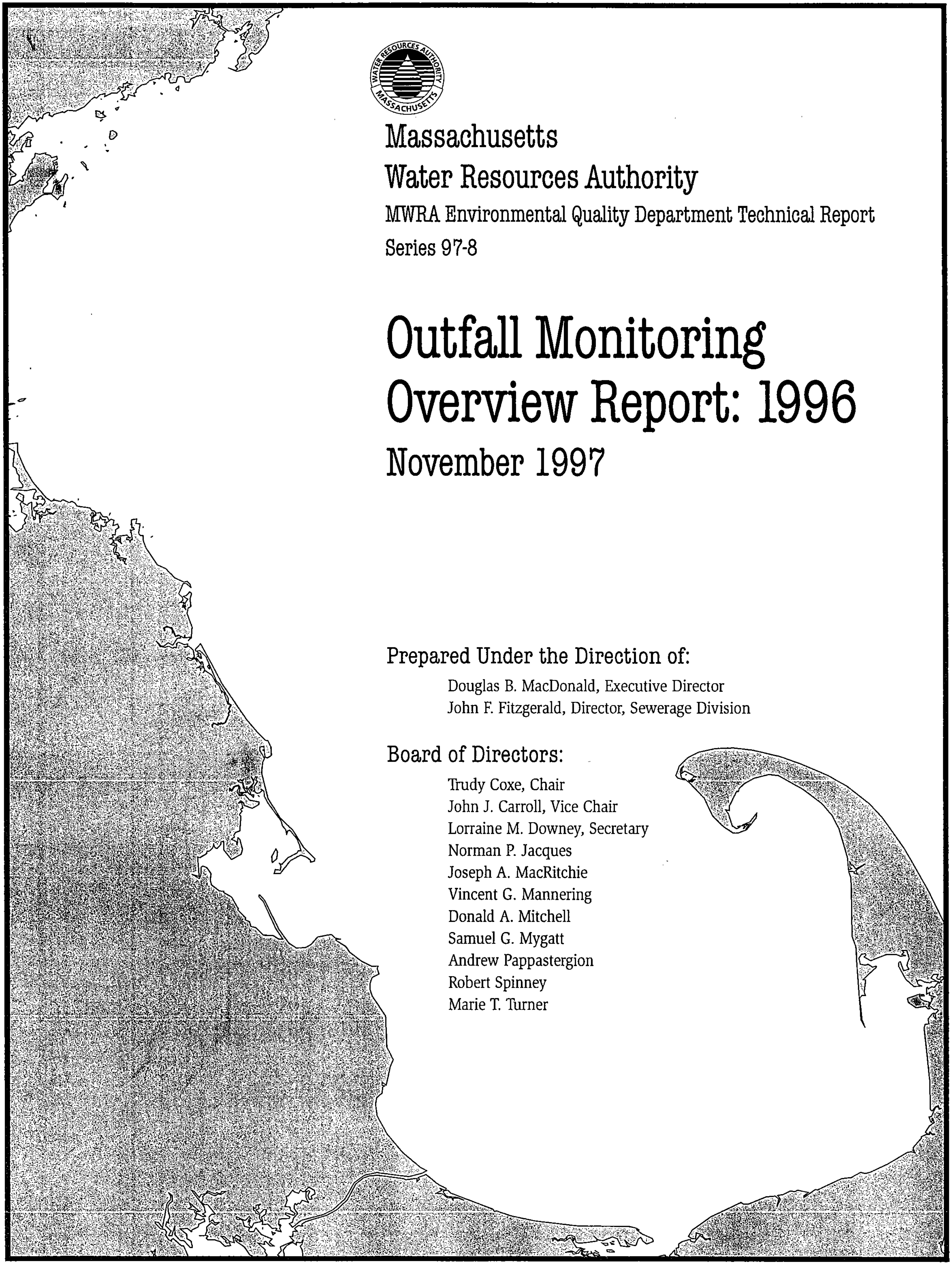

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Outfall Monitoring Overview Report: 1996

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Executive Summary

MWRA's baseline outfall monitoring program has gathered considerable information documenting existing conditions in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. Post-discharge monitoring will be used to evaluate conditions after the new outfall is operational.

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 to the harbor, construction of new primary and secondary sewage treatment plants, and relocation of the current Boston Harbor effluent discharge points to a new location in Massachusetts Bay. Sludge discharge ceased in 1991 and the new Deer Island primary treatment facility went on-line in January 1995. In August 1997, the first part of secondary treatment began operation. The second phase of secondary treatment (adequate for 90% of the effluent flow) will begin operation in early 1998, and in late 1998 the new effluent discharge outfall to Massachusetts Bay is expected to be operational. This report presents data from 1996 and reflects the primary treatment system operating during that period.

A number of concerns have been raised regarding potential environmental impacts associated with the relocation of the wastewater discharge to Massachusetts Bay. In order to assure that these concerns are addressed, MWRA developed a Contingency Plan and an outfall monitoring program, and documented these in a series of reports. The Contingency Plan (MWRA 1997) develops expectations for environmental quality in Massachusetts Bay and Cape Cod Bay. The expectations are expressed as Caution and Warning Levels that would trigger action if they are exceeded. Those trigger levels are compared to environmental monitoring results in this report, the annual Outfall Monitoring Overview, which will also describe any actions taken in response to an exceedance of a caution or warning level when the outfall is operational. The monitoring results are obtained following the procedures detailed in a report called the Outfall Monitoring Plan (MWRA 1991, 1995).

The effluent monitoring program characterizes MWRA wastewater quality.

The outfall monitoring 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 late 1998; these studies will evaluate conditions after the new outfall is operational. This report describes the baseline monitoring program, summarizes and discusses the 1996 baseline program results, and summarizes post-discharge monitoring Caution and Warning Levels. The 1999 report will be the first Outfall Monitoring Overview report that discusses formal actions under the Contingency Plan.

Both phases of monitoring evaluate six categories of wastewater constituents: nutrients, organic material, toxic contaminants, pathogens, solids, and floatables. These six parameters were evaluated as they apply to four different environmental measurement areas: effluent, water column, benthic environment, and fish and shellfish.

Wastewater Effluent Monitoring

The baseline effluent program monitors for nutrients, organic material, toxic contaminants, pathogens, solids, and oil and grease. The primary goal of this program is to ensure that discharged effluent meets required permit limitations. Effluent monitoring is also used to evaluate the future effectiveness of the secondary treatment plant by analysis of the effluent of a pilot secondary treatment plant.

Trigger parameters, thresholds, and 1996 monitoring results for the effluent monitoring program are summarized on Table ES-1. The listed warning levels for cBOD, PCB, toxicity, bacteria, and solids are taken from the expected future permit for the fully operational secondary treatment plant (year 2000). The present plant is operating under an interim permit and those limits are shown in italics in the last two columns.

In 1996, the total nitrogen Caution Level was exceeded. This exceedance is not a cause for concern as the Caution Level is set at 90% of the Warning Level, and this exceedance occurred prior to the implementation of secondary treatment. The 1995 pilot study showed that secondary treatment can remove an average of 10% of total nitrogen. Therefore, it is expected that future effluent levels will be less than the thresholds. BOD, acute toxicity, suspended solids, and plant performance exceeded the warning levels derived from the expected future permit. Only acute toxicity and plant performance exceeded the interim permit limits. Each of these parameters should also reduced by secondary treatment. Effluent monitoring results indicate that improvements made to the MWRA system during the last few years have generally resulted in improvements in wastewater effluent quality. Pilot treatment plant results indicate that secondary treatment will significantly reduce the effluent levels of organic material, suspended solids, and many toxic parameters. As additional phases of secondary treatment are implemented and toxic source control measures continue, effluent quality will continue to improve and will result in compliance with federal secondary treatment standards and Massachusetts water quality standards.

The water column monitoring program measures marine water quality and ecological conditions in Massachusetts and Cape Cod Bays.

Water Column Monitoring Program

The water column monitoring program is designed to measure marine water quality and ecological conditions 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 relocation 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, algae, and dissolved oxygen in the marine system. Interpretation of the baseline data requires an understanding of the seasonal cycle. As with other water bodies, the Massachusetts and Cape Cod Bay system follows an expected regular seasonal pattern but with considerable spatial and temporal variability of complicated interrelated processes. Starting with the cold well-mixed nutrient-rich waters of winter, the brightening sun of spring provides the light needed for algae (phytoplankton) to grow. Their abundant growth forms a spring algae bloom which begins to deplete nutrients, especially nitrogen. Spring also brings stratification of the water column due to increased sunshine and freshwater runoff that result in warmer and slightly fresher surface waters. The spring bloom ends as algae deplete the nutrients in surface waters and are blocked from nutrient-rich bottom waters by stratification. During summer, the algal biomass is less overall with the highest biomass located at the boundary between surface and bottom waters (thermocline) where there is a balance between the algal requirement for both light and nutrients. This continues until the fall, when stratification begins to weaken, so that storms are able to mix the water column, bringing nutrients to surface waters and resulting in a fall algal bloom.

TABLE ES-1

Effluent Thresholds Compared to 1996 Monitoring Results

Parameter	Caution Level	Warning Level	1996 Results
Total Nitrogen (nutrients)	Total nitrogen annual loading > 12,500 mtons/year	Total nitrogen annual loading > 14,000 mtons/year.	Annual loading = 12,692 metric tons, slightly exceeded the Caution Level.
cBOD (organic material)	None.	Expected levels: 40 mg/L weekly, 25 mg/L monthly. *Current interim permit limit = 140 mg/L monthly.*	Daily Deer Island BOD5 range from 33 to 129 mg/L with an average of 73 mg/L. Monthly Deer Island BOD5 range from 38 to 67 mg/L with an average of 52 mg/L. Pilot secondary effluent monthly average = 10 mg/L. cBOD is typically less than BOD5.
Toxics (toxic contaminants)	None.	PCB (as Arochlors) limit = 0.045 ng/L monthly.	PCBs as Arochlors were all below detection limits. Monthly total PCB concentrations: from 0 to 35.9 ng/L with an average of 8.4 ng/L.
Toxicity (toxic contaminants)	None.	Acute: effluent LC50 for shrimp <50% effluent. Chronic: effluent NOEC for fish (silverside) growth and sea urchin fertilization <1.5% effluent. *Interim acute limit: shrimp NOEC < 20% effluent Current chronic limits: minnow and red algae NOEC < 10% effluent*	Acute: 11 of 12 shrimp tests had LC50 < 50% effluent. Chronic: No fish growth tests had NOEC < 1.5% effluent; sea urchin tests are not yet implemented. *Acute: 6 of 12 tests violated interim shrimp 20% NOEC limit. Chronic: no violations of current minnow 10% NOEC limit; All tests failed current red algae 10% NOEC limit.* Pilot secondary effluent > 50% for chronic NOEC for silverside and sea urchin. Five pilot plant acute tests had LC50 = 100%
Bacteria (pathogens)	None.	Expected level: 14,000 fecal current coliform/100 mL at point of dechlorination (weekly mean, monthly 90th percentile, and 24 consecutive hours). *Current interim permit limit = 200 fecal coliform/100 mL monthly average.*	No exceedances of expected level or the current monthly limit of 200 fecal coliform/100mL.
Suspended Solids	None.	Expected levels: 45 mg/L weekly, 30 mg/L monthly. *Current interim permit limit = 110 mg/L monthly.*	Range at Deer Island from 24 to 133 mg/L, with an average of 52 mg/L. Pilot secondary effluent monthly average = 9 mg/L.
Floatables	None.	Floatables less than 5 gal/day.	Not measured until secondary treatment plant is on line.
Oil and Grease (floatables)	None.	15 mg/L weekly.	Maximum weekly = 6.5 mg/L.
Plant Performance	More than 5 violations of expected permit requirements per year.	Operating in violation of the expected permit requirements more than 5% of the time over a year.	Violation of nearly all the expected limits on BOD, solids, and acute toxicity, most of the time. *Violation of interim permit limits for acute toxicity, and on one occasion for removal efficiency of BOD.*

The reader is directed to the glossary and acronym summary at the end of the report.
Current interim permit limits are presented in the Warning Level column in italics.

Benthic studies measure bottom-dwelling ecological communities and sediment quality characteristics.

Trigger parameters, thresholds, and 1996 monitoring results for the water column program are summarized on Table ES-2. Monitoring results show that 1996 was similar to other years with some notable differences. The stratification period was relatively short because of a hurricane in early September that resulted in much earlier mixing of the water column than in previous years. The 1996 spring bloom was the largest but the fall bloom was the smallest during the baseline period. On average, chlorophyll concentrations during 1996 were relatively low compared to other baseline years. The phytoplankton species composition during spring and fall blooms was similar to previous years, with centric diatoms dominating the spring bloom and pennate diatoms dominating the fall bloom. The zooplankton community in the outfall nearfield in 1996 consisted of an assemblage of offshore and nearshore species, similar to previous years. No shellfish toxicity or significant numbers of toxic or nuisance algae were observed in 1996. Minimum dissolved oxygen concentrations in bottom waters in 1996 were higher than in 1994 and 1995 because initial dissolved oxygen concentrations were higher (greater than 12 ppm), bottom water temperatures were generally lower, and fall overturn occurred earlier. As in previous years, monthly average dissolved oxygen saturation levels declined below the Warning Level in the nearfield, and below the Caution Level in Stellwagen Basin. These low saturation levels were due more to higher water temperatures, as the concentrations and decline rates were fairly average. These findings suggest that the OMTF needs to re-evaluate the applicability of the current dissolved oxygen threshold levels.

A total of six whales were sighted during the 1996 nearfield surveys: one right, one fin, one unidentified and three minke whales.

Benthic Studies

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

Trigger parameters, thresholds, and 1996 monitoring results for the benthic program are summarized on Table ES-3. In Massachusetts Bay, the benthic sedimentary environment, or habitat, is highly diverse, with large variability in sediment type over relatively short distances. The benthic biological communities also vary spatially, reflecting a strong influence of sediment type on the benthic community characteristics. In addition, the benthic environment in the nearfield is highly changeable, with dramatic shifts in both sediment type and benthic organisms occurring after storm events. The dominant benthic species in 1996 and 1995 was also abundant in 1987, but not in 1992 through 1994. Benthic organism densities in Massachusetts Bay are moderately high and the community structure does not reflect stressed conditions. The numbers of species in the benthic community are similar in the nearfield and farfield, but the types of species are different. Sediment sampling for contaminant analysis was not performed in 1996. The most recent results, from 1995, showed contaminant concentrations that were generally below environmental criteria.

In Boston Harbor, the benthic ecosystem has improved dramatically in the past few years. This improvement is associated with an increase in abundance of a pollution sensitive amphipod, likely related to sediment quality improvement. Increased amphipod colonization, in turn, appears to be increasing the rate of sediment quality improvement.

TABLE ES-2
Water Column Thresholds Compared to 1996 Monitoring Results

Parameter	Caution Level	Warning Level	1996 Results
Dissolved oxygen concentration in Nearfield region bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)	DO saturation above Caution Level in September (87.2%). (See Table 3-2)
Dissolved oxygen concentration in Stellwagen Basin bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)	DO saturation below Caution Level in October (79.2%). (See Table 3-2)
Dissolved oxygen depletion rate in Nearfield region bottom waters	DO depletion rate is greater than 1.5 times the baseline rate during stratification (June-Oct.), -0.040 mg/L/day.	DO depletion rate is greater than 2 times the baseline rate during stratification (June-Oct.), -0.053 mg/L/day.	1992-96 Average Baseline Rate: -0.026 mg/L/day 1996 Rate: -0.025 mg/L/day
Chlorophyll in Nearfield region	Annual mean concentration greater than 1.5 times the baseline annual mean, 2.80 µg/L.	Annual mean concentration greater than 2 times the baseline annual mean, 3.74 µg/L.	1992-96 Baseline: 1.87 µg/L 1996: 1.54 µg/L
Chlorophyll in Nearfield region	Season mean concentration exceeds 95th percentile of the baseline seasonal distribution. Spring: 2.71 µg/L Summer: 2.27 µg/L Fall: 4.44 µg/L	None.	Spring: 2.43 mµg/L Summer: 0.78 µg/L Fall: 1.47 µg/L
Nuisance algae in Nearfield region	*Alexandrium tamarense* Season mean population densities exceed 95th percentile of the baseline seasonal mean. Spring: 2.34 cells/L Summer: 26.1 cells/L Fall: 7.57 cells/L	None.	*Alexandrium tamarense* Spring: 0 cells/L Summer: 0 cells/L Fall: 0 cells/L (See Table 3-3)
PSP extent in Farfield region	New occurrence. PSP has never been observed at 3 of the 18 monitoring stations (see Table 3-4).	None.	No occurrences.
Zooplankton assemblage in Nearfield region	Nearfield assemblage shifts from a transitional community towards an inshore community. Inshore: *Acartia, Eurytemora, Centropages hamatus* Offshore: *Calanus, Pseudcalanus, Centropages typicus, Oithona* Nearfield: Transitional between two regions.	None.	Transitional assemblage in nearfield region.
Initial effluent dilution at new outfall location	None.	Effluent dilution less than that set by the NPDES permit.	No data until outfall is online.

The fish and shellfish program measures toxic contaminant effects on flounder, lobster, and mussels.

Fish and Shellfish Monitoring Program

The fish and shellfish monitoring program samples and evaluates key natural resources in the marine environment, focusing on flounder, lobster, and mussels. This program evaluates potential risks to human health and the environment from toxics contamination in fish and shellfish. Fish and shellfish studies also provide a basis for evaluating the recovery of Boston Harbor biota following MWRA upgrades.

Trigger parameters, thresholds, and 1996 monitoring results for fish and shellfish are summarized on Table ES-4. In 1996, as in previous years, the contaminant concentrations in fish and shellfish at all sites have consistently been well below levels that might cause any concern through human consumption. Nevertheless, the pattern of contamination provides evidence of the degree of exposure of the fish. In general, contaminant concentrations in flounder meat decline progressively from Boston Harbor to the future outfall site to Cape Cod Bay. However, mercury concentrations did not follow any specific spatial pattern, indicating that the most significant mercury sources may be more regional (e.g. atmospheric deposition) rather than local (e.g. point source discharges) in nature. Liver lesions in flounder continue to be present at all sites. The number of lesions in 1996 were slightly increased over the 1995 levels, but are still much less than 1992 levels.

Contaminant concentrations in lobster meat generally followed the same spatial pattern as contaminants in flounder meat, with the highest organic concentrations in Boston Harbor and the lowest in Cape Cod Bay, and no definite pattern in mercury concentrations. Metal concentrations in lobster hepatopancreas showed no overall trend, with some metal concen-

TABLE ES-3
Benthic Thresholds Compared to 1996 Monitoring Results

Parameter	Caution Level	Warning Level	1996 Results
Community Structure (Diversity, Species Composition, and Species Abundance) in outfall midfield area	Species diversity, composition, and relative abundance patterns measured in the midfield appreciably depart from those measured during the baseline monitoring period, after factoring out the effect of storms on sediment texture. Specific diversity threshold values are being developed.	None.	Shannon-Wiener Diversity Index Midfield mean = 2.8 (Range 1.95 - 3.30) (See also Table 4-2) Results in similar range to previous years.
Depth of Oxygenated Sediments [Redox Potential Discontinuity (RPD) Depth] in outfall nearfield area.	RPD depth declines by half. The threshold value is under development.	None.	No 1996 data available; 1995 results: Nearfield mean = 3.5 cm (Range 1.8 - >6.2 cm)
Toxic Contaminant Concentrations in outfall nearfield area.	Nearfield mean toxic contaminant concentrations greater than 90% of EPA sediment criteria.	Nearfield mean toxic contaminant concentrations greater than EPA sediment criteria or the NOAA Effects Range Median (ER-M) value. Examples: NOAA ER-M values: PCBs = 180 ng/g Mercury = 0.71 µg/g	No 1996 data available; 1995 example results: PCBs: Geometric Mean = 4 ng/g Range = 1.1 - 53 ng/g Mercury: Geometric mean = 0.16 µg/g (See also Table 4-4)

TABLE ES-4
Fish and Shellfish Thresholds Compared to 1996 Monitoring Results

Parameter	Caution Level	Warning Level	1996 Results
Mercury in fish and shellfish from Outfall site	Annual mean mercury concentration in flounder, lobster, and caged mussel meat greater than 0.5 µg/g wet weight (50% of the US FDA action level).	Annual mean mercury concentration in flounder, lobster, and caged mussel meat is greater than 0.8 µg/g wet weight (80% of the US FDA action level).	Flounder: 0.1 µg/g Lobster: 0.18 µg/g Mussel: 0.03 µg/g
PCBs in fish and shellfish from Outfall site	Annual mean PCB concentration in flounder, lobster, and caged mussel meat greater than 1 µg/g wet weight (50% of the US FDA action level).	Annual mean PCB concentration in flounder, lobster, and caged mussel meat is greater than 1.6 µg/g wet weight (80% of the US FDA action level).	Flounder: 0.04 µg/g Lobster: 0.02 µg/g Mussel: 0.02 µg/g
Lead in mussels at Outfall site	Annual mean lead concentration in caged mussel meat greater than 2 µg/g wet weight.	Annual mean lead concentration in caged mussel meat is greater than 3 µg/g wet weight.	Mussels: 0.3 µg/g
Lipid-normalized toxics in fish and shellfish from Outfall site	Lipid-normalized toxic concentrations in flounder, lobster, and caged mussel meat greater than two times the interim baseline concentrations (i.e., average value from 1992-1996 data). The final baseline concentration will be based on 1992-1998 data. *Interim baseline (1992–1996) concentrations in µg toxic per gm lipid.* Flounder DDT: 1.62 Flounder PCB: 14.94 Lobster DDT: 0.56 Lobster PCB: 4.46 Mussel DDT: 0.66 Mussel PAH: 6.22 Mussel PCB: 2.58	None.	Concentrations in µg toxic per gm lipid Flounder DDT: 1.02 Flounder PCB: 10.19 Lobster DDT: 0.56 Lobster PCB: 4.44 Mussel DDT: 0.28 Mussel PAH: 1.35 Mussel PCB: 0.94
Liver disease incidence in fish from outfall site	Flounder liver disease (CHV) incidence greater than interim harbor prevalence (1991-1996): 48% The final baseline prevalence will be based on 1991-1998 data.	None.	Flounder CHV prevalence: 22%

trations higher in Boston Harbor, others higher in Cape Cod Bay, and others similar at all stations. All levels are below those of concern, and are expected to improve as secondary treatment leads to improved effluent and water quality in Boston Harbor.

Summary of Exceedances

In 1996, four parameters exceeded Warning Level thresholds, and another two exceeded Caution Level thresholds. Five effluent parameters were among these exceedances; BOD, TSS, toxicity, and plant peformance exceeded the Warning Levels and total nitrogen exceeded the Caution Level. Secondary treatment has been shown to reduce all of these parameters, and therefore it is expected that there will be no exceedances once secondary treatment is on-line. The Caution Level for Stellwagen Basin DO saturation was also exceeded. This exceedance, along with DO concentrations and DO saturation exceedances from previous monitoring years, strongly suggest that the OMTF needs to re-evaluate the applicability of the current DO threshold levels.

1.0 INTRODUCTION

1.1 Report Objectives and Content

The outfall monitoring program is an important component of the Massachusetts Water Resources Authority's (MWRA's) overall program to improve the quality of Boston Harbor. The outfall monitoring program provides the means to identify, measure and respond to any impacts associated with the relocated outfall, as described in the Outfall Monitoring Plan (MWRA 1991, 1997). The Contingency Plan (MWRA 1997) outlines the MWRA's response program in case any unexpected impacts occur. The Outfall Monitoring Overview Report is intended to serve as an annual companion document to the Contingency Plan.

The outfall monitoring program was developed to measure baseline conditions, changes from baseline, and potential impacts to Massachusetts and Cape Cod Bays.

The objective of the Outfall Monitoring Overview Report is to describe the monitoring program results on an annual basis and compare those results to established environmental benchmarks or threshold levels for trigger parameters (described below). In addition, the report will summarize any actions taken pursuant to the Contingency Plan during the year.

Monitoring program results and threshold comparisons for field data collected through 1996 are presented in this report. Since data collection started in 1992 and the future outfall is not yet operational, the data in this report represent the fifth year of the baseline collection period. As such, comparisons of data to thresholds are used to test the validity of the threshold values. Also, the report provides interim threshold values for those parameters for which thresholds will be determined from a full set of baseline data. Finally, since the outfall is not operational, actions pursuant to the Contingency Plan are not addressed in this 1996 report, but will be in future reports.

The Outfall Monitoring Overview Reports serve as annual companion documents to the Contingency Plan, reporting monitoring results and comparison to threshold values.

A number of related reports have been, and will continue to be, produced by MWRA. These reports provide substantially more detailed information on the monitoring program and results than the summary provided in this report. Related program reports are summarized on Table 1-1.

TABLE 1-1

Summary of Available Reports Related to the Outfall Monitoring Program

Report	Description/Objectives
Outfall Monitoring Plan Phase I — Baseline Studies (MWRA 1991) Phase II — Post-Discharge Monitoring (MWRA 1997)	Discusses goals, strategy, and design of baseline and post-discharge monitoring programs.
Contingency Plan (MWRA 1997)	Describes development of trigger parameters and threshold values, and MWRA's planned contingency measures.
Program Area Synthesis Reports (Annual)	Summarize, interpret, and explain annual results for effluent, water column, benthos, and fish and shellfish monitoring areas.
Toxics and Nutrients Issues Reports (Annual)	Discuss, analyze, and cross-synthesize data related to toxic and nutrient issues in Massachusetts and Cape Cod Bays.
The State of Boston Harbor Reports (Annual)	Discuss a range of topics related to Boston Harbor and recent harbor monitoring results.

A current listing of the technical reports can be found on the internet at http://www.mwra.state.ma.us

This report is organized into the following sections: (1) this introduction that discusses the overall background and components of the monitoring program; (2) four sections that discuss the issues, design, comparison to thresholds, and recent results for each area of the monitoring program: effluent, water column, benthic studies, and fish and shellfish; and (3) a glossary and summary of acronyms.

1.2 Background

The outfall monitoring program was developed to resolve concerns about outfall relocation.

In 1986 the 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 includes the relocation of the treated effluent discharge point to a location in Massachusetts Bay (Figure 1-1) approximately 9.5 miles from the present Deer Island outfall. Discharge of effluent through the new outfall is expected to begin in 1998.

