November 1990

The State of BOSTON HARBOR: 1990

Massachusetts Water Resources Authority

Report 1990-01

Connor MS and Gibson V. 1990. The state of Boston Harbor 1990. Boston: Massachusetts Water Resources Authority. Report 1990-01. 89 p.

EXECUTIVE SUMMARY

This report describes the environmental status of Boston Harbor as of 1990, and summarizes its condition in a report card. For each factor evaluated, five grades are recorded: one for the present condition and four for predicted conditions at various stages in the remediation plan being put into effect by the Massachusetts Water Resources Authority (MWRA). In 1992, sludge discharge to the harbor will cease; in 1995, with completion of the new outfall, effluent discharge will be halted; in 2000, full secondary treatment will be implemented; and in 2005, the CSO remediation program will begin to yield benefits.

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 it safe to swim at harbor beaches?
- Is it safe to eat fish caught in the harbor?
- Are marine resources in the harbor satisfactorily protected from pollution?
- Is the harbor a resource that people can enjoy aesthetically?

Is It Safe To Swim In Boston Harbor?

Swimming Beaches	
Now:	D
1992:	D+
1995:	C
2000:	C
2005:	B

We consider beach condition to be the best indicator of the poor state of the harbor. On average, most parts of the Inner Harbor landward of the World Trade Center fail to meet microbial standards for swimming. However, no swimming beaches are found in these areas. The less impacted parts of the harbor are along northern Dorchester Bay beaches, particularly Pleasure Bay.

KEY TO GRADES

- **A** **Excellent:** Consistently maintains conditions characteristic of other clean coastal sites.
- **B** **Good:** Frequently exceeds Federal water quality standards and expectations for an urban estuary.
- **C** **Satisfactory:** Complies with Federal water quality standards and meets expectations for an urban estuary.
- **D** **Poor:** Sometimes fails to comply with existing standards or meet expectations for an urban estuary; some uses of the harbor are maintained.
- **F** **Failing:** Consistently fails to comply with Federal water quality standards or meet expectations for an urban estuary; there is obvious environmental degradation, and uses of the harbor are lost.

REPORT CARD FOR Boston Harbor

	NOW	1992	1995	2000	2005
IS IT SAFE TO SWIM?					
Swimming beaches	D	D+	C	C	B
IS IT SAFE TO EAT FISH AND SHELLFISH?					
Shellfish: Pathogens	D-	D	C-	C-	B-
Fish: Organic contamination	C-	C-	C-	C+	B-
Fish: Metal contamination	B-	B-	B-	B	B+
ARE MARINE RESOURCES PROTECTED?					
Sediment contamination	D-	D	D	C-	C-
Water quality: Oxygen	C-	C	B	B	B
Water quality: Toxic contamination	B-	B	B+	B+	A-
Fish disease	D-	D	D+	C-	C+
Benthic communities	D-	D	D	C-	C-
HOW DOES THE HARBOR RATE AESTHETICALLY?					
Aesthetics	D	C-	B-	B-	B+
OVERALL GRADE	D+	C-	C	C+	B-

The Boston Harbor report card sums up our knowledge of present conditions and our hopes for the future.

Pathogen contamination at swimming beaches will improve slightly in the outer harbor channel after the cessation of sludge dumping. The completion of the primary treatment plant will reduce the discharge of combined sewer outflows (CSOs) by half; the remaining half of CSO cleanup awaits the completion of facilities for treatment of CSO discharge in the next decade. The Boston Water and Sewer Commission is actively eliminating illegal connections to stormwater drains, but this may not be enough to make the entire harbor, particularly Quincy Bay beaches, suitable for swimming after a moderate rainstorm.

In summary, the harbor is currently too contaminated for swimming about half of the time; in the future, except for Wollaston Beach, the harbor should be swimmable 95% of the time.

Is It Safe To Eat Harbor Fish and Shellfish?

Shellfish: Pathogens	
Now:	D-
1992:	D
1995:	C-
2000:	C-
2005:	B-

Because of pathogen contamination, none of the shellfish beds in the harbor can be harvested except by master diggers who take their harvest to cleansing plants for purification in clean water. The Division of Marine Fisheries can usually find beds that meet standards for this type of harvesting when less than a quarter inch of rain has fallen. The rate of improvement will be similar to that described for beaches, except that shellfish standards are stricter than swimming standards, so the harbor will not achieve as high a level of compliance.

Fish: Organic Contamination	
Now:	C-
1992:	C-
1995:	C-
2000:	C+
2005:	B-

Throughout the harbor, concentrations of polychlorinated biphenyls (PCBs) in lobster tomalley (or hepatopancreas) exceed the standard established by the U.S. Food and Drug Administration (FDA). 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). Most improvement will be associated with the completion of the new outfall into Massachusetts Bay. The change will not be large, however, because a reservoir of contaminants has accumulated in the sediments.

The rate of change will be slow (5 to 10 years) because of the relatively long life span of the marine organisms.

Fish: Metal Contamination
Now: B-
1992: B-
1995: B-
2000: B
2005: B+

The same considerations mentioned for organic contamination apply here, but the magnitude of improvement will be even smaller because the problem is less significant. Metal concentrations are elevated in fish and shellfish in the harbor, but not to the extent that human health standards are violated.

In summary, while shellfish purification may still be required by the state, many more shellfish beds should be open. The fish are currently safe to eat, though not desirable because of organic contamination. This contamination will slowly decline.

Are Marine Resources Protected?

Fish and bottom-dwelling (benthic) invertebrates 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
Now: D-
1992: D
1995: D
2000: C-
2005: C-

Portions of Boston Harbor contain sediments with some of the highest levels of organic and metal contamination found in 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. Most of the improvements will be associated with the completion of the new effluent tunnel. It may take decades for concentrations of toxic contaminants in the sediments to halve their current levels.

Water Quality: Oxygen

Now: C-
1992: C
1995: B
2000: B
2005: B

Because animals require oxygen for respiration, dissolved oxygen is a standard measure of water quality. Water in the Inner Harbor occasionally fails to meet standards for dissolved oxygen, but concentrations rarely approach levels that can affect species abundance. In the Outer Harbor, water quality standards are generally met, but concentrations of dissolved oxygen are sometimes depressed. Because most of the input of oxygen-consuming wastes is from the sewage effluent and sludge, completion of the outfall tunnel and sludge facilities will have the biggest impact on oxygen concentrations in the water. The sediments contain a large residue of nutrients and organic matter that may slow the rate of recovery.

Water Quality: Toxic Contamination

Now: B-
1992: B
1995: B+
2000: B+
2005: A-

Water quality criteria for most of the EPA priority 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 copper standard is the one most likely to be exceeded, especially in the Inner Harbor. Changes in priority pollutant concentrations in the harbor should be similar to the improvement in oxygen concentration noted above.

Fish Disease

Now: D-
1992: D
1995: D+
2000: C-
2005: C+

Boston Harbor is noted for the high incidence on fin rot and tumors in its winter flounder. Improvements will be associated with the cessation of sludge discharge and the completion of the new outfall. The large reservoir of contamination currently in the sediment and the relatively long (5 to 10 years) life span of fish will slow the rate of progress.

Benthic Communities

Now: D-
1992: D
1995: D
2000: C-
2005: C-

Some areas of the Inner Harbor and Winthrop Bay are nearly devoid of benthic animals, but large portions of the southeastern Outer Harbor have quite active and diverse bottom-dwelling communities of worms, clams, and crustaceans. If benthic comunites are limited by the concentrations of toxic contaminants found in the sediments, their recovery should be as slow as 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.

We conclude that harbor water quality is surprisingly good for an urban harbor and will show the most improvement over the next 15 years. The legacy of past sediment contamination will continue to affect the organisms living in the bottom of the harbor.

How Does the Harbor Rate Aesthetically?

Aesthetics
Now: D
1992: C-
1995: B-
2000: B-
2005: B+

Discharge plumes from the treatment plants have a noticeable odor and color; moreover, in a recent cleanup, Boston Harbor beaches had more trash per unit area than any other beaches in the State. On the positive side, the cessation of scum discharges has improved the overall look of the harbor. The worst source of turbidity and odor will disappear when sludge discharges cease. Completion of the new plant will decrease untreated overflows by half; the other half will require completion of CSO facilities. Trash and debris washed into the harbor with stormwater will remain a problem. *Aesthetically, the harbor is currently unsatisfactory; however, it will improve dramatically as a result of the MWRA's efforts.*

What Is the Harbor's Overall Grade?

Overall
Now: D+
1992: C-
1995: C
2000: C+
2005: B-

We rate the harbor currently as a "D+". Within the last decade, the harbor was certainly an "F". Although the quality of swimming beaches, fish, and sediment remains of concern, there is some evidence that conditions have improved in the past decade.

The fact that 10,000 gallons of scum are no longer put into the water each day has vastly improved the appearance of the harbor. The concentrations of metals in the water column and in the sediments and of PCBs inshellfish have decreased significantly. Fin rot and tumors in fish also appear to be at their lowest levels in this decade.

With the cessation of sludge discharge in 1992 and relocation of the outfalls to Massachusetts Bay, the harbor should meet most established standards by the mid-1990s. Changes in water quality should occur on a scale of months to years; changes in sediment and fish quality on a scale of decades. Improvement will come more quickly to the Outer Harbor than to the Inner Harbor.

What prevents the harbor form receiving an "A" grade in the future? Boston Harbor may never again be pristine because of the commercial traffic that moves through it, the continuing problem of stormwater runoff, and the legacy of past particles residing in the sediment. Nevertheless, in the first decade of the new century, the harbor should generally exceed water quality standard and be cleaner than most urban estuaries are today. Thus, we give it a "B" at the end of the project.

CONTENTS

PREFACE

In this report, we provide information on the current condition of Boston Harbor and the improvements that can be expected at different stages of the remediation plan. Our intent is to give the informed citizen 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 research 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 it safe to go swimming in Boston Harbor? 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 five grades, one representing the current state of the harbor and the others predicting its state at various stages of remediation. In the final section of the report, we compile all the grades into a report card for Boston Harbor and explore the question of what the harbor will be like in the future.

Like any assessment based on numerical ratings, this one is open to debate. Just as no report card can give a three-dimensional portrait of a child's abilities and character, ours does not adequately represent the complexities of Boston Harbor. We believe, however, that it serves a purpose by highlighting the harbor's strengths and weaknesses, permitting comparison of various factors, and – perhaps most importantly – stimulating debate on the picture that emerges.

The information in this report is drawn from many different sources. The MWRA Harbor Studies Department supports and participates in research 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

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 exceeds Federal water quality standards and expectations for an urban estuary (e.g., some of Puget Sound).

C **SATISFACTORY:** Complies with Federal 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).

F **FAILING:** Consistently fails to comply with Federal 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).

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 Bay Program. MWRA's Harbor Studies 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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1. THE PROBLEM AND THE PLAN

Overview of the Problem in Boston Harbor

Sewage sludge and effluent are discharged to the harbor with no treatment beyond the primary level

Today, Boston Harbor receives the residue of household waste from more than 2.2 million people in 43 communities in eastern Massachusetts. In addition, businesses and industries in the Metropolitan Boston area (about 5500 of them) flush still more waste, of various kinds, into the sewer system and, ultimately, into the harbor. By the standards current in the United States today, all of this waste receives inadequate treatment. Boston is the only major U.S. city that does not treat its sewage beyond the primary level. Primary processing essentially separates sewage into two components, effluent and sludge, by allowing it to stand until most of the solids (sludge) have settled out. Disinfectant is then added to the liquid portion (effluent) to kill bacteria. The irony is that, in Boston, both sludge and effluent end up in the harbor anyway.

The contamination in the sludge and effluent affect four issues of concern to the public:

1. Is it safe to swim at harbor beaches?

2. Is it safe to eat fish caught in the harbor?

3. Are marine resources in the harbor satisfactorily protected from pollution?

4. Is the harbor a resource that people can enjoy aesthetically?

These are the issues that are discussed in the following sections and graded in the Boston Harbor report card.

Contamination from other sources is also present

Of course, sewage is not the only cause of the harbor's problems. Materials carried by rivers, in water drained from land, and in fallout from the atmosphere contribute their share to the total load of contaminants. These sources are more difficult to identify, measure, and control than sewage, but the Boston Harbor cleanup will not be complete until they have been addressed in some way.

Overview of the Plan for Cleanup of Boston Harbor

MWRA is required by law to improve its discharges to the harbor

The Massachusetts Water Resources Authority was formed in July 1985. Its creation was a recognition of the fact that the problems in Boston Harbor were not being solved by traditional means and existing institutions. By that time, the Commonwealth of Massachusetts was being sued in both State and Federal courts because of the poor condition of the harbor. In response to these suits, MWRA has negotiated a schedule for the harbor's rehabilitation and is well on its way to making those plans a reality (Figure 1.1).

MWRA's plans to improve the quality of Boston Harbor have four key components: (1) improvements to existing wastewater treatment facilities, (2) construction of new facilities for wastewater treatment and sludge processing, (3) capture and treatment of sewage that overflows during rainstorms, and (4) reduction in the amount of toxic materials put into the sewer system.

A phased plan leads to full secondary sewage treatment by 1999

Construction of the new treatment facilities is the biggest part of the job and will cost an estimated $6.1 billion. When the system is complete, sewage will be pumped under the harbor from collection points, or headworks, to a combined primary and secondary treatment plant on Deer Island. This plant will have a capacity of 1300 million gallons (4900 million liters) of sewage per day. The treated effluent will pass through a 9.5-mile (15-km) tunnel bored through rock 400 ft (120 m) below sea level and will be discharged through an outfall under 100 ft (30 m) of water in Massachusetts Bay. The sludge will be disposed in accordance with a plan that fully complies with environmental protection and makes the best use possible of technology for beneficial reuse of sludge. The disposal plan will almost certainly call for some of the sludge to be processed for use as fertilizer or soil conditioner.

Full secondary treatment will be put into operation in 1999. However, the project is designed in stages so that some benefits will be available more quickly.

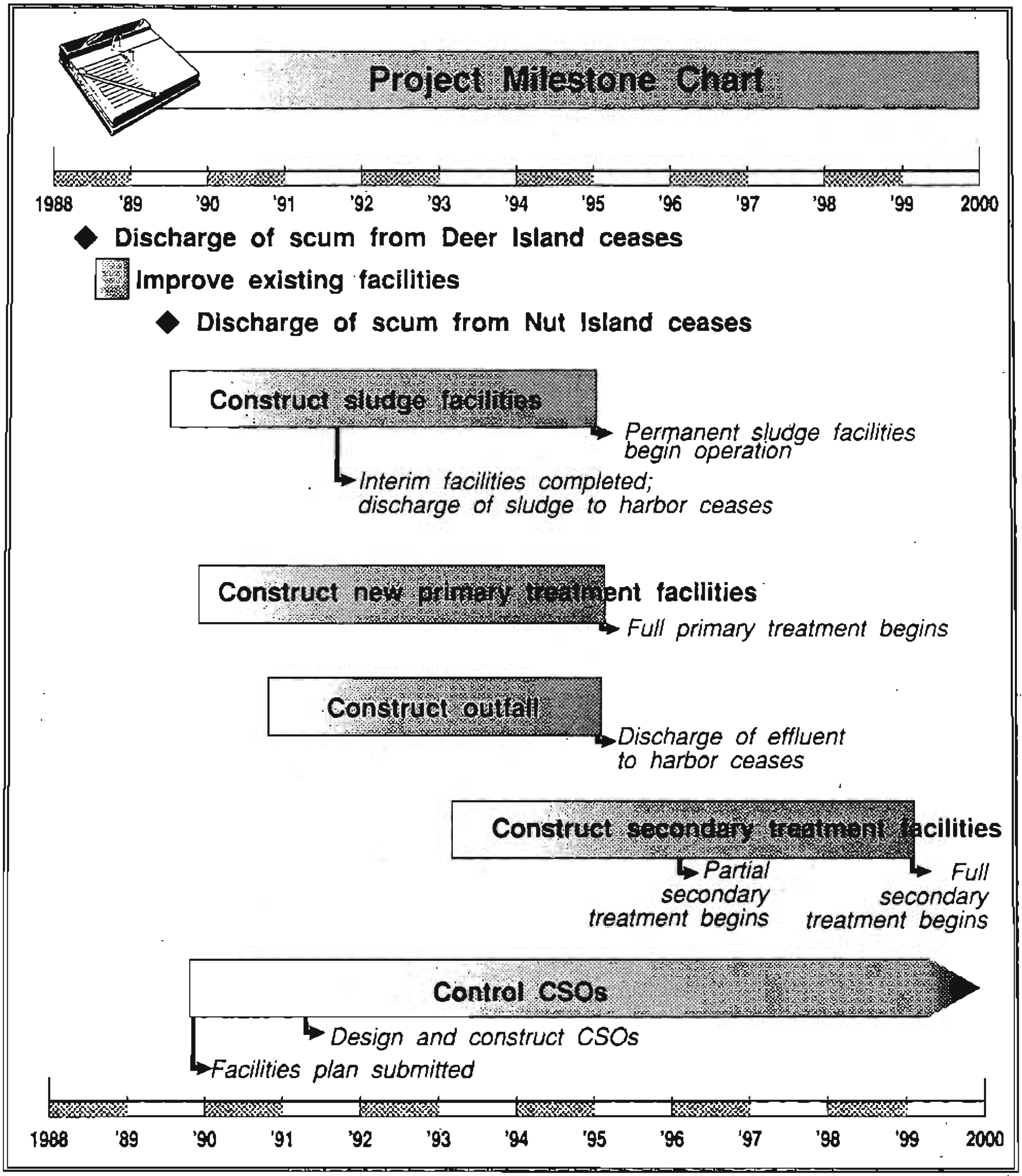

Figure 1.1. The schedule of milestones for the MWRA project reveals that the work is designed in stages so that some benefits will be realized more quickly.

