January 1992

The State of BOSTON HARBOR: 1991

Massachusetts Water Resources Authority

Environmental Quality Department

Technical Report No. 92-3

THE STATE OF BOSTON HARBOR: 1991

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PREFACE

In this report, we provide information on the current condition of Boston Harbor and compare it to the condition we reported last year. Our intent is to give an overview of the state of scientific knowledge about the harbor. For more detailed information, contact the library of the Massachusetts Water Resources Authority (MWRA) for copies of MWRA technical reports.

The report is organized around the issues we believe to be of most interest to the concerned citizen. After summarizing some of the information necessary to understand conditions in the harbor, we look at four primary concerns expressed by the public: Is Boston Harbor safe for swimming and boating? Is it safe to eat the harbor's fish and shellfish? Are fish and other marine resources being adequately protected from the effects of pollution? What about the aesthetic conditions--is the harbor a resource that people can enjoy?

As a way of summarizing the information, we grade the factors that must be considered in answering the four questions. Each factor has two grades, one representing the current state of the harbor the other, and last year's grade. In the final section of the report, we compile all the grades into a report card for Boston Harbor and explore the question of how the harbor is expected to improve now that the discharge of sludge to the harbor has stopped.

We have adjusted the grading system based on the comments that we received from a wide variety of readers of last year's report. As a result of concerns about the uses of the harbor in areas without beach access, we have separately evaluated the health risks of boating. Much of the grading in last year's report card was based on the expert opinion of our staff and outside reviewers. This year we have quantified the criteria for the grade in each category.

The information in this report is drawn from many different sources. The MWRA Environmental Quality Department supports and participates in monitoring efforts that involve cooperation between the Commonwealth and a variety of public and private research institutions. In addition, many studies with information relevant to the harbor have been or are being conducted by other organizations. These studies include routine monitoring performed by various State and local agencies, small-scale research by local universities or environmental organizations, and large national programs funded by the Federal government. Institutions involved in long-term studies of harbor quality include the Massachusetts Institute of Technology, the National Oceanic and Atmospheric Administration (National Status and Trends Program), the New England Aquarium, Northeastern University, the University of Massachusetts at Boston, the U. S. Geological Survey, and the Massachusetts Bays Program.

MWRA's Environmental Quality Department provides a valuable service by synthesizing the results of these and other studies to advance both the theoretical and the practical knowledge of conditions in the harbor. This knowledge enables MWRA to make environmentally sound and cost-effective decisions that benefit Boston Harbor.

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Grading system used for the Boston Harbor report card

A **EXCELLENT:** Consistently maintains conditions characteristic of other clean coastal sites (e.g., Provincetown Harbor).

B **GOOD:** Frequently is better than Federal and State water quality standards and expectations for an urban estuary (e.g., some of Puget Sound).

C **SATISFACTORY:** Complies with Federal and State water quality standards and meets expectations for an urban estuary (e.g., San Francisco Bay).

D **POOR:** Sometimes fails to comply with existing standards or meet expectations for an urban estuary; some uses of the harbor are maintained (e.g., Boston Harbor last year).

F **FAILING:** Consistently fails to comply with Federal and State water quality standards or meet expectations for an urban estuary; there is obvious environmental degradation and uses of the harbor are lost (e.g., New York Harbor and New Bedford Harbor).

REPORT CARD FOR *Boston Harbor*		
	1991	**1990**
IS IT SAFE TO SWIM AND BOAT?		
Swimming	**D+**	D
Boating	**B**	(not graded)
IS IT SAFE TO EAT FISH AND SHELLFISH?		
Shellfish: Pathogens	**D+**	D-
Fish: Organic contamination	**C -**	C-
Fish: Metal contamination	**B -**	B-
ARE MARINE RESOURCES PROTECTED?		
Sediment contamination	**D -**	D-
Water quality: Oxygen	**C**	C-
Water quality: Toxic contamination	**B -**	B-
Fish disease	**D -**	D-
Seafloor Animals	**D**	D-
IS THE HARBOR AESTHETICALLY PLEASING?		
Aesthetics	**D**	D
OVERALL GRADE	**C -**	**D+**

EXECUTIVE SUMMARY

This report updates last year's report on the environmental status of Boston Harbor and summarizes its condition in a report card. For each factor evaluated, both last year's and this year's grades are recorded. As a result of public response to last year's report, we have slightly changed the questions to be graded and added more extensive quantification to the grading criteria.

Throughout the report we find that environmental conditions vary from one part of the harbor to another. In general, the inner harbor and parts of the northwestern outer harbor are most affected by contamination, and the southeastern portions of the outer harbor are least affected. The environmental status of the harbor is assessed by examining four questions that respond to some common concerns:

- Is Boston Harbor safe for swimming and boating?
- Is it safe to eat fish and shellfish caught in the harbor?
- Are marine resources in the harbor satisfactorily protected from pollution?
- Is the aesthetic condition of the harbor pleasing?

The factors that are graded to make up the report card are grouped under these four questions.

Is Boston Harbor Safe for Swimming and Boating?

Swimming Beaches
1990: D
1991: D+

We consider beach condition to be the best indicator of the recent improvement of the state of the harbor. While most parts of the inner harbor, landward of Commonwealth Pier, continue to have problems, many of the swimming beach areas are showing more improvement than we anticipated last year, due to improved operation of the Deer Island treatment plant and more aggressive maintenance of the collection system by the Boston Water and Sewer Commission.

Boating

1990: No grade
1991: B

Most boating activities provide less exposure to the water than swimming. Boating, therefore, receives a better grade than swimming. The highest boating risks are faced by windsurfing enthusiasts in the Charles River basin. Except in the plumes of the treatment plant discharges, the quality of the harbor for boating is quite good.

Is It Safe To Eat Harbor Fish and Shellfish?

Shellfish: Pathogens

1990: D-
1991: D+

Because of pathogen contamination, none of the shellfish beds in the harbor can be harvested except by master diggers who take their harvest to depuration plants for purification in clean water. The Division of Marine Fisheries can usually find beds that meet standards for this type of harvesting during dry weather. While bacterial contamination of the harbor is declining, shellfish standards are stricter than swimming standards, so the harbor receives a lower grade.

Fish: Organic Contamination

1990: C-
1991: C-

Throughout the harbor, concentrations of polychlorinated biphenyls (PCB) in lobster tomalley (or hepatopancreas) exceed the standard established by the U. S. Food and Drug Administration (FDA) as acceptable. Concentrations of PCBs in fish and shellfish sometimes exceed U. S. Environmental Protection Agency (EPA) guidelines for risk assessment, as do concentrations of polynuclear aromatic hydrocarbons (PAH).

Fish: Metal Contamination

1990: B-
1991: B-

Metal concentrations are elevated in fish and shellfish in the harbor, but not to the extent that human health standards are violated.

For heavy metals as well as organic contaminants, the contamination of fish and shellfish is expected to improve very slowly. Changes since last year have been very small.

Are Marine Resources Protected?

Fish and sea-floor animals were chosen to represent the status of living resources in the harbor. These groups contain commercially valuable species and are likely to exhibit the effects of living in a contaminated environment. Contamination in both the water column and the sediments was assessed because of the possible effect on these species.

Sediment Contamination

1990: D-
1991: D-

Most of Boston's inner harbor contains sediments with levels of organic and metal contamination similar to those found in other urban harbors of the United States. In Hingham and Hull Bays (the southeastern harbor), contamination concentrations are only moderate, whereas areas in the northwestern and central portions of the harbor are intermediate in degree of contamination. Changes in sediment contamination will take several years to be observable.

Water Quality: Oxygen

1990: C-
1991: C

Water in the inner harbor occasionally fails to meet standards for dissolved oxygen, but concentrations rarely approach levels that can adversely affect marine life. In the outer harbor, water quality standards are generally met, but concentrations of dissolved oxygen are sometimes depressed.

Water Quality: Toxic Contamination

1990: B-
1991: B-

Water quality criteria for the protection of the organisms living in the harbor from toxic pollutants are met most of the time. This is particularly true in the outer harbor, which is well flushed with water from Massachusetts Bay. The concentrations of toxic pollutants are less in Boston Harbor than in many other northeast urban estuaries.

Fish Disease

1990: D-
1991: D-

Boston Harbor has been noted for the high incidence of fin rot and tumors in its winter flounder. The incidence of tumors in flounder and pre-tumor conditions for tumors has declined for the last five years, but changes in the past three years have been only slight.

Seafloor Animals

1990: D-
1991: D

Some areas of the inner harbor and Winthrop Bay are nearly devoid of seafloor animals, but large portions of the southeastern outer harbor have quite active and diverse bottom-dwelling communities. If seafloor animals are limited by the concentrations of toxic contaminants found in the sediments, their recovery should be very slow, like that described for sediment contaminants. Alternatively, benthic communities may be more affected by the availability of oxygen for respiration, implying that they might recover more rapidly.

Aesthetics

1990: D
1991: D

Is the Harbor Aesthetically Pleasing?

Discharge plumes from the treatment plants have a noticeable odor and color that mar the aesthetics of the harbor. Last year volunteers found less trash per unit area in Boston Harbor than in the previous year. However, more discarded tampon applicators are still found on Boston Harbor beaches than along any other coastline in the United States. This major factor prevented the grade from improving.

Overall

1990: D+
1991: C-

What Is the Harbor's Overall Grade?

Our 1991 assessment of the condition of the harbor shows improvement compared to last year. Although the improvement is small, and partially due to our more quantitative grading scheme, we are excited that any recovery is visible at this early stage of the Boston Harbor Project. Most of the data recorded in this report were gathered in 1988-1990, and therefore reflect past conditions. Even so, bacterial contamination of the harbor from CSOs and the treatment plants has measurably lessened. Overall, the harbor is better for swimming today than it has been in the last sixty years. Now that sludge dumping has stopped, the water in the outer harbor near the sludge outfall is noticeably clearer. The sediments in Dorchester Bay and near the tip of Long Island are beginning their recovery, though measurable improvements may take several years.

Commercial ship traffic, the continuing problem of stormwater runoff, wet weather CSOs and the legacy of past pollution bound up in the sediment will prevent Boston Harbor from attaining a pristine condition. Nevertheless, we are already seeing signs that the harbor is responding positively to the Boston Harbor Project.

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CSO	Combined sewer overflow	2-3
DDT	Dichlorodiphenyltrichloroethane	4-7
DO	Dissolved oxygen	5-1
EPA	United States Environmental Protection Agency	4-4
FDA	United States Food and Drug Administration	4-4
MDC	Metropolitan District Commission	3-8
MIT	Massachusetts Institute of Technology	3-8
MWRA	Massachusetts Water Resources Authority	1-1
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PAH	Polynuclear aromatic hydrocarbon	2-3
PCB	Polychlorinated biphenyl	4-7
RPD	Redox potential discontinuity	5-6

1. THE PROBLEM AND THE PLAN

Boston Harbor has been a busy port, an abundant source of food from the sea, a place for relaxation and appreciation of natural beauty--and a place for disposal of human wastes--for centuries. As the Boston urban area has grown, the harbor has received an increasing volume of sewage; and an increasing number of people have discovered an appreciation for the harbor as an aesthetic and recreational resource. Public concern over the impacts of sewage disposal on these other valued uses of the harbor has grown over the past decades, as beaches have been posted, shellfish beds closed, and visible sewage wastes impaired uses and enjoyment of the waters. The Massachusetts Water Resources Authority (MWRA) was created in 1985 in large part to respond to the problem of sewage pollution in the harbor by building modern sewage treatment facilities.

Sources of Pollution in Boston Harbor

Boston Harbor and its tributaries have historically received most of the domestic and industrial wastes from the city and its surrounding communities. Today, more than 500 million gallons of domestic and industrial wastes are transported through the MWRA sewer system to the Deer Island and Nut Island sewage treatment plants each day. These two outdated facilities provide only primary treatment, a process that separates the solid waste (sludge) from the liquid waste (effluent). The effluent is disinfected by chlorination, and the sludge is digested to reduce volume and kill microbes. Up until December 1991, both sludge and effluent were discharged into the harbor, with sludge being discharged on the outgoing tide. Although sludge discharges have ceased, inadequately treated sewage is still the major source of pollution in Boston Harbor.

In addition to discharges from the treatment plants, sewage is discharged by over 80 combined sewer overflows (CSOs). Boston and some of the surrounding towns have sewer systems designed to carry both sewage and stormwater (combined sewage) to the treatment plant. When very heavy rains fall, overloading the capacity of the sewerage system, the excess volume is discharged from pipes designed for this purpose into the harbor and its tributary rivers. Although some combined sewage receives minimal treatment, screening and chlorination, before discharge, CSOs are a significant source of raw sewage to the harbor.

Other sources of contamination also degrade conditions in Boston Harbor. Litter and chemicals (*e.g.*,oil) are carried in runoff from streets and land. Tributary rivers also carry a load of litter, toxic contaminants, and particles of soil and organic matter into the harbor. The atmosphere contributes airborne pollutants, especially lead. A few industrial discharges also flow into the harbor. Ship and boat traffic in the harbor and runoff from waterfront construction projects add to the pollutant load.

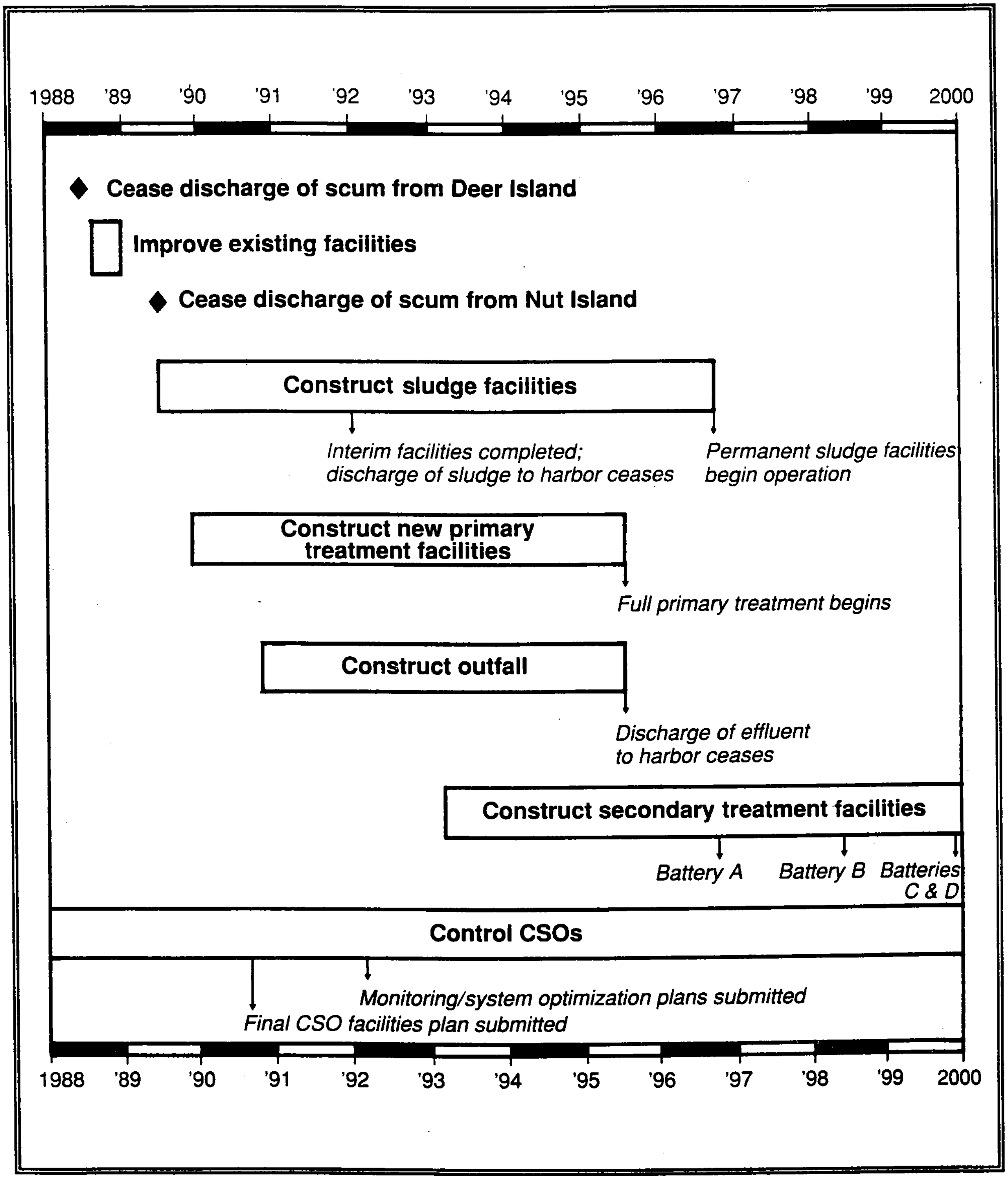


Figure 1-1. Time line for Boston Harbor Project. In response to the 1985 Federal Court order, MWRA negotiated a plan and a schedule for cleaning up Boston Harbor.

Overview of the Plan to Improve Boston Harbor

Although numerous sources contribute to pollution in Boston Harbor, the largest source of contamination and the focus of most public concern is sewage. MWRA's mission is specifically to comply with the Clean Water Act, which has the goal of making U.S. waters "fishable" and "swimmable," by providing proper treatment and disposal of sewage. Litigation over pollution of the harbor resulted in the development of a Federal court-ordered schedule to plan and build proper sewage treatment facilities (Figure 1-1). MWRA is now well into implementation of this ambitious Boston Harbor Project.

Key components of the Boston Harbor Project are:

- Improvements to existing wastewater treatment facilities.
- Building of facilities for processing sludge to fertilizer.
- Construction of new, primary and secondary facilities for wastewater treatment and construction of an ocean outfall.
- Reduction of combined sewer overflows and treatment of combined sewage.
- Reduction in the amount of toxic chemicals entering the sewer system.

Progress has already been made in each component of the plan.

What Has Been Accomplished?

Fast-track Improvements

The Boston Harbor Project was designed to be implemented in phases, so that some sources of harbor pollution would be abated quickly. These "fast-track" improvements to existing facilities have already been made by MWRA:

- More reliable and effective chlorination of the effluent.
- Removal of scum (oil and floating debris) from the effluent.
- Improvements to sludge digesters.
- Increased pumping capacity of wastewater flow to the Deer Island treatment facility. This means that more sewage reaches the treatment plants during rainstorms, decreasing combined sewer overflows.
- Improvements to the combined sewer infrastructure: construction of three new CSO treatment facilities, repair of tidegates and regulators.

In addition, the Boston Water and Sewer Commission has identified illegal sewer connections to storm drains, and the MWRA has eliminated many of these sources of pollution.

Sludge Dumping in the Harbor Ended in December, 1991

As well as the "fast-track" improvements, MWRA recently marked a major milestone in the Boston Harbor Project, beginning operation of the processing plant that converts the sludge to fertilizer. The discharge of sludge into the harbor stopped in December, 1991. After decades of receiving the pollutants and sediments in sludge, the harbor will begin a natural cleansing process--in some locations contaminated sediments will be buried in clean sediments, and in other places they will be resuspended and gradually flushed out of the harbor.

The 1991 State of Boston Harbor Report: "The Report Card"

In 1990, the MWRA published the first "Report Card," which summarized the pollution problems in the harbor and MWRA's role in addressing problems caused by improper sewage disposal in the harbor. The report was organized around the issues believed to be the most important to the concerned citizen. These issues are:

- **Can the harbor safely be used for swimming and boating?**
- **Is it safe to eat fish and shellfish caught in the harbor?**
- **Are fish and other marine resources of the harbor being protected?**
- **Is the aesthetic condition of the harbor pleasing ?**

2. UNDERSTANDING THE PROBLEM

Understanding the pollution problems caused by sewage discharges into Boston Harbor requires some knowledge of the oceanographic features of the harbor. Boston Harbor covers about 47 square miles of bays and tidal estuaries (Figure 2-1). The harbor is shallow, between 3 and 30 feet deep, except in President Roads and Nantasket Roads, the two shipping channels, where water depths approach 60 feet. Small islands are scattered throughout the harbor.

Boston Harbor is customarily separated into two main areas, the inner harbor and the outer harbor. However, the harbor is a complex system of many small bays and open-water areas that are variously influenced by different sources of contamination and that have different physical properties which, in turn, influence the fate of contaminants. As a result, environmental quality can vary throughout the harbor and different areas may be more or less suitable for some uses. For these reasons, subdivisions of the harbor will be discussed separately with respect to the four major issues. The divisions of the harbor and two tributary areas (Figure 2-1) referred to in this report are:

- Inner harbor
- Northwest harbor (Dorchester Bay and areas north of Long Island)
- Central harbor (Quincy Bay and Nantasket Roads)
- Southeast harbor (Hingham Bay)

Types of Contaminants and Their Sources

The major groups of contaminants that degrade the environmental quality of Boston Harbor are:

1. **Suspended Solids** -- small particles of inorganic materials such as sand and clay; living organisms, such as bacteria and phytoplankton; and organic matter. These particles, which are suspended in the water, can come from natural sources (, land runoff, rivers, bottom sediments) or man-made sources (*e.g.*, effluent and sludge). Suspended solids are important in evaluating water quality because toxic materials (see item 5 below) often attach to particles. Water with a heavy load of suspended solids is also murky and unattractive.

2. **Oxygen-Consuming Organic Matter** -- decomposing organic material that depletes the oxygen necessary to support marine life. In Boston Harbor, oxygen-consuming matter is commonly associated with effluent and sludge but it also is produced by marine plant growth (see item 4 below).

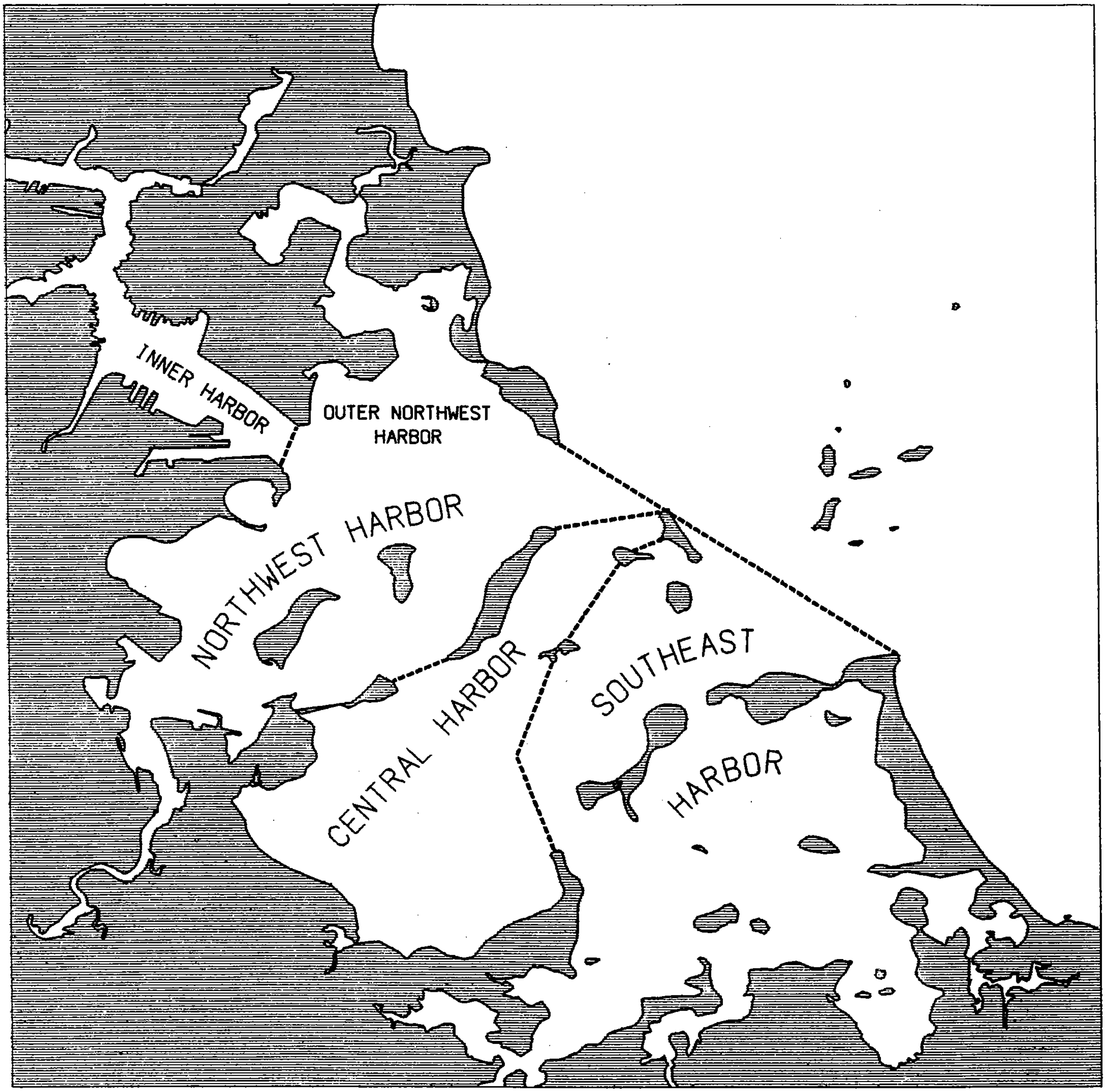


Figure 2-1. Map of Boston Harbor divisions. The harbor has been divided into sections so each can be considered separately.

