Effluent Outfall Monitoring Plan
Phase I: Baseline Studies

Massachusetts Water Resources Authority

Environmental Quality Department

Report 1991-ms-2

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MASSACHUSETTS WATER RESOURCES AUTHORITY
EFFLUENT OUTFALL MONITORING PLAN
PHASE I: BASELINE STUDIES

November 7, 1991

MASSACHUSETTS WATER RESOURCES AUTHORITY
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COASTAL ZONE
MANAGEMENT

The Commonwealth of Massachusetts
Executive Office of Environmental Affairs
100 Cambridge Street
Boston, Massachusetts 02202

November 5, 1991

Dear Interested Reviewer:

The MWRA Outfall Monitoring Task Force welcomes your comments on the following *Draft Massachusetts Water Resources Authority Effluent-Outfall Monitoring Plan, Phase I: Baseline Studies*. In addition to written comments, public meetings will be held in four coastal communities. This document is the first phase of a long-term monitoring program which, when implemented, is designed to identify ambient conditions in Massachusetts and Cape Cod Bays. Once the outfall is operational, a long-term monitoring (Phase II) program will generate information to identify potential negative impacts on the ecosystem by comparison with baseline studies results.

This plan was prepared by the Massachusetts Water Resources Authority (MWRA) with the guidance of the MWRA Outfall Monitoring Task Force. This Task Force was formed at the request of the Massachusetts Secretary of the Executive Office of Environmental Affairs (EOEA) and is composed of scientists, state and federal agency personnel and environmental interest groups. The Task Force was asked to provide scientific and technical review as the plan was developed to meet the requirements of the Secretary's Decision of May 18, 1988 of the Final Environmental Impact Report (FEIR) for the MWRA secondary treatment facilities to provide a baseline of biological, geological, chemical and physical components. The US Environmental Protection Agency (USEPA) in its 1988 Record of Decision on the Final Supplemental Environmental Impact Statement (SEIS), also requires that MWRA establish an adequate statistical baseline and include regular sampling of water quality parameters, particularly of any that may exceed water quality standards.

The *Phase I: Baseline Studies* document is the result of several months of discussions and revisions. The Task Force agrees in principle with this plan and requests public and peer review in order to refine the proposed baseline and special studies before recommending endorsement of the plan.

Therefore, on behalf of the Task Force, I am requesting written reviews of this document to assist the Task Force in recommending revisions to MWRA. Once a *Final Phase I: Baseline Studies* monitoring plan is completed, the Task Force will prepare a written recommendation for Susan F. Tierney, Massachusetts Secretary of the

EOEA and Julie Belaga, Region I Administrator of the USEPA.

For the past year and a half, the Task Force has considered several issues in identifying key approaches that should be incorporated into a monitoring plan. Their goal was to shape a monitoring program which is more responsive to public and scientific concerns expressed in the review process of previous monitoring programs. The intent is to define meaningful changes in those parameters that provide an early warning signal of environmental health. For example, by the time low dissolved oxygen is detected in the bays, the system may already be stressed. Because of the Task Force's concern to include the best scientific judgement available, members are requesting additional peer reviews and have indicated the following issues and questions for comments. In addition, the Task Force is seeking public comments on the following list of topics, other scientific and technical aspects of the plan and/or other appropriate issues that will improve the overall robustness of the monitoring plan.

1. The strategy for developing this plan is based on recommendations of the National Research Council (NRC) in *Managing Troubled Waters: The Role of Marine Environmental Monitoring*, 1990. The process being used is discussed in the *Phase I: Baseline Studies* document and the management of that process is discussed in a separate document, *Administrative Process for Implementing the MWRA Monitoring Plan*. The NRC distinguishes between local and regional monitoring responsibilities. Because of the complexity of the Massachusetts and Cape Cod Bays ecosystem, the proposed Phase I study encompasses elements of local and regional monitoring for some parameters, e.g., nutrients and related variables. The monitoring plan discusses local and regional monitoring activities and defines the areal extent of the mixing zone, nearfield and farfield in the context of the MWRA proposed sampling program. It is presumed that, in the future, the state or the Massachusetts Bays Program will develop a regional monitoring program. One question that the committee would like to have addressed in comments is, **what parameters should regional monitoring plans address?**

2. There are several questions regarding the sampling design. **Will the sampling design detect changes both spatially and temporally? Is it possible to statistically detect trends? Is the sampling design, e.g., sampling replication and locations, sufficient to detect change around the outfall and in the farfield, adequate for a statistical power analysis?**

3. The Massachusetts and Cape Cod Bays ecosystem is complex and receives pollutants from a large number of sources. **If environmental degradation is demonstrated, can cause be assigned? As presented, will an implemented plan permit the**

establishment of cause-and-effect? Specific recommendations for the use of sewage tracers or other techniques are requested.

4. The outfall is scheduled to become operational in 1995. By then, there should be three years of baseline and special studies completed and the Task Force will be requested to evaluate the data to assist with development of decision making endpoints to serve as the baseline for future comparisons. These endpoints will be based on results from the *Phase I: Baseline Studies* using ambient values and detectable changes for selected variables. The intent is to identify early warning parameters where meaningful change can be detected and that complement regulatory standards, such as Massachusetts Water Quality Standards. **Upon implementation, will this monitoring plan assist with the development of decision making endpoints?**

5. Environmental changes as a result of nutrient enrichment may lead to unacceptable eutrophication. This plan proposes to monitor several variables that, together or singly, may be indicators of change due to nutrient enrichment, e.g., nutrients, phytoplankton and zooplankton biomass, plankton species composition, chlorophyll *a* and other water quality parameters, as well as sediment and benthic components. **Are all of these variables appropriate? What other measurements should be considered?**

The Task Force will review all scientific, technical and public comments and recommend revisions to MWRA on the *Phase I: Baseline Studies* plan. MWRA is committed to implementing the *Phase I: Baseline Studies* plan in time to catch the spring 1992 phytoplankton bloom. It may not be possible to respond individually to all comments within this time frame although they will be reviewed and considered by the Task Force. Based on the revisions of Phase I, the Task Force will draft written comments on the acceptability of the Phase I plan for Susan F. Tierney, Massachusetts Secretary of EOEA and Julie Belaga, Region I Administrator of USEPA and will request implementation of the baseline study. Copies of the *Draft MWRA Effluent-Outfall Monitoring Plan, Phase I: Baseline Studies* are available at public libraries in cities and towns bordering Massachusetts and Cape Cod Bays and at MWRA. For additional information on availability, contact Bernadette McCarthy of the MWRA at (617) 242-6000.

A companion document, *Administrative Process for Implementing the MWRA Monitoring Plan* describing the review and management of the monitoring program over the next several years is also available at the same locations. This document focuses on the role of the Task Force and its successor in reviewing data from Phase I studies; revising Baseline studies as appropriate; advising on development of Phase II monitoring activities; and identifying meaningful levels of change of selected variables.

Comments on both documents will be accepted until December 7, 1991 and should be sent to

Dr. Judith Pederson, Chairman
MWRA Outfall Monitoring Task Force
Massachusetts Coastal Zone Management
100 Cambridge Street, Room 2006
Boston, MA 02202
FAX number is (617) 727-2754.

I look forward to your participation at the public meetings and through written comments which can only serve to strengthen the monitoring plan.

Sincerely yours,

Judith Pederson, Ph.D.
Chairperson
MWRA Outfall Monitoring Task Force

JP:jp

ACKNOWLEDGEMENTS

The Massachusetts Executive Office of Environmental Affairs organized an Outfall Monitoring Task Force to provide advice, guidance, and oversight during the development of the MWRA Outfall Monitoring Plan. The membership (as of 11/91) of the Task Force is:

Pederson, Judith	Massachusetts Coastal Zone Management (chair)
Barr, Brad	Massachusetts Coastal Zone Management (alternate)
Boehm, Paul	Arthur D. Little Inc.
Bothner, Michael	U.S. Geological Survey
Bradley, Polly	Safer Water In Massachusetts
Bridges, Leigh	Massachusetts Department of Marine Fisheries
Gallagher, Eugene	University of Massachusetts at Boston
Geyer, Rocky	Woods Hole Oceanographic Institution
Gould, Diane	Massachusetts Bays Program
Hubbard, William	U.S. Army Corps of Engineers
Isaac, Russell	Massachusetts Department of Environmental Protection
Labonte, Janet	U.S. Environmental Protection Agency (alternate)
Liebman, Matthew	U.S. Environmental Protection Agency (alternate for MBP)
Lipman, Steven	Massachusetts Department of Environmental Protection (alt.)
Mayo, Stormy	Center for Coastal Studies
McCabe, Janet	Massachusetts Environmental Protection Act Office
Montoya, Joseph	Harvard University
Moore, Michael	Woods Hole Oceanographic Institution
Nickerson, Susan	Association for the Preservation of Cape Cod
Shepardson, David	Massachusetts Environmental Protection Act Office (alternate)
Stelle, Will	U.S. House of Representatives Committee on Merchant Marine
Tomey, David	U.S. Environmental Protection Agency
Wallace, Gordon	University of Massachusetts at Boston

Additional input to this monitoring plan was provided by

Blake, James	Science Applications International Corporation
Connor, Michael	Massachusetts Water Resources Authority
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1.0 INTRODUCTION

The Massachusetts Water Resources Authority (MWRA) is responsible for the construction and operation of an effluent outfall from the new Deer Island Wastewater Treatment Plant. The new outfall will be located in Massachusetts Bay approximately 15 km from the Deer Island Plant at a water depth of 32 m (Figure 1). Improved effluent treatment, cessation of sludge discharge, and moving the wastewater discharge from within the confines of Boston Harbor is expected to result in a significant improvement in water and sediment quality within the Boston Harbor area without causing harm to the environment of Massachusetts and Cape Cod Bays (EPA, 1988a). Operation of the new outfall is scheduled to begin in July 1995, initially with effluent from upgraded primary treatment, secondary treatment is scheduled to be phased in from October 1996 to December 1999.

The MWRA effluent outfall will be regulated through a permit issued by the Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (DEP) under the National Pollutant Discharge Elimination System (NPDES). In addition to monitoring compliance with the new NPDES permit, additional monitoring will be necessary to assess the impact of the discharge and to collect data that would be useful for new outfall management considerations (EPA, 1988b). This document describes a monitoring program to address both NPDES monitoring and additional monitoring related to possible impact of the outfall discharge. In general, the conceptual approach that was used to develop this monitoring plan followed guidelines recommended by the National Research Council (NRC, 1990a). Also, this monitoring plan was developed under the guidance and full participation of an Outfall Monitoring Task Force that was established by the Massachusetts Executive Office of Environmental Affairs (EOEA) and fulfills both EPA and State policy (see page 9).

The focus of this document is on the technical elements of monitoring rather than on policy issues. As agreed by the Outfall Monitoring Task Force, policy issues such as enforcement of environmental regulations or development of mechanisms for making management decisions related to monitoring are the subject of a companion document by the EOEA on administrative processes for outfall monitoring. However, at points throughout this document, possible interfaces between technical and policy issues are indicated.

Also by agreement of the Outfall Monitoring Task Force, this document provides details of a baseline monitoring strategy (Phase I of the monitoring program) to describe baseline conditions such that meaningful changes from these conditions could be detected and related to the outfall after the effluent discharge commences in 1995. Details of postdischarge monitoring (Phase II of the monitoring program) will be provided in a subsequent monitoring plan document prior to commissioning the outfall in 1995. This monitoring plan is not a strategy to assess comprehensively the present condition of the near coastal ecosystem in Massachusetts and Cape Cod Bays, even though some of the measurements

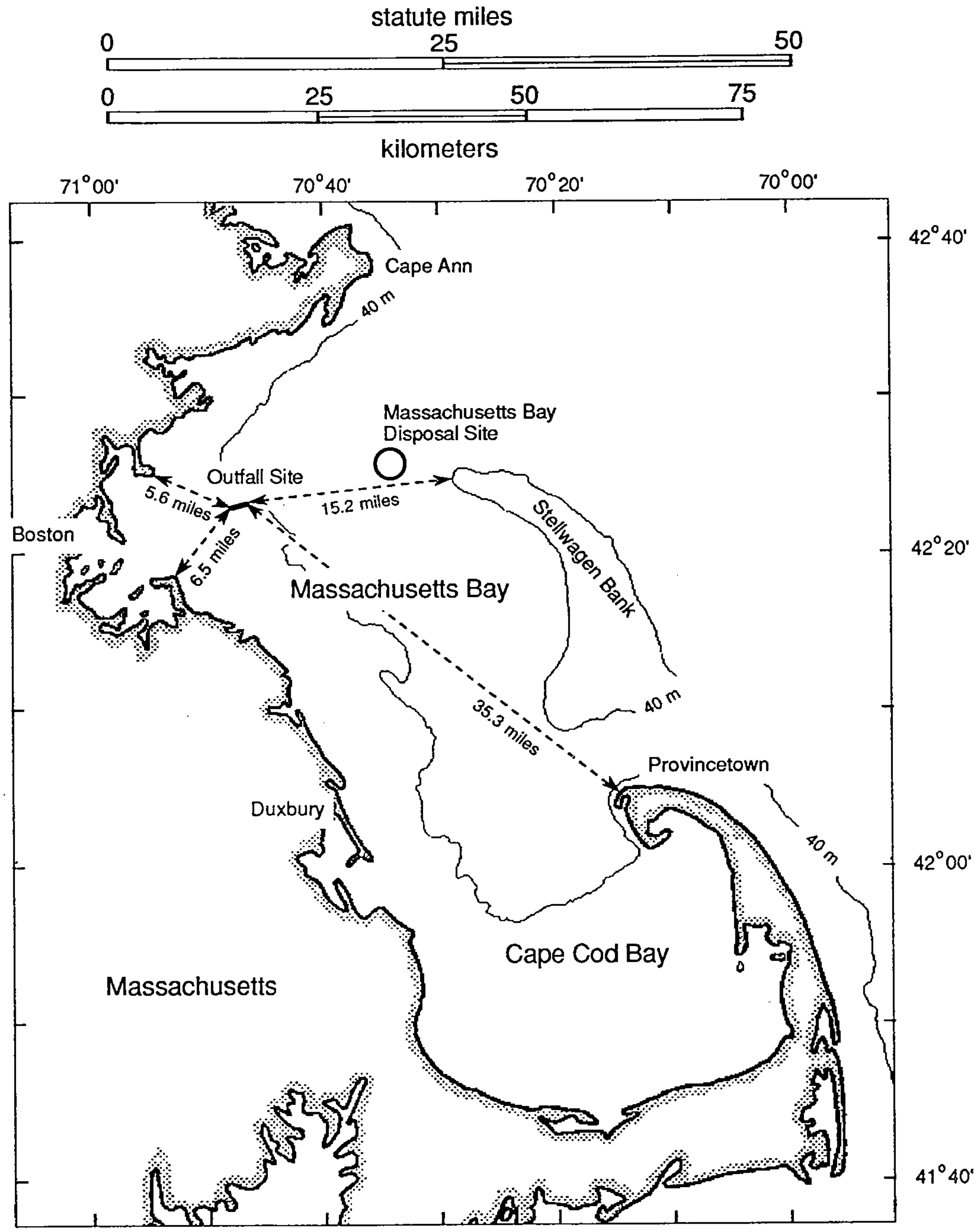


Figure 1. Massachusetts and Cape Cod Bays

would be useful for that purpose. In addition, no judgement (or assumptions) is made in this document about the acceptability of baseline conditions, the outfall site, or the level of effluent treatment.

Meaningful change, in the sense used here, has two facets: the nature of change and the magnitude of change. With respect to the nature of change, the many biological, chemical, and physical measurements were chosen to include an appropriate range of features by which to describe important aspects of the complex offshore ecosystem. Measurements were chosen to address those features that have been identified as important general public concerns and/or specifically prescribed by State and Federal regulations. Additional measurements were identified by scientists and the Outfall Monitoring Task Force based on technical considerations. Such technical concerns include, but are not limited to, whether a measurement is likely to be useful in detecting a change that might be caused by the proposed MWRA discharge and whether there is any reasonable expectation of being able to establish cause and effect.

With respect to the magnitude of change, the plan provides highest capacity to detect change where change is most expected, where it is most likely detectable, and where, in the most scientifically defensible manner, it would be ascribable to discharge from the proposed outfall. In general, these criteria dictate a spatial sampling design biased to be near the proposed outfall diffusers. Even so, baseline studies extend throughout Massachusetts and Cape Cod Bays, and these will provide some potential for later tracing a path of change carried further than is presently projected. It is possible to suggest (from historical data on some measurements) what magnitude of change is likely to be detectable by a given sampling design; however, for a number of measurements the baseline monitoring itself will provide information to define or refine estimates of the level of detectable change. Therefore, during the baseline period the monitoring scope may be adjusted to enable greater power to detect change if initial data indicate strong deficiencies. The mechanism for instituting modifications to the sampling design will be through annual assessments of the monitoring data by the Outfall Monitoring Task Force and/or other oversight committee.

There are certain measurements for which the meaningful level of change may be specified by the new NPDES permit or State standards. For these, of course, the methods and measurements must provide for detection of magnitudes of change that are specified as acceptable (i.e., a certain threshold or numerical standard is not exceeded). However, existing State standards may not be adequate to detect meaningful changes early enough (e.g., the depression of dissolved oxygen below the State standard may be followed too rapidly by biological effects), so additional measurements will be made as an early warning to violation of State standards. Additional non-standards-based measurements will be made to provide sufficient understanding of environmental/ecological processes to evaluate the cause of detected changes and to identify any additional monitoring or mitigation that might be necessary. These additional measurements do not address regulatory standards because the scientific support for required for regulatory enforcement is lacking, thus, defining a meaningful level of change in these parameters can be very difficult or impossible. However, the measurements are to provide decision-level guidance (referred to as decision endpoint in the EOEA document on administrative processes for outfall management). Therefore the measurements are a very important component of this monitoring plan and their synthesis and interpretation will be presented annually to the Outfall Monitoring Task Force and/or other oversight committee for review and comment.

The function of this technical monitoring plan is to provide sufficient information to develop a baseline from which, first and foremost, we can detect outfall-caused change across a diversity of meaningful potential changes. Change should be detected as early as possible, recognizing the significant constraints imposed by an ecologically complex and dynamic situation. The strategy is to provide detection of meaningful changes at levels far below, and hence prior in time to, those which could be judged to be of great concern.

Following this brief introduction to the philosophy for development of the plan, Section 2.0 of this document provides a brief description of the Massachusetts and Cape Cod Bays environment and lists recent and ongoing exploratory studies conducted by the MWRA and others. Section 3.0 describes the general framework of the monitoring program, especially as it relates to the NRC guidelines. The objectives of the monitoring plan are discussed in Section 4.0. The monitoring strategy is summarized in Section 5.0, and includes a list of environmental responses that might result from the outfall discharge. These environmental responses were translated into a series of monitoring questions and an associated sampling and measurement plan. A summary of the sampling plan is given in Section 6.0. The implementation of the sampling plan is discussed in Section 7.0, which includes a sampling schedule and estimated costs for the monitoring program. Discussion of the conceptual model that was used to identify these responses is given in Appendix A. The sampling plan and its rationale are discussed in detail in Appendix B.

2.0 BACKGROUND INFORMATION

2.1 CHARACTERISTICS OF MASSACHUSETTS BAY

Massachusetts Bay is defined as being within the area that is enclosed by Cape Ann to the north, an eastern limit extending southeastward to Provincetown at the tip of Cape Cod, and a southern limit from Provincetown westward to Duxbury (Figure 1). There are two prominent bathymetric features in Massachusetts Bay: Stellwagen Bank (20 - 40 m deep) near its eastern boundary and Stellwagen Basin (ca. 80 - 100 m deep) just west of Stellwagen Bank. The distribution of bottom sediments in Massachusetts Bay is highly variable. The area in the immediate vicinity of the proposed outfall is nondepositional, but significant variations in bottom type occur on the horizontal scale of tens of meters (M. Bothner, personal communication, 1991).

Most of Massachusetts Bay stratifies during the summer months, with a stable pycnocline (the boundary between layers of different density) forming at about 10 m in July, although variations can occur during the tidal cycle. In late summer, the pycnocline deepens (15 - 25 m), and fall turnover occurs during October-November. Large freshwater inflows from the north, including the Merrimack River (and others) and more localized land runoff during the spring can cause transient stratification (EPA, 1988a). Currents in Massachusetts Bay near the proposed MWRA outfall are driven largely by tidal action. Nontidal currents are generally thought to be dominated by a counterclockwise circulation, but recent studies indicate the presence of more complicated current patterns. Bothner (personal communication, 1991) has indicated that movement of water close to the proposed outfall location (at buoy B, about 1 km to the southeast) can be restricted at times to within about 10 km over a 2-day period. Ongoing studies are evaluating short-term net current vectors under a variety of conditions because present projections are based on a limited data set. Over a longer period, surface water often moves to the south, and exits the Massachusetts and Cape Cod Bays region north of Provincetown with a time scale of two to four weeks, based on recent drifter studies (R. Geyer, personal communication, 1991). Winds and freshwater inflow (e.g., from the Merrimack River) can perturb these large-scale flow patterns (EPA, 1988a).

There have been several reviews of specific issues related to Massachusetts and Cape Cod Bays in recent years. A summary of the Massachusetts Bay environment was presented in the Supplemental Environmental Impact Statement (SEIS) for the proposed MWRA outfall (EPA, 1988a). A critical review of chemical and biological information on the benthic environment in Massachusetts and Cape Cod Bays was prepared by Shea *et al.* (1991). This report also presented an overview of the sedimentary environment. A review of phytoplankton data collected prior to 1990 in Massachusetts Bay was prepared recently (Cura, 1991). Kelly (1991) prepared a synthesis of eutrophication issues in Massachusetts Bay based on recent data for nutrients, chlorophyll, and dissolved oxygen (DO) in the water column. A similar review for toxic contaminants is in preparation (Shea and Kelly, manuscript in preparation). All of these studies and reviews have provided scientific guidance toward the development of the monitoring plan.

2.2 EXPLORATORY STUDIES

Even as the MWRA is in the process of developing the outfall monitoring plan, monitoring of baseline conditions at the outfall vicinity has already begun. Eutrophication and transport of sediments and particles have been foci of the MWRA's baseline monitoring. To this end, the MWRA has entered into a Cooperative Research Agreement with the Bigelow Laboratory for Ocean Sciences of Boothbay Harbor, Maine, to characterize the general oceanographic conditions in Massachusetts Bay (Townsend *et al.*, 1990) and with Boston University to analyze the variability in primary production using remote sensing (Michelson, 1991). The MWRA has also entered into a Joint Funding Agreement with the Geological Survey (USGS) to study long-term circulation and pollutant transport in Massachusetts and Cape Cod Bays (Bothner *et al.*, 1990). Ongoing histopathological studies are providing information on the physiological condition of winter flounder at locations in Boston Harbor, Massachusetts Bay, and Cape Cod Bay (M. Moore, personal communication, 1991). Additional research studies such as benthic respiration and nutrient flux measurements (Giblin *et al.*, 1991) and an evaluation of water-quality model structures (Normandeau, 1990) have also been completed recently. All of these studies build on an extensive characterization of the outfall area for the purpose of deciding where to site the outfall (MWRA, 1988).

In addition to studies funded by the MWRA, there are other monitoring/research programs that could enhance the MWRA monitoring program. The Massachusetts Bays Program is funding research on the physical oceanographic conditions, nutrient levels, and phytoplankton in both Massachusetts Bay and Cape Cod Bay. The Gulf of Maine (GOM) Monitoring Plan was recently released (GOMWG, 1990) and implementation could begin to provide some regional information by 1992. The EPA is scheduled to begin implementing its Environmental Monitoring and Assessment Program (EMAP) in the Acadian Province in 1993, and may include stations in Massachusetts and Cape Cod Bays. Since 1984, the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program has been actively monitoring Massachusetts Bay through the Mussel Watch and Benthic Surveillance Programs. Numerous other research efforts are conducted regularly by the New England Aquarium, the Center for Coastal Studies in Provincetown, and local colleges, universities, and oceanographic institutions. Formal arrangements with State and Federal agencies and private groups to coordinate these other research and monitoring programs with the MWRA effluent outfall monitoring program could yield an effective regional monitoring program for Massachusetts and Cape Cod Bays.

3.0 FRAMEWORK OF THE MONITORING PROGRAM

This monitoring plan has been developed using the general conceptual approach recommended by the National Research Council (NRC, 1990a), and draws upon past experience with stepwise approaches to monitoring (e.g., Zeller and Wastler, 1986) that have been implemented at the 106-Mile Deepwater Municipal Sludge Dump Site (Battelle, 1988a,b, 1990) and 301(h) monitoring programs (EPA, 1987), particularly those implemented in Southern California (NRC, 1990b). The framework for designing and implementing the outfall monitoring program is summarized in Figure 2 (NRC, 1990a). This document focusses on Steps 1, 2, and 4 in Figure 2, although all steps are discussed at some level.

The process began with a definition of expectations and goals (Step 1, Figure 2) based on public concerns, regulations and permits, and relevant scientific information. The second step was to develop the overall monitoring strategy. This required the identification of resources at risk (of meaningful change) and sources of perturbation, thereby narrowing the list of environmental problems to those that should and can be addressed by the outfall monitoring program. A conceptual model of how the effluent discharge will interact with the marine environment was developed to make qualitative predictions of how the environment will respond to this new source of perturbation (i.e., possible environmental responses). These responses were then phrased in terms of questions (and at a later date stated as quantitative hypotheses) that can be tested by making environmental measurements. The sampling design (Step 4) was then developed to link the questions to useful information. This required a scientific judgment about the choice of measurements and the level of spatial and temporal resolutions of the monitoring. After more baseline data are obtained, statistical models will be employed with tests of power and optimization to better quantify the questions and numbers of measurements required to answer these questions (Can meaningful changes be detected at the required level?).

Exploratory studies (Step 3) are a necessary aid to setting permit requirements, to developing models and predictions, and to answering some basic scientific questions. These studies help to define the monitoring objectives (Step 1), overall monitoring strategy (Step 2), sampling design (Step 4), and implementation plan (Step 5). Results of exploratory studies are also used to interpret monitoring data to produce information that is useful for managers (Step 6). Thus, the exploratory studies and other research results (from the literature) are important throughout the entire monitoring design and implementation process. Several recent exploratory studies in Massachusetts and Cape Cod Bays are listed in Section 2.0.

The development of a monitoring strategy and sampling design is an iterative process that requires input from exploratory studies, regulatory agencies, and formal external review. With respect to monitoring for the MWRA effluent outfall, public concerns have been identified, but to date the information on permit requirements and on some critical scientific issues is incomplete. As new information is received over the next few years, the monitoring objectives and strategy will be refined and presented in the postdischarge monitoring plan.

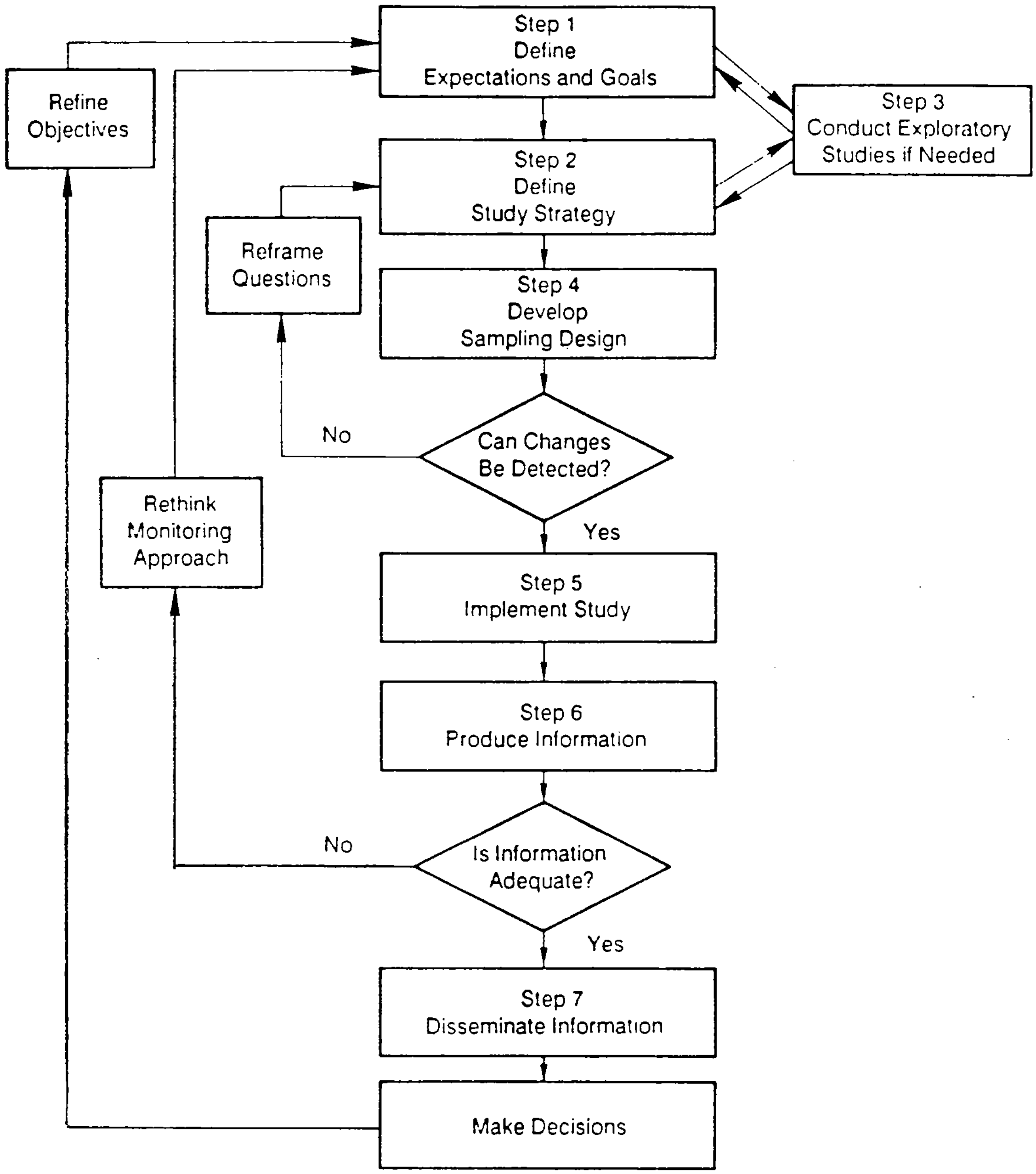


Figure 2. Elements of designing and implementing a monitoring program. [From NRC, 1990a]

4.0 EXPECTATIONS AND GOALS OF THE MONITORING PROGRAM

The general aim of an environmental monitoring plan is to establish a scientifically defensible, statistically valid, cost-effective sampling and analytical program that will provide regulators and other environmental managers with information that is useful in making management decisions (e.g., mitigation actions, treatment plant operations, future permits). At the same time, a monitoring plan must include a logical link between environmental measurements and the concerns of the public. Establishing the monitoring objectives requires the identification of critical public concerns, regulatory requirements, and critical scientific issues. Sections 4.1 through 4.4 describe the process shown in Step 1 of Figure 2.

4.1 IDENTIFICATION OF PUBLIC CONCERNS

During preparation of the Secondary Treatment Facilities Plan (MWRA, 1987), the Citizens Advisory Committee identified the following general questions of public concern regarding Massachusetts and Cape Cod Bays.

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

These questions are broad enough to encompass the concerns of MWRA management, natural resource managers, and the scientific community, but are too general for direct translation into a set of monitoring measurements. Refinement of these public questions into more specific (testable) questions follows from the identification of regulatory concerns and critical scientific issues.

4.2 IDENTIFICATION OF REGULATORY REQUIREMENTS

In accordance with the Certificate from the Secretary of the Executive Office of Environmental Affairs (May 18, 1988), an MWRA Outfall Monitoring Task Force was formed to provide the MWRA with guidance on developing the monitoring plan (i.e., this document) and to make specific recommendations for monitoring. As part of this process, EPA has provided the MWRA with a proposed set of measurements to address both NPDES permit compliance and the additional monitoring to assess any potential impact (Manfredonia, 1991).