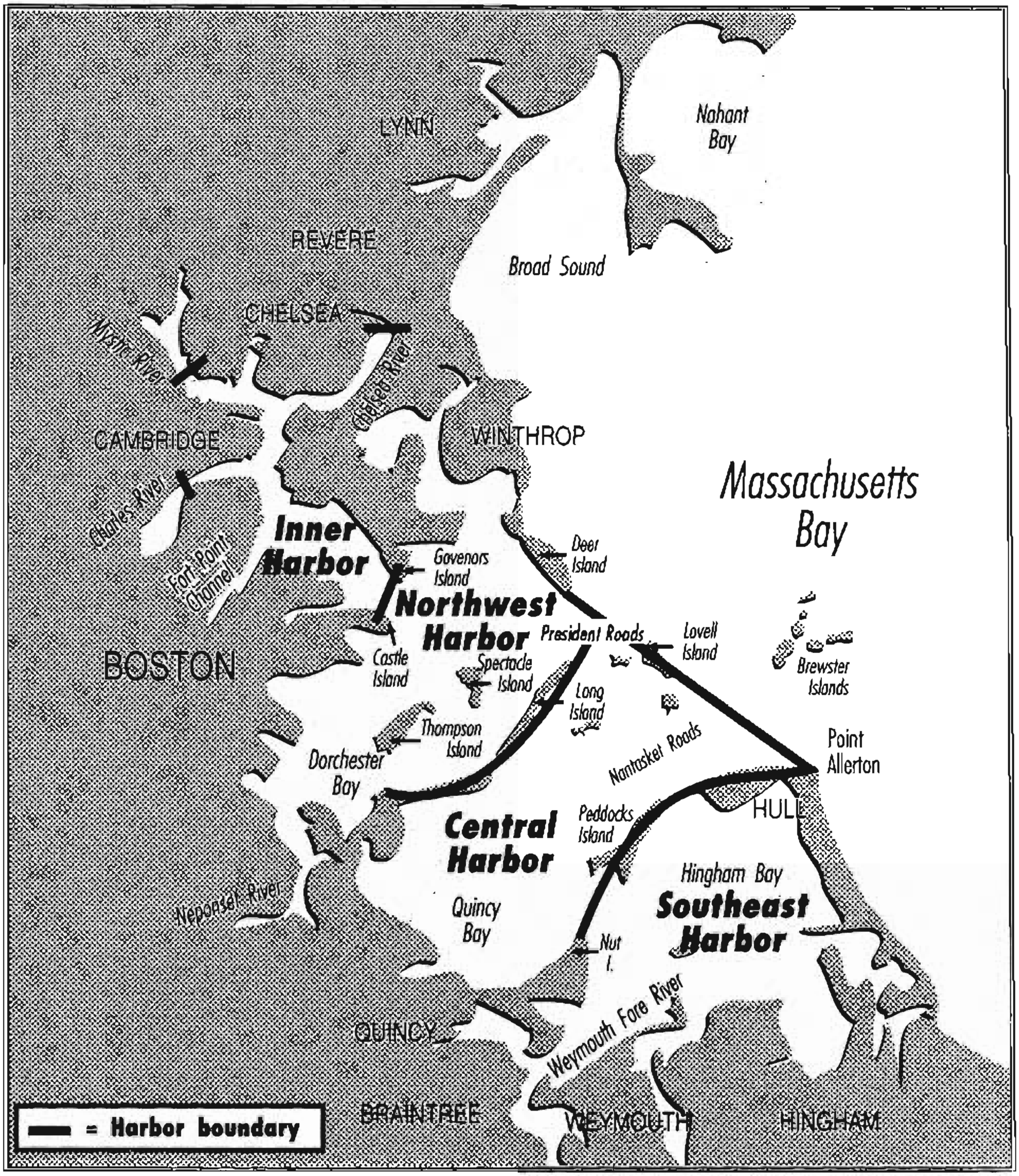

Figure 2.1. Based on degree of contamination, Boston Harbor can be divided into four broad areas: the Inner Harbor and the northwest, central, and southeast Outer Harbor.

2. UNDERSTANDING THE PROBLEM

Harbor conditions are not uniform; useful divisions are the Inner Harbor and the northwest, central, and southeast Outer Harbor

Boston Harbor, shown in Figure 2.1, covers approximately 47 square miles (122 km^2) of bays and tidal estuaries. The water is shallow, from 1 to 10 m, except for depths reaching 20 m in President Roads and Nantasket Roads, the two shipping channels. A number of small islands are scattered throughout the harbor.

The harbor is customarily separated into two main areas, an Inner Harbor and an Outer Harbor. The Inner Harbor extends from an imaginary line connecting Castle and Governors Islands to the lower reaches of the Charles, Mystic, and Chelsea Rivers. The Outer Harbor covers the rest of the area, out to a line extending from Deer Island to the tip of Hull. Because a main point of this report is that conditions in Boston Harbor vary from one place to another, we have further divided the Outer Harbor into northwest, central, and southeast sections. The northwest takes in Dorchester Bay and President Roads, the central portion includes Quincy Bay and Nantasket Roads, and the southeast comprises Hingham and Hull Bays.

Sources of Contamination

Effluent and sludge are major sources of five types of contamination to the harbor

The first thing that we need to know to understand conditions in Boston Harbor is where the contamination is coming from. The major sources of contamination to the harbor are effluent, sludge, combined sewer overflows (CSOs), rivers, stormwater, and the atmosphere. In general, effluent and sludge are major sources of all the contaminants of primary concern in the harbor. Contributions by CSOs, rivers, and stormwater can also be significant for certain contaminants. Deposition from the atmosphere is an important source for a few materials, particularly lead. Industrial discharges that go directly into the harbor (or to a river that feeds into the harbor) are relatively unimportant compared to these other sources.

The materials of primary concern as contaminants in Boston Harbor lie in five main categories:

1. Suspended solids
2. Oxygen-consuming organic matter
3. Pathogenic organisms, such as certain bacteria and viruses
4. Nutrients
5. Toxic materials.

These materials have different major sources (Figure 2.2). In general, however, effluent and sludge discharged into the harbor after passing through MWRA's two primary treatment plants are major sources of all groups of contaminants except pathogens.

Suspended Solids

Toxic materials attach to particles in the water and can accumulate in areas of sediment deposition

The solid materials suspended in coastal waters such as Boston Harbor can originate from natural as well as manmade sources. Naturally occurring particles include inorganic materials, such as sand and clays; living organisms, such as bacteria and phytoplankton; and organic detritus. Sewage effluent is by far the most significant contributor of suspended solids to Boston Harbor, followed by sludge.

An important reason for concern about suspended solids is that toxic materials such as metals and organic compounds tend to adsorb to particles of inorganic and organic matter, and thus become concentrated on the particles. These particles are transported by water movements in the harbor until the speed of the current slows enough to allow them to settle to the bottom. Areas of settlement, or deposition, may accumulate contaminants associated with the particles. Other potentially adverse effects include oxygen depletion (discussed under Oxygen-Consuming Organic Matter, following); reduction in productivity of the area because the penetration of light into the water is reduced and retards phytoplankton growth; and burial of bottom-living animals by particle deposition. Furthermore, water with a heavy load of suspended material is murky and unattractive.

Oxygen-Consuming Organic Matter

Decay of organic matter depletes oxygen in the water

Biochemical oxygen demand (BOD) is a widely used measurement of pollution from organic sources such as sewage. The measurement is based on the fact that, when it is oxidized by microorganisms, organic material decomposes and, in the process, uses up oxygen in the water around it. Thus, in an area that contains a great deal of organic matter, the water can actually be depleted of the oxygen necessary to support marine life. As is the case for suspended solids, effluent is the leading source of BOD for Boston Harbor, and sludge is the next most important.

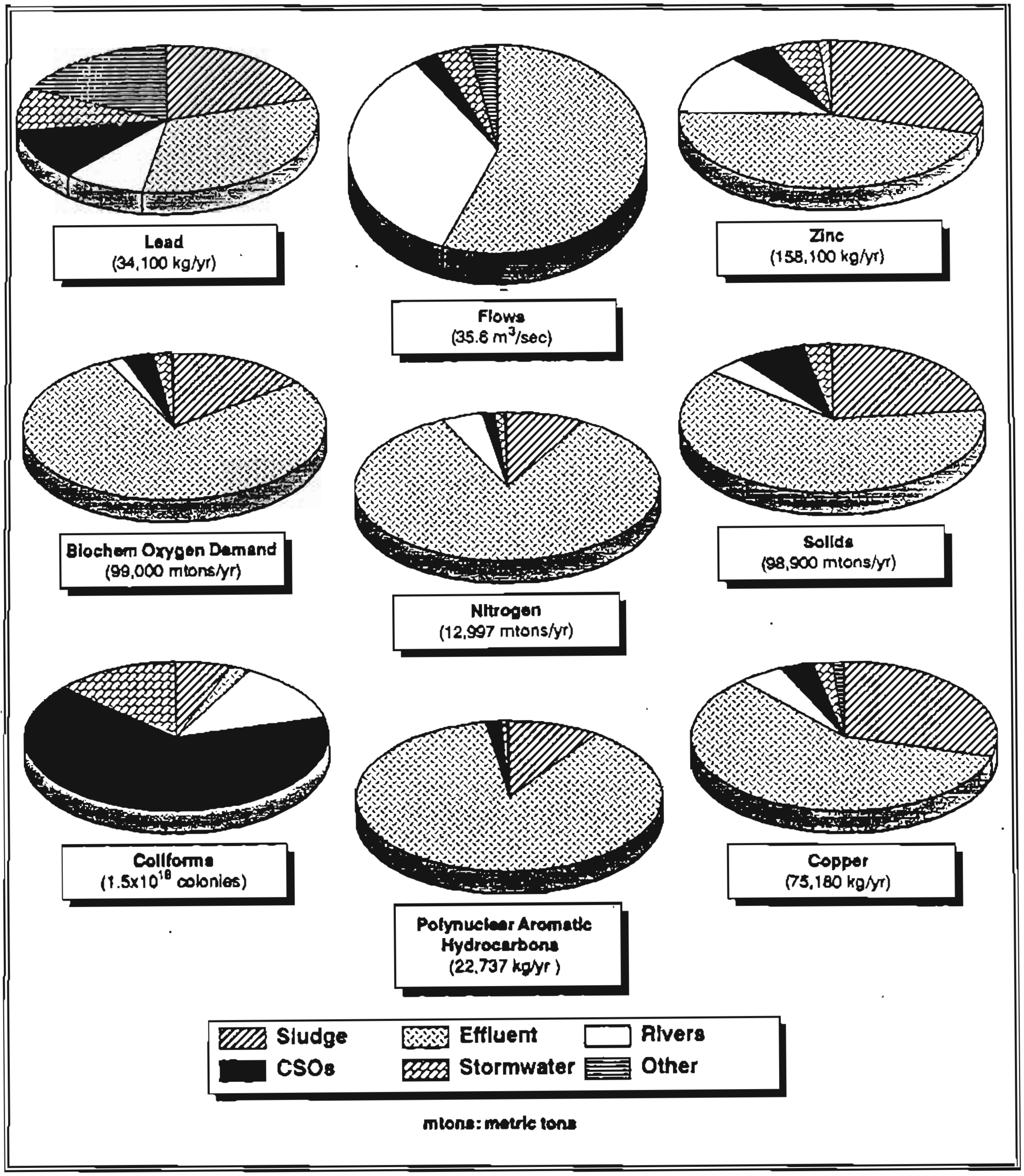

Figure 2.2. Many sources cause harbor contamination. The *other* source takes in matter from the air, groundwater, and discharges with permits from the National Pollutant Discharge Elimination System. PAH estimates have the most uncertainty.

Pathogens

High levels of pathogens result in posted beaches and closed shellfish beds

The presence of pathogens, or disease-causing organisms, is difficult to measure directly. Here, most of the values given refer to numbers of fecal coliform bacteria. This group of bacteria is used as an indicator of the presence of microorganisms that are likely to be associated with sewage and are capable of causing disease in humans. Pathogen contamination, as measured by indicator organisms, is periodically responsible for the posting of health warnings at beaches in and around the harbor and for the closure of shellfish beds to harvest for human consumption. At present, some Boston Harbor beaches are posted more than 50% of the time during summer, and all shellfish beds are either closed or restricted to harvest in dry weather by licensed commercial shellfishermen who must take the shellfish to a depuration plant for purification in clean water before they can be sold.

CSOs are the major source of bacteria to the harbor

CSOs are the major source of bacteria to Boston Harbor. There are more than 80 of these overflows, which, under certain conditions, discharge untreated sewage into the harbor, in the area served by MWRA (Figure 2.3). CSOs are active during rainstorms when water from storm drains overloads the system. Pathogens can also be discharged during dry weather, either because there are illegal sewage connections to stormwater drains or because of broken or obstructed pipes.

Nutrients

Too much nitrogen or phosphorus can cause excess plant growth, followed by adverse effects such as oxygen depletion

In marine waters, the primary nutrients are nitrogen and phosphorus. At natural concentrations, these chemical elements are essential to fuel the growth of phytoplankton, which forms the base of the marine food web. In excess amounts, however, these same necessary nutrients become pollutants because they have adverse effects on the ecosystem. An oversupply of nutrients can lead to a condition known as eutrophication. In this condition, nutrients stimulate plant growth until there is an accumulation of algae, some of which may be undesirable species, and which deplete oxygen from the water when they decompose. In areas such as Boston Harbor, availability of nitrogen is the factor that normally limits the growth of phytoplankton; thus nitrogen, in one form or another, is the nutrient of greatest concern as a contaminant.

Sewage effluent is by far the leading source of nitrogen-based nutrients to Boston Harbor. Sludge is a secondary source, followed by rivers, CSOs, and stormwater. Effluent is also the major source of phosphorus-based nutrients, with small contributions from the other sources.

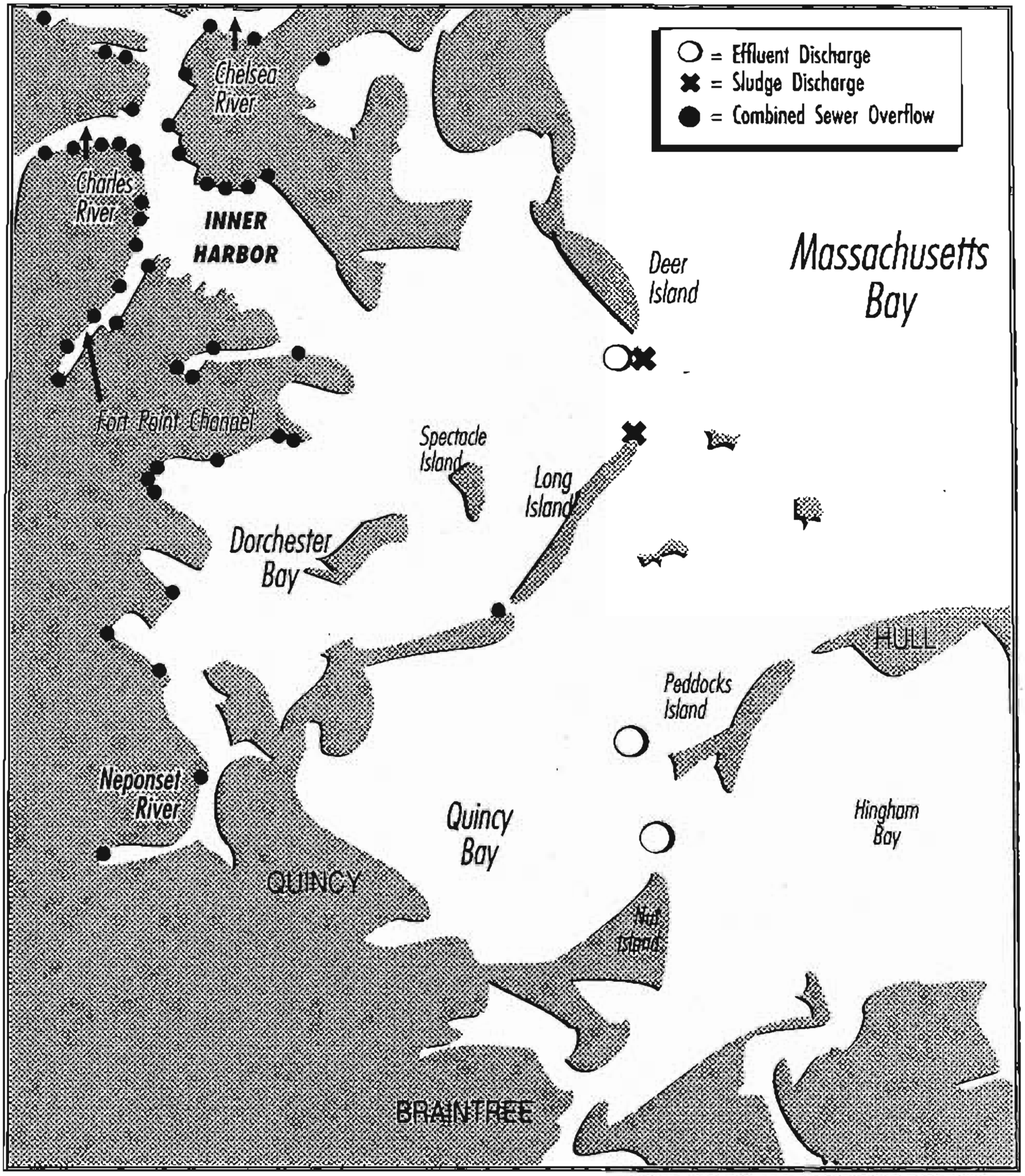

Figure 2.3. Sewage outfalls, sludge discharges, and combined sewer overflows are located throughout Boston Harbor.

Toxic Materials

A large number of metals and organic compounds are of potential concern as toxic contaminants

The toxic materials found in Boston Harbor can be subdivided into two classes—metals and organic compounds. Metals of concern include arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc. Toxic organic compounds include a variety of chemicals with industrial or household uses—for example, acetone, benzene, and naphthalene; petroleum hydrocarbons, particularly the more toxic polynuclear aromatic hydrocarbons (PAH); pesticides, and polychlorinated biphenyls (PCB).

PCBs and other toxic materials can build up in the tissues of edible marine animals

The major reason for concern about these materials is that, in addition to their known toxic effects, many have a tendency to accumulate in living tissue. Plants and animals living in an environment with even small amounts of toxic chemicals can gradually build up contaminant concentrations in their bodies. This effect is intensified when one plant or animal is eaten by another, and the process is repeated up the levels of the food web. PCBs, for example, are of major interest to regulators because they are potential carcinogens and have been shown to be present in elevated levels in species prized as seafood. Metals are known to have toxic effects in humans. For example, mercury and its compounds can cause damage to the nervous system and, at higher concentrations, can be fatal. Lead exposure can result in behavioral disorders, brain damage, and death. In general, toxic chemicals have also been implicated in disease and lesions in fish and shellfish, and in other adverse effects such as lowered reproductive success in some species.