3. **Pathogenic Microorganisms** -- disease-causing microorganisms (viruses and bacteria). Pathogens are found in untreated sewage. Combined sewer overflows (CSOs), which under certain conditions discharge untreated sewage, are the most important source of bacteria to Boston Harbor. Illegal cross connections of sanitary sewers to storm drains can also be a significant source of pathogens. The presence of pathogens is often indicated by the presence of fecal coliform and enterococci bacteria.

4. **Nutrients** -- chemicals that are essential for the growth of phytoplankton. In excess, nutrients such as carbon, nitrogen and phosphorus cause eutrophication, a condition of excess plant growth. As the excess plant material decays, oxygen in the water can be depleted (see item 2 above). Effluent and past sludge discharges have been the two significant sources of nutrients to the harbor, although runoff, river input, and CSOs also contribute nutrients.

5. **Toxic Materials** -- metals and organic chemicals that are poisonous or that can accumulate in living tissue to cause long-term effects or move up through the food chain. Most toxic chemicals enter the sewage system through industrial discharges, but household wastewater and storm runoff are also important sources.

Sewage sludge and effluent are major sources of most contaminants

The above contaminants enter Boston Harbor from sewage effluent and sludge, CSOs, rivers, stormwater, and the atmosphere. In the harbor, most kinds of contaminants, except for pathogens, come principally from effluent and sludge discharges. CSOs and failed sewer lines are the major source of pathogens. Rivers, CSOs, stormwater runoff, and industrial discharges into the sewer system are significant sources for suspended solids and certain toxic chemicals. Direct discharges of industrial waste into the harbor and its tributary rivers are less significant than other sources of contamination. Deposition from the atmosphere is an important source for a few chemicals, particularly lead and polynuclear aromatic hydrocarbons (PAHs).

Different areas of the harbor are affected by different types of pollution

Because of the location of sources and the physical differences among parts of the harbor, the key pollution problems vary among the geographic areas of the harbor. For example, in parts of the inner harbor, a warm, fresh, lighter water layer cuts off the underlying cold, saltier bottom water from the atmosphere and results in frequent depletion of dissolved oxygen, which is not observed in the well-mixed outer harbor. Fish diseases, which can result from exposure to toxic contaminants present in sewage effluent and sludge, are more prevalent on Deer Island Flats, near the sewage outfall, than in other areas of the harbor. High bacterial counts in the inner and northwest harbor areas are due to CSOs, while high counts in the southeast harbor are caused by contaminated stormwater.

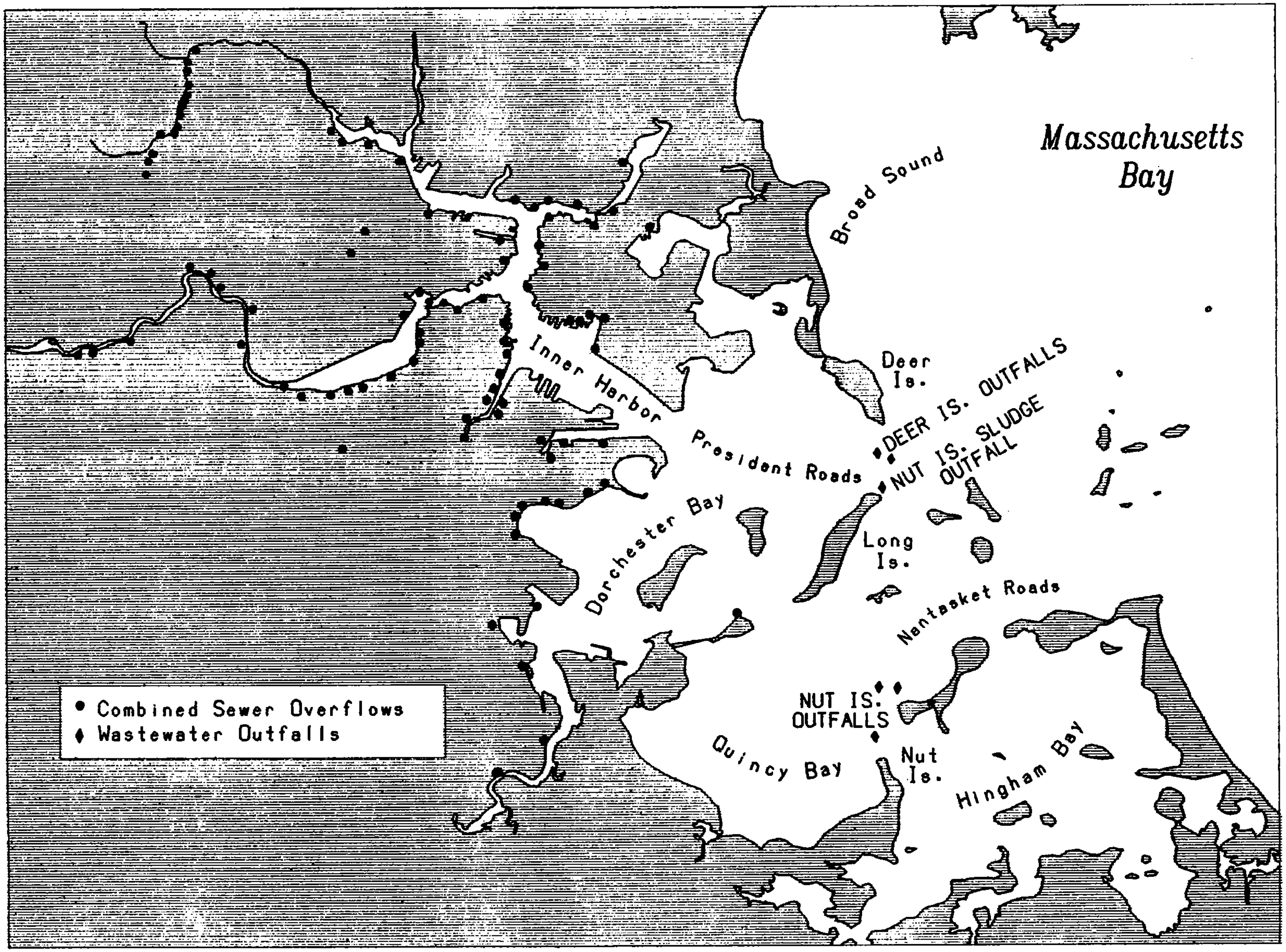


Figure 2-2. Pollution sources to Boston Harbor. Pollution sources to the harbor include sewage effluent, sewage sludge, and combined sewer overflows.

Fate of Contaminants In The Harbor

As described above, the primary sources of contamination to the harbor are sewage effluent and sludge, and CSOs which are located throughout the inner and northwest harbor areas (Figure 2-2). What happens to contaminants from these sources after they enter the harbor? Many contaminants adhere to small particles; these can either settle to the bottom of the harbor or can leave the harbor and eventually settle elsewhere. Other contaminants, such as nutrients, tend to be dissolved in--and move with--the water. Dissolved pollutants do not accumulate in the harbor, but their concentrations in harbor water may be high because of the large load entering the harbor's small volume each day. Whether contaminants are a problem in an area of the harbor depends on whether they are attached to particles, the time it takes for particles to settle, and the rate at which harbor water is exchanged with water from offshore.

Water Movement

About a sixth of the water in Boston Harbor is flushed out during a single tidal cycle

Flushing in coastal harbors depends largely on freshwater inflow, tides, wind, and depth. Boston Harbor is unique because more than one-half of its freshwater inflow, 20 cubic meters per second, comes from sewage effluent, which enters at the mouth rather than at the head of the estuary. By comparison, the combined freshwater flow of the Charles, Mystic, Chelsea, and Neponset Rivers is about 18 cubic meters per second. Water circulation in the harbor, however, is dominated by strong tides; the average tidal range is 2.7 m (9 ft). About 17% of the water in the harbor is flushed out during a single tidal cycle. Overall, most of the harbor water exchanges with Massachusetts Bay water in about 9 days; more in some areas of the harbor, less in others.

The deep shipping channels are well flushed; shallow bays flush more slowly

Water in Quincy Bay, Dorchester Bay, and Deer Island Flats in the northwest harbor does not exchange rapidly with Massachusetts Bay. In contrast, the deep channels at the harbor entrances, President Roads and Nantasket Roads (Figure 2-2) are much more energetic and well flushed. Because the large volume of tidal flow exits the harbor primarily through President Roads and Nantasket Roads, very strong currents develop there, resulting in vigorous mixing in these locations. Hingham Bay in the southeast harbor is also well flushed due to the considerable influx of Massachusetts Bay water through Nantasket Roads. Figure 2-3 shows graphically how the tides mix Boston Harbor water with Massachusetts Bay water. Water in the southeast harbor exchanges with Massachusetts Bay through Nantasket Roads; water in the inner harbor and the northwest harbor exchanges through President Roads. Quincy Bay, although adjacent to Nantasket Roads, appears to exchange primarily through President Roads. In general, the southern part of the harbor, with the exception of Quincy Bay, is better flushed than the northern part.

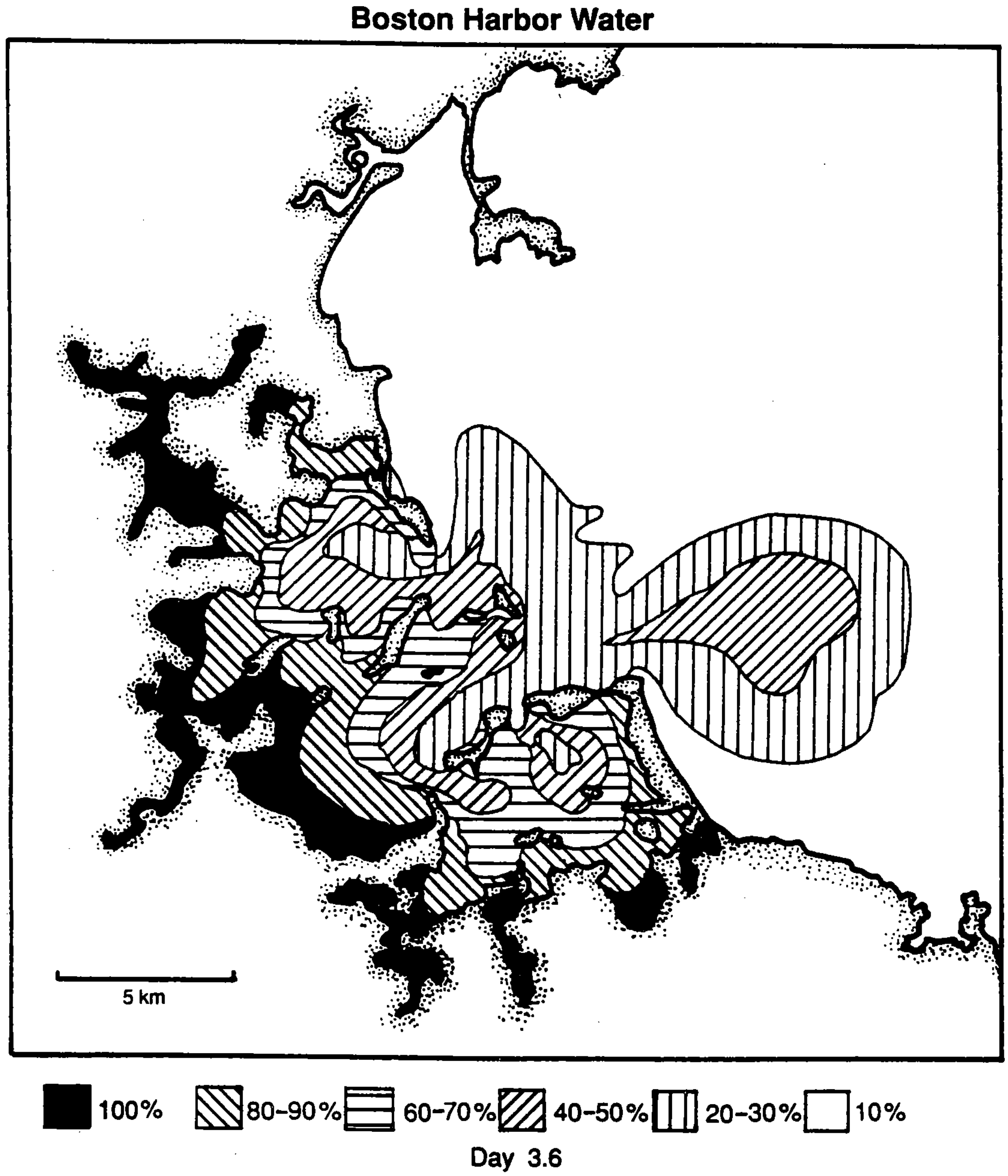


Figure 2-3. Computer model showing the flushing of Boston Harbor. A computer model was used to investigate the flushing of Boston Harbor, by defining "Boston Harbor Water" as that water which lay west of a line connecting Deer Island to Hull. The figure shows, 3.6 days later, how much of the water in each area of the harbor and Massachusetts Bay is made up of that original "Boston Harbor Water." The channels at the harbor entrances are well flushed, while the inner harbor and other small bays have not exchanged much water with Massachusetts Bay. Figure courtesy of R. Signell.

Some parts of Boston Harbor are relatively calm and other areas are very dynamic. The harbor's strong tides and numerous islands stimulate mixing of the water in most areas. Recent field studies and modeling results suggest that water movement and transport of particle-bound contaminants in Boston Harbor can vary considerably over very short distances. An example is the movement of water near the Nut Island sludge outfall on Long Island. Field observations suggest that, on an outgoing tide, this water stays near Long Island despite its proximity to the strong currents in President Roads. On the flood tide, the water near Long Island and the sludge plume could move south toward Nantasket Roads. As a result, the sludge did not necessarily move out of the harbor through President Roads, but was dispersed by strong flows from multiple directions.

During ebb tides, the effluent from the Deer Island treatment plant mixes with seawater in President Roads and is transported out of the harbor. Effluent plumes from the Nut Island treatment plant are vigorously mixed with water from the western part of Nantasket Roads in the central harbor. Studies using drifters show how water parcels from the outfalls can move on a particular day; for example, during a single ebb tide, effluent discharged into Nantasket Roads can reach Massachusetts Bay. To understand the net effect of several tidal cycles, we can use a computer model; such a model indicates that Nantasket Roads and Hingham Bay are the areas most affected by discharge from the Nut Island effluent outfalls. However, the wind can play an important role which is not captured in the model; field studies have shown that a west wind can occasionally move the Nut Island plumes into Portuguese Cove on Peddocks Island.

Particle Movement

Most sewage particles leave the harbor when first discharged or after resuspension

Most toxic chemical contaminants tend to adhere to small particles in effluent and sludge. Unlike bacteria, which generally remain harmful for only a few days in the marine environment, trace metals and organic compounds are persistent. Contaminant-laden particles can accumulate in quiescent areas of the harbor, resulting in localized high concentrations of pollutants.

Because much of the harbor is effectively flushed, it appears that most toxic contaminants introduced by sewage treatment plant discharges do not settle in the harbor. A recent computer modeling study predicted that as little as one-quarter of the contaminant particles introduced by sewage discharges are deposited in the harbor. This prediction is borne out by measurements of the sludge tracer, spores of the bacterium *Clostridium perfringens*, in Massachusetts Bay sediments. Although the concentrations of *Clostridium perfringens* spores in Massachusetts Bay sediments are generally 10-50 times lower than concentrations in Boston Harbor, the sludge tracer is spread out over a large area of the Bay. In fact, concentrations in western Massachusetts Bay are as high as the levels measured in the southeast harbor; this result indicates that a considerable amount of sludge was leaving the harbor and affecting Massachusetts Bay.

Sediment Deposition

Particle-bound contaminants that are not flushed out of the harbor eventually settle to the bottom in areas of the harbor that favor deposition. Depositional areas occur where there are depressions in the sea floor, where water is shallow, or where currents are weak. The sediment on the harbor floor consists primarily of natural particles that enter the harbor from offshore, or are created by erosion of the harbor shoreline. Particles from sewage effluent, sludge, and CSOs are deposited along with these "clean" particles throughout the harbor. The most contaminated bottom sediment is found in depositional areas, especially the inner harbor and close to sources, such as the Nut Island sludge outfall at the tip of Long Island. A computer model of deposition predicts rapid sediment accumulation in the inner harbor, moderately rapid accumulation over Deer Island Flats, and minimal sedimentation in President Roads. Swift tidal currents in the latter area scour away fine sediments, leaving heavier sand and gravel behind. In general, much of the central harbor and northwest harbor, and most of the southeast harbor, are depositional; the deep shipping channels, however, are erosional or have both processes occurring at different times, and erosion also occurs around the shorelines (Figure 2-4).

Under the influence of a storm or an unusual tide, particle-bound contaminants in the surface layer of the bottom sediments can be resuspended into the water, carried to a different location, and sink again. This process of resuspension and transport moves contaminants away from their sources and even out of the harbor. Contaminants attached to fine sediments are re-deposited on shallow mud flats or in deep less-energetic parts of the harbor and eventually become incorporated into the bottom sediment.

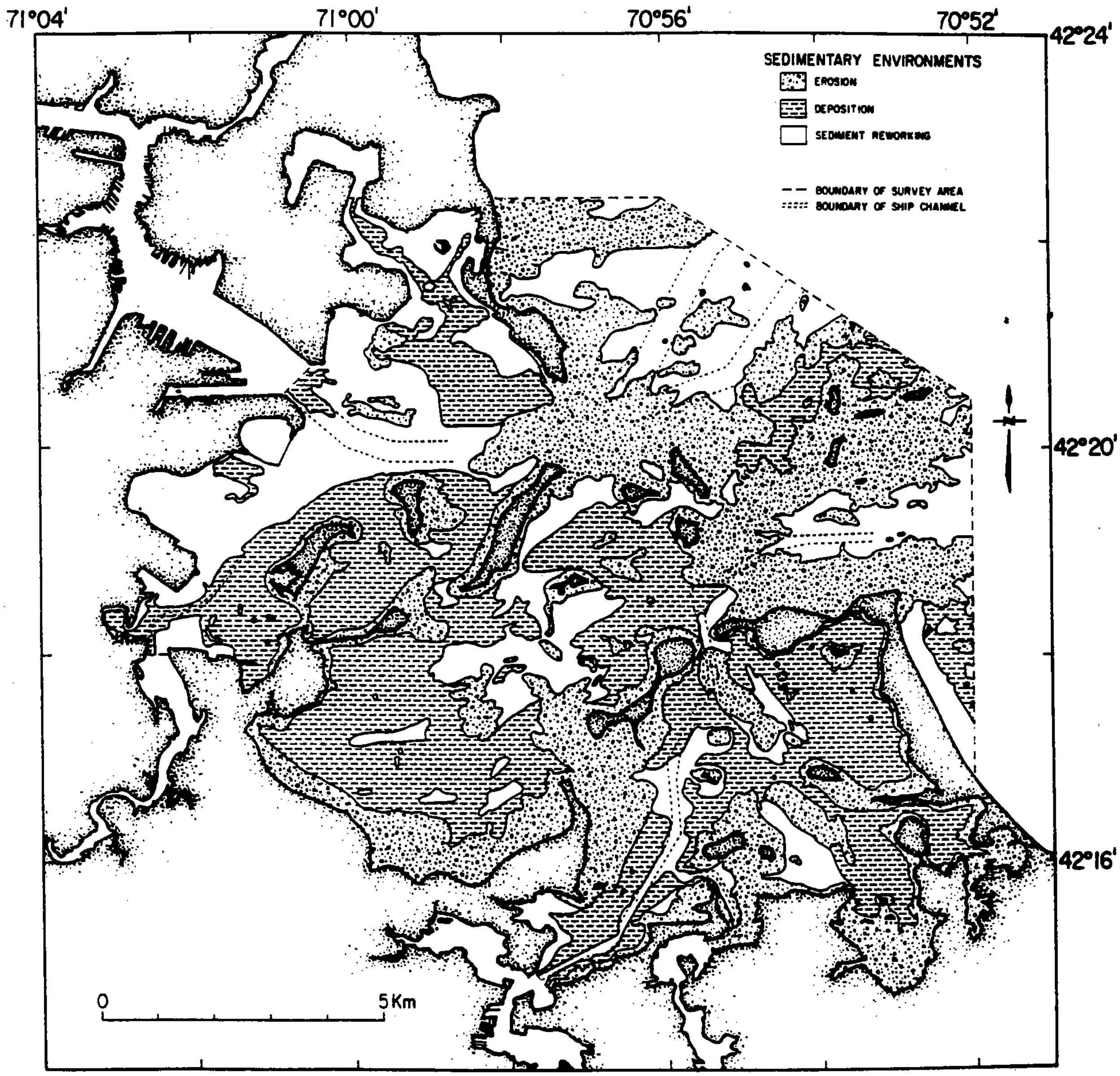


Figure 2-4. Map of erosional and depositional areas of Boston Harbor. This map, from the U.S. Geological Survey, show the areas of the harbor in which bottom sediments are swept away (erosion) or accumulate (deposition). In many areas, both processes occur at different times (sediment reworking). Figure form Knebel *et al*, 1991.

Summary

Past discharges of sludge and the continuing effluent discharges are the major sources of pollution in Boston Harbor. Types of contaminants that contribute to water-quality problems in the harbor include (1) suspended solids, (2) oxygen-consuming organic matter, (3) pathogenic microorganisms, (4) nutrients, and (5) toxic materials. Although effluent, sludge, and CSOs include all of these contaminants, other sources also contribute to the total contaminant load.

Because most contaminants are associated with particulate material, they can either be flushed out of the harbor under the influence of tides and other currents, or they can drop out of the water column and settle on the bottom. Physical and oceanographic features in different parts of the Boston Harbor influence the fate of the contaminants. Based on the most recent studies, the majority of particle-bound contaminants are transported out of the harbor; the material that remains settles in depositional areas of the harbor (*e.g.*, the inner harbor, Deer Island Flats). Resuspension processes, induced by storms, large tides, or strong currents, move particle-associated contaminants, that may have originally been deposited near their source, to distant parts of the harbor or even out of the harbor. The net result of these interacting processes is a patchy distribution of contaminants in sediments throughout the harbor and the development of "hot spots" of contamination in a few localized areas (*e.g.*, Deer Island Flats).

3. IS BOSTON HARBOR SAFE FOR SWIMMING AND BOATING?

Many people enjoy Boston Harbor's waters and beaches for swimming and recreational boating, and the impairment of these uses by sewage contamination has provoked public concern. The greatest hazard from recreational use of sewage-polluted waters is the risk of contracting infectious diseases (stomach ailments, as well as eye, ear and skin infections can result from swimming-associated exposure). Unfortunately, the major sources of untreated sewage to Boston Harbor--combined sewer overflows and contaminated storm drains--discharge along the shoreline, often at swimming beaches. The inner harbor and open-water areas of the outer harbor, used intensively for boating, can potentially be affected by CSOs and effluent or sludge from the treatment plants.