The U.S. Environmental Protection Agency (EPA) and the National Marine Fisheries Service (NMFS) assessed the potential impacts associated with the discharge of MWRA's wastewater effluent into Massachusetts Bay. Both the EPA and NMFS determined that there would not be significant water quality or biological impacts associated with the project. This conclusion was documented in the EPA's Supplemental Environmental Impact Statement (SEIS) and Biological Assessment and the NMFS's Biological Opinion.

Even though minimal impacts were predicted 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. General concerns identified

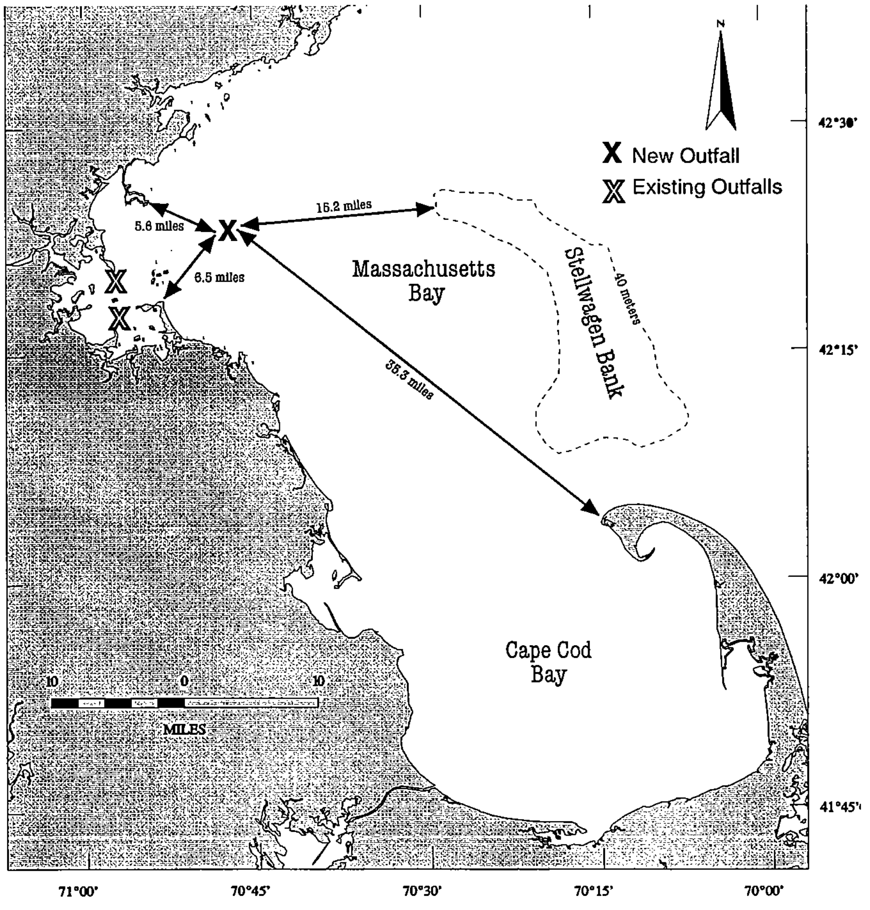


FIGURE 1-1
Distances of the new outfall from selected sensitive areas in Massachusetts and Cape Cod Bays. The existing outfalls are near Deer Island and the more southerly Nut Island. The new outfall is 9.5 miles from Deer Island.

with respect to the relocated discharge were potential aquatic life, human health, and aesthetic impacts in Massachusetts and Cape Cod Bays.

An Outfall Monitoring Task Force provides MWRA with guidance and recommendations on the outfall monitoring program.

In order to assure that discharge from the new outfall does not result in adverse impacts to human health or the environment, the EPA and the Massachusetts Executive Office of Environmental Affairs (EOEA) required the development of an outfall monitoring program. The objective of the monitoring program was to establish baseline conditions of the Massachusetts and Cape Cod Bay ecosystem and measure any future impacts on the system due to outfall relocation. At the direction of the EOEA, an Outfall Monitoring Task Force (OMTF) was formed to provide MWRA with guidance and recommendations on the development of a monitoring plan. The OMTF is composed of a science council of academic scientists, with participation by representatives from federal and state regulatory agencies and citizens' groups.

Numerous scientific studies performed as part of the outfall siting process in 1986 and 1987 were used as the basis by MWRA and the OMTF for the development of the Outfall Monitoring Plan 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 late 1998. Then, similar post-discharge studies, dedicated to determining the effects of the discharge, will begin.

The OMTF reviews the monitoring results on an ongoing basis and works with MWRA to implement cost-effective modifications that better address public and technical concerns. In May 1996, a technical workshop with MWRA scientists, OMTF members, and nationally recognized scientists was held to evaluate the outfall monitoring program. The workshop included a review of monitoring methods and results, trigger parameters and threshold values, and an evaluation of changes that would improve the effectiveness of the program. Some of the program changes implemented in 1996, with OMTF concurrence, included: (1) the temporary suspension of some portions of the benthic program (sediment toxics chemistry and sediment profile image studies), and, (2) the performance of pilot video plankton recorder studies.

1.3 Trigger Parameters and Thresholds

The outfall monitoring program provides the basis for evaluating potential impacts associated with the relocated outfall and the need for action under the Contingency Plan. This report evaluates monitoring program results based on specific measurement indicators of changes from benchmark environmental conditions. These measurement indicators were designated as trigger para-

TABLE 1-2

Summary of Trigger Parameters

Monitoring Area	Trigger Parameter
Effluent	Total Suspended Solids
	Biochemical Oxygen Demand
	Pathogenic Indicator Bacteria
	Nitrogen Loading
	Toxic Metals and Organic Chemicals
	Toxicity Testing
	Floatables
	Oil and Grease
	Plant Compliance with Permit Limits
Water Column	Dissolved Oxygen Concentration
	Dissolved Oxygen Respiration Rate
	Chlorophyll
	Nuisance and Noxious Algae
	Zooplankton
	Diffuser Mixing
Benthos	Benthic Community Structure
	Sediment Oxygen
	Sediment Toxic Metal and Organic Chemicals
Fish and Shellfish	Mercury and PCBs in Flounder, Lobster, and Mussels
	Lead in Mussels
	Lipophilic Toxic Contaminants
	Liver Disease in Flounder

meters in the Contingency Plan. A summary of the current trigger parameters is presented in Table 1-2. 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.

MWRA uses two levels of threshold values to evaluate the need for action under the Contingency Plan:

- *Caution Level exceedances indicate the need for increased study or attention.*
- *Warning Level exceedances indicate the need for action to avoid potential environmental impact, triggering the development and implementation of a response plan.*

There are two types of thresholds under development that will be used to alert MWRA and others to different degrees of potential environmental risk. Caution Level exceedances would indicate the need for more intensive study or increased attention. Warning Level exceedances would indicate the need for a response to avoid a potential environmental impact. The trigger parameters and thresholds for each of the measurement areas are discussed in detail in the corresponding report section below.

The definition of a threshold exceedance depends on the trigger parameter. It is desirable for most of the measured parameters (e.g. contaminant concentrations, treatment plant violations, algae and liver disease) to remain *below* the threshold. Other parameters (e.g. dissolved oxygen level, dilution, dissolved oxygen penetration into sediments, percent effluent with specified toxicity level, and diversity) should remain *above* the threshold.

The OMTF has used the following sources to establish threshold values for the trigger parameters:

- Limits expected in the forthcoming EPA/MADEP NPDES permit
- State water quality standards
- Predictions and assumptions made about the impacts of the discharge during the preparation of the EPA's SEIS
- Expert guidance and opinion

Expert guidance has helped refine trigger parameters and associated threshold values. The technical workshops held in May 1996 resulted in a recommendation that MWRA should revise the proposed Caution and Warning Levels. Specifically, it was recommended that MWRA focus on a reduced set of critical trigger parameters, define the trigger parameters more precisely, allow for seasonality of the natural baseline in the definition of thresholds, and choose threshold levels which are more protective of the environment. In addition, in the case where the NPDES permit limits serve to define the Warning Levels, it was determined that it would not be useful to try to define a corresponding Caution Level. This report, the 1996 Outfall Monitoring Overview Report, reflects those recommendations and decisions.

Several of the trigger parameters are expressed as change relative to baseline values. Because the baseline period is ongoing, interim thresholds are calculated as an exercise in this report based on the existing five years of monitoring data. The thresholds will be updated each year until just before the outfall begins discharging, when the final threshold values will be calculated.

1.4 Monitoring Program Summary

The outfall monitoring program is designed to provide measurements of six primary constituents of concern within the context of four program areas: effluent, water column, benthic environment, and fish and shellfish.

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, and
- Measure and evaluate potential impacts to Massachusetts and Cape Cod Bays associated with outfall relocation.

The monitoring program has focused on the following six wastewater constituents for determining the environmental impact of coastal discharges of treated sewage, as recommended by the National Research Council (NRC, 1993):

- Nutrients
- Organic material
- Toxic contaminants
- Pathogens
- Suspended solids
- Floatables

The outfall monitoring program is designed to obtain data that will allow an assessment of the water quality and ecological impacts of these constituents within the context of four monitoring program areas: effluent, water column, benthos, and fish and shellfish. A summary of the monitoring program is presented in Table 1-3.

Environmental data generally demonstrate considerable variability in both space and time due to the inherent behavior of natural systems. The outfall monitoring program is designed to provide data with sufficient temporal and spatial detail to characterize the variability of the Massachusetts and Cape Cod Bays system. Each of the different program areas has different requirements in this regard and the monitoring program design reflects these differences. For example, the water column in Massachusetts and Cape Cod Bay experiences considerable temporal variability and spatial patchiness. The combination of frequent boat-based surveys, continuous monitoring at a mooring, and satellite imagery in the water column program is designed to resolve this variability and provide detailed characterization of the water column system. The benthic environment displays at least as much spatial patchiness as the water column but much less temporal variability. Correspondingly, benthic monitoring is much less frequent than water column monitoring but provides spatial coverage that is similar.

The outfall monitoring program's data management system allows interactive use, as well as permanent archiving of monitoring data.

1.5 Data Management and Analysis

Since the beginning of the outfall monitoring program in 1992, more than 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)

TABLE 1-3

Summary of MWRA Outfall Monitoring Program

Task	Objective	Sampling Locations and Schedule	Analyses
EFFLUENT MONITORING			
Effluent Sampling	Characterize wastewater discharged from Deer Island Treatment Plant and pilot secondary treatment plant	• Weekly • Daily • Weekly (metals); 3 times/Month (organics) • 3 Times/Day • Daily • Weekly • Weekly	• Nutrients • Organic material (cBOD) • Toxic contaminants • Pathogens • Solids • Oil & Grease • Floatables (starting in 1998)
WATER COLUMN MONITORING			
Nearfield Surveys	Collect water quality data near future outfall location	• 17 surveys/year • 21 locations (See Figure 3-1)	• Temperature • Salinity • Dissolved oxygen • Plankton • Marine mammal/ sea turtle observations • Nutrients • Solids • Chlorophyll • Water clarity • Photosynthesis • Respiration
Farfield Surveys	Collect water quality data throughout Massachusetts and Cape Cod Bays	• 6 surveys/year • 26 locations (See Figure 3-1)	Same as Nearfield Surveys except no mammal/turtle observations
Plume Track Surveys	Track location and characteristics of discharge plume	• 4 surveys/year in 1999	• Salinity • Temperature • Rhodamine dye • Nutrients • Metals • Solids
Mooring	Provides continuous oceanographic data near outfall	• Continuous monitoring • Single station • 3 depths	• Temperature • Salinity • Water clarity • Chlorophyll
Remote Sensing	Provides oceanographic data on a regional scale through satellite imagery	• Available daily (cloud cover permitting)	• Surface Temperature • Chlorophyll (not available in 1996)
BENTHIC MONITORING			
Nutrient Flux Surveys	Evaluate nutrient interactions between the sediment and water column	• 5 surveys/year • 8 locations (See Figure 4-1)	• Oxygen demand • Nutrient flux • Porewater nutrients
Soft Bottom Surveys	Evaluate sediment quality in Boston Harbor and Massachusetts Bay	• 60 Boston Harbor stations (See Figure 4-2) • 20 nearfield stations (See Figure 4-3) • 11 farfield stations (See Figure 4-4)	• Sediment chemistry • Benthic community composition • Sediment profile imaging
Hard Bottom Surveys	Characterize marine communities in rock and cobble areas	• 1 survey/year • 6 transects (See Figure 4-5)	• 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 5-1)	• Tissue contaminant concentrations • Physical abnormalities (including histopathology)
Lobster Studies	Determine contaminant body burden	• 1 survey/year • 3 locations (See Figure 5-1)	• Tissue contaminant concentrations • Physical abnormalities
Mussel Studies	Evaluate biological condition and short-term contaminant bioaccumulation	• 1 survey/year • 3 locations (See Figure 5-1)	• Tissue contaminant concentrations • Physical abnormalities

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 management system is 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.

2.0 Effluent Monitoring Program

2.1 Effluent Issues

The National Research Council (1993) 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, and floatables. The issues associated with each of these constituents are described below.

The constituents of concern in wastewater effluent include:

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

Nutrients

Nutrients are essential for the growth of algae and other aquatic plants. However, excessive concentrations of nutrients in the water can be detrimental, and may lead to low dissolved oxygen levels and eutrophication. For marine and coastal environments, such as the Massachusetts and Cape Cod Bays system, nitrogen is the most important nutrient, and is the focus of effluent monitoring. However, measurements are also made regularly of phosphorous, and occasionally silica.

Organic Material

Organic material is a concern because as it decays it consumes dissolved oxygen (DO), which is critical to aquatic life. Low levels of DO may have serious effects on fish and other marine animals. The amount of DO consumed by decomposing organic material in effluent is the biochemical oxygen demand (BOD) which consists of the nitrogenous biochemical demand (nBOD) plus carbonaceous biochemical oxygen demand (cBOD). The standard measurement for BOD is the 5-day BOD test, or BOD5. The BOD5 measures both the carbonaceous and nitrogenous BOD. Because nitrogen is considered under measurements of total nitrogen in effluent, and because the ratio of oxidized/reduced forms of nitrogen vary with a number of factors including temperature, future measurements of organic material will focus on cBOD.

Toxic Contaminants

Toxic contaminants are substances that can cause diseases such as cancer in humans or organisms through direct contact with or accumulation in living tissue. Toxic contaminants include trace metals (such as lead, mercury, chromium, and cadmium); volatile organic compounds (such as benzene, toluene, and chlorinated solvents); semi-volatile organic compounds (including polyaromatic hydrocarbons [PAHs]); polychlorinated biphenyls PCBs; pesticides (such as DDT); ammonia; and chlorine. To evaluate levels of trace metals and organic contaminants in the effluent, the MWRA collects and analyzes effluent samples from the treatment plants at Deer Island and Nut Island. In addition, 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, red macroalgae, and sea urchins.

Pathogens

Human pathogens are bacteria, viruses, and protozoa 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 and to evaluate the effectiveness of chlorine addition at the treatment plant. MWRA regularly measures the levels of fecal and total coliform bacteria. Any health effect of pathogens which escape chlorination and are discharged in marine waters would not extend far from the outfall due to dilution and natural death of the microorganisms.

Suspended Solids

Suspended solids are small particles of matter, such as mud, sand, or organic debris, suspended in the water column. Solids influence the behavior of toxic contaminants and other water quality parameters but the primary concern associated with solids is deposition and the resulting potential for smothering of the 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.

Floatables

Floatables are pollutants that sit on the water surface, as opposed to being in the water column. Typical floatables are plastic tampon applicators, oil and grease. Floatables are primarily an aesthetic problem, although some floatables, such as oil, can be harmful to marine life.

The effluent monitoring includes NPDES sampling, detailed effluent studies, and pilot secondary treatment plant sampling.

2.2 Monitoring Program Design

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 allow comparison to NPDES permit limitations and evaluation of loadings and potential impacts on Massachusetts Bay.

Under the NPDES program the samples of the Deer Island treatment plant effluent were collected and analyzed as outlined below. Composite samples are taken over a 24-hour period, usually at weekly intervals (weekly composite). Compositing provides the best estimate of the average concentration of contaminants provided that they do not degrade in the storage unit; those that degrade are collected as a grab sample.

The following samples are collected under the NPDES program:

- *Nutrients.* A weekly composite sample is analyzed for total Kjeldahl nitrogen, ammonia, nitrate, nitrite, total phosphorus, and phosphate.
- *Organic material.* A daily composite sample is analyzed for 5-day Biochemical Oxygen Demand. In the future the carbonaceous BOD will be analyzed.
- *Toxic contaminants.* A weekly composite sample is analyzed for trace metals of concern: silver, cadmium, copper, chromium, mercury, lead, molybdenum, nickel, and zinc. The analyses incidentally yield data on arsenic, selenium, thallium, boron, beryllium, iron, antimony, but these are of little concern for this outfall.

Three composite samples per month are analyzed for organic contaminants: petroleum hydrocarbons, pesticides, PAH, PCB, phenols, and phthalates. Volatile organic compounds (VOA) are analyzed in three grab samples per month.

- *Toxicity testing.* Three daily composites are currently used in the monthly bioassay toxicity tests. The three toxicity tests are: 1) acute mortality in marine mysid shrimp; 2) chronic survival and growth in sheepshead minnow and 3) chronic reproduction in red algae. In the future it is likely that the fish used for testing will be changed to a more sensitive species, and the red algae be replaced by a more reliable test organism, the sea urchin.
- *Pathogens.* Three grab samples per day are analyzed for fecal and total coliform.
- *Suspended solids.* A daily composite sample is analyzed for total suspended solids.
- *Floatables.* A weekly grab sample is analyzed for oil and grease. Beginning in 1998 the amount of floating material in the final skimmer will be visually estimated.

In addition to samples collected and analyzed under the NPDES program, other samples may be collected occasionally to provide more sensitive and detailed information about the effluent. Those measurements are called the detailed effluent characterization study (DECS). In 1996 the DECS measurements were made at Deer Island only; every month from January to June and again in August, two composite samples were taken a few days apart and analyzed for toxic contaminants. Trace metals analyzed were: silver, cadmium, copper, chromium, mercury, lead, molybdenum, nickel, and zinc. Organic contaminants analyzed consisted of 17 persistent chlorinated pesticides, an extended list of PAHs, 20 PCB congeners, and C10 to C14 linear alkyl benzenes.

A pilot plant has been in operation since 1994 to estimate removal efficiencies of the full scale secondary treatment plant. Removal of toxic compounds and nutrients were studied in 1994 and 1995. In 1996 TSS and BOD removal was monitored, although the results are not representative of the expected operational efficiency of the future full scale secondary treatment plant.

2.3 Monitoring Results Compared to Thresholds

Thresholds for nine parameters are established for the effluent. The thresholds for organic material (BOD), toxic contaminants (toxics and toxicity), pathogens (bacteria), solids (TSS), and oil and grease will be based on the NPDES permit to be issued by the EPA and DEP to MWRA for the Deer Island Treatment Plant and outfall. Three other thresholds, for nutrients (total nitrogen), floatables (other than oil and grease), and plant performance, have already been specified. A summary of the expected effluent thresholds and comparison of 1996 monitoring results to thresholds are given in Table 2-1. It should be noted that the thresholds are for the future Deer Island Treatment Plant, with secondary treatment being phased in from 1997 to 2000. The 1996 monitoring results are for the Deer Island Plant with new primary treatment but no secondary treatment.

Most effluent threshold values were developed from expected NPDES permit limits.

TABLE 2-1
Effluent Thresholds Compared to 1996 Monitoring Results

Parameter	Caution Level	Warning Level	1996 Results
Total Nitrogen (nutrients)	Total nitrogen annual loading > 12,500 mtons/year	Total nitrogen annual loading > 14,000 mtons/year.	Annual loading = 12,692 metric tons, slightly exceeded the Caution Level.
cBOD (organic material)	None.	Expected levels: 40 mg/L weekly, 25 mg/L monthly. *Current interim permit limit = 140 mg/L monthly.*	Daily Deer Island BOD5 range from 33 to 129 mg/L with an average of 73 mg/L. Monthly Deer Island BOD5 range from 38 to 67 mg/L with an average of 52 mg/L. Pilot secondary effluent monthly average = 10 mg/L. cBOD is typically less than BOD5.
Toxics (toxic contaminants)	None.	PCB (as Arochlors) limit = 0.045 ng/L monthly.	PCBs as Arochlors were all below detection limits. Monthly total PCB concentrations: from 0 to 35.9 ng/L with an average of 8.4 ng/L.
Toxicity (toxic contaminants)	None.	Acute: effluent LC50 for shrimp <50% effluent. Chronic: effluent NOEC for fish (silverside) growth and sea urchin fertilization <1.5% effluent. *Interim acute limit: shrimp NOEC < 20% effluent Current chronic limits: minnow and red algae NOEC < 10% effluent*	Acute: 11 of 12 shrimp tests had LC50 < 50% effluent. Chronic: No fish growth tests had NOEC < 1.5% effluent; sea urchin tests are not yet implemented. *Acute: 6 of 12 tests violated interim shrimp 20% NOEC limit. Chronic: no violations of current minnow 10% NOEC limit; All tests failed current red algae 10% NOEC limit.* Pilot secondary effluent > 50% for chronic NOEC for silverside and sea urchin. Five pilot plant acute tests had LC50 = 100%
Bacteria (pathogens)	None.	Expected level: 14,000 fecal current coliform/100 mL at point of dechlorination (weekly mean, monthly 90th percentile, and 24 consecutive hours). *Current interim permit limit = 200 fecal coliform/100 mL monthly average.*	No exceedances of expected level or the current monthly limit of 200 fecal coliform/100mL.
Suspended Solids	None.	Expected levels: 45 mg/L weekly, 30 mg/L monthly. *Current interim permit limit = 110 mg/L monthly.*	Range at Deer Island from 24 to 133 mg/L, with an average of 52 mg/L. Pilot secondary effluent monthly average = 9 mg/L.
Floatables	None.	Floatables less than 5 gal/day.	Not measured until secondary treatment plant is on line.
Oil and Grease (floatables)	None.	15 mg/L weekly.	Maximum weekly = 6.5 mg/L.
Plant Performance	More than 5 violations of expected permit requirements per year.	Operating in violation of the expected permit requirements more than 5% of the time over a year.	Violation of nearly all the expected limits on BOD, solids, and acute toxicity, most of the time. *Violation of interim permit limits for acute toxicity, and on one occasion for removal efficiency of BOD.*

The reader is directed to the glossary and acronym summary at the end of the report.
Current interim permit limits are presented in the Warning Level column in italics.

Most of the threshold levels are expressed as a number in relation to a certain interval of time and space. For example, the *daily* bacteria limit is compared to the pooled measurements in a day. There are three measurements of bacteria in a day, and pooling is calculated in this case as a geometric mean. Likewise, the *monthly* limit is compared to the pooled measurements taken over a month. The concept of a spatial interval is more relevant to the other monitoring areas and is discussed in Section 3.3.

Nutrients

Because nitrogen is the most important nutrient to monitor when discharging effluent to marine waters, MWRA tests treatment plant effluent for the concentration of total nitrogen. The SEIS and later modelIng studies predicted little or no impact from the outfall discharge assuming a nitrogen loading of 14,000 mtons/year. The Warning Level was established to verify that the load assumed in those predictions is not exceeded. The Caution Level was set at approximately 90% of the Warning Level, or 12,500 mtons/year.

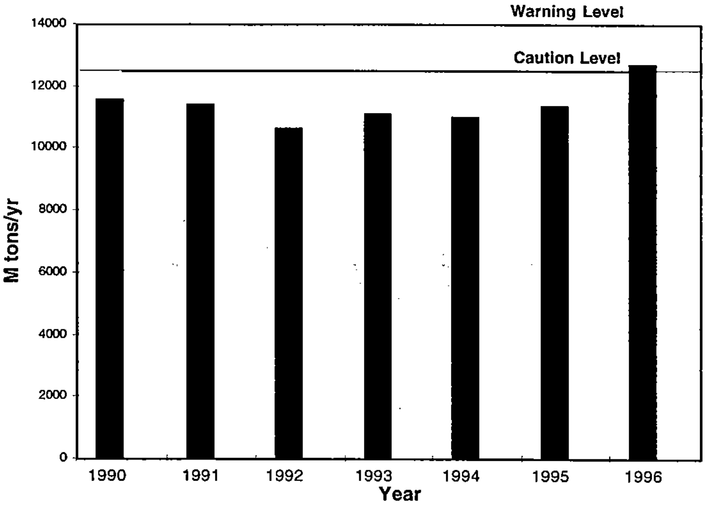


FIGURE 2-1
Total nitrogen load discharged from the Deer Island and Nut Island treatment plants from 1990 to 1996.

In the 1996 DECS sampling program, nutrients were not measured. MWRA measured total nitrogen load at both the Deer Island and Nut Island treatment plants, using composite samples of primary effluent. The total annual nitrogen load in 1996 was 12,692 metric tons, which slightly exceeds the Caution Level. The total annual nitrogen load increased from 1994 to 1996, possibly reflecting increased efficiency in the sludge dewatering process (the effluent from the sludge dewatering process is recycled back to Deer Island). Figure 2-1 shows the total nitrogen load discharged from the Deer Island and Nut Island treatment plants from 1990 to 1996. The 1995 pilot study showed that secondary treatment can remove an average of 10% for total nitrogen and it is expected that the 1997 total nitrogen load will show a decrease from the 1996 load.

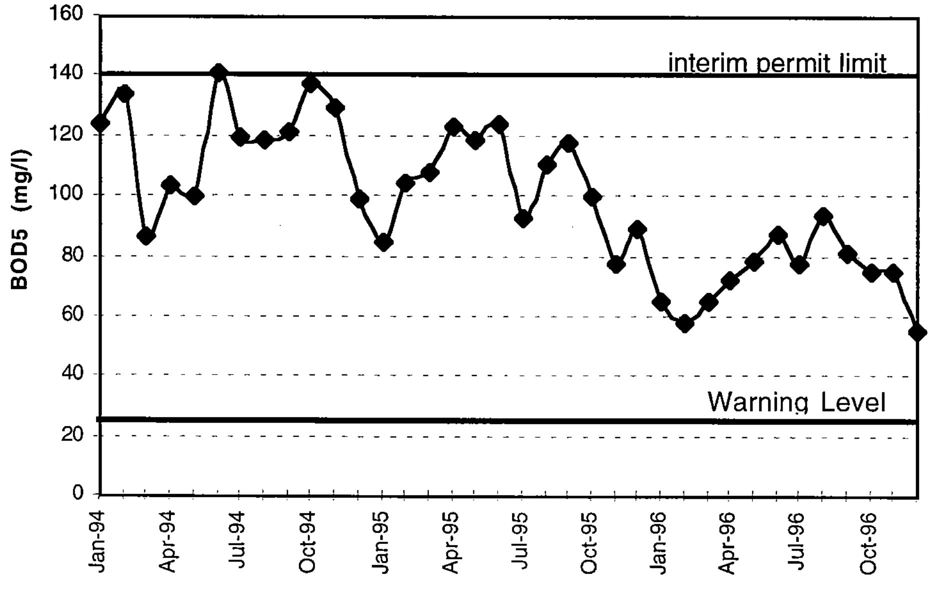
Effluent BOD and solids levels are expected to drop below Warning Levels after the new secondary treatment system is fully operational.