This report concentrates on a few representative substances

Despite the variety of chemical contaminants and their different origins and uses, evidence suggests that many of these materials behave in a similar way physically. For this reason, discussion here is limited to a few representative substances. In Boston Harbor, the main sources of toxic materials, which are frequently associated with particulate matter, are sewage effluent, sludge, and rivers, as illustrated in Figure 2.2. Toxic contaminants enter the MWRA sewerage system from industrial and commercial discharges, residential discharges, and street runoff.

Fate of Materials in the Harbor

Some contaminants are carried out of the harbor; others remain and are deposited in sediments

Having seen where most of the contaminants come from, we must look at where they go once they enter Boston Harbor. As already discussed, the major sources of contamination to the harbor are sewage effluent, sludge discharge, and CSOs. The locations of the existing discharges are shown in Figure 2.3. Contaminants from these sources tend to be associated with fine particulate material because many toxic chemicals and bacteria adhere to particles in the discharges or in the receiving

How severe is the toxic contamination in Boston Harbor?

The severity of toxic contamination in Boston Harbor can be evaluated by considering (1) levels of specific contaminants in effluent, water, and sediment; (2) the bioaccumulation of these materials in marine animals; and (3) the toxicity of the effluent as a whole.

There is evidence that the amounts of specific contaminants being added to the harbor are declining. MWRA routinely collects monthly samples of influent, effluent, and digested sludge from its facilities. These samples are analyzed for the presence of toxic metals of concern. In addition, at intervals, samples are taken for other pollutants, including PCBs and other organic compounds. Analysis of these samples shows that, on average, the amount of metals entering the two sewage treatment plants and then being discharged to Boston Harbor is about 75% lower than it was 8 years ago. For PCBs, compounds whose manufacture was banned in the 1970s, current levels are at least 100 times lower than 10 years ago. Three major factors have contributed to the decline in the amount of toxic materials being added to Boston Harbor:

- MWRA has strengthened its controls on industrial and commercial discharges. Stricter regulation includes establishment of local limits governing discharge of toxic materials, more industrial inspections, and tougher enforcement.

- Public awareness of the problem has increased. Presentations by MWRA, harbor tours by Save the Harbor/Save the Bay, exhibits at the New England Aquarium, and efforts by the Conservation Law Foundation and Greenpeace have all played roles in public education.

- The Federal government has taken action on a national level. Manufacture of many of the most toxic pesticides and other hazardous materials has been banned. In addition, EPA has developed standards for its pretreatment program, which regulates the amount of toxic materials that an industrial discharger can dispose through a sewer system.

Bioaccumulation, the second method of judging toxic contamination, is studied in the harbor through experiments using caged mussels placed near the effluent outfall and through other studies that measure tissue levels in natural populations of animals. These studies are discussed in Section 4.

Finally, the toxicity of the discharged effluent can be assessed by exposing marine organisms, typically algae or shrimp, to various concentrations of effluent for a standard period in the laboratory. The concentration at which 50% of the organisms die is known as the LC50. The toxicity of Boston Harbor effluent ranked below the midpoint of 30 effluents, from other urban sewage treatment plants, tested by EPA in 1989—that is, the wastewater discharged by MWRA was less toxic than half the other effluents tested. MWRA's goal is to produce effluent with no acute toxicity at all.

water. Broadly speaking, two things can happen to these particles and their associated contaminants – they can be flushed out of the harbor or they can remain within its confines and eventually sink out of the water and be deposited on the bottom.

Water Movement

Water circulation in the harbor is strongly influenced by the tides; this movement helps to determine the fate of contaminants

We must know how the water moves to understand where particulate matter ends up. The water circulation in the harbor is dominated by the strong tides found in New England. The tides are magnified because the natural resonance frequency of the Gulf of Maine/Bay of Fundy system is close to the frequency of the lunar semidiurnal tide. Boston Harbor lies at the southeastern end of the Gulf of Maine; although the tides, with an average range of 2.7 m, are smaller than those in the Bay of Fundy, they are still large compared to those south of Cape Cod.

The time that dissolved materials remain in the harbor is estimated to be 1 to 2 weeks

Boston Harbor is generally very shallow. At mean low water, the average depth is less than 3 m, except in President Roads and Nantasket Roads, the shipping channels. Therefore, nearly half of the water in Boston Harbor exits on an ebb tide. Based on the volume of the tidal flow, the residence time (the time that the water remains in the harbor) is about 1 or 2 days. However, the Inner Harbor and shallow areas of the Outer Harbor are flushed more slowly than the deep channels. Numerical modeling and field studies conducted by the Massachusetts Institute of Technology indicate that the residence time of dissolved constituents in the harbor is 1 to 2 weeks.

Boston Harbor is an unusual estuary in that over half of its freshwater inflow comes from sewage effluent, and this enters at the mouth rather than the head of the estuary. The major rivers that discharge into Boston Harbor are the Charles, Mystic, Chelsea, and Neponset; their combined flow is about 10 m^3/s. The effluent flow, by comparison, is about 20 m^3/s.

There is little stratification (that is, vertical layering due to differences in temperature and salinity) of the water in the harbor. Strong tidal currents act to mix the harbor water, keeping stratification to a minimum. The large volume of tidal flow must enter and leave the harbor through the narrow, deep harbor entrances. Tidal currents of 50 cm/s have been measured in these shipping channels. Constriction of this flow causes turbulent mixing, and the flow around the many harbor islands also serves to mix the water.

The U.S. Geological Survey (USGS) has constructed a two-dimensional mathematical model of the harbor, which, unlike previous models, can resolve eddying motions and variations in currents due to flow around the harbor's complicated bathymetry.

A computer model of the harbor helps to understand water movement and predict contaminant fate

Experiments with the USGS model, combined with field observations of the sewage plume from Deer Island and tidal residual flow, indicate that effluent-derived solids are being concentrated in the area of the Deer Island Flats. On the ebb tide, the discharge from Deer Island is effectively mixed with seawater in President Roads and carried out of the harbor along the North Channel. Effluent discharged on the flood tide enters the harbor and turns northward onto Deer Island Flats.

On the outgoing tide, sludge produced at the Nut Island Treatment Plant is discharged into President Roads from an outfall at the tip of Long Island. Field observations suggest that the sludge plume does not move far from its discharge site, at least during calm weather. On the flood tide, some of the sludge plume may return to the harbor. The model predicts that, on the early part of the ebb tide, the sludge leaves the harbor along the South Channel. Sludge discharged later in the ebb stays near Long Island.

Comparison of the Nut Island sludge plume with the Deer Island plume shows that the discharges behave very differently even though they are released in the same narrow channel. Drs. W.R. Geyer of the Woods Hole Oceanographic Institution and R. Signell of the USGS suggest, on the basis of current measurements in the channel, that the Nut Island sludge is released in a stagnant region caused by coastline geometry.

The motion of the effluent plume from the Nut Island outfalls has also been described. Discharges from these outfalls usually exit the harbor through Nantasket Roads on the ebb tide and enter Hingham Bay on the flood; however, the motion of this plume is influenced most by the direction and strength of the wind. The USGS model predicts that material from the Nut Island effluent plume remains in Hingham Bay and Nantasket Roads. In general, the fate of sewage particles released from the sludge and effluent outfalls is very sensitive to the phase of the tide and the location of the outfall.

Sediment Deposition

Particles, and associated contaminants, are eventually deposited to become part of sediments

The distance that particles are carried with water movements depends on the size of the particles and the strength of the currents. Eventually, the particles settle out of the water and become part of the bottom sediments. The distribution of sediment types on the harbor bottom shows the effects of tidal currents. In President Roads and Nantasket Roads, the strong currents scour the fine sediment away, leaving sandy or gravelly sediments. Fine sediments are deposited on shallow mud flats or in those deep areas that have less energetic circulation. Large depositional areas are found over much of the southern half of the harbor. Shallow areas around some of the harbor islands and some of the mainland shoreline are also sandy, because wave action does not allow fine sediment to accumulate. Areas in which the currents vary considerably in time or space have a combination of erosion and deposition of fine sediments. Sediment texture is important in determining not only the concentrations of contaminants in the sediments, but also the type of animals that live there.

Many of the solid particles from sewage have been shown to settle in the harbor

Any particles of effluent and sludge that are not transported out of the harbor with the circulation described above will settle somewhere in the harbor. A field study of sludge plumes from Deer and Nut Islands included profiles through the plume to determine if the sludge reaches the bottom in the vicinity of the discharges. The Nut Island sludge outfall discharges in and near very shallow water, so the plume essentially reaches to the bottom. Additional evidence comes from measurements of spores of *Clostridium perfringens.* This bacterium is found in the digestive systems of mammals and is excreted along with waste products. Outside of the body, the bacteria form spores, which make a good "tracer" for the presence of sewage, especially sludge, because they are resistent to chlorination, persist in the environment for a long time, and are easy and inexpensive to measure.

There is evidence that initial deposition of sewage solids from the treatment plants occurs at the northern tip of Long Island and on Deer Island Flats. No information is currently available about deposition of solids from the Nut Island effluent discharge into Nantasket Roads.

Resuspension, Transport, and Long-Term Accumulation

The fate of contaminants is complex: deposited particles can be resuspended and move from their initial settling location

Contaminated particles deposited close to their source may eventually find their way to distant parts of the harbor, or even out of the harbor, by being resuspended and transported along the harbor bottom. This may occur during particularly large tides or during storms. Solids will ultimately tend to accumulate in depositional areas where tidal currents are weak or where there are depressions in the seafloor. Transport and depositional processes are very complex, producing heterogeneity in distribution of contaminants and hot spots of accumulated material.

To determine which areas of sediment deposition are affected by sewage, MWRA has measured spores of the sewage tracer *Clostridium perfringens* in the bottom sediments of the harbor (Figure 2.4). Concentrations throughout the harbor are at least 100 times higher than

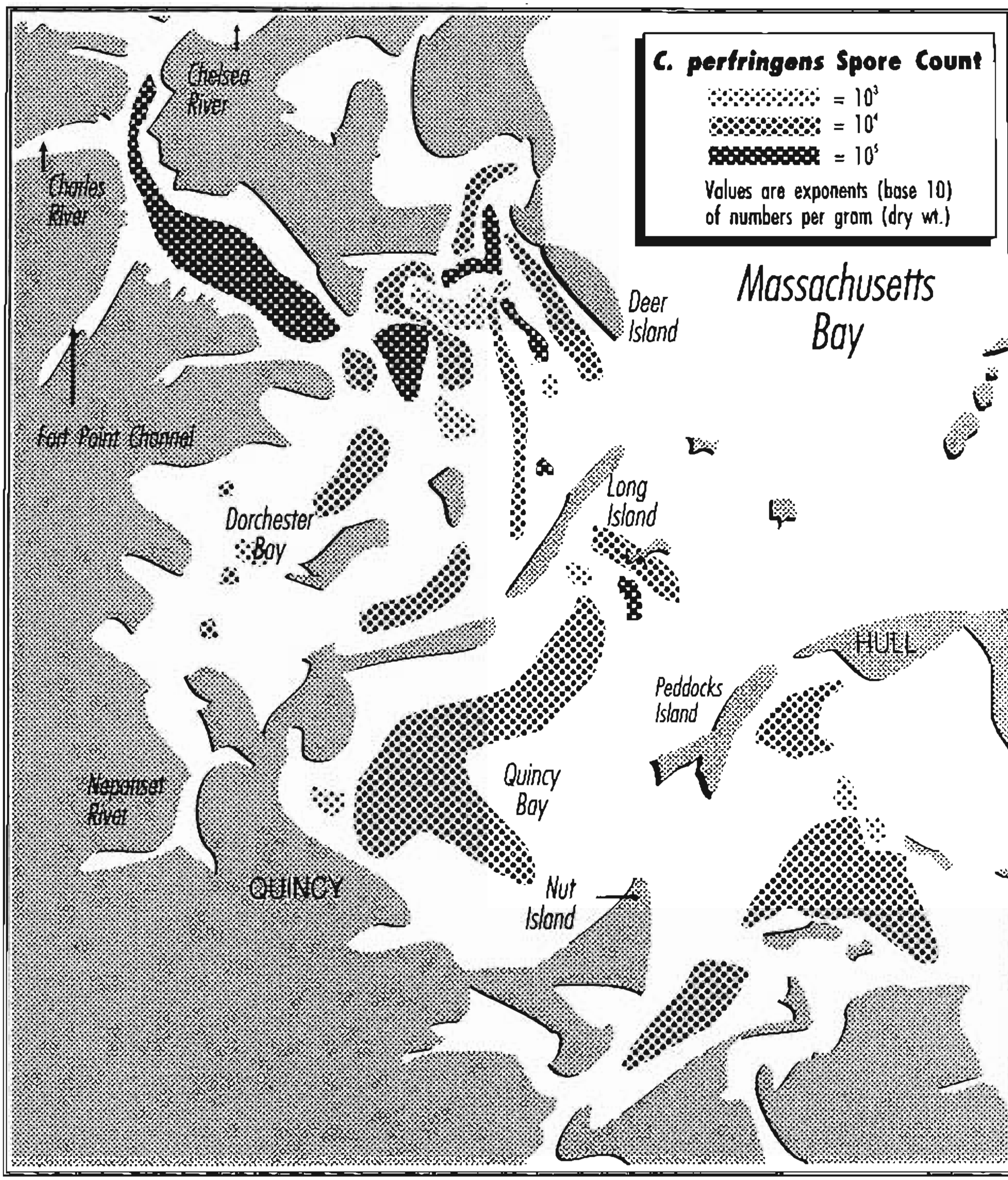

Figure 2.4. The spores of *Clostridium perfringens* show where sewage is being deposited in the harbor. Figure adapted from SAIC (1990).

those found in Narragansett Bay, Rhode Island. Especially high levels were observed near the Nut Island sludge discharge at the tip of Long Island, on Deer Island Flats, in the Inner Harbor, and in Quincy Bay.

3. IS IT SAFE TO SWIM IN BOSTON HARBOR?

Pathogen contamination at harbor beaches is monitored by the MDC during the swimming season

Most Boston Harbor beaches are not heavily used for swimming, perhaps because of a perception that they are all polluted. Although some harbor beaches, like Wollaston and Tenean, are posted with a health warning more than 50% of the time, others, like Pleasure Bay, are almost never posted (Figure 3.1).

The Metropolitan District Commission (MDC) conducts a weekly testing program at Boston Harbor beaches during warm weather. Until 1988, MDC analyzed samples for fecal coliform bacteria only; this indicator group is described in Section 2. In 1988, the program was expanded to also test for the presence of *Enterococcus*, another group of bacteria found in the feces of warm-blooded animals and thus indicative of the presence of sewage. Enterococci, like some viruses, are more able to survive in salt water than are coliform bacteria. Numbers of enterococci have been shown to correlate with rates of diseases associated with swimming. When tests show that fecal coliform concentrations exceed a geometric mean of 200 in each 100 milliliters of

What are the risks of swimming in seawater contaminated with sewage?

The most common public health risk of swimming in seawater polluted with pathogens from domestic wastewater is the possibility of contracting gastroenteritis. Gastroenteritis is an infection of the stomach and intestines; its symptoms include stomachache, diarrhea, nausea, and vomiting, sometimes accompanied by a low fever. The symptoms, although usually short-lived, can be violent, and the effects can be severe in older people or in those who have other health problems. Most cases of gastrointestinal illness associated with seawater are attributed to a virus known as the Norwalk agent. Because the symptoms tend to be self-limiting and the patient recovers without medical attention, the actual frequency of such illness is difficult to estimate. More serious risks—including typhoid, hepatitis, dysentery, and infections of the skin, eye, and ear—do exist; but again, it is difficult to estimate their frequency.

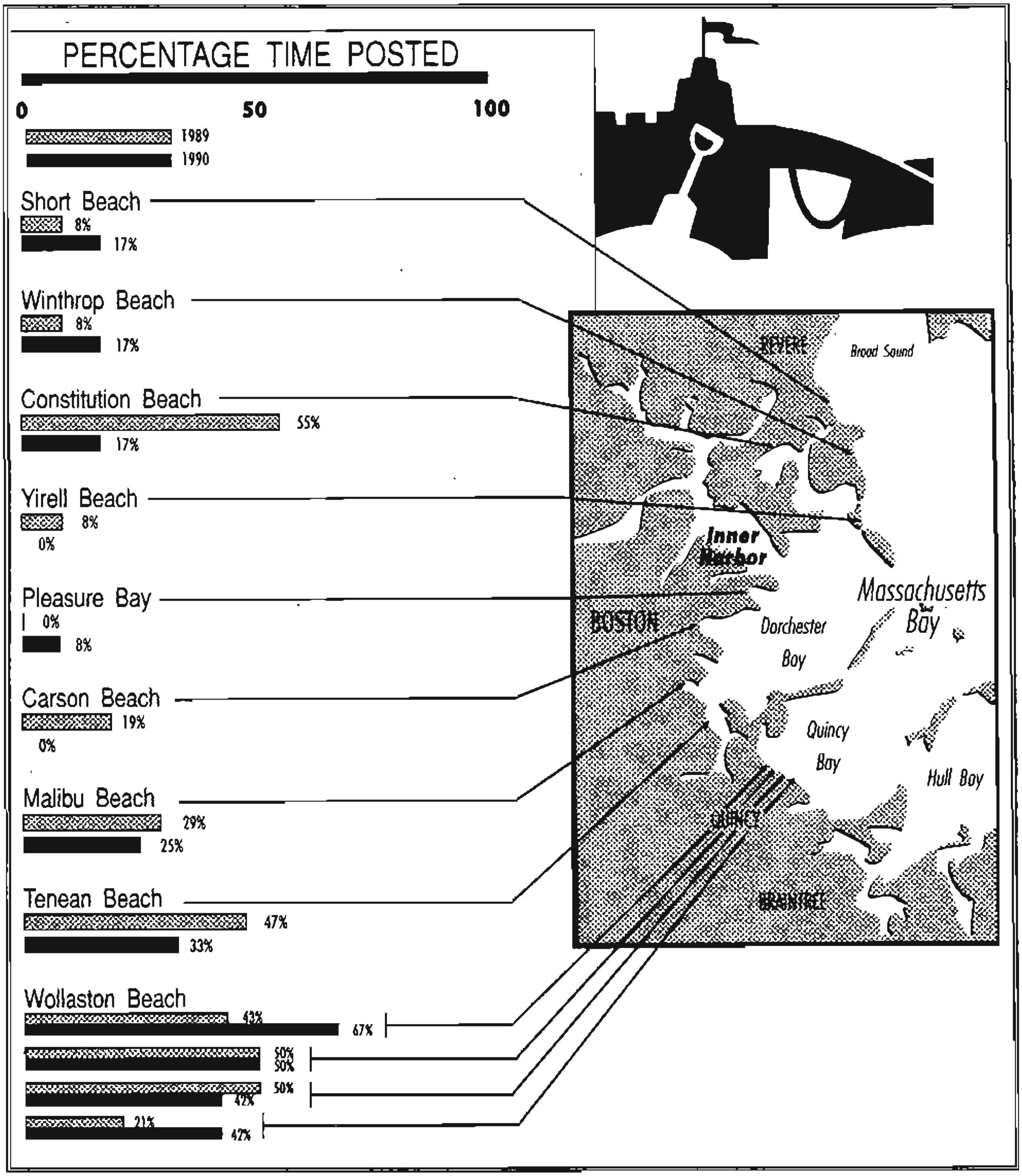

Figure 3.1. In 1989 and 1990, most of the major harbor beaches were posted as polluted at least once during the summer. Percentages represent the number of times pathogen levels exceeded standards, divided by the number of times the beach was tested.

water, or when enterococci are more abundant than 33 per 100 mL, signs are posted warning that swimming may be hazardous.