High levels of sewage indicator bacteria in the harbor are associated with rain

The greater the number of sewage bacteria and viruses in the water, the more likely it is that people swimming in the water will be exposed to an infection. As is true for all pollutants in the harbor, many factors affect the counts of bacteria in the water. Important factors are: the volume and concentration of sewage discharged into the water, whether or not the sewage is disinfected, how far away the source is, how long it has been since the discharge, the patterns of water circulation, the temperature and salinity of the water, the season, the time of day, and the stage of the tide. Probably the single most important factor affecting bacteria levels in the harbor is rainfall, which washes sewage from storm drains and combined sewer overflows into the water. Heavy rains can cause overloading of the treatment plants, forcing treatment plant bypasses. The volume of rain falling, the location of the heaviest rain, and its duration and intensity all interact in a very complex way both with other environmental factors and the sewerage infrastructure (pipes, pumps and treatment plants) to give a highly variable pattern of bacterial pollution.

Over the past two years, several studies and monitoring activities done by scientists, the Boston Water and Sewer Commission (BWSC), and MWRA have significantly increased our understanding of this interaction between the environment and the structure of the sewer system. This better understanding has developed at the same time that concrete progress has been made in reducing harbor pollution, including "fast-track" improvements at the sewage treatment plants, the construction of new CSO treatment facilities, improved routine maintenance of the system, and inspection and correction of illegal sewer hook-ups.

The rest of this section will discuss new information about microbiological pollution in Boston Harbor, and how changes in patterns of pollution relate to abatement efforts.

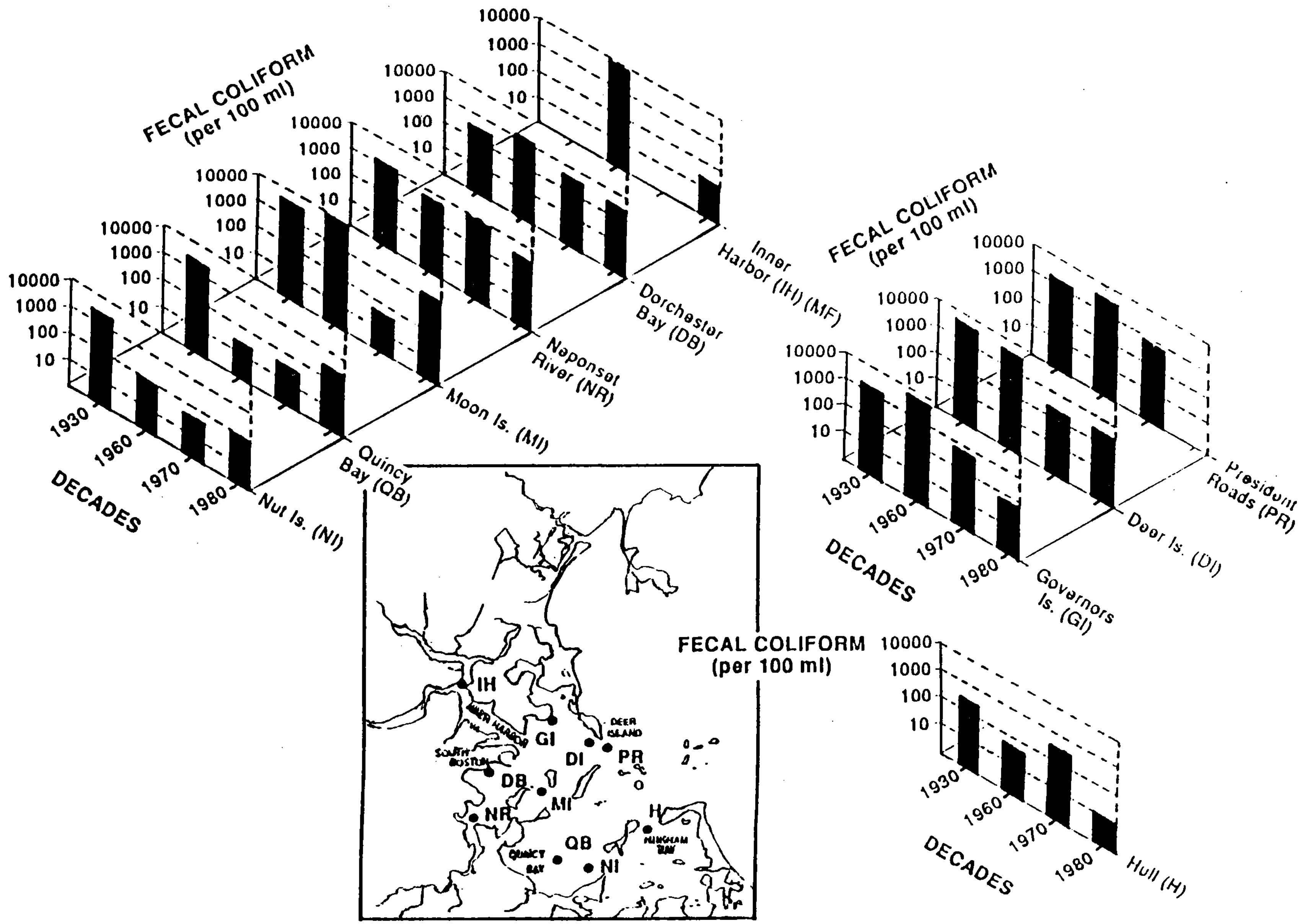


Figure 3-1. Bacterial water quality in Boston Harbor over 50 years. Each bar in the graph represents the *average* of all suitable data collected over a period of 10 years. For two decades (1940s and 1950s) there were no suitable data available. Data from the 1930 decade are based on only one study. All the data except from the inner harbor are based on the "most probable number" (MPN) method of counting bacteria, and so are roughly intercomparable.

Historical Context

To assess our current efforts to control pollution of the harbor, it is helpful to put the newest study results in an historical context. To see if there have been any broad trends in microbiological water quality over time, a study was undertaken to analyze existing historical water-quality data.

Sewage-Indicator Bacteria Used to Assess Water Quality

Two sewage-indicator bacteria are used to assess the quality of water in Boston Harbor:

Fecal coliform are bacteria normally found in the intestines of warm-blooded animals. They occur in large numbers in raw, untreated sewage. Although fecal coliform are not dangerous themselves, their presence indicates that the water is probably contaminated with raw sewage. Thus, it is likely that disease-causing bacteria and viruses (pathogens) are also in the water. In Massachusetts, beaches are posted as unsafe for swimming when the fecal coliform count exceeds 200 organisms per 100 ml of water. Fecal coliform bacteria have been used as indicators of bathing-beach water quality for decades.

Enterococcus is a bacterium also found in the intestines of warm-blooded animals, and in large numbers (but fewer than fecal coliform) in raw sewage. Recent studies have shown that disease rates in swimmers in marine waters correlate better with the counts of *Enterococcus* in the water than with fecal coliform counts. This better correlation is probably because *Enterococcus* is much hardier in salt water than fecal coliform, tends to persist in the marine environment longer, and therefore better mimics the distribution of viruses in the water. EPA calls for an average count at marine bathing beaches of no more than 33 *Enterococcus* per 100 ml of water, and recommends posting a beach when the *Enterococcus* count exceeds 104 per 100 ml.

Coliform bacteria counts (see box above) have been used by many agencies to assess the risk to public health from sewage-impacted waters, and many historical coliform count data have accumulated from studies of Boston Harbor waters, dating from as early as 1905. Despite differences in technical methodologies in the bacterial analyses done over the course of time, and the large variability in data due to different study designs, a clear trend emerged--bacterial water quality has been *improving* in Boston Harbor over the decades.

Figure 3-1 shows that counts have decreased 10- to 100-fold over the past 50 years in the inner harbor, near Deer Island, Nut Island, Governors Island, President Roads, Nantasket, Moon Head, and Dorchester Bay. Dramatic improvements in water quality were related to sewage treatment projects. For example, in 1939, the highest average bacterial counts were found near Deer Island, Moon Head, Nut Island and Quincy Bay (all were discharge points for untreated sewage). "*B. coli*" counts (an approximate equivalent of fecal coliform counts) were on the order of 3,000-5,000 per 100 mL. In the 1960s, there were still high counts found near Deer Island, Moon Head, President Roads and Governors Island, but counts had decreased 10-fold near Nut Island and in Quincy Bay. This improvement followed the opening of the Nut Island Treatment Plant in 1952. Similarly, the opening of the Deer Island Treatment Plant in 1968 was followed by a 10-fold decrease in counts near Deer Island and Governors Island in the 1970s. In the 1980s, counts were generally the same as in the 1970s, or lower, except in Quincy Bay and near Moon Head. Bacteria counts in the inner harbor were dramatically lower in the 1980s compared to the 1960s. Overall, these results contradict popular, anecdotal opinion that water quality in Boston Harbor is worse now than it has been in the past.

Effect of Recent Pollution-Control Activities on Water Quality

Fast-track improvements at treatment plants have improved nearshore and offshore water quality

While the major projects for the proper treatment and disposal of sewage (secondary treatment plant, outfall pipe, sludge treatment) are still under construction, significant improvements to the treatment system have been made through smaller projects. Two "fast-track" improvements have been important to the microbiological water quality in the harbor: installation of new pumps at Deer Island, and more reliable chlorination at both Deer and Nut Island Treatment Plants. The new pumps at Deer Island have greatly increased the amount of flow that can be directed to the treatment plant during storms (Table 3-1). This translates to reduced "choking" (excess flow diverted from the pumping station, or "headworks") and fewer overflows from combined sewers.

Because of the variation in weather conditions from year to year, data for more years are needed to tell whether there has been a statistically significant reduction in bacteria counts in the water because of this improved pumping. However, the indications are promising. For example, in 1990, the BWSC measured the overflow volume from Carson Beach CSOs and found that some large storms which were expected to produce a large volume of overflow produced little or no discharge.

While improved pumping can decrease shoreline sources of sewage, more reliable chlorination at the wastewater treatment plants has been associated with a dramatic improvement in offshore bacterial water quality. The extreme violations of fecal coliform water quality measured near Deer Island by the New England Aquarium have not been found since 1988, and water quality near Nut Island has been good since 1987. In 1990, the geometric mean fecal coliform counts in Quincy Bay ranged from 1 to 7 per 100 ml, including samples collected in the Nut Island effluent outfalls.

Table 3-1. Pumping flow and "choking time" [1] at Deer Island headworks have improved dramatically.

Time period	Ave. pump operability (pumps/day)	Ave. monthly rain (inches)	"Choking time" (hours)
July 1988-June 1989	5.89	3.47	148
July 1989-June 1990	6.75	3.94	114
July 1990-June 1991	8.28	3.05	40

1 The amount of time flow is held back from the plant at the headworks.

CSO screening and chlorination facilities can significantly improve bacterial water quality

Two new facilities to provide treatment to combined sewage at major overflow points have begun operations during the past two years. These screening and chlorination facilities are located at Fox Point and Commercial Point in southern Dorchester Bay. These facilities do not remove either oxygen-demanding material (BOD) or toxic contaminants, but have been effective in decreasing the load of sewage bacteria in the water. Table 3-2 shows that fecal coliform counts in the water near Fox Point were significantly lower after screening and disinfection began. Although we do not yet have enough post-operational data to yield statistically significant results, early indications are that counts near the new Commercial Point facility have been substantially lowered since operation began.

One of the most effective means of reducing the flow of pollutants into our waters is one of the least glamorous: routine maintenance of the sewerage infrastructure. Data collected near one of the single largest sources of raw sewage to Boston Harbor, the combined sewer overflow at the head of Fort Point Channel, illustrate this point (Figure 3-2). In the winter of 1989-90, a one-million gallon-per-day dry-weather overflow

Table 3-2. Fecal coliform counts in the water near new CSO treatment facilities have decreased.

Area	Facility status (dates)	Average fecal coliform/100 ml (95% confidence intervals)
Savin Hill Cove (near Fox Point CSO)	Preoperational (1989)	749 (403-1392)
	Operational (1990 and 1991)	79 (42-150)
Commercial Point	Preoperational (1989 and 1990)	175 (93-327)
	Operational (1991)	49 (16-147)

More aggressive maintenance has improved water quality in the inner harbor

caused by a malfunctioning regulator in the pipe was discovered and repaired. After this repair, routine fecal coliform counts in the Channel dropped approximately two-fold.

Progress in eliminating improper sewer connections to storm drains is vital in making our beaches swimmable

Combined sewer overflows are not the only source of untreated sewage to the harbor. Many pipes in the Boston area which are designed to carry only stormwater are contaminated by sewage, which is discharged into the harbor or rivers. Sometimes sewage can enter the stormwater pipes from leaks in old, poorly maintained sewer pipes. Or, wastewater pipes from homes and businesses are improperly connected directly to stormwater pipes (rather than to sewers). Finding and repairing these sources of contamination can have a dramatic effect on water quality. For example, the Boston Water and Sewer Commission discovered that a storm drain that discharges onto Constitution Beach was contaminated--all the houses on one side of a street had their sewer pipes connected to the storm drain! Repairing these illegal connections during 1990 has contributed to a significant decrease in the number of postings at Constitution Beach in 1990 and 1991, compared to 1989. Other illegal connections have been corrected on the Charles and Neponset Rivers, and BWSC continues with an active program to detect and correct these problems.

Mathematical Model of Harbor Pollution, Based on New Data

One aid to understanding patterns of water pollution and their relationship to environmental causes is to use a mathematical model to calculate the fate a pollutant in the environment. The model uses measured or estimated values such as the volume of sewage entering a body of water, the concentration of a given pollutant in the sewage, the rate of die-off or settling of a pollutant, together with the effects of the shape of a body of water, water depth, and tidal circulation. On a computer, the model gives a picture of where the pollutant will go, how long it will persist in the water, and how concentrated it will be. Using

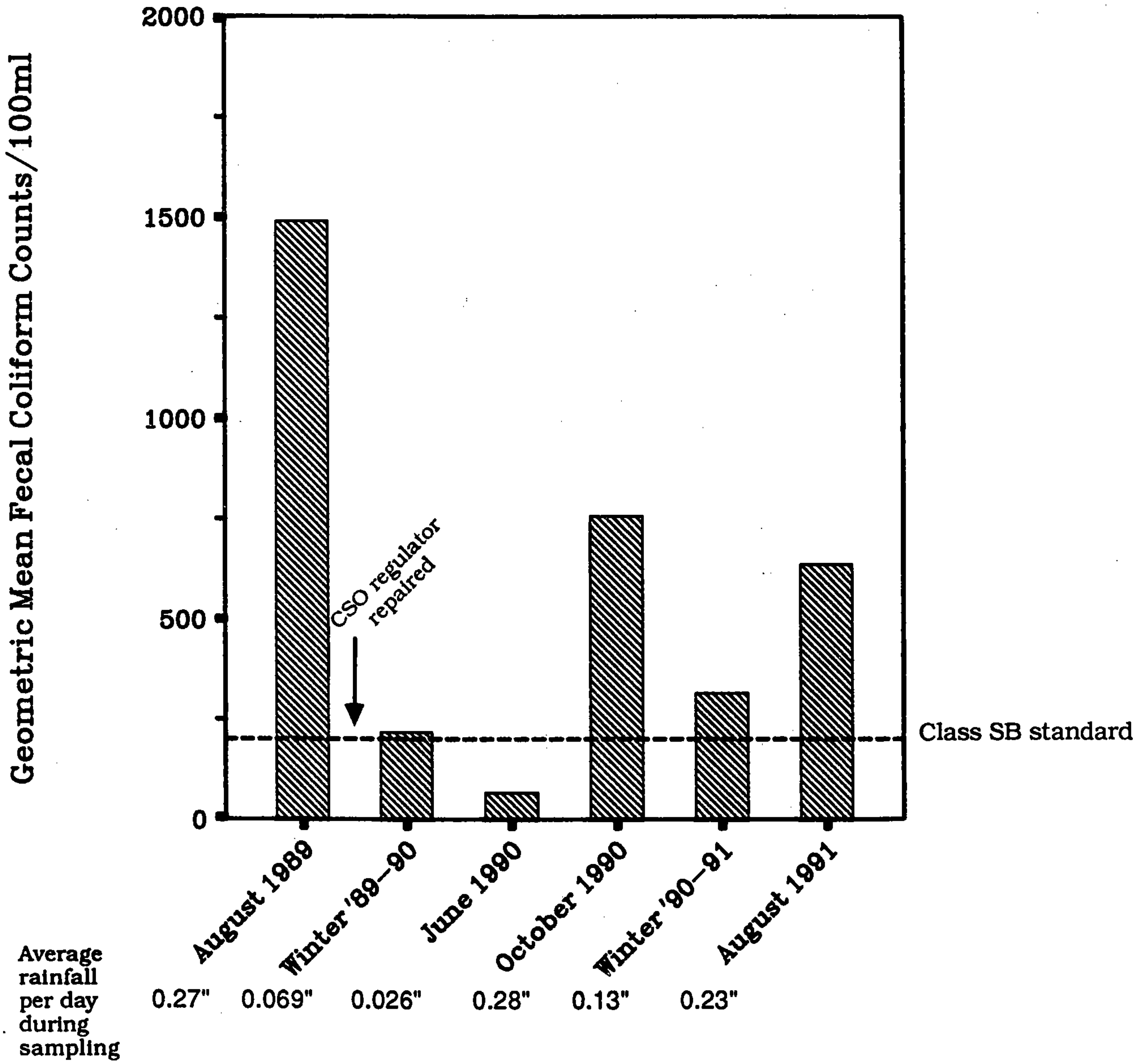


Figure 3-2. Fecal coliform counts in Fort Point Channel. Average (geometric mean) fecal coliform counts in Fort Point Channel have decreased by approximately half since a malfunctioning CSO regulator was repaired. Each bar represents the geometric mean of approximately 20 samples. Some of the variation in counts is due to weather conditions during the sampling period. There was substantial rainfall during the August 1989, October 1990 and August 1991 sampling periods, while June 1990 was very dry.

new (1990) measurements of CSO volumes and concentrations of pollutants, researchers at Massachusetts Institute of Technology (MIT) simulated water quality in the harbor after storms of different sizes. Figure 3-3 shows the predicted effect of a rainstorm of a size which, on average, occurs four times a year: "a 3-month storm". According to the model, one day after the storm the swimming standard (200 colonies per 100 mL) will be exceeded only in Fort Point Channel, and near the shoreline in Dorchester Bay. Two days after the storm, no areas of the harbor violated standards (not shown).

Water Quality for Recreational Use Varies among Different Areas of the Harbor

Swimmers in sewage-polluted water are in direct contact with the water and are more at risk than boaters. Therefore water testing for public health reasons is focused on beaches. The Metropolitan District Commission (MDC) has jurisdiction over most beaches in Boston Harbor, but some beaches in Quincy and Hingham are the responsibility of the towns. Water samples are generally collected each week from public beaches and analyzed for sewage-indicator bacteria: fecal coliform and *Enterococcus* (see box on page 3-3). If the number of indicator bacteria in the water is higher than state standards, the beach is posted as unsafe for swimming. Although boating areas are not routinely monitored or posted for public health reasons, bacterial water quality data are collected in the inner and outer harbors by MWRA, by the New England Aquarium, and by the Massachusetts Department of Environmental Protection.

Inner Harbor

Although there are no bathing beaches in the inner harbor, this area is popular for sailing and rowing small boats--activities which often mean exposure to the water. Monitoring data collected by MWRA in 1989 and 1990 showed that the inner harbor is significantly affected by combined sewer overflows. On average, if more than about an inch of rain fell over three days, bacteria counts in the inner harbor exceeded swimming standards for two to four days. During dry weather, most of the inner harbor met swimming standards. Thus, except after heavy rainstorms, especially in Fort Point Channel, water quality in the inner harbor is good for recreational boating.

Northwest Harbor

Water quality in this part of the harbor varies greatly. In 1989 and 1990, MWRA sampling showed that Carson Beach, Pleasure Bay and Northern Dorchester Bay generally met water quality standards. Samples taken near Calf Island in the outer harbor were all within swimming standards. Southern Dorchester Bay, at the mouth of the Neponset River, generally showed poorer water quality. This area is affected by the Neponset River, contaminated storm drains, CSOs and possibly sludge.

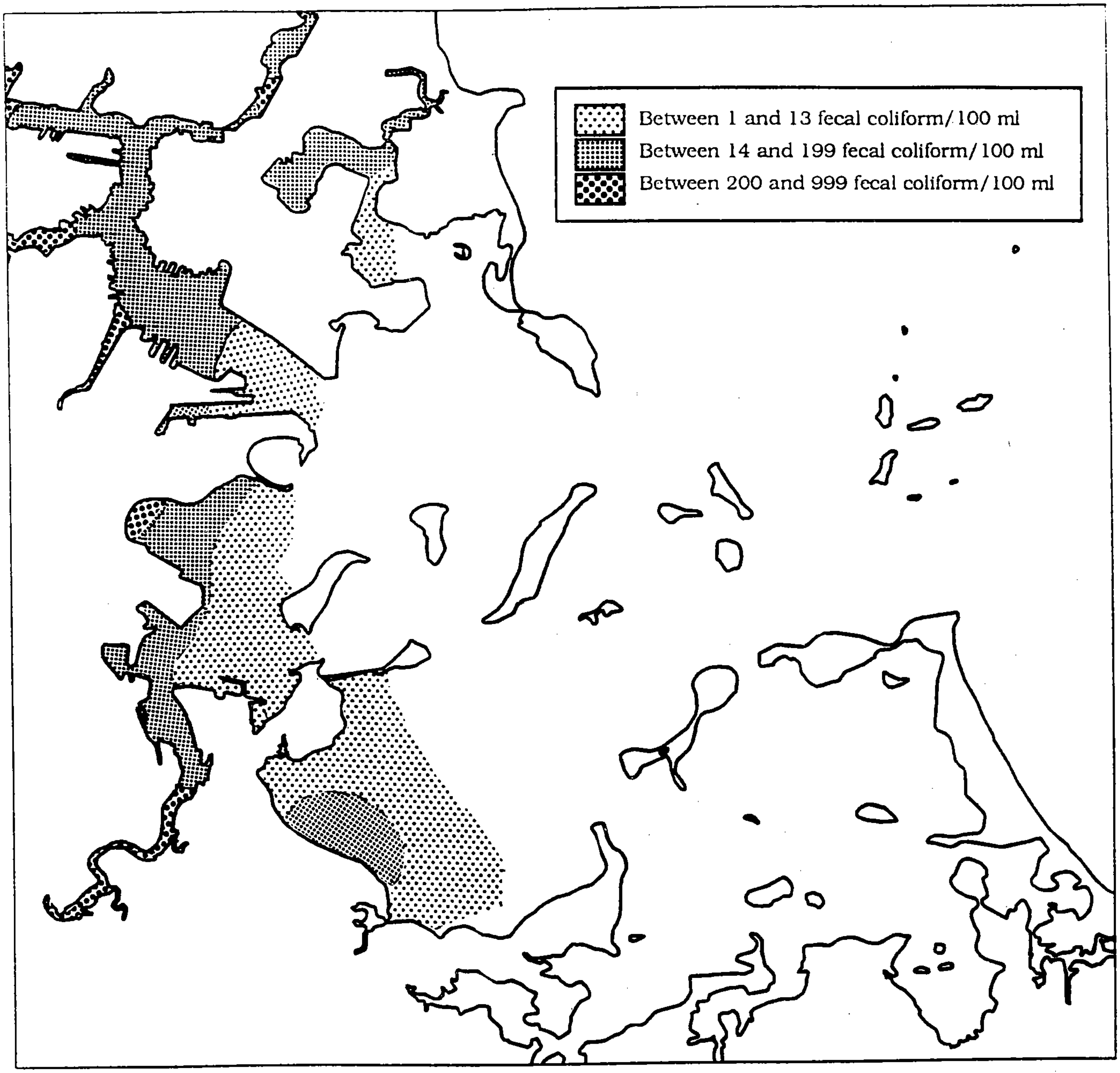


Figure 3-3. Effect of a "3-month" storm on fecal coliform counts in Boston Harbor. A mathematical model of fecal coliform counts in Boston Harbor shows the predicted levels of bacteria in the water after a "3-month storm." The model uses new loading estimates from 1990. The figure shows counts in the harbor one day after the storm. Counts are predicted to exceed the swimming standard in the Mystic, Charles, and Neponset Rivers, in portions of the inner harbor, and in Dorchester Bay.