Organic Material

Although the NPDES permit has not been issued, the expected Warning Level thresholds for effluent organic materials are 40 mg/L on a weekly average, and 25 mg/L on a monthly average. These levels are based on carbonaceous BOD. Typically, cBOD will be lower than BOD5.

In 1996, daily BOD5 in the primary effluent ranged from 33 to 129 mg/L with an average of 73 mg/L. This showed the improved performance, after the start-up period, of the new primary treatment plant that became operational in 1995. In 1995 the BOD5 range was 50 to 179 mg/L, with an average of 102 mg/L. The thresholds being developed apply to cBOD for the new secondary treatment system, but the 1996 results are for BOD5 from the primary treatment system. BOD levels are expected to drop to below the Warning Level when the new system is fully operational and cBOD measurements are used. The 1996 average BOD5 in the effluent of the pilot secondary treatment plant was 10 mg/L. Figure 2-2 shows the monthly average BOD5 in the Deer Island Treatment Plant

Figure 2-2
Monthly average BOD5 in the Deer Island Treatment Plant effluent from 1994 to 1996. Expected future warning level threshold of 25 mg/L shown for comparison.



effluent from 1994 to 1996.

Maximum 1996 toxic concentrations for all parameters, except DDT, were below dilution-adjusted water quality criteria.

Toxic Contaminants

NPDES toxic contaminant limits are based on water quality standards and very conservative assumptions about water conditions within the effluent/sea water mixing zone (i.e. stratified conditions and conservative estimates of available dilution). If limits for toxics are included in the new NPDES permit, they will serve as the Warning Levels for effluent toxic contaminant concentrations. If not, the thresholds will be revised to reflect water quality standards. Presently, the only toxic parameter expected in the permit is PCBs.

Maximum toxic analyte concentrations from DECS and MWRA sampling for the Deer Island Treatment Plant primary effluent from January to December 1996 (only seven months were actually sampled) compared to dilution-adjusted water quality criteria (WQC) are presented in Table 2-2. None of the maximum concentrations of analytes listed in the table exceed the dilution-adjusted WQC except DDT. This exceedance was for the human heath criterion which assumes long term exposure. The average DDT measured in the 1996 Deer Island primary effluent was 0.003 µg/L, which is below the dilution-adjusted WQC. The 1995 pilot secondary treatment results showed a high removal efficiency of DDT by secondary treatment. The 1996 mean effluent concentrations of these contaminants were all lower than the corresponding 1995 results except for acenaphthene (0.107 µg/L in 1996 versus 0.093 µg/L in 1995). PCBs as Arochlors will be limited in the new NPDES permit with no allowance for dilution. All samples in 1996 were below PCB Arochlor detection limits. The OMTF also requires MWRA to measure the 20 individual PCB congeners listed in NOAA's National Status and Tends protocol; total PCB is calculated in this report as the sum of those congeners. In 1996, primary effluent concentrations averaged 8.4 ng/L.

Toxicity (Bioassay Results)

In addition to concentration-based limits for toxic parameters, the NPDES permit will require the use of laboratory-based bioassays to assess acute and chronic toxicity. The Warning Level for acute toxicity is expected to be an effluent LC50 of less than 50% effluent for shrimp. The Warning Level for chronic toxicity is expected to be effluent NOEC for fish growth and sea urchin fertilization that is less than 1.5% effluent. The expected permit limits that form the basis for these thresholds differ from the present toxicity permit limits.

In 1996, 11 of 12 Deer Island Treatment Plant primary effluent acute toxicity tests for shrimp had an LC50 of less than the Warning Level of 50% effluent. Acute tests also had a NOEC range of 10 to 50% effluent, with an average of 18%. Six of the twelve tests violated the 20% interim acute NOEC limit. Chronic NOEC values from minnow tests averaged 43% effluent with a range of 20 to 60%. There were no exceedances of the thresholds or the 10% NOEC interim limit. In contrast, all of the red algae tests failed. The chronic interim NOEC limit is 10%, while the test results were between 0.2 and 7%, with an average of 2%. These results, as well as those from other treatment plants, and other practical test considerations have prompted the EPA to revisit the test species, and it is expected that sheepshead minnow and red algae will be replaced in the permit. Exploratory toxicity testing was conducted in 1996 using silversides and sea urchin. Three tests using silversides and sea urchin in pilot secondary effluent showed a 50% NOEC. These results are well above the 1.5% NOEC being considered for permit limits, i.e. the effluent is not expected to violate the toxicity limits of the new permit.

Pathogens

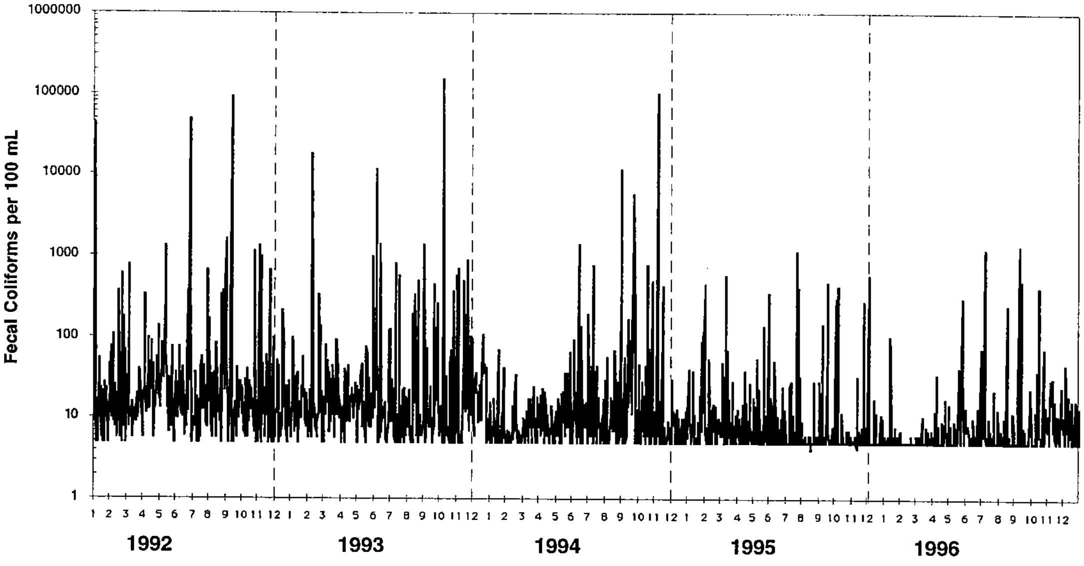


FIGURE 2-3
Daily Average Fecal Coliform in Effluent

The Warning Level threshold is based on the expected NPDES permit level of 14,000 fecal coliform/100mL at the treatment plant. Because of the increased contact time that will be provided by the outfall tunnel and the dilution that will be achieved at the point of discharge, it is nearly inconceivable that any bacterial water quality standards for shellfishing or swimming would be exceeded (except in the immediate vicinity of the outfall, where the Division of Marine Fisheries prohibits fishing and shellfishing) if effluent bacteria concentrations were below the NPDES permit limits.

Fecal coliform levels in Deer Island effluent vary widely (Figure 2-3). In 1996, there were no exceedances of the Warning Level or the interim monthly limit of 200 fecal coliform/100 mL. This level of performance is expected to be continued when the new treatment plant is on-line. The new treatment plant will have a longer chlorine contact time, resulting in increased pathogen destruction.

Solids

The current interim permit limit for TSS is 110 mg/L as a monthly average. The expected NPDES permit limits for total suspended solids (TSS) are used as the MWRA Warning Level thresholds. These limits are 45 mg/L of TSS weekly, and 30 mg/L of TSS monthly. In 1996, TSS concentrations in Deer Island Treatment Plant effluent averaged 52 mg/L with a range between 24 and 133 mg/L. Although the TSS appears to be lower in the new primary plant effluent than in previous years, these values are still substantially higher than the established threshold values. 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. The average pilot secondary treatment plant effluent TSS concentration in 1996 was 9 mg/L. Figure 2-4 shows the average monthly TSS in Deer Island Treatment Plant primary effluent from 1994 to 1996.

FIGURE 2-4
Monthly average TSS in the Deer Island Treatment Plant effluent from 1994 to 1996. Future Warning Level threshold of 30 mg/L shown for comparison. (Current interim permit limit of 110m/L not shown)

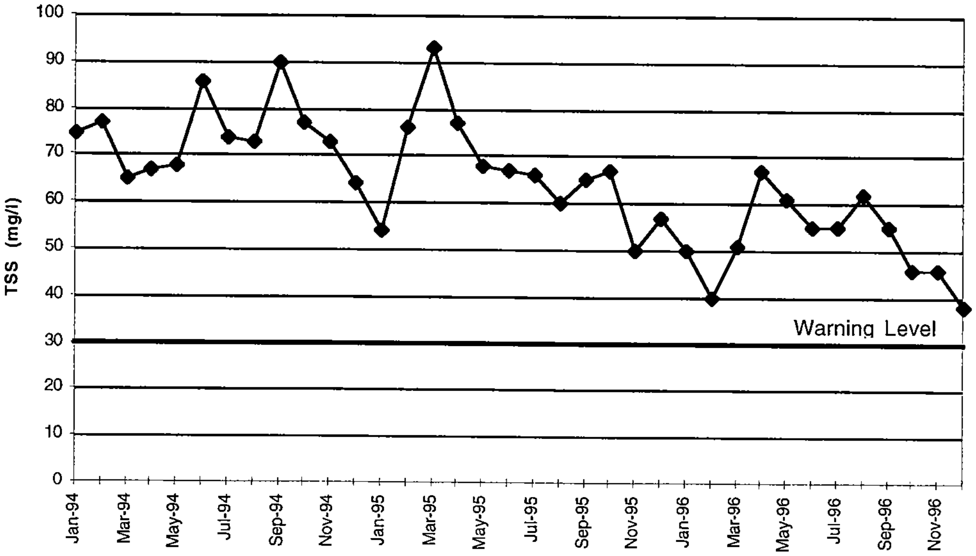


TABLE 2-2

Maximum 1996 Primary Effluent Contaminant Concentrations Compared to Dilution Adjusted Water Quality Criteria

Parameter (mg/L)	1996 Maximum Effluent Concentration[1]	Human Health WQC x 364 (µg/L)	Chronic WQC x 60.8 (µg/L)	Acute WQC x 48.3 (µg/L)
Pesticides				
Aldrin	ND	0.027	NA	62.8
4, 4'-DDT	0.025	0.0087	0.061	6.3
Dieldrin	ND	0.026	0.116	34.3
Endrin	ND	364	0.14	1.8
Heptachlor	ND	0.102	0.22	2.6
Heptachlor Epoxide	ND	0.036	0.22	2.6
Lindane	0.028	6.8	NA	7.7
PAH				
Acenaphthene	0.180	NA	43,200*	46,800*
Fluoranthene	0.300	15,300	975*	1,900*
Naphthalene	1.20	NA	NA	113,000*
ΣPAH	14.4	NA	NA	NA
PCB (as Arochlors)	ND	0.000045[2]	NA	NA
Metals		18,200	NA	NA
Silver	5.1	3,600	322	110
Cadmium	< 2.0	18,200	3,040	2,000
Chromium (VI)	12.5	NA	176	53,000
Copper	105	52.4	1.5	140
Mercury	0.62	4,880	500	100
Nickel	8.3	18,200	340	3,600
Lead	24.2	NA	5,200	6,800
Zinc	128			4,500

[1] Maximum concentration in samples in which contaminant was detected.

[2] The Human Health Criteria for PCB as Arochlors is reported as an undiluted value, as the NPDES permit will not allow for dilution.

* Insufficient information for development of WQC. NOEC used instead.
ND = Not detected.
NA = Not Available

Floatables

The Warning Level for oil and grease is the same as the expected NPDES permit limits, 15 mg/L in weekly grab samples. One anomalously high result in January of 1996 exceeded the level but was rejected as a laboratory error. For the remaining data, the maximum weekly value was 6.5 mg/L which occurred in September.

A separate threshold is being established for floatables (visible floating debris) which are assessed by a different method from oil and grease. Floatables cause aesthetic problems. Current sewage treatment operation includes regular 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. A more comprehensive procedure for assessing visible floatables will be instituted when the secondary plant is on line. The floatables Warning Level was set in relation to the performance of the future secondary treatment plant, which has a series of floatables-removing skimmers. The expectation is that the final skimmer is redundant. If as much as 5 gallons of floating matter accumulates in that final skimmer over the course of a day, that would indicate that it is not redundant and the upstream skimmers may be overloaded or inefficient. The visual inspections will begin in 1998 and be conducted weekly. The design of the present primary plant does not allow for any such quantification of floatables now, and so the 1996 floatables results portion of Table 2-1 is blank.

Plant Performance

The MWRA Caution Level for plant performance is the Association of Metropolitan Sewerage Agencies' (AMSA) standard of 5 violations/year, while the Warning Level is the EPA standard of noncompliance 5% of the time. The expected future permit for the fully operational secondary treatment plant (year 2000) lists limits for cBOD, PCB, toxicity, bacteria, and solids. BOD, acute toxicity, and suspended solids exceeded those limits most of the time and thus exceeded the Warning Level for plant performance. Expressed in relation to the interim permit the plant exceeded acute toxicity half the time, plus one occurrence when BOD removal efficiency was slightly less than required by the interim permit. Thus plant performance violated the Warning Level in relation to the expected permit as well as the interim permit. Results of the pilot secondary treatment plant shows that once the new treatment system is on line, TSS and BOD will be effectively removed and the frequency of violations is expected to drop below the threshold.

3.0 Water Column Monitoring Program

3.1 Water Column Issues

Potential water column issues due to the relocation of the outfall are associated with the effects of the effluent organic material, nutrients, and toxic contaminants. Of these, changes in the nutrient balance in Massachusetts and Cape Cod Bays have the most potential for significant effects on the health of marine life in the Bays.

3.1.1 Organic Material

Organic material occurs naturally in water bodies and may also be introduced by wastewater effluents. Decomposition of organic material consumes dissolved oxygen (DO). DO is oxygen dissolved in water and available to marine mammals for respiration. If DO concentrations are low, a condition known as hypoxia, sensitive animals may suffocate. Hypoxia can occur when the DO demand of decomposition is greater than the natural resupply. The oxygen depletion rate is a measure of this difference between DO supply and demand, and describes how quickly DO concentration decreases.

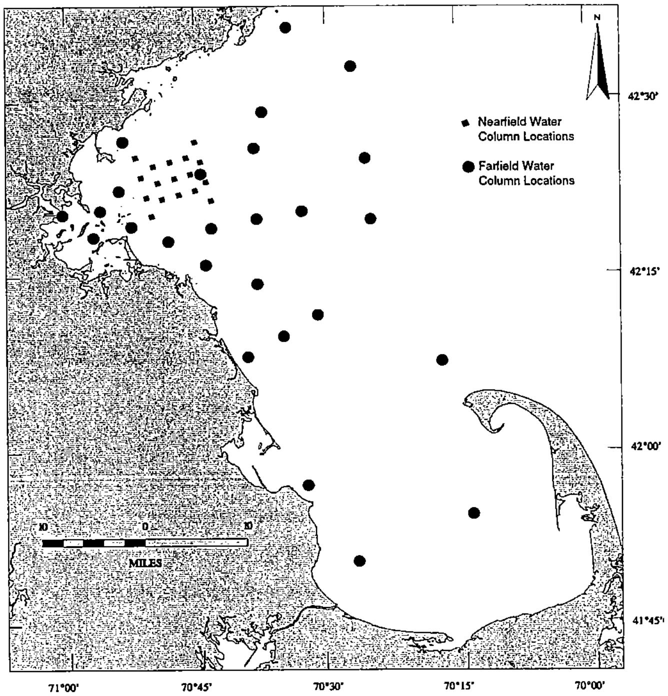


FIGURE 3-1
Nearfield and Farfield water column sampling locations

3.1.2 Nutrients

Nutrients are necessary for the growth of all plants, aquatic and terrestrial. The amount of nutrients in the water, along with several other factors, controls the growth of aquatic plants, including algae. Since algae are the foundation of the aquatic food web, nutrients have a great effect on how much life a marine ecosystem can support. In particular, there are two basic ways in which nutrients from wastewater effluent could have a negative effect on marine environments: through the effects of algae on dissolved oxygen concentration and through changes in algal community structure. Nitrogen is the nutrient of greatest concern.

Low Dissolved Oxygen (Hypoxia)

An algal bloom is a burst of algal growth, which occurs when a variety of conditions come together. A sufficiently high nutrient level is one of the requirements, but other factors such as sunlight and temperature are also important. Algal blooms are the base of the food web, without which fish, whales, and most other marine life would not survive. Algal blooms are necessary, common occurrences in the marine environment, but they can be a cause for concern, depending on the intensity and frequency of the bloom, and the types of algae that bloom.

Water column issues primarily consist of potential hypoxia effects associated with organic matter and nutrients, and shifts in the algae community assemblage.

If a body of water receives too great a nutrient load, it may become subject to eutrophication: over-stimulation of algal growth and excessive algal blooms. When algae grow faster than they are consumed, the excess algae die, sink to the bottom, and decompose. Decomposition of the algae consumes DO, just as with the decomposition of organic material, as discussed above. This DO consumption can contribute to the creation of hypoxic conditions.

Algal Community Structure (Growth of Undesirable Algae)

Adding effluent to the marine environment may change the relative levels of different nutrients so that undesirable algae dominate or are present along with useful algae. The nutrient composition of effluent is different from that in Massachusetts Bay, and there is public concern that undesirable algae may be better able to take advantage of this difference than desirable algae. Two types of undesirable algae can have direct effects on the marine environment: 1) nuisance algae, such as brown and red tides, which affect the appearance of the water; and 2) noxious algae, such as some red tides, which are toxic to marine mammals, some fish, and, if concentrated in shellfish, to humans. Undesirable algae can also have an indirect effect on the marine environment by out-competing another algal species. If the out-competed species is a primary food source for a marine mammal, that animal may suffer. For instance, it has been suggested that right whales in Cape Cod Bay are linked through the food chain to a kind of algae that might be affected by effluent-induced changes in nutrient concentrations.

3.1.3 Toxic Contaminants

Toxic contaminants are not always toxic. They are harmful at and above certain concentrations, but at lower levels they may be harmless. Some even may be essential to life (e.g., copper and zinc, whereas mercury and lead are not). The timing of exposure is also an important factor: temporary exposures are less harmful than constant ones. This is reflected in higher water quality criteria for acute exposure than for chronic exposure. Animals passing briefly by the outfall would be only temporarily exposed. Because the harmful effect of contaminants decreases with decreasing concentration, the dilution of the effluent is key to minimizing the impact of the outfall.

The potential for increased levels of toxic contaminants in the vicinity of the new outfall is generally low. The new outfall will minimize the environmental impact of effluent by maximizing dilution. Because outfall relocation is unlikely to have a significant effect on the concentrations of toxic contaminants in waters of Massachusetts Bay, toxic contaminant concentrations are monitored in the other three program areas but not in the water column program. Because adequate dilution is central to the expectation of no impact, the effluent dilution achieved by the diffuser will be evaluated using data obtained from the plume tracking surveys (described below).

3.2 Monitoring Program Design

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

The monitoring program, which began in 1992, is designed to characterize background 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 Bays will be assessed.

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

The water column monitoring program includes nearfield and farfield surveys, plume tracking surveys, mooring measurements, and remote sensing imagery.

Nearfield Surveys

Nearfield water column surveys are designed to collect frequent intensive sets of water quality and plankton data near the outfall location. Impacts are most likely to be measurable near the outfall site, and are likely to be confined to the nearfield area. The nearfield area is defined by a rectangle surrounding the 1.2 mile outfall diffuser line at a distance of 3 miles. The stations are spatially intensive to document the decrease of impacts with distance from the outfall in the region where the decrease is expected to be strongest and most detectable. Data are collected at 17 locations (Figure 3-1) 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 electronically measured *in situ* throughout the depth of the water column. Water samples are collected at selected stations and depths in the water column for laboratory analysis of constituents including nutrients, chlorophyll, suspended solids, dissolved oxygen, phytoplankton, zooplankton, primary productivity, and respiration. Primary productivity (i.e., photosynthesis, the algal growth rate) measurements are performed to evaluate how the algae are responding to ambient nutrients and light. Respiration measurements evaluate the rate of oxygen consumption due to metabolic activity including degradation of algal biomass and other organic matter. Observations of whales, other marine mammals, and sea turtles are also performed during the nearfield surveys.

Farfield Surveys

Farfield water quality surveys are designed to collect intensive sets of water quality, plankton, and primary productivity data over a broad spatial scale, and to cover Massachusetts and Cape Cod Bays. Stations are not spatially intensive as they are in the nearfield, but are spread out over the Bays with adjustments to cover special resource areas and to detect the influence of coastal and offshore sources of nutrients to the Bays. The main 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 at 26 stations throughout Massachusetts and Cape Cod Bays (Figure 3-1). Plankton and primary productivity data are collected at selected stations. Farfield and nearfield methods are comparable.

Plume Tracking Surveys

Plume tracking surveys are performed to determine the location of and physical, chemical and biological characteristics of the effluent discharge plume leaving the outfall and mixing with ambient waters. Sampling will include measurement of salinity, temperature, rhodamine dye and suspended solids. The dilution and transformation of components characteristic of the effluent will be tracked using salinity, nutrients, and metals as well as other chemical, isotopic, and microbial constituents. Intensive studies will begin when the outfall is on line.

Moorings

A mooring is maintained by the US Geological Survey near the future outfall site to measure currents, temperature, salinity, light transmission, chlorophyll, and sediment processes. In addition to a mooring, which physically consists of instruments suspended from a float and anchored by a weight, the USGS also deploys tripods mounted on the sea floor. The purpose of moorings and tripods is to obtain continuous data at a location. The outfall monitoring program uses the data to capture temporal (i.e., time-dependent) variations in water quality between nearfield surveys.

Remote Sensing

Satellites provide remote sensing imagery which the outfall monitoring program uses to capture spatial variations in water quality on a regional scale. The images provide a snapshot of sea surface temperature over the Bays at one time. Sometime after 1996, chlorophyll data will also become available. Remote sensing fills in the information between survey sample locations. Data from remote sensing complements the data from the ship surveys and moorings.

3.3 Threshold Comparison

Trigger parameters associated with DO include the DO concentration in the outfall nearfield and Stellwagen Basin, and DO depletion rate in the nearfield.

Several thresholds for water column monitoring parameters have been developed in order to assess the potential impacts of the new outfall. The trigger parameters, threshold levels, and 1996 monitoring results for the water column are summarized on Table 3-1. A detailed discussion of the thresholds and current status of compliance with thresholds is provided below.

Most of the threshold levels are expressed as a number in relation to a certain interval of time and space. The relevant data are pooled over those intervals and then compared to the threshold number. The pooling may be done by calculating an average, a geometric mean (bacteria) or other statistic (benthic diversity). Pooling yields a number which is less extreme than that of the worst-case individual reading, and so the spatial and temporal intervals have to be chosen carefully: large enough to reflect the ecological response scale of the resource to be protected but small enough to not mask transient problems that occur. The thresholds are designed to be compared to pooled rather than individual data because the latter are dependent on the sampling effort. An example of how the pooling is done is that the "monthly mean DO in nearfield bottom waters" is calculated by averaging the deepest DO measurements from all the nearfield stations during one survey that result is averaged over all the surveys (there are up to two) within a calendar month to give the nearfield monthly mean.

TABLE 3-1
Water Column Thresholds Compared to 1996 Monitoring Results

Parameter	Caution Level	Warning Level	1996 Results
Dissolved oxygen concentration in Nearfield region bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)	DO saturation above Caution Level in September (87.2%). (See Table 3-2)
Dissolved oxygen concentration in Stellwagen Basin bottom waters	Monthly mean DO is less than 6.5 ppm or 80% of saturation levels for any one month during stratification (June-Oct.)	Monthly mean DO is less than 6 ppm or 75% of saturation levels for any one month during stratification (June-Oct.)	DO saturation below Caution Level in October (79.2%). (See Table 3-2)
Dissolved oxygen depletion rate in Nearfield region bottom waters	DO depletion rate is greater than 1.5 times the baseline rate during stratification (June-Oct.), -0.040 mg/L/day.	DO depletion rate is greater than 2 times the baseline rate during stratification (June-Oct.), -0.053 mg/L/day.	1992-96 Average Baseline Rate: -0.026 mg/L/day 1996 Rate: -0.025 mg/L/day
Chlorophyll in Nearfield region	Annual mean concentration greater than 1.5 times the baseline annual mean, 2.80 µg/L.	Annual mean concentration greater than 2 times the baseline annual mean, 3.74 µg/L.	1992-96 Baseline: 1.87 µg/L 1996: 1.54 µg/L
Chlorophyll in Nearfield region	Season mean concentration exceeds 95th percentile of the baseline seasonal distribution. Spring: 2.71 µg/L Summer: 2.27 µg/L Fall: 4.44 µg/L	None.	Spring: 2.43 mµg/L Summer: 0.78 µg/L Fall: 1.47 µg/L
Nuisance algae in Nearfield region	*Alexandrium tamarense* Season mean population densities exceed 95th percentile of the baseline seasonal mean. Spring: 2.34 cells/L Summer: 26.1 cells/L Fall: 7.57 cells/L	None.	*Alexandrium tamarense* Spring: 0 cells/L Summer: 0 cells/L Fall: 0 cells/L (See Table 3-3)
PSP extent in Farfield region	New occurrence. PSP has never been observed at 3 of the 18 monitoring stations (see Table 3-4).	None.	No occurrences.
Zooplankton assemblage in Nearfield region	Nearfield assemblage shifts from a transitional community towards an inshore community. Inshore: *Acartia, Eurytemora, Centropages hamatus* Offshore: *Calanus, Pseudcalanus, Centropages typicus, Oithona* Nearfield: Transitional between two regions.	None.	Transitional assemblage in nearfield region.
Initial effluent dilution at new outfall location	None.	Effluent dilution less than that set by the NPDES permit.	No data until outfall is online.