The MWRA effluent outfall will be regulated through a permit issued by EPA and DEP under the National Pollutant Discharge Elimination System (NPDES). Additional monitoring was recommended in accordance with the EPA Record of Decision on the Final SEIS (EPA, 1988b), which states

> *A monitoring program relative to the proposed discharge should be developed in cooperation with the new State/Federal Massachusetts Bay/Cape Cod Bay Program. The goals of the monitoring program would be to document the impacts of the discharge within the bounds projected by the Draft and Final SEIS and to collect data that would be useful for future outfall management considerations. The monitoring effort should be keyed into those parameters used to determine the degree of environmental impact from the effluent discharge such as dissolved oxygen level and consistency with EPA Water Quality Criteria. These results could then be used to assess the necessity and implementability of potential mitigation measures. EPA recommends that a State/Federal agency working group, in coordination with the newly formed Massachusetts Bay/Cape Cod Bay Technical and Citizen Advisory Committees, develop the specifics of the monitoring program. This group should establish specific discharge monitoring goals, review the existing database, and make recommendations on the type and extent of the monitoring program to be undertaken. EPA will actively participate on the Technical Advisory Committee for the program and will review proposals and data reports, and make recommendations for further study needs and potential mitigation requirements . . . permanent sampling stations can be established for periodic collection of oceanographic, chemical and biological data. Several years of preoperational data will be required to establish an adequate statistical baseline. Once the outfall is operational, periodic sampling can be statistically compared with baseline to quantify potential discharge impacts. EPA feels that the monitoring should include at least:*
>
> - *Periodic sampling of water quality parameters, such as dissolved oxygen, nutrients, and phytoplankton production, and*
> - *Regular sampling for those parameters identified as exceeding water quality criteria (PCBs, pesticides, mercury, copper, and arsenic) in the water column, sediments and tissues of ecologically sensitive and economically important aquatic species.*
>
> *This should be done in conjunction with any regular discharge sampling or bioassay/ bioaccumulation testing that may be required in the new NPDES permit to assess long term effects of the discharge.*

The monitoring plan presented in this document was based on information received from the Outfall Monitoring Task Force (and others) as of October 21, 1991. This document contains a proposed set of questions and measurements that should satisfy the requirements of the new NPDES permit. Also, the plan should satisfy the additional requirement to provide an adequate statistical baseline to assess postdischarge impact, as well as address other technical and public concerns voiced by the Outfall Monitoring Task Force. The measurements proposed in this document can be easily modified when the actual NPDES permit is issued and as new information becomes available. The formal mechanism for modification of this monitoring plan is being developed by the EOEA.

4.3 IDENTIFICATION OF SCIENTIFIC ISSUES

The public and regulatory concerns discussed above relate to four categories of possible anthropogenic perturbation to the environment, based on scientific studies and past experience throughout the Nation's coastal waters:

- Enrichment of nutrients and organic carbon (eutrophication) and suspended particulate matter (physical disturbance)
- Exposure of marine life and humans to toxic chemicals
- Exposure of marine life and humans to pathogens
- Visual (esthetics) degradation of the water (clarity, color, and floatable wastes).

These four categories of possible perturbation encompass the general public and regulatory concerns and have been used to derive more specific questions that can be addressed through monitoring.

4.4 DEFINITION OF MONITORING OBJECTIVES

Marine environmental monitoring programs can cover a broad spectrum of spatial scales. Local monitoring near a major discharge site (to verify permit compliance) usually encompasses areas ranging from about 10 to 100 km^2 (NRC, 1990a). By contrast, regional monitoring of a near-coastal area (e.g., Massachusetts and Cape Cod Bays, Gulf of Maine) can have spatial scales exceeding hundreds of square kilometers. The roles of local and regional monitoring programs in managing the marine environment have been reviewed by the NRC (1990a). The potential for local versus regional monitoring programs to address various management objectives is summarized in Table 1. The role of a local, site-specific monitoring program (such as the MWRA monitoring program) should focus on the effects of the specific point source. In contrast, a regional monitoring program must provide a means for addressing specific questions about the environmental condition of the entire region and the cumulative effects of all sources of pertubation to the resources within the region.

In addition, the NRC identified regional monitoring programs as having the greatest potential to contribute information to effectively manage the coastal marine environment and that both State and Federal governments have the responsibility to develop and implement regional monitoring programs. The NRC recommends that specific dischargers should participate in a centrally coordinated regional monitoring effort, but there is presently no regional monitoring program for Massachusetts and Cape Cod Bays. Following the recommendations of the NRC, the MWRA monitoring program will be as centrally coordinated and as nonfragmented as possible.

Table 1. **Potential for Environmental Montoring Programs to Contribute to Management Objectives.**

Objective	**Scale of Monitoring Program**	
	Site-Specific	Regional
Permit compliance	**High**	Low
Measure effects of specific source	**High**	Moderate
Evaluate effects of source abatement	**High**	Moderate
Determine public health risks	**High**	Moderate
Assess risks to living resources	Low	**High**
Address public concerns	Moderate	**High**
Assess cumulative effects	Low	**High**
Place effects in context of natural variation	Moderate	**High**
Set State environmental priorities	Moderate	**High**

Adapted from National Research Council (1990). *Managing Troubled Waters: The Role of Marine Environmental Monitoring.* National Academy Press, Washington, DC.

A site-specific monitoring program has great potential to address management objectives directly related to the point source that is being regulated, particularly where compliance is concerned. However, assessing the broader issues of risks to living resources, cumulative effects from multiple sources, and public concerns of regional (e.g., Massachusetts and Cape Cod Bays) environmental health is best addressed through a regional monitoring program. This limits the role and effectiveness of the MWRA effluent outfall monitoring program to objectives that are linked directly to measurable changes that might be caused by the outfall discharge and are confined to appropriate spatial scales (focused on the nearfield, but including the farfield). As described in the introduction, this outfall monitoring plan is designed to detect meaningful change as a result of outfall discharging, i.e., monitoring for the effects of the outfall rather than assessing the overall environmental condition of the region. The MWRA outfall monitoring plan is set at the scale, and has the primary objectives of, a site-specific plan as described in Table 1. Additionally, however, in order to establish a broad baseline upon which to detect meaningful change, there are many measurements included in the MWRA outfall monitoring plan that are far removed from the point source itself and would be categorized under the regional scale of monitoring (along with the associated objectives) in Table 1. Thus, the MWRA monitoring program will be a valuable aid to environmental managers, when a comprehensive regional and/or state monitoring and management program is developed.

From the discussion above, two broad objectives of the MWRA effluent outfall monitoring program can be identified.

Objective 1: Test for compliance with future NPDES permit requirements

Objective 2: Test whether the impact of the discharge on the environment is within the bounds projected by the SEIS

The first objective is readily achievable with unambiguous, quantitative questions and measurements, once the new NPDES permit has been issued. The second objective is more difficult to achieve. The EPA Record of Decision (see Section 4.2) requires that monitoring test whether the impacts of the outfall are within the bounds projected by the SEIS. This assumes that the projected environmental responses given in the SEIS are accurate and acceptable. Therefore, monitoring related to this second objective must provide information to test the accuracy of models and assumptions used in the SEIS (or in improved models that might be developed) by assessing the robustness of the predictions. This will ensure adequate verification of possible impact and provide regulators and managers with useful data to make future outfall management decisions. The formal mechanism for making these decisions has not been determined by the Outfall Monitoring Task Force and is beyond the scope of this document.

5.0 MONITORING STRATEGY

The second step in the NRC monitoring design process (Figure 2) is to define the study strategy. This step is described below, and implicitly drew upon many of the exploratory studies given in Section 2.2 (Step 3 of Figure 2). To develop the monitoring strategy, the two general monitoring objectives identified above were translated into more specific questions that could be tested. This approach required the development of a conceptual model that would help to focus a large number of possible questions on those that will produce the specific information needed to meet the two objectives given above. A simple, qualitative conceptual model of the at-risk resources in Massachusetts and Cape Cod Bays, of the various sources of perturbation, and of the complex biogeochemical processes that influence the environmental response to these perturbations is presented in Appendix A.

Given the diversity of perturbation sources in Massachusetts and Cape Cod Bays and their different spatial scales, a primary conclusion of the conceptual modeling exercise (Appendix A) was that monitoring should be directed at measuring (assessing) local effects, with reference measurements made farther away from the outfall and some measure of the transport and fate of effluent contaminants beyond the local region. The spatial scale of monitoring can be either expanded or contracted if indicated by baseline or postdischarge monitoring results. In general, the simple modeling exercise revealed that the most appropriate components for MWRA's monitoring program are those that

- Are likely to be highly influenced by the MWRA outfall, but less so by other sources
- Have a predominantly local spatial scale of concern (although larger scales may have greater ecological significance)
- Have an associated measurement(s) that is likely to have high utility as an indicator of change

This qualitative assessment (Appendix A) provides an effective starting point for the identification of possible environmental responses to be monitored. Identification of these responses was made through the selection of resources at risk (particularly those that owe a large part of that risk to the MWRA outfall), an assessment of possible change to and impact on those resources, consideration of the transport and fate processes that cause or mitigate such impact, identifying environmental trends that should be monitored, and identifying information gaps. As more baseline data are obtained, an updated synthesis and review of available information and the possible environmental responses will be presented to the Outfall Monitoring Task Force for annual review and comment. This review will be used to modify (and quantify in terms of specific testable hypotheses) the possible environmental responses given below.

The qualitative conceptual model (given in Appendix A) has been translated into a series of possible environmental responses to the outfall discharge. At present, the information is insufficient to make quantitative predictions about probable environmental responses (particularly for enrichment/eutrophication issues) and, thus, corresponding null hypotheses have not yet been developed. However, listed below are a set of possible environmental responses, posed as questions, from which more specific, testable questions were derived that form the basis for deciding on appropriate measurements (see Section 6.0). The possible responses (designated R-*n*) are categorized by the four broad questions raised by the public, and are further separated into the four categories of potential environmental perturbation: enrichment, toxics (toxicants), pathogens, and visual degradation.

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

Perturbation: ***Toxics***

R-1 Will toxic chemicals accumulate in the edible tissues of fish and shellfish, and thereby contribute to human health problems? (see also R-7)

Perturbation: ***Pathogens***

R-2 Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissue of shellfish and contribute to human health problems?

Public Concern: Are natural/living resources protected?

Perturbation: ***Enrichment***

R-3 Will nutrient enrichment in the water column contribute to an increase in primary production?

R-4 Will enrichment of organic matter contribute to an increase in benthic respiration and nutrient flux to the water column?

R-5 Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?

R-6 Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment?

R-7 Will nutrient enrichment in the water column contribute to changes in plankton community structure (species composition, biomass, and vertical distribution)? Such changes could include stimulation of nuisance or noxious algal blooms and could affect fisheries (see also R-1 and R-15).

R-8 Will benthic enrichment contribute to changes in the community structure (species composition and biomass) of soft-bottom and hard-bottom macrofauna, possibly also affecting fisheries?

Perturbation: ***Toxics***

R-9 Will the water column near the diffuser mixing zone have elevated levels of some contaminants?

R-10 Will contaminants affect some size classes or species of plankton and thereby contribute to changes in community structure (species composition, biomass, and vertical distribution) and/or the marine food web?

R-11 Will finfish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations?

R-12 Will the benthos near the outfall mixing zone and in depositional areas farther away accumulate some contaminants?

R-13 Will benthic macrofauna near the outfall mixing zone be exposed to some contaminants, potentially contributing to changes in community structure (species composition and biomass)?

Public Concern: Is it safe to swim?

Perturbation: *Pathogens*

R-14 Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?

Public Concern: Are esthetics being maintained?

Perturbation: *Visible Degradation*

R-15 Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species (see also R-7)?

R-16 Will the loading of floatable debris (e.g., plastics) increase, contributing to visible degradation?

These responses are not predictions of probable impact. Rather, they are possible environmental responses that have been considered while developing the sampling and measurement plan. Results from continued baseline monitoring and special studies over the next several years will be used to develop a more quantitative estimate of the possible responses and changes. This will lead to a refinement of the list of possible environmental responses, and the development of predicted quantitative responses (with some estimate of uncertainty) and corresponding null hypotheses. This is part of the iterative process shown in Figure 2 and being formalized by the EOEA. The development of quantitative predictions and hypotheses is beyond the scope of this document. For now, these possible responses are simply restated as a more specific question or set of questions that can be tested by monitoring environmental parameters (see Figure 3).

6.0 SAMPLING DESIGN

Following the NRC model (Figure 2), Step 4 is to develop a sampling design. The basic strategy of this monitoring plan is to take measurements of the loading, movement, and fate/impact of matter discharged from the outfall and, when necessary for proper interpretation of monitoring data, to conduct special studies to better understand relevant physical and biogeochemical processes. Several types of monitoring studies will be used.

1. Effluent monitoring
2. Water-column monitoring of nutrients and plankton both nearfield and farfield
3. Nearfield and farfield benthic monitoring
4. Monitoring fish and shellfish for contamination and physiological condition
5. Special studies of water circulation and particle fate, effluent tracers, benthic nutrient flux and denitrification, effluent plume tracking, and others

These monitoring studies and the overall sampling design are discussed in detail in Appendix B.

This sampling design will facilitate the interpretation of monitoring results with respect to cause and effect and predictions/modeling of impact. For example, the measurement of water-column contaminants at fixed or random sampling stations will answer questions about whether water-quality criteria are exceeded, but it will offer little information on why the levels were observed or what would be expected in the future. If the same measurements were made during a plume-tracking exercise, exceedances of water-quality criteria could be evaluated (from worst case to background), along with estimates of dilution and modeling of transport and fate. If effluent-specific tracers (e.g., *Clostridium*) also are measured, cause-and-effect relationships may be developed with greater certainty. This design strategy is discussed briefly here to introduce the overall sampling plan before individual measurements are discussed.

The proposed spatial scale that defines nearfield and farfield is shown in Figure 3b. The inner box (1.5 km^2) represents the approximate boundary between the mixing zone and the nearfield region. The actual mixing zone dimensions will be based on estimates of the effluent dilution (EPA, 1988a) and will be written into the new NPDES permit, but these dimensions have not yet been defined by EPA and the State. The outer box represents the boundary between the nearfield and farfield as defined here. This boundary is about 5 km (twice the length of a tidal excursion) from the diffuser in the direction of tidal currents (east/west) and 5 km from the diffuser in the direction perpendicular to the tidal currents. This area appears to coincide with the movement of the majority of the surface water within a 48-h period under unstratified conditions in one model projection using a time series of current-vector data (Bothner, personal communication, 1991). In addition, model predictions (EPA, 1988a; Kelly, 1991; Shea and Kelly, manuscript in preparation) indicate that easily detectable changes outside the larger box are unlikely, based on present understanding of diffusive and advective processes in the area (see Appendix B for more detail). There have also been numerous studies in this nearfield region that characterized the water column, sediments, and biota to provide adequate information to determine the site of the outfall (MWRA, 1988; EPA, 1988a), although most of these studies were not designed with the specific intent to detect change from these baseline conditions.

The monitoring questions and the associated sampling and measurement plan are discussed in detail in Appendix B and summarized below in a series of maps (Figure 3). The environmental responses from above (e.g., R-1) corresponding to each question are listed after each question. Questions that are likely to be part of the new NPDES permit (Manfredonia, 1991) are identified with **[NPDES]** after the question. Further detail on the sampling design and rationale for choosing specific measurements are given in Appendix B.

Prior to implementing the monitoring plan (Step 5 in Figure 2) the monitoring design will be reviewed by the Outfall Monitoring Task Force to determine whether meaningful environmental changes can be detected. Additional scientific and public review may be part of this process. As baseline monitoring data become available, the continuing review process (Figure 2) will include synthesis and interpretation of baseline data and a reassessment of the capability of the monitoring design to detect meaningful environmental change as well as to determine cause and effect. As discussed above, specific magnitudes of change that are considered meaningful are not given in this document (see questions in Figure 3); these can only be specified after the NPDES permit for the new outfall has been issued and an adequate baseline is established. Even then, there is very little precedent for setting meaningful levels of change for parameters that do not have regulatory criteria (e.g., benthic community parameters).

Figure 3 on the following pages consists of

(a) Effluent monitoring

(b) Nutrient enrichment in the nearfield water column

(c) Nutrient enrichment in the farfield water column

(d) Soft-bottom benthos in the nearfield and farfield

(e) Hard-bottom benthos

(f) Fish and shellfish contamination and physiological condition

(g) Special studies

- **Water circulation and particle fate**
- **Detailed effluent characterization**
- **Effluent tracers in the environment**
- **Benthic nutrient flux, denitrification, and oxygen demand**
- **Plume studies**

EFFLUENT MONITORING

Purpose:	**Test for compliance with new NPDES permit limits for effluent, evaluate the effectiveness of treatment (facility performance), and evaluate the effectiveness of the source reduction program.**
Question:	**Do effluent pathogens exceed permit limit? (R-2, R-14) [NPDES]** **Does acute or chronic toxicity of effluent exceed permit limits? (R-11) [NPDES]** **Do effluent contaminant concentrations exceed permit limits? (R-9) [NPDES]** **Do conventional pollutants in the effluent exceed permit limits? (R-15, R-16) [NPDES]**
Measurement:	Bacterial indicators (e.g., fecal and total coliform and *Enterococcus*) Acute and chronic toxicity tests as specified in NPDES permit Toxic contaminants as specified in NPDES permit Conventional parameters (e.g., BOD, TSS, pH) as specified in NPDES permit See Appendix B for list of parameters in the current NPDES permit; these parameters may be modified in the new NPDES permit. Analytical methods used for chemical measurements must meet stringent data quality objectives as described in Appendix B (e.g., method detection limits are generally 100 times lower than standard EPA methods).
Location:	Effluent grab or composite samples as specified in new NPDES permit.
Frequency:	Set by new NPDES permit (see Appendix B for sampling frequency in current permit).
Detectable change:	Depends on parameter: $<25\%$ for coliform and many priority pollutants. Detailed effluent characterization during baseline period, using improved analytical methods, will provide better data set to evaluate the variability in contaminant concentrations.
Data analysis:	Compare effluent concentrations to NPDES limit. These effluent data can also be used as input to dilution and transport models.

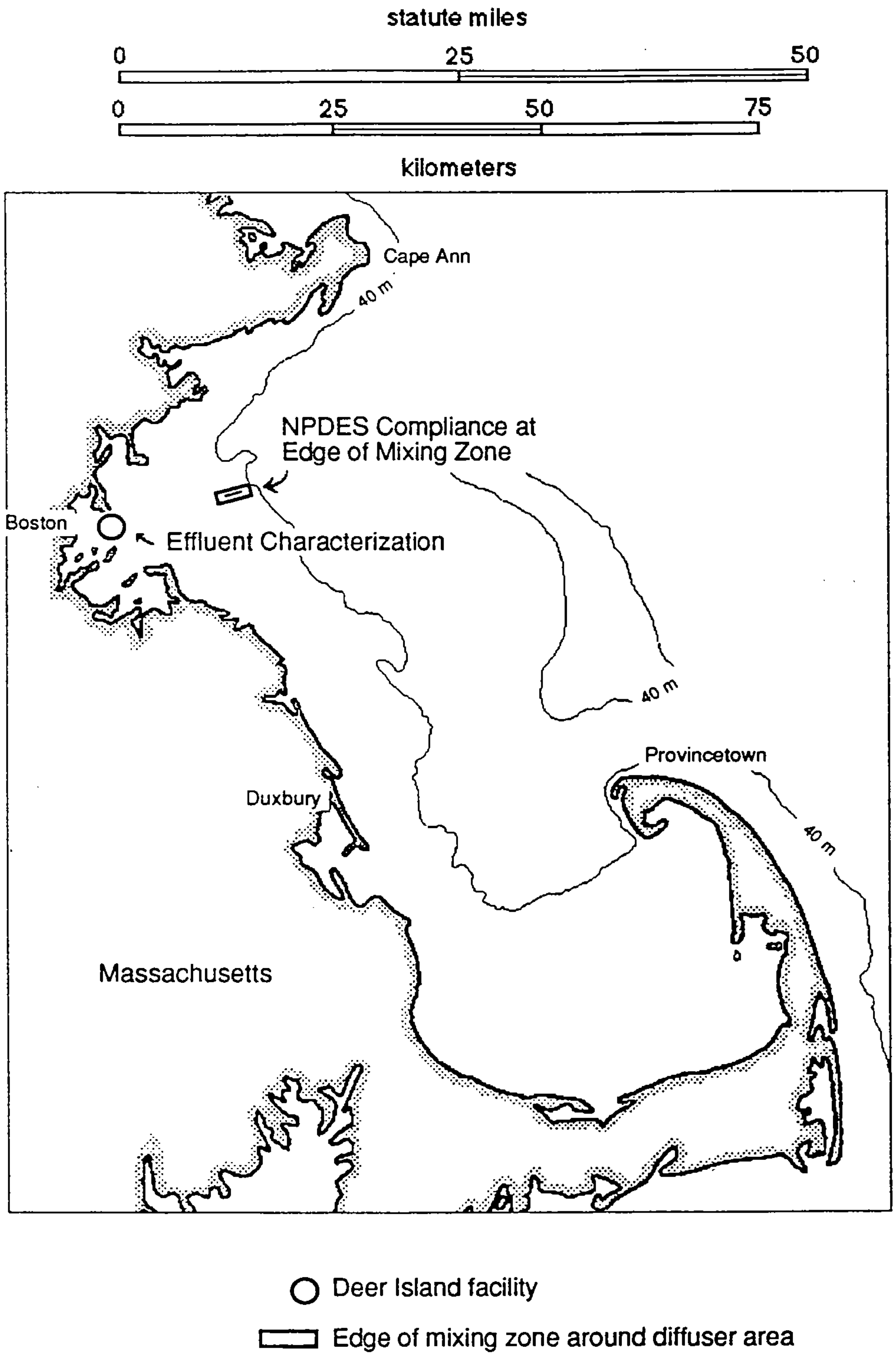


Figure 3(a). Effluent monitoring.

NUTRIENT ENRICHMENT IN THE NEARFIELD WATER COLUMN

Nutrients and Hydrography

Purpose: **Determine whether any changes take place in the levels of nutrients, dissolved oxygen, and phytoplankton biomass within the water column near the outfall.**

Question: **Have nutrient concentrations changed in the water near the outfall? (R-3, R-7)**

Have the concentrations (or percent saturation) of dissolved oxygen in the water changed relative to predischarge baseline or a reference area and, if so, can changes be correlated with effluent or ambient water nutrient concentrations? (R-5) [NPDES]

Do the concentrations (or percent saturation) of dissolved oxygen in the water column meet the State Water Quality Standard? (R-5) [NPDES]

Has the phytoplankton biomass changed and, if so, can changes be correlated with effluent or ambient water nutrient concentrations? (R-3, R-7)

Measurement: Dissolved ammonia, nitrite, nitrate, phosphate, silicate, *in situ* chlorophyll *a*, transmissometry, irradiance, salinity, temperature, and dissolved oxygen.

Location: Discrete samples at 24 stations along rectangular cruise tracks (see Figure 3b) at 5 depths: 1 surface sample, 2 middepth samples that will span the pycnocline when it exists, 1 middepth sample at the chlorophyll maxima, and 1 bottom sample. Continuous vertical profiles of hydrographic measurements will be taken from surface to bottom at each station and a continuous horizontal profile that crosses the pycnocline will be taken between stations. Continuous dissolved oxygen will be measured at a mooring near the outfall.

Frequency: 16 cruises every year. 1 cruise each in February, May, June, October, November, and December; 2 cruises each in March, April, July, August, and September.

Detectable change: An adequate baseline to assess detectable change has not been established for these parameters throughout all seasons in this region. Baseline data will be used to evaluate these parameters as indicators of change and a postdischarge sampling plan (Phase II) with corresponding detectable change will be established prior to 1995.

Data analysis: Perform statistical analysis to assess interstation differences (gradients) and temporal trends. Estimate both intra- and inter-annual variability. Perform regression on parameters to assess relationships (e.g. Are nitrogen and biomass correlated?).
Compare dissolved oxygen against Massachusetts Water Quality Standard.

Biology and Productivity

Purpose: **Determine whether any changes take place in the phytoplankton and zooplankton community composition, zooplankton biomass or phytoplankton production rates within the water column near the outfall.**

Question: **Have the phytoplankton production rates changed in the vicinity of the outfall and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations? (R-3)**

Has the species composition of phytoplankton or zooplankton changed in the vicinity of the outfall and, if so, can these changes be correlated with effluent or ambient water nutrient concentrations? (R-7)

Has the abundance of nuisance or noxious phytoplankton species changed? (R-7)

Measurement: All of the nutrient and hydrography measurements listed above, plus dissolved organic carbon and nitrogen, particulate carbon and nitrogen, total suspended solids, chlorophyll *a* (on filters along with phaeopigments), phytoplankton and zooplankton identification and enumeration, zooplankton biomass, 14-C primary production.

Location: Discrete samples at 5 stations along the rectangular cruise tracks at 5 depths: 1 surface sample, 2 middepth samples that will span the pycnocline when it exists, 1 middepth sample at the chlorophyll maxima, and 1 bottom sample. Continuous profiles of hydrographic measurements will be taken from surface to bottom at each station.

Frequency: Every year, 6 cruises per year, February, March, April, June, August, and October.

Detectable change: An adequate baseline to assess detectable change has not been established for these parameters throughout all seasons in this region. Baseline data will be used to evaluate these parameters as indicators of change and a postdischarge sampling plan (Phase II) with corresponding detectable change will be established prior to 1995.

Data analysis: Perform statistical analysis to assess interstation differences and temporal trends. Estimate both intra- and inter-annual variability. Perform regression on parameters to assess relationships (e.g.: Are nitrogen and primary production correlated?). Use irradiance and phytoplankton biomass to model primary production and compare to direct measurement.

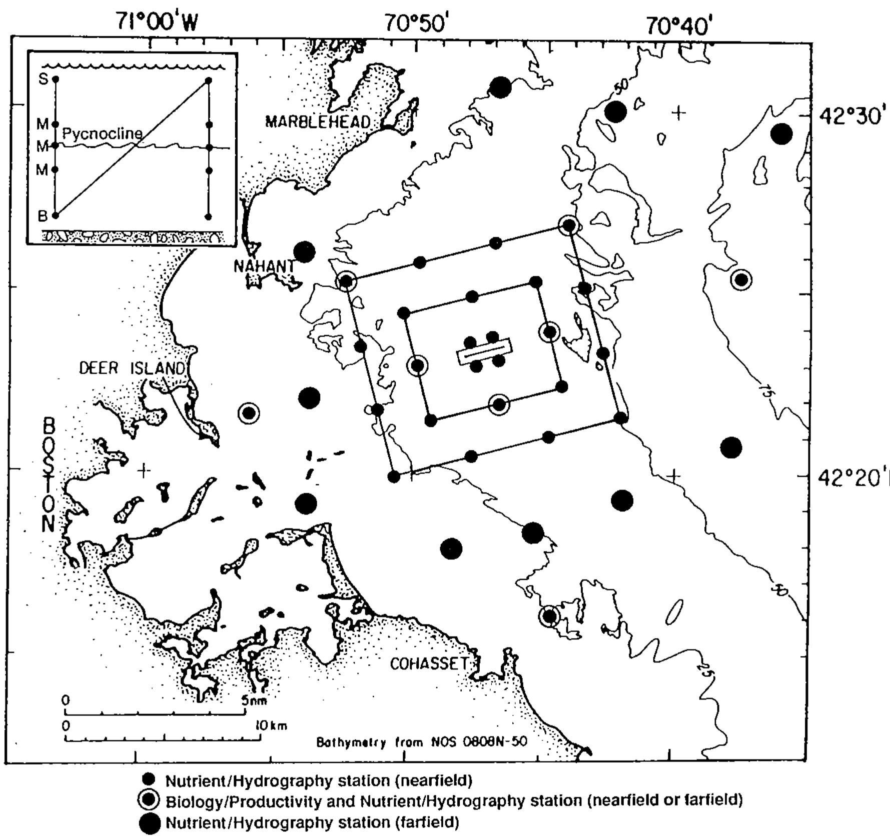


Figure 3(b). Nutrient enrichment in the nearfield water column.

NUTRIENT ENRICHMENT IN THE FARFIELD WATER COLUMN

Nutrients and Hydrography

Purpose: **Determine whether any changes take place in the levels of nutrients, dissolved oxygen, or phytoplankton biomass at selected stations in farfield areas of Massachusetts Bay and Cape Cod Bay.**

Question: **Have water-column nutrient concentrations changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are they correlated with changes in the nearfield? (R-3, R-7)**

Have the water-column concentrations (or percent saturation) of dissolved oxygen changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-5)

Do the water-column concentrations (or percent saturation) of dissolved oxygen at selected farfield stations meet the State Water Quality Standard? (R-5)

Has the phytoplankton biomass changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-3, R-7)

Measurement: Dissolved ammonia, nitrite, nitrate, phosphate, silicate, *in situ* chlorophyll *a*, transmissometry, irradiance, salinity, temperature, dissolved oxygen.

Location: Discrete samples at 25 stations (hydrography/nutrient stations) along "transects" at five depths: 1 surface sample, 2 middepth samples that will span the pycnocline when it exists, 1 middepth sample at the chlorophyll maxima, and 1 bottom sample. Continuous profiles of hydrographic measurements will be taken from surface to bottom at each station.

Frequency: Every year, 6 cruises per year, February, March, April, June, August, and October.

Detectable change: An adequate baseline to assess detectable change has not been established for these parameters throughout all seasons in this region. Baseline data will be used to evaluate these parameters as indicators of change and a postdischarge sampling plan (Phase II) with corresponding detectable change will be established prior to 1995.

Data analysis: "Transects" will be established to provide baseline conditions at positions expected to be "upstream" and "downstream" of outfall area, and inshore to characterize the existing gradient from Boston Harbor (see Appendix B). Transects extend from the outfall toward Boston Harbor, Cape Ann, down the axis of Stellwagen Basin, and along the South Shore into Cape Cod Bay (providing a regional reference). Shorter transects from the coast are placed north and south of the North River, across northern Massachusetts Bay where any input from the Merrimack River would be expected. Statistical analysis will be performed to assess interstation differences (gradients) and temporal trends, along with an estimation of both intra- and inter-annual variability. Irradiance and phytoplankton biomass will be used to estimate primary production. Regression will be performed on parameters to assess relationships (e.g., are nitrogen and biomass correlated?). Dissolved oxygen will be compared against State Water Quality Standard.

Biology and Productivity

Purpose: **Determine whether any changes take place in the phytoplankton and zooplankton community composition, zooplankton biomass, and phytoplankton productivity at selected stations in farfield areas of Massachusetts Bay and Cape Cod Bay.**

Question: **Has the phytoplankton and zooplankton species composition changed at selected farfield stations in Massachusetts Bay or Cape Cod Bay and, if so, are the changes**

correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-3, R-7)

Has the primary production at selected farfield stations in Massachusetts Bay or Cape Cod Bay changed and, if so, are the changes correlated with changes in the nearfield or changes in nutrient concentrations in the farfield? (R-3)

Measurement: All of the measurements listed above, plus, dissolved organic carbon and nitrogen, particulate carbon and nitrogen, total suspended solids, chlorophyll *a* (on filters along with phaeopigments), phytoplankton and zooplankton identification and enumeration, and zooplankton biomass, 14-C primary production.

Location: Discrete samples at five stations in the farfield (biology/productivity stations) and at five depths: surface, two fixed middepth, one flexible middepth, and bottom. Fixed middepth samples will span the pycnocline when it exists, the flexible middepth sample will be at the middepth cholorophyll maximum. Continuous profiles of hydrographic measurements from surface to bottom at each station.

Frequency: Every year, six cruises per year, February, March, April, June, August, and October.

Detectable change: See Detectable Change for nutrients and hydrography above.

Data analysis: Perform statistical analysis to assess interstation differences and temporal trends. Estimate both intra- and inter-annual variability. Perform regression on parameters to assess relationships (e.g.: Are nitrogen and primary production correlated?). Use irradiance and phytoplankton biomass to model primary production and compare to direct measurement.

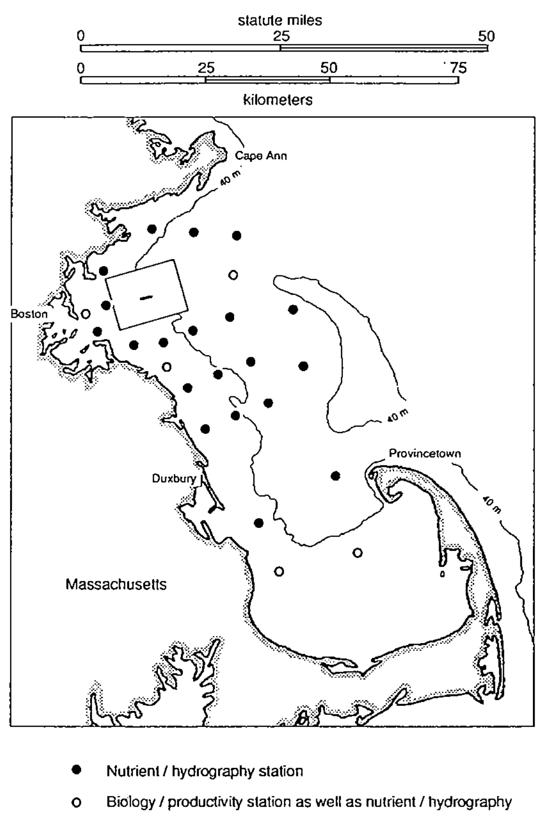


Figure 3(c). Nutrient enrichment in the farfield water column.

SOFT-BOTTOM BENTHOS IN THE NEARFIELD AND FARFIELD

Purpose:	**Detect either short- or long-term change in the sediment depositional areas. Provide information on spatial extent of changes.**
Question:	**Has the soft-bottom community changed? (R-8, R-13)** **Have the concentrations of contaminants in sediments changed? (R-12)** **Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased? (R-6)** **Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments? (R-13)**
Measurement:	Benthic species composition and abundance using nested 0.3 mm and 0.5-mm sieves; PAHs, LABs, PCBs, pesticides, metals, TOC, grain size, and *Clostridium perfringens* in 0- to 2-cm fraction; sediment profile camera images.
Location:	15 - 20 sites within nearfield and 12 farfield sites throughout Massachusetts Bay and Cape Cod Bay for traditional grabs; same sites in nearfield for sediment profile camera imaging. Site locations will be identified from previous soft-bottom studies (see Appendix B).
Frequency:	Once per year (end of summer) for biology, chemistry, and sediment profile camera imaging. A single replicate will be taken in the nearfield and triplicates taken in the farfield.
Detectable change:	10 - 100% in nearfield and 10 - 10000% in farfield for most parameters based on results of power analyses using existing data (see Appendix B).
Data analysis:	Traditional benthic ecological statistical analysis to define stations and interrelationships between stations based on faunal composition and chemistry. Regression analysis among parameters to assess possible cause of changes (see Appendix B).