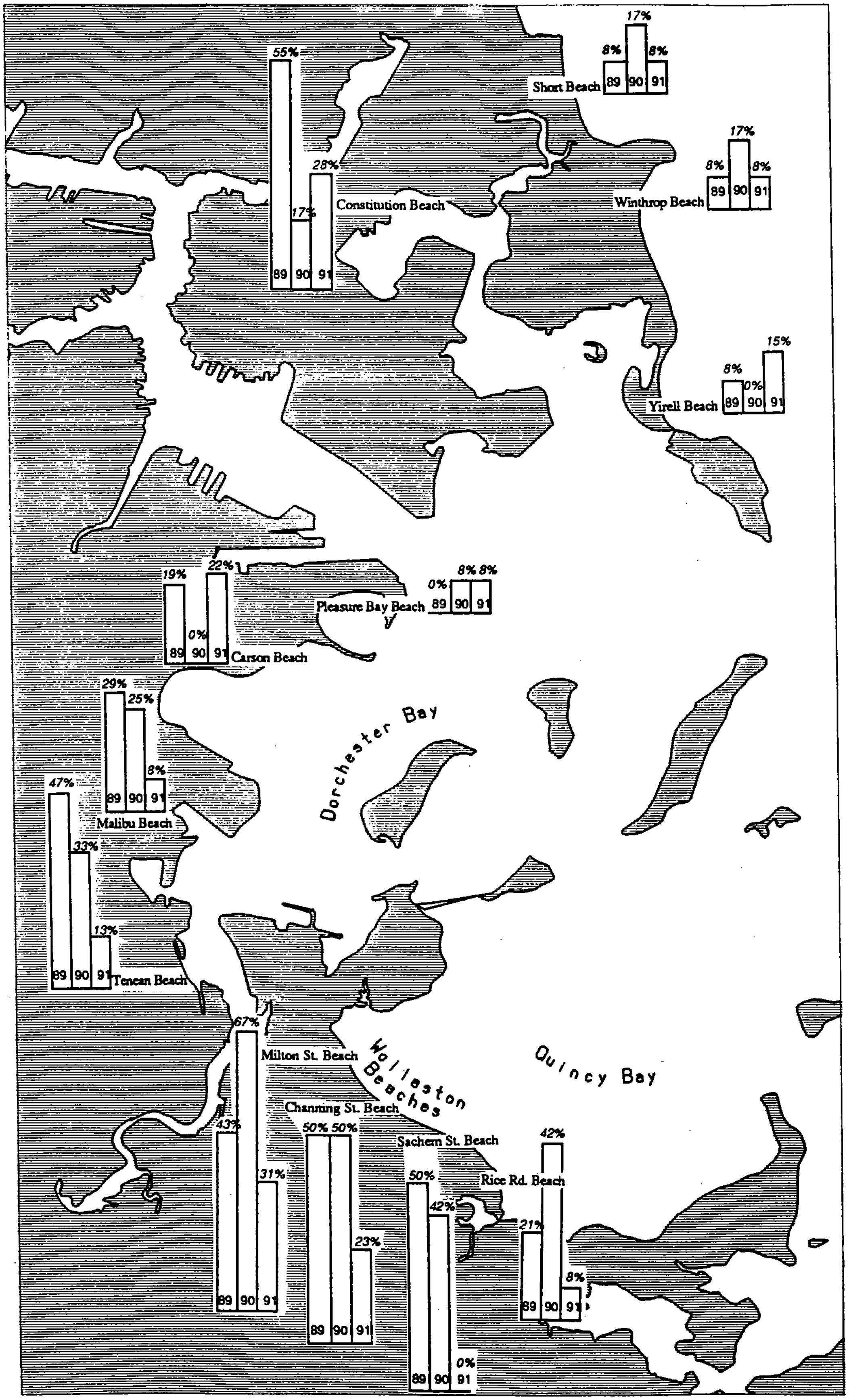


Figure 3-4. Beach postings in Boston Harbor: 1989-1991. Bar graphs show the *percent of water samples which exceeded state water quality standards.* Beaches shown are under the jurisdiction of the MDC. Data for three years are shown: 1989-91. Much of the annual variation is due to differing rainfall patterns.

Samples collected at Dorchester Bay beaches in 1991 by MDC (Figure 3-4) indicate a decrease in the number of postings at the two beaches in southern Dorchester Bay: Tenean and Malibu. In the past, these beaches have been affected by two major combined sewer outfalls, Fox Point and Commercial Point. The decrease in postings at these areas can probably be attributed to the operation of new disinfection facilities at these outfalls.

Central Harbor

Water quality monitoring in the Quincy Bay area over the past two years has shown generally rather poor quality and frequent postings at Wollaston Beach, but good water quality in the offshore areas: even in the Nut Island effluent outfalls. Results from sampling at Wollaston Beach have implicated sewage-contaminated storm drains as a source of sewage to the beach. When this problem is corrected, water quality at Wollaston Beach should improve.

REPORT CARD

Is Boston Harbor Safe for Swimming and Boating?

	1990	1991
Swimming	D	D+
Boating	not graded	B

4. IS IT SAFE TO EAT FISH AND SHELLFISH?

Flounder, lobster and softshell clams in Boston Harbor are important commercial and recreational food resources. Public concern about the effect of pollution on seafood safety centers on two major issues: (1) the risk of catching an infectious disease from shellfish harvested from sewage-polluted water, and (2) the risk of consuming toxic chemicals possibly present in shellfish or fish living in polluted waters.

Pathogen Contamination in Shellfish

By far, most seafood-borne illnesses are infectious diseases caused by bacteria and viruses from sewage. Shellfish have a high potential for spreading infectious disease for three reasons: (1) their habitat is in coastal areas most subject to sewage pollution, (2) shellfish can filter and concentrate disease-causing bacteria and viruses from the water, and (3) shellfish are often eaten raw or lightly cooked. In the past, serious diseases like typhoid fever and cholera were commonly spread in oysters and clams. Because of this problem, the National Shellfish Sanitation Program was developed to promote regulations for the microbiological safety of shellfish and shellfish-growing areas. In the U.S., outbreaks of typhoid fever and cholera from contaminated shellfish have virtually been eliminated by stringent regulations that permit unrestricted and recreational shellfishing only in relatively pristine waters.

In the U.S., the most common disease acquired by eating contaminated shellfish is viral gastroenteritis, which is relatively mild, not usually requiring medical treatment. Hepatitis A is a more serious, but rarer viral disease sometimes spread by contaminated shellfish. The most common shellfish-acquired bacterial diseases are caused by vibrios--bacteria that live naturally in the marine environment and are not necessarily associated with sewage contamination of shellfish.

*Because of the risk of sewage-born infectious disease, it is **not** safe to eat unpurified shellfish from Boston Harbor*

In Boston Harbor productive clam beds, shown in Figure 4-1, cover about 4,700 acres. None of these beds are open for recreational clamming because sewage indicator bacteria counts (see box on page 3-3) are too high. About 2,900 acres of clam beds are restricted to harvest only by "master diggers." These licensed diggers must take all clams harvested to a depuration facility, where the shellfish are held in clean water for two days to cleanse themselves of bacteria.

The Massachusetts Division of Marine Fisheries monitors shellfish-growing waters as well as the clams themselves for bacteriological safety. Some areas of Boston Harbor, especially in Quincy Bay and Hingham Bay, are often conditionally opened, while other areas, like Dorchester Bay, are virtually never opened (see Table 4-1).

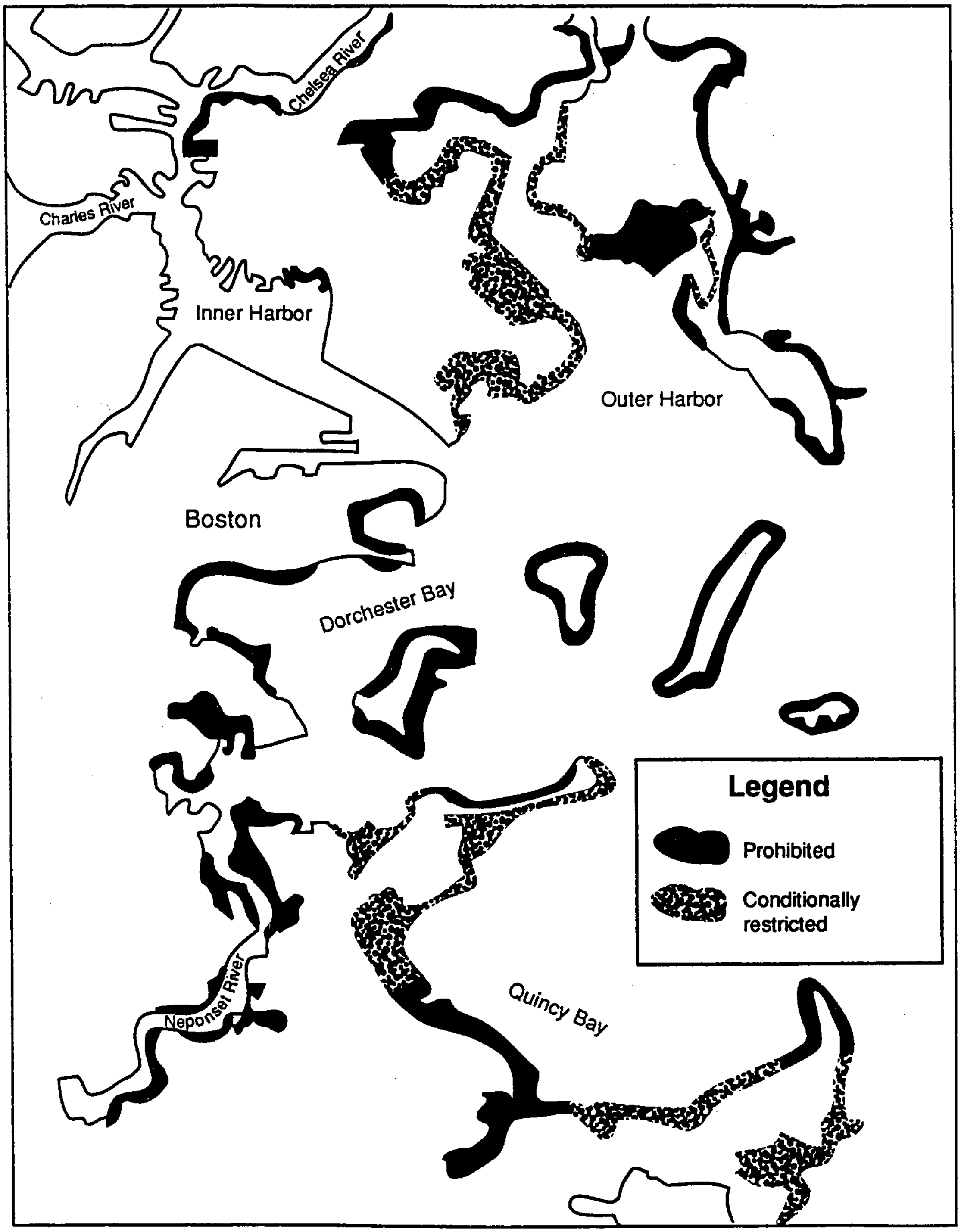


Figure 4-1. Prohibited and restricted clam beds in Boston Harbor. There are many acres of soft-shell clam beds in Boston Harbor, but none are open for unrestricted harvest.

Table 4-1. Restricted and prohibited productive clam beds in Boston Harbor. Some productive clam beds in Boston Harbor are virtually always closed, while other areas are frequently harvested.

Harbor area	Acres of productive beds	Percent of clam beds classified as		
		Open	Restricted	Prohibited
Inner Harbor	3	0	0	100
Outer Northwest				
Winthrop	311	0	64	36
Islands or other	1,920	0	71	29
Dorchester Bay	519	0	18	82
Central	551	0	74	26
Southeast	1,381	0	58	42

Toxic Chemicals in Fish and Shellfish

Fish and shellfish can accumulate toxic chemicals by absorbing them from the water, from direct contact with contaminated sediments, or from their food. People who eat fish and shellfish contaminated with toxic chemicals may suffer adverse health effects. The health risk depends on the level of contamination, the toxicity of the chemicals and the amount of contaminated seafood consumed.

The incidence of obvious disease in humans from eating chemically contaminated seafood is very low, compared to outbreaks of infectious diseases carried by fish and shellfish. Because of this low rate, the effects on people of eating chemically contaminated seafood are not well understood. Most knowledge of toxic effects from contaminated fish is from epidemiological studies which compare disease rates in people who have consumed seafood to disease rates in people who have not eaten the seafood. There have been only a few cases in the world where contaminated fish was clearly the source of a serious disease.

FDA and EPA have used statistical risk-assessment techniques to establish criteria for contaminants in food which might cause health problems. These include:

(1) Risk-based limits. Concentration of contaminant which may be high enough to cause health problems. Two types of risk-based limits are:

> **a) Lifetime cancer risk level.** This measure is used for chemicals that have or may have a cancer-causing effect. It is the level of a contaminant calculated to produce a given number of excess cases of cancer above the background rate in the population. Thus a 1-in-10,000 lifetime cancer risk level is the amount of a chemical estimated to produce one additional case of cancer per 10,000 people per lifetime of exposure. (The background risk of cancer is 20 cases per 100 people per lifetime.)
>
> **b) Reference dose**. This measure is used to characterize chemicals not thought to cause cancers, but which might have other adverse health effects. It is an estimate, based on animal testing, of the daily amount that is unlikely to produce adverse health effects during a lifetime.

(2) Regulatory limits. Concentration of contaminant which is high enough for the FDA to remove foodstuff from interstate commerce. These "action levels" are calculated considering marketplace effects together with potential health effects.

There have been no known outbreaks of diseases caused by toxic chemicals in seafood from Boston Harbor nor have there been any epidemiological studies of people who consume seafood from Boston Harbor. Therefore, the only way to judge the risk from toxic contaminants in Boston Harbor fish and shellfish is to compare measured levels of contaminants to levels which are presumed to have health effects. These levels are established by the Food and Drug Administration (FDA) and the Environmental Protection Agency (EPA), and are described in the box above.

This section discusses toxic chemicals found in three food species in the harbor: winter flounder, lobster, and blue mussel. Flounder and lobster live and feed on the bottom, and are thus potentially exposed to toxic chemicals in the water, sediment and food organisms. The mussel lives attached to rocks and pilings, and feeds by filtering particles from the water, potentially accumulating chemicals associated with the particles.

Table 4-2 shows the average concentrations of selected contaminants in winter flounder, lobster meat (not including the lobster "green organ" or tomalley, which can have elevated concentrations of metals and organic pollutants) and blue mussels. Average values are an appropriate measure because persons who regularly consume harbor seafood would experience the average concentration over a long period of time.

Metals in Seafood Species in Boston Harbor

Figure 4-2 shows how the average concentrations of seven metals in different food species compares to the FDA risk-based limit. The bars show the ratio of the average metal concentrations found in each species in the harbor to the FDA limit. All of the average metals concentrations

Table 4-2. Average concentrations of contaminants in edible tissues of fish and shellfish from Boston Harbor [parts per million (μg/g wet weight)]. Data are from NOAA 1991a.

	Winter Flounder	Lobster Meat[1]	Mussels
PAHs	0.0004	0.024	0.275
PCBs	0.337	0.118	0.149
DDT	0.065	0.005	0.016
Mercury	0.028	0.125	0.041
Cadmium	0.002	0.006	0.264
Lead	0.013	0.071	1. 73
Copper	0.230	11.5	1.72
Chromium	0.022	0.043	0.249
Nickel	ND	0.039	0.389
Zinc	ND	20.4	22.0

[1] Data are for lobster meat only, not the tomalley (hepatopancreas)

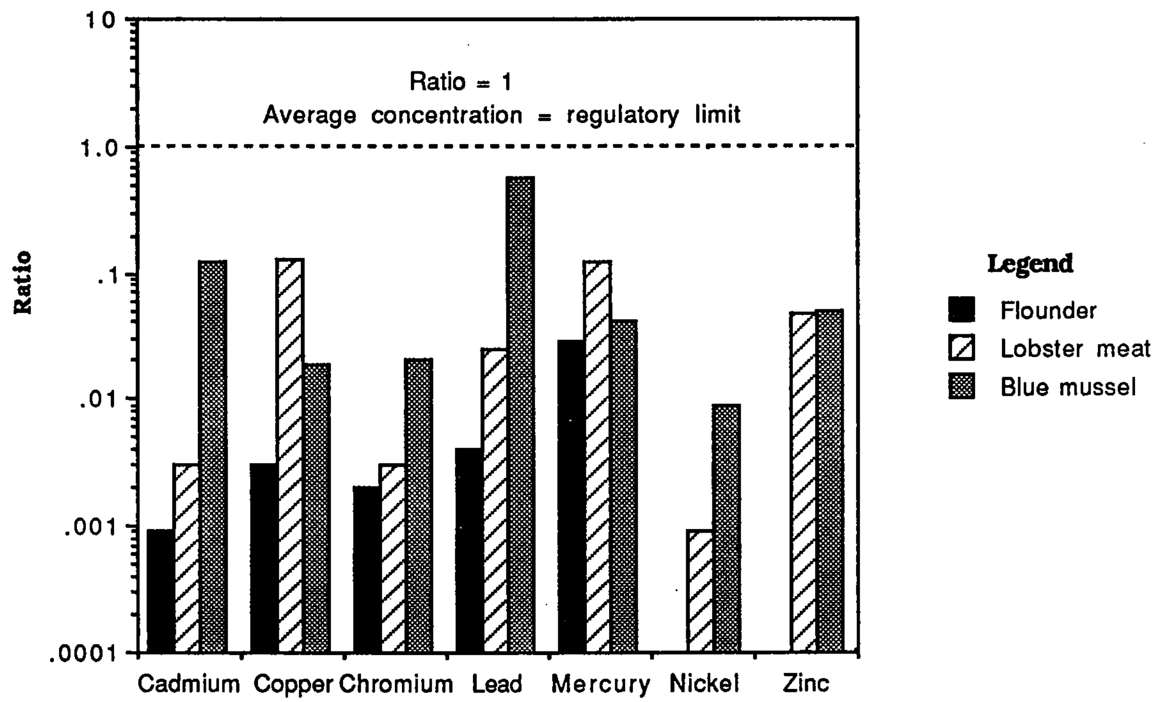


Figure 4-2. Average metals in Boston Harbor seafood compared to regulatory limits. The average concentrations of toxic metals from three seafood species from Boston Harbor fall below the risk-based regulatory limits for health effects.

Toxic Chemicals in Edible Fish and Shellfish

Organic chemicals

DDT: insecticide used world-wide, banned in 1972. Most "DDT" measured is actually the DDT breakdown products DDD and DDE.

PAHs (polynuclear aromatic hydrocarbons): complex organic chemicals, found in petroleum and in products of combustion of fossil fuels. Many PAHs are known carcinogens.

PCBs (polychlorinated biphenyls): a group of complex chlorinated organic chemicals that are industrial in origin.

Metals

All metals occur naturally in trace amounts, but higher concentrations enter the environment through discharge of sewage and industrial wastes. Because of their toxicity, copper, mercury and lead are of concern.

were below the FDA limits (ratio was less than 1), and except for lead in mussels, metals concentrations were 10- to 1,000- fold lower than the limits. Lead in mussels approached the FDA risk-based limit.

Spatial Patterns of Metals in Mussels

Because mussels attach and grow in one spot, they are useful for comparing conditions at different locations. The National Oceanic and Atmospheric Administration (NOAA) has gathered "Mussel Watch" data on concentrations of contaminants in mussel tissue at several different locations within Boston Harbor. Only cadmium showed a statistically significant spatial pattern, decreasing in levels from the inner harbor to the southeast harbor.

To show how Boston Harbor compares to other urban harbors, Mussel Watch data from the East Coast are presented in Figure 4-3. Boston mussels showed higher levels than the average for all New England sites. Mussels from Boston Harbor showed higher levels of mercury and lead, and lower levels of silver and copper than Chesapeake Bay and Delaware Bay mussels. Boston Harbor and Hudson-Raritan Bay mussels had generally similar metals levels.

Organic Compounds in Flounder, Lobster, and Mussels from the Harbor

PAHs, PCBs, and DDT are three groups of organic compounds of concern (see box). Table 4-2 shows average concentrations of these contaminants in flounder, lobster meat and blue mussels. How these concentrations compare to FDA action levels (for PCBs and DDT) or estimated action levels (PAHs: see Appendix for explanation) is shown in Figure 4-4a. The average concentrations of these organic chemicals were lower than the action levels. Except for PAHs in blue mussel and PCBs in flounder, concentrations of organic compounds were 10- to 1,000- fold lower than action limits. Another way of looking at these data is to see how the levels of contaminants translate to cancer risk. Figure 4-4b shows that only PAHs in mussels and PCBs in flounder and mussels exceed the 1-in-10,000 lifetime cancer risk level.

Spatial Patterns of Organic Pollutants in Mussels

Figure 4-5a shows how organic chemicals in mussels vary in different parts of the harbor. The highest PAHs are found near Deer Island, intermediate levels in Dorchester Bay, and the lowest levels in the outer harbor islands (Brewsters) and in Hingham Bay.

How Boston Harbor compares to other Mussel Watch sites on the East coast is presented in Figure 4-5b. Boston Harbor mussels have organic contaminant levels that are higher than the mean of New England sites, but intermediate among other urban harbors.

Patterns of Organic Pollutants in Mussels over Time

NOAA found that the only toxic contaminant that showed a change over time was the pesticide DDT, which has been declining over the last few decades. DDT was banned from production and use in 1972.

Summary of Chemical Contamination in Boston Harbor Fish and Shellfish

Overall, available information indicates that Boston Harbor fish and shellfish contain levels of chemicals that are higher than cleaner offshore areas but comparable to those found in other urban areas. Average concentrations are below action levels.

For organic chemicals the grade of C- results from an average of levels of PCBs, PAHs and DDT from mussels, the species that has had the highest levels of organic contamination. Concentrations of PCBs and PAHs in mussels were relatively high, exceeding cancer risk levels of 1 in 10,000, while concentrations of DDT were relatively low. For metals, the grade of B- is a reflection of the average metals levels in all three species, which were well below risk-based limits.

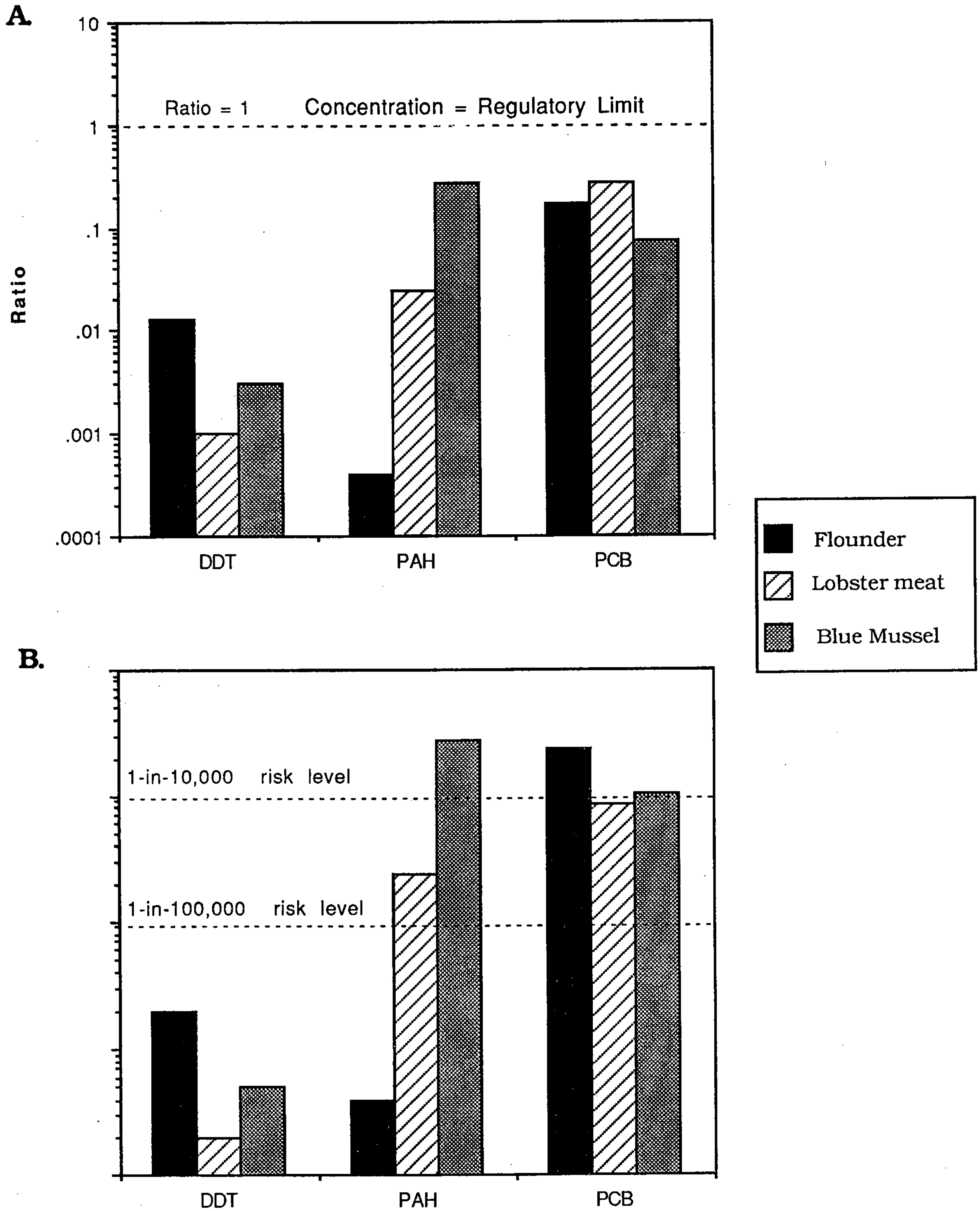


Figure 4-4 . Organic chemicals in seafood from Boston Harbor. A. Average concentrations of organic chemicals in seafood from Boston Harbor (excluding lobster tomalley) were less than the regulatory limits. B. The estimated increased risk of cancer from consumption of seafood is shown, assuming ingestion of 6.5 grams of fish per day. PAHs and PCBs in blue mussels exceeded the 1-in-10,000 lifetime risk level, as did PCBs in flounder.