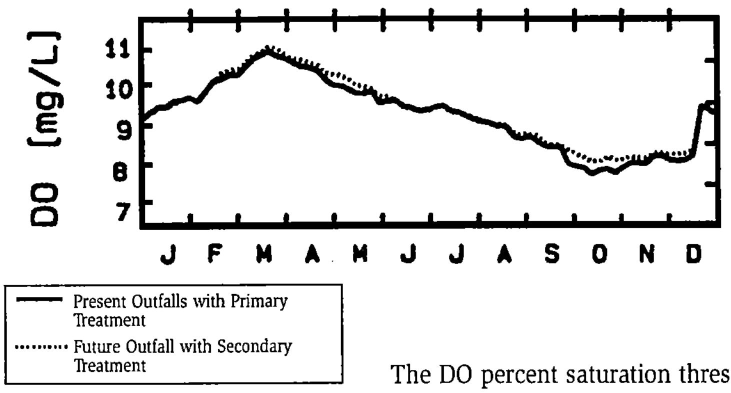


Figure 3-2
Water quality modeling results near future outfall: Existing (1992) conditions and post outfall relocation/secondary treatment (Source: HydroQual. and Normandeau 1995)

Dissolved Oxygen Concentration and Saturation

Aquatic animals are sensitive to the concentration of DO in the water column. Low levels of DO can have negative impacts on marine life. Because of the importance of DO, the state has set a water quality standard that a discharge should not cause DO to fall below 6 mg/L nor below 75% of saturation in Massachusetts Bay.

The DO percent saturation threshold is unique in that, even with pooling, it has already been exceeded in the baseline period before the future outfall is operational. The issue of causality implied in the state standard is pivotal in such a case and will be decided on by the OMTF. Water quality modeling studies have indicated that dissolved oxygen levels will improve at the future outfall site as a result of outfall relocation and secondary treatment (Figure 3-2). In the post-discharge period, when the Contingency Plan becomes active, action will be taken in response to an exceedance. (It should be noted that for DO an "exceedance" is less than the threshold value.) The first action to be taken is to notify the OMTF. Even if low DO is determined to be unrelated to the MWRA discharge, it is appropriate to have in place such a mechanism for keeping the OMTF immediately informed of episodes of low DO, given the ecological importance of that parameter. Actions could also include water quality modeling studies to evaluate the cause of the violation.

In 1996 the lowest nearfield monthly mean DO concentration, 7.7 mg/L in September, was above the Caution Level of 6.5 mg/L (Table 3-2). The lowest individual measurement was 7.2 mg/L in October. During the entire baseline period to date (1992-96), the lowest nearfield monthly mean was 6.5 mg/L in September 1994, and the lowest individual measurement was 4.8 mg/L in October 1994.

In Stellwagen Basin in 1996, the lowest nearfield monthly mean DO concentration, 7.7 mg/L in October, was also above the Caution Level of 6.5 mg/L (Table 3-2). The lowest individual measurement was 7.6 mg/L in October. During the entire baseline period to date (1992-96), the lowest nearfield monthly mean was 6.6 mg/L in October 1994, and the lowest individual measurement was 6.3 mg/L, also in October 1994.

TABLE 3-2
Minimum DO Concentration and Percent Saturation: 1996 and Baseline Period

Location & Trigger Parameter	1996				Baseline (1992 – 1996)			
	Minimum Individual		Minimum Monthly		Minimum Individual		Minimum Monthly	
Nearfield Concentration	7.2 mg/L	Oct. 96	7.7 mg/L	Sept. 96	4.8 mg/L	Oct. 94	6.5 mg/L	Sept. 94
Stellwagen Concentration	7.6 mg/L	Oct. 96	7.7 mg/L	Oct. 96	6.3 mg/L	Oct. 94	6.6 mg/L	Oct. 94
Nearfield % Saturation	77.1%	Sept. 96	87.2%	Sept. 96	55.6%	Oct. 94	74.0%	Oct. 94
Stellwagen % Saturation	75.0%	Aug. 96	79.2%	Aug. 96	68.2%	Oct. 94	71.0%	Oct. 95

In 1996 the lowest nearfield monthly mean DO percent saturation, 87.2% saturation in September, was above the Caution Level of 80% saturation (Table 3-2). The lowest individual measurement was 77.1% saturation in September. During the entire baseline period to date (1992-96), the lowest nearfield monthly mean was 74.0% saturation in October 1994, and the lowest individual measurement was 55.6% saturation, also in October 1994.

In Stellwagen Basin in 1996, the lowest nearfield monthly mean DO, 79.2% saturation in August, was between the Caution (80%) and Warning (75%) Levels (Table 3-2). The lowest individual measurement was 75.0% saturation in August. During the entire baseline period to date (1992-96), the lowest nearfield monthly mean was 71.0% saturation in October 1995, and the lowest individual measurement was 68.2% saturation, also in October 1994.

There are several trigger parameters for algae, including seasonal and annual chlorophyll concentration, the presence of nuisance algae, and occurence of Paralytic Shellfish Poisoning.

In summary for 1996, both the nearfield and Stellwagen Basin monthly mean DO concentration values were above the Caution Level and monthly mean DO saturation levels were above the Warning Level. However, the Stellwagen Basin minimum monthly mean DO saturation was below the Caution Level. The nearfield region experienced a minimum monthly mean DO saturation of 87.2% in September, while Stellwagen Basin experienced a minimum monthly mean of 79.2% in August.

During the five year baseline period, the nearfield and Stellwagen monthly mean DO saturation Caution Levels have been violated four and five times respectively (Table 3-3). Two of the four nearfield, and three of the five Stellwagen low monthly means also violated the DO saturation Warning Levels. No DO concentration thresholds have been violated, although the nearfield Caution Level was equaled in both September and October, 1994. The frequency and degree of DO saturation threshold violations during the baseline period strongly suggest that the OMTF needs to re-evaluate the applicability of the current DO threshold levels.

TABLE 3-3

DO Saturation Threshold Violations

Date	Nearfield		Stellwagen	
	Concentration	Saturation	Concentration	Saturation
Oct. 92	7.6 mg/L	79.5%	7.6 mg/L	76.7%
Sep. 94	6.5 mg/L	75.9%		
Oct. 94	6.6 mg/L	74.0%	6.6mg/L	72.6%
Nov. 94	7.0 mg/L	79.4%		
Aug. 95			7.5 mg/L	73.9%
Sep. 95	6.9 mg/L	74.8%		
Oct. 95			6.7 mg/L	71.0%
Aug. 96			8.1 mg/L	79.2%

Dissolved Oxygen Depletion Rate

The DO depletion rate thresholds are based on the calculated average rate from the baseline period. The rates over the four years of baseline to date vary from a low of -0.024 mg/L/day in 1992 to a high of -0.031 mg/L/day in 1994. Both 1994 and 1995, which experienced low DO concentrations and saturation levels, had higher rates of DO decline than 1992, 1993 and 1996. Based on the data collected to date, the interim threshold for the average baseline DO depletion rate is -0.026 mg/L/day (Table 3-1). As additional baseline data are collected, this value will be updated. Based on this average value, the DO depletion rate thresholds would be -0.040 mg/L/day for the Caution Level and -0.053 mg/L/day for the Warning Level. The 1996 DO depletion rate was -0.025 mg/L/day, which is below the Caution and Warning Levels.

TABLE 3-4

Plankton Thresholds Comparison

Location	Trigger Paramater	Season	Caution Level	Warning Level	1996 Results
Nearfield	Annual Mean Chlorophyll Concentration	Year	2.80 µg/L	3.74 µg/L	1.54 µg/L
Nearfield	Seasonal Mean Chlorophyll Concentration	Spring	2.71 µg/L	none	2.43 µg/L
		Summer	2.27 µg/L	none	0.78 µg/L
		Fall	4.44 µg/L	none	1.47 µg/L
Nearfield	Seasonal Density of *Alexandrium tamarense*	Spring	2.34 cells/L	none	0 cells/L
		Summer	26.1 cells/L	none	0 cells/L
		Fall	7.57 cells/L	none	0 cells/L
Nearfield	Seasonal Density of *Nitzschia pungens*	Spring	1,050 cells/L	none	1,000 cells/L
		Summer	17,600 cells/L	none	5,000 cells/L
		Fall	15,600 cells/L	none	1,000 cells/L
Nearfield	Seasonal Density of *Phaeocystis pouchetii*	Spring	2.46 x 10^6 cells/L	none	5,000 cells/L
		Summer	0	none	0 cells/L
		Fall	48,700 cells/L	none	0 cells/L

Chlorophyll and Nuisance Algae

Adding effluent to the marine environment could change the amount of nutrients or the relative levels of different nutrients so that excessive or prolonged algal bloom could occur. As discussed earlier, the settling and decomposition of algal biomass in the bottom water can lead to low DO conditions. Algal biomass is most commonly measured as chlorophyll, a photosynthetic chemical in all green plants. Chlorophyll a is the type of chlorophyll measured in the EPA approved standard test for chlorophyll and adopted by MWRA, and is the form implied when the "a" is omitted.

As there are no state or federal regulations for chlorophyll, the Warning Level was developed based on expert peer review comments to the OMTF. The commentators agreed with the rule of a thumb that appeared in 1993 in the National Oceanographic and Atmospheric Administration's Estuarine Eutrophication Survey: "normal blooms become problematic when chlorophyll values reach 20 ug/L." The commentators wanted a greater level of protection for Massachusetts Bay, however, because present levels are so much lower (2-3 ug/L) and deleterious changes would be apparent long before chlorophyll reached the NOAA level of 20 ug/L. Therefore the Warning Level was set at twice the baseline value of the annual mean nearfield chlorophyll concentration, or well before there is a likelihood of biologically significant change.

In addition to the trigger parameter above which focuses on the annual average, another was established which recognizes the inherent seasonality of chlorophyll over the year and is designed to protect against unusually high algal biomass in any one season. By allowing for seasonality the new trigger parameter would be more sensitive to meaningful change. The statistic chosen to reflect the meaning of "unusual" in this case was chosen to be the 95th percentile. A measurement would be deemed to be unusually high if it were to exceed 95 percent of the baseline values. There is a 5 percent chance of a false alarm with this approach but it is appropriate nevertheless to notify the OMTF immediately of such an occurrence.

The interim chlorophyll thresholds (shown on Table 3-4) were developed from the existing five years of baseline monitoring data. The chlorophyll concentrations for 1996 were below the existing threshold values.

Nuisance and noxious algae naturally occur in Massachusetts and Cape Cod Bays in small numbers annually. There is public concern that effluent nutrients could stimulate a red tide or similar noxious algae bloom in the vicinity of the new outfall. At the 1996 peer review workshop, it was recommended that the Massachusetts shellfish toxicity monitoring program be used to set red tide Caution Levels. The state program monitors the toxicity of Paralytic Shellfish Poisoning (PSP) at shellfish beds along the edge of Massachusetts and Cape Cod Bays. A list of Department of Marine Fisheries (DMF) shellfish monitoring stations is provided in Table 3-5.

TABLE 3-5
Shellfish Monitoring Stations for PSP

Primary Stations	Secondary Stations
Gloucester-Annisquam Yacht Club	Rockport-Granite Street
Hull-Pt. Allerton (not sampled each week)	Cohasset-Border Street
Cohasset-Little Harbor	Scituate/Marshfield-South River Humarock
Scituate-Scituate Harbor	Marshfield-Green Harbor
Marshfield-Damon's Point	Duxbury-Eaglenest Creek
Plymouth-Manomet Point	Plymouth-Plymouth Harbor
Sandwich-Cape Cod Canal (east entrance)	Plymouth-Ellisville Harbor
Dennis-Sesuit Harbor	Sandwich-Sandwich Harbor
	Barnstable-Marispan Creek
	Provincetown-The Dike

To date, no shellfish toxicity has been observed at the monitoring stations in Dennis, Barnstable, or Provincetown. Prior to the large *Alexandrium* bloom which occurred in 1993, toxicity had not been observed beyond the Cape Cod Canal. However, toxicity was observed for the first time in Sandwich as a result of the 1993 bloom. Such an occurrence will be viewed as a trigger parameter for contingency planning in order to fully evaluate its origin.

The nuisance algae thresholds are being developed from the baseline conditions. The Caution Levels will be set as the 95th percentile of seasonal mean concentrations of the three target species of nuisance algae (Table 3-4). In 1996, only *Alexandrium tamarense* was undetected in the monitoring samples. Other studies in Massachusetts Bay confirmed that 1996 was uneventful for *Alexandrium* throughout Massachusetts Bay and much of the New England coastal waters. All nuisance algae were below threshold values in 1996.

Zooplankton

Zooplankton assemblages vary with location in Massachusetts Bay. The species composition of inshore communities is dominated by *Acartia, Eurytemora,* and *Centropages hamatus,* while the species composition of offshore communities is dominated by *Calanus, Pseudocalanus, Centropages typicus,* and *Oithona.* The nearfield region represents a transition between the two communities.

The zooplankton species in inshore communities are known to require the high concentrations of nutrients and algae that are found in Boston Harbor for maximal growth and reproduction. Once the new outfall is online, the nutrient concentrations in both the Boston Harbor and the nearfield region may change. The zooplankton community in Boston Harbor may change to resemble that presently in Massachusetts Bay. The Caution Level seeks to protect the zooplankton community in the nearfield of Massachusetts Bay from changing to one similar to an inshore community.

Dilution

Since all evaluations of toxic impacts depend on concentrations after initial mixing, the MWRA will measure the actual dilution of effluent by seawater around the new outfall to test predictions of effluent dilution. Testing will focus on measurements of tracers to determine dilution in the immediate discharge mixing zone of the diffuser. The results will be compared with predictions of contaminant concentrations. Because EPA dilution estimates are very conservative, it is extremely unlikely that actual dilution will be less than the EPA predicted dilution. However, if the study showed that real dilutions were less than anticipated and did not reduce toxic contaminant concentrations enough to protect the environment, the EPA and the state could revise MWRA's NPDES permit by lowering the allowable discharge concentrations. Thus, effluent dilution tests provide a Caution Level which would lead to revision of Caution and Warning Levels for toxic contaminants if it were exceeded. As the new outfall is not on-line, no data is available to evaluate this trigger parameter.

3.4 Monitoring Results

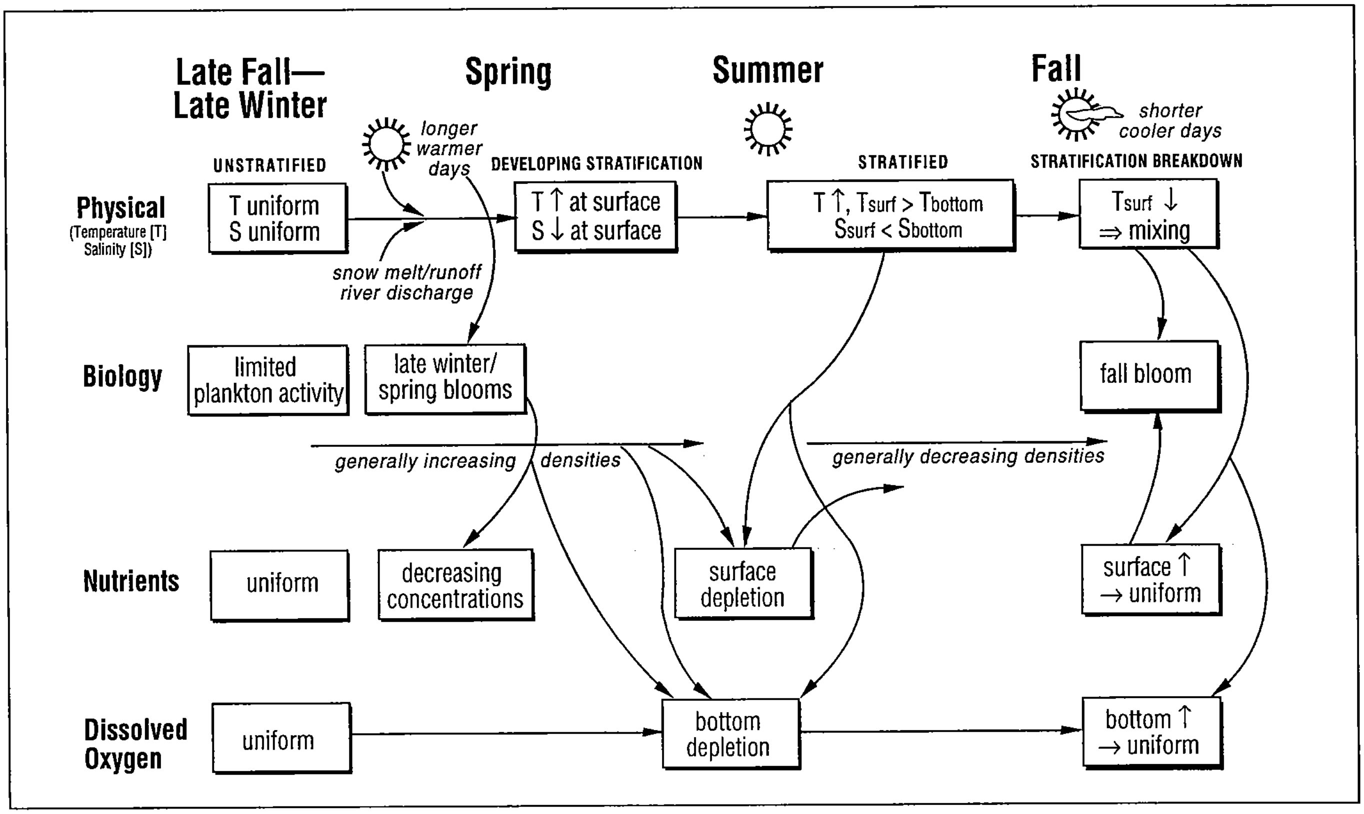
The behavior of the Massachusetts Bay system is primarily controlled by the annual weather patterns and cycle, although the individual system components (physical, chemical, and biological) are also largely influenced by complex system interactions (Figure 3-3).

The monitoring program measures the annual behavior of the Bay system and provides data sufficient to quantify the annual variability of each parameter. In 1996 the behavior of the Bay system was similar to that observed in previous years. The following sections present the components of the annual Bay cycle as they were measured in 1996.

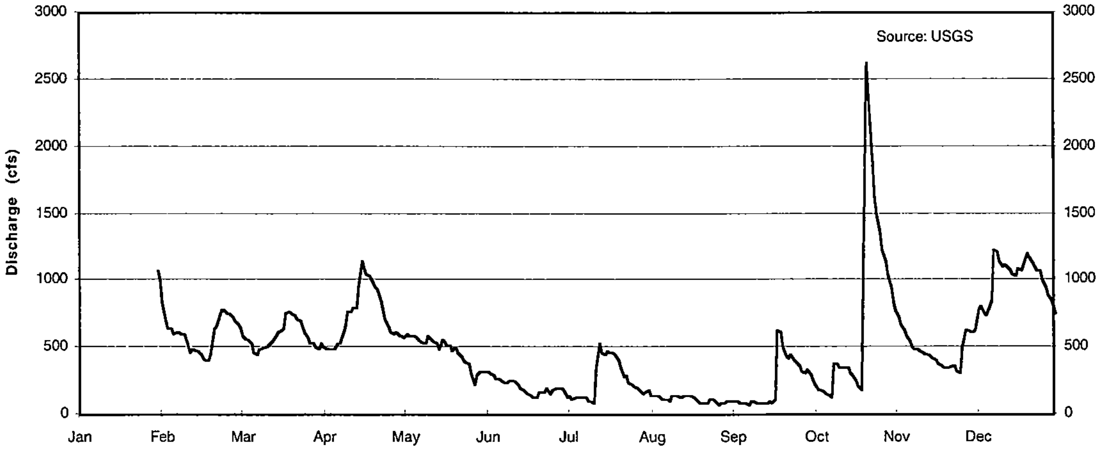
Physical Characterization of the Water Column

The annual cycle of the Massachusetts Bay system begins in late winter when the Bay is unstratified. Water temperature and salinity are vertically uniform throughout the water column. As the snow melts in the spring, the runoff increases freshwater input to the Bay

Figure 3-3
Annual Water Column Cycle of Massachusetts Bay



(a) Charles River Discharge



(b) Merrimack River Discharge

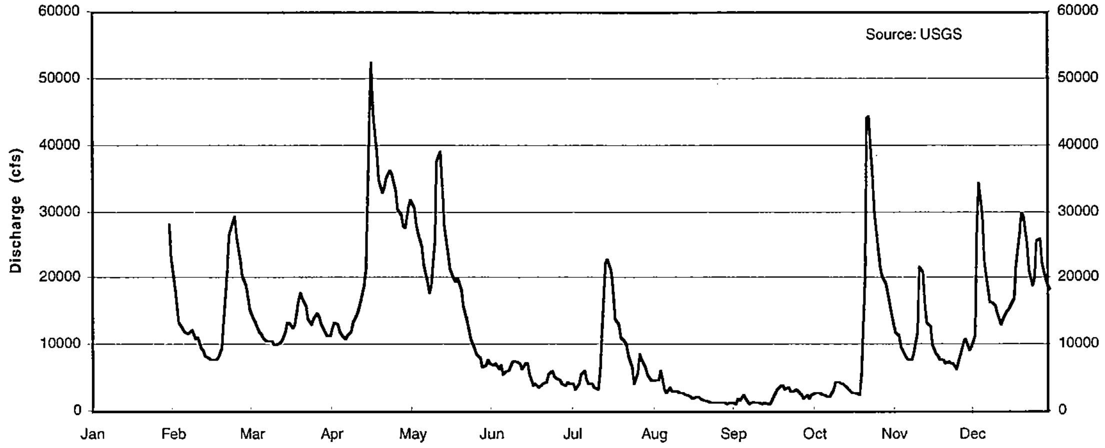


Figure 3-4
1996 Daily Precipitation and River Discharge Data. Merrimack and Charles Rivers.

from the Merrimack, Charles and other rivers (Figure 3-4). This fresh water runoff enters the Bay at the surface, and because it is less dense than the salty water in the Bay, it stays on the surface. As a result, a vertical salinity gradient develops (Figure 3-5). Simultaneously, as the days get longer, the sun heats the surface water and a vertical temperature gradient begins to develop (Figure 3-6). By the end of the spring (late May) the water column is stratified (Figure 3-7), with fresher, warmer water in a surface layer and saltier, colder, denser water in a bottom layer. During the summer, the water column becomes more stratified due to continued solar heating at the surface.

Storms and upwelling events can temporarily break down stratification and mix the water column. No large scale upwelling events occurred during 1996; however, one nearshore mixing event occurred in August. Upwelling is characterized by a drop in surface water temperature as substantially cooler bottom waters are brought to the surface.

In the fall, the water column completely re-mixes in a process known as overturn. Overturn occurs because as the days get shorter and cooler, the surface water cools. When the density of the surface water becomes greater than that of deeper waters, it sinks. This process generally takes place in October, after which time the water column gradually and uniformly cools throughout the winter. The overturn process during this time of year is enhanced by increased mixing energy from storms which erode the stratification. In 1996,

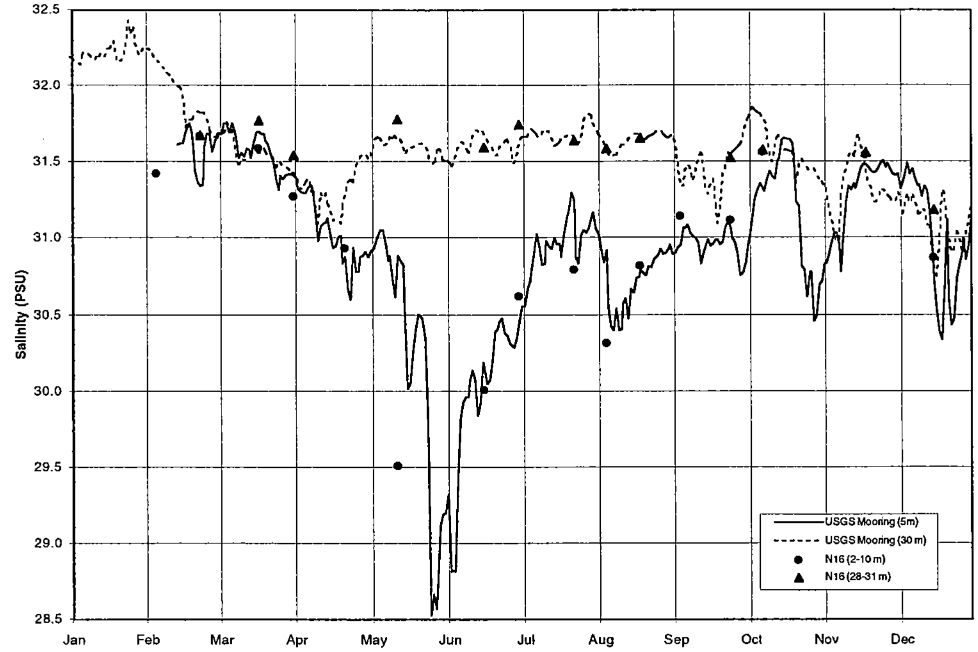


Figure 3-5
1996 Moored Salinity Sensor Data

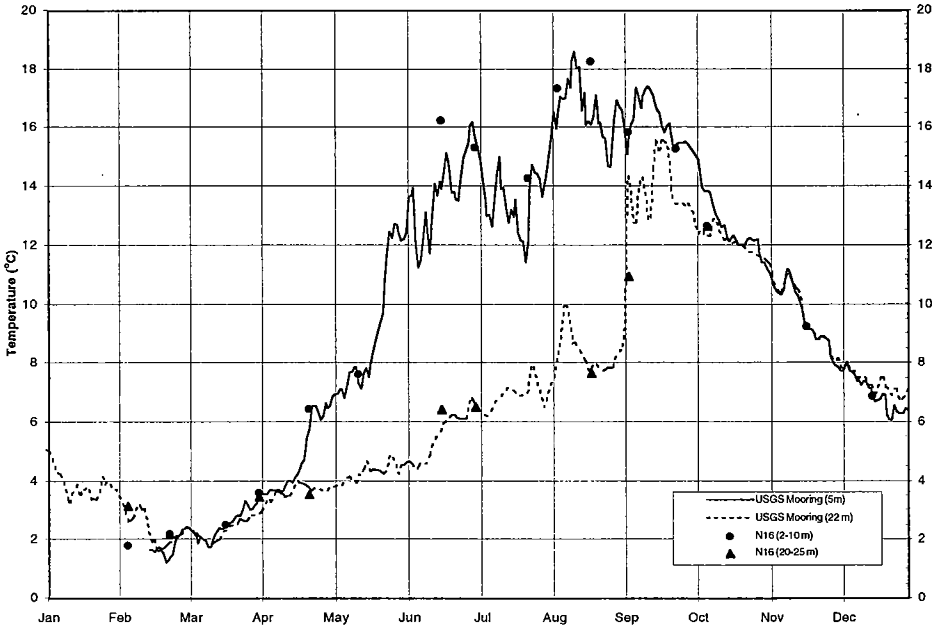
the fall overturn began in early September (Figure 3-6) with mixing caused by the passing of Hurricane Eduoard. Subsequently, a strong northeaster during mid-September produced a second mixing event where surface and bottom temperatures almost converged. Complete turnover occurred by mid-October (Figures 3-6 and 3-7).