Pathogen concentrations are affected by many factors, but rainfall increases the likelihood of contamination

Pathogen contamination is found in localized hot spots that are caused by different factors, depending upon location. However, rainfall is a triggering mechanism for beach pollution, whether the immediate source is CSO discharge, stormwater, river influence, or effluent. It takes 3 to 4 days for the harbor to recover after a large rainstorm washes pathogens into its waters. Beach contamination is also influenced by water circulation in the area. Beaches in open areas swept by strong currents are less likely to suffer from contamination than those in enclosed or depositional areas. The factors that affect water quality are complex, and we are still learning about how they interact to determine conditions in a given location.

The Outer Harbor

At Outer Harbor beaches, pathogen conditions are influenced by different sources

In the Outer Harbor, sources of pathogen contamination include effluent and sludge discharges, CSOs, storm drains, and river inflow. The relative importance of different contamination sources differs from beach to beach.

Effluent

Wollaston Beach can be affected by effluent discharge if heavy rains cause some sewage going to Nut Island to bypass the treatment plant. Sludge and effluent discharges may affect the harbor island beaches, and may occasionally be carried to Malibu and Tenean beaches by tidal currents.

Storm Drains

Many beaches that experience pathogen contamination are in proximity to one or more storm drains. Although stormwater carries some bacteria from land drainage, illegal sewage connections to storm drains are the main origin of contamination. The Boston Water and Sewer Commission is working to eliminate such illegal connections. Storm drains are a major source of pathogens to Wollaston Beach, Tenean Beach, and Constitution Beach. Figure 3.1 shows that water quality at Constitution Beach improved in 1990, mostly because illegal connections were eliminated.

CSOs

Water quality at Malibu, Constitution, and Tenean Beaches has historically been affected by discharge from CSOs in these areas. Now, however, treatment facilities have been installed near these three locations to alleviate beach pollution. As mentioned above, Constitution Beach shows improvement. At these facilities, waste is screened and chlorinated before it is released to the harbor. In the past, Wollaston Beach was also affected by a large CSO on Moon Island, but discharges from Moon Island are now much less frequent and are chlorinated.

Rivers

In several rivers that flow into Boston Harbor, bacterial contamination upstream of all CSOs is high enough to violate standards, but the source of the problem is incompletely understood. Contamination from the Neponset River is responsible for continuing problems at Tenean Beach.

The Inner Harbor

The Inner Harbor is often unsuitable for swimming, but a new goal for water quality signals interest in improvement

The State has recently reclassified water in the Inner Harbor from a goal of Class SC (suitable for boating and fishing) to a goal of Class SB (swimmable). Although there are no swimming areas in the Inner Harbor, it is surrounded by residential areas, tourist attractions, walkways, and parks; it is also heavily used for recreational boating. The upgrade in classification reflects public interest in improving water quality in this area.

Nevertheless, a study conducted by MWRA in 1989 to monitor water quality and the effects of CSOs showed that most areas in the Inner Harbor violated less stringent Class SC standards during wet weather. Two areas, Fort Point Channel and a station in the lower Mystic River, violated Class SC standards during dry weather as well. During dry weather, much of the Inner Harbor had counts of indicator bacteria below 200 colonies/100 mL (swimmable, or Class SB, standard), but the high counts caused by wet weather meant that the Inner Harbor did not, overall, meet the swimmable standard.

CSOs and stormwater cause most pathogen contamination in this area

In the Inner Harbor, CSOs are the major source of pathogens, followed by stormwater. A major issue is whether contamination from the Inner Harbor affects beaches in the Outer Harbor. Recent dye studies showed that contaminated water, especially in Fort Point Channel, stayed in the Inner Harbor long enough for a large proportion of the pathogenic bacteria to settle and die off before they reached the Outer

Harbor. Inner Harbor water is diluted with relatively clean Outer Harbor water over the distance to the nearest beaches (Carson Beach and Pleasure Bay). Thus, after an average storm, high bacterial counts at beaches can usually be attributed to sources other than the Inner Harbor.

REPORT CARD	Now	1992	1995	2000	2005
IS IT SAFE TO SWIM?					
Swimming beaches	D	D+	C	C	B

4. IS IT SAFE TO EAT FISH AND SHELLFISH?

Another question of great interest to the public is whether fish and shellfish from Boston Harbor are safe to eat. At present, some fish and other animals in the harbor are diseased and some have high levels of toxic or pathogen contamination.

Bacterial Contamination in Shellfish

Because of pathogens, no clam beds in the harbor are open for unrestricted harvest

There are extensive beds of soft-shelled clams *(Mya arenaria)* in Boston Harbor. At present, however, all of them are either entirely closed or are restricted to harvest by master diggers who must subject the shellfish they collect to a purifying procedure known as depuration. These measures are required because of the high levels of pathogen contamination, as measured by indicator organisms, found in the beds.

The State's Division of Marine Fisheries (DMF) assesses levels of pathogens in harvesting areas by monitoring indicator bacteria; that is, bacteria whose presence is associated with sewage. DMF uses standards established by the National Shellfish Sanitation Program. The program is overseen by the Interstate Shellfish Sanitation Conference, and incorporates action levels approved by the U.S. Food and Drug Administration (FDA). These action levels specify that a harvesting area must be closed if the geometric mean of the most probable number (MPN) of fecal coliform bacteria, the indicator used, exceeds 14/100 mL or if more than 10% of the samples exceed an MPN of 43.

Harvesting with depuration is sometimes allowed in selected beds

On any given day, DMF tries to locate at least three areas that can be open for harvest with depuration—one area in the East Boston/Winthrop region; one in Quincy Bay; and one in either Weymouth, Hingham, or Hull. It is usually relatively easy to find an acceptable area in Hingham or Hull, because these have the best overall water quality. In Quincy Bay, the large number of flats means that the odds are in favor of finding one with acceptable pathogen levels. It is most difficult to keep beds open in Weymouth, East Boston, and Winthrop. Interestingly, the most productive beds are found on Bird Island Flats, an area that is sometimes closed because of contamination by effluent from Deer Island.

Even when fecal coliform contamination is low enough that beds are open in all three areas, there is still one obstacle to harvesting. The only place the shellfish can be taken to cleanse themselves of bacteria is a depuration plant in Newburyport, and it can handle only 200 to 250

Experience has shown that levels of pathogens in the harbor's shellfish beds are directly related to rainfall

The Massachusetts Division of Marine Fisheries has formulated general rules for the management of the shellfish resource in Boston Harbor. These rules are based on studies of pathogen concentration after rainfall. When the amount of rain is between 1/2 and 1 in., all beds are automatically closed for at least 3 days. When the amount of rain exceeds 1 in., the beds are closed for at least 5 days. When an unusual amount of rain falls in a short time, the beds are closed until testing can demonstrate that pathogen concentrations have declined to an acceptable level.

bushels of shellfish each day. Thus, the capacity of the purification facilities may limit the number of acres open to restricted harvesting.

Threat of some types of disease has been virtually eliminated; other illnesses can still be contracted from contaminated shellfish

The answer to the question of whether it is safe to eat Boston Harbor shellfish is complex. As a result of the State monitoring program, legally harvested shellfish can be assumed not to have unsafe levels of bacteria that have a direct association with sewage. For example, the Shellfish Sanitation Program has virtually eliminated outbreaks of typhoid fever, which was formerly the major disease caused by consumption of contaminated shellfish.

Today, the most common illness from eating shellfish is gastroenteritis. As noted in the section on swimming (Section 3), symptoms are usually self-limiting – principally involving stomachache, diarrhea, and nausea, with perhaps a low fever or vomiting – and seldom require medical attention. Microorganisms responsible for gastroenteritis include bacteria belonging to the genus *Vibrio,* and viruses, especially the Norwalk agent. Hepatitis A, a more serious, but rarer, viral illness, can also be contracted from contaminated shellfish.

Proper cooking of shellfish can reduce the chance of illness

Studies suggest that the presence of viruses and vibrio bacteria does not correlate well with the presence of fecal coliform bacteria, the indicator organism on which routine testing is now based. There is also evidence that depuration may not offer protection against illness from these pathogens. However, the odds of contracting such illnesses are reduced by proper cooking of shellfish. Although a clam will open after about a minute of steaming, 4 to 6 min are needed to inactivate viruses. In 1986, the *New England Journal of Medicine* published an article recommending that the practice of eating raw shellfish from *any* area should be reconsidered in light of evidence that the risks are higher than previously realized.

Toxic Contamination in Marine Animals

Most studies of toxic contamination in marine animals have concentrated on winter flounder, mussel, and lobster. A few other species (other bivalves such as oyster and soft-shelled clam; crab; and other fish) have been examined in some studies, but not consistently enough to build a good information base.

Fish

Winter flounder are a good subject for study of toxic contamination

Winter flounder *(Pseudopleuronectes americanus)* are chosen for study for a combination of reasons. First, they are abundant and thus easy to sample. Second, they represent a significant resource – the recreational fishery for this species is the largest fishery in the harbor. Third, because of their living and feeding habits, winter flounder are susceptible to the effects of a contaminated environment. Like all flatfish, winter flounder, or blackback, live on the bottom, frequently burying themselves in the sediments. They feed on small invertebrate animals found on or in the sediments. Flatfish are exposed to contaminants directly (from sediment particles taken in during feeding) and indirectly (from their prey, which absorb contaminants as they feed). One invertebrate, the polychaete worm *Capitella capitata,* is a common food for bottom feeders and is able to tolerate contaminated environments. This species is found in abundance on the Deer Island Flats, which are near the Deer Island outfall that discharges sludge and primary effluent into Boston Harbor. Flatfish, because of their lifestyle, are more susceptible to adverse effects and disease due to contaminated sediments than are roundfish (e.g., silver hake) that live and feed in the water column.

PCBs, PAHs, and trace metals have been investigated in harbor flounder

The contaminants that have received the most attention in Boston Harbor are polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), and trace metals. Three investigations (EPA's Quincy Bay study, and studies performed for the National Oceanic and Atmospheric Administration [NOAA] and the Massachusetts Division of Marine Fisheries) compared levels of PCBs in winter flounder tissue between fish in Boston Harbor and areas farther offshore. All found higher levels in harbor flounder than in offshore specimens. The EPA and NOAA studies examined PAH tissue concentrations in flounder from the harbor and found them to be very low (< 10 ppb) or below the detection limits of the analysis. The EPA study also looked at sediment PAHs and found very high concentrations at two of the sites

The question of PAHs in harbor sediments and seafood

Polynuclear aromatic hydrocarbons (PAH) are natural components of petroleum, but are also formed by the incomplete combustion of hydrocarbons or by the breakdown of hydrocarbon compounds by ultraviolet radiation. PAHs occur naturally in many plants and in fossil fuel and are produced as a result of burning of coal, oil, gasoline, wood, and other fuels. The main source of PAH to the harbor is the combustion of fossil fuels. In the Inner Harbor, petroleum (from waste oil, spills, etc.) is also a significant source of PAH.

Certain PAH compounds are known to cause cancer in man and animals. Early studies described tumors in chimney sweeps and coke-oven workers. Although not all PAHs have known carcinogenic effects, the EPA Quincy Bay study reports that there is sufficient evidence for five PAHs identified in seafood from Boston Harbor to be classed as carcinogenic to animals. These five are benzo(a)anthracene, benzofluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, and dibenz(a,h)anthracene. There is some evidence that PAHs are associated with the development of tumors in fish.

The fact that high levels of PAHs have been found in sediments at the bottom of Boston Harbor is cause for concern about whether local seafood species are accumulating these potentially hazardous chemicals in their tissues. Because PAHs are metabolized by fish and lobster, the absence of these compounds does not always indicate safety because some of the metabolites may be toxic.

sampled (near Moon and Nut Islands). The authors hypothesized that, because PAHs are metabolized rapidly by fish, tissue concentrations may not be a good indicator of exposure. In the one study (EPA) that examined selected trace metals, levels were relatively low in all samples of flounder tissue.

EPA judged the risk of eating Quincy Bay seafood to be average

EPA also assessed the potential public health implications of consumption of seafood from Quincy Bay. It was concluded that consumption of "typical" amounts of flounder (less than 10 meals per year) had risks similar to other eating and drinking activities. Even when PCB levels were elevated in the tissue of food species, concentrations were less than the 2 ppm set as a standard by the FDA.

Mussels

Mussel Watch studies monitor toxic contaminants in shellfish

Until the inception of the Mussel Watch Project established by NOAA as part of the National Status and Trends (NS&T) Program, data regarding contaminants in shellfish in Boston Harbor were relatively patchy with respect to species covered, locations, and chemicals. The NOAA Mussel Watch Project began sampling bivalves at selected sites on the east and west coasts of the United States in 1986. Four sites were established in the Boston Harbor area: one near the Deer Island sewage outfall, one in Dorchester Bay, one in Hingham Bay, and one at Outer Brewster Island. Samples of the blue mussel *(Mytilus edulis)* have been collected once annually since the late winter of 1986 and analyzed for several organic contaminants and trace metals.

Both NOAA and the New England Aquarium have Mussel Watch sites in Boston Harbor

In 1987, the New England Aquarium began its own Mussel Watch research, establishing three sites, including the same Outer Brewster Island site being monitored by the NOAA project, and two additional sites, one near the Central Wharf and one at Peddock's Island. A reference site near Nahant is also sampled. The Mussel Watch studies have provided the first comprehensive overview of the status of contaminants in Boston Harbor shellfish populations. Figure 4.1 shows Mussel Watch sites for both the NS&T and New England Aquarium programs.

Four years of NOAA Mussel Watch data reveal only one temporal trend at harbor sites: PCBs declined at Deer Island

Just how contaminated are Boston Harbor shellfish? Based on measurements of contaminants in fish, shellfish, and sediments by an earlier (1976-1978) U.S. EPA Mussel Watch Program and the first 2 years of the NS&T Program, Boston Harbor was accused of being the most polluted harbor in the country. To examine the validity of this conclusion, we have used the mean contaminant concentration for the past 4 years as a baseline against which contaminant concentrations may be compared among sites and with other sites around the country. This is a reasonable approach because no temporal trends have been detected in any contaminant in mussels at any of the Boston Harbor sites except for a significant decline in PCB concentrations at the Deer Island site over the past 4 years. The mean concentrations can also be compared to results of earlier measurements of contaminants in Boston Harbor shellfish to assess possible long-term changes in contaminant loads in the Harbor's shellfish.

Table 4.1 shows the mean concentrations for five organic contaminant groups and 11 metals monitored annually at the four Boston Harbor NS&T sites. For general comparison, the table also shows regulatory action levels established by the FDA, where they exist. When levels of contamination exceeding the action level are found in a food species from a particular area, FDA issues either a warning or an advisory (depending upon the circumstances) to alert the public to risks

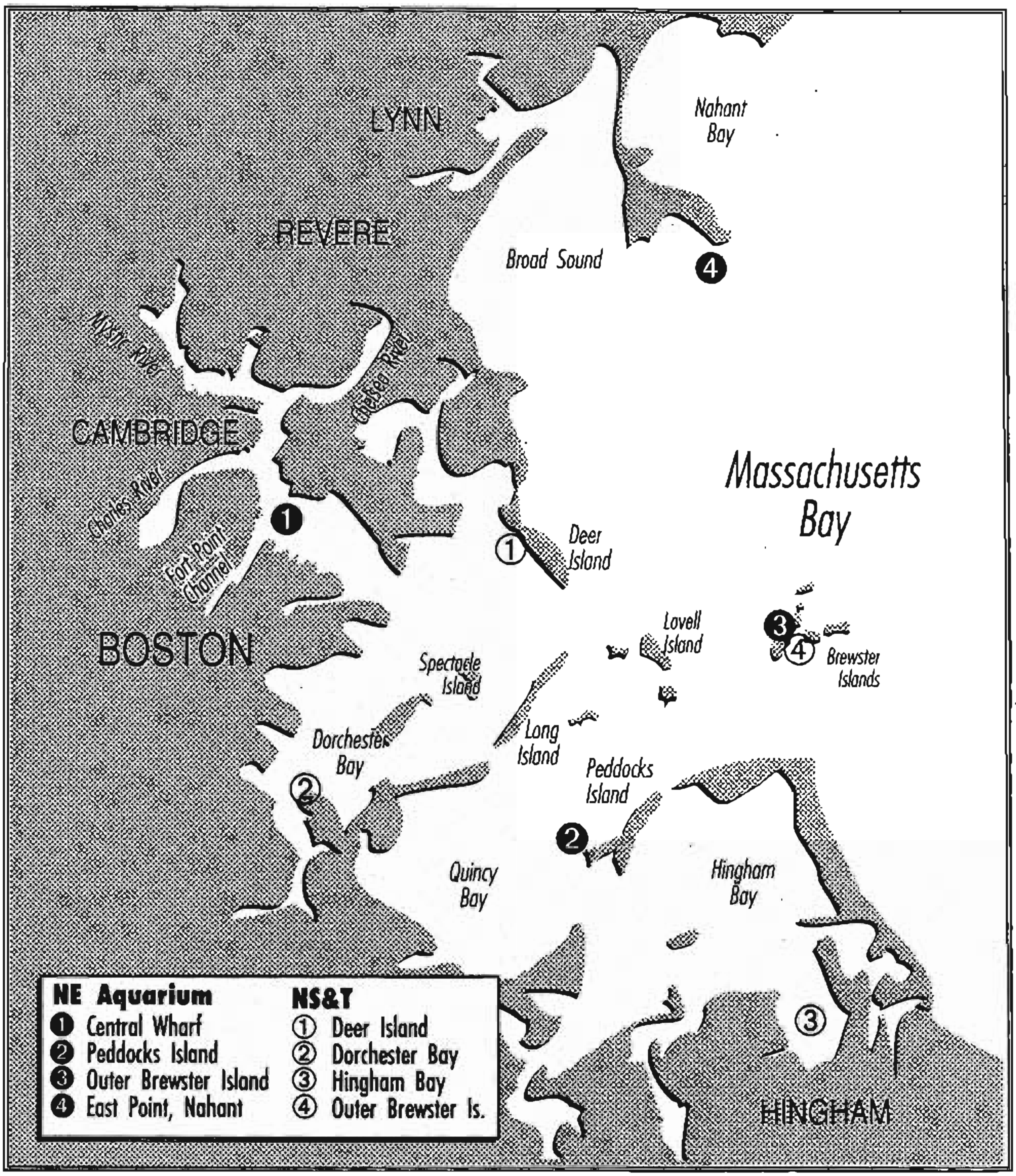

Figure 4.1. Mussel Watch sites monitor the status of contamination in Boston Harbor shellfish.

associated with consumption of that type of seafood. At present, such standards have been set for only a few substances. For other contaminants, the table shows values based on standard EPA methods for assessment of health effects.