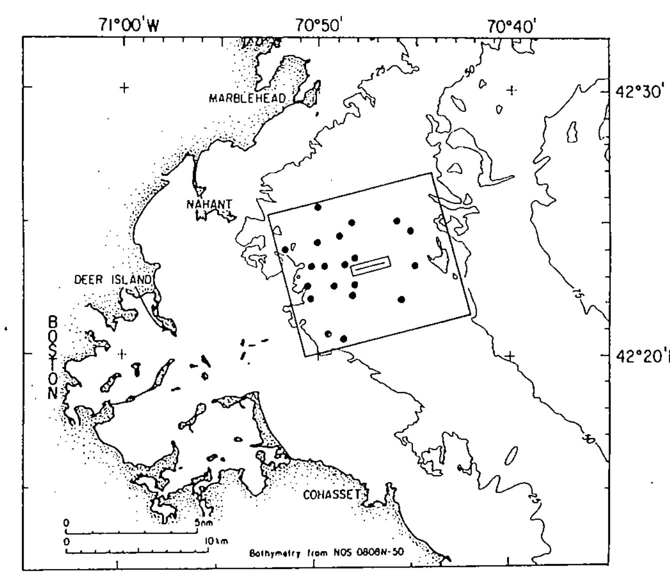


Figure 3(d). Soft-bottom benthic stations in the nearfield.

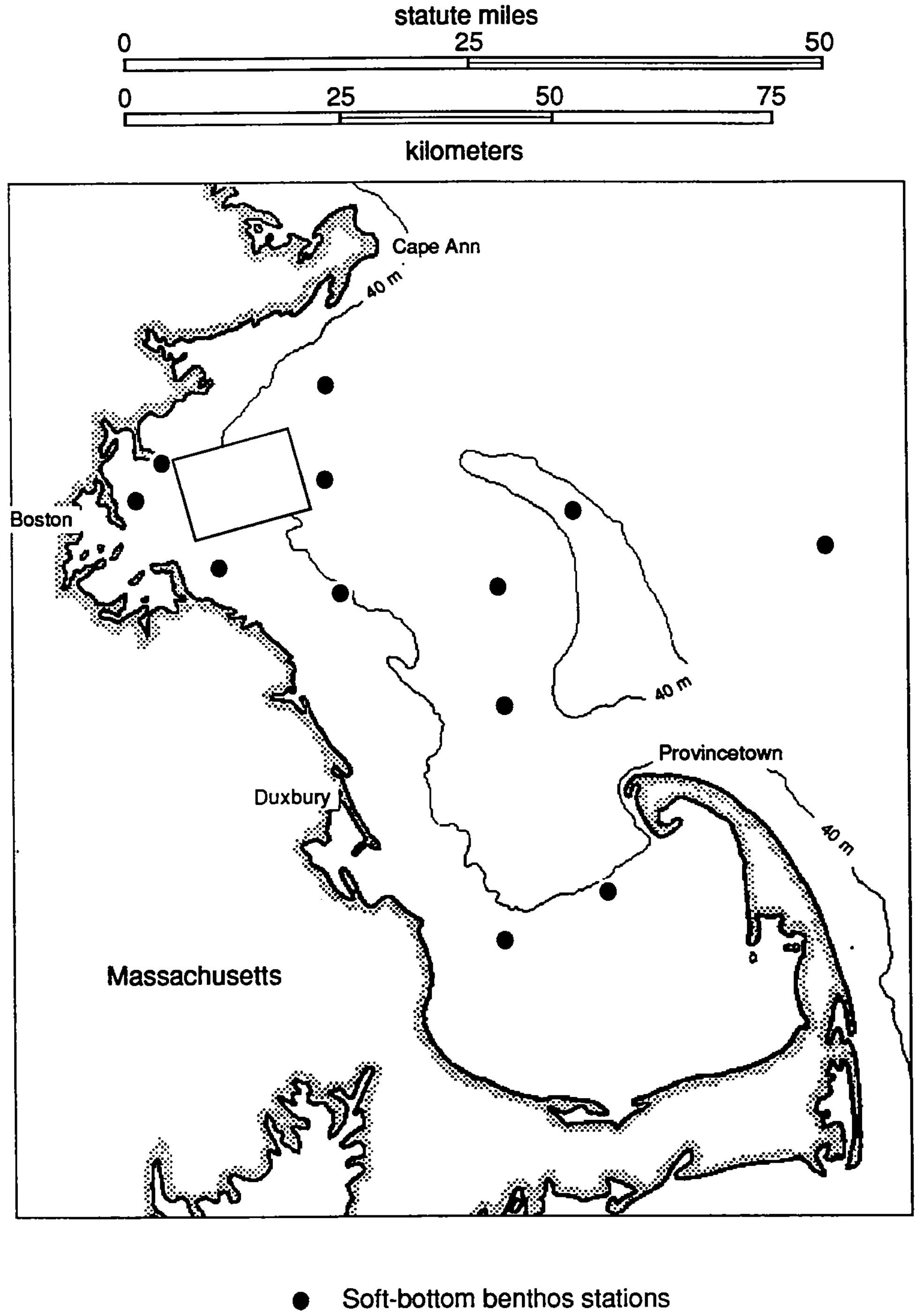


Figure 3(e). Soft-bottom benthic stations in the farfield.

SOFT-BOTTOM BENTHOS IN THE NEARFIELD AND FARFIELD

Purpose:	**Detect either short- or long-term change in the sediment depositional areas. Provide information on spatial extent of changes.**
Question:	**Has the soft-bottom community changed? (R-8, R-13)**
	Have the concentrations of contaminants in sediments changed? (R-12)
	Have the sediments become more anoxic; that is, has the thickness of the sediment oxic layer decreased? (R-6)
	Are any benthic community changes correlated with changes in levels of toxic contaminants (or sewage tracers) in sediments? (R-13)
Measurement:	Benthic species composition and abundance using nested 0.3 mm and 0.5-mm sieves; PAHs, LABs, PCBs, pesticides, metals, TOC, grain size, and *Clostridium perfringens* in 0- to 2-cm fraction; sediment profile camera images.
Location:	15 - 20 sites within nearfield and 12 farfield sites throughout Massachusetts Bay and Cape Cod Bay for traditional grabs; same sites in nearfield for sediment profile camera imaging. Site locations will be identified from previous soft-bottom studies (see Appendix B).
Frequency:	Once per year (end of summer) for biology, chemistry, and sediment profile camera imaging. A single replicate will be taken in the nearfield and triplicates taken in the farfield.
Detectable change:	10 - 100% in nearfield and 10 - 10000% in farfield for most parameters based on results of power analyses using existing data (see Appendix B).
Data analysis:	Traditional benthic ecological statistical analysis to define stations and interrelationships between stations based on faunal composition and chemistry. Regression analysis among parameters to assess possible cause of changes (see Appendix B).

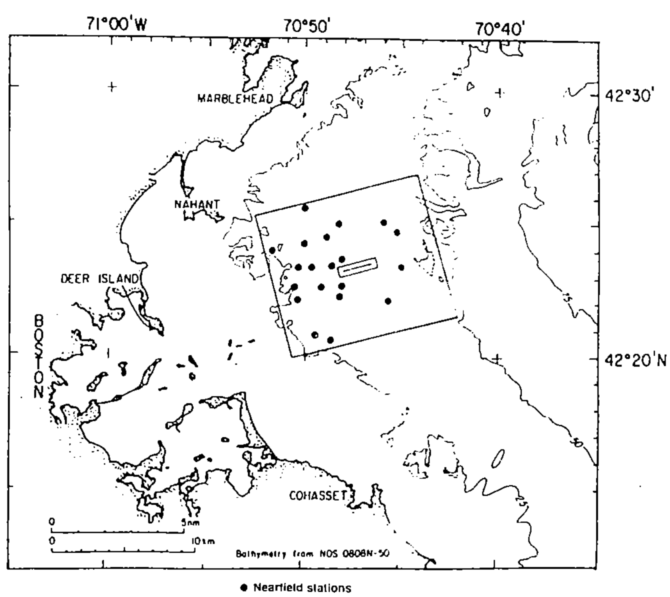


Figure 3(d). Soft-bottom benthic stations in the nearfield.

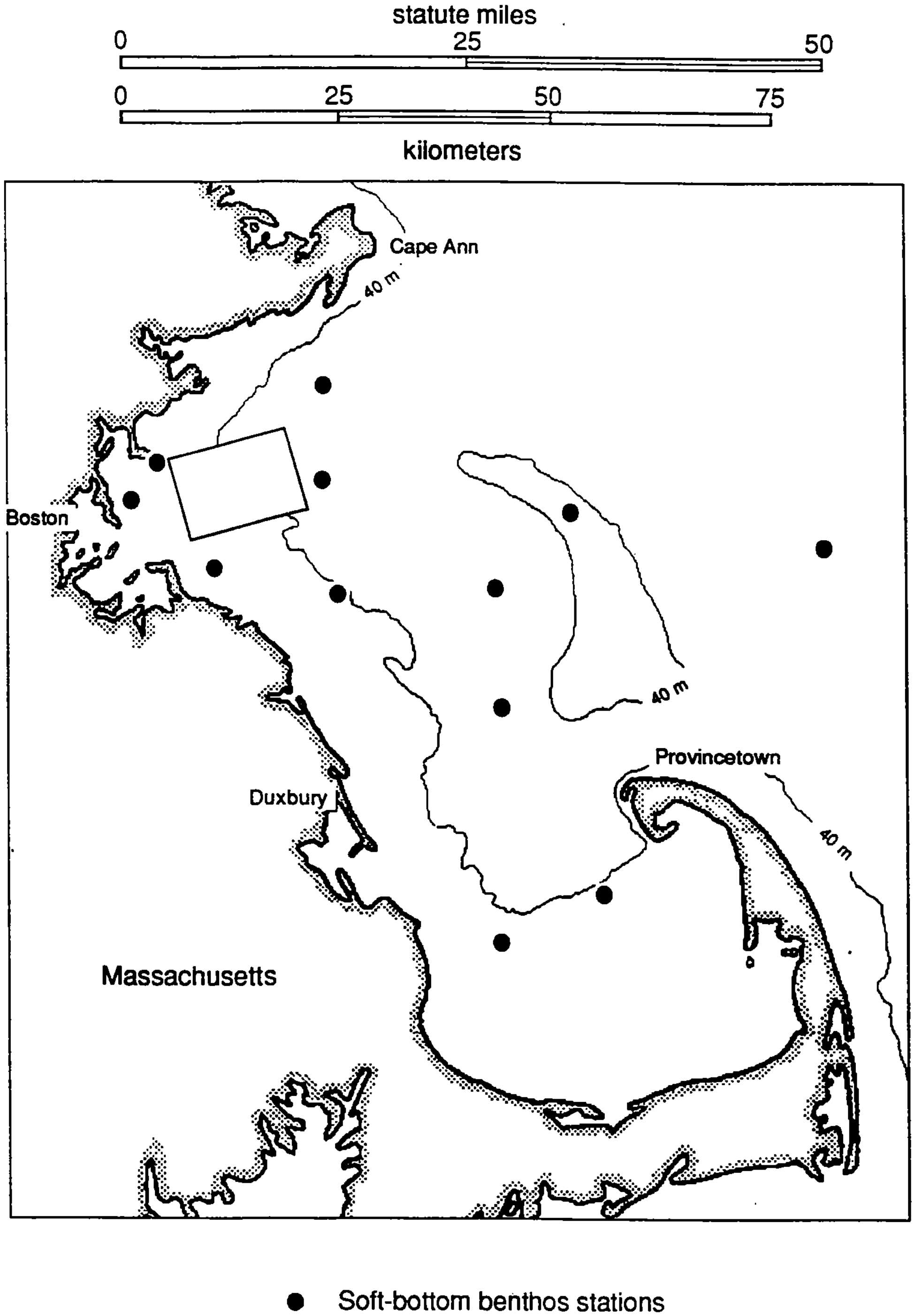


Figure 3(e). Soft-bottom benthic stations in the farfield.

FISH AND SHELLFISH CONTAMINATION AND PHYSIOLOGICAL CONDITION

Purpose: **Monitor accumulation of toxic contaminants in fish and shellfish consumed by humans to assess human health risk. Determine physiological condition of fish to assess impact on fish health.**

Question: **Has the level of contaminants in the tissues of fish and shellfish around the outfall changed since discharge began? (R-1, R-11)**

Do the levels of contaminants in the edible tissue of fish and shellfish around the outfall represent a risk to human health? (R-1)

Are the contaminant levels in fish and shellfish different between the outfall, Boston Harbor, and a reference site? (R-11)

Measurement: Caged mussels deployed to assess bioaccumulation — PAH, PCB, pesticides
Winter flounder fillet — PCB, pesticides, Hg
Winter flounder liver — PAH, PCB, pesticides, Ag, Cu, Cd, Hg, Pb, Zn
Lobster meat — PCB, pesticides, Hg
Lobster hepatopancreas - PAH, PCB, pesticides, Ag, Cu, Cd, Hg, Pb, Zn
Individual animals will be collected and may be pooled according to histological indices to yield six samples of each tissue type for analysis (24 samples total for flounder and lobster at each station). Animal size, mass, and dry/lipid weight will also be recorded. If total Hg exceeds FDA action limit, organic Hg will also be measured. For caged mussels, 2 cages with 30 mussels each will be deployed at middepth or below the pycnocline; mussels from 6ach cage will be pooled for a single sample.

Location: Deer Island Flats, near the proposed outfall, and in Cape Cod Bay. Caged mussels will be outside the mixing zone at the proposed outfall only.

Frequency: Caged mussels will be deployed for 2 months during the summer. Flounder and lobster will be sampled every year during spring.

Detectable change: 50%-100% change from present levels for most contaminants, based on power analysis of existing body-burden data in flounder and lobsters. Current levels in flounder and lobster meat are about 10-100 times lower than FDA Action Levels; current levels in lobster hepatopancreas are about 3-10 times lower than FDA Action Levels.

Data analysis: Perform statistical analysis to determine difference between pre- and post-discharge and between outfall site and other sites. Compare concentrations in edible tissue against either FDA Action Levels or the proposed National Shellfish Sanitation Program Alert Levels (see Appendix B).

Question: **Has the incidence of disease and/or abnormalities in fish or shellfish changed? (R-11)**

Measurement: Histology (see Appendix B) in winter flounder, gross abnormalities (see Appendix B) in lobster. Sample size: $n > 50$ for flounder, $n > 10$ for lobster

Location: Deer Island Flats, near the proposed outfall, in Cape Cod Bay, near Lynn (flounder only), and east of Stellwagen Bank (flounder only). Lobster sampling will be coordinated with the Massachusetts Division of Marine Fisheries.

Frequency: Once each year, every year during spring.

Detectable change: <50% for most flounder and lobster indices (Appendix B), <10% for neoplasia in flounder.

Data analysis: Perform statistical tests to determine difference between pre- and post-discharge and between outfall site and other sites. Perform regression to test for correlation among physiological and body-burden data.

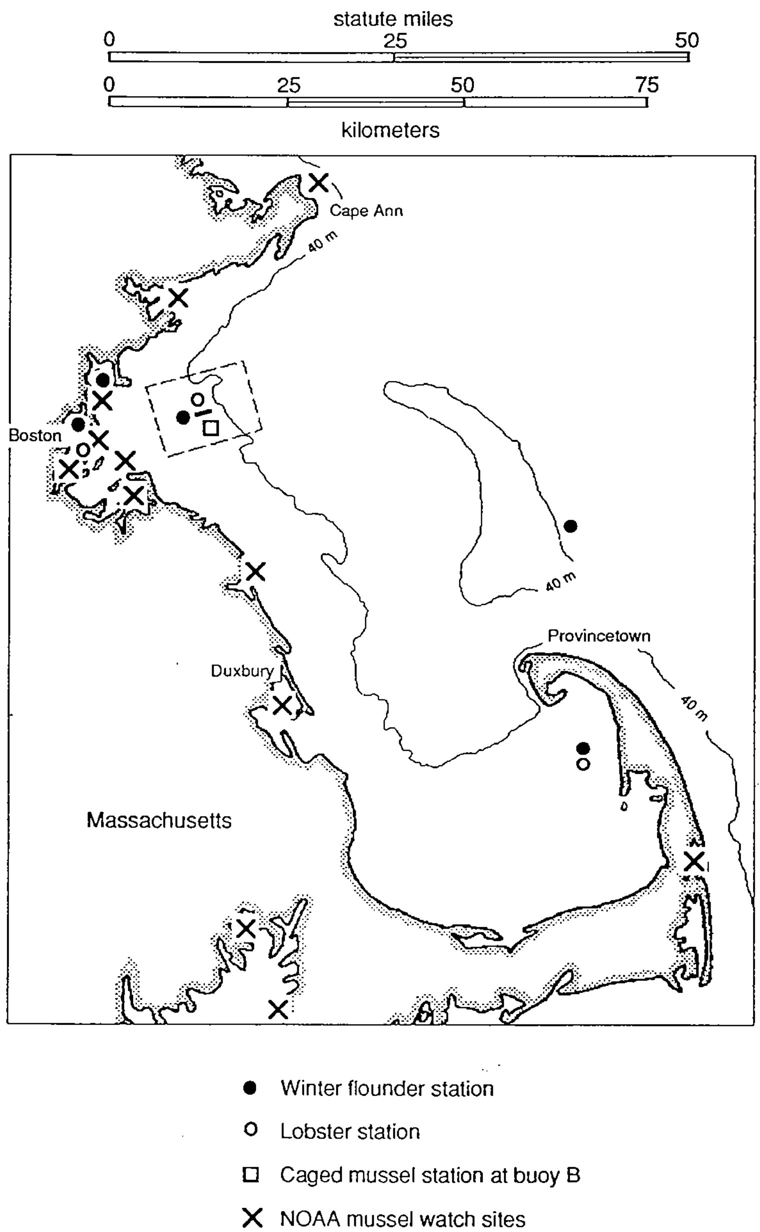


Figure 3(f). Fish and shellfish contamination and physiological condition stations.

Special Studies
WATER CIRCULATION AND PARTICLE FATE

Purpose:	**Develop simulation model of water circulation in Boston Harbor and Massachusetts and Cape Cod Bays. Provide continuous measurement of current velocity and direction near the outfall. Assess farfield fate of particles.**
Question:	**What are the nearfield and farfield water circulation patterns?**
	What is the farfield fate of dissolved, conservative, or long-lived effluent constituents?
Measurement:	Current velocity and direction using moored surface and subsurface current meters and surface and subsurface drifters
Location:	Moored current meter at the large navigational buoy (Buoy B) near the outfall. Multiple drifter deployments from the outfall area under various oceanographic conditions, and additional current meters may be deployed at several locations during routine nearfield water-column surveys.
Frequency:	Continuous current measurements at mooring, frequency of drifter deployment is being determined
Detectable change:	[Not applicable]
Data analysis:	Use data to develop models of water circulation and to help to interpret other monitoring data
Question:	**What are the rates of sediment deposition, resuspension, and mixing in selected sediment-focusing areas of Massachusetts and Cape Cod Bays?**
	What is the farfield fate of effluent particles?
Measurement:	Rates of sediment deposition, resuspension, mixing (physical and bioturbation) using sediment traps at multiple depths and taking sediment cores. Trace metals, sewage tracers (e.g., *Clostridium*), short- and long-lived radioisotopes and other parameters will be measured in trap material and in sectioned sediment cores. Sampling will be coordinated with the soft-bottom benthic monitoring (see above) and the sewage tracer surveys (see below).
Location:	7 stations in depositional areas of Massachusetts and Cape Cod Bays, including Stellwagen Basin
Frequency:	[To be determined]
Detectable change:	An adequate baseline has not been established for these parameters. Baseline data from the first survey will be used to evaluate these parameters as indicators of change and a sampling plan with corresponding detectable change will be established at that time.
Data analysis:	Use data to develop models of the transport of effluent particulates to farfield depositional sites and to help to interpret other monitoring data.

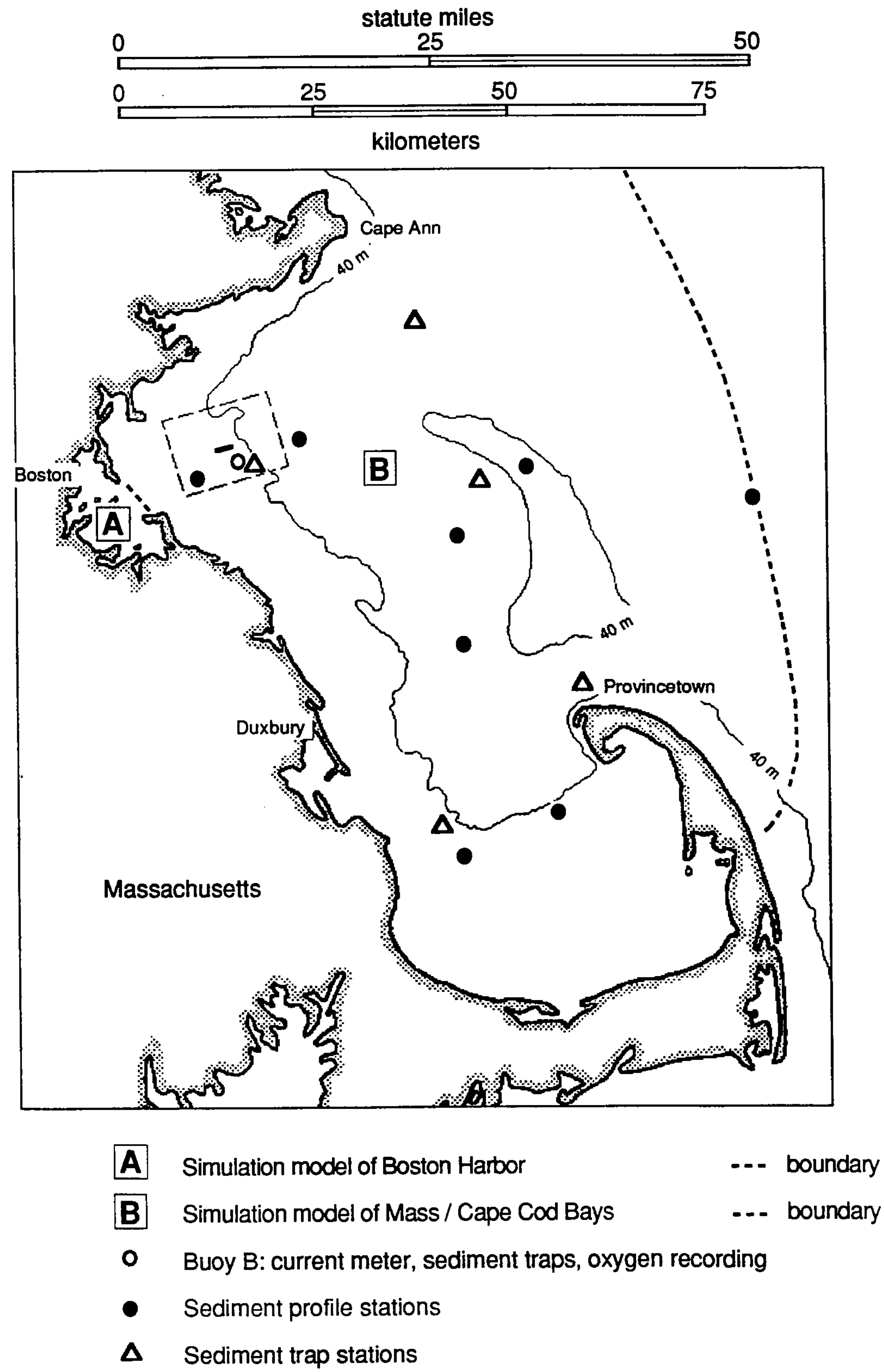


Figure 3(g). Water circulation and particle fate study areas and sampling stations.

Special Studies
DETAILED EFFLUENT CHARACTERIZATION

Purpose: **Provide data on influent and effluent contaminant concentrations at part-per-trillion levels along with estimates of short-term (day to week) and long-term (month to year) variability. Identify unique tracers of sewage in the environment and provide nonroutine data for effluent transport and fate modeling (e.g., particulate, dissolved, and colloidal fractions of contaminants)**

Question: **What are the concentrations of contaminants in the influent and effluent and their associated variability?**

Measurement: Concentrations of trace metals, PAHs, PCBs and pesticides, and other sewage tracers in the effluent at the parts-per-trillion level using the best-available analytical methods and compare to standard EPA methods (see Appendix B). Other tracers as necessary (e.g., 15-N). Samples will be cold-storage archived to allow future analysis of selected analytes as may prove useful.

Location: Influent and effluent

Frequency: To be determined by using historical data and statistical sampling models

Detectable change: [To be determined]

Data analysis: Use these data to establish better estimates of contaminant loads, priorities for other monitoring activities, and use these data with water circulation and transport and fate models to assess potential impact of outfall

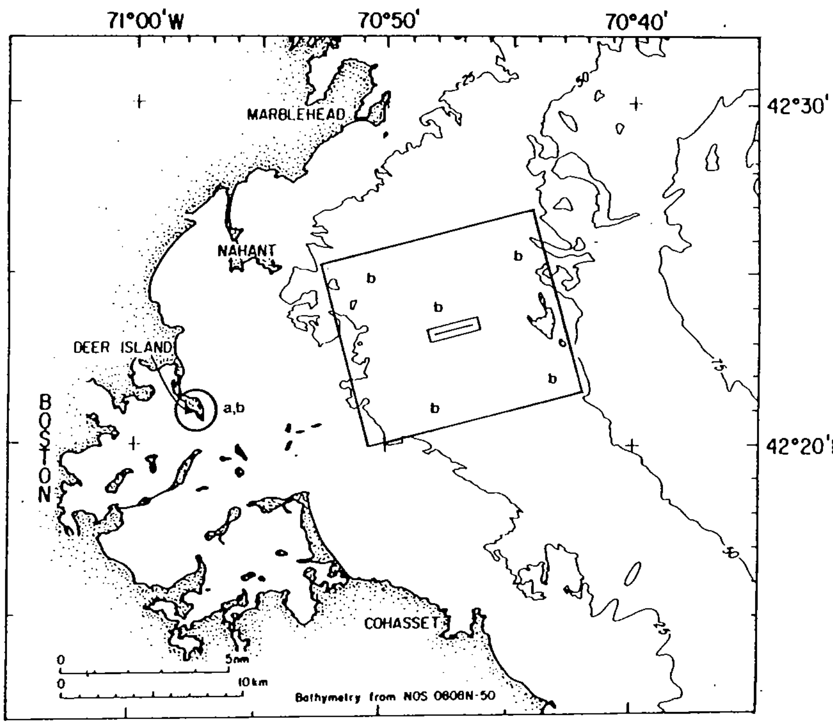


Figure 3(h). Detailed effluent characterization and sewage tracer studies.

Purpose:	**Identify potential sewage tracers in the environment. Assess the spatial extent of particulate-bound sewage constituents in Massachusetts and Cape Cod Bays before and after discharge through the new outfall.**
Question:	**What is the level of sewage contamination and its spatial distribution in Massachusetts and Cape Cod Bays sediments before discharge through the new outfall?** **Has the level of sewage contamination or its spatial distribution in Massachusetts and Cape Cod Bays sediments changed after discharge through the new outfall?**
Measurement:	Levels of *Clostridium perfringens* will be measured in surface sediments and sediment cores throughout Massachusetts and Cape Cod Bays. Linear alkyl benzenes will also be measured in any sediment samples where PAH are measured. Sampling and analysis will be coordinated with the soft-bottom benthic monitoring and the joint MWRA/USGS particle fate study (see above). Sediment samples will be archived for possible future analysis of new sewage tracers.
Location:	25 stations in depositional areas of Massachusetts and Cape Cod Bays, including Stellwagen Basin.
Frequency:	Initial survey in fall of 1991; additional surveys will be determined based on initial results.
Detectable change:	An adequate baseline has not been established for these parameters. Baseline data from the first survey will be used to evaluate these parameters as indicators of change and a sampling plan with corresponding detectable change will be established at that time.
Data analysis:	Use data to map the distribution of sewage particles in the sediments of this region. Use power analysis to establish the sensitivity of these sewage tracers to detect change in the sediment. Use these data with water circulation and sediment transport and deposition models to model transport of sewage particles before and after discharge at the new outfall and to help to interpret other monitoring data.

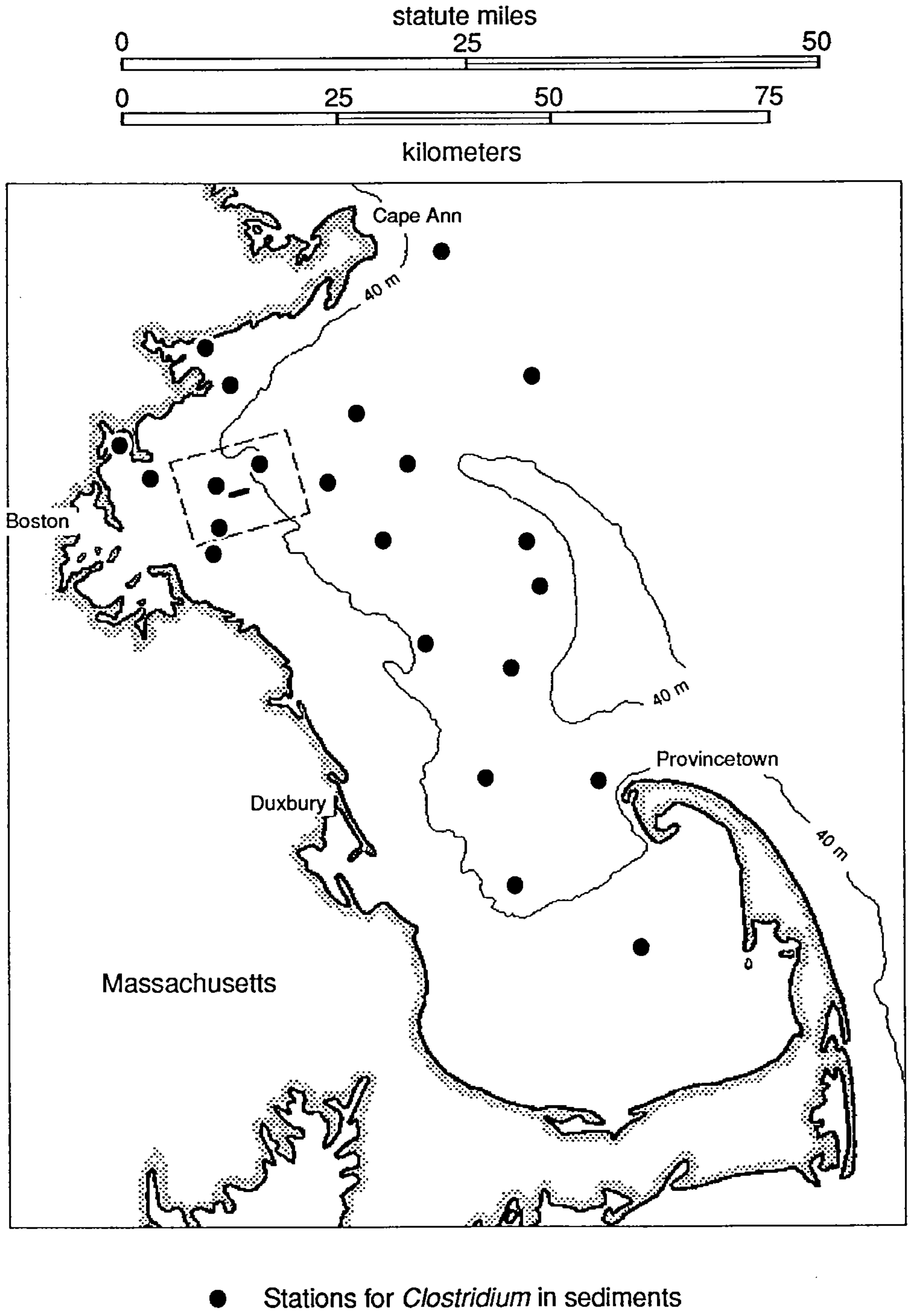


Figure 3(I). Survey of sewage tracers in sediments.