Plankton and Chlorophyll

Typically there are two major plankton blooms each year. The increasing sunlight and water temperatures in spring trigger the first phytoplankton bloom, and turnover with its inherent mixing drives another phytoplankton bloom in the fall. An increase in the zooplankton population follows each phytoplankton bloom, as phytoplankton are the main food source for zooplankton. Grazing of phytoplankton by zooplankton controls the size and duration of phytoplankton blooms and can often end them.

In 1996, the largest spring bloom (as measured by average nearfield chlorophyll concentrations) during the MWRA baseline record (1992-1996) occurred (Figure 3-8). The 1996 bloom was 40 percent larger than any previous baseline year. In contrast, the 1996 fall bloom was the smallest during the baseline period, and summertime blooms ranked fourth in intensity among the five baseline years. Conditions were apparently favorable for a large and prolonged spring bloom, yet the sequence of events around the time of the fall turnover resulted in an uneventful fall bloom. The species composition of these bloom events (centric diatoms in spring, pennate diatoms in fall) was similar to that of other years.

FIGURE 3-6
1996 Moored Temperature Sensor Data



There was no evidence in 1996 of any significant occurrence of the three toxic or nuisance plankton species monitored by the MWRA monitoring program. There were also no occurrences of shellfish toxicity reported by the Massachusetts DMF in 1996. The zooplankton community measured in the nearfield in 1996 was similar to that of previous years, consisting of a transitional community between nearshore and offshore species.

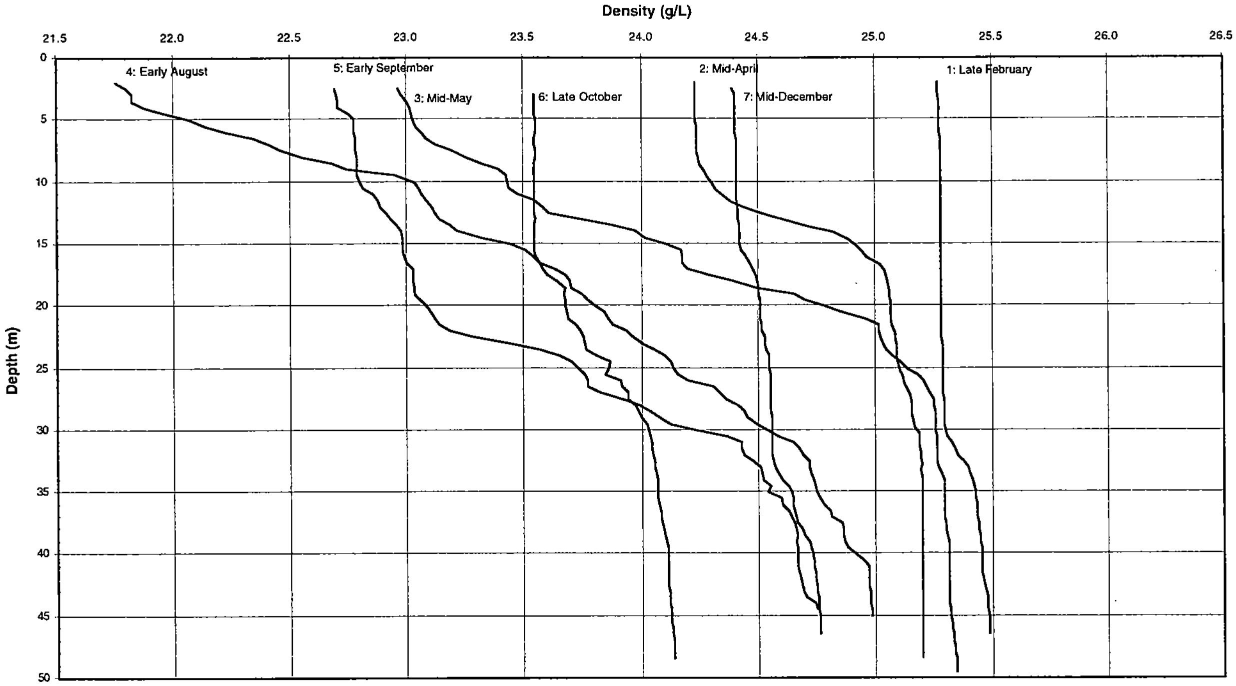


FIGURE 3-7
1996 Seasonal Density Cycle in the Nearfield

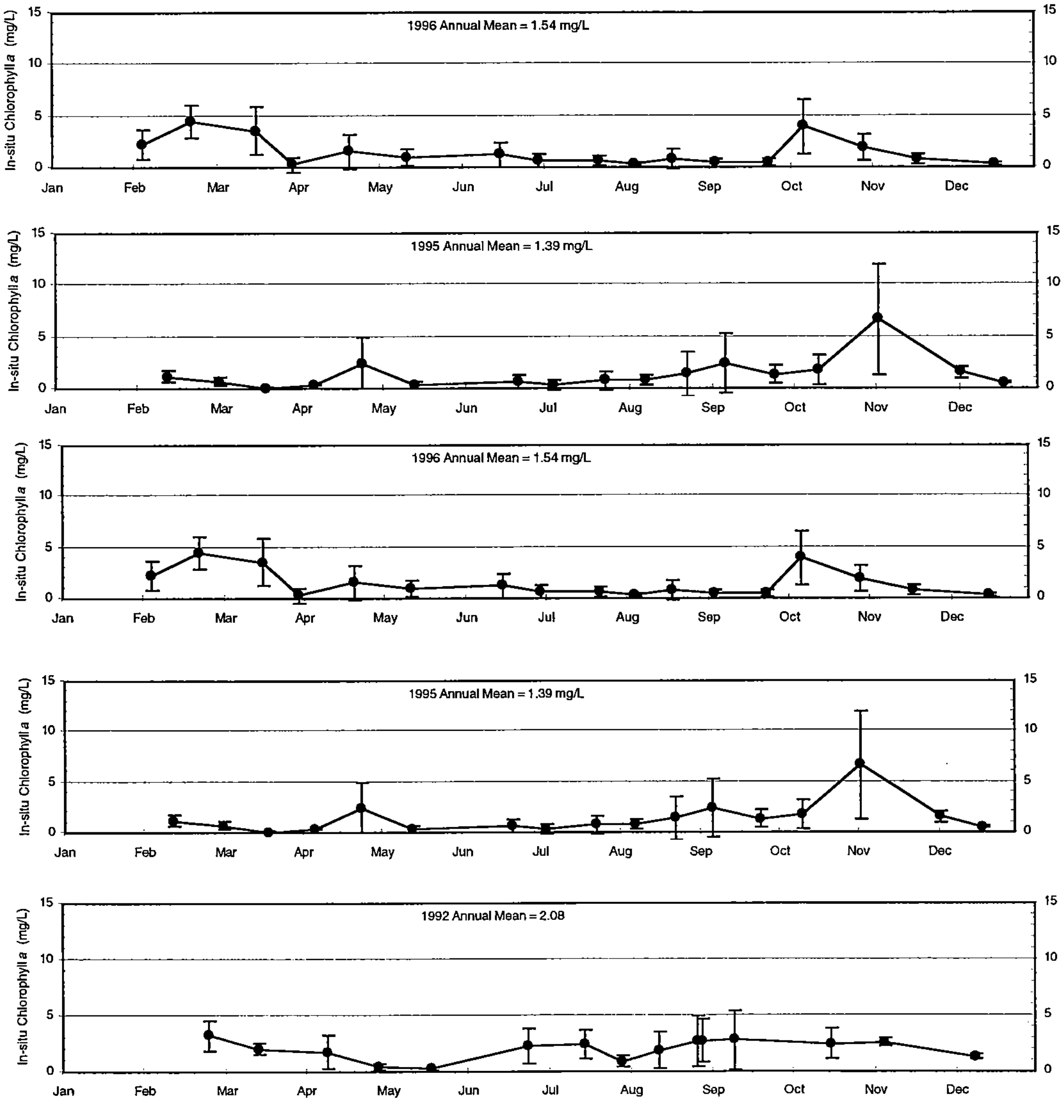


FIGURE 3-8
1992-1996 Chlorophyll a Averages in the Nearfield
(Error bars represent +/– one standard deviation.)

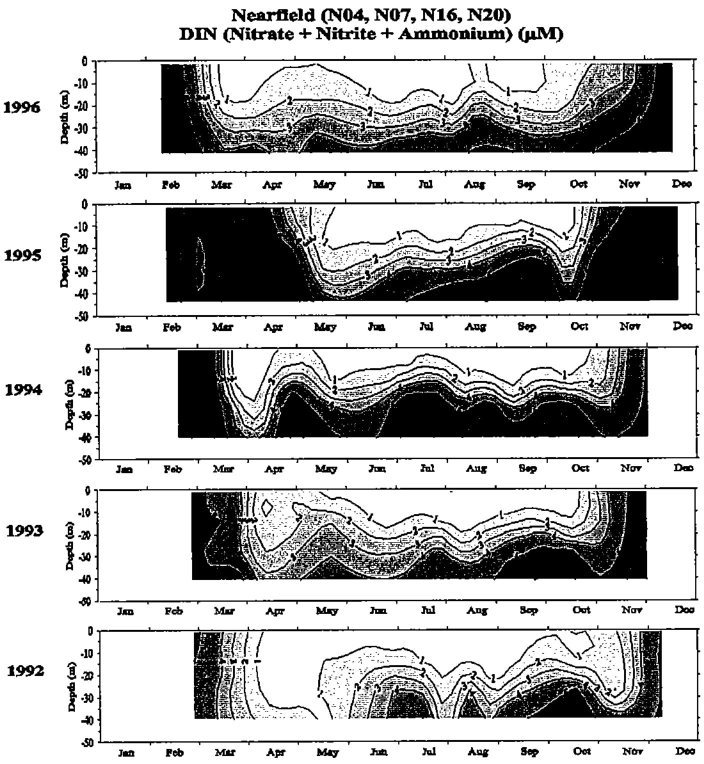
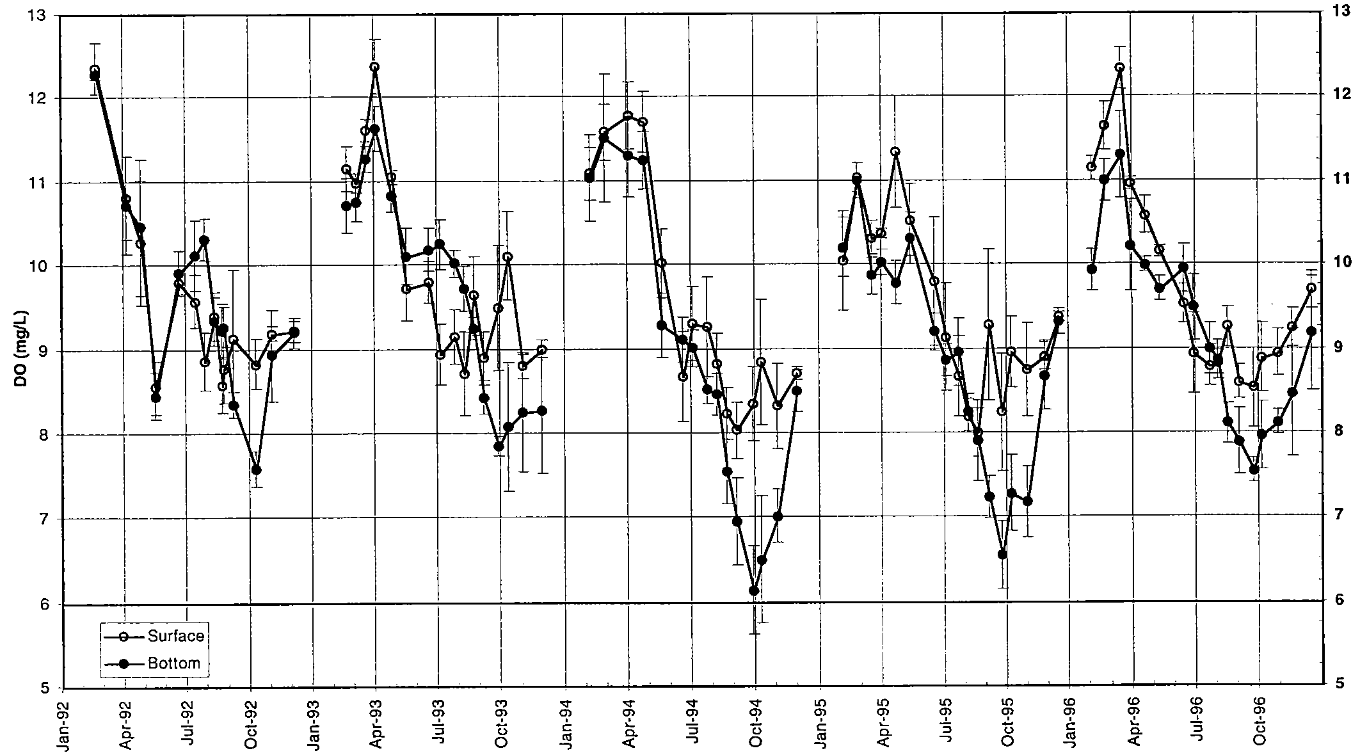


FIGURE 3-9
Nearfield DIN Concentrations for 1992-1996

Nutrient Cycle

The nutrient cycle in Massachusetts Bay is closely linked to the physical and biological changes that take place through the year. Nutrients, like the physical parameters, become vertically mixed during the winter, and begin the year at their highest levels (Figure 3-9). The spring plankton bloom partially depletes nutrients throughout the water column, as phytoplankton growth consumes nutrients. As spring and summer progress, continued plankton growth and stratification cause nutrient depletion in the surface layer. Lack of algal growth prevents nutrient depletion in the bottom layer. In fact, plankton death and subsequent settling to and decomposition in the bottom layer cause nutrient concentrations to increase somewhat in the bottom waters. Stratification prevents the nutrients in the bottom layer from vertically mixing into the surface layer. Overturn releases the nutrients trapped in the bottom waters to mix throughout the water column (Figure 3-9).

FIGURE 3-10
1992-1996 Dissolved Oxygen Cycle in Surface and Bottom Waters in the Nearfield
(Error bars represent +/– one standard deviation.)



Upwelling events during the summer can release some of the nutrients trapped in the bottom layer into the surface layer. Nutrient releases into the surface layer can result in increased phytoplankton growth. In 1996, the mid-August upwelling event described earlier, resulted in a localized increase in phytoplankton density (as measured by chlorophyll a) in the inner nearfield region. This increase is not seen in Figure 3-8 because values in that figure represent an average over all 17 nearfield stations.

Dissolved Oxygen

As with nutrients, dissolved oxygen (DO) is closely linked to the physical and biological changes in the Bay. Water column DO concentrations are the highest during the winter and early spring (Figures 3-10 and 3-11) and are well mixed throughout the water column. The highest DO concentration measured in bottom waters (12 ppm) in 1996 occurred in mid-March in the nearfield and early-April in the Harbor.

Once the water column is stratified, the bottom waters are effectively cut off from the atmosphere (the source of DO). However, consumption of DO via respiration continues. As a result, bottom water DO concentrations decline continuously throughout the stratified period. In addition, the saturation level of oxygen varies with temperature. Cooler water can hold more DO than can warmer water. Therefore, DO concentrations will decrease naturally as the water column warms during the spring and summer. The fall water column overturn ends the isolation of the bottom layer and results in increased DO concentrations in the bottom waters.

Minimum DO concentrations in the bottom layer are reached just before overturn, and in 1996 equaled 5.5 mg/L in Cape Cod Bay, 7.2 in the nearfield region and 7.6 mg/L in Stellwagen Basin (Figure 3-11). The survey-average minimum DO concentrations in the nearfield were higher in 1996 than in either 1994 or 1995, although the 1996 concentrations were still significantly lower than in 1992 and 1993. The lower minimum concentrations in 1994 and 1995 were caused by lower pre-stratification DO concentrations in late spring, faster rates of DO decline during stratification (Figure 3-12) and the length of the stratification period. The faster rates of DO decline in 1994 and 1995 were driven by warmer bottom water temperatures. In 1996, DO concentrations in early spring were higher, bottom temperatures in summer were generally lower, and stratification breakdown began earlier, all resulting in higher minimum DO concentrations.

Productivity and Respiration

Productivity measurements during 1996 showed that peak production in the more offshore areas of the nearfield occurred during the late winter bloom in February. Smaller peaks occurred in early July when a bloom developed offshore, and in late September with the overturn of nutrients. The more inshore areas of the nearfield and Boston Harbor experienced peak production in early summer (June), with smaller peaks in the late spring and August. Surface respiration was highest during the late spring and early summer as the winter/spring bloom decayed. Bottom water respiration was highest during the late summer and early fall.

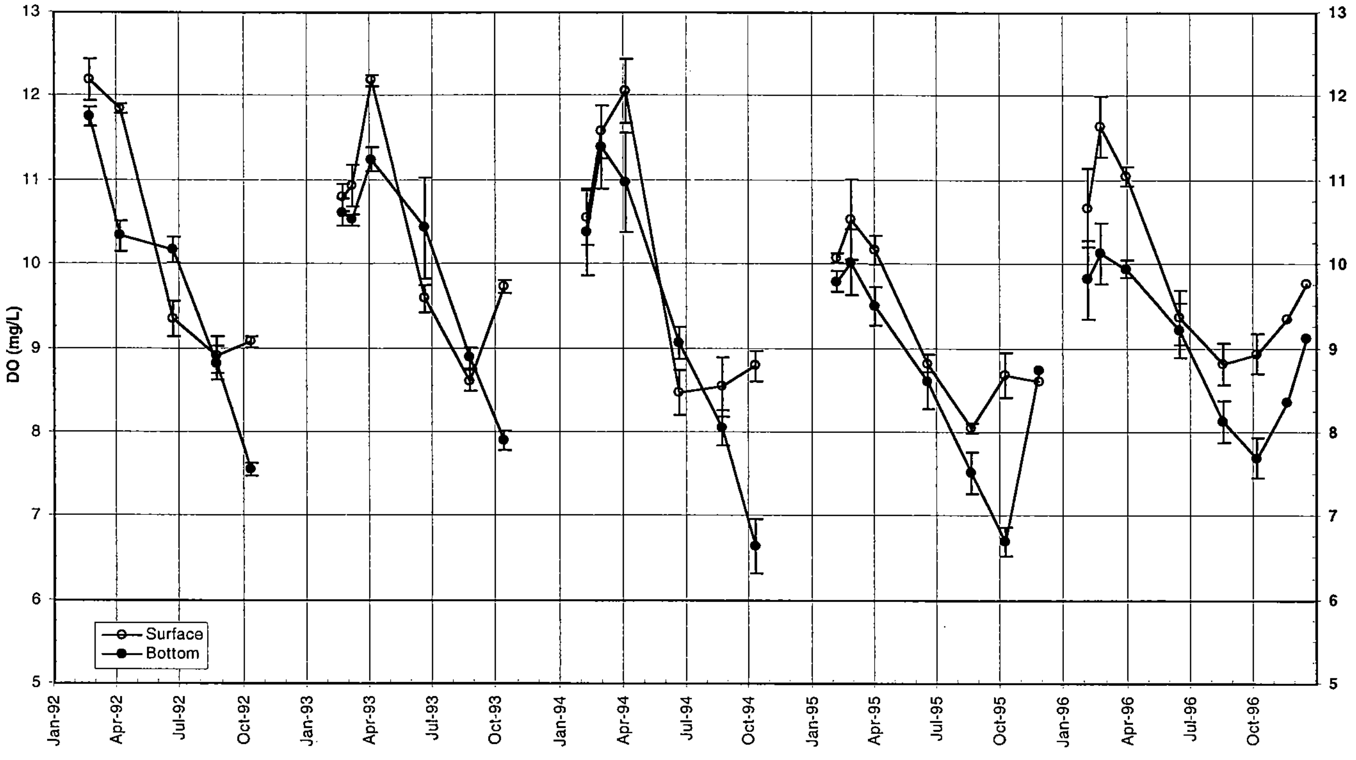
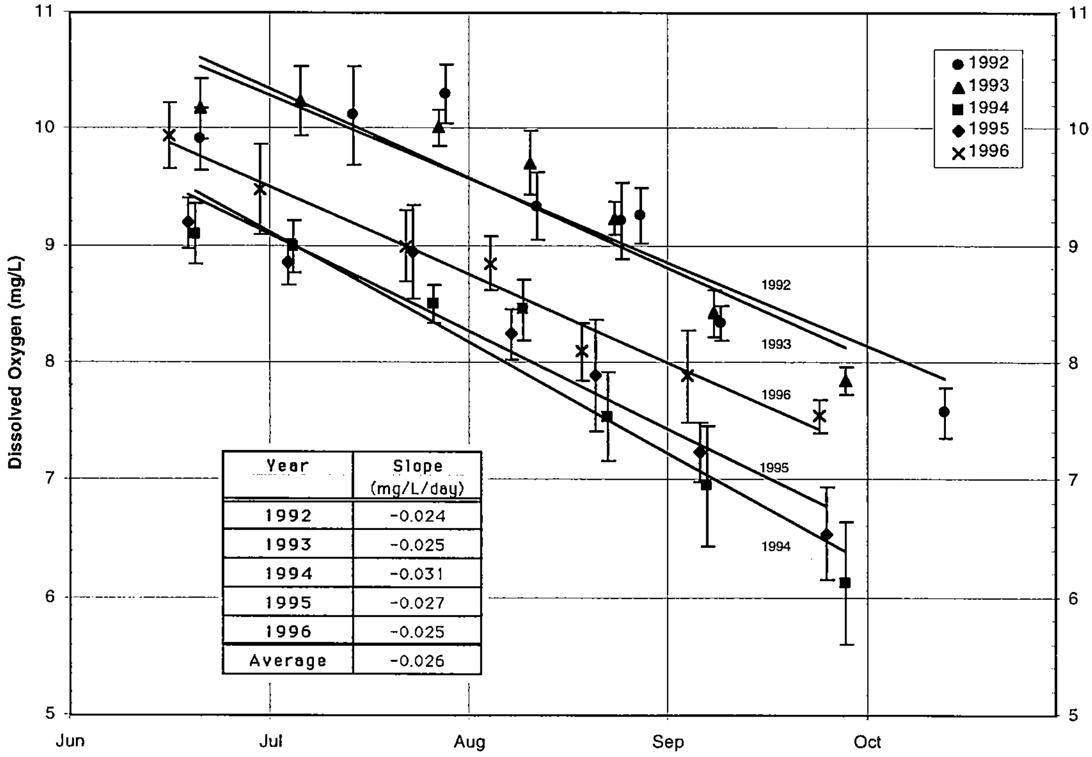


FIGURE 3-11
1992-1996 Dissolved Oxygen Cycle in Surface and Bottom Waters in Stellwagen Basin
(Error bars represent +/– one standard deviation.)



Year	Slope (mg/L/day)
1992	-0.024
1993	-0.025
1994	-0.031
1995	-0.027
1996	-0.025
Average	-0.026

FIGURE 3-12
Rate of Decline of Dissolved Oxygen Concentrations in Bottom Waters in the Nearfield.
(Error bars represent +/– one standard deviation.)

Marine Mammal/Sea Turtle Observations

A number of whales, harbor porpoises, and harbor seals were sighted during the nearfield surveys. A right whale was observed during the early April survey. An unidentified whale was observed during the mid-June survey. During the early August survey, a fin whale and three minke whales were sighted. A total of 16 harbor porpoises were observed during surveys in February, April, and November, with the majority of observations during the early April survey. A total of seven harbor seals were sighted during surveys in February, April, and September. No sea turtles were sighted during the surveys.

4.0 Benthic Studies

4.1 Benthic Issues

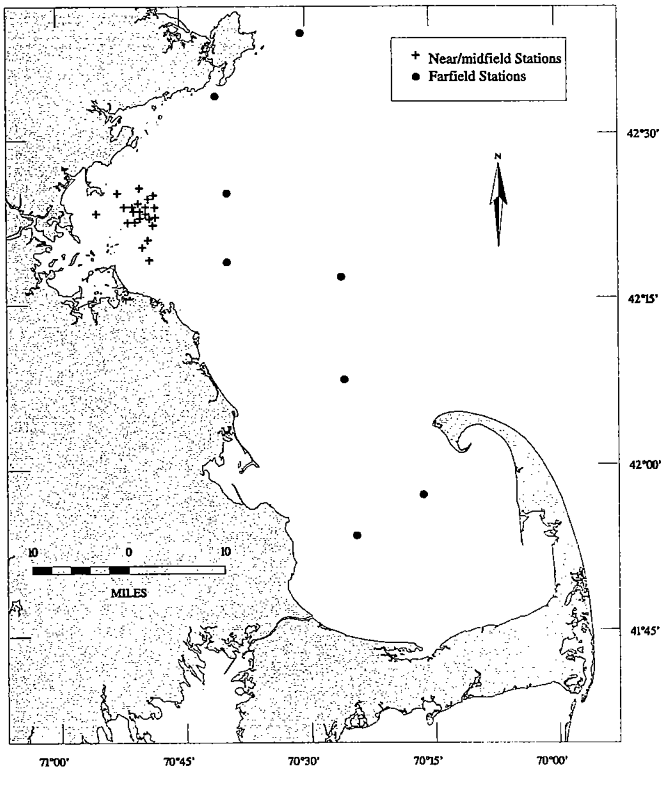
One of the concerns about relocating the sewage outfall to a relatively unpolluted area of Massachusetts Bay is that the discharge might result in unexpected impacts to the bottom-dwelling organisms in the vicinity of the outfall. In a healthy environment, both the infauna (organisms living in the bottom sediments) and epifauna (organisms living on the sediment surface or attached to large rocks or surface features) will be diverse and indicative of clean environmental conditions. In addition to studying the biological composition of the communities in the vicinity of the new outfall, several additional parameters which might also influence the distribution of species are also measured either annually or at longer intervals. Such parameters include sediment grain size composition, amounts of total organic carbon and toxic contaminants present in the sediments, and depth of oxygen penetration.