PCB values must be interpreted with some caution because the analytical method used in the NS&T Program yields a total PCB value that is about half that obtained by the method used by FDA to set standards.

In general, mussels at all harbor sites have similar levels of contamination

Table 4.1 also shows that, except for low molecular weight PAHs (from a petrogenic source such as oil) in Deer Island mussels and lead in Dorchester Bay mussels, the sites are very similar. Furthermore, results of metal analyses in mussel tissue from the New England Aquarium Mussel Watch study are generally similar to those of the NS&T Program. For the years 1987, 1988, and 1989, concentrations of silver, cadmium, chromium, and zinc are comparable in mussels collected for both programs at the site that they share in the Outer Brewster Islands. Copper results in the New England Aquarium study tend to be somewhat lower, probably because the Aquarium depurates the mussels before analysis, whereas those collected for the NS&T Program are analyzed with full guts that may be high in copper because of the elevated copper content of the sediments.

The fact that results from all sites are quite comparable is worrisome in one respect. The sites range from a location in the Inner Harbor all the way to a reference site near Nahant, but the more distant locations are not demonstrably less contaminated. This suggests that, even when sources of contamination are reduced, improvements in metal contamination will not be detectable for a long time. Changes in organic contaminants, on the other hand, are more likely because the amount of contamination is higher compared to pristine sites.

Boston is among the nation's most contaminated sites for 25% of the contaminants

Table 4.2 illustrates how Boston Harbor sites compare to other NS&T sites nationwide (209 sites). On a national scale, Boston Harbor sites appear on the top 10 most contaminated list for only 4 of the 16 contaminants examined (low molecular weight PAHs, PCBs, lead, and mercury).

Concentrations of PCBs seem to be declining in the harbor

Trends over Time: As stated earlier, no trends over the last few years, except for the downward trend in PCBs, have been detected through either the NS&T or New England Aquarium programs. Because of the inconsistency in species, sampling seasons, and probable changes in analytical technique, it is difficult to make meaningful comparisons of NS&T or Aquarium data with results of earlier shellfish contamination studies in Boston Harbor. Some comparisons, however, might be

Table 4.1. Mean concentrations (ppm dry weight) of selected contaminants in mussels collected at four NS&T sites in Boston Harbor from 1986 through 1989 are very comparable.

Contaminant	Deer Island	Dorchester Bay	Hingham Bay	Brewster Islands	Comparative Value[a]
LMW PAH	2.0	1.6	0.9	1.0	43 (EPA)[b]
HMW PAH	1.7	1.8	1.2	0.8	NA
PCB	0.7	1.4	0.8	0.6	2 (FDA)
DDT	0.1	0.1	0.1	0.1	5 (FDA)
Dieldren	0.02	0.02	0.01	0.01	0.3 (FDA)
Silver	1.1	1.0	1.0	0.7	NA
Arsenic	9.0	9.3	8.7	10.4	11 (EPA)
Cadmium	1.4	1.5	1.0	1.2	11 (EPA)[c]
Chromium	1.7	2.6	1.8	2.1	54 (EPA)[d]
Copper	12.0	14.6	11.5	10.5	430 (EPA)[e]
Mercury	0.3	0.2	0.2	0.2	1 (FDA)[f]
Nickel	0.8	1.1	1.4	1.1	215 (EPA)
Lead	7.3	13.8	8.7	6.3	NA
Selenium	1.5	1.9	1.9	1.9	3 (EPA)
Tin	0.4	0.3	0.2	0.3	6460(EPA)[g]
Zinc	122.4	121.9	109.2	132.5	2150 (EPA)

LMW PAH: low molecular weight PAH; HMW PAH: high molecular weight PAH; NA: not available.

[a]FDA values are regulatory action levels; EPA values are target levels (used for comparative evaluations only) calculated using Risk Reference Dose chronic values. Both are parts per million wet weight.

[b]Based on naphthalene.

[c]Risk Reference Dose for food.

[d]Chromium IV.

[e]From drinking water.

[f]Organomercury.

[g]Inorganic tin.

relevant. For example, comparison of PAH and PCB results from the NS&T samples collected at Deer Island from 1986 through 1989 with results from the earlier EPA collections at the same site shows that PAH and PCB concentrations were somewhat lower in 1976 and 1977 than in 1986 and 1987, respectively. There has been no major shift in PAH concentrations in mussels at Deer Island since 1976, but the decreasing trend in PCB levels since 1986 is apparent in Figure 4.2.

Table 4.2. Boston Mussel Watch sites are compared to the 10 most contaminated sites nationwide. No Boston site ranked in the top 10 for DDT, dieldrin, arsenic, chromium, copper, nickel, selenium, silver, tin, zinc, or high molecular weight PAH.

Mercury	**Lead**
Tampa Bay, FL	Marina del Rey, CA
Hudson - Raritan Upper Bay, NY	Salem Harbor, MA
San Miguel Island, CA	Hudson - Raritan Upper Bay, NY
San Francisco Bay, Emeryville, CA	**Dorchester Bay, MA**
Papys Bayou, FL	Monterey Bay, CA
Matagorda Bay, TX	Anaheim Bay, CA
Moriches Bay, NY	Sandy Hook, NJ
Honolulu Harbor, HI	**Hingham Bay, MA**
San Francisco Bay, San Mateo, CA	Throgs Neck, NY
Deer Island, MA	**Deer Island, MA**

PCBs	**Low Molecular Weight PAHs**
Buzzards Bay, Angelica Rock, MA	Panama City, FL
Hudson - Raritan Lower Bay, NY	St. Andrew Bay, FL
Buzzards Bay, Round Hill, MA	Elliott Bay, WA
Hudson - Raritan Upper Bay, NY	Hudson - Raritan Upper Bay, NY
Sandy Hook, NJ	**Deer Island, MA**
San Diego Harbor, CA	**Dorchester Bay, MA**
Throgs Neck, NY	Jamaica Bay, NY
Dorchester Bay, MA	Throgs Neck, NY
Shark River, NJ	Coos Bay, OR
Galveston Bay, TX	San Diego Bay, CA

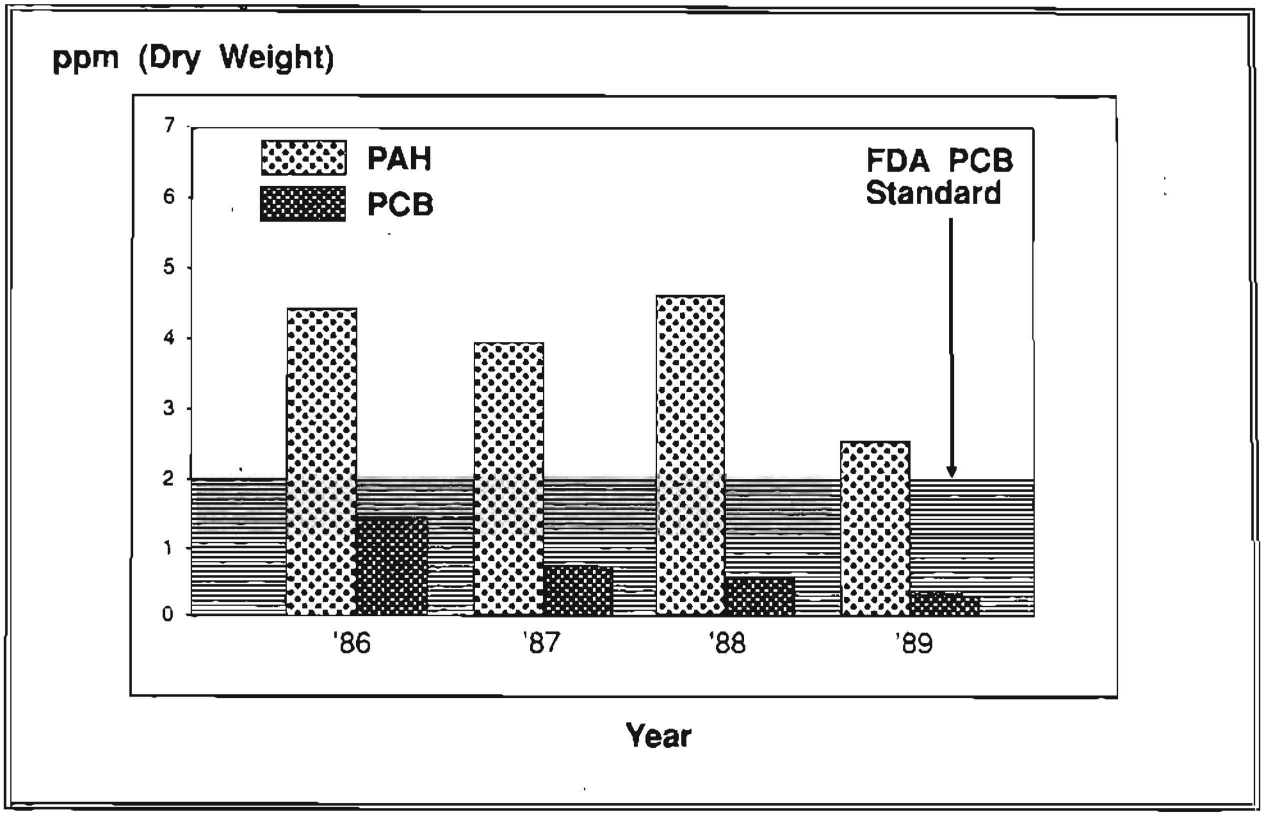

Figure 4.2. PCB concentration in mussels from Deer Island appears to have declined since 1986. No trend is apparent for PAHs. Data are from the NOAA NS&T Mussel Watch program.

Bioaccumulation in Caged Mussels: At least four studies have investigated the rates at which mussels deployed at Boston Harbor sites bioaccumulate selected contaminants in their tissues. These studies were performed with mussels taken from uncontaminated areas and suspended near outfalls at Deer Island, Nut Island, or both. After intervals of about a month, tissue of mussels at the outfall sites was compared with tissue from mussels at control sites.

Mussels kept in cages at outfall sites seem to accumulate some contaminants

In general, all of the studies showed some bioaccumulation for some contaminants at some of the outfall sites. For metals, copper and zinc increased in all four studies, lead and mercury in three out of four, and cadmium, nickel, and arsenic in two. Silver, chromium, and iron increased in at least one study. For the organic compounds, PCBs increased measurably in three studies, and results were inconclusive in the fourth. PAH results were inconclusive in one study and not investigated in a second; in the other two studies, however, PAHs were found to accumulate at least slightly. Although variable, the results of these four studies permit us to conclude that a number of toxic contaminants are both present and available to marine organisms in Boston Harbor.

Lobster

Several studies have analyzed toxic contamination in tissue of lobster *(Homarus americanus)* in and around Boston Harbor.

PCB concentrations in lobster muscle are below the FDA action level

PCBs: The FDA action level for PCBs in marine animals is 2 ppm (wet weight). Concentrations (parts per million wet weight) of PCBs in muscle from lobster caught in Boston Harbor have been found to range from as low as 0.03 to as high as 0.7. Animals examined in the EPA 1987 study of Quincy Bay had concentrations ranging from 0.20 to 0.27. Although these levels are considerably below the action level, differences in analytical methods mentioned previously must be kept in mind. Studies that analyzed concentrations in all edible tissue, including the hepatopancreas, or tomalley, found much higher levels of PCBs. Values for these studies ranged from 0.1 to 61.8 ppm wet weight.

PCB accumulation is higher in lobster tomalley than in muscle tissue

The marked difference in concentrations for different tissue has led to the suggestion that consumers of lobster should avoid eating the tomalley. In evaluating the risk of eating Quincy Bay fish and shellfish, the EPA study concluded that the risk of regular consumption of tomalley from Quincy Bay lobster is high compared to that from other types of eating and drinking activities and is comparable to that associated with consumption advisories or fishery closures in upper New York Harbor and Lake Michigan. Risk of consuming "typical" (about 10 meals per year) amounts of lobster muscle (without the tomalley) was judged to be similar to that of other eating and drinking activities.

PAH concentrations are higher in lobster than in fish

PAHs: Few data are available for PAHs in lobster tissue. The Quincy Bay study, which did analyze PAH levels, found concentrations (parts per million wet weight) up to 0.8 in lobster muscle and up to 4.2 in tomalley. These concentrations are high compared to PAH levels found in winter flounder tissue.

Among metals studied, copper, zinc, and mercury had the highest concentrations

Metals: Of three studies that examined metal concentrations, all found copper to be relatively high. However, the highest mean value (14.4 ppm wet weight) is still below the 430 ppm calculated as a target level using the EPA Risk Reference Dose chronic values, and is comparable to values found by the same study in Salem Harbor. This study, conducted by investigators from the University of Massachusetts Boston Harbor Campus, also found relatively high mean wet weight levels of zinc (17.6 ppm) and mercury (0.14 ppm). Once again, however, these concentrations do not approach the target (2150 ppm for zinc) or action (1 ppm for organomercury) levels for either metal.

Summary

PCBs and pesticides seem to be decreasing in shellfish

For purposes of comparison, FDA action levels are available for PCBs, DDT, dieldrin, and organomercury (see Table 4.1). For some other contaminants, a screening assessment of impacts to human health can be conducted using EPA's health effects assessment methods. The resulting target values have no regulatory significance and serve only to indicate that contaminants at these concentrations should be monitored. Major metal contaminants have been consistently below the action or target levels. As already mentioned, direct comparison of data for PCBs is problematic. A number of the contaminants are found at concentrations among the highest in the region and, in some cases, the country. Only PCBs and the pesticides appear to have been decreasing in harbor shellfish over the past 15 years. Nevertheless, it is reasonable to conclude that from the standpoint of toxic contaminants, Boston Harbor shellfish are relatively safe for human consumption.

Disease in Fish and Other Animals

The issue of disease and abnormal conditions such as fin rot in marine animals is discussed in detail in the next section, *Are Fish and Other Marine Resources Being Protected?*, which deals with the health of the living marine resources in Boston Harbor. The related question of whether animals suffering from these conditions are safe for human consumption is examined here.

The risk of eating diseased fish has not been fully evaluated

The term *safe* does not have a precise definition in this context. Most activities have some risk associated with them, and the key is to decide at what point the risk in a given situation is unacceptable – that is, outweighs the benefits. To date, no such evaluation has been made for consumption of diseased fish.

Transmission of cancer from diseased animals is unlikely, but consumption of carcinogens is a potential risk

One aspect of the question was addressed at a symposium on Chemically Contaminated Aquatic Food Resources and Human Cancer Risk held by the National Institute of Environmental Health Sciences. Participants and members of the steering committee considered the risks associated with consumption of fish or other seafood with tumors and related conditions. These scientists unequivocally agreed that the risk of becoming infected with cancer through transplantation of viable tumor cells, infection by a virus or bacteria, or more subtle mechanisms involving transfer of the genetic material of the consumed tissues is too remote to be worth considering. Any cancer risk, therefore, is confined solely to the effects of ingesting carcinogens present in the animal at the time of consumption. Thus the key question is whether animals with neoplasms have elevated levels of cancer-causing chemicals in their tissue.

Results of various studies show that, although the edible flesh of *some* tumor-bearing fish may contain residues of animal carcinogens such as PAHs and PCBs, this is not the case for *all* tumor-bearing fish. In fact, residues measured in the edible tissue of tumor-bearing fish are usually low. It is true, however, that fish with elevated concentrations of PCBs and PAHs have been found in Boston Harbor, and the implications of this issue are discussed above.

REPORT CARD	Now	1992	1995	2000	2005
IS IT SAFE TO EAT FISH AND SHELLFISH?					
Shellfish: Pathogens	D-	D	C-	C-	B-
Fish: Organic contamination	C-	C-	C	C+	B-
Fish: Metal contamination	B-	B-	B-	B	B+

5. ARE FISH AND OTHER MARINE RESOURCES BEING PROTECTED?

The well-being of marine animals is related to conditions in the water and sediments

Concern about whether marine resources are being protected from pollution is not the same as concern about whether we will be able to safely eat fish and shellfish. In this section, we are interested in the well-being of the resources themselves. We focus on fish and benthic animals as groups that contain commercially valuable species and have been subject to enough investigation to make useful data available. A third factor influencing the choice is the likelihood that members of these groups will show effects that can be related to contamination of the environment. The health of fish and benthic animals is affected by conditions in the water and in the sediments.

What are the priority pollutants?