HARD-BOTTOM BENTHOS

Purpose: **Characterize summertime (stratified period) changes in hard-bottom areas. Provide information on spatial extent of changes.**

Question: **Has the hard-bottom community changed? (R-8, R-13)**

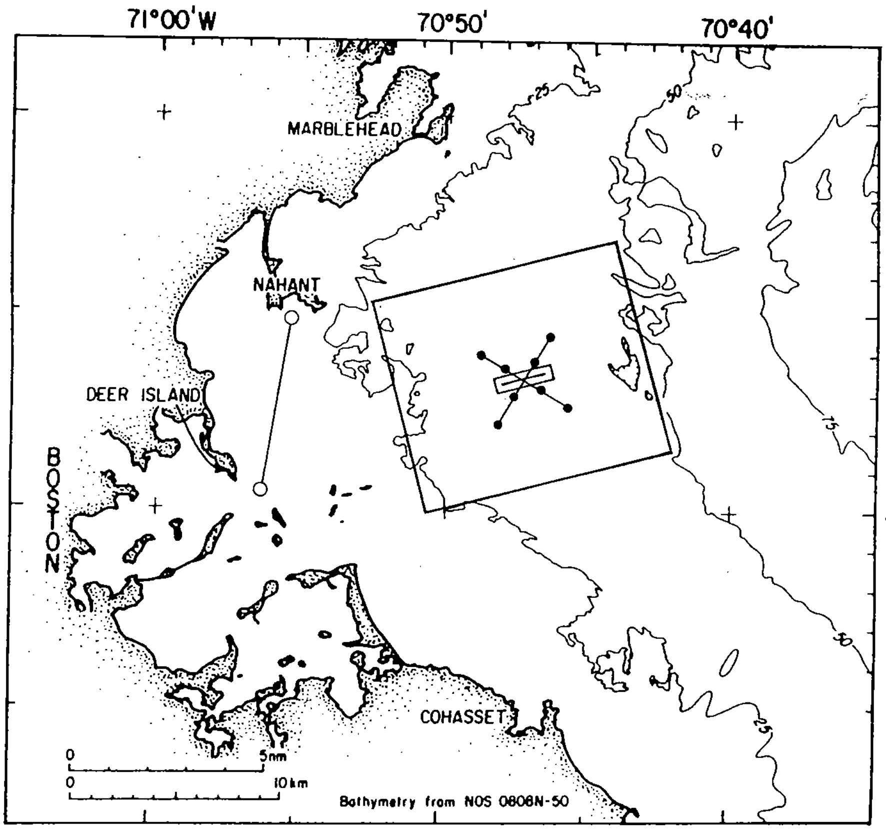
Measurement: Color video camera images to determine semiquantitative percent cover and identify dominant species

Location: 8 sites, ideally along two transects in **X** pattern within nearfield. Exact locations to be determined based on bottom geology and with reference to previously occupied stations.

Frequency: Once per year (end of summer).

Detectable change: An adequate baseline has not been established for these parameters. Baseline data from the first survey will be used to evaluate these parameters as indicators of change and a sampling plan with corresponding detectable change will be established at that time.

Data analysis: Qualitative and semiquantitative interpretation of video images. Also, use data from other hard-bottom studies in region (e.g., Broad Sound survey and near-diffuser site surveys conducted by Northeastern University).



● Video observation stations (8)
O–O Northeastern University study transect

Figure 3(j). Hard-bottom benthic stations.

Special Studies

BENTHIC NUTRIENT FLUX, DENITRIFICATION, AND OXYGEN DEMAND

Purpose:	**Measure rates of denitrification (nitrogen gas flux), sediment oxygen demand, and the flux of nutrients from the sediment in vicinity of the outfall. Assess the importance of these processes on nutrient and oxygen levels.**
Question:	**How do the sediment oxygen demand, the flux of nutrients from the sediment to the water column, and denitrification influence the levels of oxygen and nitrogen in the water near the outfall? (R-5, R-6)** **Have the rates of these processes changed? (R-4)**
Measurement:	Rates of sediment oxygen demand, nitrogen flux, and denitrification
Location:	8 sites from Boston Harbor, Nahant, and within nearfield
Frequency:	5 times every year (seasonal, with 2 in summer) at 6 sites, twice per year (in summer) at 2 additional sites
Detectable change:	An adequate baseline has not been established for these parameters. Baseline data from the first annual survey will be used to evaluate these parameters as indicators of change and a sampling plan with corresponding detectable change will be established at that time.
Data analysis:	Compare predischarge rates to postdischarge rates. Use data to verify (or modify) models and to help to interpret other monitoring data.

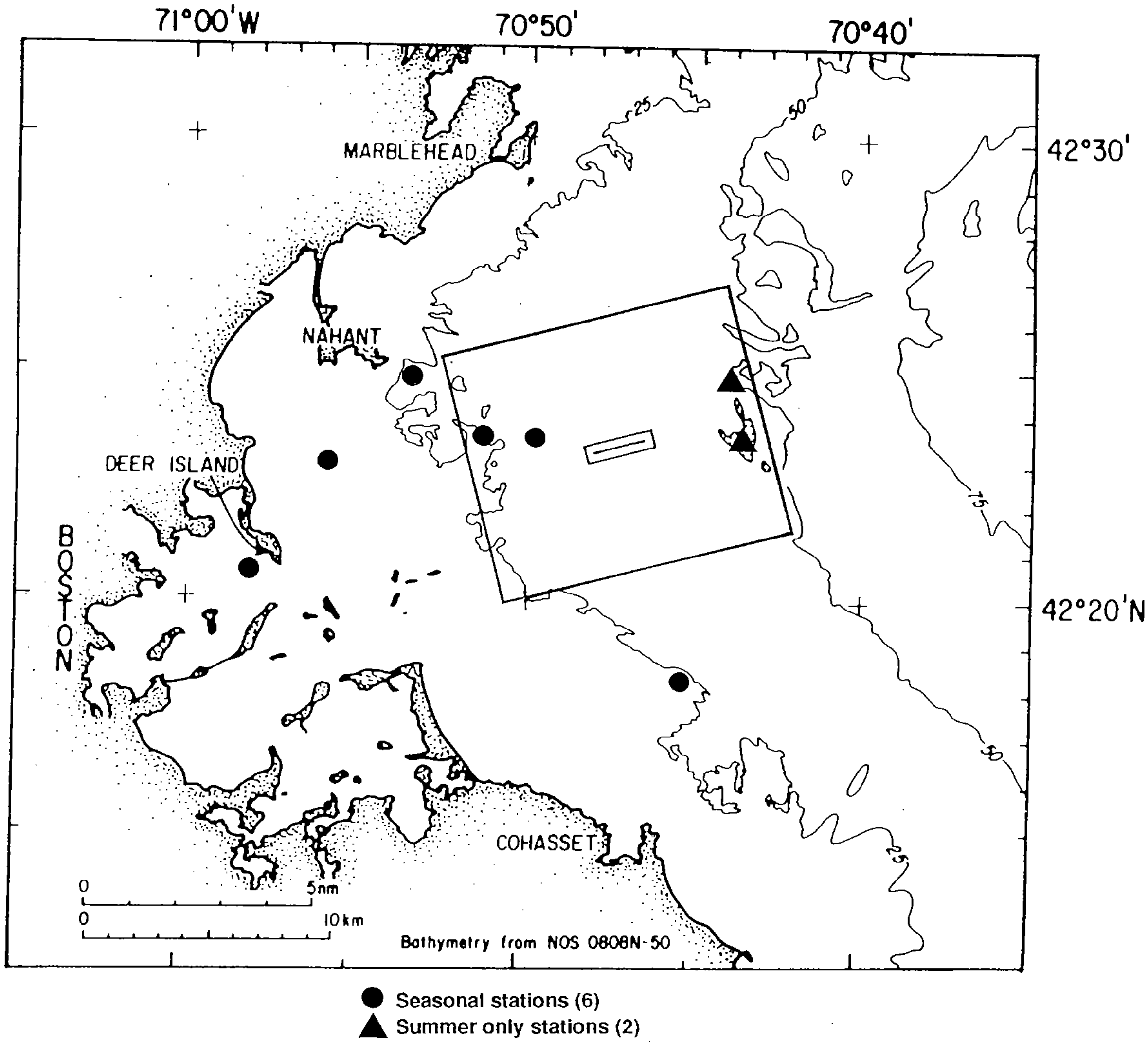


Figure 3(k). Benthic flux study locations.

Special Studies
PLUME STUDIES — TO BE CONDUCTED AFTER THE PROPOSED OUTFALL IS DISCHARGING

Purpose: **To assess dilution and transport of effluent (verify models) and provide data on contaminant concentrations in water outside the mixing zone for comparison against water quality standards. Dilution and transport/fate models will be used to interpret much of other monitoring data.**

Question: **Are the model estimates of short-term (less than 1 day) effluent dilution and transport accurate? (R-9, R-14)**

Do the levels of contaminants in water outside the mixing zone exceed State Water Quality Standards? (R-9, see also R-10)

Are pathogens transported from the outfall toward swimming beaches or shellfishing areas? (R-2, R-14)

Measurement: Bacterial indicators (e.g., fecal and total coliform and *Enterococcus*)
Toxic contaminants as specified in NPDES permit (e.g., priority pollutants)
Conventional parameters as specified in NPDES permit (e.g., BOD, TSS, pH)
Parameters for modeling transport and fate will be determined after a detailed chemical characterization of the effluent (e.g., dissolved and particulate contaminants; see Appendix B for discussion).

Location: Continuous measurement of plume signal and other hydrographic parameters. Discrete ambient water samples collected along cruise (plume) track. (See Appendix B for discussion)

Frequency: Multiple plume tracks during both stratified and unstratified conditions during the first year after discharge begins. Plumes will be tracked with *in situ* measurements (e.g., salinity) until no longer detected, followed by continuation in direction of prevailing current or toward valued resource area (e.g., shoreline) to locate any packets of water mass from the outfall. Drifters will be used to aid identification of prevailing current.

Detectable change: An adequate baseline has not been established for these parameters. Baseline data from the first survey will be used to evaluate these parameters as indicators of change, and a sampling plan with corresponding detectable change will be established at that time.

Data analysis: Compare ambient contaminant concentrations to State Water Quality Standards. Use data to verify (or modify) dilution and transport models. Use data from mooring at Buoy B and from fixed station rectangular cruise tracks to help to identify plumes or packets of water from the outfall.

Purpose: To assess esthetics in the surface water near the outfall.

Question: **Has the clarity and/or color of the water around the outfall changed? (R-15)**

Has the amount of floatable debris around the outfall changed? (R-16)

Measurement: Transmissometry, visual observations from ship, neuston tows for floatable debris.

Location: Along plume study transects

Location: Ambient water collected during plume studies

Frequency: One baseline cruise just prior to discharge. Multiple plume tracks during both stratified and unstratified conditions during the first year after discharge begins.

Detectable change: An adequate baseline has not been established for these parameters. Baseline data from the first survey will be used to evaluate these parameters as indicators of change and a sampling plan with corresponding detectable change will be established at that time.

Data analysis: Compare predischarge conditions to postdischarge. Identification and enumeration of debris from neuston tows.

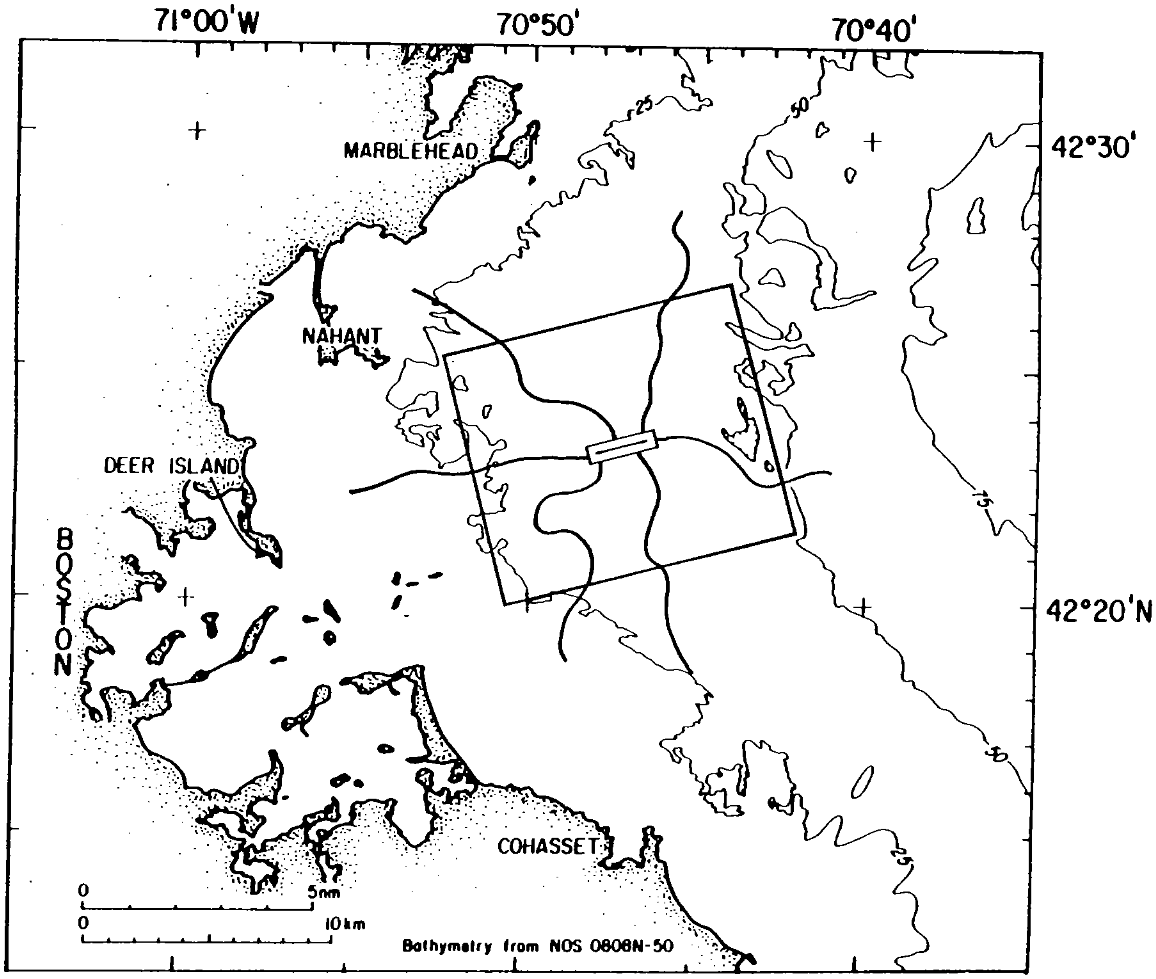


Figure 3(l). Graphical depiction of plume study tracks.

7.0 MONITORING IMPLEMENTATION

Following the NRC model (Figure 2), Step 5 is to implement the monitoring program. To parallel the operation of the outfall, monitoring will proceed in two phases. Baseline monitoring (Phase I) will take place prior to commissioning the new outfall in 1995. Postdischarge monitoring (Phase II) will commence when the new outfall begins discharging effluent and will continue as long as the outfall is in operation, including the period of change from primary to secondary treatment.

This document focuses on baseline monitoring, and the sampling plan described in Section 6.0 and Appendix B must be able to characterize the baseline for all the monitoring questions. These questions will be reframed as necessary (see Figure 2), when new information is obtained during the baseline monitoring and more regulatory decisions are made (e.g., issuance of new NPDES permit or development of new criteria or standards).

7.1 PHASE I — BASELINE MONITORING

The first phase will establish the baseline conditions and the spatial and temporal variability as a basis for comparing against postdischarge conditions. Several measures will be taken that are considered experimental because they may not be a part of postdischarge monitoring, but a baseline will be established in case they are identified as good indicators of change. The baseline data will be used to evaluate the utility of all measurements to detect change and to establish the final sampling plan for postdischarge monitoring. Baseline monitoring has been discussed in detail above and in Appendix B, and implementation will begin in 1992 [although much has already been initiated by the Massachusetts Water Resources Authority (MWRA) and others]. The baseline monitoring described here is intended to satisfy the requirement in the Environmental Protection Agency (EPA) Record of Decision (EPA, 1988b) to establish an adequate statistical baseline prior to discharge. There will be no tiered strategy for developing the baseline — everything will be monitored at the locations and frequency specified above. Modifications to the baseline monitoring plan can be made, if necessary. Such modifications would be made only after review by the Outfall Monitoring Task Force and/or other oversight committe.

An important aspect of the baseline monitoring is to provide data that are amenable to statistical analysis, comparing pre-discharge data to post-discharge data. The principal sampling design of this plan with fixed locations repeatedly sampled over time (at varying frequencies depending on the parameter) is appropriate for such direct statistical comparisons. However, interpretation of data certainly is not limited to the straightforward and obvious pre- and post- statistical comparisons of data points in space or time.

All monitoring information should also be interpreted in proper context, especially recognizing the dynamic and heterogenous nature of the environment being monitored. Intentionally, the baseline studies have been designed to facilitate additional analytical uses. For example, the frequency and spatial density of water column sampling of hydrographic features and nutrients/biology could be examined in view of physical mixing models and in the context of physical motion of water that will be measured during the sampling exercises. In such an analysis (be it modeling or model calibration) the whole field surrounding the outfall would be the frame of reference being examined, rather than a sample-by-sample or station-by-station statistical comparison. Additionally, data will be amenable to analyses to derive empirical relationships between different types of parameters. For example, spring chlorophyll levels could be compared to summer dissolved oxygen levels in bottom waters or the presence/absence of indicator benthic taxa. Sedimentary chemical parameters might be compared with either plankton or benthos parameters across space or time scales as defined by the hydrographical data. In essence, a wide variety of plausible relationships might serve as useful models to develop tests of pre- and postdischarge comparisons. These general examples are offered as a part of data interpretation and synthesis activities, but prior to available baseline information the exact scope and range of analyses are appropriately left unspecified; however, this plan calls for explicit effort during the baseline period to define useful additional methodologies for interpretation of ecosystem change.

7.2 PHASE II — POSTDISCHARGE MONITORING

Although the focus of this document is on baseline monitoring, some general discussion of what is being considered for postdischarge monitoring is presented below and in Appendix B. During development of this monitoring plan there was much discussion on utilizing a tiered strategy for implementing postdischarge monitoring. Implementation strategies of several recent monitoring programs have been based on a tiered approach, where data collected in each hierarchy of tiers are necessary to provide the foundation for the design and/or the extent of monitoring activities to be implemented in the next tier. Tiered monitoring strategies can provide a cost-effective way to assess impact by beginning with inexpensive screening tests and, if necessary, progressing to more definitive testing methods.

For example, one approach to implementing the MWRA postdischarge monitoring program would be to have the first tier of measurements focus on the source (effluent monitoring), with subsequent tiers providing information on the water, sediment, and biota around the outfall (and into the farfield). Effluent monitoring could be required at a specified frequency, but ambient monitoring would be required only if a specified effluent threshold was exceeded (e.g., contaminant concentrations or toxicity levels). However, many ambient measurements may be required to satisfy both National Pollutant Discharge Elimination System (NPDES) monitoring and impact assessment monitoring (see baseline monitoring above). In addition, transport and fate studies (e.g., plume studies) are very important to assessing potential impact, and therefore they should also take place (regardless of effluent concentrations) until results indicate otherwise. Thus, many measurements that could be considered for subsequent tiers, under this example, are already incorporated into baseline monitoring and will likely be measured during postdischarge monitoring at a frequency specified in the new NPDES permit. The actual content and structure of the postdischarge monitoring plan cannot be developed until additional baseline data are obtained, the new NPDES permit is issued, and several policy issues are resolved (e.g., what is the management structure, how is the monitoring plan reviewed and revised). These policy issues fall under the last step of the NRC model (Figure 2) and are beyond the scope of this technical baseline monitoring plan.

7.3 SUMMARY OF SAMPLING DESIGN, SCHEDULE, AND ESTIMATED COSTS

The MWRA effluent outfall monitoring program is designed to address both future NPDES permit compliance through routine monitoring and the additional requirement to assess potential impact as described in the SEIS (EPA, 1988a). The monitoring program extends across appropriate time scales, ranging from initial transport-and-fate processes in the water to longer-term accumulation in sediment and animals. Spatial scales are established with recognition of the physical setting and biogeochemical processes affecting dispersion and distribution, and with an appreciation for the behavior of particles in dynamic bottom waters. The design establishes a framework for evaluating effluent fate within a region surrounding the outfall in a way that will signal if and when effluent constituents are moving to more distant areas. Suitable additional fate-and-effects monitoring in other areas will be conducted if data from the network of regular monitoring should indicate that it is warranted. Thus, the design is adaptable. The baseline monitoring plan described above will provide a rich data set upon which to base the postdischarge monitoring plan.

A summary of the types of measurement and a proposed schedule of implementation with estimated costs (constant 1991 dollars) are given in Table 2. The cost estimates are on based on a small, informal sampling of regional scientists capable of performing this work and, therefore, may not reflect the actual costs incurred by the MWRA. Although discharge through the outfall will not begin for almost 4 years, and changes to this monitoring plan will be made over this time, the proposed schedule gives a general picture of how this monitoring plan would be implemented.

Table 2. Summary of Sampling Activities and Estimated Costs

Monitoring Activity	Estimated Cost of Sampling Activity (thousand dollars, constant 1991)[a]									
		Predischarge				Postdischarge				
	Pre-1992	1992	1993	1994	1995	1996	1997	1998	1999	2000
Effluent										
Toxicity testing and pathogens	00	00	00	00	100	200	200	200	200	200
Chemical and physical analysis (NPDES)	00	00	00	00	75	100	100	100	100	100
Water Column										
Nearfield water quality cruises	X[b]	200	200	200	200	200	200	200	200	200
Farfield and biology/productivity cruises	X	250	250	250	250	250	250	250	250	250
Continuous DO	X	20	20	20	20	20	20	20	20	20
Data synthesis and reporting		150	150	150	150	150	150	150	150	150
Softbottom Benthos										
Surveys	X	60	60	60	60	60	60	60	60	60
Sediment profile camera imaging	X	20	20	20	20	20	20	20	20	20
Biology	X	40	40	40	40	40	40	40	40	40
Chemistry	X	75	75	75	75	75	75	75	75	75
Data synthesis and reporting	X	50	50	50	50	50	50	50	50	50
Fish and Shellfish Contamination										
Winter flounder										
Histopathology	X	40	40	40	40	40	40	40	40	40
Chemistry	X	40	40	40	40	40	40	40	40	40
Lobster										
Histopathology	X	05	05	05	05	05	05	05	05	05
Chemistry	X	40	40	40	40	40	40	40	40	40
Caged mussel chemistry	X	10	10	10	10	10	10	10	10	10
Data synthesis and reporting	X	25	25	25	25	25	25	25	25	25
Special Studies										
Water circulation and particle fate	X	200	200	200	200	200	200	200	200	200
Other physical oceanography (dye studies, current meas., moorings, etc.)	X	100	100	100	100	100	100	100	100	100
Sewage tracer survey	X	?	?	?	75	75	?	?	?	75
Benthic nutrient flux/oxygen demand	X	150	150	150	150	150	150	150	150	150
Hardbottom biology	X	25	25	25	25	25	25	25	25	25
Plume studies	00	00	00	00	100	400	400	?	?	?
Detailed effluent characterization	X	50	50	50	50	50	50	50	50	50
Other modeling	X	100	100	100	100	100	100	100	100	100
Other special studies		?	?	?	?	?	?	?	?	?
Sea Grant Matching Funds	00	100	100	100	100	100	100	100	100	100
Data Management										
Sample tracking, logistics		40	20	20	20	20	20	20	20	20
Data coordination and loading		75	75	75	75	75	75	75	75	75
GIS management		75	75	75	75	75	75	75	75	75
Data exchange		25	25	25	25	25	25	25	25	25
System integration (LIMS, DB, GIS)		35	20	?	?	?	?	?	?	?
Other Data Synthesis and Reporting	X	100	100	100	100	100	100	100	100	100
Total		**2100**	**2065**	**2045**	**2395**	**2820**	**2745**	**2345**	**2345**	**2420**

[a] Costs are rough estimates.
[b] X: Unspecified number performed.
[c] ?: Level of sampling activity and/or cost is too uncertain to estimate.

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Appendix A

CONCEPTUAL MODEL OF RESOURCES AT RISK AND SOURCES OF PERTURBATION

To identify resources in Massachusetts Bay that would be at risk from multiple sources of perturbation, an exercise was carried out to derive from a large number of possible questions about impacts resulting from the proposed Massachusetts Water Resources Authority (MWRA) sewage outfall a subset that will produce the specific information needed to meet the objectives stated in Section 4.4. Perturbation, used in this context, means an agent or action capable of inducing observable change (i.e., a response) but carries no specific connotation of the acceptability of change (Kelly and Harwell, 1989). The effort described above made use of two types of conceptual model:

1. The simple, numerical models used in the development of the supplemental environmental impact statement (SEIS) for the proposed outfall (EPA, 1988)
2. A model that takes a more comprehensive, but qualitative view of the resources that could be at risk, of the various sources of perturbation, and of the complex biogeochemical processes that influence the environmental response of a new perturbation, the proposed sewage outfall.

The models used for the SEIS were a first-order approximation of predicted environmental responses in the nearfield and the farfield. The predictions that resulted from these models (EPA, 1988) formed the basis of decisions related to outfall citing and design. They will be useful also in setting the requirements for the National Pollutant Discharge Elimination System (NPDES) permits.

These numerical models were necessarily simple, when compared to the real environment. Their predictions have met with considerable criticism (e.g., Gallagher and Wallace, 1988). Therefore, the predictions listed in the SEIS have been used only as initial input to the qualitative conceptual model that is presented below. The MWRA is conducting a thorough and critical review of the predicted responses; the results of that review will be used to modify and better quantify the conceptual model described below. In addition, results from future monitoring will help to validate and/or improve these initial models.

RESOURCES AT RISK AND SOURCES OF PERTURBATION

The conceptual model presented here is a simple qualitative description of the causal links in the Massachusetts Bay ecosystem. This includes the

- Resources at risk
- Sources of perturbation
- Direct and indirect links among the resources and perturbations
- The variability in and uncertainty of these links
- Boundaries of spatial and temporal scales, based on biological, chemical, and physical descriptions of the ecosystem and sociopolitical realities
- Ability to predict and measure ecological responses and processes.

This qualitative assessment necessarily relies on expert judgment that has taken into account previous predictive modeling, as discussed above, some qualitative understanding of the nature of the discharges, and extensive experience with responses of marine ecosystems to different qualities (e.g., intensity, spatial extent, duration) of perturbation. A graphical summary of this assessment is given in Figure A-1. The matrix presents the reasonable initial concerns with the MWRA point-source discharge, as distinguished from the larger group of concerns throughout Massachusetts Bay. The figure is only a guide; it is not meant to convey predictions of probable impact.

The row headings of Figure A-1 provide a range of sources of perturbation to Massachusetts Bay. Individual sources of possible perturbation from the MWRA outfall are identified (nutrient loading, carbon loading, suspended loads, toxic chemicals, and pathogens or diseases); the other listed sources represent composites of their individual sources of perturbation. The column headings in the matrix are valued components of the ecosystem, grouped into three areas: biological components, special habitats and life, and environmental quality. The listing of biological components and special habitats and life is self-explanatory. Environmental quality changes are separated into two categories.

1. Processes affecting water quality deal with the issue of ecosystem status or health and include ecosystem processes affecting water quality
2. Water quality affecting human health deals with the ecosystem as a vector affecting human health

A third category, not explicitly considered in the scheme, is sediment quality. While specific sediment quality criteria have not been adopted by State or Federal agencies, this is an important area of environmental concern (cf., Shea, 1988). For the purpose of this document, sediment quality was implicitly considered in classifying benthic biological components of the matrix, most notably the soft-bottom benthos.

Toxics and nutrient enrichment, both of concern for the MWRA, have contrasting emphasis across the two specified environmental quality categories, as next described. With toxic input, the strongest public concern is for human health because we consume fish and shellfish; therefore, measures of tissue burdens would provide a useful indicator for this concern. It is possible for toxics to impact ecosystem structure and function, including processes affecting water quality, yet such types of impact are more difficult to demonstrate. Nutrients can be involved in human health issues — for example, they play a probable role in the development of blooms responsible for paralytic shellfish poisoning (which is routinely monitored by State health agencies). However, the highest influence of nutrients on environmental quality is not as a vector for impact on human health but as a perturbation of ecological processes, including changes in the food web and biogeochemical cycling that contribute to the development of hypoxia/anoxia.

Figure A-1 summarizes a large volume of information, detailed discussion of which would detract from the main objective of this document. The proper focus here is broader than individual cells of the matrix, and is intended to illustrate four points relative to monitoring.

1. A complex discharge, such as a sewage outfall, has some separable perturbation elements. These individual elements will impact different components of the marine environment on different spatial and temporal scales. A monitoring plan should recognize these different perturbation elements, and it should include measurements that will encompass the different mechanisms for change and points of impact.

2. There are multiple sources of perturbation in Massachusetts Bay. Some sources will have an influence on valued ecosystem components that is similar to that of the MWRA outfall. The influence of other sources will be quite different. Each of these sources will have a degree of uncertainty associated with their expected influence. Thus, detecting change and attributing the change to a particular source can be extremely difficult without a well-focused monitoring design.
3. The spatial scale and geographic distribution of the possible perturbation is critical to forecasting effects and to developing an appropriate monitoring design. For example, although the effluent from the proposed outfall could perturb some special habitats near shore (e.g., attached macroalgae), those habitats are not highlighted for the MWRA because all current projections do not suggest transport to those areas. Those habitats *are* highlighted for other wastewaters that are near shore. The matrix indicates that the scale of primary expected concern is the local surrounding waters of the proposed MWRA outfall, extending to a mesoscale (tens of kilometers) for some effects (depending on transport and fate). The monitoring design that is described below therefore focuses on the nearfield, and has a major transport and fate component that will be applied to refine the scale of monitoring as needed.
4. Careful consideration should be given to the choice of measurements that will indicate effects because ecosystem components that are equally affected do not necessarily have equal usefulness as monitors. The specific choice of indicators needs to be based on ease and economy of measurement, signal-to-noise (S/N) ratios in response, relative mobility of a given component (e.g., population), and the directness of an influence on the measure (e.g., fish are many steps removed from the nutrients that stimulate primary producers).

In summary, the valued ecosystem components that are most easily monitored and provide the least ambiguous data are those that

- Are highly influenced by the MWRA outfall but not by other sources of perturbation
- Have a local spatial scale of concern (although larger scales may have greater ecological significance)
- Have an associated measurement(s) that has high utility as an indicator of change

These ecosystem components are evident from Figure A-1 (the filled squares form a V within the cell of the matrix) and are discussed below. The conceptual model presented in Figure A-1 is translated into a series of possible environmental responses in Section 5.0 (Monitoring Strategy).

An important result of this qualitative assessment is that it provides an effective starting point for developing more specific monitoring questions through the selection of resources at risk (particularly ones that owe a large part of that risk to the MWRA outfall), an assessment of possible change and impact on those resources, consideration of the transport and fate processes that cause or can mitigate this impact, identifying environmental changes or trends that

Figure A-1. Sources of perturbation and resources at risk.

Explanation of the Matrix on the Facing Page

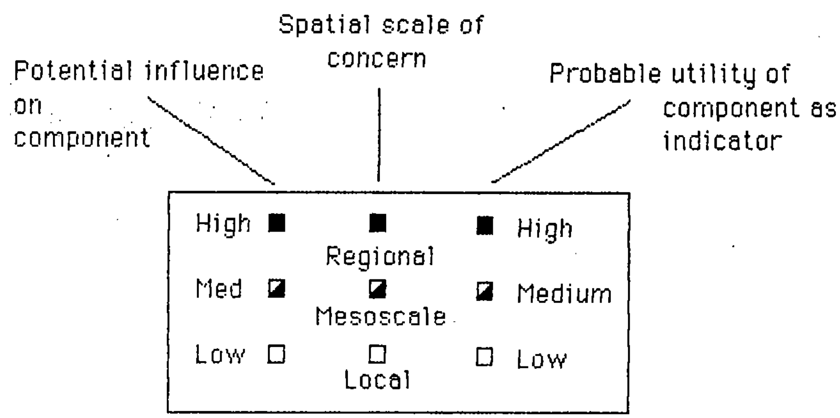
The results of the qualitative assessment of how the possible sources of perturbation (row headings) interact with valued components of the ecosystem (column headings) are shown within each cell (located at each intersection within the matrix). Each cell contains three columns of boxes that indicate the nature of this interaction.

The **first column** of boxes within each cell provides a ranking of the potential for a source of perturbation to influence change in a component. High (filled box), medium (half-filled box), and low (entire cell empty) rankings were based only on scientific information and not on what level of change is acceptable. The physical oceanography, the local fate/transport phenomena, and the nature of the biological community at the site were the main factors used to assess how a particular component responds to a given perturbation.

The **second column** of boxes within each cell indicates the appropriate spatial scale(s) of concern, from regional to meso to localized scales.

The **third column** of boxes within each cell ranks the utility of measurements related to a valued component to assess perturbation of that component (high utility: filled box; medium utility: half-filled box; low utility: empty box).

Cells with question marks indicate that the influence and/or utility was considered too uncertain or variable to adequately assess (indicating that there may be large data/information gaps). Where the potential influence was ranked low, the entire cell was left blank to reduce unnecessary clutter of presentation. Cells that contain two boxes in a single column indicate either an uncertainty over which ranking is correct or that there is more than one scale of concern.