Benthic issues include potential hypoxia effects of nutrients and organic matter, accumulation of toxics, and smothering caused by solids deposition.

4.1.1 Community Structure

In general, a healthy benthic community comprises many different species with a balanced distribution of individuals among species. Several statistical measures can be used to determine the diversity of these communities. Healthy, well-established communities will have high diversity values. Communities in areas that have been adversely impacted and are environmentally degraded will have low diversities and will be dominated by one or a few pollution-tolerant species.

FIGURE 4-1
Soft-Bottom Benthic Stations in the Bays



4.1.2 Sediment Grain Size Composition

Studies of animal-sediment relationships have shown that many benthic species have definite associations with particular sediment types. For example, some polychaete worms are found only in areas of very coarse-grained sediments, while other species are associated with muddy (fine-grained) sediments. Information on the pre-discharge pattern of sediment types in the Bays and the natural faunal changes associated with storm-induced or other natural shifts in sediment composition is necessary to help distinguish potential impacts of the outfall discharge from natural cycles of a healthy environment.

4.1.3 Nutrients/Oxygen

The concern regarding the potential impact of nutrients is that eutrophication (as discussed in the Water Column Monitoring section) might lead to low levels of oxygen (hypoxia) in bottom waters overlying the seafloor and, consequently, decreased oxygen within the sediments. A healthy benthic community depends on well-oxygenated overlying water to deliver the oxygen necessary for benthic respiration and metabolism. Generally, the healthier and better established the community, with larger and more active animals present, the deeper the penetration of oxygen into the sediment. Therefore, the depth of oxygen penetration in soft sediments is monitored by the MWRA as a measure of environmental health with respect to sediment oxygen supply and demand.

4.1.4 Toxic Contaminants

Metals or other toxic substances in the wastewater discharge could potentially accumulate in the sediments near the outfall. Metals may precipitate directly out of the water column, whereas other toxic substances may attach directly to solids which then settle to the bottom. In areas where sediment depositional rates are high, these contaminants could concentrate and adversely impact the health of the bottom communities. Therefore, toxic contaminant concentrations in sediments are monitored periodically by the MWRA to assess the validity of the prediction that discharge of wastewater from the outfall will not lead to toxic contamination of the sea floor.

4.1.5 Solids and Organic Material

Suspended solids are tiny particles (mud, organic debris) that are present in the water column and in the effluent discharged at the outfall. A potential impact of solid particles on the habitat is smothering of the benthic organisms. Smothering would occur if the rate of particulate deposition became so great that the organisms could not maintain contact with oxygenated water at the sediment/water interface. The problem would be even greater if the settling solids consisted of organic material that consumes oxygen. Sediment grain size composition and total organic carbon content of the sediments are measured as part of the soft-bottom benthic program.

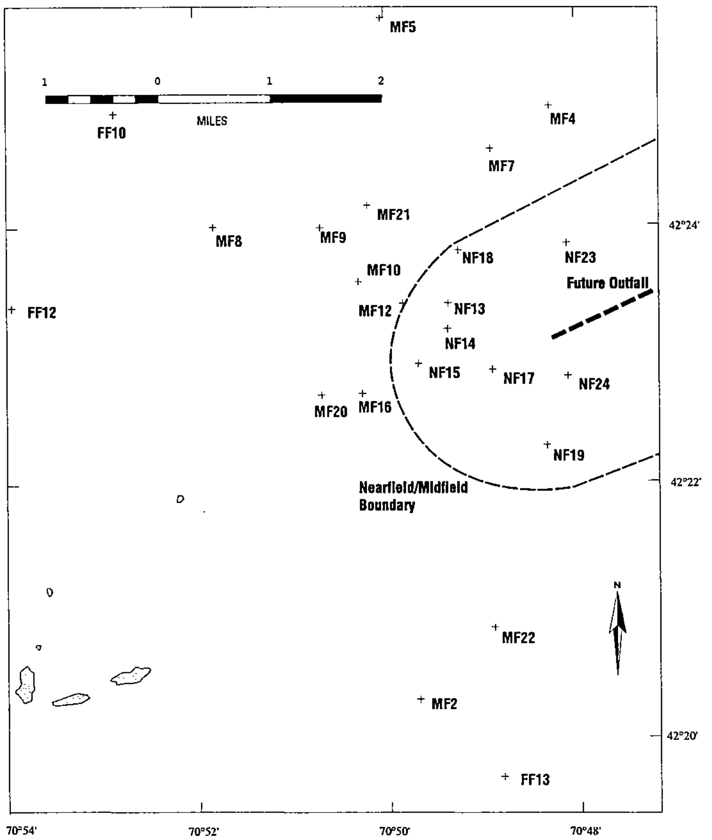


FIGURE 4-2
Nearfield and Midfield Soft Bottom Stations

The benthic program includes soft-bottom surveys, a hard-bottom survey, and nutrient flux surveys.

4.2 Monitoring Program Design

The benthic monitoring program is designed to provide qualitative and quantitative descriptions of the benthic environments of Boston Harbor and Massachusetts and Cape Cod Bays. The goals of the benthic program are twofold. The first objective is to document the recovery of benthic conditions in Boston Harbor following the cessation of sludge discharge and improvements in Combined Sewer Overflow (CSO) treatment and discharge. Comparison of benthic parameters measured before and after termination of sludge disposal into the Harbor has provided valuable information on bottom sediment response and benthic ecosystem recovery. Further improvements in sediment quality in Boston Harbor should be seen after the transfer of sewage discharge from the existing Deer Island outfall to the new Massachusetts Bay outfall in 1998.

The second objective of the benthic program is to collect background data on 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 the discharged effluent on the surrounding benthic ecosystem.

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

4.2.1 Soft-Bottom Benthic Surveys

The soft-bottom benthic surveys are designed to assess sediment quality and the status of the infaunal benthic communities. Sediment grab samples taken at each station are processed to determine the number of species and individuals present in each sample. Replicate samples are taken at selected stations. Previously, sediment samples were analyzed for toxic contaminants and sediment profile images were taken at selected locations to determine the apparent redox potential discontinuity (RPD) depth and other sediment properties. Toxic contaminant analyses and sediment profile image studies were not performed in 1996. Having collected baseline data in several previous years, OMTF allowed MWRA to suspend these portions of the monitoring program in 1996. Sediment profile image studies will be performed again in 1997 and sediment toxic contaminant analysis will resume in 1998.

The soft-bottom sampling regions are Massachusetts and Cape Cod Bays and Boston Harbor. Sampling stations in Massachusetts and Cape Cod Bays are shown on Figure 4-1; stations in the vicinity of the new outfall are shown on Figure 4-2. The soft-bottom surveys around the new outfall location in Massachusetts Bay are designed to provide baseline data on the sedimentary environment, including concentrations of contaminants and benthic infaunal communities. These data will be used as a benchmark to evaluate the effects of sewage disposal from the outfall when it becomes operational in 1998.

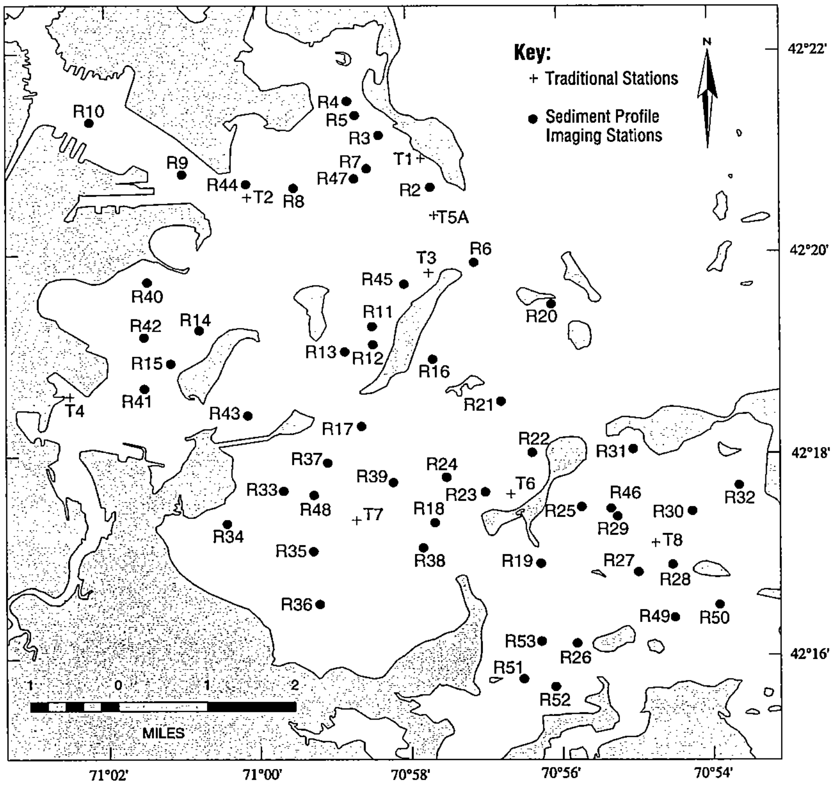


FIGURE 4-3
Boston Harbor Benthic Sampling Stations

The benthic monitoring program uses a different definition of nearfield from that used by the water column monitoring program. For the water quality program, the nearfield is a rectangle with sides five kilometers (three miles) from the outfall and farfield stations are those outside the rectangle. The benthic program originally followed a similar convention, but greater sophistication of spatial analyses has allowed discrimination among three subareas of the study area: the nearfield is 0-2 kilometers, the midfield is 2-7 kilometers, and the farfield is greater than seven kilometers from the new outfall. The nearfield coincides with the area that is most likely to be impacted according to the SEIS. The midfield and farfield are farther from the outfall and should not show impacts. Three stations originally designated as farfield stations are now considered to lie within the midfield area. The original designations for these stations (FF10, FF12, FF13) have been retained because there already are midfield stations MF10, MF12, and MF13. The reassignment of these three farfield stations was implemented in the 1996 program.

Farfield soft-bottom sediments are also sampled once per year at eight locations throughout Massachusetts and Cape Cod Bays (Figure 4-1). The farfield stations are used as a reference for the nearfield and midfield stations and as true monitoring stations in the unlikely event that the effects of the sewage discharge extend farther than expected.

The sampling design for the soft-bottom benthic program provides at least the minimum number of samples (12) necessary to detect change in each area (Coats, 1995). There are eight stations (two with triplicate samples = 12 samples) in the nearfield, 15 stations (four with triplicate samples = 23 samples) in the midfield, and eight stations (all with triplicate samples = 24 samples) in the farfield.

The soft-bottom surveys in Boston Harbor are designed to measure the long-term recovery of benthic communities and sedimentary conditions as sewage discharge has been phased out of this area. These surveys are performed twice each year. Replicate grab samples are collected at eight stations (Figure 4-3) during each survey. Sediment profile images are taken during the summer survey at the same eight stations, as well as an additional 52 stations.

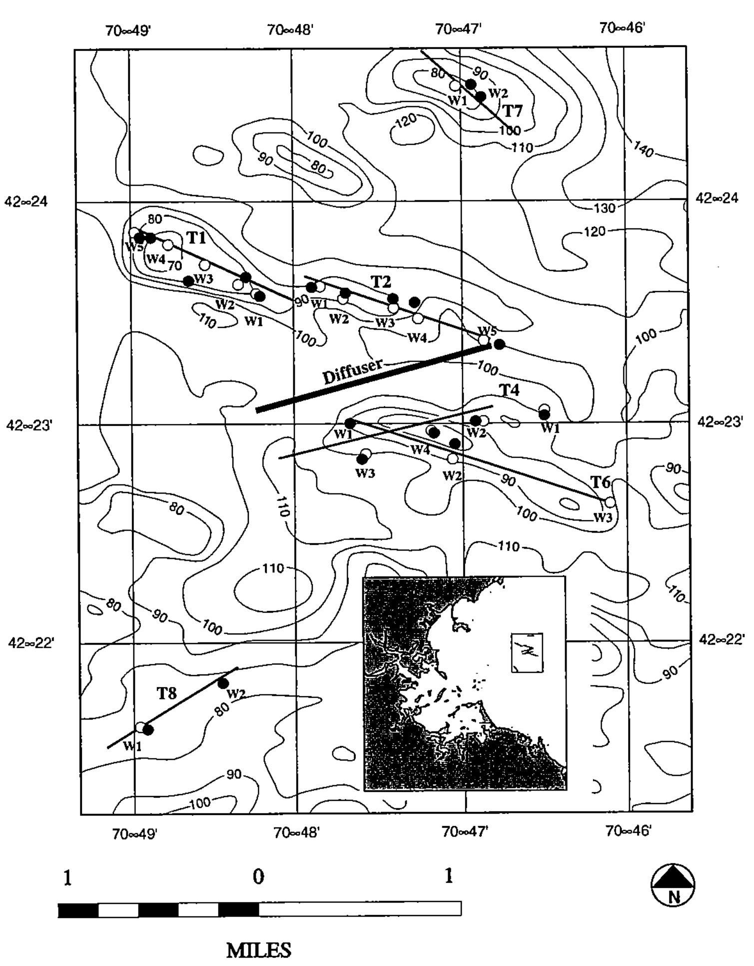


FIGURE 4-4
Transect locations for nearfield hard-bottom video survey. Open circles are 1995 stations; filled circles are 1996 stations.

4.2.2 Hard-Bottom Surveys

A video survey of the nearfield hard bottom is performed annually to supplement the nearfield soft-bottom surveys. A considerable part of the area closest to the new outfall is hard bottom, consisting of drumlins that shoal to about 25 meters. Grab samples for quantitative faunal analyses cannot be obtained in these areas. The hard-bottom survey provides semi-quantitative visual information on the benthic habitat and the organisms occupying these rock and cobble areas. Both video and still photographs are taken during this survey: the video survey provides greater areal coverage and the still photographs provide fine detail and more accurate assessments of the benthic communities inhabiting these areas.

A Remotely Operated Vehicle (ROV) equipped with both a color video camera and a 35-mm still camera is used in these surveys. The ROV travels along established transects in order to permit detection of year-to-year changes In 1996, 20 stations along six transects were surveyed (Figure 4-4).

TABLE 4-1
Benthic Thresholds Compared to 1996 Monitoring Results

Parameter	Caution Level	Warning Level	1996 Results
Community Structure (Diversity, Species Composition, and Species Abundance) in outfall midfield area	Species diversity, composition, and relative abundance patterns measured in the midfield appreciably depart from those measured during the baseline monitoring period, after factoring out the effect of storms on sediment texture. Specific diversity threshold values are being developed.	None.	Shannon-Wiener Diversity Index Midfield mean = 2.8 (Range 1.95 - 3.30) (See also Table 4-2) Results in similar range to previous years.
Depth of Oxygenated Sediments [Redox Potential Discontinuity (RPD) Depth] in outfall nearfield area.	RPD depth declines by half. The threshold value is under development.	None.	No 1996 data available; 1995 results: Nearfield mean = 3.5 cm (Range 1.8 - >6.2 cm)
Toxic Contaminant Concentrations in outfall nearfield area.	Nearfield mean toxic contaminant concentrations greater than 90% of EPA sediment criteria.	Nearfield mean toxic contaminant concentrations greater than EPA sediment criteria or the NOAA Effects Range Median (ER-M) value. Examples: NOAA ER-M values: PCBs = 180 ng/g Mercury = 0.71 µg/g	No 1996 data available; 1995 example results: PCBs: Geometric Mean = 4 ng/g Range = 1.1 - 53 ng/g Mercury: Geometric mean = 0.16 µg/g (See also Table 4-4)

TABLE 4-2
1996 Diversity Data for the Midfield Stations (2-7 km from the outfall)

Trigger Parameter	Caution Level	Warning Level	Range and Mean ($\bar{x}$)
Shannon-Wiener H'	Appreciable change	No criteria	1.95 (MF4) - 3.30 (FF10) $\bar{x}$ = 2.80
Evenness J'	Appreciable change	No criteria	0.48 (MF4) - 0.72 (MF9, MF16) $\bar{x}$ = 0.65
Hurlbert Rarefaction # species./50 ind.	Appreciable change	No criteria	11.21 (MF4) - 21.87 (FF10) $\bar{x}$ = 17.09
Hurlbert Rarefaction # species./100 ind.	Appreciable change	No criteria	15.65 (MF4) - 31.01 (FF10) $\bar{x}$ = 23.71
Hurlbert Rarefaction # species./500 ind.	Appreciable change	No criteria	34.47 (MF4) - 65.38 (FF10) $\bar{x}$ = 45.74

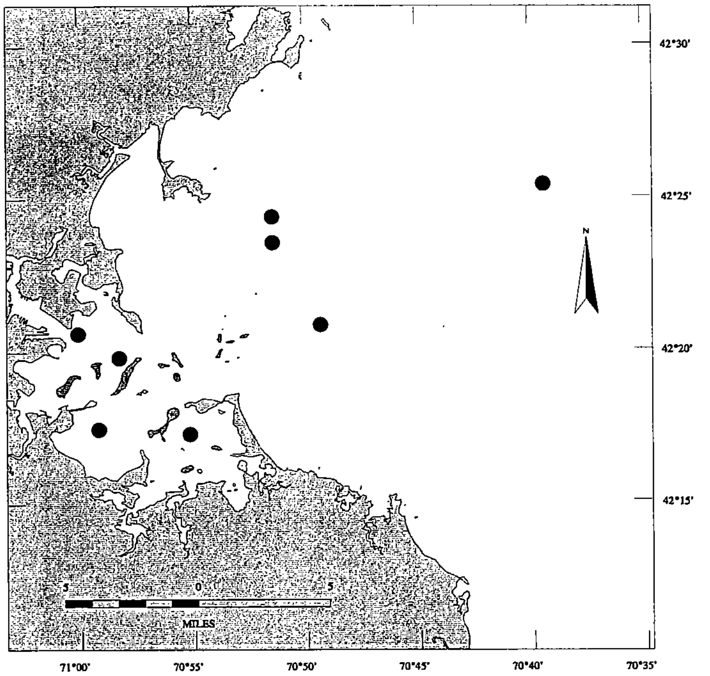


FIGURE 4-5
Benthic Nutrient Flux Sampling Locations

4.2.3 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 take place five times per year at seven sampling locations (Figure 4-5). An eighth station (Quincy Bay) was added during the last three surveys in 1995; data collection at this station has continued in 1996. Using a sediment coring technique, vertical columns of sediment are removed and brought to the surface intact. For each sediment core, measurements are made of sediment oxygen demand and oxygenation, sediment nutrient flux, and nutrients in the sediment pore water (water contained between sediment particles). Analysis of these parameters provides information necessary to assess nutrient and oxygen exchanges between the sediments and the water column, as well as the potential for impacts on sediment and water column oxygen.

4.3 Threshold Comparison

Trigger parameters and their thresholds for the benthic sediments and 1995 monitoring results are summarized in Table 4-1. The basis of the trigger parameters and threshold values, as well as progress in comparing monitoring results to threshold values are discussed below.

Benthic Community Structure

Benthic community thresholds are intended to verify the prediction in the SEIS that there will not be appreciable change in the benthos outside the 2 kilometer nearfield boundary. The trigger level to describe community change is under development, and MWRA has been considering the utility of various measures of benthic species composition, diversity, and relative abundance. The trigger level developed will involve comparison of a measure of the community in the midfield area against baseline values.

Diversity values measured in 1996 at the midfield stations are given in Table 4-2. Three measures of species diversity, Shannon-Wiener diversity (H'), evenness (J'), and Hurlbert rarefaction are given. The station east of Nahant (FF10) continues to be the most diverse, with H' and Hurlbert # species/50 individuals and # species/100 individuals slightly higher than measured in 1995. Station MF4, north of the new outfall and east of FF10, was the least diverse.

TABLE 4-3
Comparison of Mean Regional Diversity Values

	Boston Harbor	Nearfield/Midfield	Farfield
Shannon-Wiener H'	1.94	2.80	2.71
Evenness J'	0.53	0.65	0.61
Hurlbert Rarefaction # species/100 ind.	13.89	23.71	25.20

Mean diversity values in Boston Harbor, the outfall mid-field, and the farfield are shown on Table 4-3. These values show that diversity is generally lower in Boston Harbor than in the mid-field or farfield, indicating that diversity may be a useful measure of benthic communicity degradation.

Nevertheless, establishment of the final threshold values and comparison of threshold values to post-discharge monitoring results will need careful consideration. A decrease in species diversity or a change in species composition is not necessarily reflective of environmental degradation. While a moderate organic enrichment of the sediment may cause the disappearance of some sensitive species, the overall effect may not be detrimental if increased biomass is available as a food source for bottom fishes. Also, the existing data from previous years show that year-to-year changes in diversity or other community parameters can occur naturally.

Redox Potential Discontinuity

The Redox Potential Discontinuity (RPD) depth is the location where the sediment changes from oxic, or oxygenated, to anoxic, or depleted of oxygen. The RPD depth provides an important measure of the overall health of the benthic infauna habitat. In the absence of a state standard for the RPD depth, a threshold was developed to measure and evaluate significant changes in RPD depth which could provide an indication of adverse impacts from the deposition of discharged organic material. The RPD depth threshold is applicable to the nearfield area.

Since sediment profile image studies were not performed in 1996, the most recent RPD depth data is from 1995. The 1995 RPD depth results indicated that, in general, sediments appear to be well-oxygenated and are healthy with respect to the depth of oxygenated sediments. The 1995 RPD depth data showed a range of 1.8 cm to greater than 6.2 cm (sediments oxygenated at maximum depth reached), with a mean value of 3.5 cm. Comparison of the results from 1995 and previous years indicates that RPD depth values are similar and have not changed significantly.

Toxic Contaminants

Thresholds for toxic contaminants in sediments are established to be protective of benthic organisms. Monitoring results from the post-discharge operation period will be compared to sediment threshold values to verify predictions of potential toxic contaminant concentration in sediments and to assure that adverse toxic effects to benthic organisms do not occur. Specific threshold values are based on EPA sediment criteria and NOAA ER-M values. Draft EPA sediment criteria exist for five organic contaminants: acenaphthene, fluoranthene, phenanthrene, dieldrin, and endrin. NOAA ER-M values are available for a variety of organic and metal contaminants.

No sediment samples were obtained for toxic contaminant analysis in 1996. Comparison of 1995 sediment concentration data to relevant thresholds is provided on Table 4-4. The trigger parameter is expressed as a sediment concentration averaged over the nearfield stations. As in previous years, organic contaminant concentrations were generally low and did not exceed any of the thresholds; even stations with relatively high organic content had contaminant concentrations well under EPA sediment criteria. Metal concentrations were similar to those measured in previous years. The nearfield mean concentrations for all heavy metals were below the warning level. One individual nearfield station (NF24), however, had a mercury concentration of 1.69 µg/g, exceeding the warning level of 0.71 µg/g. Elevated mercury was also apparent in the 1994 data and reflects the very highly depositional nature of those sites.

TABLE 4-4

Toxic Contaminant Thresholds and 1995[1] Data for the Eight Nearfield Stations (0-2 km from the outfall)

Trigger Parameter (units)	Caution Level: 90% EPA criterion[2]	Warning Level: EPA criterion[2] or (NOAA ER-M)[3] level	Range and Mean ($\bar{x}$), and (Geometrical Mean)
Organic Contaminants			
Total PAH (ng/g)	—	(44,792)	78 (NF17) - 10,903 (NF24) $\bar{x}$ = 2,380; (870)
Acenaphthene (ng/g)	1170	1300 (500)	ND (2 stations) - 41(NF24) $\bar{x}$ = 11; (NA)[5]
Fluoranthene (ng/g)	5580	6200 (5100)	8.8 (NF17) - 1050 (NF24) $\bar{x}$ = 245; (96)
Phenanthrene (ng/g)	1620	1800 (1500)	4 (NF17) - 570 (NF24) $\bar{x}$ = 132; (49)
Total PCB (ng/g)	—	(180)	1.1 (NF13, NF17, NF23) - 53 (NF24) $\bar{x}$ = 10; (4)
Total Chlordane (ng/g)	—	(6)[4]	ND (7 stations) - 1.09 (NF24) $\bar{x}$ = 0.136; (NA)[5]
Total Dieldrin (ng/g)	99	110 (8)[4]	ND[6] (8 stations) $\bar{x}$ = 0; (NA)[5]
Endrin (ng/g)	37.8	42	ND[6] (8 stations) $\bar{x}$ = 0; (NA)[5]
Total DDT (ng/g)	—	(46.1)	ND (3 stations) - 11.21 (NF24) $\bar{x}$ = 2.2; (NA)[5]
Trace Metal Contaminants			
Cadmium (µg/g)	—	(9.6)	0.05 (NF13) - 0.46 (NF24) $\bar{x}$ = 0.12; (0.09)
Chromium (µg/g)	—	(370)	23.2 (NF23) - 177.0 (NF24) $\bar{x}$ = 53.5; (41.7)
Copper (µg/g)	—	(270)	3.41 (NF23) - 54.25 (NF24) $\bar{x}$ = 16.60; (11.22)
Lead (µg/g)	—	(218)	25.8 (NF23) - 92.9 (NF24) $\bar{x}$ = 44.9; (41.3)
Mercury (µg/g)	—	(0.71)	0.029 (NF23) - 1.69 (NF24) $\bar{x}$ = 0.36; (0.16)
Nickel (µg/g)	—	(51.6)	7.2 (NF17) - 31.8 (NF24) $\bar{x}$ = 13.8; (12.3)
Silver (µg/g)	—	(3.70)	0.08 (NF17) - 1.1 (NF24) $\bar{x}$ = 0.3; (0.2)
Zinc (µg/g)	—	(410)	25.2 (NF17) - 131.5 (NF24) $\bar{x}$ = 49.5; (42.7)

[1] No sediment samples were obtained for toxics analysis in 1996.

[2] Values for EPA sediment quality criteria assume 1% organic carbon. Hull and Suter (1995)

[3] NOAA ER-M levels taken from Long *et al.* (1995)

[4] From Long and Morgan (1992)

[5] NA = Not Available. Geometric means cannot be calculated for data sets that include zeroes.

[6] Detection levels: Dieldrin = 0.022 ng/g; Endrin = 0.0061 ng/g.

4.4 Monitoring Results

4.4.1 Biological Community Results

Surveys of benthic biological communities are used by the MWRA to evaluate the overall ecological health and environmental quality of Boston Harbor and the Massachusetts Bay/Cape Cod Bay ecosystems. In addition to species composition and density, sediment grain size distribution and total organic carbon, which may influence species distribution patterns, are measured.