As defined by the Federal Clean Water Act, priority pollutants are selected compounds considered to be the most persistent, prevalent, and toxic. In marine waters, the following priority pollutants are closely regulated:

Aldrin	Dieldrin	PCB
Arsenic	Endosulfan	Pentachloro-phenol
Cadmium	Endrin	Selenium
Chlordane	Heptachlor	Silver
Chromium	Lindane	Toxaphene
Copper	Lead	Zinc
Cyanide	Mercury	
DDT	PAH	

The harbor usually meets standards for toxic materials; dissolved oxygen and pathogens are sometimes outside established limits

One way to judge the condition of the water in Boston Harbor is by comparing observed conditions with standards established by agencies that regulate the environment. In general, concentrations of the priority pollutants in the harbor are rarely greater than established standards, dissolved oxygen concentrations in the Inner Harbor are sometimes lower than the minimum standard, and concentrations of fecal coliforms and enterococci often do not meet established standards.

Water

Water Quality Criteria

The State has set a goal that Boston Harbor be suitable for swimming and fishing (in some areas, harvested shellfish may require depuration)

The Federal Clean Water Act requires EPA to develop water quality criteria for marine waters. These criteria are then used by the States to set water quality standards designating different classes of waters, based on goals for the use of those waters. Marine and coastal waters are separated into classes, each with a set of minimum criteria as goals for water quality. Waters in Boston Harbor are rated as either SA or SB, as shown in Figure 5.1. Class SA waters are designated for the protection and propagation of fish, other aquatic life, and wildlife. They are intended to be suitable for primary and secondary contact recreation, and for shellfish harvesting without depuration in approved areas. Class SB waters have a similar designation, except that any shellfish harvested must undergo depuration.

Studies show that Boston Harbor usually meets standards that support the State goals

One program that monitors water quality in the harbor is being conducted by the New England Aquarium. Measurements of water temperature, salinity, pH, dissolved oxygen concentration, suspended solids, and turbidity are made monthly between March and November. Data are available for measurements between April 1987 and July 1989. Results from 10 stations in the harbor and one just outside, in Broad Sound, show that, overall, few water quality criteria are being violated in Boston Harbor. The main exceptions are criteria for pathogens and dissolved oxygen in the Inner Harbor. Pathogens are discussed in the previous two sections, because they affect human users of the harbor rather than its marine resources.

Pathogens and dissolved oxygen are sometimes outside set limits

For dissolved oxygen, standards were not met on 10 of 22 sampling dates. Most of these cases were in the Inner Harbor, especially in Fort Point Channel. The minimum oxygen concentration seen, 4.07 mg of oxygen per liter of seawater, could cause physiological stress in marine animals such as fish, but is not low enough to kill a healthy animal. These conclusions are supported by results of other studies conducted by the Massachusetts Audubon Society and the Massachusetts Division of Water Pollution Control.

Metal Contamination

Metal concentrations are generally below established guidelines

Massachusetts has not yet adopted criteria for the maximum concentrations of metals allowed in marine waters; however, some Federal guidance is available. EPA has established Criteria Maximum Concentrations, which are concentrations of contaminants considered safe. For the most part, metal concentrations in the harbor are below these levels.

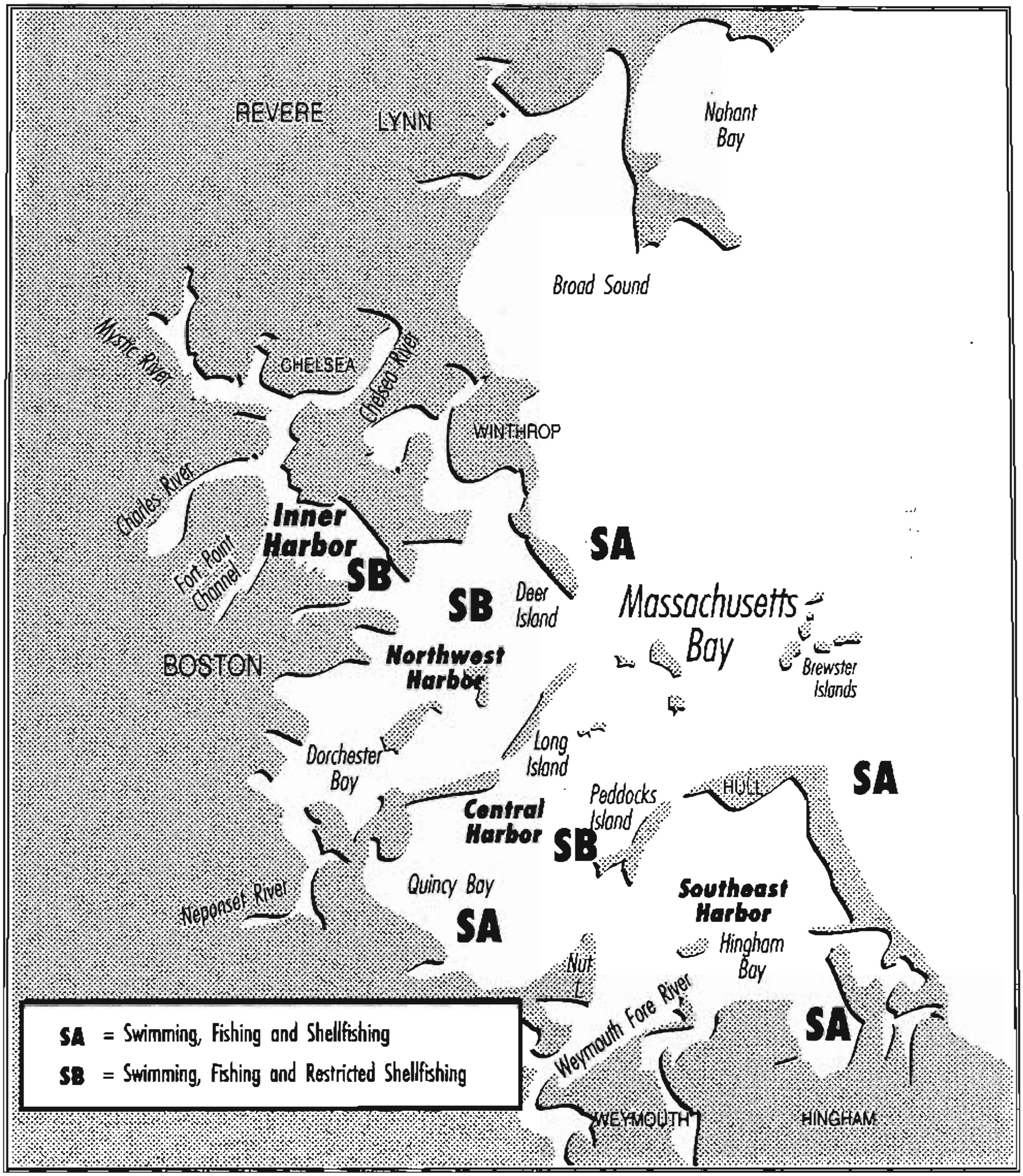

Figure 5.1. Massachusetts Surface Water Quality Standards set goals for Quincy and Hingham Bays of Class SA, the highest quality with the strictest standards. All other harbor areas are Class SB.

Over the years, data have been collected in a number of studies on concentrations of metals in Boston Harbor. To try to establish what the harbor's conditions are now, and how they are changing, MWRA has examined data from six studies by different groups. To simplify the comparisons, two representative metals were examined in detail: copper because of its well-known toxicity and zinc because it is found in relatively high concentrations in the harbor. One further simplification was used. Metals in seawater can be dissolved in the aqueous phase or be adsorbed to particles, but most of the studies found that the particulate concentrations of zinc and copper are about 30% of the dissolved amount. Therefore, only dissolved metals were considered.

Studies suggest that metal concentrations in the harbor are decreasing

Comparison of data from the six studies suggests that concentrations of metals dissolved in Boston Harbor water are decreasing (Figure 5.2). This agrees with the observation, discussed in Section 2, that the amount of metals in sewage entering the MWRA system has declined about 75% over the past 8 years. Additional work is needed to study the remobilization of metals from the sediment to the water column, but indications are that levels of metals in harbor water will respond quickly once the sludge discharge is stopped and the effluent outfall is moved to Massachusetts Bay.

Sediments

Contaminants accumulated in sediments are an environmental problem, but no regulatory standards now exist

The levels of contaminants in the water and biota have been of concern for many years. It has also been recognized for some time that contaminants accumulate in sediments, but most people considered this process a means of removing toxic contaminants and keeping them "in place." It has now become clear that toxic contaminants in sediments also pose a threat to aquatic and human health and that these in-place contaminants can be transported on sediment particles to other areas and released to the overlying water column. Therefore, the levels of contaminants in sediments are as important as those in water. Unfortunately, it is more difficult to assess the condition of sediments than the condition of water because no numerical standards have been established for sediment contaminants. Although EPA and several states are currently developing quality criteria for sediment, the scientific basis for determining what levels of contaminants constitute a problem is not well developed, and several technical difficulties must be overcome before any standards can be implemented.

Current methods used to assess the condition of sediments in Boston Harbor are (1) description of the geographic extent of contamination, (2) comparison of contaminant concentrations in Boston Harbor with other areas, (3) direct observation of the fish and other organisms

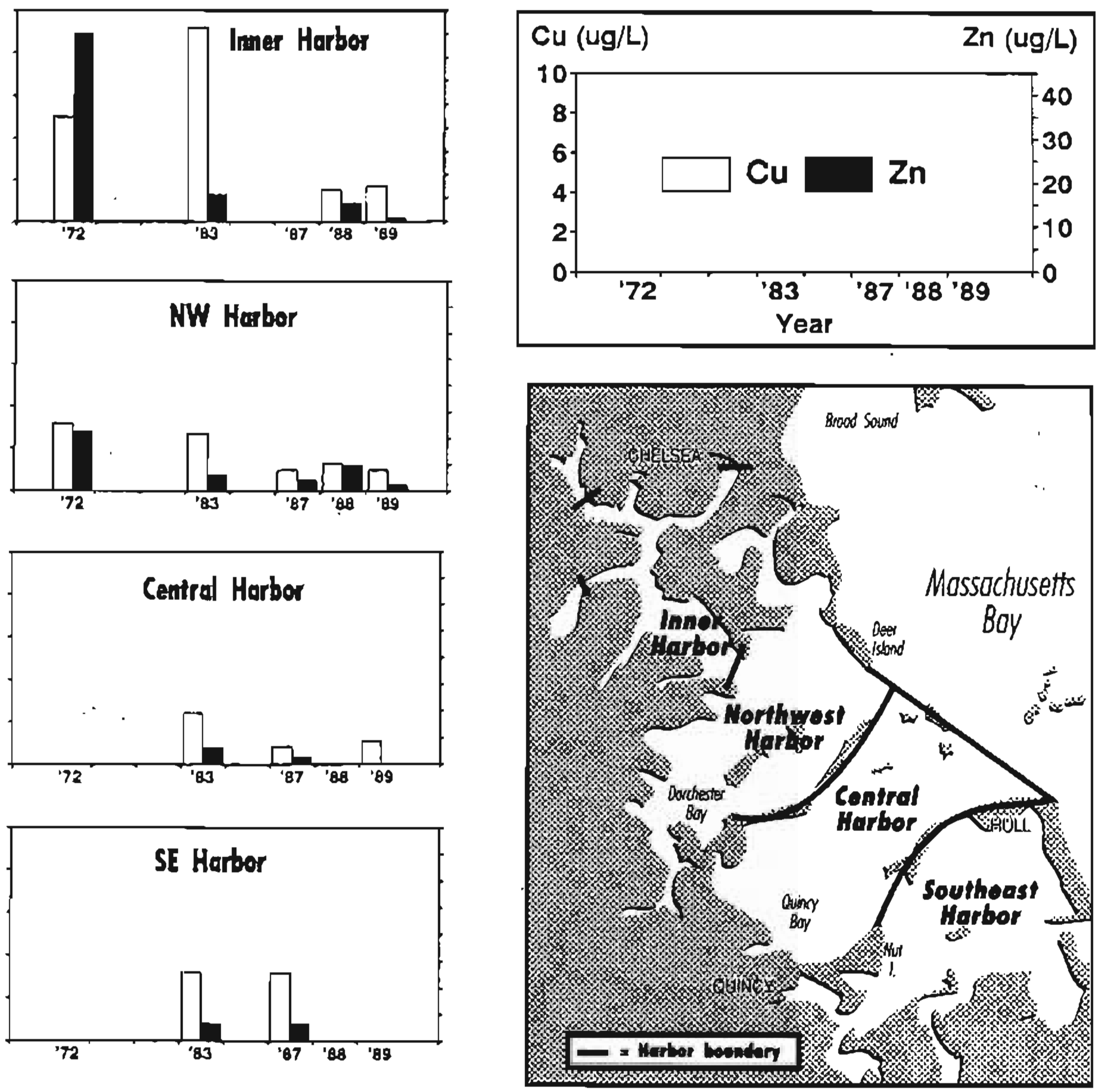

Figure 5.2. Concentrations of copper and zinc in Boston Harbor water seem to have declined between 1972 and 1988. Data from Gilbert et al. (1972), Wallace et al. (1988), MWRA (1988), Sunda and Huntsman (1989a,b).

Why are we concerned about contaminants in sediments?

Many organisms have direct contact with sediments, so contaminants in sediment may have as much of an impact on their health and survival as those in the water.

Many contaminants are not very soluble in water, but readily bind to sediment particles. For example, the levels of PCBs are usually a million times greater in sediments than they are in the overlying water.

Low-level discharge of a contaminant may meet State and Federal water quality standards, but long-term accumulation in sediments can result in high levels. In addition, sediment-bound contaminants will remain for long periods of time, even after the sources of contamination are shut off. This sink can later serve as a source, as contaminants are released from the sediments and sediment particles are transported to other areas.

residing in or near the sediment, and (4) determination of any trends in the levels or geographical extent of contaminants (are the problems getting better or worse?).

Data on present conditions will help assess future changes

The contamination of Boston Harbor began a hundred years ago when domestic and industrial waste was first discharged to harbor waters. Scientific studies, on the other hand, have been conducted for only about 20 years, and any study can provide a picture of contamination levels and locations at only a particular point in time. Nevertheless, data gathered over two decades have helped us reach some conclusions about present conditions. We can now use this baseline of information to monitor changes and assess the response of the harbor to mitigation measures.

Improvements in sediment conditions will take place slowly

The harbor will not recover overnight. Not all sources of contamination are being eliminated, and contaminants built up over the years are tightly bound by sediments. Processes that result in the removal of the accumulated contamination are slow. These processes include gradual release of contaminants to the overlying water, followed by dispersal, or burial by the cleaner sediment that will be deposited in the future. We should, however, begin to see a stabilization of conditions and eventual improvement.

What Is the Extent of Sediment Contamination in Boston Harbor?

Our most reliable information is on the amount of contamination for particular times and places

Several scientific studies have identified the sources and estimated the amounts of contaminants entering Boston Harbor each year. Results from these studies clearly indicate that sewage and CSO discharges are the primary sources of most contaminants and that atmospheric deposition, direct river inflow, and direct land runoff are less important, but still significant. However, the fraction that each source contributes to the total input cannot be estimated very accurately. We also do not know for sure how long the contaminants remain in the harbor or where they eventually end up. What we do know is the concentration of contaminants in many locations within the harbor at a particular time.

Data must be interpreted carefully: a few atypical areas can bias results

The extent of sediment contamination is often expressed as the mean (average) level of a contaminant in a particular area. This assumes that the mean value represents a value typical of the area. In reality, the distribution of contaminants is often uneven: there will be some hot spots and many cleaner areas. For example, a study of organic contaminants in the sediments at five locations in Boston Harbor yielded a mean PAH level of 180 ppm, but only one value exceeded 6.5 ppm. A hot spot on Deer Island Flats had a concentration of 880 ppm and caused the high mean value. If that hot spot is excluded, the mean value becomes only 4.4 ppm. Furthermore, the median value was only 6 ppm, and is much more representative of the typical PAH level in Boston Harbor. The median value in a set of numbers is the value in the middle; 50% of the values are higher and 50% are lower. We can obtain a very different picture of the sediment quality, depending on the distribution of contamination (more or less homogeneous and with or without hot spots) and how we present the data (mean or median). The information presented below includes the mean values with and without hot spots to illustrate this difference.

Most contaminants are highest in the Inner Harbor and decrease in the Outer Harbor from north to south; hot spots are found in areas where sediments accumulate

Levels of contaminants in the sediments of the four regions in Boston Harbor have been reported by several investigators and these data are summarized in Table 5.1. Although it is often difficult (and sometimes inappropriate) to compare data from different scientific studies when different procedures were used for sample collection and analysis, the methods used to obtain these data are considered sufficiently comparable (within a factor of 2 or 3) to develop a general picture of Boston Harbor. Most contaminant levels are highest in the Inner Harbor, decrease slightly in the northwest harbor, decrease still further in the central harbor, and are lowest in the southeast harbor. This pattern is particularly true for PCBs and most metals (copper, lead, cadmium, nickel, zinc, chromium, mercury, and arsenic). Silver and the pesticide DDT are more evenly distributed throughout the harbor. PAHs have an uneven distribution, with locally elevated concentrations, or hot spots, in the Inner Harbor, on Deer Island Flats, and off Moon

Table 5.1. Mean contaminant concentrations (ppm dry weight) in the sediments of Boston Harbor.

Contaminant	Region					Reference Value[a]
	Overall Harbor	Inner Harbor	Northwest Harbor	Central Harbor	Southeast Harbor	
PAH[b]	7.9 (84)	20 (173)	4.4 (154)	4.4 (8)	2.2	35
PCB	0.56	0.75	0.67	0.37	0.17	0.4
DDT[c]	0.035	ND	0.050	0.029	0.025	0.35
Arsenic	14.2	20.3	9.7	10.5	15	85
Cadmium	2.75	4.32	2.91	1.48	1.28	9
Chromium	133	166	145	107	86	145
Copper	105	150	105	84	57	390
Lead	131	192	127	83	101	110
Mercury	1.33	1.61	1.57	0.98	0.71	1.3
Nickel	34	52	27	33	24	50
Silver	3.12	3.32	3.40	3.21	1.22	2.2
Zinc	219	348	184	151	134	270

Data are from Battelle (1990), Boehm *et al.* (1984), COE (1981), DEQE (1986, 1987), Gilbert (1972), Isaac and Delaney (1972), Iwanowicz *et al.* (1973), Shiaris and Jambard-Sweet (1986), U.S. EPA (1987), White (1972). ND = no data.