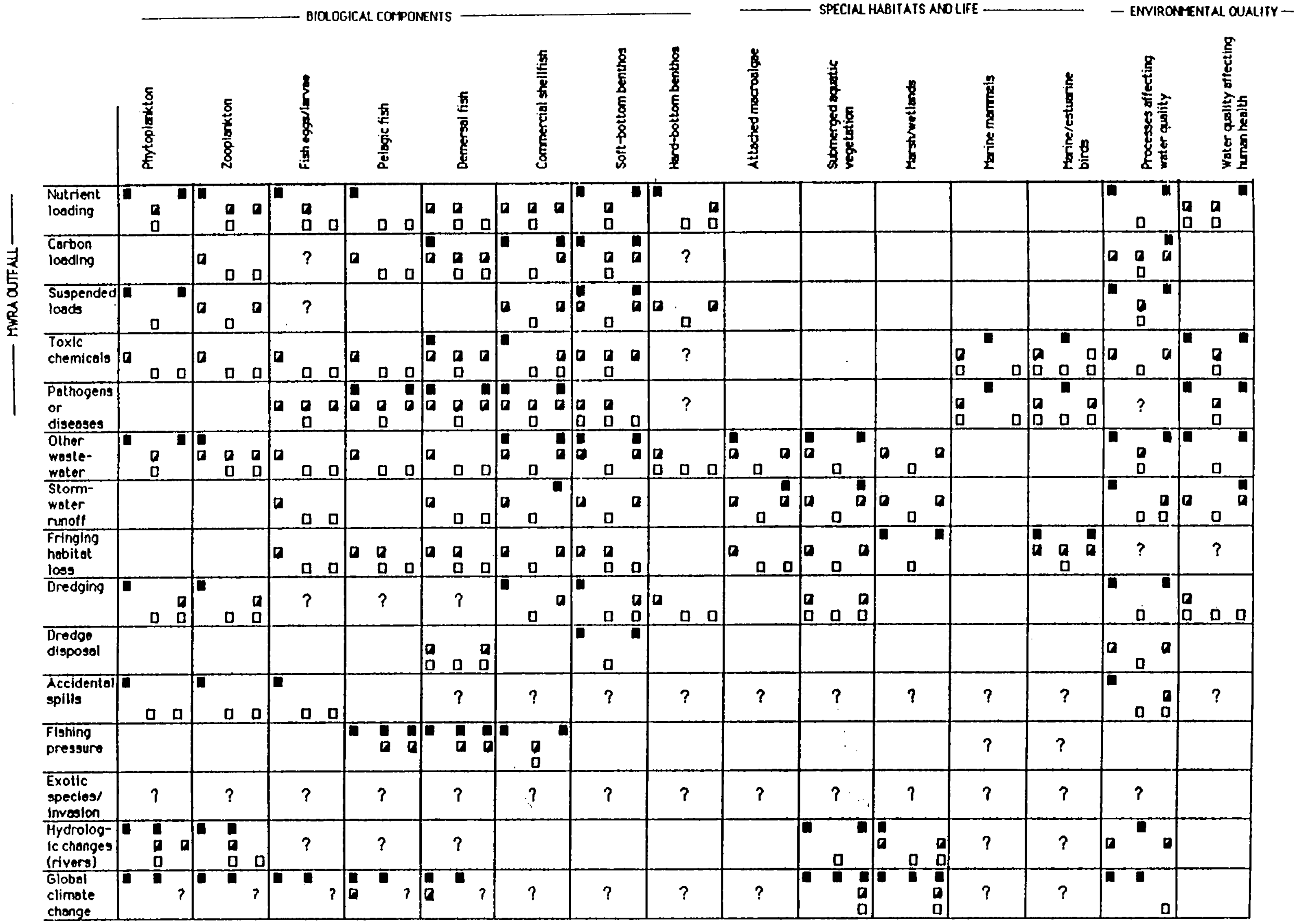


Figure A-1. Sources of perturbation and resources at risk.
See facing page for explanation of the matrix.

should be monitored, and identifying information gaps. However, it is recommended that, as further quantitative understanding of each perturbation is gained for Massachusetts Bay, the matrix should be revisited and reassessed by the MWRA.

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Appendix B

GENERAL SAMPLING PLAN

The basic strategy of this monitoring plan is to measure the loading and movement of matter discharged from the outfall and concomitantly to measure biological parameters that could be highly responsive to the discharge. Predicted areas of change for biological and chemical parameters largely fall within the immediate area of the outfall. Therefore, sampling is highly concentrated in that area in order to not only detect, but also to spatially characterize, changes in various parameters. Sampling is not limited to the immediate area; stations extend into most distant areas of Massachusetts Bay such as Stellwagen Basin and also Cape Cod Bay.

The principal intent of the sampling design is to detect changes in the water, sediments, and biota in the area surrounding the proposed outfall and related to the discharge. Farfield stations will provide a baseline against which to measure change, but they will also serve as regional reference sites. The farfield stations as well as those in the nearfield will be monitored during the entire baseline monitoring period prior to commencement of offshore discharge. Data collected during the baseline period will be analyzed to assess whether modifications to the plan need to be made. As an example, statistical analyses of variability observed over the initial 2 years of monitoring various nearfield and farfield regions of Massachusetts Bay and Cape Cod Bay could provide estimates of the power of the design to detect change. Based on such analyses, the numbers of stations, the numbers of samples, and the frequency of sampling events could be adjusted during remaining baseline monitoring and for postdischarge monitoring. An adaptive plan is necessary, in part, because there is not an adequate baseline for statistical power analyses for all parameters; MWRA will provide the Outfall Monitoring Task Force with suggested modifications for review and comment.

The purpose of this appendix is to provide more detail on the rationale for the parameters to be measured in the program and on the questions and possible environmental responses that the measurements address. Additional detail describes the rationale for sampling of various parameters over space and time. Where possible, the expected level of change that should be detectable is given. Where relevant, present parameter values are listed and predicted detectable change relative to any standards or action levels is estimated.

Several types of monitoring studies will help to resolve the transport, fate, and potential effects of the effluent. The sampling design will include

- Effluent monitoring
- Nearfield water-column monitoring for nutrients and related biological effects
- Farfield water-column monitoring for nutrients and related biological effects at sites throughout Massachusetts and Cape Cod Bays
- Nearfield benthic monitoring for biological and chemical changes
- Farfield benthic monitoring at areas where long-term focusing of particles is expected and at sites throughout Massachusetts and Cape Cod Bays
- Monitoring of fish and shellfish contamination in Massachusetts and Cape Cod Bays
- Special studies, including those on physical oceanography and water circulation, effluent plume tracking (includes nearfield compliance monitoring), and special aspects of the fate of toxic chemicals and nutrients

Each of these elements is discussed next.

Table B-1. Summary of the Existing MWRA NPDES permit (1987-1991).

ENCLOSURE II

2. Effluent Limitations and Monitoring Requirements for POTW Outfalls Listed in Attachment A

a. Effluent Limitations and Monitoring Requirements

During the period beginning the effective date and lasting through expiration, the permittee is authorized to discharge effluent to Boston Harbor from POTW outfalls listed in Attachment A. Such discharges shall be limited and monitored by the permittee as specified below and shall be reported by the permittee pursuant to section D on pages 19 and 20 of Part I:

Effluent Characteristic	Discharge Limitations			Monitoring Requirement	
	Average Monthly	Average Weekly	Maximum Daily	Measurement Frequency	Sample Type See Footnote 2
Flow-m^3/Day (MGD)				Continuous	
BOD[1,3]	30 mg/l	45 mg/l	50 mg/l	Daily	24 Hour Composite
TSS[1,3]	30 mg/l	45 mg/l	50 mg/l	Daily	24 Hour Composite
Settleable Solids		0.1 ml/l	0.3 ml/l	Daily	Grab
pH	(See A.1.a on page 4 of Part I)			Daily	Grab
Fecal Coliform	200/100 ml	400/100 ml	400/100 ml	3xDaily	Grab
Total Coliform	(See footnote 4)			3xDaily	Grab
Chlorine, Total Residual	(See A.1.c on page 4 of Part I and A.2.b on page 7 of Part I)			3xDaily	Grab
Chlorides (Influent only)				Daily	Grab
Oil and Grease of Petroleum Origin			15 mg/l	Weekly	Grab
NOEC[5]	10% or greater[6]			Monthly	24 Hour Composite
LOEC[7]; MATC[8]; LC50[9]	(See A.2.b on page 7 of Part I)			Monthly	24 Hour Composite
NOAEL[10]			20% or greater[11]	Monthly	24 Hour Composite
Volatile Organic Compounds	*** Use EPA Test Method 624 ***			Monthly	Grab

The discharges shall not cause a violation of the water quality standards of the receiving waters.
FOOTNOTES ON PAGES 22 AND 23 OF PART I.

Effluent Monitoring

Background. Effluent monitoring will be required to test for compliance with any toxicity and contaminant-concentration limits which may be established through the new NPDES permit. The measurement parameters and frequency for effluent compliance monitoring will be specified in the NPDES permit (see Table B-1). Monitoring the effluent will provide an early warning to many potential problems in the receiving water and can act as a screen for more extensive (and expensive) measurements in the environment. However, measurements at the edge of the mixing zone also will be necessary to confirm expectations of dilution and verify compliance with the National Pollutant Discharge Elimination System (NPDES) permit (this will be done during plume studies; see below).

The NPDES permit will likely include a requirement for measurement of pathogens, biological toxicity evaluation, and specific chemical contaminants. Further details on these three types of measures are given in sections below.

In addition to measurements required by the NPDES permit, effluent monitoring may also include a quantitative chemical characterization of the sewage to determine the identity and concentration of potential sewage tracers and some additional contaminants of concern. This characterization could include measurements of polynuclear aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), chlorinated pesticides, transition and heavy metals of concern (dissolved and particulate phases), and the potential sewage tracers: linear alkyl benzenes (LAB), 15-N, and *Clostridium perfringens*. The actual measurements to be made that are not required by the NPDES permit will be determined during baseline monitoring. Frequent monitoring of the effluent is important because its characteristics can change with variations in sources, treatment operations, and flow rates. Measurements will be made of the present effluent (on 24-h composite samples) to evaluate variability. The frequency of subsequent baseline and postdischarge measurements will be based on these initial data.

Pathogen measurements. In order for open shellfishing to take place, waters must be classified Class SA, in which fecal coliforms do not exceed a geometric most probable number (MPN) of 14 organisms per 100 mL of water, and not more than 10% of the samples may exceed an MPN of 43 per 100 mL. Waters approved for restricted shellfishing (Class SB) should not exceed a fecal coliform median or geometric mean MPN of 88 organisms per 100 mL, and not more than 10% of the samples should exceed an MPN of 260 organisms per 100 mL.

Fecal coliforms are indicators only of the presence of enteric pathogens in the environment, and their lifetime is generally short. In addition, coliform levels are highly variable with both space and time. Thus, fecal coliform should be used only in comparison against standards, rather than in comparison of postdischarge against baseline or even gradients with distance from a suspected source. It might prove useful to measure concentrations of other microorganisms, such as *Enterococcus* and *Clostridium perfringens*. *Enterococcus* has longer survivability than does fecal coliform and might be a better water-column indicator. *Clostridium perfringens* has a much longer lifetime than do either coliform or *Enterococcus*, making it a preferable indicator of sewage in the water and in sediment.
Analysis of the samples for coliforms and enterococci should be by accepted standard microbiological techniques. *Clostridium* should be enumerated on the basis of the number of spores per unit dry weight of sediment or unit volume of filtered water.

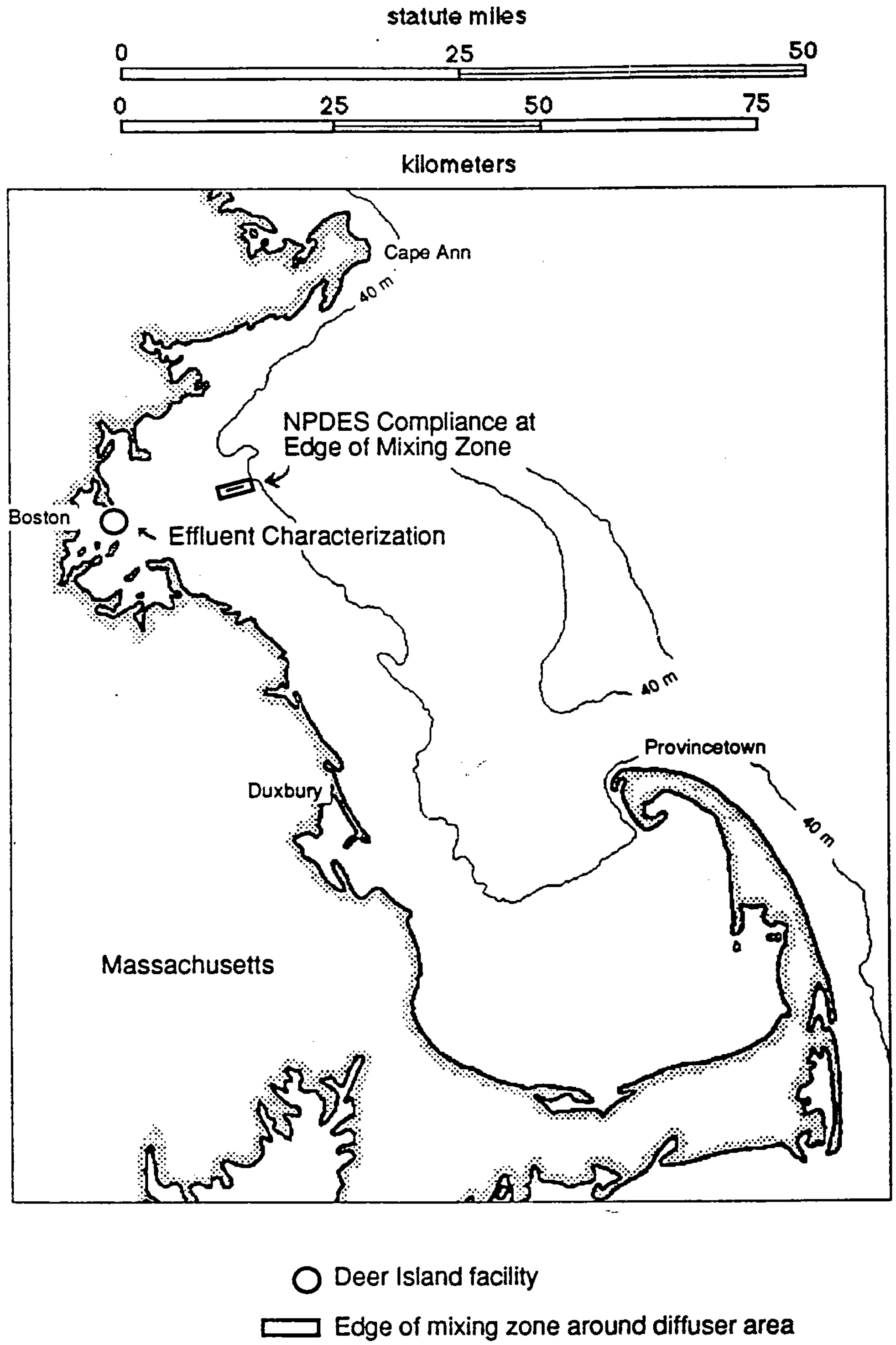


Figure B-1. Effluent monitoring

The primary sampling location is the effluent (Figure B-1). Monitoring fecal coliform and *Enterococcus* in the effluent will take place routinely to verify compliance with the NPDES permit. The only ambient water sampling for these two pathogen indicators will be done in the area of the outfall during plume studies. Plume transects oriented toward the shoreline are of most value. Because the densities of certain fecal indicators in the sediments can exceed those in the overlying water column by as much as three orders of magnitude, sediment samples in the nearfield and farfield toward shorelines should also be collected and the longer-lived *Clostridium perfringens* measured.

Bacterial indicators currently measured in the effluent will provide baseline effluent data. Ambient water-sample collections are not required during the baseline period, with the possible exception of *Clostridium perfringens*, which could be measured during the baseline evaluation for plume studies (see below). Once the effluent is being discharged, effluent will continue to be monitored, and water samples should be collected at the outfall during the special plume studies. An additional collection should be made at the outfall after a storm event.

Expectations from pathogen monitoring. Shellfishing will be restricted or prohibited if the total fecal coliform levels on the shellfish beds exceed State standards. Postdischarge monitoring of the effluent and ambient water will provide an estimate of the potential for the standards to be exceeded because of the discharge. Postdischarge monitoring could provide an early warning of potential problems over the shellfish beds. The levels of bacterial indicators in the current effluent indicate that the levels will be extremely low, especially after chlorination of the effluent.

Biological toxicity testing. The NPDES permit for the MWRA sewage outfall is likely to require that the whole effluent have practically no acute toxicity (100% strength). To verify that this condition be met, chronic as well as acute effluent toxicity tests will be required. The current NPDES permit requires chronic toxicity tests on the sheepshead minnow *(Cyprinodon variegatus)* and red marine alga *(Champia parvula)*, and a 96-h acute toxicity test on 1- to 5-day-old mysid shrimp *(Mysidopsis bahia)*. The use of these particular indicator organisms needs to be evaluated critically with respect to how well they represent actual organisms living in Massachusetts Bay.

The primary sampling location is the effluent stream just prior to entry into the tunnel. As a baseline data set, data from current outfall will be used for comparison. Special studies will be undertaken to design a statistically valid scheme to characterize effluent load as a function of flow rates and thereby be capable of highly accurate quantification of loads over time.

Sampling and effluent toxicity test methods will be the same as those currently used, unless new indicator organisms are found to better represent actual organisms living in Massachusetts Bay. Ambient environment water samples may be taken and tested for toxicity if effluent toxicity data indicate its necessity. This testing would provide verification that the whole effluent toxicity tests and water-column contaminant measurements adequately protect sensitive water-column species. Toxicity tests similar to those employed for effluent testing would be performed on water samples collected during the special plume studies. If any toxicity is observed, toxicity tests should be continued on subsequent plume studies.

Expectations for biological toxicity monitoring. The expectation is that the effluent will exhibit no acute toxicity as is likely to be required by the new NPDES permit.

Chemical measurements: Conventional pollutants. Conventional pollutants will be measured in the effluent as specified in the NPDES permit; the current permit list is given in Table B-1.

Measurements will also include a variety of nitrogen forms, not necessarily specified in the NPDES permit. These include inorganic forms: ammonia, nitrate, and nitrite. Also, dissolved organic nitrogen (DON) and particulate organic nitrogen (PON) should specifically be analyzed. *Together,* all these forms are summed to arrive at total nitrogen values; but, the *individual* forms have different chemical fate and effects and should be measured separately. Some forms may act as a distinct chemical signature of the effluent when compared to environmental concentrations and, therefore, may be useful as nearfield tracers.

Chemical measurements: Metals. The NPDES permit for the MWRA sewage outfall may require that the effluent meet specific limits on the concentrations of conventional and priority pollutants. The current NPDES permit includes measurements of the metals antimony (Sb), arsenic (As), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), thallium (Th), and zinc (Zn). Several of these metals have little utility in documenting possible impact of sewage discharge. The list of NPDES-permitted metals should be reevaluated in light of their toxicity (or lack thereof), their utility as indicators, and historical effluent data that indicate that some of these metals are not a problem.

The sampling and analytical methods used for measuring trace metals must meet stringent data quality requirements – for example, low contamination, low method detection limits, and high precision and accuracy. A recent interlaboratory comparison exercise conducted by the Environmental Protection Agency (Battelle, 1991) has shown that traditional sampling methods can introduce significant contamination and that standard EPA methods often are not able to meet the data quality objectives necessary for making good management decisions. Many metals that were thought to be a problem in sewage effluents in New York City are actually below water quality criteria (WQC) (Battelle, 1991). Inadequate analytical methods were the major cause of this problem. All effluent trace-metal measurements should provide accurate (80%-100% recovery of reference material or matrix spike sample) and precise (<20% relative standard deviation) measurements of concentrations at least 5 times below the permit limit or State water quality standard. This may require a chelation-extraction or coprecipitation sample-preparation procedure for many metals prior to analysis by, preferably, graphite furnace atomic absorption spectrometry (GFAAS) or inductively coupled plasma/mass spectrometry (ICP/MS).

There are some additional measurements that would be useful to help to document potential impact from the outfall. Measurements of aluminum could be used to normalize other metal concentrations. These ratios might provide an effluent signature (or tracer) that would be useful in modeling the transport and fate of the effluent and possibly discriminate effluent metal loadings from those of other sources (e.g., the Merrimack River). Data on both particulate and dissolved metals would also be useful in modeling effluent transport. For example, the particulate silver/aluminum ratio often is higher in sewage effluent than in atmospheric or riverine sources and would be particularly useful as an aid to interpreting data from plume-tracking studies and sediment and/or sediment-trap analyses. These additional measurements should not be included on the NPDES list because they have no direct regulatory significance, but they should be a part of additional effluent characterization.

Chemical measurements: Organic contaminants. The current NPDES permit requires the measurement of certain priority pollutant organic compounds in the effluent. Most of the data generated from these measurements are of little value in predicting potential impact or modeling transport and fate because the priority pollutant list does not contain several analytes useful for assessing these issues, and the detection limits of the EPA Contract Laboratory Program (CLP) analytical methods are often too high. Important analytes for assessing transport and fate that are not on the priority pollutant list include several PAH, alkylated PAH, PCB congeners, and specific tracers of sewage (LABs). Because some or all of these additional compounds will be measured in tissues and sediments to address other monitoring questions, accurate source loads are necessary to interpret the other environmental monitoring data. Again, analytical methods should yield accurate and precise measurements at least 5 times below the permit limits or WQC, if possible. Preliminary results from a recent characterization of the Deer Island effluent indicates that PAH, PCB, and pesticide concentrations may be 100 to 1000 times lower than previously estimated using EPA CLP methods (Shea, unpublished data). This new effluent study utilized modified EPA methods similar to those used in the NOAA Mussel Watch and EPA EMAP monitoring programs (see for example, Battelle, 1990). These methods should be used for all effluent monitoring in the future.

For both metals and organics, the effluent will be sampled prior to entry into the tunnel pipe and as specified by the NPDES permit. Data from the current outfall will be used as a baseline for comparison of treatment effectiveness. The frequency of compliance measurements will be set by the NPDES permit.

In addition to effluent sampling and mass load characterization, ambient water-column sampling for contaminants (with State WQC) will be performed just prior to the commencement of discharge and only during the first plume study. If the WQC are exceeded, additional sampling should take place on subsequent plume studies for verification.

Expectations for effluent and nearfield compliance monitoring. Potential toxic contaminants, nutrients, BOD, etc., will be characterized sufficiently to allow accurate mass loads to Massachusetts Bay to be determined. The effluent and nearfield environment measurements will be used to verify/refine model estimates of initial dilution and to determine compliance with NPDES permit requirements.

Nutrient Enrichment in the Nearfield Water Column

Background and general sampling design. The focus of this monitoring activity is on nutrients, dissolved oxygen, and potential related water-column effects on phytoplankton and zooplankton. Nearfield sampling will include vertical profile stations in an array surrounding the 2-km length of the outfall diffuser (Figure B-2). Sampling activities will include vertical profiles made routinely (16 times per year) at 24 stations. These stations are termed *nutrient/hydrography* stations, where continuous vertical profile readings of some parameters (e.g., by CTD) will be made and water samples for nutrient analyses at selected depths will be taken. Continuous horizontal profile sampling will be performed along a linear depth gradient from the bottom of one nutrient/hydrography station to the surface of the next. This profile sampling will pass through the pycnocline and will describe conditions, in terms of a number of parameters, between the 24 stations during each of the 16 cruises per year.

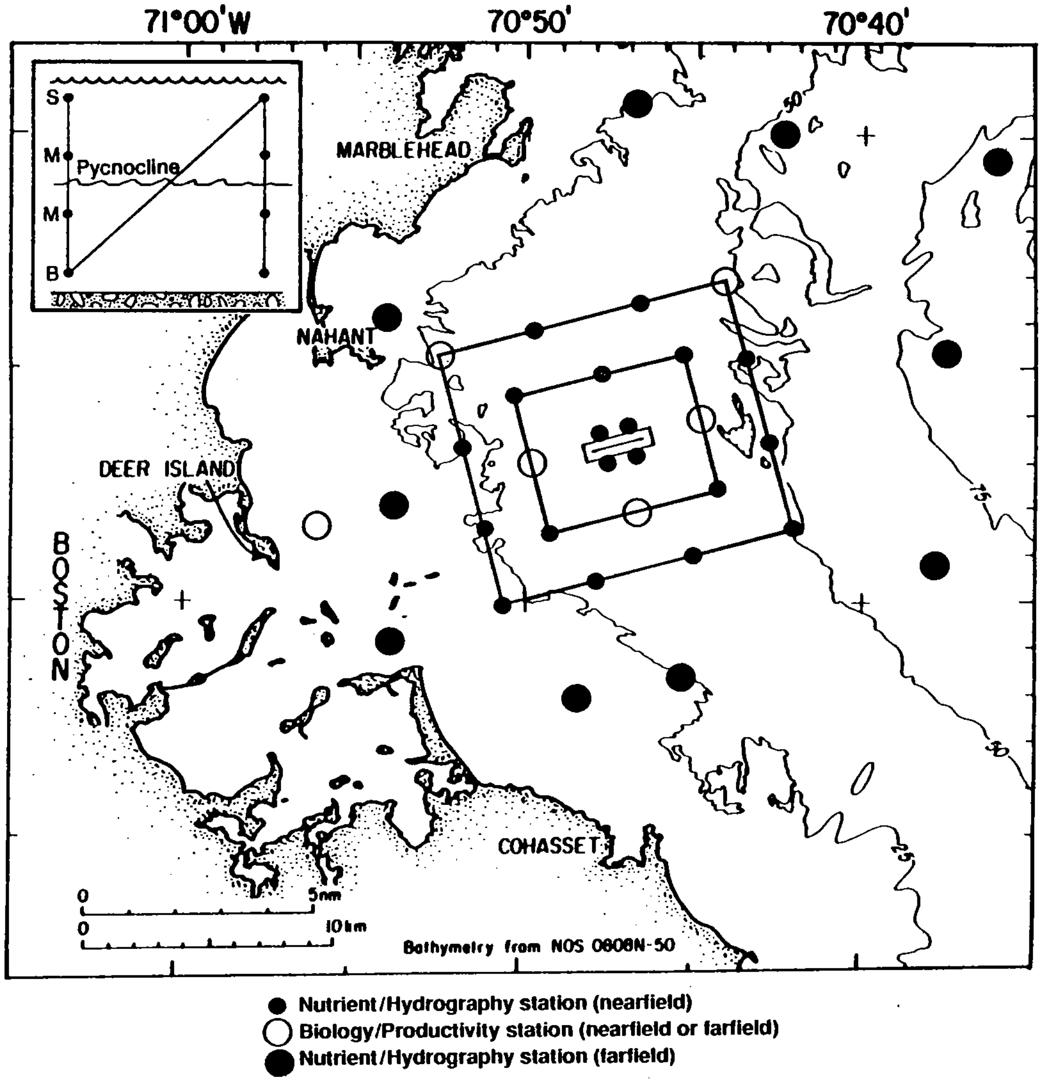


Figure B-2. Nutrient enrichment in the nearfield water column.

At a lower frequency, a subset of the nutrient/hydrography stations will be sampled in the vertical dimension for a variety of biological parameters, including 14-C productivity. These special stations are termed *biology/productivity* stations. These stations occur in the nearfield (5 total), and also the farfield (5 total). The biological measures to supplement the nutrient/hydrography measures at these stations will be made for six of the 16 regular cruises spaced throughout the productive season from February to October.

Nutrients [dissolved forms of inorganic nitrogen (ammonia, nitrate, and nitrite), phosphate, and silicate] will be routinely measured in vertical sampling at the 24 nearfield nutrient/hydrography stations. Dissolved oxygen, selected hydrographic variables [temperature, conductivity/salinity, beam transmittance, light (irradiance)], and *in situ* chlorophyll fluorescence will be measured along the continuous horizontal profile sampling transects along routine cruise tracks as well as vertically at the 24 nutrient/hydrography stations. Measurements at the subset of biology/productivity stations will include chlorophyll *a* and phaeopigments (extraction of filtered sample), 14-C primary production, phytoplankton identification and enumeration (including identification of toxic dinoflagellate species), net zooplankton biomass (settled volume), zooplankton identification and enumeration, and additional chemical measurements not routinely measured at the nutrient/hydrography stations [dissolved organic carbon (DOC) and nitrogen], particulate carbon and nitrogen, and total suspended solids).

The spatial sampling strategy for continuous horizontal profile sampling and the nutrient/ hydrography station grid is to occupy a series of three rectangular cruise tracks representing a distance gradient out to as far as 5 km from the diffuser pipe (in all directions; see Figure B-2). The positioning is biased along the axis of the 2-km diffuser linear orientation of the outfall diffusers to extend 5 km away from the nearest diffuser. Due to the 2-km length of the diffuser series, the outer sampling track therefore is 10 x 12 km. Given that the tidal excursion length is on the order of about 2 to 3 km, the distance of the outer track is well outside this distance, and the middle track is positioned approximately at this distance.

From initial studies of the physical setting (Bothner, personal communication), there is a perception of no dominant, consistent direction of nearfield transport (over about 2 days). However, it is not known if this is the case at all seasons and under all meteorological/hydrographic conditions. The strategy of multiple stations radiating from the diffuser axis and continuous information from increasingly larger rectangular tracks is based on a prime need to detect change within the nearfield and well to resolve spatial aspects relative to the discharge. The sampling will allow a quantitative three-dimensional description to be made of parameters in the nearfield. It is designed to firmly depict change if it occurs in any direction and, furthermore, to describe the spatial and temporal extent of that change within this field. The design will facilitate measurement and description of strong directional transport in the event that it were to dominate over the physical mixing process that would, alternatively, tend to spread material in a symmetrical pattern grading evenly with distance in all directions away from the discharge diffusers.

The inner cruise track is placed at the outer edge of the approximate mixing zone. The expectation is that no exceedence of WQC will be recorded along this track (useful for NPDES compliance monitoring). The outer cruise track is intended roughly to be where outfall-related water-column effects are not predicted based on simple dilution arguments, barring bottom particle focusing processes. In essence, this track is the beginning of the farfield. The middle track is positioned near the length of the tidal excursion distance from either end of the diffuser. This third track is necessary to give adequate spatial resolution, providing a three-point distance gradient in all directions away from the diffuser and thus allow a three-dimensional description of change.

During baseline studies, sampling of the nearfield by this strategy will provide a full description of seasonal and interannual variability at each station and at spatial scales from hundreds of meters to tens of kilometers. Given the variety of physical processes operating in this region, the complex hydrographic variability, and the sensitivity of biology and chemistry (outfall or not) to such physical processes (Kelly, 1991), intensive sampling during baseline is required to develop the strongest understanding of this field prior to effluent discharging. The sampling strategy postdischarge is not expected to be modified from that during baseline.

The description and rationale for various measures, their frequency, spatial arrangement, and expectations of change are described next for some basic categories: nutrients, dissolved oxygen, plant biomass as chlorophyll and activity as 14-C production, and biological community composition. Intertwined with discussion of these measures, mention is made of supporting hydrographic measures.

Nutrient measurements. The nutrient regime surrounding the outfall determines, in part, the biological response and, thus, must be characterized. Nutrient loading, as modified by water residence time and vertical stratification, influences *in situ* nutrient concentrations. Dissolved nutrients themselves are not a biological indicator of response, but biological responses are expected from changes in nutrients. Thus, monitoring of nutrients, like toxics, is to characterize the environmental condition and serve as "exposure" indicators that will help in evaluating cause/effect relations. Nutrients of concern with the outfall include forms of nitrogen, phosphorus, and silicate.

All nutrient measurements will be made on discrete samples taken at five depths per station: surface, three middepths, and near bottom. Two middepth samples will span the pycnocline when it is present, and the third will target the region of the middepth chlorophyll maximum. Hydrographic data from continuous profile sampling will be used in real-time to determine the presence of the thermocline/pycnocline and chlorophyll maximum.

Nitrogen is of prime concern, for most marine systems appear to have productivity limited by this element and the biological community is responsive to enhanced nitrogen levels. The survey data of Townsend *et al.* (1990) demonstrate consistently low inorganic N/P ratios (mostly in the range of 4/1 to 10/1) at stations immediately inshore and offshore of the proposed outfall; this condition is suggestive of nitrogen limitation. N/P ratios were particularly low during summer months, even below 1 in upper waters during stratification.

In addition to dissolved inorganic forms of nitrogen (nitrate, nitrite, and ammonium), particulate organic nitrogen (PON) should be measured. PON changes, to an extent, should parallel chlorophyll responses because nitrogen is being assimilated into phytoplankton tissue. PON values can be a measure of effect, but this measure is also relative to element budgets and to tracing fate of particle dispersion and settling to the benthos. PON can be the major form of nitrogen within the water column at some seasons in Massachusetts Bay (Kelly, 1991). Moreover, the sum of PON and dissolved organic nitrogen (DON) may be a useful indicator of loading and the ratio of PON to DON an indicator of eutrophication status and capacity for nutrient retention (Kelly *et al.*, 1985; Kelly and Levin, 1986).

