxic contaminants discharged by MWRA: 1993.** 68 pp. +appendices.

Smith, R.I. (ed.), 1964. **Keys to marine invertebrates of the Woods Hole region.** Contribution No. 11. Systematics-Ecology Program, Marine Biological Laboratory, Woods Hole, MA. 208 pp.

USGS Web Site. http:\\vineyard.er.usgs.gov\arc\data\seafloor.gif

Watling, L., 1979. **Marine Flora and Fauna of the Northeastern United States, Crustacea: Cumacea.** NOAA Technical Report NMFS Circular 423:1-23.

Weiss, H.M., 1995. **Marine animals of Southern New England and New York.** State Geological and Natural History Survey of Connecticut, Department of Environmental Protection.

Wilson, E.B., 1881. The origin and the significance of the metamorphosis of Actinotrocha. **Quarterly Journal of Microscopical Science, New Series.** 21:202-218.

Acronym Summary

BOD biochemical oxygen demand
cBOD carbonaceous biochemical oxygen demand
CHV centrotubular hydropic vacuolation, a fish liver lesion
DIN dissolved inorganic nitrogen
DO dissolved oxygen
ER-L NOAA low effects range values for sediment, rarely associated with toxic effects
ER-M NOAA median effects range values, often associated with toxic effects
LC50 concentration for 50% lethality of bioassay test organisms
nBOD nitrogenous biochemical oxygen demand
NOEC no observable effect concentration
NPDES National Pollutant Discharge Elimination System
PAHs polyaromatic hydrocarbons
PCBs polychlorinated biphenyls
ppb parts per billion
ppm parts per million
RPD redox potential discontinuity
TSS total suspended solids