4.4.1.1 Boston Harbor

Prior to the abatement of sludge discharge in December 1991, some stations in the northern portion of Boston Harbor were generally characterized by the presence of a few, pollution-tolerant species. Stations in the northern part of the Harbor (i.e., closest to the outfalls) were characterized by opportunistic, highly variable assemblages able to tolerate high levels of organic material in the sediments. Stations in the southern part of the Harbor were generally more diverse, with somewhat more stable assemblages of organisms that require better sediment quality. In the years since sludge abatement, stations in the north have become progressively more similar to stations in the south. This trend continued in 1996.

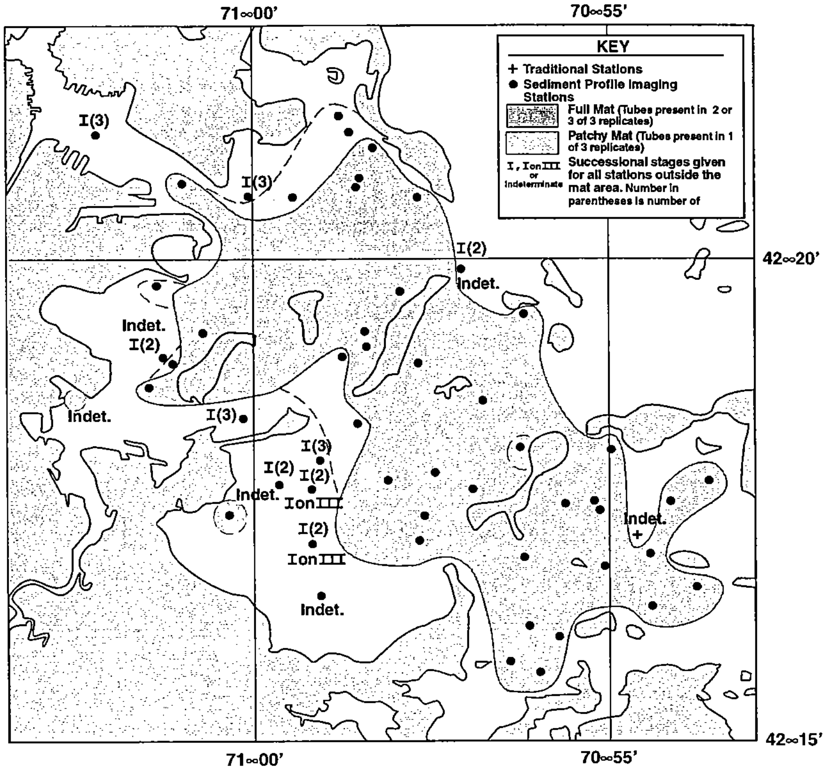


FIGURE 4-6

Distribution of Amphipod Tube Mats in Boston Harbor.

The most significant change in the benthos since sludge abatement has been the widespread development of dense tube mats of the opportunistic, yet pollution-sensitive, amphipod *Ampelisca abdita*. The powerful northeaster in October 1991 may have helped to set the stage for the establishment of *Ampelisca* mats in the Harbor by causing a shift in bottom sediments from mud to mostly fine sand, which is the substrate preferred by settling larvae of this species. Prior to 1991, less than 20 percent of stations surveyed showed the presence of amphipod tube mats; by 1995, more than 60 percent of the stations showed well-developed mats. In 1996, tube mats were seen at all but a few of the southern inshore stations (Figure 4-6).

Infaunal species richness has increased Harborwide since 1991, especially at the northern stations. Several species that were previously rare or absent are now becoming dominants (e.g., *Chaetozone vivipara* and amphipods belonging to the genus *Corophium*). Stations in the north that were affected by the old Deer Island outfall were, prior to sludge abatement, overwhelmingly dominated by one or a few pollution-tolerant species. These stations continued to show increasingly diverse assemblages.

4.4.1.2 Massachusetts Bay/Cape Cod Bay

Benthic biology surveys in Massachusetts and Cape Cod Bays provide baseline data that can be used as a benchmark to evaluate the potential effects of sewage disposal from the new outfall when it becomes operational in late 1998.

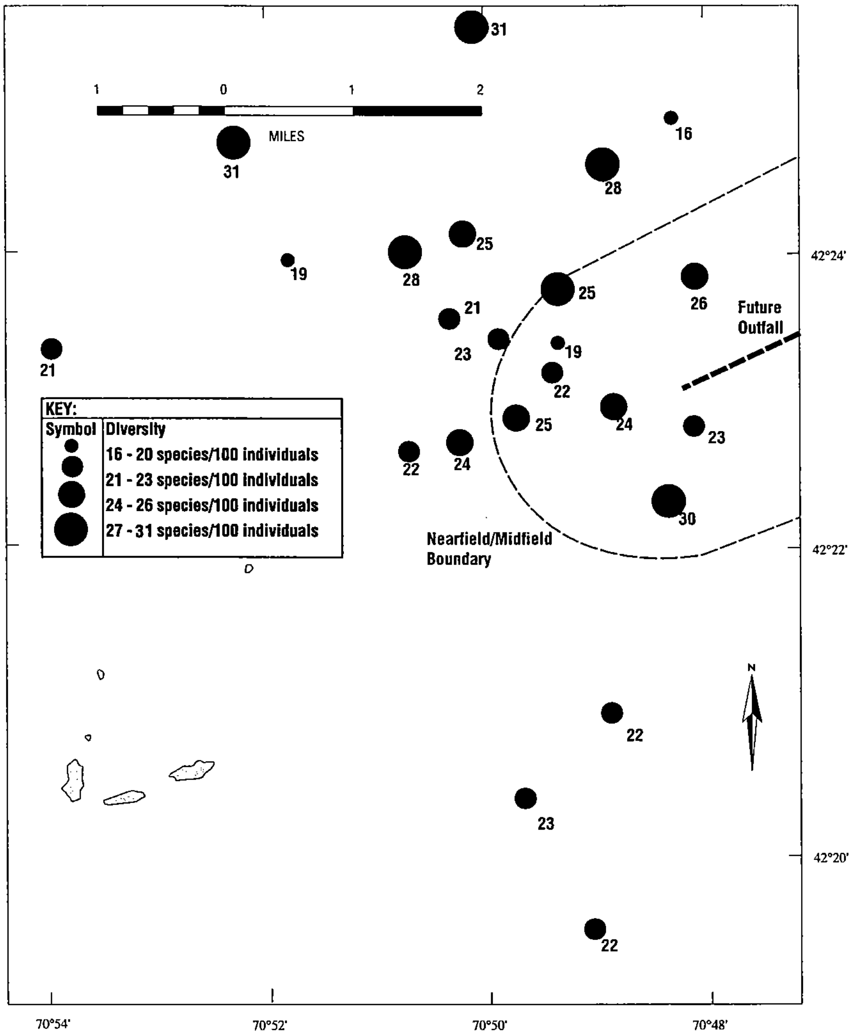


Figure 4-7
Soft-Bottom Benthic Community Diversities at Nearfield and Midfield Stations.

Nearfield and Midfield Soft-Bottom Communities

The nearfield and midfield stations are all in Massachusetts Bay. Unlike Boston Harbor, Massachusetts Bay is not a stressed environment, and the benthic community composition is generally reflective of a clean offshore environment. Statistical analysis of the 1996 data indicates that the stations are roughly grouped in bands or patches approximately parallel to the mouth of the Harbor. This pattern may reflect sediment distribution patterns, which are influenced by water circulation patterns and occasional storm events.

The species composition of the benthic communities is largely determined by sediment grain size. In fine-grained sediments, some polychaete species (spionids and capitellids) are most abundant; whereas in sandier sediments other polychaetes (syllids and paraonids), amphipod crustaceans, and certain oligochaetes predominate. These basic community structures have been observed since the inception of this program, with changes at individual stations reflecting changes in sediment composition, perhaps due to storm-generated currents. Results of the August 1996 benthic survey were generally similar to those obtained in 1995 and previous years.

As in 1995, the most common dominant species in the nearfield were two spionid polychaetes, *Prionospio steenstrupi* and *Spio limicola*, the capitellid *Mediomastus californiensis*, and the lumbrinerid *Ninoe nigripes*. The last species has been relatively widespread throughout the duration of this study, but was especially common in 1996, possibly because sampling took place just as the postlarvae settled. As much as 80 percent of the individuals in a single sample were tiny juveniles which may succumb to intense predation in the time period following settlement.

Species diversity as measured by several statistical methods indicated that Station MF4 (north of the future outfall) had the lowest diversity and FF10 (east of Nahant) had the highest diversity (Table 4-2). However, no particular geographical pattern in the distribution of diversities could be identified (Figure 4-7). The number of species ranged from 19 to 29 species per 100 individuals in the nearfield, and from 15 to 31 species per 100 individuals in the midfield.

Farfield Soft-Bottom Communities

Benthic community structure at the farfield stations is influenced by water depth and location (Massachusetts versus Cape Cod Bays). The two stations in Cape Cod Bay differ in terms of dominant species, probably because of a different sedimentary environment. In 1996 as in 1995, cossurid polychaetes were dominant at the Cape Cod Bay stations, but the spionid polychaete *Prionospio steenstrupi* ranked first at all Massachusetts Bay stations.

Diversities at the farfield stations were basically similar to those at the near- and midfield stations, ranging from 18 to 31 species per 100 individuals. Species richness and diversity was slightly higher in 1996 than in 1995, but was within the range of previous observations. Species diversity, species composition, and infaunal density all exhibit fluctuations from year to year, as they do in the nearfield. These variations probably reflect changes in area-wide environmental conditions that in turn influence the timing and success of larval settlement of benthic organisms. However, faunal assemblage patterns in the farfield are more consistent than those in the nearfield, indicating that monitoring the farfield stations will help to distinguish changes due to natural processes from those caused by discharges from the new outfall.

Nearfield and Midfield Hard-Bottom Communities

Only about one-third of the seafloor in the near-field consists of the sands and muds that are the focus of the soft-bottom monitoring program. The remainder is made up of a variety of gravel, cobble, and boulder fields covering the tops and sides of submerged drumlins which shoal to about 25 meters. Because most potential impacts caused by sewage pollution are associated with suspended solids that do no permanently settle in hard-bottom areas, there is little likelihood for adverse impacts. However, the OMTF required that MWRA study rocky environments in the nearfield to ensure no dramatic impacts occur.

The complex topography in the hard-bottom areas in western Massachusetts Bay has a substantial influence on epibenthic communities. These communities are primarily determined by depth, with red algae dominating the shallower drumlin tops (about 25 meters depth) and macroinvertebrates dominating the deeper bottoms. Location on the drumlins (top versus flanks), depth, bottom type, and habitat relief all appear to play a role in determining the structure of benthic communities inhabiting hard-bottom areas. Some species show strong preferences for specific habitats, while others are broadly distributed. Some areas are homogeneous in terms of bottom type and the fauna inhabiting them, while others exhibit more patchiness. The communities of attached and encrusting animals and plants in rocky bottom environments in the vicinity of the outfall are broadly similar to those found throughout the Massachusetts Bay and the larger Gulf of Maine (the arm of the Atlantic Ocean between Nova Scotia (Canada) and Cape Cod.

4.4.2 Nutrient Flux Results

4.4.2.1 Boston Harbor

Rates of total infaunal community respiration, while showing significant inter-annual variability, appear to be increasing in portions of Boston Harbor. While sludge was being discharged in the Harbor, the benthic community was apparently overwhelmed by the amount of settling organic material. When this practice ended, the benthic community began to degrade the material that had accumulated over the years. Rates of the organic matter breakdown process, or remineralization, were more than twice as high in 1995 than reported in any previous monitoring period. Results from 1996 studies suggest that depuration of sediment nutrients and organic matter is relatively rapid following infaunal recolonization. Rates of denitrification and community metabolism declined and sediment oxidation began to increase in 1996, suggesting that the labile organic matter present in the sediments may be declining under continued bioturbation.

The colonization of Harbor sediments by infauna, particularly the development of dense amphipod mats (*Ampelisca* and *Leptocheirus*), are likely responsible for the changes in these rates. Both the degree of sediment oxidation and rates of sediment/water column exchange has increased through bioturbation and burrow ventilation by these organisms. Remineralization rates and denitrification were significantly enhanced in areas densely colonized by amphipods (north of Long Island and Hull Bay) compared to areas with lower total infaunal densities (Quincy Bay). Infauna affected carbon mineralization directly through their metabolism and indirectly through irrigation of surficial sediments. The result was increased oxidation of surficial sediments and higher rates of nitrification/denitrification.

4.4.2.2 Massachusetts Bay

In contrast to Boston Harbor, where large and rapid changes are evident, the stations sampled in Massachusetts Bay showed an inter-annual variability in respiration of less than 20 % (generally only 10%). Rates of biogeochemical cycling were similar in 1996 to those measured in 1995 and previous years. The stability of these measurements indicates that they will be sensitive tools for detecting relatively small changes in carbon enrichment.

The Massachusetts Bay benthic environment plays less of a role in contributing to nutrient flux and DO depletion than it does in Boston Harbor. The greater water depth in the Bay allows more remineralization to take place within the water column before particles reach the benthos, and stratification tends to isolate the benthos from the upper water column. Bottom waters may be affected by the benthos during periods of stratification.

5.0 Fish and Shellfish

5.1 Fish and Shellfish Issues

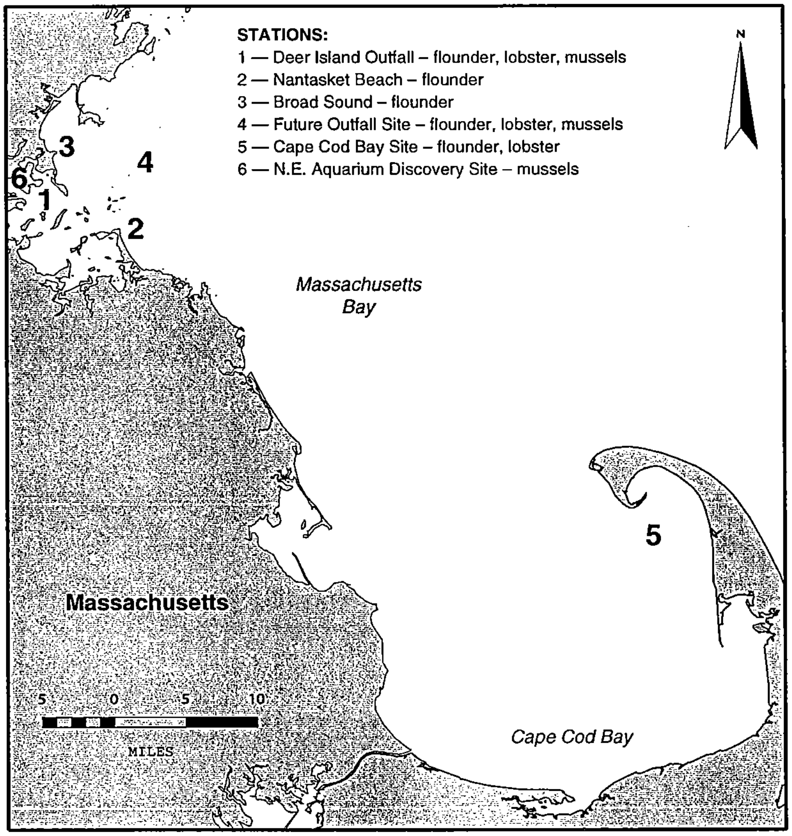
One of the recurrent public concerns regarding the relocation of the outfall is the potential impacts to water chemistry and marine life. These concerns include potential impacts of the outfall to the health and well-being of local fishery stocks and, of perhaps greater public interest, the potential effect on the quality and safety of fish and lobster caught in Boston Harbor and Massachusetts. Toxic contaminants in the effluent have the potential to cause a variety of problems throughout the food chain. 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 potential bioaccumulators of toxic contaminants. Exposure of flounder or lobster to toxic contaminants may result in fin rot, black gill disease, or other gross abnormalities. Consumption of contaminated organisms results in exposure of predators through the food chain including ultimately human consumers of fish and shellfish.

Fish and shellfish issues are mainly associated with the potential effects of toxics bioaccumulation.

5.2 Monitoring Program Design

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. The primary goals of this monitoring program are (1) to evaluate the health of these marine resources in terms of disease, and (2) to evaluate organic and inorganic contaminant concentrations in the organs and edible tissues of these organisms. 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 between pre- and post-discharge periods will allow evaluation of spatial and temporal trends in the fisheries. In addition, the biomonitoring programs provide baseline data that may be used to assess the potential environmental impact of the effluent discharge on Massachusetts Bay, and to evaluate the facility's compliance with the NPDES effluent discharge permit requirements. The three biomonitoring surveys are outlined below.

FIGURE 5-1
Sampling Stations for Winter Flounder, Lobster and Mussels during 1996.



The flounder survey is designed to collect sufficient mature winter flounder to perform general and histopathological examinations

The fish and shellfish program consists of monitoring of flounder, lobsters, and mussels.

and determine bioaccumulation of priority pollutant organics, metals, and other constituents. Flounder surveys began in 1991 and are performed annually at five locations: the Deer Island outfall, future outfall site, Cape Cod Bay site, Broad Sound and Nantasket Beach (Figure 5-1). Fish are collected using a bottom trawl deployed by a commercial dragger.

Similarly, 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 each year since 1992, lobsters have been collected in 25 to 60 commercial lobster traps deployed at each of three locations: the Deer Island outfall, future outfall site, and Cape Cod Bay site (Figure 5-1).

In the mussel bioaccumulation survey, blue mussels are obtained from a clean location, deployed in floating cages or "arrays", and recovered for determination of biological condition and short-term accumulation of contaminants in tissues. Mussels are used as test organisms because of the extensive database available on the rate at which they bioaccu-

TABLE 5-1
Fish and Shellfish Thresholds Compared to 1996 Monitoring Results

Parameter	Caution Level	Warning Level	1996 Results
Mercury in fish and shellfish from Outfall site	Annual mean mercury concentration in flounder, lobster, and caged mussel meat greater than 0.5 µg/g wet weight (50% of the US FDA action level).	Annual mean mercury concentration in flounder, lobster, and caged mussel meat is greater than 0.8 µg/g wet weight (80% of the US FDA action level).	Flounder: 0.1 µg/g Lobster: 0.18 µg/g Mussel: 0.03 µg/g
PCBs in fish and shellfish from Outfall site	Annual mean PCB concentration in flounder, lobster, and caged mussel meat greater than 1 µg/g wet weight (50% of the US FDA action level).	Annual mean PCB concentration in flounder, lobster, and caged mussel meat is greater than 1.6 µg/g wet weight (80% of the US FDA action level).	Flounder: 0.04 µg/g Lobster: 0.02 µg/g Mussel: 0.02 µg/g
Lead in mussels at Outfall site	Annual mean lead concentration in caged mussel meat greater than 2 µg/g wet weight.	Annual mean lead concentration in caged mussel meat is greater than 3 µg/g wet weight.	Mussels: 0.3 µg/g
Lipid-normalized toxics in fish and shellfish from Outfall site	Lipid-normalized toxic concentrations in flounder, lobster, and caged mussel meat greater than two times the interim baseline concentrations (i.e., average value from 1992-1996 data). The final baseline concentration will be based on 1992-1998 data. *Interim baseline (1992–1996) concentrations in µg toxic per gm lipid.* Flounder DDT: 1.62 Flounder PCB: 14.94 Lobster DDT: 0.56 Lobster PCB: 4.46 Mussel DDT: 0.66 Mussel PAH: 6.22 Mussel PCB: 2.58	None.	Concentrations in µg toxic per gm lipid Flounder DDT: 1.02 Flounder PCB: 10.19 Lobster DDT: 0.56 Lobster PCB: 4.44 Mussel DDT: 0.28 Mussel PAH: 1.35 Mussel PCB: 0.94
Liver disease incidence in fish from outfall site	Flounder liver disease (CHV) incidence greater than interim harbor prevalence (1991-1996): 48% The final baseline prevalence will be based on 1991-1998 data.	None.	Flounder CHV prevalence: 22%

mulate contaminants and because they provide good spatial and temporal experimental control. Each year since 1987, mussels have been deployed in replicate arrays consisting of moored cages in waters near Deer Island and in Massachusetts Bay near the outfall location (Figure 5-1). Mussel arrays are deployed using a subsurface and surface buoy system.

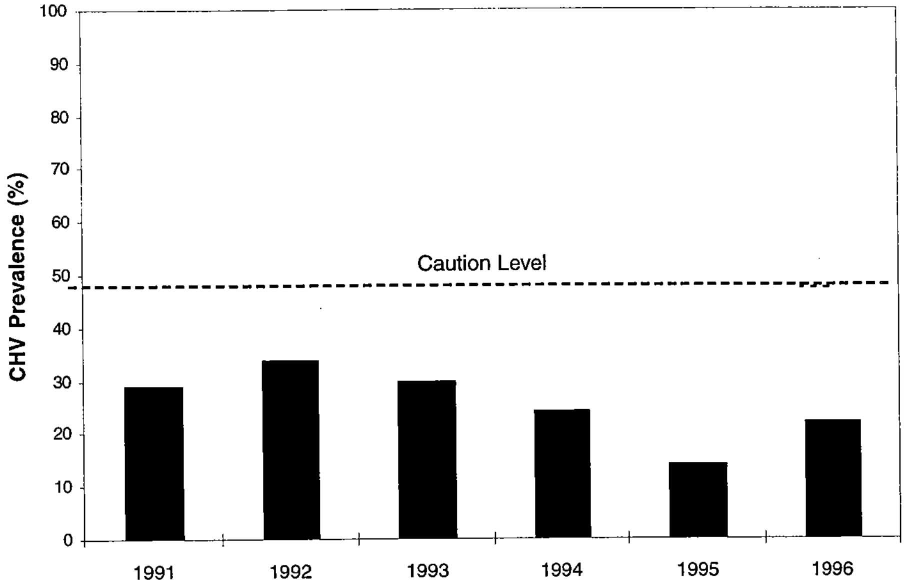


FIGURE 5-2
Prevalence of CHV near the future outfall site, 1991-1996.

5.3 Threshold Comparisons

To track the chronic environmental impact of the toxic contaminants, the MWRA measures the concentrations of a variety of toxic contaminants in flounder, lobster, and mussels from various locations in Boston Harbor and Massachusetts and Cape Cod Bays. Thresholds for fish and shellfish, summarized in Table 5-1, are designed to identify any effects on marine life and potential effects on human consumers of fish and shellfish. The thresholds apply to fish and shellfish caught or deployed at the new outfall site.

Of the five monitoring thresholds, three are associated with the potential for edible tissue (flounder, lobster, mussel) to exceed warning levels for mercury, lead, or PCBs. Except for lead, the Caution levels are 50% of the U.S. Food and Drug Administration (FDA) Action Limits; the Warning levels are 80% of the FDA Action Limits. Lead thresholds are based on an EPA risk assessment that determined the amount of lead that can be consumed without adverse health effects. The flounder, lobster, and mussel data show that current tissue concentrations are generally an order of magnitude or more below the Caution and Warning levels (Table 5-1). Values approaching the Caution or Warning levels should be readily detectable.

Because some toxics tend to concentrate in lipid-rich (fatty) tissues, a lipid-normalized threshold was established to identify significant increases in these contaminants. This threshold is exceeded if bioaccumulative lipophilic contaminants are twice the baseline average at the outfall site. This baseline is the average of contaminant levels during the years prior to the outfall relocation. Presently, the baseline data covers the years 1992-1996, but will eventually include data from 1992-1998. The concentrations for 1996 are shown in Table 5-1. Results from 1996 for the flounder liver and lobster hepatopancreas, which are not considered edible tissue for any of the thresholds, indicate levels within the range of values previously observed at the outfall site or (for lobster) slightly elevated from last year.

In order to monitor and assess the potential impacts of toxic contaminants on flounder, a threshold concerning the prevalence of flounder liver CHV was developed which compares the postdischarge prevalence of CHV with the baseline average prevalence in the Harbor.

The 1996 CHV prevalence at the future outfall site (22%) is below the interim threshold value (Figure 5-2). The monitoring design will be able to detect changes approaching the Caution Level.

5.4 Monitoring Results

The results of the fish and shellfish program have revealed temporal and areal patterns, and illustrated the variability of the ecosystem. In general, levels of contaminants and the number of physical abnormalities in the fish and shellfish studied have decreased over the study period. Boston Harbor organisms are the most affected by toxic contaminants, while those in Cape Cod Bay are least affected. The following sections present the 1996 fish and shellfish monitoring results, along with comparisons to previous data.

5.4.1 Flounder

In 1996, winter flounder were collected at each of the five monitoring program sites: Deer Island Flats, the future outfall site, Nantasket Beach, Broad Sound, and eastern Cape Cod Bay (Figure 5-1). All flounder were examined for physical abnormalities and histopathological liver lesions. In addition, the tissue from fifteen of the fifty flounder from all five locations was analyzed for concentrations of organic and inorganic contaminants.

Physical Condition and Histology

The external condition of the collected fish indicated few abnormalities, although fin erosion was seen in fish from all stations. The flounder from the future outfall site showed significantly lower levels of fin rot than fish caught at Deer Island or Nantasket Beach. The overall levels of fin erosion observed throughout is considered low, and is well below that observed in the late 1980s.

The flounder liver histology results indicated that flounder from all sampling locations experienced some degree of liver lesions. The flounder from Deer Island Flats and Broad Sound exhibited the greatest prevalence of lesions (43-44%). The prevalence of one type of liver lesion, centrotubular hydropic vacuolation (CHV), has been used by MWRA since 1991 as a sensitive indicator of contaminant exposure in flounder from Boston Harbor and the bays. Although there is significant regional variability, sampling results indicate that the incidence of CHV in winter flounder has been generally decreasing since 1991. The presence of CHV in fish from the future outfall site increased slightly in 1996 from 14% to 22%. The reasons for this slight increase are not known, but may be due to the capture of older fish in 1996 (mean age = 4.5 years) as compared to 1995 (mean age = 4.1 years). This value still represents a decline from about 30% of the population in 1992. Meanwhile, the prevalence of CHV in flounder from Broad Sound has dropped from more than 75% to about 44% over the same period. In areas such as Cape Cod Bay, the prevalence of CHV has been relatively low and constant (e.g., 1996 prevalence is 2%).

Bioaccumulation

In 1996, contaminant concentrations were measured in 15 flounder meat (e.g., fillet) samples, and 15 flounder liver samples from the Deer Island Flats, future outfall site, and Cape Cod Bay sampling locations. All samples were analyzed for PCBs, chlorinated pesticides, and mercury. The liver samples were also analyzed for a number of other organic and inorganic contaminants. Annual trends for selected contaminants in flounder are shown in Figure 5-3. Comparing 1996 data to last year's results, it can be seen that mercury and total PAH body burdens increased, while total PCBs and total DDT values decreased slightly. This amount of variability in tissue concentrations is not unusual and supports the use of several years data to establish baseline levels for contaminants. [Note: flounder fillet results are reported on wet weight basis, while flounder liver concentrations were normalized for lipid content.]