PON need not be measured at all stations. Relationships between chlorophyll and PON at selected stations may be used to calculate PON if necessary. PON will be sampled only at biology/productivity stations. Additional samples for chemical measurements at these stations will include particulate organic carbon (POC). POC is valuable to measure in support of 14-C production measurements (see below), to give a sense of the "quality" (detritus or sewage versus plankton) of suspended organic matter (POC/PON and POC/chlorophyll ratios), and knowledge of POC may be important relative to fate and transport of some chemical contaminants. Finally, both DON and DOC will also be measured at biology/productivity stations. These are to provide a complete quantification of all forms of nitrogen (total nitrogen) and organic carbon for modeling and possible budgetary purposes, are potentially relevant to stimulation of some types of phytoplankton, are potential indicators of sewage (high in both DON and DOC), and are relevant to chemical fate since some chemical contaminants may strongly associate with this water-column fraction. All nutrient, DOC/DON, and POC/PON analytical methods will follow standard oceanographic methods. In general, the report of Townsend *et al.* (1990) provides description of such methods.

Phosphate monitoring is helpful even if P is not limiting phytoplankton growth. Ratios of N and P in effluent characteristically are different from environmental ratios and, thus, may provide a tracer for effluent relative to different water masses.

Silicate is of interest also. During the winter/spring diatom bloom, silicate may become limiting and control phytoplankton growth. Moreover, the relative availability of N, P, and Si, can influence the species composition of the phytoplankton. In particular, sewage effluent is very low in Si, and it has been suggested that low Si/high N conditions may promote the success and dominance of flagellate forms, including nuisance and noxious forms. Since species composition of the phytoplankton will also be monitored, measurement of silicate concentrations may help to determine causes of major community shifts if they occur.

Nutrient/hydrography cruises will be conducted 16 times per year. Such frequency is necessary to describe seasonal features and to allow accurate definition of annual mean values of nutrient concentrations. Annual mean values are highly useful in describing the trophic status of a nearshore marine ecosystem and to relate biological response (e.g., chlorophyll and production), as demonstrated by Kelly (1991) for Massachusetts Bay. During baseline and postdischarge monitoring, regular cruises are planned for months of a calendar year as follows (with the number of cruises within the month following in parentheses): February (1), March (2), April (2), May (1), June (1), July (2), August (2), September (2), October (1), November (1), and December (1). Sampling frequency is biased to capture a dynamic change period of the spring bloom, and will occur approximately every 2 weeks from mid-June almost through October, a major period of high biological rates and rapid nutrient dynamics in euphotic layers up to and including a fall phytoplankton bloom characteristic of the near-field area in Massachusetts Bay. Note that this sampling strategy can not be expected to capture all aspects of biological events during high summer temperatures, when fluctuations may be on time scales of a few days and suitable sampling to describe such events would have to be conducted daily or even diurnally. The sampling frequency is intended to describe events in a timeframe adequate to capture essential seasonal features of nutrient dynamics, including periods of high biological activity and major physical features of spring and fall water-column stratification and mixing events.

Expectations for nutrient monitoring. Recent data suggest seasonal variability in nutrients, with perhaps some variability due to varying contributions of different water-mass sources at the outfall site throughout the year (Townsend *et al.*, 1990). These data are not fully sufficient to do power analysis to determine detectable change in concentrations; data from baseline studies will be used for such purposes. However, given the large mass of projected nutrient loading from the diffuser, detectable changes in nutrient concentrations surrounding the outfall are expected. Horizontal and vertical scales of dispersion will determine resulting concentrations, and nutrient tracking must be done to couple biological effects to enrichment.

Ambient nitrogen concentrations in the water column around the proposed diffuser site are about 0.2 - 18 μM N (equal to the range of dissolved inorganic nitrogen (DIN) at all depths throughout the season at two stations immediately inshore and offshore of the proposed outfall site; Townsend *et al.*, 1990). In Boston Harbor at present, the annual average nutrient concentrations are in the range of about 10 to 11 μM N expressed as DIN and values in the nearfield could reasonably be expected to be no more than this amount elevated above ambient background, which presently appears to average about 6 - 9 μM N as DIN in the nearfield region (Kelly, 1991). In short, neither the present outfall area, the present Boston Harbor area, nor projected values through most of the nearfield region indicate a very eutrophic situation (Kelly, 1991). The current levels in the offshore region that will become the nearfield must be, in part, maintained by the outflow of nutrients now delivered to Boston Harbor in the discharges that will diverted from there to the proposed outfall site (Kelly, 1991). The sampling strategy should be sufficient to identify persistent changes in DIN on the order of 1 μM. It is expected that increases of as much as 10 μM on average may occur in the mixing zone but will not be achieved through most of the nearfield. This is expected in part because rapid dispersive mixing and greater dilution (because of greater depth than in the Harbor) are expected at the site. Elevated nutrients at some depths and at some seasons are expected within the boundaries of the nearfield, and, if directional transport rather than more symmetrical dilution occurs, some stations may experience elevated nutrient loads. As discussed above, the sampling strategy is designed fully to detect such events.

Dissolved oxygen measurements. Dissolved oxygen (DO) levels are a primary endpoint relative to nutrient and organic enrichment from the outfall. The concern, of course, is for the depression of oxygen to very low levels (hypoxia) or to absence (anoxia). Recent data (Townsend *et al.*, 1990) suggest that the area of the proposed outfall is, throughout most of the year, near about 95% to 105% of oxygen saturation values. The exception is that the bottom waters at stations just inshore (about 23 m depth) and just offshore (about 43 m depth) of the proposed outfall can fall to as low as 79% to 91% saturation in late summer/early fall, when bottom temperatures are highest. For reference, these are not low levels — biological effects on benthic organisms would likely be difficult to establish unless values fell below about 25% saturation for an extended period.

Several constituents in the outfall effluent can affect DO. A direct impact can be exerted by discharge of organic matter (particulate and dissolved) that becomes oxidized and other chemicals that are chemically or biologically oxidized (e.g., such as through nitrification of ammonium). Additionally, nutrients can stimulate primary production; rapid decay of this phytogenous organic matter in either water or sediments (especially those sealed from "ventilation" by the atmosphere by strong vertical water-column stratification) can exert a considerable impact on DO.

DO may or may not be a highly responsive indicator (dependent on physical factors), but, since it is an endpoint itself, it clearly must be part of the suite of variables for monitoring. It should be routinely measured whenever other water-quality parameters are. More intensive monitoring of selected bottom waters should be the focus of summer seasons when stratification and higher temperatures occur, for both of these enhance the potential for DO depletion.

Sampling should take place along the routine cruise tracks and at nutrient/hydrography vertical profile stations. This will be done at each of the 16 regular cruises throughout a calendar year. Simultaneous continuous information on temperature and salinity will allow calculation of per- cent saturation. Additional information on irradiance, beam transmittance, and *in situ* chlorophyll will be related to DO levels, and three-dimensional graphics will display DO distribution in space as related to hydrographic variables. Oxygen levels can fluctuate diurnally in waters influenced by phytoplankton production and respiration through the daily light/dark cycle. Although normally not highly pronounced in deeper waters, with the high levels of nutrient loading that will occur at the outfall diurnal variability may be large, and the lowest DO levels are likely to be observed either at the end of the dark period (due to respiration) or perhaps with a short time lag (Oviatt *et al.*, 1986; Sanford *et al.*, 1990; Breitburg 1990). Therefore, the strategy for cruise-track sampling should be devised so that stations (or, more appropriately, the water masses therein) along the initial leg for the day are first sampled at dawn and then are resampled at dusk. Differences between dawn and dusk might be used to derive a measure of system productivity (cf., Oviatt *et al.*, 1986); such information (dawn/dusk deviations and system production) could be highly useful in forecasting short-term potential for oxygen depletion and will provide feedback more rapidly than 14-C production studies (see below).

During summer stratified periods, a baseline site within the nearfield, but not in the mixing zone, should be intensively monitored remotely by an *in situ* continuous DO sensor. A continuous sensor is planned for Buoy B within the nearfield, where other current-meter studies and sediment-trap arrays are positioned. Deployments should cover the summer stratified period at a minimum. Because sensors provide reliable information over a limited period, deployments should be sequential, with DO sensors switched out every 1 to 4 weeks (cf., Sanford 1990).

The overall nearfield strategy allows (1) detailed water-column profiling 16 times per year, with highest frequency during summer as for nutrients, and (2) continuous high-resolution temporal monitoring of one site within the nearfield (buoy B) during the summer.

Expectations from DO monitoring. Midwater hypoxia from phytoplankton bloom events is possible and would be detected by the cruise tracks as well as near-bottom hypoxia or anoxia in the nearfield. With respect to each of these locations, the main season of concern is during stratification and at high temperature, for under those conditions the potential magnitude of depletion is maximal and the potential onset the swiftest. Lowered oxygen may occur close to the diffuser, associated with oxygen consumption due to particles and dissolved substances — the inner-track monitoring would easily detect this. Lowered DO over wider scales would be closely associated with the decay of particles (discharged from the outfall and from extra production caused by the outfall). Such events are most probable in areas where particles accumulate, either in the water (e.g., a pycnocline) or in the bottom sediments — outer-track monitoring, as well as additional plume studies and farfield monitoring (see below) are designed to address these.

The scales of temporal variability are presently unknown, but at a fixed location DO variability is a function of diffusive and advective (tidal and nontidal) processes as well as oxygen consumption processes in water and underlying sediments. In general, lowest percent DO saturation levels may occur at deeper stations that are not ventilated by water-column destratification until late in the fall. Around the immediate outfall area, destratification appears to occur in September/October (cf., Kelly, 1991). The physical complexity at the proposed outfall site complicates predictability; nevertheless, the various components of the monitoring design should provide adequate resolution to detect long-term trends and describe the magnitude of oxygen depression at critical spatial and temporal scales.

***In situ* chlorophyll and extracted chlorophyll measurements.** Primary production of the organic matter biomass that forms the main energy basis for marine food chains is, in part, regulated by nutrient levels. Nutrient enrichment is expected to cause a direct response by primary producers. Aside from very shallow areas where the primary producers can include seagrasses and macroalgae, the phytoplankton are the principal primary producers. Chlorophyll *a* in the water is the most common measure of phytoplankton biomass and can be measured by fluorescence techniques *in situ* (e.g., Townsend *et al.*, 1990).

Chlorophyll concentrations in coastal waters usually vary with season and depth, and there also may be some horizontal patchiness. Even with such variability, chlorophyll *a*, if measured at appropriate space and time scales, appears to be a responsive indicator of nutrient loading in many coastal areas (Nixon and Pilson, 1983; Nixon *et al.*, 1986). Higher chlorophyll levels characteristically are seen at higher nutrient loading and higher *in situ* nutrient concentrations, unless phytoplankton growth and biomass accumulation are limited by light (turbidity) or controlled by animal grazing.

Historical records (pre-1989) of chlorophyll *a* concentrations in Massachusetts Bay were summarized by Cura (1991), and a recent comprehensive survey (1989-1990) was reported by Townsend *et al.* (1990). Chlorophyll *a* concentrations in the surface euphotic zone in the vicinity of the proposed outfall site range mostly from about 1 to 8 mg/m^3 through the year, although surface values during midsummer stratification can reach 13 mg/m^3 (Townsend *et al.*, 1990). Massachusetts Bay data thus reveal chlorophyll levels that are typical of coastal waters that are not highly nutrient-loaded (cf., Nixon and Pilson, 1983). It is reasonable to expect that an increase in chlorophyll could be stimulated by nutrient loading from the outfall and be detectable in the surrounding water. Kelly's (1991) summary of relationship between chlorophyll and nutrients in Massachusetts Bay and other coastal areas provides an initial guide on the level of stimulation that might be expected given a nitrogen concentration increase.

Sampling will occur via continuous *in situ* fluorometry (see Townsend *et al.*, 1990, for common oceanographic methods) at the locations and frequencies given for continuous horizontal profile sampling and nutrient/hydrographic stations. Monitoring thus will encompass the entire water column, which is well mixed for much of the year. Extracted chlorophyll samples collected on filters from discrete water samples at the five biology/productivity stations will be analyzed for chlorophyll *a* and phaeopigments for comparison to fluorometry data. Baseline studies will allow characterization of spatial variability at a mesoscale surrounding the outfall. During baseline studies, the strategy also will give adequate characterization of intra- and inter-annual variability surrounding the outfall. A regional scale assessment via remote sensing of chlorophyll is planned (see Special Studies).

Expectations of chlorophyll monitoring. Chlorophyll increases may be expected to occur in direct proportion to nutrient loading, with deviations possible if light or grazing alter the present relationship (Kelly, 1991). The nutrient input rate, rate of physical dispersion, and vertical mixing/stratification will determine the spatial scales at which a chlorophyll response will be detectable. Given the projected N loading at the outfall (EPA, 1988), detectable chlorophyll increases as far as the outer sampling box around the outfall seem possible. Response of chlorophyll to the outfall discharge would be expected within a short timeframe, and perhaps discernible within a year. Recent coastal and estuarine studies suggest that depth-integrated annual mean chlorophyll concentrations are highly correlated to nitrogen loading (J. Garber, personal communication). Moreover, annual mean chlorophyll values are broadly correlated with annual mean DIN concentrations. To estimate annual means, sampling needs to be done frequently throughout the year and at least every 2 weeks during summer. Throughout an annual cycle, data from about 16 sampling surveys will provide excellent estimates of annual means and seasonal variations.

Given current chlorophyll levels and the projected N loading, it is expected that changes close to the outfall could easily be detected against the backdrop of seasonal variability. The strategy of collecting data to enable good estimates of annual mean values is to provide maximum power for this discrimination at some distance from the outfall. Accumulation of chlorophyll *a* biomass can also be used as a forecast indicator for low-oxygen events, which can be initiated by rapid decay of a large bloom of phytoplankton.

Phytoplankton 14-C production measurements. To determine the production response of phytoplankton to possible nutrient enrichment in the nearfield, this will be measured at the five biology/hydrography stations six times per year. Standard oceanographic techniques for 14-C productivity will be used (e.g., Townsend *et al.*, 1990). Normally, samples from two of the five depths sampled for nutrients (e.g., at the surface and at a middepth chlorophyll maximum) will be used in 14-C incubations (following rationale and precedence of Townsend *et al.* [1990] for their Station 7, just inshore of the outfall. A third sample near 1% incident light level depth may be processed in some cases. It is expected that rapid shipboard incubation techniques using controlled irradiance levels will be followed. The maximum 14-C incorporation rates (P_{max}) at 100% incident irradiance will be determined, for these are the basis for many integral models of primary production. Determination of production as a function of light intensity may be accomplished using shipboard incubations with a light intensity gradient; incubations would be done across irradiance levels corresponding to sample depths determined by continuous hydrographic measurements at a given station.

The months chosen for these measurements are based primarily on the seasonal pattern of production described by Cura (1991) for Massachusetts Bay and include once each during February, March, April, June, August, and October. Sampling thus spans the productive seasons of the year and should allow a rough estimate to be made of annual productivity for use in carbon budget calculations.

Expectation for 14-C production measurements. Production estimates are expected not to be more sensitive to nutrient stimulation effects, but to provide an additional level of information relative to nutrient, carbon, and oxygen dynamics in the nearfield area. Measurements will provide baseline information on production rates through the main seasonal cycle and as a function of depth, and post-discharge rates will be compared to these baseline studies. The power to detect change will be determined during baseline studies.

Studies at the five biology/productivity nearfield station subset could be used to develop/calibrate/verify appropriate models for extrapolation across space. For example, primary production may be modeled, rather than measured, throughout the nearfield by calculating production at stations where chlorophyll biomass and irradiance have been measured, by extrapolation from production/biomass vs. irradiance relationships at the five select stations.

Phytoplankton species measurements. One of the possible biological responses to enrichment (or to some other perturbation from the outfall) is a change in the species of phytoplankton. A concern centers on an outfall-induced dominance by species classified as nuisance (e.g., surface scums or "brown tides") or noxious (e.g., organisms causing paralytic shellfish poisoning or "red tides"). An additional concern is with shifts in the community structure that could radiate throughout the food web and affect growth, distribution, or species composition of fish and shellfish communities. Thus, the endpoint of phytoplankton species change is relevant to include in the monitoring program.

Species changes can occur fairly swiftly, and there is usually significant vertical and horizontal variability in phytoplankton species distribution over areas the size of Massachusetts Bay and in the area immediate to the proposed outfall. Available historical records for phytoplankton species in Massachusetts Bay are of limited utility, but they do not appear to suggest the presence of problem species to the degree noted in other temperate coastal areas (Menzie-Cura, 1991).

Phytoplankton species analysis will be performed on samples taken at the selected biology/ productivity stations (5) in the nearfield. Samples will be taken at each of the six cruises planned within each calendar year. Whole water samples will be taken in duplicate from all five depths sampled for nutrients. Initially, only surface and one middepth (usually the chlorophyll maximum) will be processed to identify taxa and enumerate individuals. Additionally, a single vertical net tow (25 μm mesh) through the extent of the euphotic zone will be taken and the sample processed to identify less-common larger cells.

Expectations for phytoplankton species monitoring. Detection of problem species is a key objective; full taxonomic analysis and comparison of pre- and post-discharge conditions is a second objective. If certain species are seen in large numbers within the area of the outfall, additional spatial coverage could be implemented as needed. Of note is that the Massachusetts Department of Health currently conducts sampling for paralytic shellfish poisoning.

Within timeframes suitable for monitoring, it is possible to quantitatively characterize only a relatively small number of stations. Given the analytical problem of adequate characterization and considerable temporal and spatial variability for phytoplankton, one should not expect that phytoplankton species monitoring will detect subtle community changes or ascribe their cause to the outfall. Nevertheless, samples should be available for both baseline conditions and postdischarge conditions to provide a full taxonomic comparison at selected points through the nearfield region. However, Cura (1991), among others, points out that responses to nutrient enrichment generally are not subtle, but occur as major blooms of a given species.

A change to overwhelming dominance of "undesirable" species should be detectable if it occurs at stations within the sampling scheme. The stations were chosen to be at different distances and directions from the outfall; based on data analysis from the baseline period, the power to detect change will be determined and sampling modifications will be made if necessary. During baseline studies, techniques for rapid screening to detect certain nuisance species may be developed to provide more rapid feedback to the monitoring program.

Should directional transport of water masses occur, there are stations chosen north, south, east and west of the outfall, which could represent "upstream" and "downstream" sites depending on flow direction. Additional farfield stations extend in eastward and southward directions to supplement this scheme (see below).

Net zooplankton biomass and species measurements. At the selected biology/productivity stations (5) in the nearfield, measurements of the net zooplankton community (the larger species sampled by net, hence the term "net zooplankton") will be made. In the offshore area, compared to shallower waters where grazing benthic organisms are a significant structuring force for the pelagic food chain, zooplankton are the primary grazers of phytoplankton expected at water depths encompassed by the nearfield sampling frame (Figure B-2). Zooplankton grazers may influence chlorophyll biomass and affect distribution of carbon and other matter by effectively transferring matter to deeper waters across a pycnocline. As grazers, they are a second-level biological response measurement to nutrients, although they may be affected by some toxicants more readily than are the phytoplankton. Accordingly, measurements of their biomass and species composition to indicate possible alterations in the structure of the food chain are warranted as supplemental indicators of the nature of a change.

Net zooplankton biomass will be determined crudely as settled volume from net tows, as will species composition. These studies will be conducted six times per year at the five nearfield biology/productivity stations. Dual vertical or oblique tows (mesh size to be determined) through the water column at each station will be used to estimate which species are present and which are dominant in number.

Expectations for zooplankton monitoring. Although zooplankton are not viewed as a first-level biological response to nutrients, the studies will provide information on the character of any change seen within the nearfield region and offer potential additional insight on the fate of organic matter and associated chemicals. Correlations with other nutrient, DO, and phytoplankton changes will be examined. The power to detect change can not be described from existing information, and will be examined using baseline information. Zooplankton may be responsive to some types of chemical contaminants; alteration of the food chain could indirectly result from such changes, but nutrients are the greater concern in the present case. The main objective for monitoring of this component is to give some potential insight into a variety of potential food chain changes in the nearfield by giving a baseline description of species and biomass of the larger zooplankton.

Targeted sampling of selected depth intervals (e.g. a middepth chlorophyll maximum) is not an objective. Such an objective would require efforts well beyond the scope of monitoring, and not warranted for a component that is not the first line of response with respect to nutrient enhancement, especially where there the first line (phytoplankton) is extensively monitored. First, a chlorophyll maximum layer (a prime target for sampling) may be defined on a scale of decimeters (e.g., Bjornsen and Nielsen, 1991); it is not simple to sample over sufficient space the net zooplankton while maintaining a precise vertical position relative to a such a precisely-defined biological (or hydrographic) feature. Moreover, zooplankton move extensively diurnally and targeted sampling would require substantial understanding of this movement; sampling throughout the water column thus is to integrate the whole community rather than capture a select fraction in a location at a certain time of day.

Nutrient Enrichment in the Farfield Water Column

Background and general sampling design. The farfield stations are to provide a baseline at locations where effects are not presently predicted from the outfall. Thus, these will function to verify that this either is or is not the case, and provide a set of regional reference stations for evaluating time trends for effects against reference backgrounds. Should effects be expressed farther from the outfall, measurements at these stations will be available as baseline information against which to make time comparisons.

The nearfield monitoring seeks a high level of spatial and temporal resolution appropriate for a site-specific monitoring program and aimed at a scale commensurate with the perturbation (see Section 4.4). In contrast, the farfield monitoring is to not to define conditions as finely at a place where effects are least expected, but instead to provide background conditions in the event effects were to extend much further than forecast and thus will serve as a necessary historical base for such judgement; the farfield may serve usefully to suggest some larger scale changes, but not focused at points far removed from the point of perturbation (see Appendix A). In short, the overall nutrient enrichment component of the monitoring design is a site-specific plan with farfield components for reference and with potential for detecting larger-scale changes in certain measures (see below).

The farfield coverage is extensive in space. The number of farfield stations equals or exceeds the number in the nearfield but are spread over greater area and the locations logically are keyed to important hydrodynamic and bathymetric features.

There will be two types of farfield stations (a total of 25), corresponding to the nutrient/hydrography station type and to the biology/productivity station type in the nearfield. As is the case for the nearfield, the biology/productivity stations are a special subset (5) of the nutrient/ hydrography stations. Both station types will be vertical profile stations only; there will be no continuous horizontal profile sampling between stations into the farfield. For both types of station, the frequency of sampling is the same as for the biology/productivity stations in the nearfield: namely, six cruises per year at the same times as are listed in the preceding nearfield section.

The nutrient/hydrography stations will give sufficient description of the Massachusetts Bay/Cape Cod Bay region. These will enable postdischarge assessment of large-scale and/or long-term changes of a potential causative agent (nutrients) as well as two principal indicators of effects (chlorophyll biomass and dissolved oxygen).

The spatial array for stations (Figure B-3) has multiple purposes. The first is to provide regionally representative nutrient/hydrography station coverage north, south, east, west, inshore, and offshore of the nearfield. Many station groupings have special purposes and occupy precise locations to correspond either to historical station sites or to specific hydrographic features within Massachusetts Bay or Cape Cod Bay, or both. For example, to the northeast of the nearfield, stations run from shore along a transect intended to capture the chemical and biological character, surface to bottom, of waters that may sweep from the north through the nearfield area of the proposed outfall. The stations run from about the 25-m depth contour eastward to the sill north of Stellwagen Basin. As an additional example, stations to the immediate inshore of the nearfield, including toward Nahant, President Roads, Nantasket Roads, Hull, and Cohasset, are to characterize any changes toward the shoreline points closest to the outfall. Indeed, stations towards Boston Harbor will be valuable to monitor to further examine the notion of Harbor nutrient export (Kelly, 1991) and how it will change postdischarge from the proposed offshore outfall.

Since there is evidence and speculation that transport could generally take material toward the south, there are additional farfield stations in that direction. Stations are shown in a southerly direction along the coast, north and south of the North River, whose export would complicate interpretation of any effects as due only to the outfall. Additional stations run along the axis of the Stellwagen Basin to examine if any water-column effects are effectively transported downslope from the nearfield area. Finally, reference stations for which there is historical information will be occupied in two different regions of Cape Cod Bay.

The biological/productivity stations are much less to suggest scales of change, will function more to provide baseline reference conditions at particular sites, but may be used in conjunction with more extensive nutrient/hydrography information. Three of the five biology/productivity stations simply compliment the nearfield sites and extend into the "near" farfield immediately to the east, west, and south (Figure B-3). The remaining two farfield stations are those most distant (in Cape Cod Bay). The simple assumption that a nutrient-biology cause and effect relationship appropriate for the northern area of the region is applicable to the southern area could be challenged (cf. timing of chlorophyll blooms as suggested by remote sensing data of Michaelson, 1991). The plan gives an efficient design for assessing such an assumption under baseline conditions and therefore determining the extent to which modeling extrapolations (such as derived production and light relations) may be appropriate.

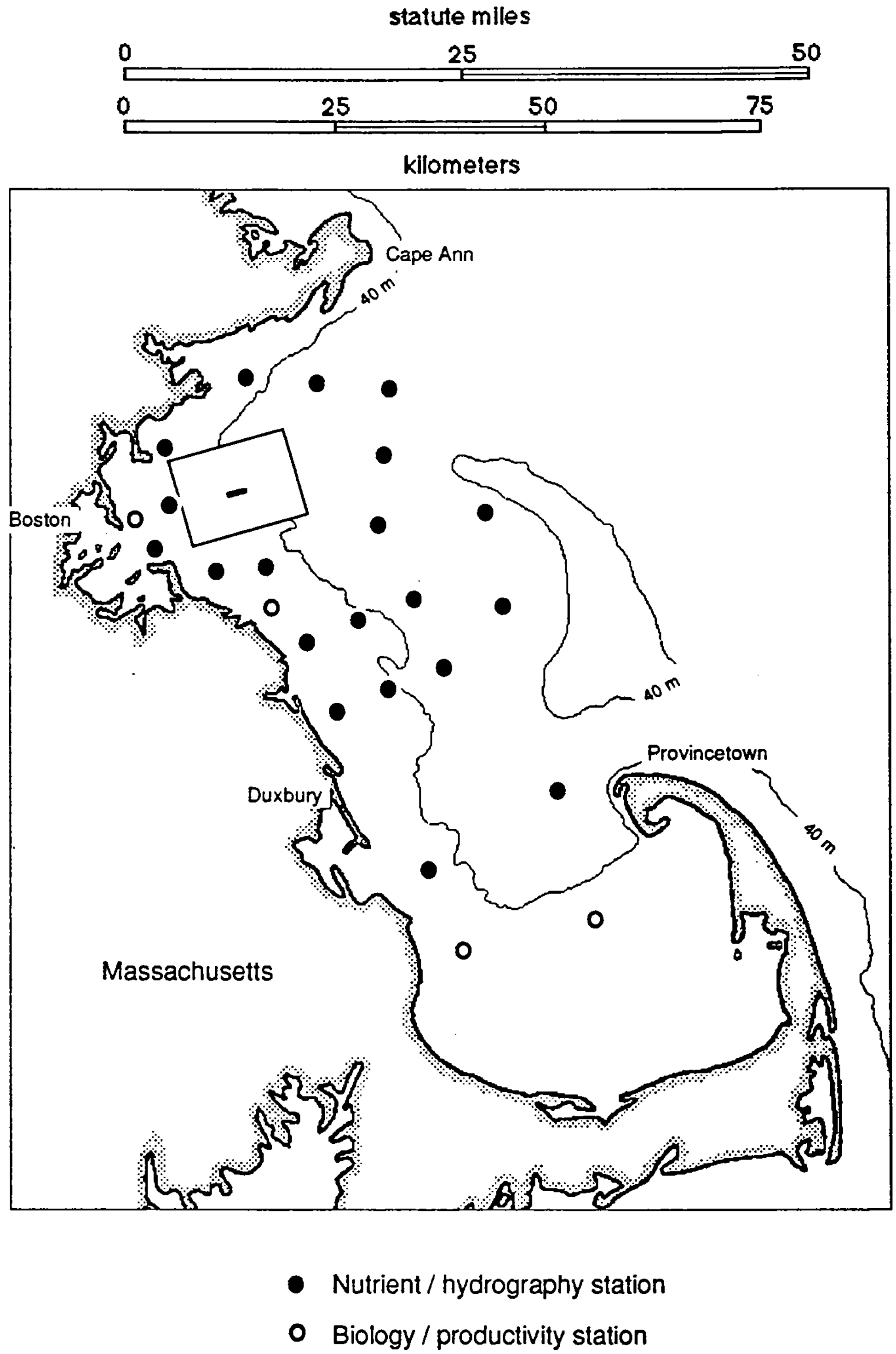


Figure B-3. Nutrient enrichment in the farfield water column.

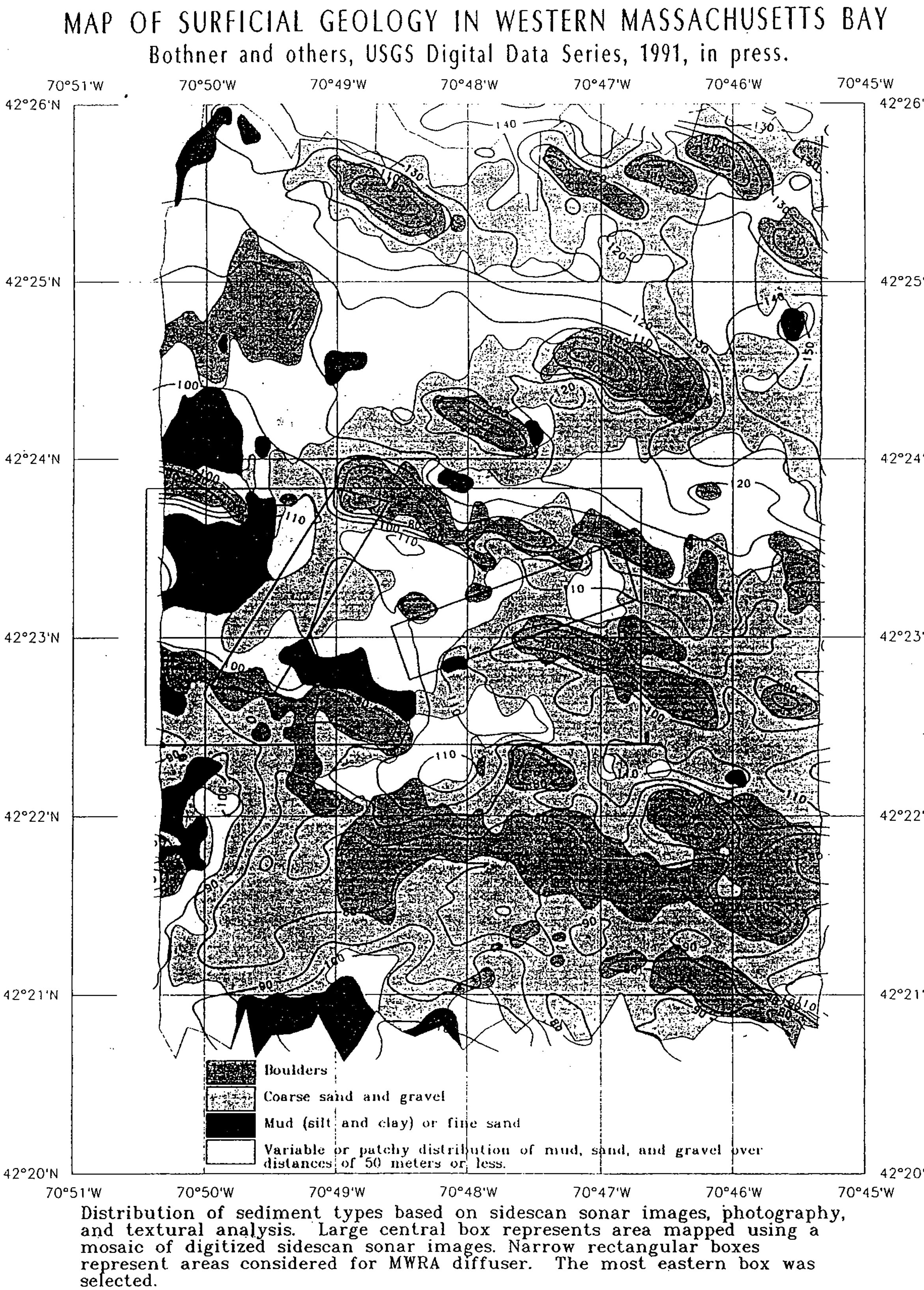
Farfield water-column measurements. Measurements taken for the 25 nutrient/hydrography stations will be the same as for similar nearfield stations, with five depths again being sampled for discrete measurements as well as continuous profiling. Special measurements will be made at the biology/productivity stations, which are located in the farfield: two in Cape Cod Bay, one outside Boston Harbor inshore of the outfall (Station 6 of Townsend *et al.*, 1990), one off Cohasset to the south of the nearfield area (Station 18 of Townsend *et al.*, 1990), and one offshore of the proposed outfall area (roughly Station 9 of Townsend *et al.* 1990 near the northern entrance to Stellwagen Basin). The samples taken and analyses conducted taken will be the same as for similar nearfield stations and include extracted chlorophyll and phaeopigments, 14-C productivity, phytoplankton and zooplankton biomass and taxonomy, PON, POC, DON, DOC, and total suspended solids measurements to supplement hydrographic measurements.