[a]Effects level (Effects Range – Median) calculated by NOAA (Long and Morgan, 1990) from collated data (see text).

[b]Number in parentheses includes all "hot spots."

[c]Includes DDT and its metabolites. The data set is very small.

Island. Mean PAH levels were calculated both with and without the hot spots, yielding about a factor of 10 difference. The geographic distribution of five of these contaminants is shown in Figure 5.3, along with National Status and Trends (NS&T) data from the remaining New England sites and for the five cleanest NS&T sites in the nation. There are clear differences in the levels of contaminants in different regions of Boston Harbor and very dramatic differences when one considers the hot spots that exist. These hot spots are usually a result of high rates of sediment accumulation – areas where the transport of contaminated suspended particles tends to focus. Thus, small areas within the harbor have become much more contaminated than the overall harbor.

Boston Harbor sediments are generally 2 to 5 times more contaminated than those typical of New England coastal areas

It is clear from the data in Table 5.1 and Figure 5.3 that all of these contaminant levels are significantly above the most pristine sites in the nation. Contaminant levels are elevated by factors from 3 (for arsenic) to nearly 1000 (for PAH), and are even greater at the hot spots. However, the levels of contaminants in Boston Harbor sediments are only 2 to 5 times higher than those typical of coastal New England sediments. Although there are no State and Federal guidelines for sediments, NOAA has collated results of studies for which data on both sediment concentrations and biological effects are available. This information was used to develop effects levels at the midrange of reported values associated with biological effects. On average, PCBs, lead, mercury, and silver concentrations in Boston Harbor exceed the NOAA effects levels. PAHs, chromium, and zinc can exceed those levels in contaminated hot spots.

How Do Boston Harbor Sediments Compare to Other Urban Areas?

Geographical comparisons must be kept in proper perspective

The contamination of Boston Harbor sediments with toxic chemicals received immense public and political attention in the last few years. Comparison of Boston Harbor to other urban coastal regions resulted in the label "the dirtiest harbor in the nation." Comparisons such as these are easily misinterpreted and often inappropriate – comparing apples to oranges. Nevertheless, general comparisons are useful for putting the levels of contaminants in perspective and selecting the areas in greatest need of attention to mitigate environmental degradation.

NOAA NS&T data are useful for general comparisons

The data most commonly used to compare harbor contamination are from the NS&T Program. This is a large data set that does not include a lot of hot spots, so the mean and median values are similar for most sites, and all of the sampling and analytical methods are identical. The mean and range of PAH levels in the sediments of several urban coastal areas measured over the past 4 years is shown in Figure 5.4. Although the mean PAH level in Boston Harbor is elevated above background (Table 5.1 and Figure 5.3), it is similar to other urban areas on

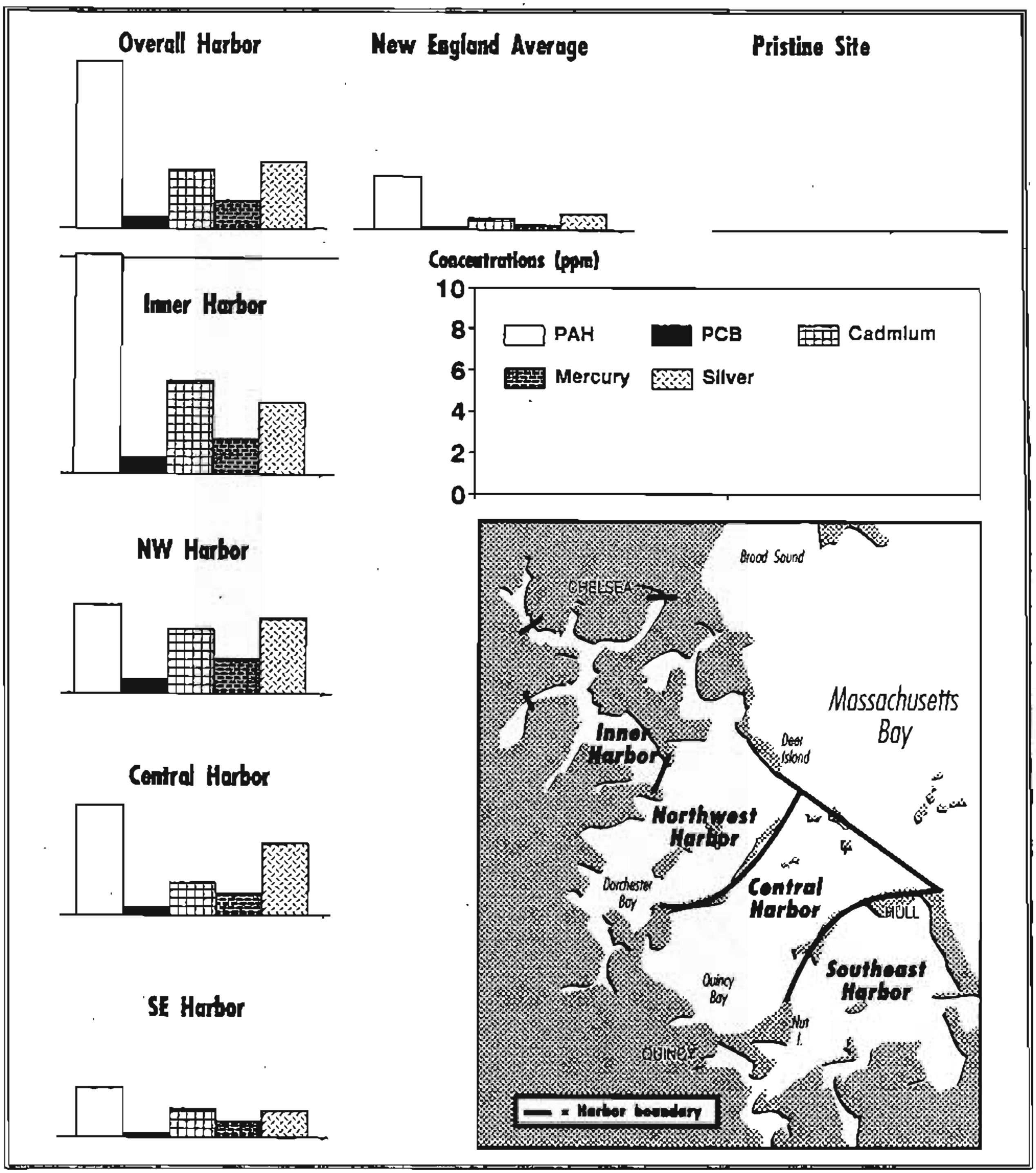

Figure 5.3. The distribution of toxic chemicals in Boston Harbor sediments illustrates the geographic pattern of contamination (excluding hot spots).

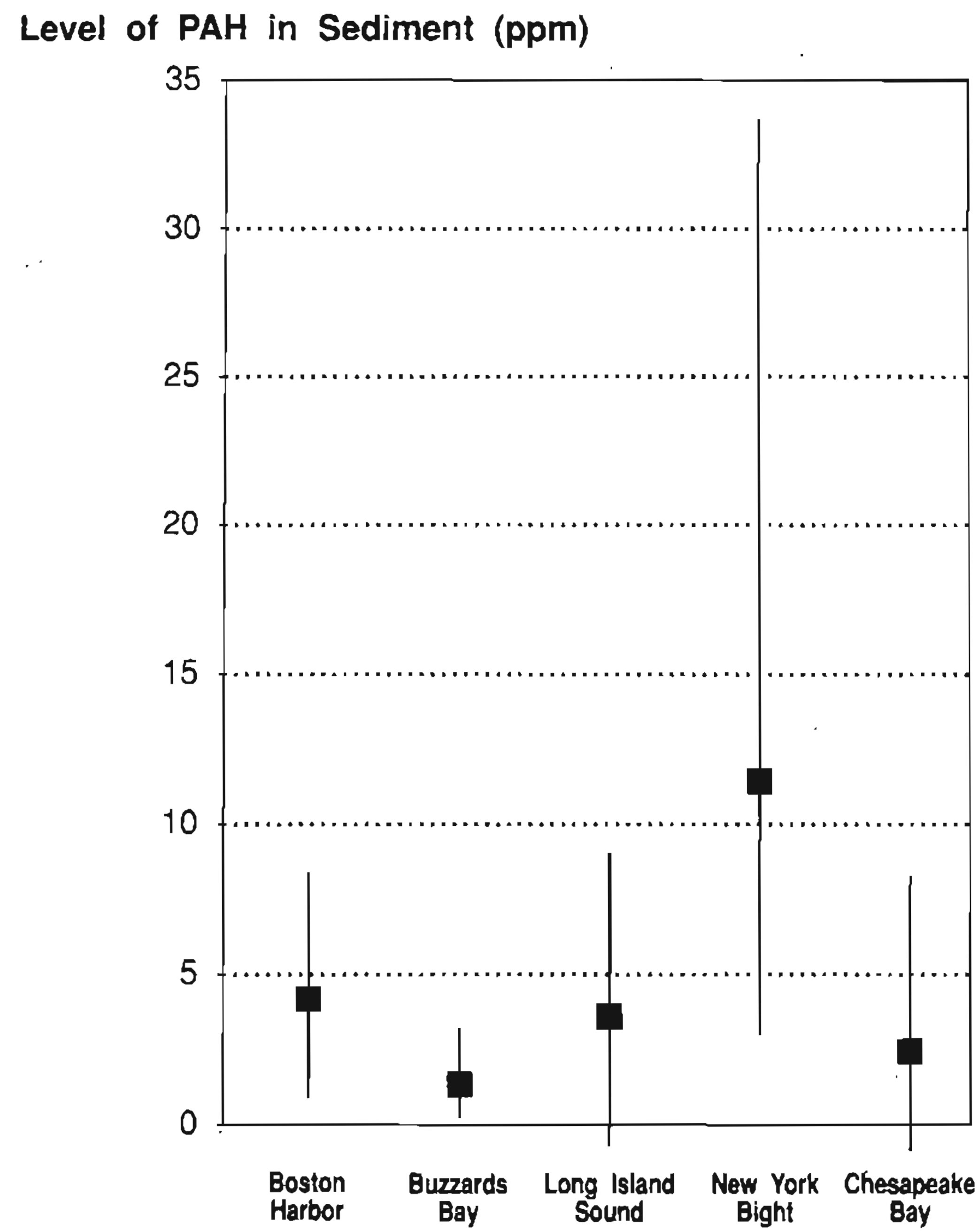

Figure 5.4. Comparison of the levels of PAHs in sediments from several locations on the east coast. The vertical lines represent the range of values and the squares represent the mean. All data are from the NS&T Program.

the east coast. The same type of comparison can be found for PCBs, pesticides, and metals. Thus Boston Harbor ranks among the highest in contamination, but it has a lot of company.

Are the Problems in Boston Harbor Getting Better or Worse?

Some research indicates that concentrations of metals are decreasing

We do not have data from the NS&T program over a long enough time period to determine with confidence whether contaminant levels in Boston Harbor sediments are increasing or decreasing. Only now are we beginning to establish the baseline from which future measurements can be used to determine trends in sediment contamination.

However, some scientists have suggested that the levels of some contaminants, primarily metals, may be decreasing already. These claims are based on data from sediment cores where contaminant levels were measured at depth intervals down into the sediment, rather than just at the sediment surface (all of the data presented above). The core measurements allow one to estimate the historical accumulation of contaminants by measuring the concentration of contaminants at a particular depth in the sediment and using lead-210 dating to determine when those contaminants reached the sediment. 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 could be due to the reduced metal content in the sewage discharges mentioned above. The rates of reductions in input suggest it could take more than 100 years to lower the metal input by 50%. However, this assumes that no further mitigation will occur. With the removal of sewage sludge from the discharge (in 1991), the extension of the outfall 15 km into Massachusetts Bay, and the remediation of most CSOs, the time required to see a noticeable improvement should be much shorter.

Fish

The relation between pollution and abnormal conditions in fish has been studied in winter flounder

A number of diseases and conditions have been observed in fish and linked, at least circumstantially, to pollution. Conditions can be broadly categorized as *external abnormalities*, including fin erosion, skin and gill lesions, parasites, skeletal abnormalities, and abnormal pigmentation; and *internal abnormalities*, involving lesions such as tumors.

Although several recreationally and commercially important fish species are exposed to contaminants in Boston Harbor, investigations of disease

Glossary of disease-related terms

Carcinogen: A cancer-producing substance.

Carcinoma: New and abnormal tissue growth that is malignant.

Fin rot: A condition characterized by the progressive death and erosion of the tissue of the fins in fish; also known as fin erosion.

Hepatic: Pertaining to the liver.

Lesion: An abnormal change in the structure of tissue, caused by disease or injury.

Lymphocytosis: A condition characterized by an excess of normal lymphocytes in the blood; lymphocytes are a type of white blood cell.

Neoplasm: New and abnormal tissue growth that may be either malignant or benign; a tumor.

Preneoplastic: An abnormal change in the structure of a tissue prior to the formation of a tumor.

Vacuolated cells: Cells whose protoplasm contains spaces or cavities; also known as preneoplastic lesions.

and abnormalities in harbor fish have concentrated on winter flounder *(Pseudopleuronectes americanus)*. These studies have focused on winter flounder for the same reasons discussed in Section 4; that is, because they are an abundant and valuable species and because their behavior makes them susceptible to the effects of contamination in the environment.

External Abnormalities

Fin rot is frequently observed in fish

A variety of external abnormalities occur in fish. Fin rot, also known as fin erosion, is the condition recognized most frequently; it attacks the dorsal and pectoral fins. Pathologists disagree about the cause of this condition. No conclusive evidence exists to confirm that fin rot is caused by bacteria, vitamin deficiencies, or pollution.

Authors of a NOAA special report suggested that a fin rot prevalence of greater than 25% is alarming because (1) fin rot seen in 25% of an individual fish stock is rare and indicates the likelihood of other pollutant-induced effects (e.g., lesions) that may or may not have been

Other kinds of external abnormalities in fish

The presence in winter flounder of the other diseases discussed below is not reported in the literature as frequently as fin rot and liver lesions. There is no conclusive evidence to suggest that the occurrence of these diseases in fish is caused by contaminants in the marine environment. Some of these conditions were observed during Fish Day, a monitoring effort sponsored by the New England Aquarium.

Epidermal Lesions
Epidermal (skin) lesions include skin tumors (benign or malignant), viral-induced lesions, and other types of lesions. Epidermal lesions may result from direct exposure to contaminated sediments. Topical application of contaminated sediments to the brown bullhead (Ictalurus nebulosus), under laboratory conditions, resulted in the production of epidermal lesions. Six of 914 winter flounder collected during a series of trawl surveys off Boston from 1979 to 1983 and examined by the Division of Marine Fisheries had skin lesions.

Parasites
Pepper spot disease was reported in 26% (20 of 79) of fish examined for Fish Day. Pepper spot disease is caused by encysted trematodes (parasitic flatworms). It is diagnosed most often in fish collected from inshore areas. Trematodiasis of the gills was observed in 90% of winter flounder collected from Quincy Bay.

Gill Neoplasms/Lesions
Gill neoplasms, a type of tumor, were diagnosed in winter flounder collected during the National Status and Trends Program. Gill lesions were detected in winter flounder collected in Quincy Bay.

Skeletal Abnormalities
Skeletal abnormalities were diagnosed in 4 of 914 winter flounder examined by the Department of Marine Fisheries. Fish Day results indicated that 39% (31 of 79) of fish examined had bent fin rays. The majority (58%) of these fish were caught on Deer Island Flats. Also, 5% (6 of 120) of fish examined for Fish Day were dwarfs.

Abnormal Pigmentation
Color anomalies were diagnosed in 2 of 914 winter flounder examined by the Division of Marine Fisheries. Ambicoloration was diagnosed in 28% (22 of 79) of the fish examined for Fish Day. Most of the fish (63%) with ambicoloration were caught on Deer Island Flats.

measured; and (2) the portion of the fish stock with fin rot may cause increased mortality through fishing (the fish is unable to avoid the net because the fin is damaged), and predation (the strong prey on the weak), and thus may have economic and aesthetic consequences for both commercial and recreational fishing.

Studies disagree about the incidence of fin rot in harbor flounder

Boston Harbor Studies: Some studies found the prevalence of fin rot to be more than 25%—what the NOAA report called the *warning* level—in Boston Harbor winter flounder. However, at least one study found a similar result in coastal areas (<27 m in depth) of Cape Cod and Massachusetts Bays. Fin rot was found to be prevalent in winter flounder collected for the Metropolitan District Commission near Deer Island during the summers of 1978 and 1979. Forty-two percent of all flounder collected during the 1979 survey exhibited some degree of fin erosion. During the Fish Day exercise in May 1989, only 2.5 % (2 of 79) of the fish were observed with active fin rot. Sixteen percent (13 of 79 fish) examined had fin rot that was in the process of healing.

Circumstantial evidence links fin rot to contamination

Evidence for an Environmental Connection: Although the etiology of fin rot has not been conclusively determined, it has been generally associated with coastal environments degraded by pollutants and directly associated with the discharge of municipal wastewater. Fin rot was induced in spot *(Leiostomus xanthurus)* and Dover sole when each species was exposed to contaminated sediments. A study of disease in commercially valuable fish stocks in the Northwest Atlantic revealed that fin rot and other abnormal conditions such as lymphocystis and skeletal abnormalities were more numerous in flatfish than in roundfish such as hake. In addition, several of these conditions reached maximum levels in fish stocks located near major cities.

Internal Abnormalities

Lesions, especially of the liver, are the most common internal abnormality seen in fish

Internal abnormalities may be diagnosed using histopathologic techniques that study the microscopic structure of tissue. Histopathologic studies of fish most often involve the examination of lesions—abnormal changes in the structure of tissue—in the liver, skin, and gill. Lesions involving the liver, known as hepatic lesions, are very prevalent in fish residing in contaminated marine environments.

The liver is susceptible to tissue damage because it metabolizes toxins taken up by fish inhabiting contaminated environments. The metabolism of the toxins may result in the formation of lesions. Hepatic lesions have been compared microscopically to several types of liver cancer found in warm-blooded animals, including man.