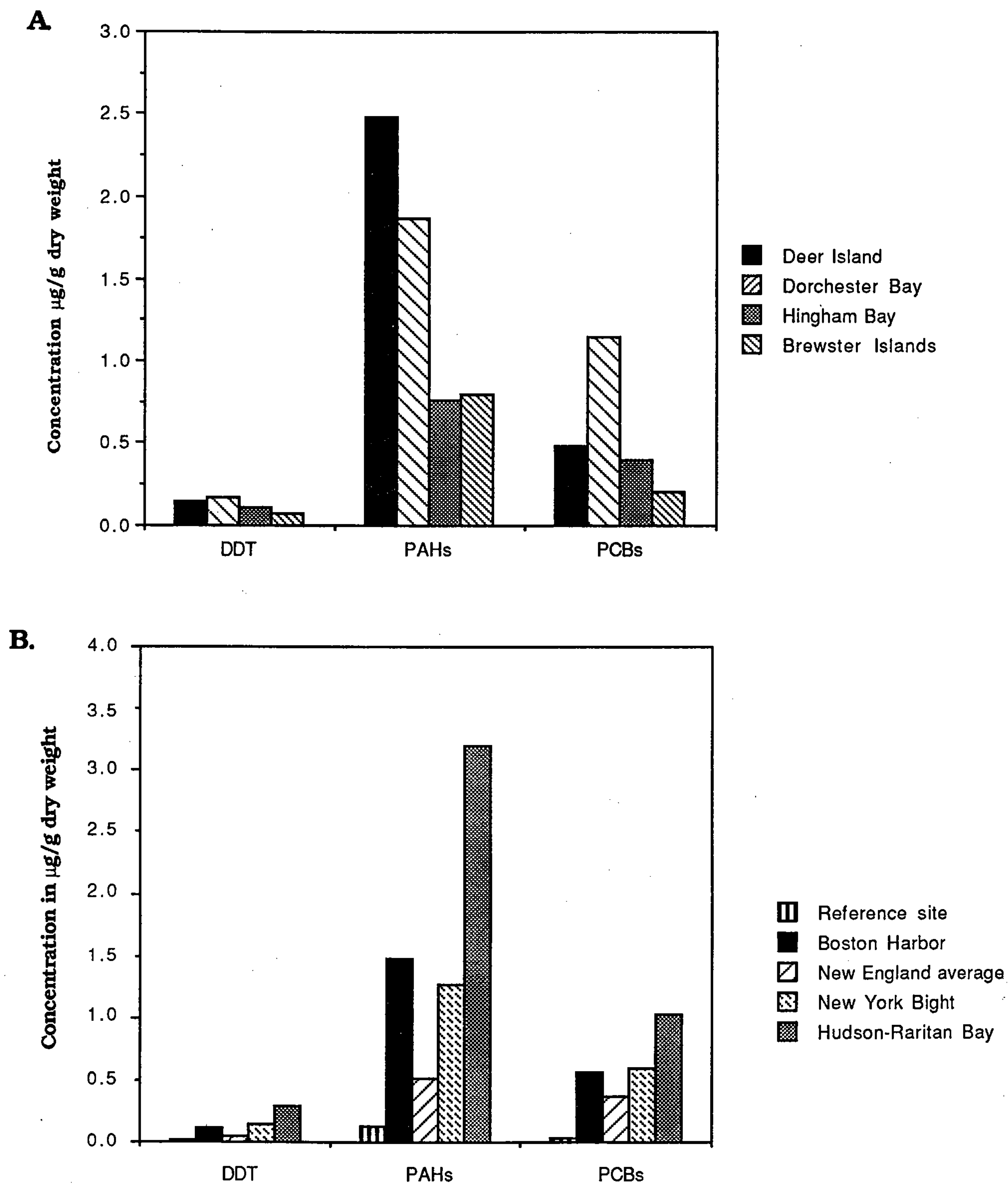


Figure 4-5. Organic chemicals levels in mussels within Boston Harbor and compared to other urban estuaries. A. Average DDT, PAHs and PCBs measured in mussels in different areas of Boston Harbor, 1990. There is no consistent geographic trend among the three organic chemicals measured in mussels from different areas of Boston Harbor, except that outer harbor islands and the southeast harbor show lower levels than near Deer Island and in Dorchester Bay (data from Battelle, 1990). B. Comparison of organic chemical levels in mussels from Boston Harbor and other east coast estuaries. Levels of toxic organic chemicals in Boston Harbor mussels are similar to other urban estuaries along the east coast. The reference site is an uncontaminated site off the Maine coast (data from Battelle, 1990).

Report Card:

Although the grades for safety of fish and shellfish have changed this year, the changes are due to the use of more refined and well-defined criteria for determining grades, and do not indicate an improvement since 1990.

REPORT CARD

Is it Safe to Eat Fish and Shellfish?

	1990	1991
Shellfish: Pathogens	D-	D+
Fish/Shellfish: Organic Contamination	C-	C-
Fish/Shellfish: Metal Contamination	B-	B-

5. ARE FISH AND OTHER MARINE RESOURCES BEING PROTECTED?

The well-being of marine animals is affected by conditions in the water and sediments

Concern about whether marine resources are being protected from pollution differs from concern about whether we will be able to safely eat fish and shellfish. This section considers the well-being of the resources themselves. We focus on fish and seafloor (benthic) animals because these groups contain commercially valuable species and because data about the health of these animals are available. Members of these groups show effects that can be related to contamination of the environment.

The health of marine animals is affected by conditions in the water and in the sediments. Thus, this section focuses not only on the condition of the animals themselves, but the pollution levels in the waters and sediments where they live. The quality of the harbor's waters is discussed first, then sediment conditions, and finally indications of the health of fish and benthic species.

Water Quality

Dissolved Oxygen

While terrestrial animals, as well as seabirds and marine mammals can breathe oxygen from the air, marine organisms use oxygen dissolved in seawater. Depletion of some (hypoxia) or all (anoxia) of the oxygen in the water or in sediments can cause loss of habitat, stress, or death. For this section, hypoxia is defined as occurring when the concentration of dissolved oxygen is less than 5 milligrams/liter (mg/L), the Massachusetts standard for "fishable, swimmable" (Class SB) waters.

Sewage discharged into the marine environment will decay, which uses up oxygen dissolved in the water. Dissolved oxygen problems aggravated by sewage discharges are likely to be most severe in the summer. There are two reasons for this condition: (1) oxygen is chemically less soluble in warmer water, so oxygen levels are lower in warmer waters; and (2) the metabolic rates of marine organisms increase in warmer water, which means they use oxygen more quickly.

MWRA routinely measures dissolved oxygen (DO) in the inner harbor, the central harbor, the northwest harbor, and in the harbor's tributary rivers. The New England Aquarium also measures dissolved oxygen at sites throughout Boston Harbor. These studies give a good indication of summertime DO levels at mid-day, when the measurements are made. However, aquatic plants, both large (seaweeds) and microscopic (phytoplankton) produce oxygen in daylight (*increasing* DO), and consume oxygen *(decreasing* DO) at night. Therefore, the available data

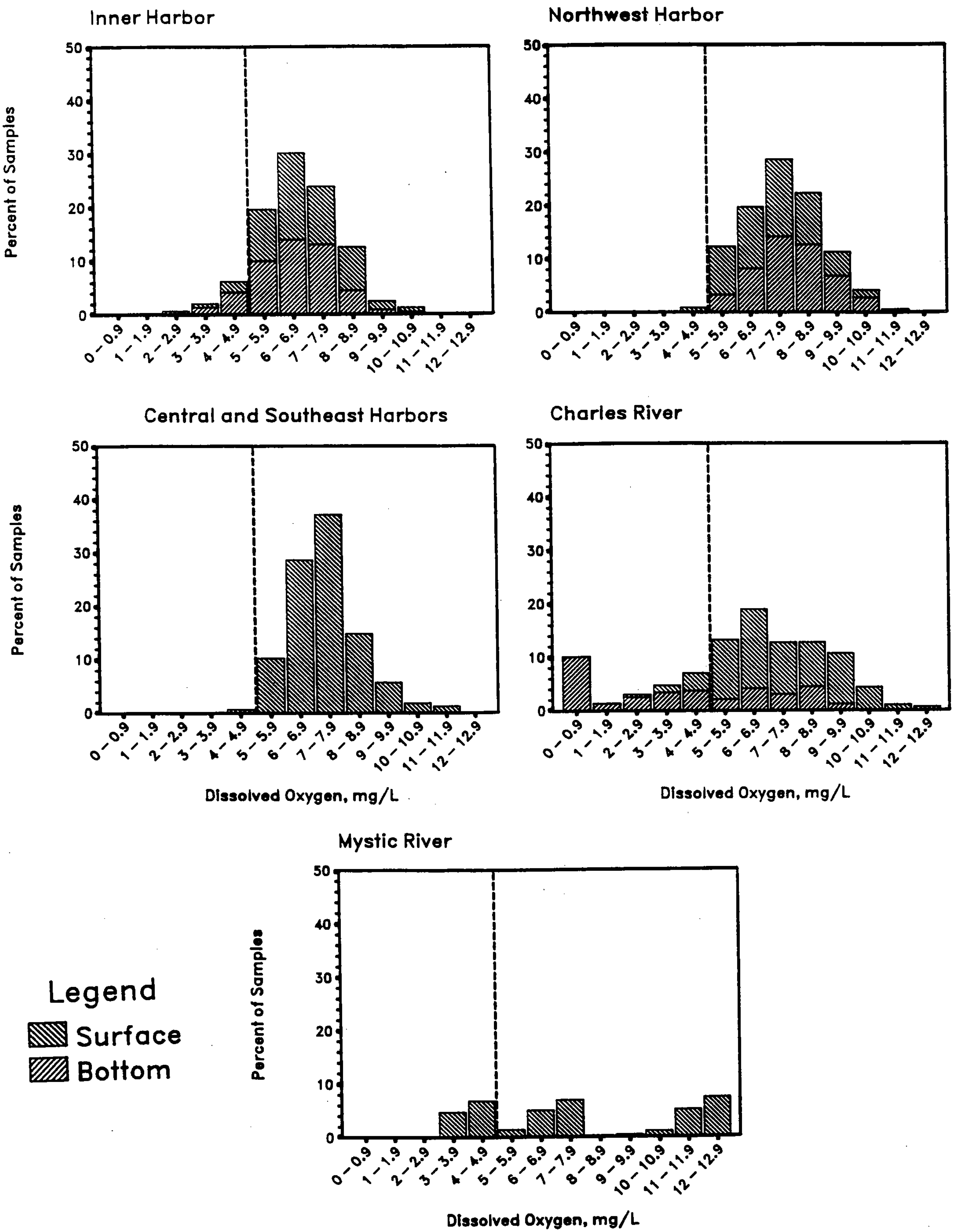


Figure 5-1. Histograms of dissolved oxygen measurements in Boston Harbor. Distribution of summer surface and near-bottom dissolved oxygen concentrations in the regions and major tributaries of Boston Harbor. The dashed line at 5.0 mg/L indicates the Massachusetts DO standard for Class SB waters. Data from MWRA (1991a).

may *underestimate* the true extent of low oxygen levels in the harbor. Future monitoring by MWRA will include early morning measurements designed to address this question. Figure 5-1 shows the dissolved oxygen measurements in different areas of the harbor.

- Inner harbor: Bottom waters in the inner harbor frequently violate the DO standard of 5.0 mg/L, with occasional measurements below 2 mg/L. Low oxygen conditions are much rarer in surface waters, and tend to occur in restricted channels with high CSO input, such as Fort Point Channel and the Reserved Channel.

Most areas of the harbor have sufficient amounts of oxygen dissolved in the water for the health of fish and other marine animals

- Northwest harbor: Dissolved oxygen in Dorchester Bay and other parts of the northwest harbor measured by the MWRA monitoring program are nearly always above the 5 mg/L standard, with only two measurements between 4 and 5 mg/L at the mouth of the Neponset River. Similarly, no depressed oxygen levels have been noted in the northwest harbor by the Aquarium's monitoring program.

- Central and southeast harbors: As discussed in Section 2, most of Quincy and Hingham Bays are well flushed with water from offshore, and the sewage effluent from the Nut Island treatment plant seems to disperse relatively quickly. DO concentrations are good in this area.

- Charles River: A large amount of seawater infiltrates through the locks in the Charles River Dam. Since salt water is heavier than fresh water, this causes a pool of saline (salty) water to form under the fresh water. The saline water is cut off from the air, and does not mix well with the freshwater flow of the river. All of the dissolved oxygen is consumed, so that there is often no DO in summer in the bottom waters of the Charles River Basin. Surface DO levels in the Charles River are occasionally near or below the state standard, usually following storms that cause CSO discharges.

- Mystic River: The freshwater part of the Mystic River generally shows satisfactory oxygen levels. However, low concentrations of dissolved oxygen are common in the sluggish, heavily polluted Alewife Brook, which feeds into the Mystic.

Toxic Contaminants in the Water

The EPA has developed water quality criteria designed to protect aquatic organisms from the adverse effects of environmental contaminants. Massachusetts has adopted the EPA's criteria as part of the State's Water Quality Standards. As described in last year's State of the Harbor report, Boston Harbor generally meets the water quality criteria for toxic contaminants, and there is some evidence that metal concentrations in harbor waters are decreasing.

Bioaccumulation

Clams and mussels, which filter food particles out of the water, often concentrate toxic metal and organic compounds in their tissues to levels well above those found in the water itself. This process is called bioaccumulation. Studies of bioaccumulation can be used as an indication of the potential effects of contaminants present in the water at concentrations so low that they are difficult to measure. The level of bioaccumulation is, therefore, useful as a measure of water quality.

The inner harbor has more toxic chemicals in the water than the outer harbor near the sewage treatment plants

Bioaccumulation studies with mussels showed that copper and PAHs accumulated in mussels near Deer Island and the inner harbor, near the Aquarium, to a greater level than in mussels at a relatively clean reference site near Gloucester. This 1991 study showed that mussels at the inner harbor site accumulated more toxic chemicals from the water than did mussels near the Deer Island effluent and sludge outfalls. The inner harbor location was distant from the MWRA effluent discharges but potentially affected by CSOs, runoff from industrial and oil storage facilities on the Mystic and Chelsea Rivers, shipping activities, and contaminated sediments. Both sites showed less bioaccumulation of toxic chemicals than in a similar study carried out in 1987.

Toxic metals in the waters of Boston Harbor have been decreasing

The 1990 State of the Harbor report discussed recent decreases in the amount of toxic metals in MWRA effluent discharges. There has been a 4-fold decrease in metals discharged to the harbor from 1981 to 1991. The results of the 1991 bioaccumulation study, along with other studies previously discussed in the 1990 State of the Harbor report, suggest that the improvements in MWRA discharges are being reflected in improvements in water quality.

Sediments

Dissolved Oxygen

Just as marine aquatic organisms need oxygen, so do animals living in sediments. Marine sediments typically have an oxygenated layer (often grayish-looking) overlaying a black layer with no dissolved oxygen. The organisms living in sediments create a constant demand for oxygen as they respire. This oxygen can be replaced by the slow diffusion of oxygen from the water above the sea floor into the sediments. If the amount of organic matter decomposed by microorganisms in the sediments is too high, for example from too much sewage, microorganisms use oxygen faster than it can be replaced. When this occurs, the oxygenated layer becomes very shallow. The zone that separates oxygenated

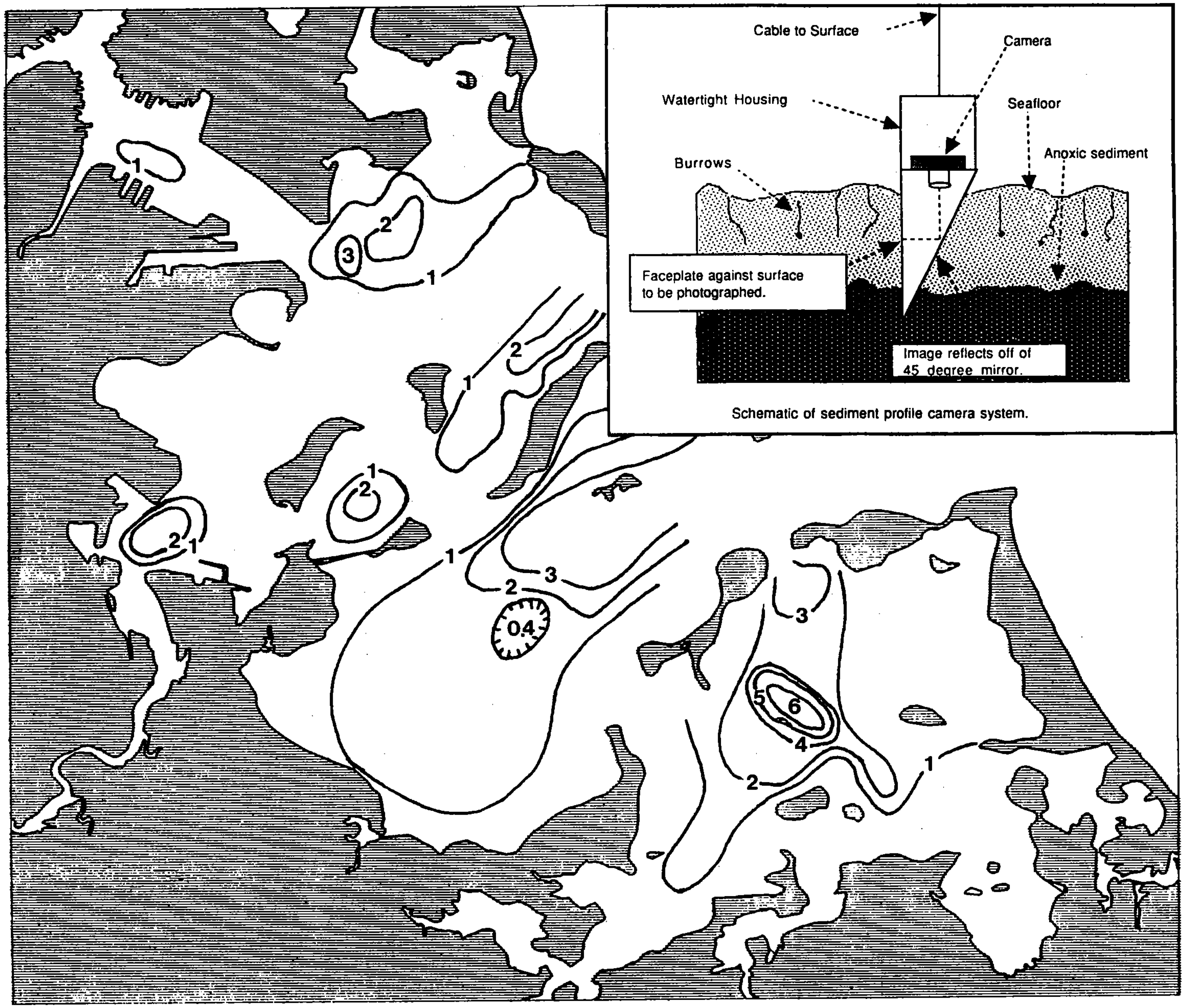


Figure 5-2. Depths of redox potential discontinuities in Boston Harbor. Depth of dissolved oxygen penetration into the sediments (the RPD) during June of 1989 and 1990, along with a schematic of the sediment profile camera system used to gather this data. The contours are computer-generated lines of constant RPD, calculated from measurements at over 100 stations. Redrafted from SAIC (1990).

sediments (the upper layer) from the sediments lacking dissolved oxygen (the bottom layer) is called the "redox potential discontinuity" (RPD). As the level of oxygen in sediments decreases, the RPD becomes very shallow. Under these conditions, animals that cannot tolerate depressed oxygen levels disappear from the community. This situation can leave dense communities of only the few species that can thrive in a degraded environment. If sewage deposition increases further, the RPD moves near or to the sediment surface, and only a small number of individuals from one or two species can tolerate such conditions. Extreme amounts of organic deposition to the sediments can result in areas of the seafloor being unable to support any benthic animals at all. The depth of the RPD is a useful indicator of sediment quality: a shallow RPD indicates that the sediments are likely to stress the organisms living in them. The average RPD in other open coastal systems in New England is greater than 3 cm (2.5 cm = 1 in).

Dissolved oxygen concentrations are low in sediments in the inner harbor and northwest harbor

In the summers of 1989 and 1990, MWRA carried out surveys of sediment conditions in Boston Harbor using a camera that photographs a cross section of the top 20 cm (20 cm = approximately 8 in) of the seafloor (see inset on Figure 5-2). Photographs of several cross sections at every station allowed us to determine the average depth of oxygen penetration into the sediments, the RPD, at over 100 stations within the harbor during the 1989 and 1990 surveys (Figure 5-2).

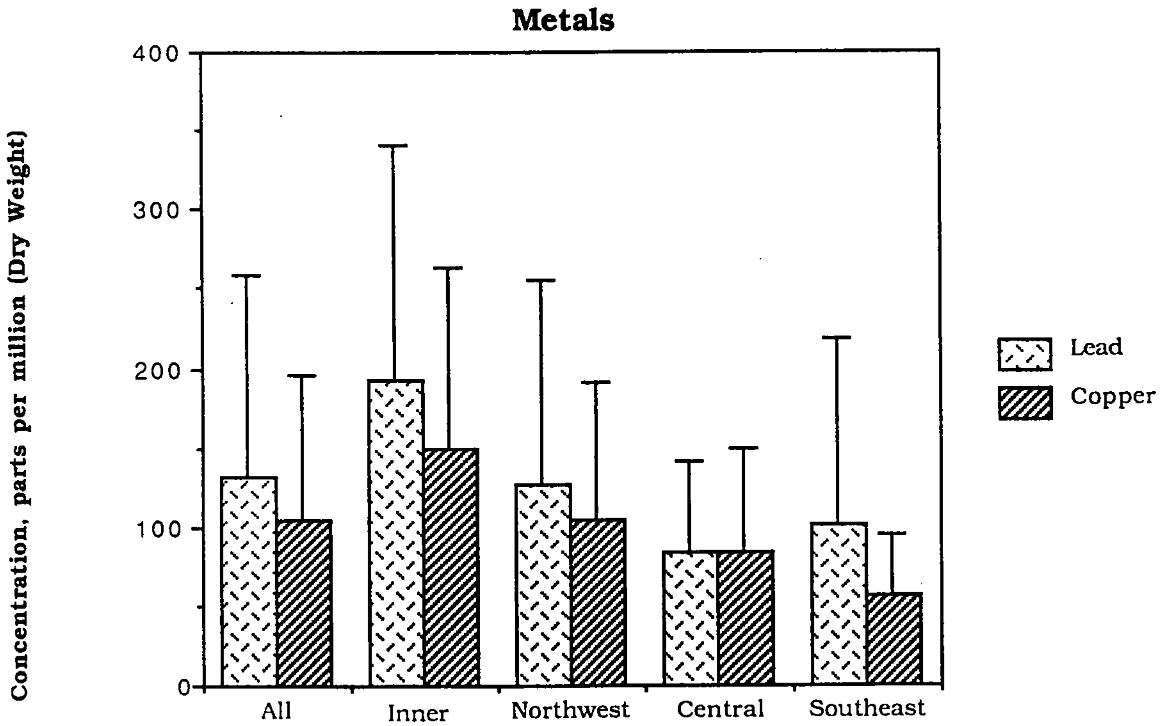
- Inner and northwest harbors: The average RPDs in the inner and northwest harbor are quite low, with most stations having an RPD of 1 cm or less, with many stations near Deer Island and in Winthrop Bay having no oxidized layer in the sediments. Some sandy areas near the airport have RPDs greater than 2.5 cm.
- Central harbor: Shallow, muddy areas of Quincy Bay near Squantum and Wollaston Beach also have shallow RPDs, ranging from 1.8 cm to less than 0.3 cm. Deeper parts of Quincy Bay, which are well flushed by the strong tides, show much deeper RPDs, as deep as 3.6 cm.