Expectations for farfield water-column monitoring. As stated above, the primary purpose is to obtain baseline information at sites outside the area where effects are predicted in the event that effects do extend farther. Sites will function as regional reference sites and there may be some potential for assessing broad-scale trends in certain parameters. Moreover, the specific spatial array of stations is to provide information at sites "upstream" and "downstream" of special hydrographic features, bathymetric features, or existing nearshore point sources such as Boston Harbor. Data from these stations will assist in the larger-scale understanding of outfall effects and material budgets that may relate to the nutrient-enrichment phenomenon.

Soft-Bottom Benthos: Nearfield and Farfield

Background and general sampling design. A number of benthic stations will be established at depositional areas in the nearfield to serve in both transport-and-fate and trends/effects monitoring. With respect to fate considerations, surface sediments will be collected and analyzed for a suite of compounds of toxic concern as well as tracers of the sewage effluent. With respect to trends/effects monitoring, a few benthic stations included in outfall citing studies (see MWRA, 1988; 1990) will be reoccupied. Effects of the discharge within the nearfield are expected to occur for soft-bottom macrobenthic infauna, but there are few depositional sites immediately surrounding the outfall diffuser. Areas for macrobenthic study will center on known and suspected nearfield areas inshore of the proposed outfall, areas that may function as fine-sediment and organic-matter traps because of the low energy of the currents (Rhoads, pers. comm 1991, and in Shea et al. 1991). The map of Bothner *et al.*, (1991) was used to establish stations in the nearfield; primarily these are mud patches as identified in Figure B-4.

Benthic monitoring in muddy and sandy sediments has been the mainstay of biological monitoring for the last several decades (cf., Warwick, 1988). Characteristically, organisms greater than 0.5 mm are sampled, identified, and enumerated. Sediments are the long-term depository for particles and associated organic and inorganic chemicals. Benthic species are fairly long-lived and stationary, so they are viewed as suitable integrators of conditions that often are transient and difficult to detect in the water column.



Distribution of sediment types based on sidescan sonar images, photography, and textural analysis. Large central box represents area mapped using a mosaic of digitized sidescan sonar images. Narrow rectangular boxes represent areas considered for MWRA diffuser. The most eastern box was selected.

Figure B-4. Soft bottom areas identified in the vicinity of the proposed outfall site.

Changes in benthic communities — abundance, numbers of species, and types of species — have been documented as responsive to many kinds of disturbances. These parameters are not uniquely responsive to eutrophication, but the benthic monitoring plan is to detect overall change, independent of cause. It may be possible to suggest, from the qualities of change and from select indicator species, one mechanism (i.e., toxic impact versus organic enrichment versus "smothering" by high particulate loads, etc.). This is a secondary aspect, for the main goal is to detect the scale and magnitude of change as related to the outfall.

Methods recently have been developed to more rapidly characterize the benthic community via remote measures, such as sediment camera profile imaging techniques (e.g., Rhoads and Germano, 1986). By such techniques, an evaluation of various biological and geochemical characteristics of the sediments is possible. This makes it possible to survey a large area quickly and obviates much of the tedium of sorting, identifying, and counting individual organisms. The biology for the remote studies still must be ground-truthed against traditional grab samples for full taxonomic analysis, but it can be done on a comparatively small number of grabs.

Measurements. From 15-20 nearfield and 12 farfield stations in soft-sediments will be sampled using traditional grabs and full macrobenthic taxonomic analyses. The procedures will be to use nested sieves, a 0.5-mm-mesh over a 0.3-mm-mesh sieve, with fractions analyzed separately. Using the 0.3-mm-mesh sieve provides additional information on the smaller-size organisms that may be responsive to effluent, and includes for some species the juvenile forms of those captured as adults by using the 0.5-mm mesh. The locations will ensure that depositional areas of critical concern in the nearfield and in the near farfield are sampled, as well as reference sites in the farfield. Farfield sites have been chosen to correspond to previous benthic studies and are coupled with other sediment studies in this plan (Figure B-4 and Special Studies).

The strategy for nearfield benthic monitoring is to be able to describe the scale, as well as nature, of change extending from the diffusers. Indeed, nearfield changes in the benthos are expected and the scales are predicted by the SEIS and the monitoring objective is to test whether the impact is within the bounds projected by the SEIS (Section 4.4).

The spatial design defines soft-bottom mud patches of minimum size within the heterogenous sedimentary environment surrounding the proposed outfall site. This exercise drew on recent work by USGS (Figure B-4). The minimum patch size was determined in part by the navigational requirement to be able to reoccupy a location. From 15-20 sites will be sampled, the sites being arrayed, to the extent possible, in a radial pattern away from the center of the diffusers (see Figure 3(d) in Section 6.0). One grab sample for chemistry, one for biology, and about five sediment camera images will be done at each site. Assessing the pattern of change in space and time and between chemistry and biology is the objective, thus the use of more stations rather than more replicates at few stations. Relationships between chemistry and biology pre- and postdischarge will be examined using analysis of covariance, and other statistical regression techniques to establish trends over time and space. End-of-summer surveys will be conducted once each year to establish annual variability during baseline measurements.

Sediment camera profile imaging will be performed at all nearfield and farfield stations. This technique provides an additional quality of information relevant to macrofauna as well as sediment chemical quality. Since essentially all of the patches of soft-sediment in the nearfield will be sampled by traditional methods, use of the camera technique here is viewed as complimentary rather than supplementary.

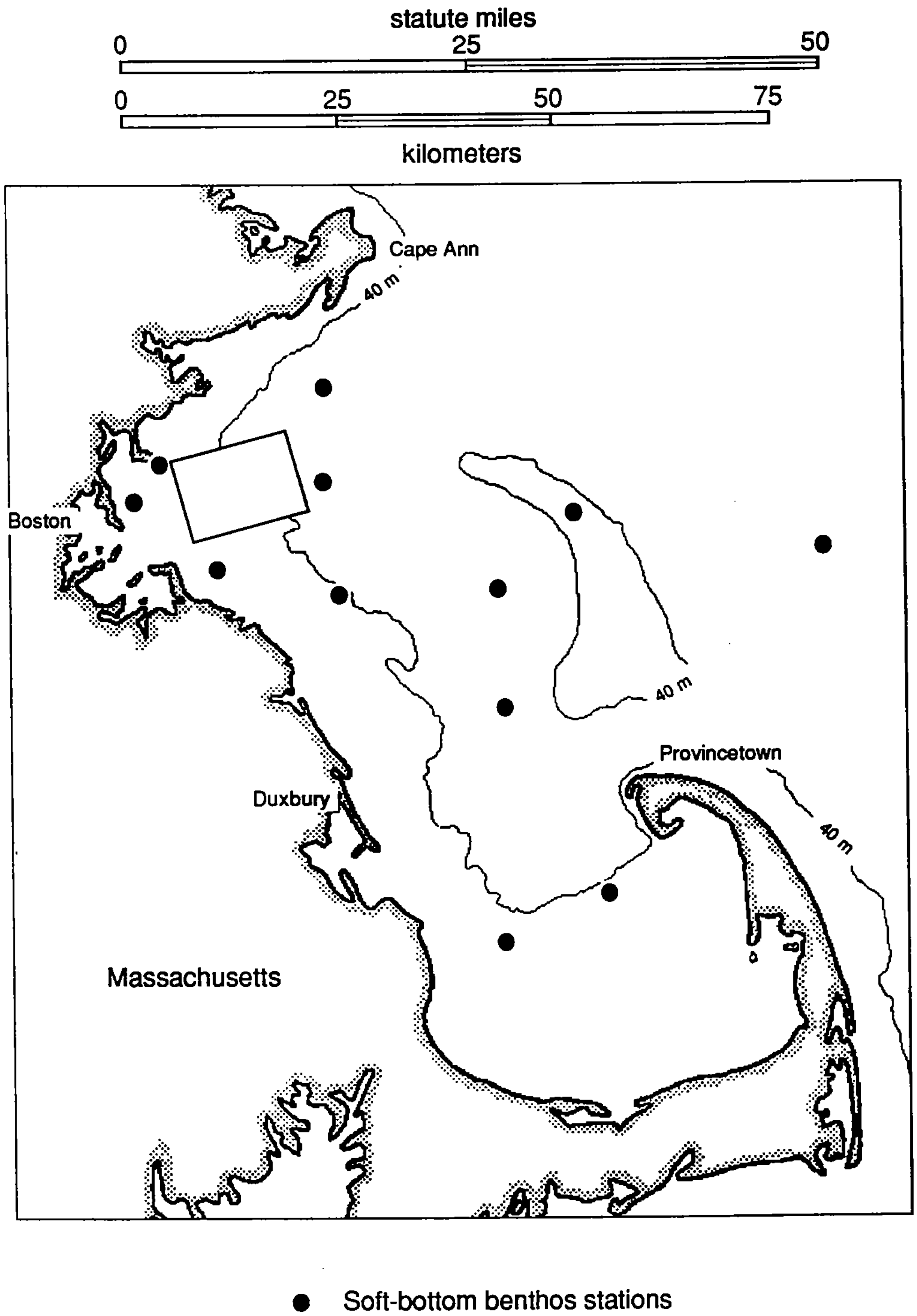


Figure B-5. Soft-bottom benthic stations in the farfield.

Sediment chemistry analyses of surface (0 to 2 cm) samples will be made annually at all nearfield and farfield grab stations. Parameters include PAHs, LABs, PCBs, pesticides, metals, and *Clostridium perfringens*. Additional measurements will include Fe, Al, total organic carbon (TOC), and grain size. Methods should follow those of the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (NS&T) Mussel Watch Program (Battelle, 1990).

Farfield benthic monitoring has the goal of detecting change at a given site and thus will use triplicate biological grabs and duplicate chemical grabs, rather than adopt the nearfield sampling strategy.

Expectations for soft-bottom benthic monitoring. With respect to enrichment, changes may be expected, within the first year of outfall discharging, close to the outfall and/or sediment depositional areas where particles are concentrated. Stations surrounding the outfall, including areas of low kinetic energy, will provide adequate spatial resolution to map the extent of any change. Repeated annual monitoring will provide evidence of biological and surface chemical changes in depositional areas and indicate the scale of change within an expected impact area.

With respect to enrichment, the magnitude of change depends on the nutrient and particulate loading rates. Although there are some eutrophication indicator species or guilds in coastal ecosystems, the often observed response is one of fundamental community change.

Detectable by the remote imaging, the general change from oligotrophic to eutrophic conditions is from deeper-dwelling species and active bioturbators to surface-dwelling species capable of existing with a fully anoxic sediment only millimeters from the sediment/water interface. In many physical environments, change can be evidenced as a fairly smooth gradient from a source. In the physically dynamic Massachusetts Bay environment with heterogeneous distribution of different sediment types (Bothner *et al.*, 1990), benthic responses may be highly discontinuous and the extent of impact at given points is difficult to predict. The designed monitoring strategy should be adequate to suggest both scale and magnitude of any changes within a fairly broad geographic area, including "reference" sites that are reasonably far afield.

Based on power-analysis results using data from the MWRA Secondary Treatment Facilities Plan (MWRA, 1988), the level of detectable change in the farfield for most parameters ranges from about 10% to 1000% using three replicates for benthic grabs and two replicates for chemical analyses. For some parameters, at certain stations the level of detectable change exceeds 100,000%.

Fish and Shellfish Contamination and Physiological Condition

Background and general sampling plan. One of the most important endpoints in this monitoring program is fisheries. However, sewage discharge is only one of many possible sources of perturbation to fish health and populations. Consequently, sampling and analysis to address possible effects on fisheries must attempt to maximize discrimination among the sewage outfall and other sources. This would be best accomplished by sampling fish with restricted migration and sessile shellfish at the outfall site. Since many fish and lobster populations in the area of the outfall do migrate, without a major widescale sampling effort it would be difficult to assess impacts on population size. Hence, the measurements in the monitoring program are restricted to measurements of contaminant burdens and the health of individual organisms gathered from areas near and very far from the outfall. Data on contaminant body burdens, incidence of disease, and histological indices can then be compared against data on fish and shellfish collected prior to discharge and from reference sites.

Winter flounder is the fish of choice based on the fact that its present distribution provides for suitable nearfield, coastal, and farfield reference sites. Moreover, the precedent for using winter flounder in this region is established in other programs, and techniques are in place for body-burden and disease/histopathology analyses (Moore, 1991). The migration of winter flounder is thought to be limited to about 1 nmi, particularly with the rich food source expected near the outfall.

Monitoring of sessile shellfish has several disadvantages. For example, there is little known about indigenous shellfish species that might be suitable and present in the immediate vicinity of the outfall, and there are problems with maintaining their physiological health at the depth (32 m) of the outfall. Despite these problems, caged mussels will be used at the outfall to test for accumulation of contaminants from the water column. Two cages of mussels will be suspended just below the pycnocline for 2 months during the summer at a convenient site outside the mixing zone but within the nearfield (e.g., Bouy B).

Lobsters will also be used for the monitoring program. Lobster body-burden data may be problematic because of this organism's short-term mobility, some seasonal migration between inshore and offshore, and the lack of literature and baseline information on contaminant uptake, bioaccumulation, and the resulting effects. However, they will be monitored because of their commercial importance in Massachusetts Bay.

Measurements. Based on the results of measurements of contaminants in fish, shellfish, and sediments by an early (1976-1978) EPA Mussel Watch Program and the NOAA NS&T Program, there is significant precedent for certain measurements of fish and shellfish contamination and a corresponding large database. The NS&T Program monitors concentrations of PAHs, PCBs, and a number of pesticides including, DDT and chlordane, and over a dozen trace metals. The chlorinated organic compounds have been shown to have relatively high concentrations in tissues of animals in Boston Harbor and their genotoxicity and/or carcinogenicity are documented in the literature, although human health risk from fish consumption in Boston Harbor is not as well documented (EPA, 1989). PAH compounds are also high in the sediments and mussels found in Boston Harbor, although a clear gradient is observed with distance from the Harbor (Shea and Kelly, in preparation). In addition, PAHs are readily metabolized in the liver of fish, effectively detoxifying the PAH with respect to human health risk. Conversely, lobsters and mussels have very little capacity to metabolize PAH, resulting in greater bioaccumulation and threat to human health, but their utility as an indicator for human health risk has not been established. The Food and Drug Administration (FDA) has set an action level for total PCBs (2.0 ppm, wet weight), but not for pesticides or for PAHs.

The trace metals that can be acutely or chronically toxic to humans include cadmium, chromium, copper, lead, mercury, silver, and zinc. The FDA Action Level for mercury is 1.0 ppm (wet weight), and the National Shellfish Sanitation Program has proposed Alert Levels of 25 ppm (wet weight) for copper, 30 ppm for zinc, and 5.0 ppm each for cadmium, chromium, and lead.

Winter flounder, which are closely associated with the sediments, feed primarily on benthic animals. They have wide distribution throughout the study area (in both the water and on the dining table), and there is a relatively well established baseline of body NOAA NS&T Benthis Surveillance and burdens. The edible flesh of winter flounder should be monitored for PCB/pesticides. The ongoing Mussel Watch programs can provide considerable baseline and reference data to augment the MWRA program. Lobsters caught at the outfall site could also be monitored for contaminant body burdens in the edible tissue simply because of their commercial importance in Massachusetts Bay.

Reference data for regional trends can be obtained from sites where indigenous mussel populations are sampled for the NS&T Mussel Watch Program (outer Brewster Islands, Duxbury Bay, and Cape Cod Bay). In addition, data from the other Boston Harbor NS&T Mussel Watch sites (Deer Island, Dorchester Bay, and Hingham Bay), the Gulf of Maine Gulf Watch Program, and the New England Aquarium Mussel Watch Program will be available for comparative purposes. However, the different exposure times must be considered when comparing caged mussel data with these other data.

Measurements to determine trends in the contaminant levels of the fish and shellfish around the outfall will be similar to those discussed above. These would include PAHs, PCBs, selected chlorinated pesticides, and the metals specified in Section 6. Note that the metals and organics to be measured vary with the species and the tissue considered. Measurements of PAHs, PCB/pesticides, and metals should also be made in flounder liver and lobster hepatopancreas. Additional measurements of bio-indicators of contaminant exposure (e.g., cytochrome P-450, PAH metabolites in bile) were considered but not included because more research is needed to assess the utility of these measures to detect change in fish health and to relate any changes to the chronic low-level input of contaminants associated with the outfall. More direct measures of contaminant body burden and histological abnormalities offer the selectivity and specificity that these new methods lack. Note that a recent review of monitoring in the Southern California Bight indicated that all physiological and biochemical measurements in fish are useful research efforts, but they have not provided answers to questions related to outfall monitoring (NRC, 1990).

There are several manifestations of disease in winter flounder that have been studied recently in Boston Harbor, and these would be useful for monitoring. Liver neoplasms and related nonneoplastic lesions have perhaps received the most attention. Although these lesions have not been related directly to contaminant concentrations in the sediments, there is strong circumstantial evidence to suggest that contaminated sediments play a role in the occurrence of these lesions in the Harbor flounder populations.

The liver neoplasms appear to be age-dependent, being more prevalent in 4-year-old and older fish. Fin rot and other skin ulcerations have, on the other hand, been linked directly to contaminated sediments. Perhaps the most significant pollution indicator is the severe hydropic degeneration (or vacuolation) that shows up as large, vacuolated cells in the liver parenchyma. They were found in virtually all winter flounder collected in Boston Harbor by Battelle in 1981, 1982, and 1984, and were almost completely absent from fish collected from a reference station off Plymouth Beach. More recent data from Moore (1991) have shown a trend of decreasing histological effects in winter flounder from Boston Harbor since the mid-1980s. Anemia and micronuclei in red blood cells are also easily monitored. Associated biochemical measurements, such as cytochrome P-450, ascorbic acid, and hepatic glycogen, can be made in conjunction with the pathological investigations during baseline surveys to assess their potential as indicators of health stress. Histopathological measurements in the monitoring plan thus include observations with respect to severe hydropic vacuolation, neoplasia, necrosis, hyperplasia, and external abnormalities.

For lobster, gross abnormalities indicative of disease will be monitored. These include black gill disease, shell erosion, and evidence of parasites.

Sampling areas for flounder and lobster include the outfall area as well as the Deer Island Flats in Boston Harbor and a reference site in Cape Cod Bay (Figure B-6). Lobster sampling will be coordi

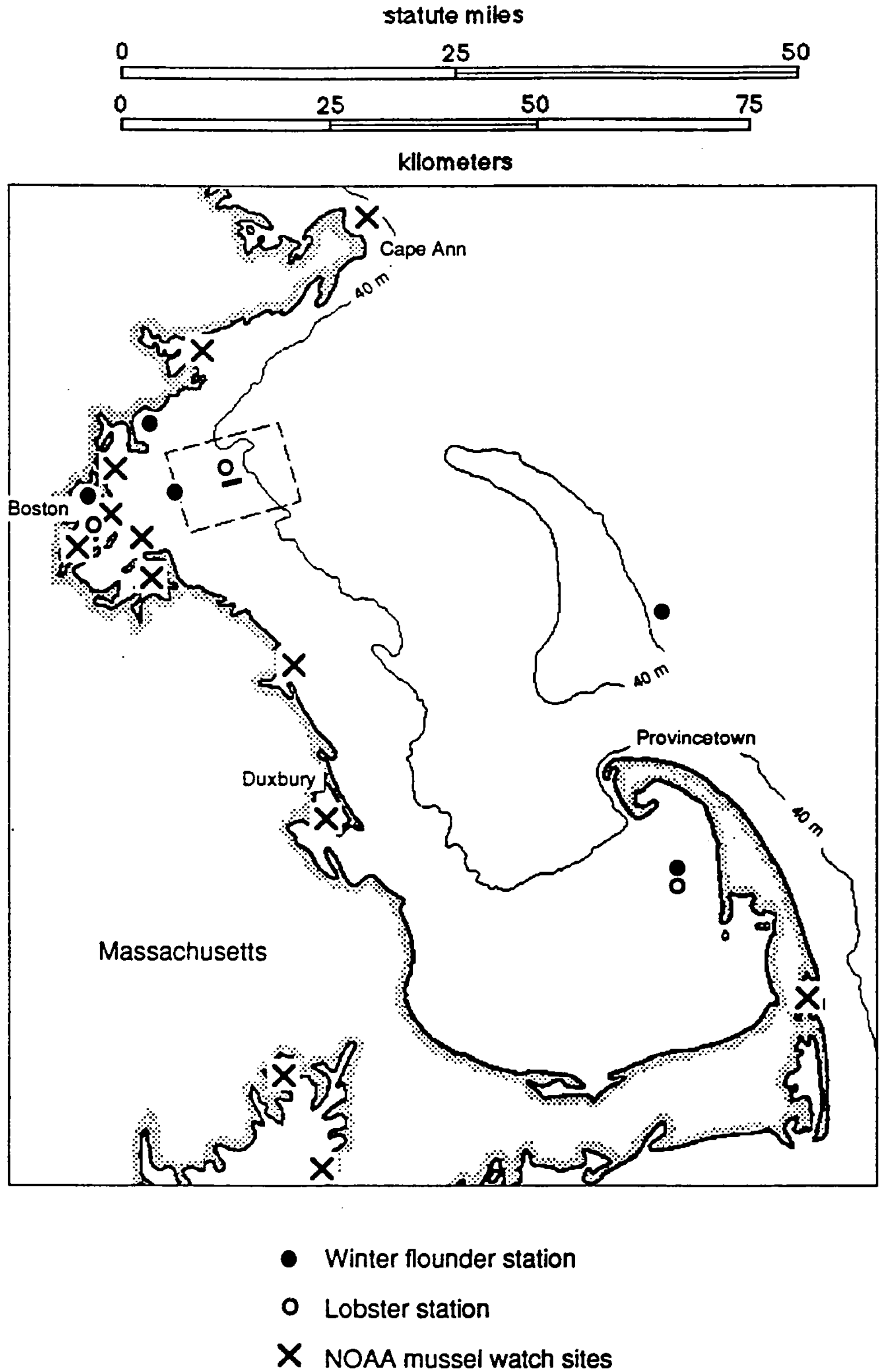


Figure B-6. Fish and shellfish contamination.

nated with the Massachusetts Division of Marine Fisheries. For histology in winter flounder, there are two additional sites removed from the outfall, one near Lynn that would represent a coastal reference site and one east of Stellwagen Bank that is intended as a clean reference site.Baseline sampling for winter flounder and lobster will be conducted once per year, every year during spring.

Expectations for fish and shellfish monitoring. Determinations of contaminant levels in the outfall and reference populations of flounder and shellfish over time can be compared to FDA Action Levels and National Shellfish Sanitation Program Alert Levels for the same contaminants. Pre- and post-discharge levels can also be compared to help to establish cause and effect.

The proper statistical trends analyses of contaminant levels at any of the stations should provide an indication of whether the accumulation of any of the contaminants has changed significantly over the length of the monitoring period. However, based on the results of the NS&T Mussel Watch trends analyses, it might be difficult to determine that trends actually exist.

In addition to determining whether there are any changes in pathology among the various populations over time, correlations between pathological conditions and chemical concentrations can be attempted. Results of these analyses could prove useful in determining possible cause-and-effect relationships between pathology and contaminants as well as providing useful observations on the incidence of anomalies as the Harbor becomes cleaner.

Special Studies

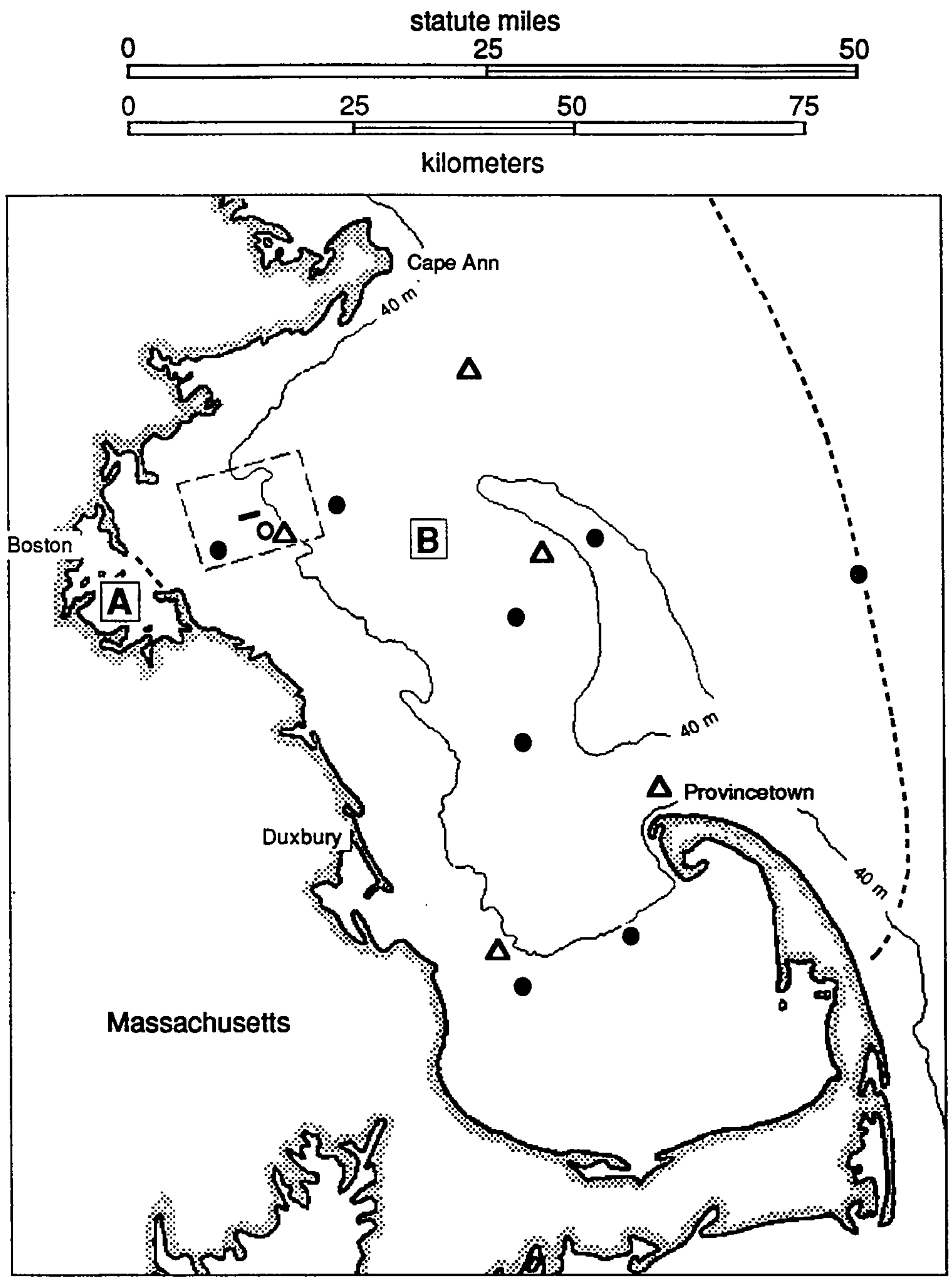
Included in this grouping are a variety of monitoring activities that will provide additional detail on the effluent, its fate and effects, and the ecological/environmental dynamics of Massachusetts Bay and, to a lesser extent, Cape Cod Bay. Some of these studies are ongoing and are/will be supplemented by the MWRA. They are characterized as special studies in part because they are key to developing a broader understanding of the outfall's relationship to the environment. These studies have specific supplemental goals that extend beyond the principal purpose of the monitoring plan to detect change.

Water-circulation studies. Water-circulation studies are key to understanding the transport and fate of effluent constituents in Massachusetts Bay. Ongoing physical oceanographic studies are listed in Section 2.0. Continued measurements of conductivity/temperature/depth (CTD) profiles and current measurements, Lagrangian (drogues) and Eulerian (moored), are required. These are part of the focus of the Department of the Interior [U.S.] Geological Survey/MWRA (USGS/MWRA) studies, which also include continuous DO monitoring at a site in the nearfield area (Figure B-7).

USGS scientists are refining a physical simulation model of Boston Harbor. Additionally, they are designing a similar model of Massachusetts Bay. Drogue and drifter studies by the MassBays Program and the USGS are ongoing to determine the direction of particle movements from the outfall area and to calibrate the models with such information.

Additionally current-meter measurements will be made at several locations during the routine nearfield water-column studies. These would facilitate interpretation of stations in relation to each other, especially whether some are downstream from others with respect to net current vectors.

Particle fate studies: Transport, deposition, resuspension, and bioturbation. Consideration has been given to deployment of sediment traps at stations to collect rapidly settling material. The main purpose of sediment traps is to collect material that will provide information on vertical deposition



A Simulation model of Boston Harbor --- boundary

B Simulation model of Mass / Cape Cod Bays --- boundary

o Buoy B: current meter, sediment traps, oxygen recording

● Sediment profile stations

Δ Sediment trap stations

Figure B-7. Water circulation and particle fate study areas and sampling stations.

and resuspension processes, as well as horizontal dispersion. The advantage of sediment traps over traditional surface sediment collection is the higher S/N ratio that one obtains by measuring contaminants and sewage tracers in the traps (i.e., there is less dilution). The monitoring plan, on the advice of experts, will use data from the one USGS mooring in the nearfield to compare baseline data with postdischarge particle depositional flux through the water column. Supplemental moored arrays of sediment traps may be deployed in the future by USGS and have been in the past.

Sediment-trap material would be analyzed to allow resolution of time-averaged transport of particles that has not been provided by nearfield cruises and plume studies (which offer a picture on a given day only). A vertical moored array is required to help to assess fallout from the water versus resuspension from settled material. Horizontal transport of material either directly released in the effluent (e.g., metals, organics, particulate organic matter, sewage tracers) or stimulated by the nutrients in the effluent (e.g., chlorophyll) will be assessed by comparing enrichment of sewage tracers in the trap material with that of the effluent. The object would be to provide information relative to the transport of particles over a large region. Information on material concentrations over time in surface sediments will compliment analysis of trap material and be invaluable in assessing any enrichment/depletion of elements as the settle and are resuspended.

The USGS/MWRA also are studying sediment depositional history and bioturbation rates at selected stations throughout Massachusetts Bay and Cape Cod Bay (Figure B-7).

The particle fate studies will aid in providing long-term historical background for comparisons. Understanding the role of bioturbation in affecting contaminant concentrations in surface sediments is critical to defining the ability to detect change and to developing material budgets for sediment burial rates. The sediment stations used in these studies, to the extent practical, are coordinated with other benthic studies of the monitoring program.

Plume studies. An environmental system exposed to a new continuous input can be expected to have a transient response toward a new equilibrium within a span of several times the residence time of its slowest dominant internal structuring factor. With respect to chemical fates, if physical and biogeochemical actions determining removal rates and residence times can be established, both the area encompassed and the time involved for initial response become more clearly defined (as do the nearfield-fate and short-term effects). For example, if the time for particle deposition is within one or two tidal mixing cycles, the primary scales of initial concern (with respect to particle loading effects) are roughly expected to be within 1 week, and a spatial area would be defined by advection during that period.

This image is overly simplified, of course. A system does not have to adjust within this time scale. Nonlinearity in response is probable when biological features influence transport and fate, and especially when the system's response involves not just chemical fate but attendant biological changes. Moreover, both particles and dissolved constituents have possible impact, but they can have different transport and fate mechanisms and time scales. Additionally, for both dissolved and particulate forms, interactions with the sediments (e.g., resuspension, nutrient regeneration) are regulated in part by biology and thereby are subject to biological change. This adds considerable complexity to simple models based on dilution and first-order removal rates from water. Indeed, a system may change over time with continuous discharge and develop a new set of relevant space/time response scales because of a biological change (e.g., if the nearfield capture of particles into sediments is lessened because the benthos becomes depauperate and can not perform this function).

Precisely because there is no other way to obtain the information on initial response, intensive initial characterization of transport and fate processes has extremely high value and is necessary to provide useful information relative to calibrating and upgrading numerical simulation models capable of projecting longer-term dynamics. Further, the initial period is the prime time for acquiring information relative to biogeochemical half-lives, because compartments will be either losing or accumulating new material, and there is the possibility of detecting some chemical signals against background noise. If too much time elapses between the start of discharge and taking measurements, the S/N ratio of those measurements could decrease significantly. In fact, after a relatively short time, the initial distinct plumes will become a field of multiple, well-mixed plumes that are indistinguishable.

Thus, an initial phase of postdischarge monitoring will involve tracking plumes through tidal cycles and into areas considered farfield (Figure B-8). The focus of this monitoring activity is on the water column. Measurements will include temperature, salinity, total suspended particles, fecal coliform, DO, chlorophyll, dissolved and total nutrients, sewage tracers (e.g., *Clostridium perfringens*), and certain contaminants of concern. Cruise tracks will traverse the axis of the tidal excursion and identify the length and breadth of any distinct effluent plumes. Vertical profiles of parameters will be obtained, along with any horizontal profiles that can be obtained by using towed sensors.

Additionally, tracking of chemical and other measures in water advecting away from the outfall diffusers will be monitored in special studies that follow surface, mid-, or bottom water drifters released at the outfall diffusers. Studies using acoustical techniques or special dye/tracer techniques may be used. Details for these studies will be defined during the baseline study period.