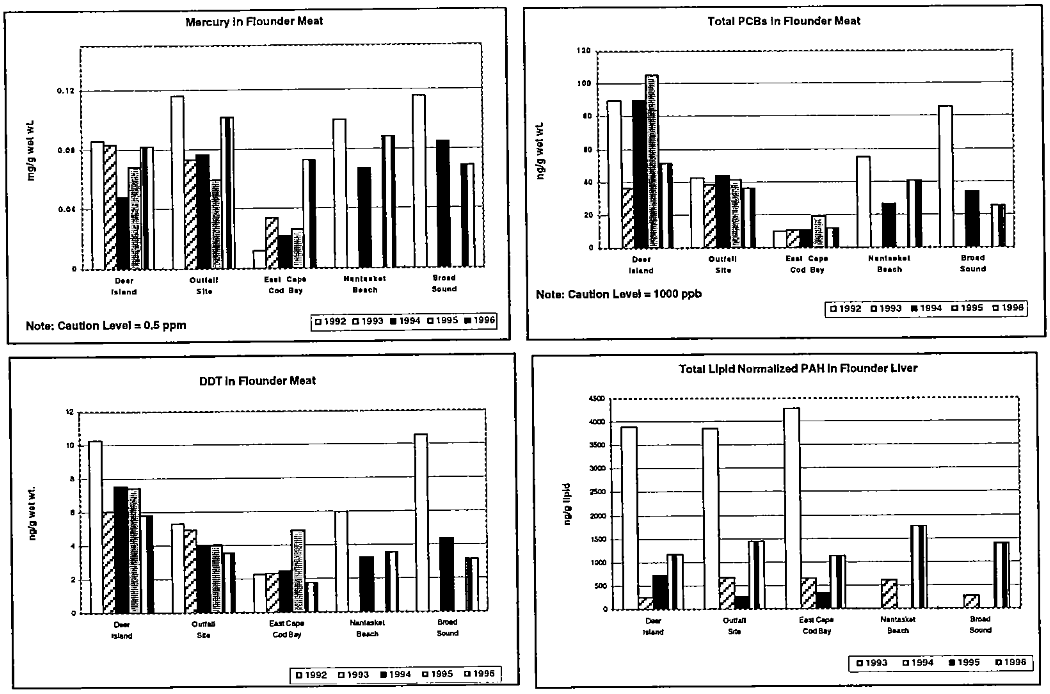


FIGURE 5-3
Mercury, PCB, DDT and PAH concentrations in flounder, 1992 - 1996.

The 1996 monitoring results continue the general trend previously observed in the monitoring program (1992-1995) that contaminant concentrations in flounder meat and liver are generally highest in Boston Harbor near the Deer Island outfall, intermediate at the future outfall site, and lowest at the Cape Cod Bay site (Figure 5-3). Contaminant concentrations at the Broad Sound and Nantasket Beach stations are generally intermediate between values at Deer Island and the future outfall site.

As shown in Figure 5-3, the levels of flounder fillet total DDT, total PCBs, and liver hepatopancreas PAHs exhibit a spatial trend, with a gradient of decreasing contaminant levels from Deer Island to the outfall site to Cape Cod Bay. The two other nearshore stations (Nantasket Beach, Broad Sound) are more variable but appear to be comparable to the outfall site levels. In contrast, there is little evidence of a similar gradient in the flounder fillet mercury levels. Other than generally lower levels at Cape Cod, there is little difference between stations. This suggests that the distribution of mercury in the environment may be less localized than for the organic contaminants and subject to regional influences (e.g., atmospheric deposition).

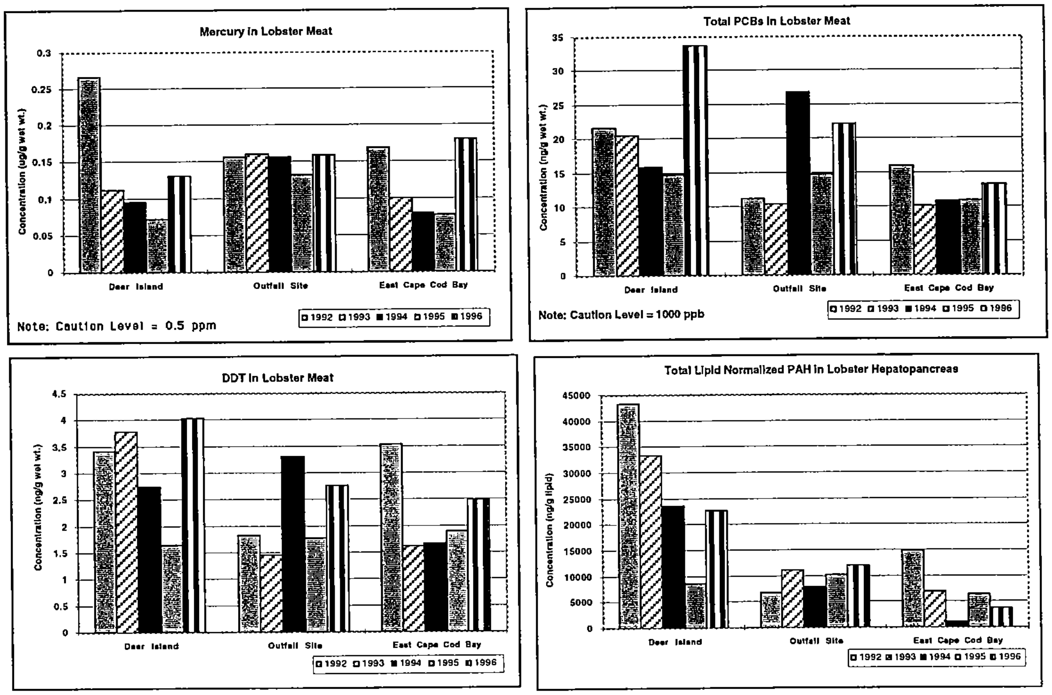


FIGURE 5-4
Mercury, PCB, DDT and PAH concentrations in lobster, 1992 - 1996.

5.4.2 Lobster

Fifteen northern lobsters were collected from each of three sites (Deer Island Flats, future outfall site, Cape Cod Bay; Figure 5-1) for the 1996 monitoring program. With the exception of two observations of shell erosion (one each at the future outfall site and Cape Cod Bay), no deleterious external conditions were noted. Edible tissue (i.e., tail meat) and hepatopancreas (a.k.a., "tomalley") samples were taken from each lobster and analyzed for PCBs, chlorinated pesticides, and mercury. The hepatopancreas samples were also analyzed for a number of other organic and inorganic contaminants. Annual trends for selected contaminants in lobster are shown in Figure 5-4. The levels of most contaminants increased from the 1995 levels, but do not suggest an increasing trend. Generally the 1996 values fall within the range of values observed during the previous 4 years. [Note: lobster meat concentration are reported on wet weight basis, while lobster hepatopancreas concentrations were normalized for lipid content.]

Following a similar pattern to flounder tissue chemistry, mean concentrations of organic compounds in edible tissue were generally highest at Deer Island Flats and lowest in Cape Cod Bay (e.g., lobster meat total DDT, total PCBs, and PAHs in hepatopancreas). Concentrations of mercury in lobster meat showed little spatial or temporal resolutions between stations. Metals in lobster hepatopancreas (not shown) exhibited variable results with lead, silver, and chromium showing a decrease between Deer Island to the outfall site and Cape Cod Bay, while nickel showed the reverse trend, and zinc was similar throughout the stations.

In 1996, tissue body burdens of selected organic contaminants were reported as lipid-normalized concentrations (i.e., ng/g lipid) in addition to dry and wet weight concentrations. Lipid-normalized concentrations were compared to dry weight concentrations to examine how reporting results in different units potentially affect interannual trends. As Figure 5-5

TABLE 5-2

Comparison of Average Body Burdens of Deployed Mussels for Selected Organic Compounds and Metals

Parameters	1995			1996			
	Predeployment Gloucester/Sandwich	Deer Island	Discovery	Predeployment Gloucester	Future Outfall Site	Deer Island	Discovery
PAH (ppb wet weight)							
LMW PAH	28.00	161.76	139.16	53.65	28.55	253.04	355.24
HMW PAH	21.24	83.08	267.03	37.18	19.61	144.18	498.46
Total PAH	49.22	244.84	406.19	90.83	48.16	398.22	853.70
Pesticides (ppb wet wt)							
Total Chlordane	0.46	1.53	2.87	1.60	1.66	5.20	4.72
Total DDT	3.33	5.35	12.11	7.47	4.91	10.24	16.59
Polychlorinated Biphenyls (ppb wet wt)							
Total PCB	10.84	20.16	57.78	20.58	16.83	32.67	75.00
Metals (ppb wet wt)							
Mercury	0.01	0.01	0.01	0.02	0.03	0.02	0.02
Lead	0.70	0.99	1.12	0.51	0.30	0.89	1.53

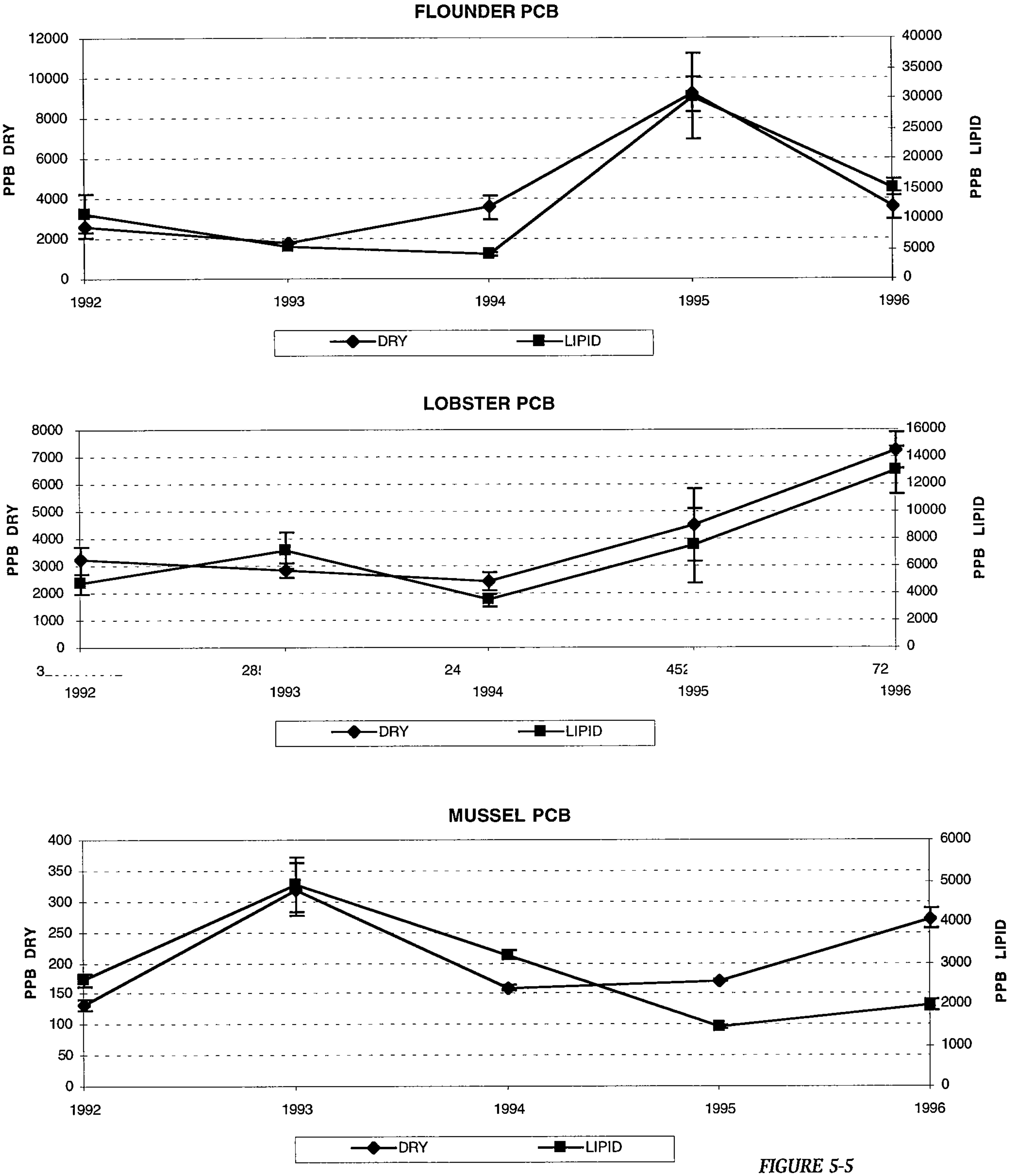


FIGURE 5-5
Comparison of PCB body burdens reported as dry weight or lipid-normalized concentrations (note different scales) for flounder, lobster and mussel (1992-1996).

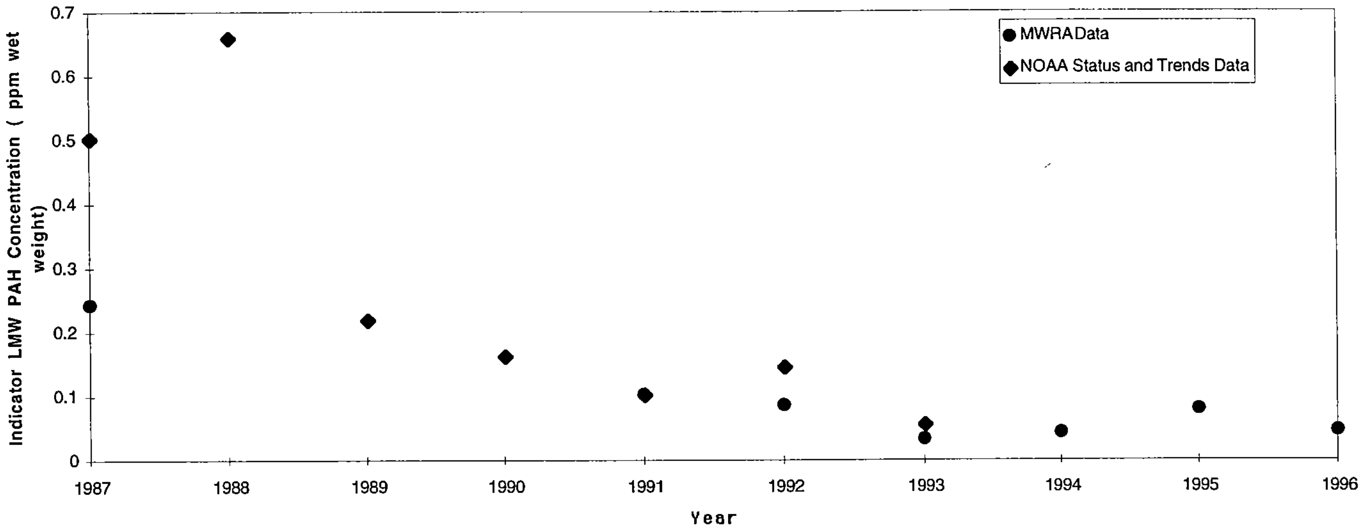


FIGURE 5-6
Indicator LMW PAH Bioaccumulation in Mussels Near Deer Island Discharge, 1987-1996.
** Set of 12 Low Molecular Weight (LMW) PAHs (i.e. total of 2&3 ring groups) used by NOAA for Status and Trends monitoring.*

indicates (using PCBs as an exemplary organic contaminant), there was little difference between trends reported in different units. This figure is consistent with the small differences observed between coefficients of variation (CV) for PCBs in these three organisms (during the reporting period 1992-1996). For example, the mean CVs in lobster were 27% with a range of 16-52% for dry weight concentrations, and 31% with a range of 16-64% for lipid-normalized concentrations. Similar results were observed for flounder (mean 30%, range 16-43% for dry weight; mean 30%, range 5-59% for lipid-normalized) and mussel (mean 10%, range 6-14% for dry weight; mean 11%, range 5-16% for lipid normalized—1995-1996 data only) PCB concentrations. These results indicate that the trends observed are largely independent of the various reporting units.

5.4.3 Blue Mussel

A series of mussel bioaccumulation studies have been conducted since 1987 to determine whether selected contaminants (PCBs, pesticides, PAHs, and metals) bioaccumulate in shellfish. Mussels were collected from two relatively clean locations: Gloucester and Sandwich, Massachusetts and deployed in cages in three locations (Figure 5-1): near the present outfall location at Deer Island Flats; at the future outfall site; and in the inner Harbor (hanging off the New England Aquariumís barge, the Discovery). After 60 days, mussels were harvested for biological and chemical analyses. In 1996, the arrays were successfully retrieved at all sites due to an improved mooring system and increased redundancy in mussel cage arrays. Predeployment organic contaminant levels at Gloucester were higher than previous years (Table 5-2). Also, lipid levels in mussels were higher than in previous years.

Some study contaminant levels, particulary low molecular weight PAHs, at the Boston Harbor station at Deer Island, have generally decreased since 1987. As shown in Figure 5-6, indicator low molecular weight PAH (i.e., a set of 12 low molecular weight PAHs selected to allow direct comparison between NOAA Status and Trends and MWRA data) levels near the Deer Island outfall decreased by over a factor of five between 1987 and 1996. The spatial distribution of contaminant concentrations shows higher levels of most contaminants at the Discovery site, with lower levels at the Deer Island Flats sampling location and significantly lower concentrations at the outfall site (Table 5-2).

Mussel PAH, PCB, and pesticide (DDT, chlordane, dieldrin) body burdens for the Deer Island and Discovery sites in 1996 were higher than those seen in 1995 (Table 5-2). In particular, the PAH fractions (i.e., low and high molecular weight fractions) were about twice the levels seen in 1995 at all stations. [Note: the 1995 and 1996 PAH fractions reported in Table 5-2 include an extended PAH analyte list not analyzed prior to 1995 and not directly comparable to the NOAA Status and Trends PAHs. Thus, these PAH fractions are not directly comparable to those depicted in Figure 5-6]. Also, DDT and chlordane concentrations were anomalously high compared to previous years. A potential explanation of the high concentrations is the relatively high lipid content of the mussels in 1996. It is possible that the organic parameters were concentrated in the mussel lipids. As shown in Figure 5-5, the 1996 dry-weight PCB concentration was substantially higher than the 1995 level, while the lipid-normalized concentrations were similar. Levels of lead and mercury in 1996 were similar to 1995 levels.

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Glossary

The following descriptions are not formal definitions but convey the sense of usage in this report.

Algae – phytoplankton, the microscopic plants that drift with the currents. They are usually single celled but may form colonies. There are many species that form the community assemblage in a sample of seawater. Phytoplankton are eaten (grazed on) by zooplankton, larger but still very small animals which also drift with the currents. Zooplankton, in turn, are eaten by animals higher up the food chain. Large multicellular algae are called macroalgae and are usually attached to the sea floor. Although plants are an essential part of the food chain, excess nutrients may make them too numerous or favor undesirable forms.

Algal community assemblage – the composition of the algal community, or the relative numbers of various algae species. Approximately 30 to 50 algae species typically are observed in the Massachusetts Bay community assemblage . These include species co monly known as diatoms, blue-green algae, and flagellates. Flagellates are planktonic algae that have self- propelled mobility, albiet limited. 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.

Amphipod – benthic crustaceans commonly found in the Boston Harbor ecosystem. Examples are the deposit-feeding *Ampelisca abdita* and *A. vadorum*, which build extensive tube mat systems. Tube mats are often several centimeters thick, and may reach densities of more than 100,000 individuals per square meter. The widespread colonization of Boston Harbor sediments by this infaunal complex has increased both the degree of sediment oxidation and rates of sediment/water column exchange through bioturbation and burrow ventilation.

Apparent redox potential discontinuity depth – RPD. The visually measured thickness of upper light-colored, and thus apparently well-oxygenated, layer in bottom sediments.

Bioassays – laboratory tests that measure the response of indicator species such as shrimp to toxics in the effluent under specified conditions. Bioassays designed to assess acute toxicity are expressed in measurement units known as "LC50s." An LC50 is the concentration at which 50% of test organism survive. For example, an LC50 of 60 means that half of the organisms survived a mixture that was 60% effluent and 40% dilution water. To assess chronic toxicity, the effluent "No Observed Effects Concentration (NOEC)" is generally used. The NOEC is the highest concentration of effluent at which there is no statistical difference in test organism response when compared against a control with no effluent.

Biomass – the total amount of a biological material. For example, algal biomass is a measure of the total amount of algae present in the water.

Bioturbation – mixing of the sediment strata by animals, which bring deeper sediment to the surface as they burrow, and flush aerated bottom water into the mud by way of their burrows and feeding activity.

Chlorophyll – the green pigment in plants that supports photosynthesis in the presence of adequate light. Chlorophyll a is commonly used as a measure of algal biomass.

Community diversity – relative abundance and types of various species that live in a particular habitat. Measures of diversity are often used to evaluate environmental change and health; typically, the more diverse the assemblage (i.e., the more species present, taking into account the number of animals collected) the healthier the community.

Denitrification – the reduction of nitrate to nitrite and then to nitrogen gas.

Dissolved oxygen saturation level – the amount of dissolved oxygen (DO) that can be held, or dissolved in water. The DO saturation level varies with temperature. Cooler water can hold more DO. Therefore, DO concentrations will decrease naturally as the water column warms during the spring and summer.

Drumlin – elongated piles of glacial debris left behind after the glacier recedes.

Epibenthic organisms – bottom-dwelling animals that live upon, rather than within, a substrate such as impenetrable rock.

Eutrophication – a process of excessive algal growth that may result in dissolved oxygen depletion (hypoxia).

FDA Action Levels – limits established by the U.S. Food and Drug Administration (FDA) 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.

Histopathology – the study of adverse changes in animal tissue structures, such as liver lesions, often used as a sensitive indicator of contaminant exposure.

Hypoxia – a state of low dissolved oxygen in which sensitive animals may suffocate.

Infauna – bottom-dwelling animals that live within the sediments.

Mixing zone – region in the immediate vicinity of the diffuser where initial mixing and dilution occurs. The defined size of the mixing zone reflects the designed dilution properties of the diffusers. An outfall would violate expectations if dilution is not sufficient to meet water quality criteria at the edge of the mixing zone.

Nearfield or near field – a region near the new outfall which receives more intensive sampling due to the expectation that effects are most likely to be manifest there. The definition of the nearfield varies with the study type, reflecting the mobility of water as compared to sediments. Water column monitoring defines the nearfield as the area within a rectangle with sides 5 km from the outfall. Beyond that is the farfield, which includes the rest of Massachusetts Bay, Cape Cod Bays, and Boston Harbor. Benthic monitoring defines the nearfield as the area within 2 km of the new outfall. Beyond that is the midfield (2-7 km away) and the farfield (greater than 7 km).

Primary production – the process by which algae produce organic carbon from carbon dioxide through photosynthesis. Growth requires this carbon as well as nitrogen for protein and phosphorus for nucleic acids. In addition, silica is required by diatoms for their outer cell walls.

Primary treatment – wastewater treatment process involving solids removal via settlement and effluent chlorination prior to discharge. Primary treatment removes 30 to 35% of organic matter and 20 to 40% of toxic pollutants.

Priority pollutants – substances that the EPA has determined to be of national concern because of their toxicity at certain concentrations.

Redox potential discontinuity (RPD) – depth of oxygen penetration, or location where the sediments change from oxic (having oxygen) to anoxic. The RPD depth can be accurately measured using a microelectrode, but more readily can be estimated (apparent RPD) by visual examination of sediment cores or, more reliably, sediment profile images. The appearance of the oxygenated (aerobic) near-surface layer is light-colored; the deeper anaerobic (having no oxygen) layer is generally full of sulphides and looks dark blue or black.

Remineralization – Degradation of algal biomass into soluble components which are then available again for uptake and growth by other algae. The carbon, nitrogen, and phosphorus in particulate organic matter are decomposed to carbon dioxide, urea, nitrate, ammonia, and phosphate. Remineralization is the reverse of growth.

Replicates – multiple samples that are used to increase the reliability and accuracy, and reduce the uncertainty of experimental data.

Respiration – the process of dissolved oxygen consumption by living organisms. It is the reverse of photosynthesis.

Secondary treatment – wastewater treatment consisting of a combination of bacterial decomposition and a physical settling process. Secondary treatment results in removal of more than 75 to 90% of organic matter and most toxic pollutants prior to effluent discharge.

Sediment quality criteria/guidelines – sediment quality values established by EPA as guidelines to evaluate potential impacts to benthic organisms. Draft EPA sediment criteria exist for five organic contaminants: acenaphthene, fluoranthene, phenanthrene, dieldrin, and endrin. In addition, NOAA has developed effects- based sediment quality 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.

Stratification – the process of developing water column layers. Stratification is caused by differences in water density. Water density increases with decreasing temperature and increasing salinity. When the water column is unstratified, the density of the water is similar from top to bottom, and mixing of the entire water column can occur. When the water column is stratified, two distinct layers exist in the water column: the surface layer which is in contact with the atmosphere and the oxygen it contains, and the bottom layer which is isolated from sources of oxygen. These two layers are separated by strong differences in density.

Upwelling – a nearshore process involving the displacement of warm surface waters with colder, deeper waters. Upwelling is caused by westerly and southwesterly winds which blow surface waters away from the coast. Colder bottom waters move in toward shore, and then upwards to replace the warmer outgoing surface waters.

Water quality criteria – ambient concentration values that were established to protect aquatic life. Acute criteria values were developed to be protective of relatively short-term (generally less than 96 hours as measured in the laboratory) exposure to pollutants. Chronic criteria are values that provide protection from relatively long-term pollutant exposure.

Acronym Summary

BOD	biochemical oxygen demand
cBOD	carbonaceous biochemical oxygen demand
CHV	centrotubular hydropic vacuolation, a fish liver lesion
DECS	Detailed Effluent Characterization Study
DIN	dissolved inorganic nitrogen
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
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
FDA	U.S. Food and Drug Administration
LABs	linear alkyl benzenes
LC50	concentration for 50% lethality of bioassay test organisms
MADEP	Massachusetts Dept. of Environmental Protection
nBOD	nitrogenous biochemical oxygen demand
NMFS	National Marine Fisheries Service
NOAA	National Oceanographic and Atmospheric Administration
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
SEIS	Supplemental Environmental Impact Statement
TSS	total suspended solids
USGS	U.S. Geological Survey
WQC	Water Quality Criteria