Sediment oxygenation in the central and southeast parts of the harbor is generally satisfactory

- Southeast harbor: Although there are some muddy areas where the RPD is less than 2 cm, much of Hingham and Hull Bays have the deepest oxygen penetration into the sediments measured in our surveys, as deep as 6.3 cm.

Toxic Contamination in Sediments

It has been recognized for some time that contaminants accumulate in sediments, but most scientists considered this process a means of removing toxic contaminants from the water and keeping them in place. It has now become clear that toxic contaminants in sediments can pose a threat to aquatic and human health, and can be transported on resuspended sediment particles to other areas and released to the overlying water. Contaminants in sediments are important, but it is more difficult to assess the condition of sediments than the condition of water. No numerical standards have been established for sediment contaminants, although EPA and several states are currently developing quality criteria for sediment.



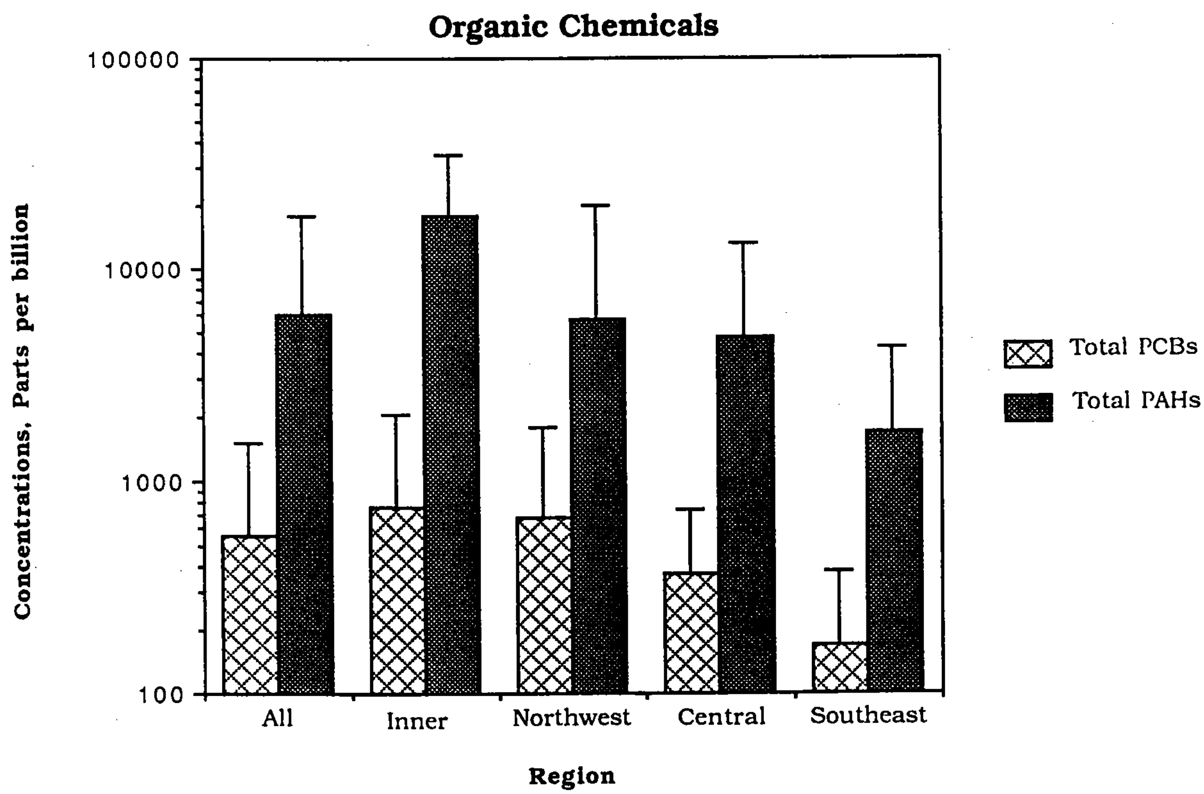


Figure 5-3. Patterns of sediment contamination in the harbor. Comparison of the concentrations of selected toxic chemicals in the sediments of Boston Harbor by region. The error bars indicate the average plus 1 standard deviation. The data are from NOAA (1991a).

Geographic Patterns of Sediment Contamination in the Harbor

Recent studies have summarized historical data on sediment contamination in Boston Harbor. These studies indicate that metals and organic contaminants are widespread in Boston Harbor sediments, and that the concentrations in the harbor are higher than naturally occurring concentrations at uncontaminated reference locations.

The inner harbor generally has the worst sediment contamination in Boston Harbor

Within the harbor, the pattern of sediment contamination is similar for most chemicals. The highest concentrations are typically found in sediments from the inner harbor, with progressively lower levels in the northwest harbor, the central harbor, and the southeast harbor (Figure 5-3). In the inner harbor, for example, the concentrations of PAHs in sediments are five to ten times higher than concentrations in sediments from other regions of the harbor. Within this general trend, however, sediment concentrations of toxic chemicals show a high degree of variation within the individual regions. For example, in a recent study of sediments in Dorchester Bay, concentrations of PAHs varied by a factor of over 100, from 0.55 parts per million (ppm) to 66 ppm. This variation may be caused by the multiple sources that contribute to sediment contamination. Sources include point-source discharges from local CSOs and stormdrains, as well as more distant sources like sewage effluent and past sludge discharges.

Comparison of Boston Harbor Sediments With Those in Other Areas

Levels of toxic contaminants in Boston Harbor sediments are similar to other urban estuaries

Although the results of the NOAA National Status and Trends Program shows that concentrations of most contaminants in Boston Harbor sediments are higher than those found at New England reference sites, the results also show that sediment concentrations are similar to other urban harbors (Figure 5-4).

Biological effects of toxic chemicals in sediments: While toxic chemicals are elevated in Boston Harbor compared to New England reference areas, that does not necessarily imply that the sediments throughout the harbor are toxic to marine organisms. High concentrations of hydrogen sulfide (the compound that gives rotten eggs their characteristic smell) in sediments have recently been shown to bind metals so strongly to the sediment grains that often little or no metals toxicity exists, even in highly contaminated sediments. Similarly, bulk organic carbon in sediments strongly binds organic contaminants like PCBs and DDT, lessening their toxicity.

One recent University of Massachusetts/Boston study found that the effects of sediment metal concentrations on the types and numbers of sea floor animals in Dorchester Bay was slightly more important than the effects of oxygen-consuming organic matter in the sediments.

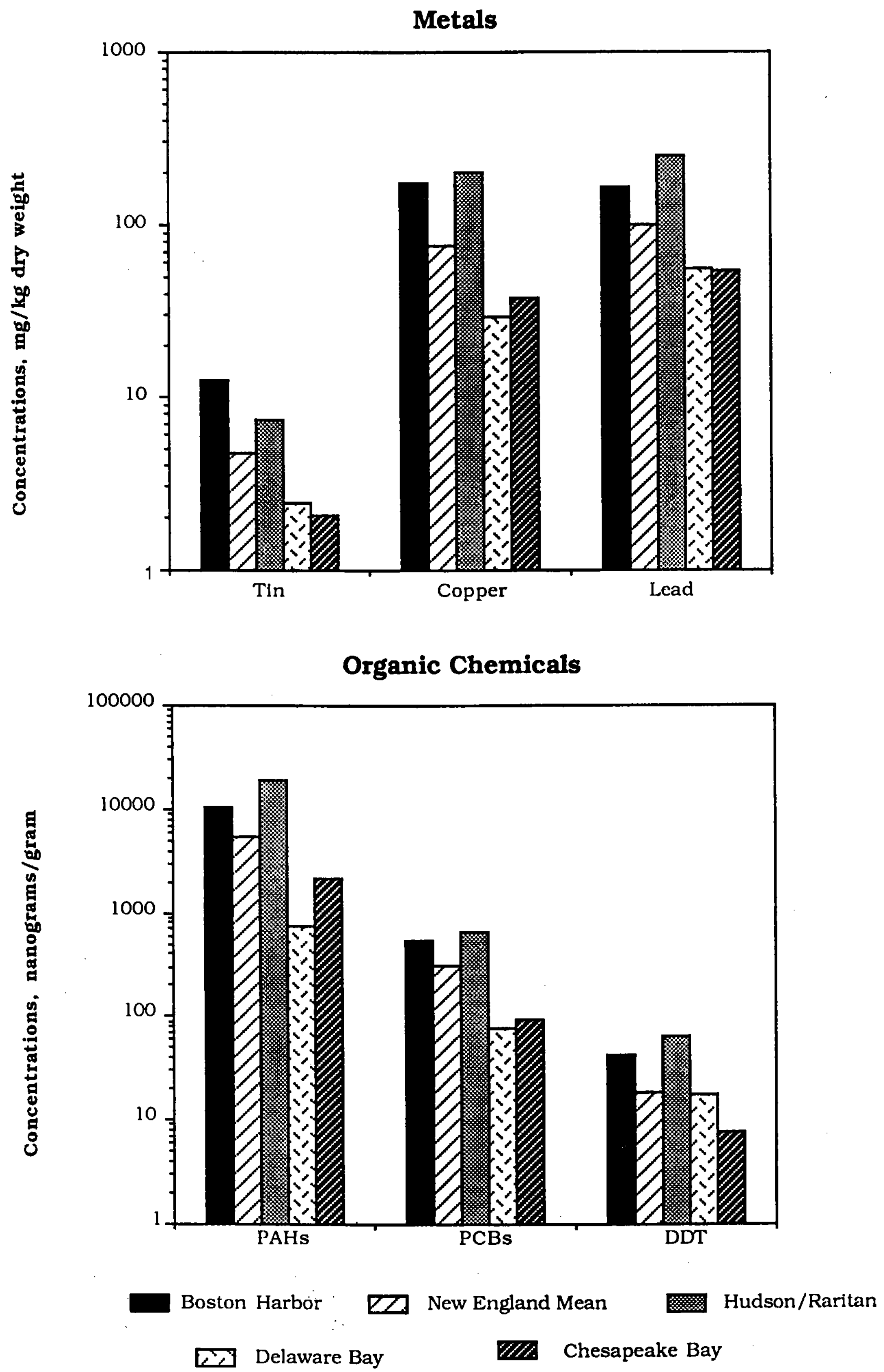


Figure 5-4. Comparison of sediment contamination to other areas. Comparison of the concentrations of selected toxic chemicals between Boston Harbor and other areas. The data are the averages of the NOAA Status and Trends sediment monitoring, 1984-1989.

Some scientists have suggested that the sediment concentrations of some contaminants, particularly metals, may be decreasing in the harbor. These claims are based on data from sediment cores in which contaminants were measured at different depths. One study indicated that there has been a significant reduction in the input of copper and cadmium (and possibly other metals) to the sediments of Boston Harbor in recent years. This observation may be related to the recent reduction in toxic chemical concentrations in MWRA's sewage effluent and sludge. The trends noted in these sediment cores were subtle: at the rate observed, it would take a century to reduce contaminant concentrations by half. However, there will be dramatic decreases in loadings of toxic chemicals to the harbor because sludge is no longer being discharged, and the new treatment plants will remove toxic chemicals more effectively. The decrease in toxic loadings should speed the natural cleansing of sediments.

Summary of Habitat Conditions in Boston Harbor

The habitat in which the marine resources of the harbor live is stressed in several ways. While conditions in the harbor's waters usually meet water quality standards for most chemicals, there are regions in which dissolved oxygen concentrations are likely to be at least intermittently stressful. The shallow oxygenated zones in the harbor's sediments are also likely to stress the organisms living within them, and there may be some effect of toxic chemicals in the sediments.

Living Resources

Winter Flounder (Pseudopleuronectes americanus)

Boston Harbor supports a large sportfishery. Migratory striped bass and bluefish spend the summer and fall months in the harbor following schools of mackerel and menhaden. Historically, the mainstay of the sportfishing industry in Boston has been the winter flounder, but declining numbers (a New England-wide phenomenon) and a public perception that the flounder from the harbor are contaminated has led to a substantial decrease in the number of people fishing for flounder.

Assessments of the health and condition of winter flounder in Boston Harbor are conflicting. On the one hand, although the actual stock of winter flounder has decreased, the population in the harbor appears to be capable of sustaining itself. On the other hand, a number of abnormalities, such as fin rot and organ lesions (injuries), are found on fish from Boston Harbor. These abnormalities can be strongly linked to a degraded environment.

"Fish Day," sponsored by the New England Aquarium in 1989, was described in detail in the 1990 State of Boston Harbor report. The results of the "Fish Day" studies indicate that flounder from Deer Island Flats in the northwest harbor typically have a higher incidence of fin rot, liver lesions, and a host of other abnormalities than do fish from other parts of the harbor. The New England Aquarium and MWRA will be sponsoring "Fish Day II" in the spring of 1992, to investigate how the health of the flounder has changed from 1989.

A new study conducted by researchers from the Woods Hole Oceanographic Institution suggests that the prevalence of liver lesions has declined in recent years (Figure 5-5). The data gathered in the next "Fish Day" will allow researchers to see if this trend is reflected in other indicators of the flounder population's health.

Lobster (Homarus americanus)

Boston Harbor is a suitable habitat for lobster spawning, development and growth. Lobsters can live in different habitats in the harbor, including mud bottoms, sands, gravel, and rock outcrops. In the spring, summer, and fall, the harbor is heavily fished for lobster. The majority of lobsters landed in Boston during these months comes directly from the harbor. In winter the lobsters migrate offshore to warmer waters.

Marine animals in the harbor show signs of physiological stress, but they have abundant populations

Throughout much of the harbor, lobsters are found in mud burrows. They can tolerate low concentrations of dissolved oxygen, and so are generally not impacted by short-term conditions of low oxygen. The Massachusetts Division of Marine Fisheries reports that lobsters from Boston Harbor generally do not exhibit symptoms of pollution (e.g., black-gill disease) observed in other areas. Histopathological evaluation of lobsters from Quincy Bay indicated that they were generally healthy and did not exhibit symptoms of disease.

Soft-shell Clams (Mya arenaria)

Although there are restrictions on harvesting soft-shell clams due to bacterial contamination caused by sewage pollution, Boston Harbor is productive: about 20,000 bushels are harvested annually. Thus, the clam population within Boston Harbor is sustaining itself despite contamination in the sediments where they live. The few studies that have looked for evidence of diseases in clams have found more abnormalities in clams from the harbor compared to other areas.

Seafloor (Benthic) Communities

Animals living on or in the sediments at the bottom of a body of water are called the benthic community. A marine benthic community can include lobsters, clams, and crabs, as well as worms and small crustaceans that are a food source for bottom-feeding fish and lobster.

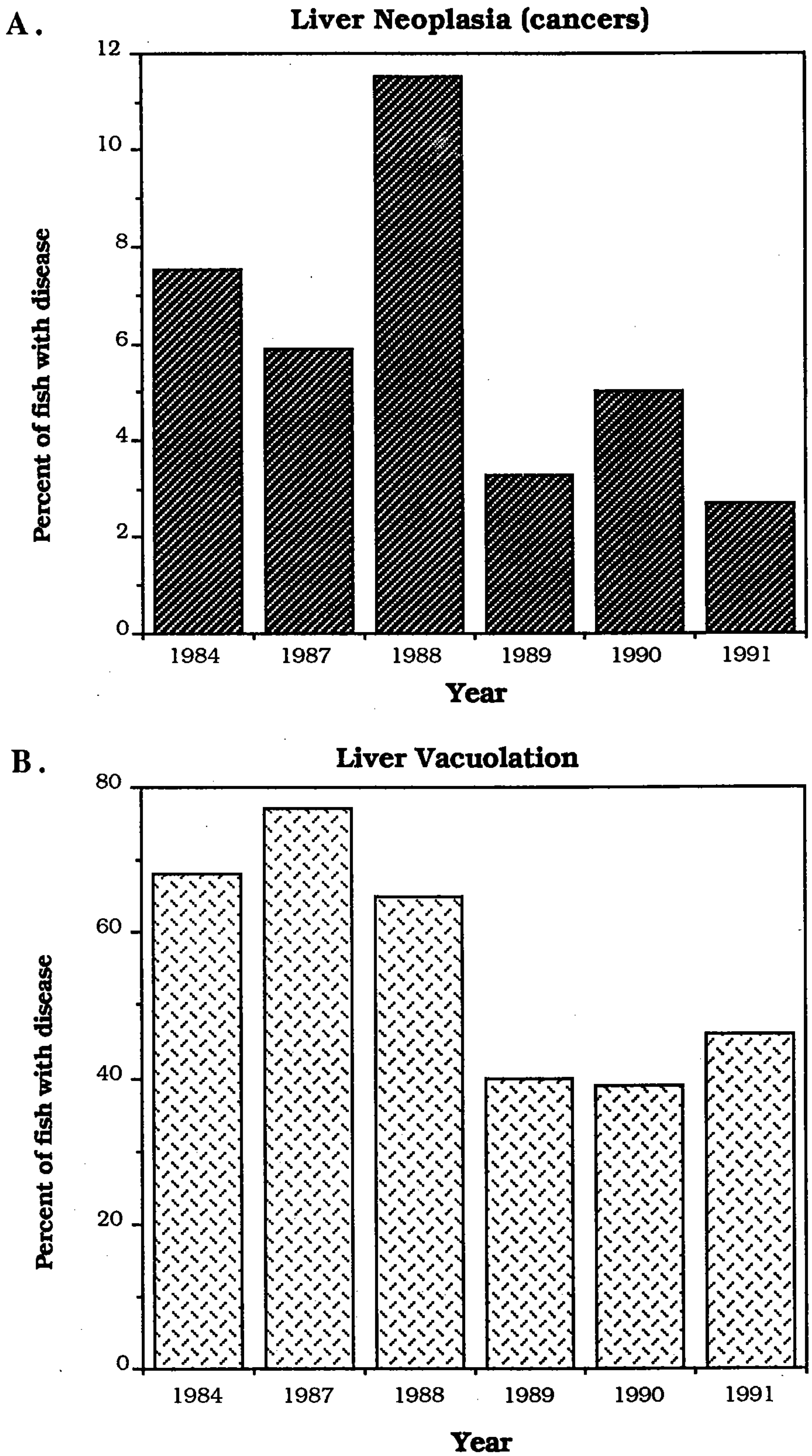


Figure 5-5. Declining liver lesions in winter flounder. Percent of winter flounder from Deer Island Flats with two types of liver disease, including data from 1984 (Murchelano and Wolke 1985), and 1987-1991 (Moore *et al.* 1991) A. Liver neoplasia, or cancer. B. Liver vacuolation, a condition in which abnormal fluid-filled cells appear and increase in abundance within liver tissue. This condition is commonly associated with the early stages of systemic stress.

Benthic communities have long been monitored as indicators of environmental health. Because most of these animals are sedentary, and cannot leave a polluted area, they are more susceptible to contamination than are more mobile animals. Pollution can change the kinds of animals found at a particular site (community composition), the number of different species present (diversity), and the total number of individuals of all species (abundance or density).

Many factors besides pollution influence what types of benthic communities develop in a given area. One of the most important determinants of the benthic community is bottom type: mud, sand, or rocky bottom.

Hard Bottom

Hard or rocky bottoms are usually found where currents or waves prevent the accumulation of particles (sediment). The hard-bottom community in and around Boston Harbor consists of organisms that attach to rocks; for example sea anemones, tunicates (sea squirts), mussels, and seaweeds. Other members of the hard bottom community are sea urchins, whelks, and crabs that live with or eat the attached plants and animals. The main impacts of sewage pollution seem to be from sewage solids coating the rocks with a thin layer of temporary sediment. This layer may prevent juvenile organisms from attaching to the rocks in a normal manner, or it may smother them or have a toxic effect if the organisms do settle on the rocks.

Sewage effects on rocky-bottom communities are obvious only within two or three miles of the sludge discharge

Researchers from Northeastern University's Marine Science Center on Nahant have carried out a multi-year study of the effects of MWRA sewage discharges on the rocky-bottom communities from Lovell Island, which is near the former sludge discharge from the Nut Island treatment plant, to a relatively pristine area off of Nahant (Figure 5-6). They found that sewage tracers (copper and *Clostridium perfringens* spores) in the fine sediment on the rocks decreased dramatically with distance from the harbor. Near Lovell Island where sediment on the rocks was sewage-derived, the rocky bottom community was sparse and dominated by worm tubes. Near Nahant, there was less mud-covered rock and a more natural, diverse community (Figure 5-6).

Soft Bottom

Mud bottoms are found where water movement is slow enough for fine sediments to settle, and sandy bottoms where current and wave strength prevent permanent deposition of fine particles, but are not strong enough to wash the sand away. The assemblages of organisms that inhabit sand and mud bottoms are called the soft-bottom benthic community. Muddy-bottomed areas are natural centers for the accumulation of fine sewage particles and the toxic chemicals associated with them.

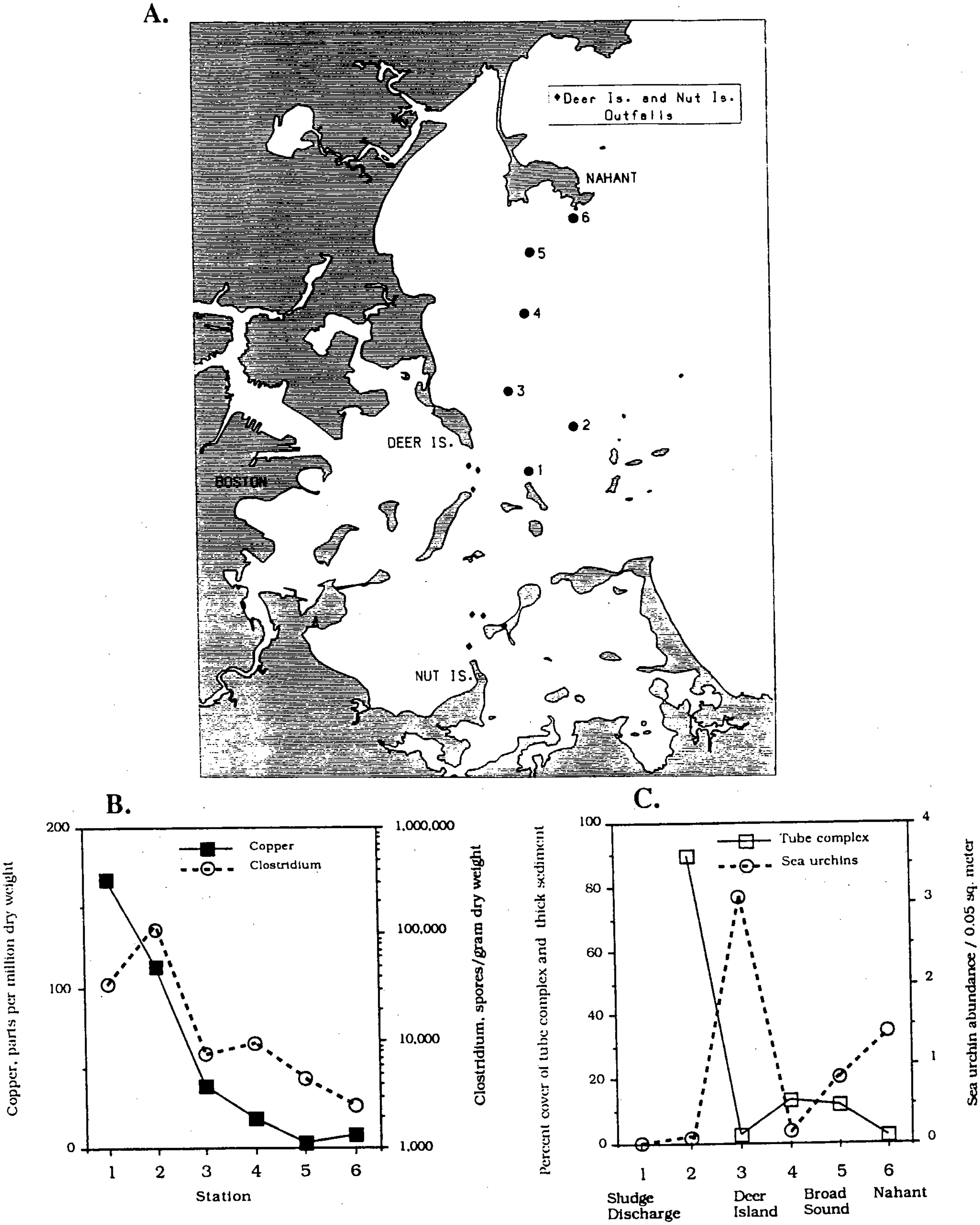


Figure 5-6. Rocky bottom benthic communities and sewage tracers from Lovell Island to Nahant. A. Map of the rocky bottom sites sampled from Lovell Island to Nahant. Station 1 is approximately 1 km from the old sludge discharge from the Nut Island plant, while Station 6 is almost 9 km from the nearest MWRA discharge. B. Concentrations of copper and counts of the sewage indicator bacteria *Clostridium perfringens* at the sampling sites. C. Two measurements of the health of the bottom community at the sites sampled. "Tube Complex" is the sum of the percent cover of mud covered rock and the tube worms that live in the mud. "Urchins" represents the abundance of sea urchins. While the data show high variation, there is a trend showing stressed conditions near the harbor as opposed to normal conditions near Nahant. Data from Sebens and Witman (1990).