Plume tracking will be an initial exercise conducted under stratified and nonstratified conditions during the first year when discharging commences. If logic and accumulated data dictate, the activity might be revisited after an extended period following commencement of discharge operations. One purpose of continuation would be to compare the extent and character of the transport in a plume at early as well as at late dates as a way to interpolate (between two points in time) possible degradation of ecosystem function in the nearfield. Additional plume tracking under high- and low-flow conditions could be performed to obtain the two flow-rate endpoints.

In addition to providing transport and fate information, measurements of contaminants taken during plume-tracking studies can be compared to predicted values (based on dilution) and to WQC for verification of NPDES compliance. Water samples could also be collected for toxicity testing to confirm the results of effluent toxicity tests. These last two sets of measurements should be performed only during the first year of operation, unless their results indicate that further measurement is required (i.e., the water is toxic or exceeds the WQC).

Excessive coliform levels would not be expected in the area of the proposed outfall. However, after the discharge is operational, if there is a rise in levels of pathogenic microorganisms at the outfall, it would be relatively easy to determine whether and how often State limits are exceeded by additional measurements in the plume studies.

It would be necessary only to examine the data generated from the plume monitoring to determine if bacterial indicators are transported from the outfall toward shellfishing or swimming areas. Water temperatures should be low enough to prevent rapid multiplication (regrowth) of the microorganisms between the outfall and the shellfishing areas.

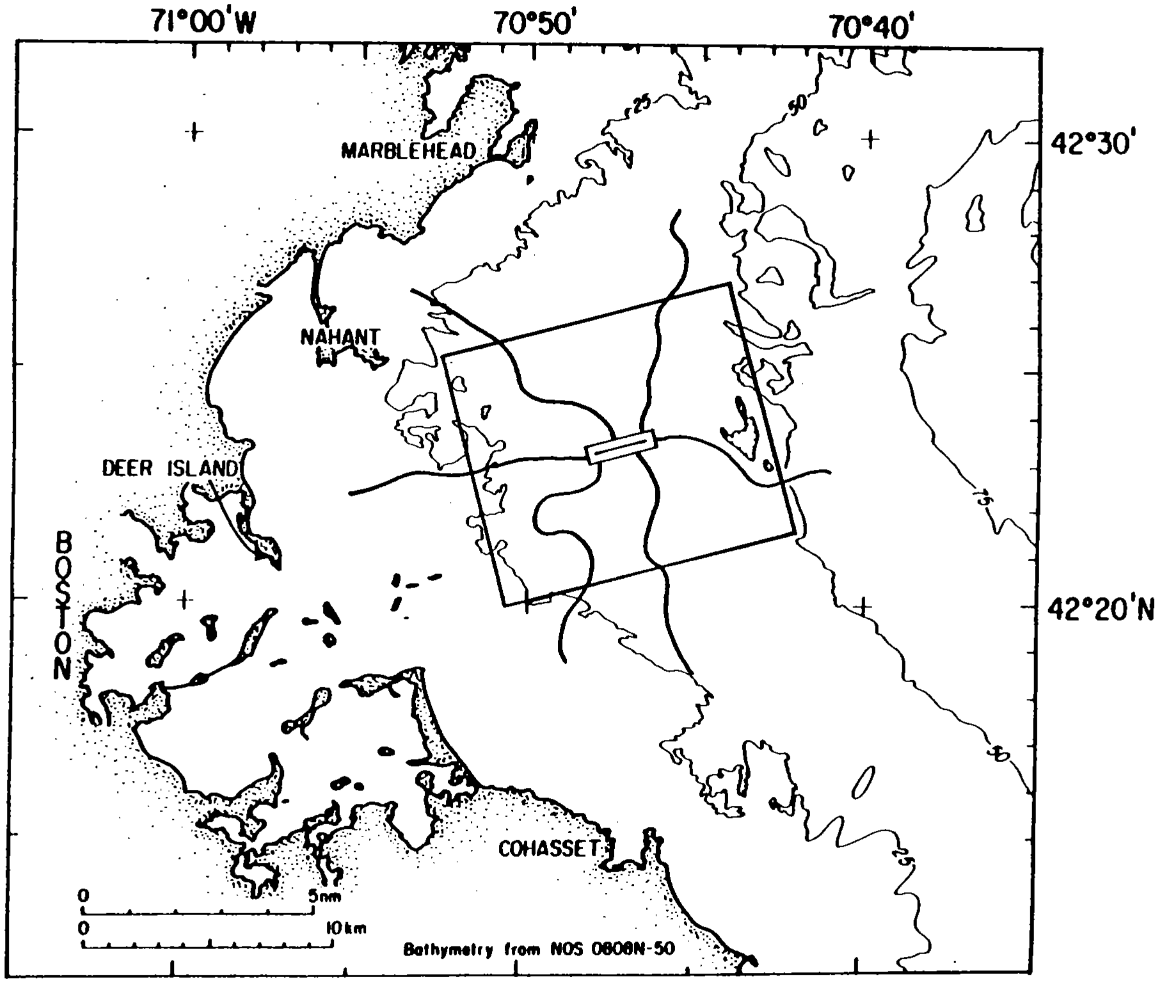


Figure B-8. Graphical depiction of plume study tracks.

It is expected that the monitoring program would provide information on the transport of microorganisms toward the beaches as well as toward the shellfishing areas. The baseline monitoring is expected to show that the study organisms (e.g., coliforms and enterococci) are present throughout the region, but not at critical levels. Nonchlorinated effluent might be expected to cause the number of organisms to rise at the outfall. Any elevations can be tracked on both the ebb and flood tides to indicate whether the discharge has caused an increase in pathogens on the beaches.

Water clarity and/or color could change as a result of increased loading of suspended solids and other colored effluent matter. Transmissometry measurements will be made during plume studies and on routine water-column surveys. Visible observations of the surface-water color and light penetration will be made at fixed water-column survey stations. Verification and quantification of any potential problem could be made with a spectroradiometer.

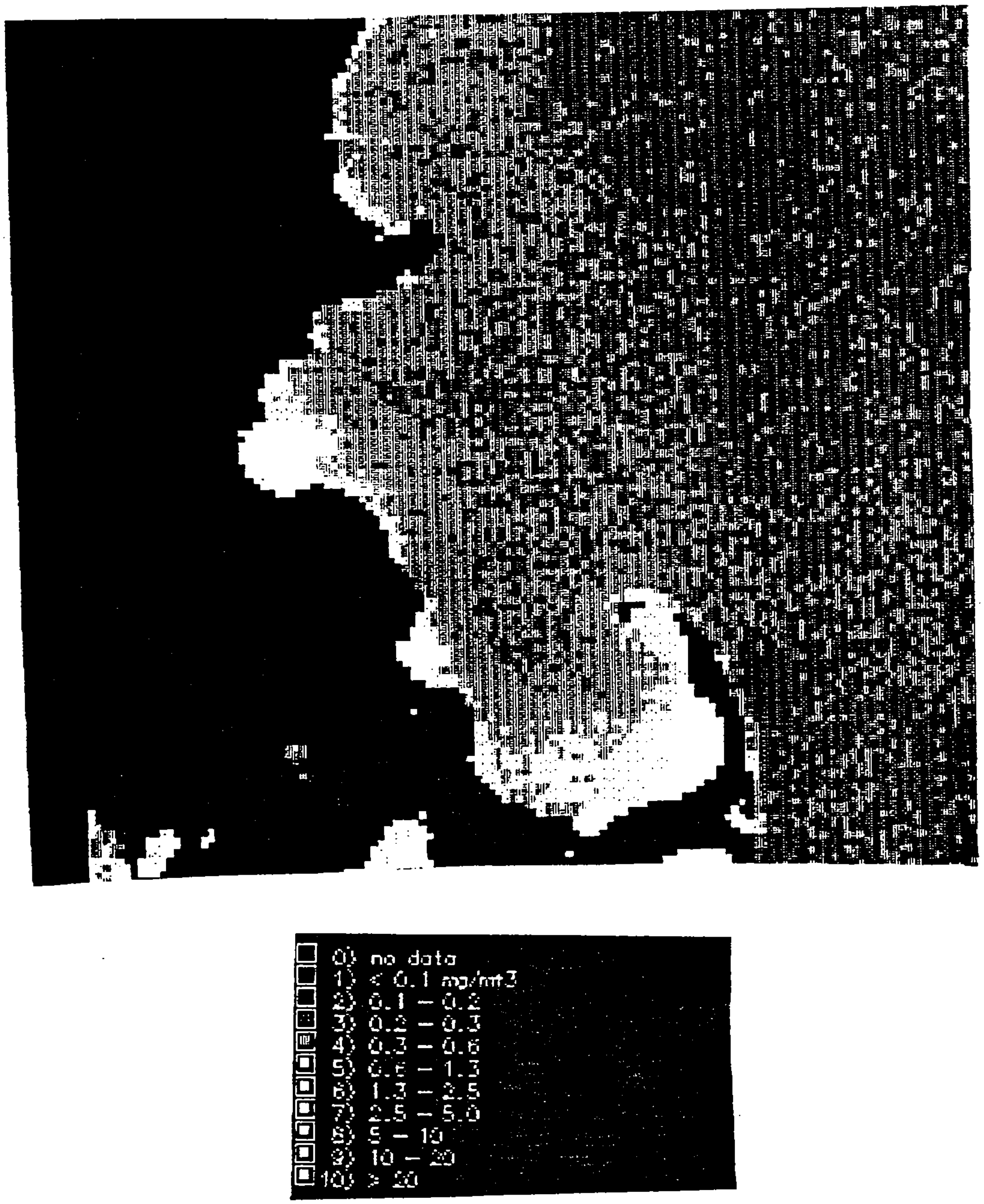
Finally, debris floating on the water could change as a result of increased loading of plastics or other floating effluent matter. Plastics are not expected to change significantly because of the screens used in the treatment plant and because even the present outfall source is small relative to combined sewer overflows (CSO) and other sources. Verification can be made by visible observation of the surface water during plume studies and water-column surveys. If a problem arises, identification and enumeration of floatables can be performed on samples collected from neuston tows.

Remote sensing of chlorophyll. Recently, Michelson (1991) examined remotely sensed data, available from the early 1980s, with respect to surface chlorophyll in Boston Harbor, Massachusetts Bay, and Cape Cod Bay. The images (cf., Figure B-9) provide a spatial resolution at the regional and mesoscale that is less easily obtained by shipboard surveys and are particularly important in extending biological monitoring more synoptically into the farfield. Kelly (1991) summarized annual chlorophyll values in northern Massachusetts Bay, including the region of the proposed outfall. Kelly's summary was remarkably consistent with Michelson's average annual values in terms of the fundamental spatial distribution, with the exception of some deeper-water areas. Remotely sensed data do not capture midwater chlorophyll maxima at some of these stations.

The monitoring program may utilize remote sensing. Presently, the plan is to make use of the NOAA's SEAWIFS satellite that may become available as of 1993. This activity will be coordinated with NOAA's Coastal Ocean Program. It is recognized and expected that this information would be significant to assessing phytoplankton effects at a larger scale than will be assessed by other methods in the monitoring program.

Detailed effluent characterization. To accurately characterize the mass loads to Massachusetts Bay from the proposed offshore outfall, it is imperative to develop statistically designed studies to sample influent and effluent at proper frequencies and flow conditions. In particular, there are some constituents that are present at extremely low concentrations, and using limits of detection to calculate mass loads may vastly overestimate the loading. These in particular must be considered in designing an effluent monitoring scheme.

The purpose of these species studies is to supplement the measures being made in the routine effluent monitoring, and additionally to identify the utility of tracers (e.g., 15N and other specific nitrogen forms, LABs, and *Clostridium perfringens*) and the potential to accurately assess their mass loads in the effluent. Measures could include defining fractions of a contaminant, such as particulate, dissolved, and colloidal, for recent synthesis studies of the present effluent and Boston Harbor suggest that these phase distinctions may provide a measure of prediction with respect to contaminant transport or retention in sediments (Shea and Kelly, manuscript in preparation).



Special Studies: Remote sensing
(e.g. Chlorophyll image of 11/3/78)

Figure B-9. Special studies: Remote sensing.

Such data could be used as input to water-circulation or transport-and-fate models to assess potential distribution of effluent in the field. Additionally, these studies would go hand in hand with tracer studies in the environment (next section).

Sewage tracers in the environment. Planned during the baseline period are sediment surveys throughout Massachusetts and Cape Cod Bays to determine the distribution of *Clostridium perfringens* in surface sediments. The survey will encompass 25 stations, many of which coincide with regular benthic monitoring stations, but others are at other depositional sites (Figure B-10). The purpose is to broadly assess present baseline concentration of this known sewage tracer and therefore aid in the determinations of the power of this measure to detect the fate of outfall particles in the near- and far-fields.

Other chemical or biological measures will be examined, especially with respect to their baseline concentrations in the outfall nearfield, as unique tracers of the effluent are examined and identified in the detailed effluent characterization studies (above). As these studies progress, the extent to which long-term fate of effluent material may be rigorously quantified for accounting purposes as well as for determining cause and effect over longer time frames.

Benthic nutrient flux, denitrification, and oxygen demand. Benthic fluxes of oxygen, and nutrients could be significant to monitor for two reasons. Fluxes contribute to oxygen and nutrient concentrations in the water are critical information for the development of coupled hydrodynamic water-quality models that would be used to predict effluent management options. Additionally, benthic fluxes are responsive to nutrient enrichment — fluxes are dependent on particulate deposition, strongly parallel primary production response to nutrient loading (Kelly *et al.*, 1985). At very high levels of loading, fluxes and productivity can become uncoupled, providing an indication that the ecosystem has been highly disturbed (and this may occur before water-column anoxia is experienced). We do not know the point at which this condition may be reached in different types of hydrographic conditions (mixed versus stratified) and water depths, although we do know that the relative importance of benthic metabolism can be scaled to water depth (Hargrave 1973; Oviatt *et al.*, 1986). At loading rates well below a "critical eutrophication level," uncoupling benthic fluxes and overlying water activity may occur by the action of toxicants.

A basic and scientifically accepted method for benthic flux measurements involves collection of cores and flux incubations, with pelagic bottle controls, run in the laboratory at the *in situ* collection temperature in the dark (cf., Giblin *et al.*, 1991). *In situ* flux chambers could, alternatively, be used.

The present scales of variability for benthic fluxes near the outfall site are not well known, although a preliminary study by Giblin *et al.* (1991) offers some data on this. Benthic fluxes can be assessed and usefully compared, using data collected seasonally and biased to the warmest part of the year. Empirical models exist for comparing fluxes to primary production levels and chlorophyll biomass (cf., Kelly, 1991); the standard for comparison and for assessing integrated change should be (as for chlorophyll) an annual value.

Six stations (Figure B-11), three from Boston Harbor to the Broad Sound/Nahant area depositional sediments, a fourth at an identified low kinetic area site in the nearfield that may focus outfall-related particles, a fifth in a small patch of soft-sediment in the inner nearfield, and a sixth site off Cohasset, all will be sampled five times per year. Measurements will be made in early spring prior to water-column stratification, in late spring after the onset of water column stratification, twice during mid-/late summer when rates are usually highest, and during late summer/early fall around the period when the water column is again becoming mixed.

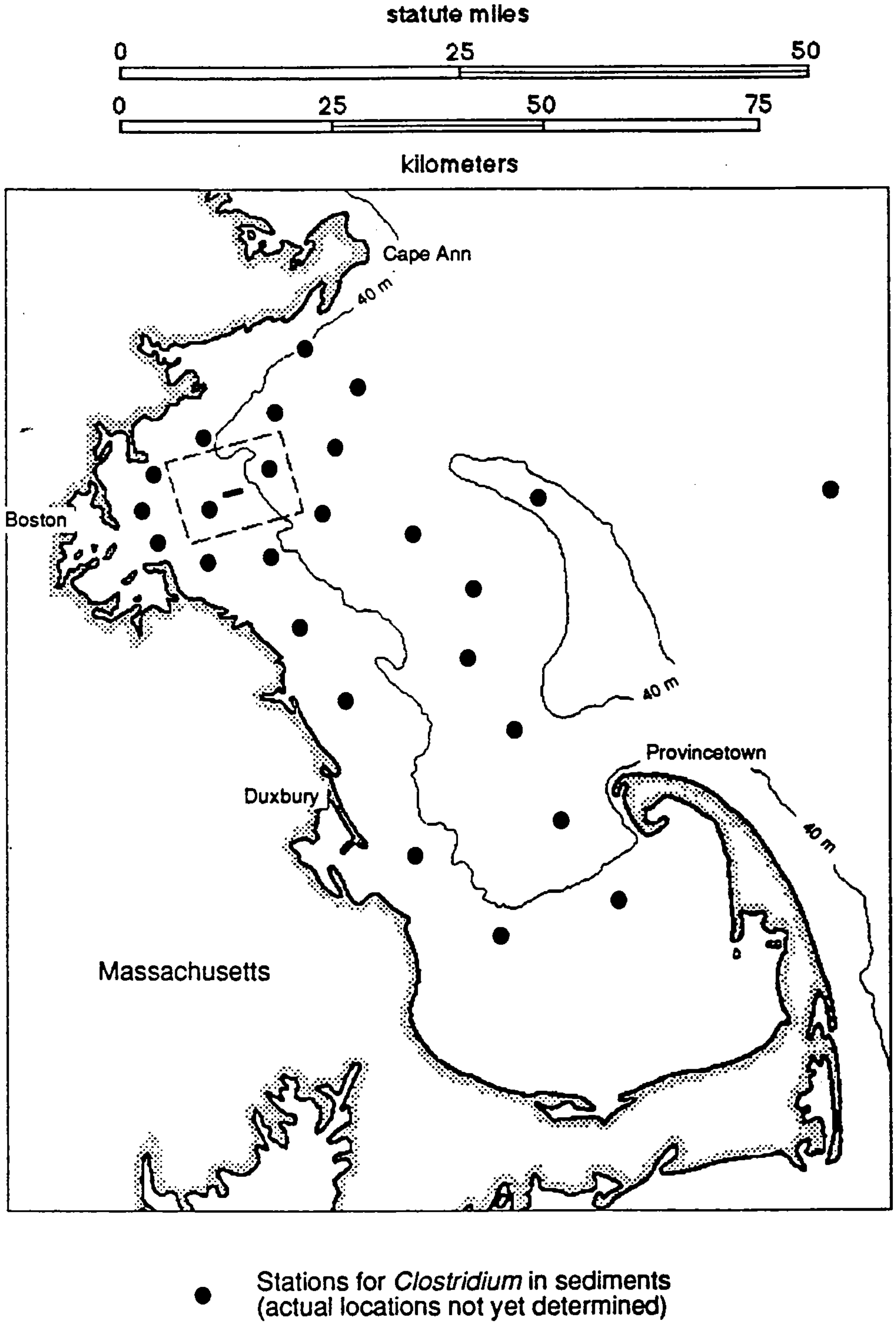


Figure B-10. Survey of sewage tracers in sediments.

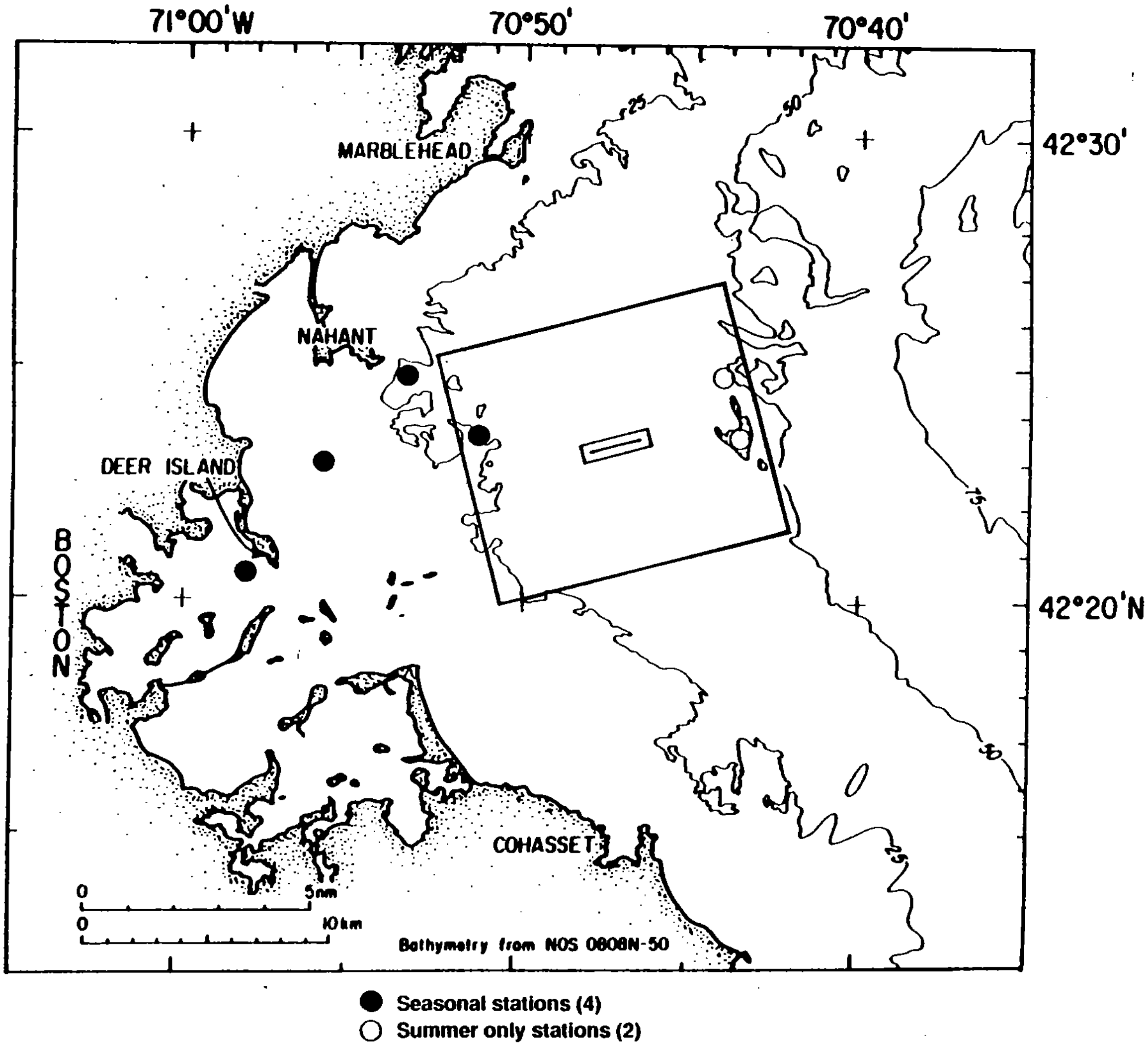


Figure B-11. Benthic flux study locations.

These six stations may all be accessible to the scuba diver. If not, cores will be taken either by a core-retrieval system to obtain relatively undisturbed surface sediments (e.g., either subsampled from a box core, hydraulic piston core, or other special equipment). Seasonal studies will provide a rough estimate of annual fluxes for modeling purposes and in budgeting organic matter and nutrients, as well as being indicators of elevated organic input.

Two other possible depositional sites more to the offshore (Figure B-11) will be the subject of flux studies, but these will be measured only twice and during the summer only (mid and late). These sites are in soft sediments to the east of the outfall in the nearfield region on a track toward Stellwagen Basin. They are not easily diver-accessible, and all cores will be obtained remotely. The purpose of these stations is to assess, by measuring flux changes postdischarge relative to baseline conditions, if near-bottom horizontal transport of organic matter is occurring to any detectable ex- tent in the direction of Stellwagen Basin. Increases in flux rates can be a strong indicator of recent elevated organic input and more easily detected than slight increases in the sediment organic pool itself (Kelly and Nixon, 1984).

Measurements of benthic fluxes will include rates of nitrogen exchange [ammonia, nitrate, nitrite, and N_2 gas (denitrification)], and oxygen demand. A study being conducted in the Harbor is presently measuring these constituents, and similar techniques will be employed in Massachusetts Bay.

The timeframe for a response to eutrophication generally is rapid and could be detectable within the first year of discharge (Smith *et al.*, 1981; Kelly *et al.*, 1985). It is expected that the stations being occupied will detect change if it occurs in depositional areas at the edge of the nearfield. Additional cores could be retrieved for incubation if the spatial extent and heterogeneity of change warranted.

Depending on the element of interest, empirical models predict that the magnitude of change correlates with the magnitude of increase in phytoplankton loading plus additional particulate organic loading from the outfall scaled for the depth of the water column (Kelly, 1991).

The measurements additionally will confirm the relative importance of benthic versus water-column metabolism as they may affect oxygen concentrations and will provide data to address the role of sediments in nutrient cycles.

Hard-Bottom Benthos

Background and general sampling strategy. There is considerable heterogeneity of bottom type in the area proximal to the proposed outfall site (Bothner *et al.*, 1990), with substantial hard-bottom (gravel, boulder) areas. It has been noted that a "dusting" of sediment may accumulate in such areas at some times during the year (see review by Shea *et al.*, 1991). Organisms may colonize and utilize the energy resources of this material. Accumulation of sediment and growth of an epifaunal community may be transient and disturbed by strong physical events.

Smith *et al.* (1981) showed that a hard-bottom community provided substantial response to a sewage diversion in Kaneohe Bay, so there is precedence for use of this general type of benthic community as an indicator for nutrient and particulate enrichments. Due to the water depth being prohibitive to scuba diving, an alternative method, that of video observation, will be used. The purpose is simply to describe in qualitative terms the accumulation of material and biological activity on/in these deposits seasonally accumulated in hard bottom in the immediate vicinity of the diffusers.

Measurements. Qualitative observations may be made at eight stations along two transects in an **X** pattern crossing the line of diffusers (Figure B-12). Additional sites to be considered for observations include those north and south of the proposed diffuser axis that were examined during the STFP (Reference). Color video camera observations will be made during summer during baseline years prior to discharge and thereafter postdischarge as needed. The percentage cover and identifiable taxa would be documented if possible.

Expectations for hard-bottom monitoring. The scale of change will probably be time-varying and spatially patchy, driven by physical processes and filtration rates of any epifaunal suspension-feeding forms. The ability to detect outfall impact is not currently estimated.

In one situation, where it was thoroughly investigated through an annual cycle, the biomass of hard-bottom fauna was shown to be responsive to changes in sewage effluent loading (Smith *et al.*, 1981). Moreover, if suspension-feeding forms reach high density/biomass, considerable focusing of particles from outfall discharge could occur. It is possible that such a situation could have significant effects on the fate of toxicants and other materials; for example, production of biodeposits by suspension feeders can modify particle-size distributions and subsequent transport elsewhere (Kautsky and Evans, 1987).

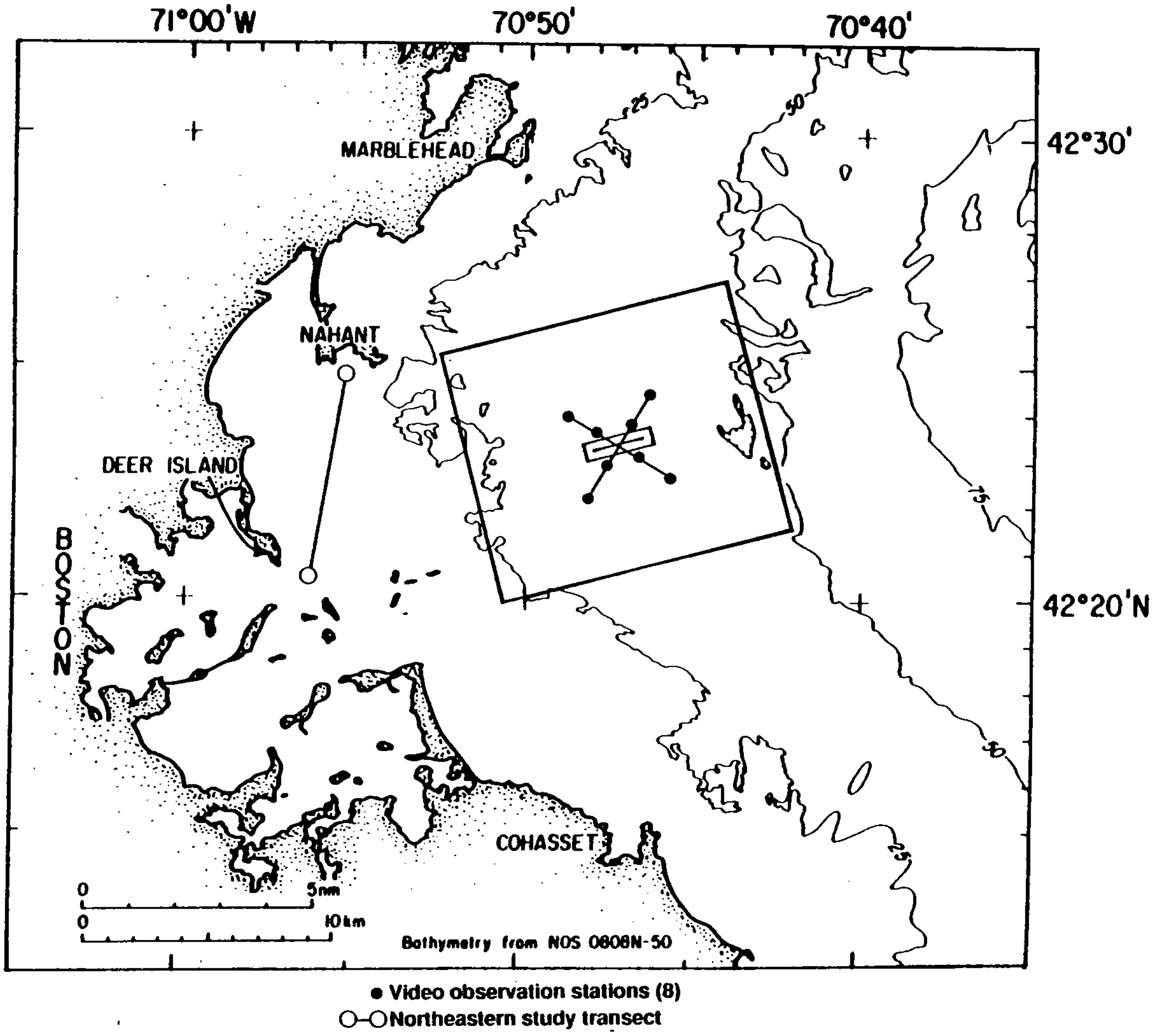


Figure B-12. Hard-bottom benthic stations.

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Appendix C

QUALITY ASSURANCE, DATA SYNTHESIS, AND DISSEMINATION OF INFORMATION

Quality Assurance

All activities under this monitoring plan will be conducted under well-defined Quality Assurance programs that set standards for personnel qualifications, equipment, facilities, and recordkeeping. All activities will be conducted under project-specific plans (e.g., survey, laboratory, or other work plan) that specify at a minimum the project goals, the relationship of the specific project to the overall monitoring plan, the hypotheses from the monitoring plan that are being tested, schedules of activities, data quality requirements, sample- or data-collection procedures, analytical and quality control measures, and data documentation and validation procedures. Analytical laboratories performing chemical analysis should participate in the Quality Assurance program used in the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends (NS&T) Program. This will help to ensure the accuracy, precision, and comparability of sediment and tissues results that are being generated by the various laboratories.

Data Synthesis and Dissemination of Information

The final essential component of any monitoring program is data synthesis, interpretation, and communication of this information to appropriate managers, scientists, and the public. The diverse data generated during monitoring must be integrated across disciplines and over the temporal and spatial scales of the monitoring program. These data must then be translated into information that can be used by the Massachusetts Water Resources Authority (MWRA) managers and environmental regulators to make management decisions. This information should also be summarized in a way that can easily be disseminated to and understood by the segments of the public who use and value Massachusetts Bay. The links between actual measurements and the public concerns should be clearly described.

Several reports have been and will continue to be prepared by the MWRA to document the plans and results of the program. Records of work to be performed, including details about sampling locations and methods for sampling and analysis, are currently documented in work plans or work/quality assurance project plans and survey plans. These types of documents are required for all projects and surveys. Results are documented in survey, data, and final project reports. Other reports also may be issued as necessary. So that information will be shared among the MWRA, Environmental Protection Agency (EPA), the Department of Environmental Protection (DEP), and others, regular meetings will be held to plan activities and discuss results.

A single centralized data management system containing all data generated under the monitoring plan is being developed to allow ready access to the information generated during the various monitoring and research efforts. Each investigator participating in the program will be responsible for maintaining easily accessible data. Data-submission requirements will be defined as the program progresses. Information and data will be exchanged among the various studies as necessary to complete data interpretation and to prepare reports. Only approved independently quality-assured final data will be exchanged.

Cooperating agencies and individuals will also work together to ensure appropriate recognition of data sources. Investigators will work together to provide timely interpretive reports. Investigators may also be requested to provide preliminary information to the monitoring task force or annual reports as required by the MWRA managers, particularly in the event of a critical alarm (e.g., low dissolved oxygen).

The information generated through implementation of the monitoring plan shall also be reviewed formally. The monitoring task force will aid the MWRA in making decisions about discharge-management issues and future research and monitoring needs. Expert review of the results of the program will also take place at various symposia or workshops. Representatives from Federal, State, and local governments, scientific institutions, fishermen's groups, and environmental groups will be invited to review results of monitoring and research activities.

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