The effects of sewage pollution and other organic-rich discharges (such as paper-mill effluent) on soft-bottom communities are well understood.

Populations of seafloor animals in the harbor are affected by low oxygen levels in the sediments

Low levels of sewage act as an additional food source, stimulating growth and resulting in increased abundance and diversity of the natural community. Greater amounts of sewage can outstrip the capacity of the soft-bottom community to use it. This excess matter leads to a buildup of oxygen-consuming organic matter in the sediments, and the depth of the oxygenated layer decreases. As sediment conditions deteriorate, more and more species disappear from the community. Intermediate levels of sewage input can result in dense communities of a small number of tolerant species. High levels of sewage result in communities with only a few scattered individuals of one or two pollution-tolerant species. Extreme pollution can result in areas of the bottom having no animals at all. Direct effects of toxic chemicals upon soft-bottom communities are noted only infrequently; most of the degradation seen is attributable to this enrichment (excess nutrients) effect.

Evaluation

To evaluate the conditions of benthic communities in Boston Harbor, we have compiled data from multiple sources, including surveys conducted by the MDC in support of the secondary treatment waiver application, studies conducted by the U.S. Army Corps of Engineers in the inner harbor, and recent surveys carried out by MWRA.

Figure 5-7 shows a simplified representation of the distribution of benthic communities within the harbor.

Inner Harbor

Just as the inner harbor contains some of the most toxic-contaminated sediments in Boston Harbor, it also contains the most degraded benthic communities. There are only a very few species present, and some large areas seem to have no benthic organisms living there during the late summer and fall. Sediments from the inner harbor showed significant toxicity to the marine amphipod *Ampelisca*, a shrimp-like organism commonly used in sediment-toxicity studies. *Ampelisca* is abundant in the other parts of the harbor.

Northwest Harbor

The northwest harbor is a complex area. Areas highly degraded by sewage effluent and sludge are found in Winthrop Bay, on Deer Island Flats, and the adjacent anchorage area.

The bottom near the northwestern shore of Long Island appears to be impacted by sludge from the Nut Island treatment plant. Recent sampling by MWRA indicates that much of this area is somewhat degraded, with high densities of shrimp-like amphipods that feed on recently deposited sediments. These types of communities are often associated with moderate levels of enrichment impact.

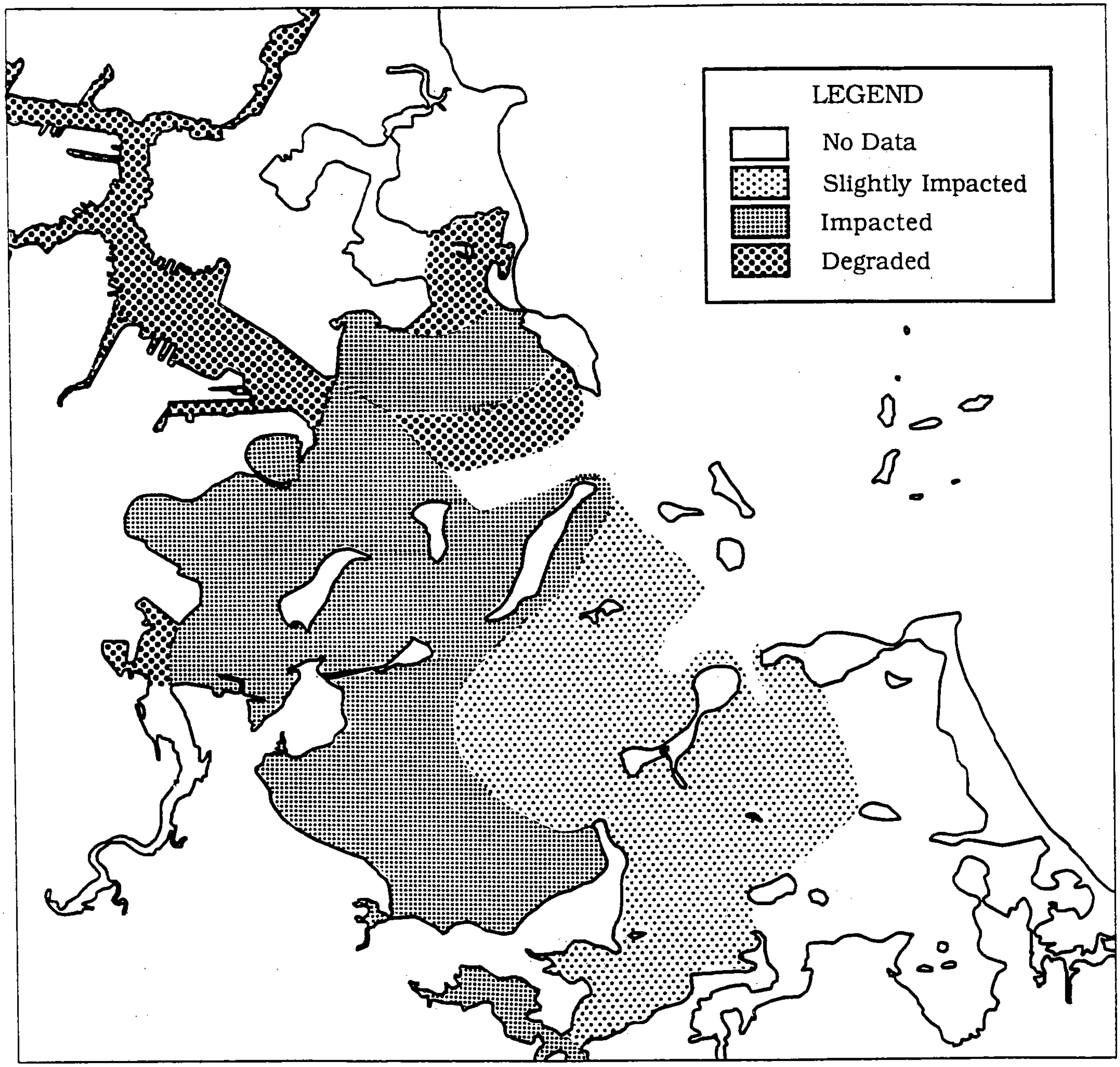


Figure 5-7. Benthic communities in the harbor. A simplified representation of the distribution of soft-bottom communities in Boston Harbor, summarizing the data and conclusions from various studies: Blake *et al.* (1989), Gallagher and Grassle (1990), Hubbard and Bellmer (1989), Michael and Menzie (1991), and SAIC (1990). The borders of the zones are approximate. "Slightly impacted" denotes areas of bottom that, while not pristine, have communities similar to those from un-impacted coastal New England estuaries. "Impacted" areas have communities that are adversely affected by pollution. "Degraded" areas have extremely polluted communities.

Dorchester Bay is relatively distant from most large sources of sewage contamination, but the University of Massachusetts/Boston study mentioned above suggests that much of the bay may be affected by sludge from Nut Island. Small areas of Dorchester Bay, for example Savin Hill Cove, are highly degraded.

Central and Southeast Harbors

Most of the benthic studies in the central harbor have been done in the well-flushed outer portions of Quincy Bay. Many of these samples, as well as the few samples available from the southeast harbor, reveal a diverse, abundant benthic community very similar to unimpacted estuaries in New England. However, sediment camera images from inshore areas in these regions, nearer to Wollaston Beach and in the mouth of the Fore River, reveal extensive areas with shallow oxygen penetration in the sediments. Computer modelling and the results of sampling for spores of the sewage tracer bacterium *Clostridium perfringens* indicate that these near-shore areas are somewhat impacted by sewage discharges from the Nut Island treatment plant, but there are no benthic samples to describe those communities.

The interplay of sediment types, water flow, and sewage impact creates a complex mosaic of benthic communities within the harbor. Within any given subregion (except possibly the inner harbor, which may be uniformly bad) there is a range of impact from multiple near and far-field sources. Despite this variation, a general trend is seen of extreme pollution impacts upon benthic communities in the inner harbor, with seriously degraded conditions prevailing in the northwest harbor. The southern portions of the harbor, perhaps due to greater flushing with Massachusetts Bay, in general appear to contain "healthier" benthic communities than the northern harbor.

REPORT CARD

Are Fish and Other Marine Resources Being Protected?

	1990	1991
Sediment Contamination	D-	D-
Water Quality: Oxygen	C-	C
Water Quality: Toxic Contamination	B-	B-
Fish Disease	D-	D-
Seafloor Animals	D-	D

6. IS BOSTON HARBOR AESTHETICALLY PLEASING?

Aesthetic quality is an integral part of the environmental health of the harbor

Although chemical and microbiological contaminants are important in assessing the environmental health of the harbor, the public's perception of environmental quality is often based on more conspicuous signs of contamination. Offensive odors and unsightly floating debris instinctively suggest pollution. The presence of scum, effluent, and sludge from sewage treatment plants, as well as turbid water and marine debris all degrade aesthetic quality. These conditions, as they relate to aesthetics, were discussed in the 1990 State of the Harbor report. New information and data related to these topics are presented below.

Scum and Sewage-Related Floating Debris

Since installation of scum-removal equipment in 1988, the MWRA has removed 23,000 tons of scum and debris from the wastewater

Scum is material in wastewater that floats. It is made up of oil, grease, and plastic debris. Before 1988, nearly 10,000 gallons (33 tons) of scum were pumped into the harbor each day. Since 1988, scum has been removed from wastewater as part of the treatment process at the Deer Island and Nut Island facilities. New screens and skimmers have removed approximately 12,000 tons per year of scum and floating debris that would formerly have been discharged directly into the harbor. The scum has been mixed with a chemical stabilizer and landfilled at Deer Island, but now will be processed with the sludge at the Quincy sludge processing facility.

Effluent and Sludge

Until December, 1991, sludge was discharged from both Deer and Nut Island on every outgoing tide in a black and offensive-smelling plume.

Although effluent from the sewage treatment facilities is still being discharged into Boston Harbor, the volume of waste materials decreased significantly (see Section 7) when discharge of sludge ceased. Sludge is now transported to a processing plant in Quincy where it is made into fertilizer. Discharge of treated effluent into the harbor will continue until 1995 when the new outfall, extending into Massachusetts Bay, is completed. Then, the unsightly plumes and odors that result from discharging sewage wastes into Boston Harbor will be eliminated.

Turbidity

Turbidity within the sludge plume was as high as 90%

Measurements made in the sludge plumes from the Nut Island treatment facility indicated that water turbidity--a measurement of lack of clarity--was very high, ranging between 80 and 90%. Turbidity of the harbor water normally is highly variable, but measurements showed

Water clarity has improved, now that sludge is treated onshore

that it generally did not exceed 50%. One hundred percent turbidity means suspended particles are totally blocking light in the water. Now that sludge discharges have stopped, this source of turbidity is gone. However, particulates are still contributed by effluent, and during periods of heavy rain and increased river flow, some particulate matter will still be transported into the harbor and will temporarily decrease water clarity.

Marine Debris

Dangerous and unsightly floatable debris has many sources

Marine debris is made up of a wide assortment of plastic, metal, paper, glass, and wood waste materials. There are many sources of these wastes, including commercial and recreational vessels, sewage treatment plants, CSOs, beach and street litter, and deteriorating piers and waterside structures. Either floating on water or littering the shores, marine debris degrades aesthetics of the environment, endangers wildlife, affects commercial and recreational activities, and poses threats to human safety.

Debris collected at Boston Harbor beaches in 1990 was 30% lower than the amount collected in 1989

During the 1990 Coastweeks beach cleanup, coordinated by the Massachusetts Office of Coastal Zone Management, almost 60,000 lbs. of debris were removed from 211 miles of the Massachusetts coast. Nearly 23% of this total weight came from debris collected along 22 miles of shoreline around Boston Harbor. In 1990, cleanup at Boston Harbor beaches produced an average of 604 lbs of trash per mile of beach. This amount is two times the state average and five times the average for Cape Cod beaches, but 30% less than the average weight of trash collected per mile of beach in Boston Harbor in 1989.

In 1990, more tampon applicators were removed from the shores of Massachusetts than from any other coastal state

The composition of the beach debris can provide some insight about the possible sources of the litter. For example, plastic tampon applicators and condoms are sewage-related wastes that escape treatment facilities or are discharged through CSO pipes. According to data collected and published by the Center for Marine Conservation, 17,125 tampon applicators were removed from beaches nationwide during the 1990 cleanup effort. Approximately 38% of the national total was collected from Massachusetts beaches; 6.5% came directly from Boston Harbor shores.

The average number of tampon applicators collected per mile of beach in 1990 was the same as the average number in 1989; in other words, the number of these sewage-related articles did not decline between 1989 and 1990. Although in 1988 MWRA implemented new methods for collecting scum and floating debris such as tampon applicators, no beach cleanup data were collected prior to that date to provide a measure of the effectiveness of the scum and debris-collecting process in removing the plastic applicators. Some sewage-related debris may still escape the screening and skimming processes to be discharged with the effluent or may enter the harbor through CSO discharges.

EPA's "Items of Concern"

- Tampon Applicators
- Condoms
- Syringes
- Fishing Nets, Lures, Traps
- Fishing Line, Rope
- 6-Pack Rings
- Plastic Bags, Sheeting
- Uncut Strapping Bands

In Boston Harbor, fishing gear and tampon applicators made up 50% of the total "items of concern"

In 1990, the EPA identified marine debris "items of concern." This list (see box) includes articles that endanger marine life, pose risks to human health and safety, or significantly degrade aesthetics of the marine environment. One approach to evaluating the aesthetic quality of Boston Harbor can consider the total number of "items of concern." During the 1990 beach cleanup in Boston Harbor, 44,595 total items of debris were collected and categorized on data cards. Approximately 20% of the debris articles was from EPA's "items of concern." This is an alarming proportion when compared to 8% for the nation. For both Boston Harbor and the state, fishing equipment and tampon applicators made up half of the "items of concern."

Evaluation

Criteria for grading the aesthetic quality of Boston Harbor consider the amount of debris as well as the type of debris

Because the perception of aesthetic quality is somewhat subjective and because some of the conditions that influence overall aesthetic quality cannot readily be quantified (odors, for example), the grading criteria were developed to specifically include quantitative data. The beach cleanups provide specific information on types and amounts of beach debris, and are conducted on a regular annual schedule. Therefore, future assessment of aesthetic quality can be based on the same criteria developed for this report.

REPORT CARD

Is Boston Harbor Aesthetically Pleasing?

	1990	1991
Aesthetics	**D**	**D**

7. COMPARISON AMONG DIFFERENT AREAS OF BOSTON HARBOR

Although throughout this report we have graded Boston Harbor as a whole, it is important to remember that this large area encompasses a variety of physical environments. These different areas are affected by different sources of pollution. The quality of the marine environment varies within the harbor, and the response to pollution abatement programs will also be different in different areas.

Figure 7-1 summarizes how conditions differ among the four different areas of the harbor and its tributary rivers. Data are not available for all pollution problems for all regions, but it is clear that the inner harbor is the worst area for bacterial contamination, low dissolved oxygen concentrations, and toxic contamination. The inner harbor is in poor condition, even though it is less affected by treatment plant discharges than are outer harbor regions. Many sources contribute to the degradation of the inner harbor, including CSOs, street runoff, contaminated storm sewers, commercial and recreational ship traffic, and leaching from old industrial sites. Other areas showing severe degradation are the rivers tributary to Boston Harbor: the Charles, the Neponset, and the Mystic. These rivers are affected by sources similar to those affecting the inner harbor (except for commercial ship traffic which only affects the lower Mystic River).

Thus, although sewage from the treatment plants is the single largest source of pollution to Boston Harbor, smaller sources can cause more severe local environmental impacts. The Boston Harbor Project is necessary for the recovery of Boston Harbor, and will especially benefit the outer harbor areas, but in order to achieve all the desired uses of the harbor in the future the smaller sources of pollutants must also be addressed.

REPORT CARD FOR *Boston Harbor, by geographic area*	Overall	Inner	Northwest	Central	Southeast	Tributaries
IS IT SAFE TO SWIM AND BOAT?						
Swimming	D +	F	C	C+	B	F
Boating	B	B	B	A -	A -	C+
IS IT SAFE TO EAT FISH AND SHELLFISH?						
Shellfish: Pathogens	D +	F	D	C	C -	
Fish/Shellfish: Organic Contamination	C -	C				
Fish/Shellfish: Metal Contamination	B -					
ARE MARINE RESOURCES PROTECTED?						
Sediment Contamination	D -	F	D -	D	C -	
Water Quality: Oxygen	C	D	C -	A -	A -	D -
Water Quality: Toxic Contamination	B -					
Fish Disease	D -					
Seafloor Animals	D	F	D	C	C	
IS THE HARBOR AESTHETICALLY PLEASING?						
Aesthetics	D					
OVERALL GRADE	C -					

Grading system used for the Boston Harbor report card

A **EXCELLENT:** Consistently maintains conditions characteristic of other clean coastal sites (*e.g.*, Provincetown Harbor).

B **GOOD:** Frequently is better than Federal and State water quality standards and expectations for an urban estuary (*e.g.*, some of Puget Sound).

C **SATISFACTORY:** Complies with Federal and State water quality standards and meets expectations for an urban estuary (*e.g.*, San Francisco Bay).

D **POOR:** Sometimes fails to comply with existing standards or meet expectations for an urban estuary; some uses of the harbor are maintained (*e.g.*, Boston Harbor last year).

F **FAILING:** Consistently fails to comply with Federal and State water quality standards or meet expectations for an urban estuary; there is obvious environmental degradation and uses of the harbor are lost (*e.g.*, New York Harbor and New Bedford Harbor).

Figure 7-1. Geographic variation in environmental quality in Boston Harbor. The inner harbor has the worst environmental quality, while the southeastern harbor has the healthiest environment.

8. HOW WILL THE HARBOR BENEFIT, NOW THAT SLUDGE DISCHARGES HAVE STOPPED?

One of the worst aspects of metropolitan Boston's inadequate sewage treatment has been the decades-long practice of dumping sewage sludge into the waters of Boston Harbor. Discharged on every outgoing tide, sludge has contributed huge amounts of pollutants to Boston Harbor and Massachusetts Bay: 23,000 tons of total solids, 15,000 tons of BOD (biochemical oxygen demand, a measure of how much oxygen-consuming matter is in the waste) and more than 1,000 tons of the nutrients nitrogen and phosphorous per year. Sludge was the second most important source of solids, BOD, nutrients, toxic metals, and PAHs to the harbor and bay. In 1991, the primary-treated effluent discharged by the two treatment plants contributed 5 to 6 times more of these pollutants (Figure 8-1) than sludge.

Despite the intentions of the designers of the treatment plants, who hoped that tidal currents would disperse the sludge to Massachusetts Bay, recent studies showed that most of Nut Island sludge and some of Deer Island sludge (approximately 7,200 tons per year) returned to the harbor on the incoming tide. Most of the environmental impacts of sludge in the harbor have been on the sediments: sludge particles and their associated contaminants have settled and accumulated near the Nut Island sludge outfall at the tip of Long Island and in more distant depressions and embayments. Sewage particles have accumulated in some parts of the harbor to form a black, oozy mud, devoid of life. Contrary to popular belief, there are no plans to dredge and remove these contaminated sediments, because the resuspension of contaminants caused by dredging would cause more environmental damage.

Stopping the sludge discharges means that the amount of sewage solids accumulating in the harbor has decreased by about 20%--effluent still contributes approximately 31,000 tons of sewage solids to the harbor annually. As primary treatment becomes more efficient, and more solids end up in the sludge, the pollution load to our waters will decrease even more.

Since December 1991, no sludge has been put into the water. Instead, it is being converted into fertilizer pellets at MWRA's new processing plant in Quincy. Some changes after the sludge discharge stopped are immediately noticeable. Other improvements will take months to a few years, while the most fundamental recovery processes will happen over years to decades.

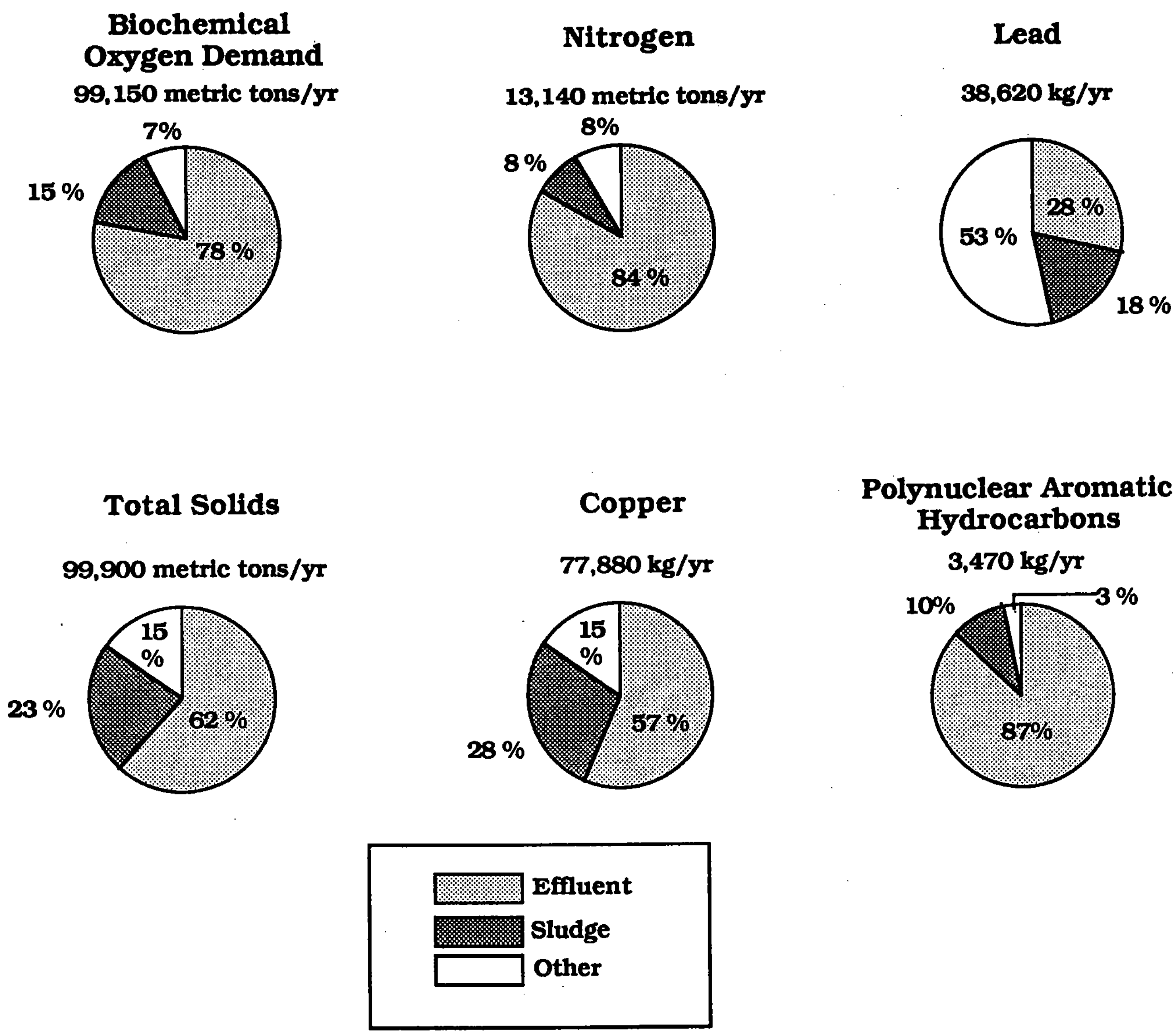


Figure 8-1. Relative loadings of sludge, effluent and other sources of pollutants. These pie charts show the relative amounts of pollutants contributed by different sources. Sludge is the second most important source of most pollutants to Boston Harbor. "Other" includes atmospheric deposition, street runoff, and CSOs.

Short-term Recovery (Days to Weeks)

Water Clarity and Aesthetics near the Sludge Outfall

The dense, black, foul-smelling plume of sludge from Nut Island, visible at the northeast tip of Long Island on every outgoing tide, is gone. Because the Deer Island sludge was mixed with the effluent, there was never a very pronounced plume due only to sludge, so there is no dramatic effect at the Deer Island discharge.

Bacterial Water Quality

Because the sludge could not be effectively disinfected, fecal coliform levels near the Nut Island sludge discharge were often high--ranging up to 10,000 per 100 mL. Future monitoring should show a sharp decrease in sewage indicator bacteria counts near the discharge, and decreases may be detectable farther away at long-term MWRA monitoring stations.

There may also be fewer closure of clam flats near the airport; anecdotal evidence has suggested that sludge may have contributed to bacterial contamination of these beds when carried there by strong southeasterly winds.

Medium-Term Recovery (Months to Years)

Hard-Bottom Communities

Although the harbor floor near Long Island is typical for New England rocky coasts, few of the plants or animals characteristic of this habitat can be found there. The area has been severely impacted by silt deposits, probably from the sludge. Within the year, ocean currents should wash the silt away, permitting the beginning stages of colonization by characteristic New England rocky coastal species: kelp, sea urchins, mussels and anemones. However, it will take years for the community to reach maturity.

Longer-Term Recovery (Years to Decades)

Soft-Bottom Communities

Small worms, clams and snails live in sand or mud at the bottom of the harbor and are important links in the harbor's food chain. Large areas of soft-bottom communities near Long Island appear to be suffering the consequences of sludge accumulation: they are dominated by a few species usually found only in disturbed marine environments. Eventually, as the reservoir of organic material and toxic chemicals is depleted or covered up, more species will find these areas habitable, and the impacted communities will develop into those typical of healthy soft-bottom marine environments.

Winter Flounder

Winter flounder collected in 1984 from Boston Harbor were reported to have high rates of diseases like fin rot and liver abnormalities, including cancers. Presumably, these fish were affected by the toxic materials in sludge deposited on the bottom. The flounder may have been exposed to toxic chemicals through direct contact with contaminated sediment and by eating contaminated food organisms. Recently, researchers from the Woods Hole Oceanographic Institution have found that the flounder in the harbor are healthier now than in 1984. This improvement may correlate with the decreasing discharge of toxic chemicals from the MWRA plants. Now that sludge is no longer contributing toxic materials to the harbor, the physical health of the flounder should continue to improve.

Stopping the dumping of sludge is a major milestone in the Boston Harbor Project. Because sludge has been accumulating for years, the most important improvements will take years to be fully realized. These environmental changes will be difficult to distinguish from the effects of better primary treatment and moving the effluent discharge offshore. Nevertheless, the abatement of sewage sludge discharges is critical for the recuperation of our marine environment from decades of abuse.

APPENDIX

Evaluation Criteria for Grades in 1991 Report Card.

As mentioned in the Introduction, many of the comments we received on the 1990 *State of Boston Harbor* report were that the grades as assessed were too subjective, and that MWRA should investigate better ways of quantifying our grade scales. For most of the grades given in this report we have reevaluated our grading criteria, relating grades to conditions that may form a public health threat or that violate state or federal standards.

Depending on the amount of information available, we calculated the grades in one of two different ways. For parameters where very limited geographic data are available, such as toxic chemicals in the flesh of fish and shellfish, we pooled all available recent data and graded the harbor as a whole. For parameters where adequate data were available to grade the subregions separately, we did so. We then weighted the grades from the subregions by the area of the regions, and calculated an average grade for the harbor. Table 1 describes the computation of the harbor-wide grade for dissolved oxygen in the water column. We did not include the tributaries in this grading.

Table A-1: Calculating a weighted average grade for dissolved oxygen in the water column. The region grades were based upon MWRA 1989 and 1990 harbor monitoring data.

Subregion	Area (Acres)	Percent of Total (A)	Grade, Region	Grade Point, Region (B)	Weight, (A * B)
Inner Harbor	2,479	11 %	D	1.0	0.11
Northwest Harbor	6,611	29 %	B	3.0	0.87
Central Harbor	7,438	33 %	B	3.0	0.99
Southeast Harbor	5,991	27 %	B	3.0	0.81
Total	22,519	100 %			2.78/4 = B-

Section 3: *Is it Safe to Swim?*

Bacterial Water Quality

We developed grades to evaluate the safety of Boston Harbor waters for swimming and for boating based upon (1) interviews with microbiologists who study human pathogens in surface waters and (2) a thorough review of the literature. The swimming grades are based upon state and EPA criteria for bacterial indicators of sewage pollution in surface waters.

Grade	Criteria For Swimming
A	Geometric mean for *Enterococcus* is less than 35 colonies/100 mL; no *Enterococcus* counts exceed 104 colonies/100 mL; no fecal coliform counts exceed 200 colonies/100 mL. Under these conditions, beaches would never be posted and health risks associated with pathogens would be negligible.
B	Geometric mean for *Enterococcus* is less than 35 colonies/100 mL; *Enterococcus* counts are less than 104 colonies/100 mL 90% of the time; geometric mean for fecal coliforms is less than 200 colonies/ 100 mL; fecal coliform counts are less than 200 colonies/ 100 mL 90% of the time. Under these conditions, beaches would normally be open but may be posted during or after rain.
C	Geometric mean for *Enterococcus* is less than 35 colonies/100 mL; *Enterococcus* counts are less than 104 colonies/100 mL 75% of the time; geometric mean for fecal coliforms is less than 200 colonies/ 100 mL; fecal coliform counts are less than 400 colonies/ 100 mL 90% of the time. Under these conditions, beaches would be open 75% of the time.
D	Conditions for C are not met, but *Enterococcus* are less than or equal to 500 colonies/100 mL 90% of the time. This level of *Enterococcus* is the EPA criterion for waters that are infrequently used for contact recreation.
F	Conditions for D are not met.

Although the cause and effect association between swimming in sewage-contaminated water and incidence of disease has been relatively well defined, little information is available on the potential risks resulting from limited ingestion of or skin contact with contaminated water such as may occur during boating. The state water quality standard for fecal coliform bacteria in waters designated for secondary contact (boating) requires that (1) fecal coliforms not exceed 1000 organisms/100 mL and that (2) 10% of the water samples do not exceed 2000 organisms/100 mL. For waters in which human contact is infrequent, EPA guidelines specify that enterococci bacteria do not exceed 500 organisms/100 mL.

We decided to assign Boston Harbor waters that meet the Massachusetts surface water standards for secondary contact (i.e., boating) a grade of "C" (i.e., waters are acceptable for this use). Because some boating activities involve significant contact with water (for example windsurfing) we assigned grades higher than a "C" based on the standards for swimming. Grades "A" and "B" have been defined based on standards that would protect swimmers, water-skiers, and wind-surfers.

Grade	**Criteria for Boating**
A	Geometric mean for *Enterococcus* is less than 35 colonies/100 mL; *Enterococcus* counts are less than 104 colonies/100 mL 75% of the time; geometric mean for fecal coliforms is less than 200 colonies/ 100 mL; fecal coliform counts are less than 400 colonies/ 100 mL 90% of the time. These are criteria for a swimming grade of C .
B	Conditions for A are not met, but *Enterococcus* counts are less than 500 colonies/ 100 ml 90% of the time.
C	Conditions for B are not met, but the geometric mean for fecal coliform bacteria is less than 1,000 colonies/100 mL; no more than 10% of the samples exceed 2,000 colonies/100 ml.
F	Conditions for C are not met.

Section 4: *Is it Safe to Eat Fish and Shellfish?*

Shellfish: Pathogens

The criteria for grading the safety of eating shellfish from Boston Harbor are based on the availability of open or conditionally opened shellfish beds in Boston Harbor.

Grade	Criteria for Shellfish Beds
A	All shellfish beds are classed as open by Division of Marine Fisheries.
B	No beds are prohibited, but all may be restricted.
C	No more than 50% of the acreage of shellfish beds classed as prohibited.
D	No more than 75% of the acreage of shellfish beds classed as prohibited.
F	All beds prohibited.

Shellfish: Toxic chemicals

We evaluated chemical contamination in fish and shellfish from Boston Harbor by comparing average concentrations in edible tissue to:

- Concentrations in tissues from "clean" areas
- Risk-based levels derived using Massachusetts DEP guidance
- FDA action levels for PCBs, pesticides, and mercury, and a derived action level for carcinogenic PAHs.

As mentioned in the text, risk-based concentrations for carcinogenic compounds are concentrations in seafood calculated to cause a given increase in the lifetime risk of cancer above the background cancer risk of approximately 1 case per 5 persons per lifetime. Table A-2 shows the risk-based concentrations we derived for potentially carcinogenic organic compounds.

For chemicals that are not thought to cause cancer, the risk-based limits were set in relation to reference doses that are unlikely to cause adverse health effects during a lifetime. Target levels for these chemicals are evaluated by comparison of tissue concentrations to available Risk Reference Dose (RfD) or Acceptable Intake Chronic (AIC) values. To be consistent with risk-assessment methodology used by the Massachusetts Department of Environmental Protection (DEP), these levels are based on 20 percent of the RfD value (see DEP, 1989). Table A-3 shows the reference doses we derived for non-carcinogenic compounds. Development of the risk-based criteria is described in more detail in Menzie *et al.* (1991).

Table A-2: Concentrations (ppm wet weight) of Organic Contaminants in Edible Tissues. Concentrations are Shown for Three Lifetime Risk Levels[a] and FDA Limits.

	1 in 1,000,000	1 in 100,000	1 in 10,000	FDA Limits
PCBs	0.0014	0.014	0.142	2.0
DDTs	0.032	0.32	3.25	5.0
PAHs	0.001	0.01	0.11	-

[a] Assumes ingestion rate of 6.5 g/day

We used mean tissue concentrations calculated by NOAA (1991a) to estimate human health risks associated with eating fish and shellfish from the harbor. For flounder and lobster this involved comparison of the risk-based concentration levels to the average tissue levels calculated for flounder and lobster from the harbor. For blue mussels the NS&T Mussel Watch data were examined with respect to individual harbor locations. In cases where tissue data were reported as dry weights, we converted them to wet-weight equivalents using the U.S. Food and Drug Administration (FDA) factors to allow comparison with the FDA action levels and estimated risk-based guidelines. For example, to convert dry weight concentrations for mussels to wet weights, multiply by 0.167

Grade	Criteria for Toxic Chemicals in fish and shellfish
A	Levels of toxic chemicals in fish and shellfish tissue are similar to levels found in animals from "clean" areas; toxic chemical levels are below the 1 in 1,000,000 risk-based levels.
B	Levels of toxic chemicals in tissues are higher than in animals from "clean" areas; body burdens are higher than the 1:1,000,000 risk-based concentrations but are less than the 1:100,000 risk based level.
C	Levels of toxic chemicals in tissues are higher than the 1:100,000 risk-based concentrations, but are less than the 1:10,000 risk-based concentration.
D	Toxic chemical levels in tissues are higher than the 1:10,000 risk-based concentrations, but are below FDA action levels.
F	FDA action levels are exceeded.

Table A-3: Target-level Concentrations (ppm wet wt) of Metal Contaminants in Edible Tissues.

	Target Level (ppm wet wt)	Comments
Mercury	1	FDA limit
Cadmium	2.1	DEP Risk Value of 0.2 RfD at ingestion rate of 6.5 g/day. EPA risk-based target level is 11 ppm.
Lead	3	Derived from EPA's Integrated Uptake Biokinetic Model (IU/BK) for lead concentrations in children.
Copper	89.2	DEP Risk Value of 0.2 RfD at ingestion rate of 6.5 g/day. EPA risk-based target level is 430 ppm.
Chromium	12.3	Chromium VI; DEP Risk Value of 0.2 RfD at ingestion rate of 6.5 g/day. EPA risk-based target level is 54 ppm.
Nickel	43	EPA risk-based target level.
Zinc	440	DEP Risk Value of 0.2 RfD at ingestion rate of 6.5 g/day. EPA risk-based target level is 2150 ppm.
Arsenic	2.1	DEP Risk Value of 0.2 RfD at ingestion rate of 6.5 g/day. EPA risk-based target level is 11 ppm.

The grading scheme we developed incorporates (1) FDA action levels, (2) an estimated "action level" of 1 ppm for carcinogenic PAH compounds based on the 2 ppm FDA level for PCBs, and (3) risk-based criteria. We made some simplifying assumptions in the development of the criteria for Boston Harbor. We assume an average fish and shellfish ingestion rate of 6.5 g/day (approximately one quarter ounce/day). This is the consumption rate used by EPA in the development of Water Quality Criteria for protection of human health. It is probably higher than the average ingestion rate of fish and shellfish from the harbor. For example, EPA (1988b) used a lower rate as an average for estimating risks of eating fish (1 g/day) and lobster (2.1 g/day) from Quincy Bay. Thus, the risk-based criteria we used are probably somewhat conservative for the average person, that is the criteria may overestimate the small risks associated with consumption of seafood from the harbor. However, it is likely that a small fraction of the population may consume more than 6.5 g/day, particularly if harbor fish and shellfish are relied on for subsistence (EPA 1988a,1988b).

Section 5: *Are Fish and other Marine Resources being Protected?*

Water Quality: Dissolved Oxygen

We developed grades for dissolved oxygen in the water column based upon Massachusetts State water quality criteria. Regions graded an "A" have DO would meet the Class SA criteria 99 percent of the time. Regions graded a "B" would meet the State Class SB standard 99 percent of the time. Progressively lower grades indicate an increasing frequency or severity of violations of the DO water Quality Standard.

Grade	Criteria for evaluating Water Column Dissolved Oxygen
A	The Massachusetts State standard for dissolved oxygen in Class SA waters (6 mg/L) is met or exceeded in at least 99% of samples.
B	Massachusetts State DO standard for class SB waters (5 mg/L) is met or exceeded in at least 99% of all samples.
C	Massachusetts State DO standards for Class SB is met or exceeded in 80% to 99% of samples; Dissolved Oxygen of less than 4.0 mg/l in fewer than 1% of all samples.
D	Between 20% and 30% of samples violate 5 mg/l DO standard for Class SB water; 1-10% of samples less than 4 mg/L.
F	Conditions for D are not met.

Water: *Toxic Contaminants*
Sediments: *Toxic Contaminants*

We were unable to quantify grading schemes for toxic contaminants in either the water column or in the sediments. Therefore, grades for these parameters are based upon the same relative criteria as the grades assessed last year. These evaluations are based upon comparisons of conditions in Boston Harbor to other urban estuaries.

Grade	Criteria for Evaluating Toxics in Water and sediments
A	**EXCELLENT** Consistently maintains conditions characteristic of other clean coastal sites, for example Provincetown Harbor.
B	**GOOD** Frequently exceeds water quality standards and expectations for an urban estuary (e.g. Puget Sound).
C	**SATISFACTORY** Usually complies with Federal Water Quality Criteria; meets expectations for an urban estuary (e.g. San Francisco Bay).
D	**POOR** Frequently fails to comply with existing standards; does not meet expectations for an urban estuary; some uses of the harbor are maintained (e.g. Potomac River).
E	**FAILING** Consistently fails to comply with Federal Water Quality Criteria; there is obvious environmental degradation, and uses of the harbor are lost (e.g. New Bedford Harbor).

We evaluated the health of the winter flounder population in Boston based upon the results obtained in "Fish Day 1989", as described in the text. The grading scale is based upon an index compiled by O'Connor *et al.* (1987).

Grade	Criteria for evaluating winter flounder - fin rot
A	The prevalence of fin rot in winter flounder from an area does not exceed 0.5 percent.
B	Fin rot prevalence is between 0.5 and 5 percent.
C	The incidence of fin rot is between 5 and 10 percent.
D	Fin rot prevalence is between 10 and 25 percent.
F	Fin rot prevalence in winter flounder from an area exceeds 25%.

In 1991 these fin rot data were supplemented by data collected by Moore *et al.* (1991) on the prevalence of liver lesions in winter flounder and a pre-cursor to such lesions, the occurrence of hydropic vacuolation in liver cells. NOAA will be releasing a study this spring that reports this measure of flounder health for fish throughout New England. A grading scale for this measure is reported below. Currently both fin rot and histopathology criteria result in the same grade for the harbor.

Grade	Criteria for evaluating winter flounder - histopathology
A	The prevalence of hydropic vacuolation in flounder is less than 5 percent.
B	The prevalence of hydropic vacuolation is between 5 and 25 percent.
C	The prevalence of hydropic vacuolation is between 25 and 45 percent; there are no grossly visible liver lesions.
D	Presence of hydropic vacuolation between 45 and 60 percent; prevalence of grossly visible liver lesions is between 0 and 5 percent.
F	Conditions for D are not met.

Gathering data on soft-bottom benthic communities involves taking a sample of the bottom using any of a variety of devices collectively known as grabs or corers. The sediment in the grabs are sieved through a fine-mesh screen, typically one with a either a 0.5 mm or a 0.3 mm mesh (0.3 mm = 12 thousandths of an inch), and preserved with formaldehyde. In the laboratory, the preserved sample is sorted under a microscope and the animals are counted and identified.

Benthic communities are normally very "patchy", with large differences between stations in the species present and their abundances, and at stations between sampling periods. There are even noticeable differences in replicate samples taken in the same location at the same time. Therefore, the data resulting from benthic studies is quite complex, usually requiring sophisticated statistical analysis and experience with the communities in an area before trends such as those described in Section 5 are seen. Even then, the results of such analyses are often too esoteric to explain easily to environmental managers or to the general public.

The development of a simple index that could be used to grade the condition of benthic communities has been an area of intense work during the past two decades. Unfortunately, benthic communities are complex enough that none of the proposed schemes have shown themselves to be of general utility. An index that works well with data from one study or area may break down completely when applied to other benthic communities.

In attempting to quantify grades given to the soft-bottom benthic communities in Boston Harbor we restricted ourselves to considerations of the numbers of species present in samples taken within Boston Harbor. This is one estimate of species diversity, an aspect of benthic communities that is well known to have a negative association with the level of pollution enrichment. The number of species present in a sample is influenced by the area of the bottom sampled. Since larger grabs sample more species from a benthic community, we restricted ourselves to comparing data from studies using roughly comparable sample sizes. The studies reviewed included the environmental assessments carried out by the MDC in 1978 - 1984 during its application for a waiver of secondary treatment requirements (summarized in Blake *et al.*, 1989), benthic sampling carried out by the U.S. Army Corps of Engineers in the inner harbor, and sampling performed by MWRA.

The data available on harbor communities do not support the development of a 5-grade scale. We decided to develop a four grade scale of A, B, C/D and F; to correspond roughly to conditions that are Good, Impacted, Degraded, and Highly Degraded. This scale was developed **only** to intercompare the different regions within the harbor, and is not intended to suggest, for example, that an area graded as an "A" is completely un-impacted by pollution.

The similarities in terms of what types of species are present (species composition) and the diversity of species in benthic communities in parts of the central and southeast harbors to much cleaner areas outside of Boston Harbor has been well documented (Blake *et al.*, 1989). We decided that those samples with the most species present would set the end-point for determining what number of species at a station received an "A". We also compared the species number in the historical data to the more complex information available on species composition, which means looking at the types of species present, how they feed, or if they are recognized as either sensitive to or resistant to pollution. Using this information we set the species number cutoffs for the grades below "A".

Grade	Criteria for Grading the Benthic Community
A	Benthic habitat is presumed representative of relatively un-impacted estuarine conditions. The number of species present in samples from a site is greater than or equal to 100.
B	Benthic habitat is presumed modified, but the community is relatively robust. The number of species present at a site is between 50 and 99.
C/D	Benthic community is presumed to be degraded, with fewer species present, although the number of individuals present at a station may be quite high. The number of species present at a site is between 11 and 49. For calculating average grades the grade C/D was assigned a grade point of 1.5
F	The benthic community is presumed to be highly degraded; characterized by few individuals or azoic conditions (no animals present). The number of species present is less than or equal to 10.

Table A-4 illustrates the process followed, and contains the station identifiers, number of species present, and assigned grade for the grading the central and southeast harbors. All of the data for these regions are from the 1978-84 MDC surveys, which were reviewed and summarized in Blake *et al.* (1989).

Table A-4 **Calculating an average grade for the benthic (sea-floor) community in the central and southeast harbors.**

Station name	Number of Species	Grade Assigned	Grade Point
T13	25	C/D	1.5
T14	40	C/D	1.5
T15	68	B	3
T16	33	C/D	1.5
T17	71	B	3
T18	59	B	3
T19	50	B	3
T20	69	B	3
T21	50	B	3
T22	77	B	3
NI	43	C/D	1.5
B11	87	B	3
B12	105	A	4
B9	45	C/D	1.5

Number of Stations: 14 Total Grade points = 47 Average = 35.5/14 = 2.5 = C/D

Section 6: *Is the Harbor Aesthetically Pleasing?*

We assigned grades to harbor aesthetics, on the basis of the amount of debris collected per mile of beach during the 1990 beach cleanup and also considering the total number of debris items on EPA's list of "items of concern". A single grade was assigned to Boston Harbor and, for comparison, to the north shore, south shore, and Cape Cod regions. The amount and types of debris collected in each one of these areas are compared to state and national averages obtained from the Center for Marine Conservation's (CMC) National Marine Debris Database.

Grade	Criteria for Evaluating the Aesthetic Quality of Boston Harbor
A	Weight of debris collected per mile of shore 25% less than the national average; EPA's "items of concern" less than 5% of total items collected.
B	Weight of debris collected per mile of shore 10% less than the national average; EPA's "items of concern" less than 5% of total items collected.
C	Weight of debris collected per mile of shore about equal to the national average; EPA's "items of concern" less than 10% of total items collected.
D	Weight of debris collected per mile of shore 10% greater than the national average; EPA's "items of concern" more than 10% of total items collected.
F	Weight of debris collected per mile of shore 25% greater than the national average; EPA's "items of concern" more than 10% of total items collected.

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REPORT CARD FOR *Boston Harbor*		
	1991	**1990**
IS IT SAFE TO SWIM AND BOAT?		
Swimming	**D+**	D
Boating	**B**	(not graded)
IS IT SAFE TO EAT FISH AND SHELLFISH?		
Shellfish: Pathogens	**D+**	D-
Fish: Organic contamination	**C -**	C-
Fish: Metal contamination	**B -**	B-
ARE MARINE RESOURCES PROTECTED?		
Sediment contamination	**D -**	D-
Water quality: Oxygen	**C**	C-
Water quality: Toxic contamination	**B -**	B-
Fish disease	**D -**	D-
Seafloor Animals	**D**	D-
IS THE HARBOR AESTHETICALLY PLEASING?		
Aesthetics	**D**	D
OVERALL GRADE	**C -**	**D+**

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