Studies suggest that some internal abnormalities may be related to contamination

Boston Harbor Studies: Relatively few studies have been conducted on the occurrence of histopathological conditions in finfish from Boston Harbor, but those that have been done have created considerable interest. Attention was originally focused on Boston Harbor fish histopathology by a study from the National Marine Fisheries Service that described a high prevalence of carcinomas in winter flounder from the harbor. Winter flounder collected from the southern shore of Deer Island had a number of visible hepatic lesions that might be indicative of the fish livers' efforts to metabolize toxic substances. The fish also had a large number of unusual vacuolated cells, and 10% of the animals examined had preneoplastic or neoplastic lesions.

Another author examined winter flounder collected near Deer Island and from a reference site off Plymouth Beach during the summers of 1981 and 1982. The livers in these Deer Island fish also had a disproportionately large number of the unusual vacuolated cells. More intensive study revealed that these abnormal cells were often found in large nodules of several hundred cells and that the same nodules often contained clumps of neoplastic cells.

The Benthic Surveillance Project of the NOAA NS&T Program reported on the results of histopathological observations of winter flounder collected from Boston Harbor and other northeastern sites during 1984, 1985, and 1986. Seventy-five percent of the tumors found in the flounder were in fish from the Boston Harbor area. Of winter flounder collected in Quincy Bay during 1987, 29 of 100 had neoplastic growths. Most of the neoplasms were tumors of the liver and bile ducts.

A characteristic of most of these studies was that larger/older fish exhibited more severe lesions than smaller/younger fish. This may be due to a longer period of exposure for older fish indigenous to a contaminated area.

Data from other areas suggest a relation to contamination

Links between Disease and a Contaminated Environment: Comparisons can be made between the results of histopathological studies of Boston Harbor winter flounder and Puget Sound English sole *(Parophrys vetulus)*. Puget Sound is an estuary that is contaminated, like Boston Harbor; English sole is a flatfish, like winter flounder. The results of studies conducted on Puget Sound English sole to determine the cause of hepatic carcinoma and other hepatic lesions revealed that (1) the number of hepatic lesions (nonspecific) was significantly correlated (positive) with levels of PAHs and metals in sediments, and (2) the number of neoplasms had a significant positive correlation only to PAH concentrations in the sediments. Neither the number of hepatic lesions nor the number of neoplasms was significantly correlated with chlorinated hydrocarbons such as PCBs. The results indicate that the presence of chemical agents in the sediments can be correlated with the prevalence of hepatic lesions. This type of study has yet to be done on Boston Harbor winter flounder.

Fish Day at the New England Aquarium

May 13, 1989, was Fish Day in Boston Harbor. In an unprecedented enterprise organized by the New England Aquarium and the Massachusetts Audubon Society, 100 fishermen turned out to catch fish for study by scientists from 12 organizations. The purpose of the effort was to assess the health of the fish population and provide information useful to those responsible for decisions about the harbor.

The fishermen caught more than 200 winter flounder at 10 locations. Participating scientists performed 13 separate studies, looking at everything from stomach contents (to provide information about diet) to enzyme analysis (to evaluate exposure to toxic chemicals). The study produced valuable background information such as fish size and age and gave scientists a chance to test certain diagnostic techniques.

Some conditions, including liver lesions and neoplasia, were puzzlingly less prevalent than expected among the catch. On the other hand, more than a third of the fish, especially those from Deer Island, had bent fin rays. Many had other abnormalities that suggested they were suffering from the effects of a contaminated environment. Clearly, the results of Fish Day must be interpreted with caution, and more studies will be needed to evaluate trends with confidence.

The fishermen near Deer Island caught more fish than their counterparts elsewhere in the harbor. Half the fish from Deer Island Flats had stomachs filled with a marine worm whose presence is frequently associated with sewage pollution. It seems that even if Deer Island fish are unhealthy, they make extensive use of the large food reserves found there.

In Boston Harbor, hepatic lesions can be circumstantially linked to environmental contamination

At present, the co-occurrence of neoplastic lesions in Boston Harbor winter flounder and sediments containing high concentrations of PAHs and PCBs is circumstantial and inconclusive. Inferences that specific chemical agents cause hepatic neoplastic lesions found in Boston Harbor winter flounder are unsubstantiated by experimental data. However, the high prevalence of hepatic lesions can be linked, in general, to poor environmental quality. This link has been substantiated by a panel of the National Institute of Environmental Health, which reported a definite correlation between the high prevalence of hepatic and epidermal tumors and the presence of carcinogens in the habitats of the fish. Further circumstantial evidence is provided by the fact that morphological changes observed in the livers of Boston Harbor winter flounder are comparable to changes experimentally induced with carcinogens in rodents.

The effects of disease on fish are not well known; flounder appear to live successfully in contaminated areas

Effects on Population: The consequences of hepatic carcinomas (malignant hepatic lesions) on winter flounder populations are not known. Most winter flounder containing hepatic carcinomas appear to be as robust as fish without cancers. In a summary report, the National Status and Trends Program reported that, because winter flounder appear to thrive (e.g., grow and reproduce) in contaminated environments such as Boston Harbor, winter flounder may be an inappropriate indicator species (the indicator would be the formation of tumors) to be used as an early warning of environments that are beginning to degrade as a result of increased presence of contaminants.

Benthic Animals

Bottom-living animals are also studied to gain information about the environment

Benthic animals live in or on sediments at the bottom of a body of water. Common benthic marine animals include polychaetes (worms); clams, mussels, and other bivalves; starfish, sea urchins, and other echinoderms; amphipods (a type of crustacean related to shrimp), crab, and lobster; and other sessile, creeping, or burrowing forms. Some members of the benthic community are important for their commercial value (e.g., lobster, crab, and clam); others serve as food for bottom-feeding fish and lobster. In addition, benthic communities have traditionally been monitored as an indicator of environmental health. Because most of these animals live a sedentary existence, they are susceptible to contamination from a localized source and show its effects by changes in the structure of their communities. These changes are expressed as variations in the kinds of animals found at a particular site (composition), the number of different species (diversity), and the total number of individuals (abundance or density).

In the late 1970s and early 1980s, parts of the harbor were found to show signs of environmental stress

In support of an application for a waiver from the requirement to institute secondary treatment for effluent discharged to Boston Harbor, benthic samples were collected during the summers of 1978, 1979, and 1982. In general, the results suggest that the environment is stressed in the middle of the harbor and in the Inner Harbor, and on the mud flats west of Deer Island where the water is shallow and the currents weak. Stations in the rest of the Outer Harbor are more similar to stations in Massachusetts Bay than to stations in the Inner Harbor and the northwest Outer Harbor, indicating that they are less affected by pollution.

CSOs have been shown to adversely affect nearby benthic communities

Intensive studies near one CSO indicated that these overflows have severe, localized effects on the adjacent benthic communities. A 1987 investigation of the benthos near the Fox Point CSO demonstrated that both diversity and abundance were significantly lower at the mouth of the discharge than at a nearby reference site. Similarly, other studies have found that the abundance and diversity of the benthos decline as Fox Point is approached.

Recent research suggests that benthic communities near discharges are affected by contamination, but other areas of the harbor are relatively unimpacted

A recent study, performed using sediment profile imaging, identified general areas showing environmental stress. In this technique, a camera designed like an inverted periscope photographs a cross section of the top 15 to 20 cm of sediment, and the photographs are analyzed in several ways. With the exception of one replicate from a station on Deer Island Flats, all sites showed evidence of benthic fauna. However, results showed that the fauna on Deer Island Flats, in Winthrop Channel, and in the approach channels to East Boston and Cambridge was mostly restricted to small organisms that inhabit a thin layer of oxygenated sediment that overlies a thick layer devoid of oxygen. Large, deep-dwelling organisms that introduce oxygen into the sediments by their burrowing and feeding activities were apparently missing from these areas. Such large organisms are among the most sensitive to large amounts of organic matter, which suggests that the locations mentioned are being affected by additions of sewage to the bottom habitat.

A combination of other observations, including biological mixing, dissolved oxygen, and size of particles making up the bottom sediments, also pointed to Deer Island Flats, Winthrop Channel, the entrance to the Inner Harbor, an area immediately north of Spectacle Island, and most of the Inner Harbor and Dorchester Bay as impacted sites. Most sites in Quincy, Hingham, and Hull Bays were less stressed. In general, conditions improved with distance offshore toward Massachusetts Bay.

In summary, these results all suggest that the benthos in some areas of the harbor (particularly those close to discharges) shows adverse effects due to contamination, but that other areas (particularly the Outer Harbor) are relatively healthy. This reinforces the general picture that conditions in the harbor cannot be summed up as uniformly bad. It also suggests that monitoring of benthic populations in the more affected areas offers a means to detect whether there are improvements over time.

Are Fish and Other Marine Resources Being Protected?

REPORT CARD	Now	1992	1995	2000	2005
ARE MARINE RESOURCES PROTECTED?					
Sediment contamination	D-	D	D	C-	C-
Water quality: Oxygen	C-	C	B	B	B
Water quality: Toxic contamination	B-	B	B+	B+	A-
Fish disease	D-	D	D+	C-	C+
Benthic communities	D-	D	D	C-	C-

6. HOW DOES THE HARBOR RATE AESTHETICALLY?

Sights and smells related to sewage interfere with enjoyment of the harbor

Aesthetics are an important part of the cleanup effort. To some people, a harbor that looks and smells clean is almost as important as one that is free of chemicals and microorganisms that are a threat to health. Unpleasant sights and odors keep people away from the harbor and interfere with its use as a recreational resource. The main considerations in the aesthetic rehabilitation of Boston Harbor are scum, sludge, and effluent from treatment plants, turbidity, algal blooms, and floatable debris.

Scum

MWRA has halted the daily discharge of 10,000 gal of scum

MWRA has already taken a major step by implementing a new system of handling scum, the floating material generated by the wastewater treatment process at a rate of 10,000 gal per day. In 1989, MWRA eliminated scum discharges to the harbor. Under the new system, grease, fats, most tampon applicators, and other floating pollutants are removed from wastewater. The dewatered and chemically fixated scum is now being disposed in a landfill, but by the end of 1991 it will be processed along with the sludge.

Effluent and Sludge

Sludge discharge will cease in 1991; effluent discharge will be moved offshore in 1995

Plumes of waste material flowing into the harbor from treatment plant discharges will be a thing of the past within a few years. Streams of malodorous and unsightly sludge will be eliminated in 1991 when sludge is treated at land-based facilities instead of being discharged into the harbor. As for effluent, by 1995 the new outfall will be completed, permitting discharge farther offshore in Massachusetts Bay.

Turbidity

Water clarity should improve

Cessation of particle-laden sludge and effluent discharges will also have a positive effect on turbidity. Water transparency is expected to improve substantially except when river flow is heavy or if the altered conditions in the harbor increase blooms of algae. Concentrations of suspended solids are about 100 times higher near the sludge outfall and some CSOs than they are in other parts of the harbor.

Algal Blooms

Algal blooms could become more frequent

Blooms of the minute algal species that make up the phytoplankton could become more of a problem than in the past. Such blooms can discolor the water, produce unpleasant odors when their cells decay, and potentially result in fish kills that cause further undesirable sights and smells. Two factors that influence such blooms are concentrations of nutrients, especially nitrogen and phosphorus, and available light. The New England Aquarium describes Boston Harbor's current nutrient concentrations as high, but within the ranges observed for temperate estuaries. Of the stations sampled by the Aquarium, nutrient concentrations were highest in the Inner Harbor and lowest at the southern stations in Hingham Bay, Weymouth Fore River, and Quincy Bay. Both nutrients and available light are expected to change as the harbor cleanup progresses. When sludge and effluent are no longer put into the harbor, available light will increase and nutrient levels are predicted to decrease.

Floatable Debris

Dangerous and unsightly floatable debris has many sources

The problem of marine debris floating in coastal waters and washing up on beaches and shorelines has attracted considerable public attention in recent years. Floating marine debris can be made up of an assortment of waste materials. Plastic articles are one of the biggest categories of floatable debris. The list includes bottles, bags, and six-pack yokes; cups, plates, and utensils; fishing line, nets, floats, and ropes; diapers, tampon applicators, and condoms; and polystyrene particles of all sizes. Articles of metal, glass, paper, wood, and other substances are also common.

What items of beach debris are most common?

These are the 12 most common debris items reported to the Center for Marine Conservation from beach cleanups in 1988, in order of abundance. Together these items accounted for more than 50% of the items collected.

- Fragments of plastic
- Small foamed-plastic particles
- Plastic eating utensils
- Metal beverage cans
- Foamed-plastic cups
- Glass beverage bottles
- Plastic caps and lids
- Paper pieces
- Plastic trash bags
- Other plastic bags
- Glass pieces
- Plastic beverage bottles

In addition to its unsightly appearance, floatable debris in the marine environment is a danger to fish, birds, marine mammals and turtles. These animals can ingest floatable debris—with dire consequences—or become fatally entangled in it. Still another possible undesirable effect is damage to vessels through collision, fouling of propellers, or clogging of engine intakes with floating waste.

Floatable debris originates from a variety of sources, including sewage treatment plants and CSOs; solid-waste disposal facilities; commercial fishing vessels (nets and other fishing gear as well as general trash); recreational, commercial, military, and research vessels; offshore drilling operations; and the general public (beach and roadway litter). Data compiled by the Center for Marine Conservation in 1989 showed that in Massachusetts about 2% of the debris collected in beach cleanups originated from sewage treatment plants. The national percentage varied from less than 1 to about 3.5.

Cleanups at Boston beaches produced more trash than elsewhere in Massachusetts

Cleanups were conducted at several Boston Harbor beaches in 1988 and 1989. These volunteer efforts were sponsored by the Massachusetts Office of Coastal Zone Management. In 1989, cleanup at four Boston Harbor beaches produced an average of 2090 lb of trash per mile of beach (Figure 6.1). This was 20 times more than found on Cape Cod beaches.

The ocean outfall and CSO controls will reduce the amount of sewage-related debris

MWRA estimates that between 1000 and 50,000 plastic tampon applicators enter the wastewater system each day. It is not known how many escape the screening and skimming processes and are discharged with the effluent. In addition, of course, some enter the harbor through CSO discharges. The number of these and other sewage-related floatable items will decline in Boston Harbor after construction of the ocean outfall and implementation of CSO controls.

REPORT CARD	**Now**	**1992**	**1995**	**2000**	**2005**
HOW DOES THE HARBOR RATE AESTHETICALLY?					
Aesthetics	D	C-	B-	B+	B+

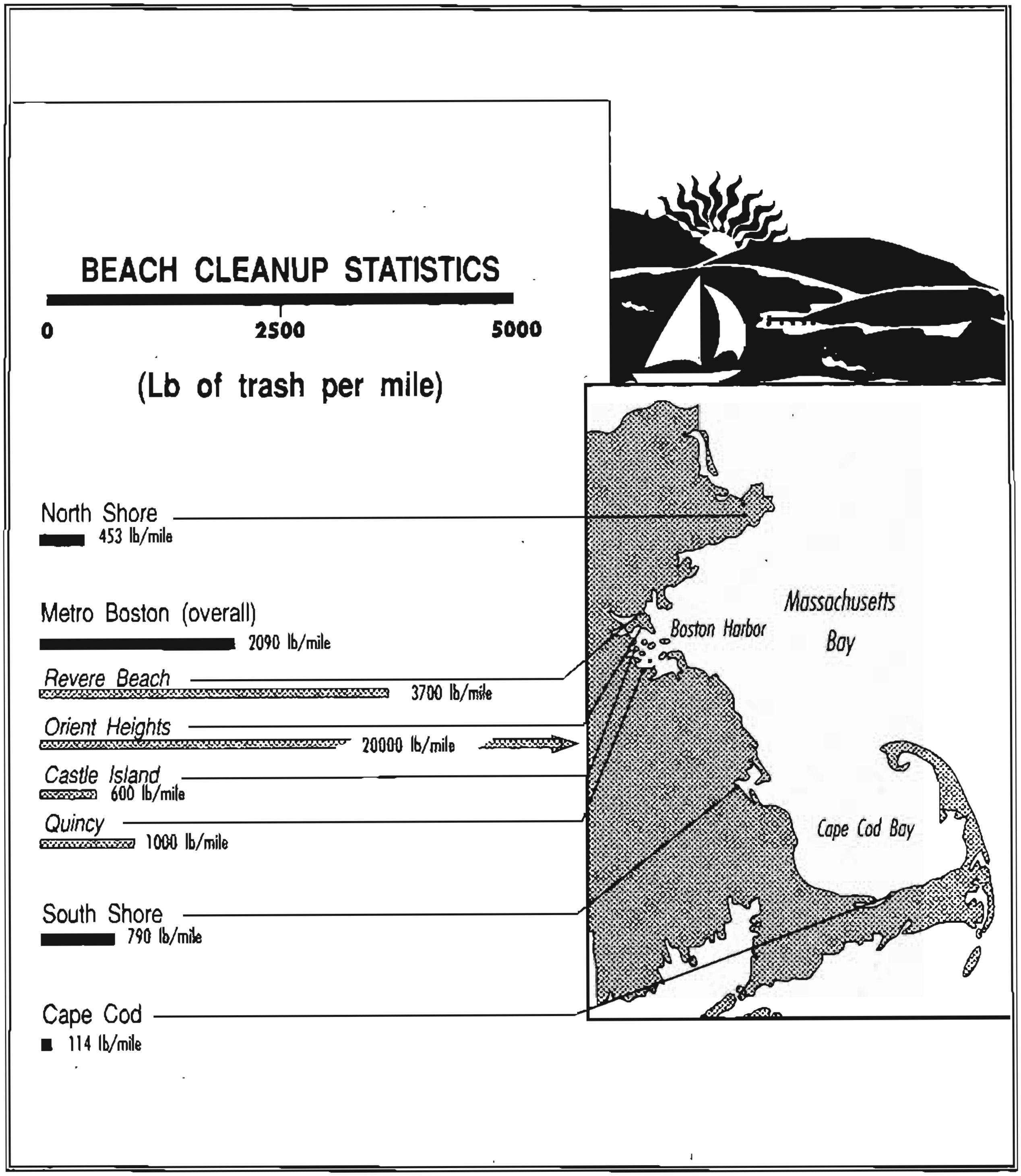

Figure 6.1. In the 1989 Coastsweep cleanup, Boston Harbor beaches produced more trash per mile than beaches in other areas of Massachusetts.

7. PRESENT AND FUTURE: A SUMMARY

Predictions for the Harbor's Future

Some improvements will be rapid; others will not be seen for years

In Section 2, we pointed out that different contaminants have different major sources. This fact has implications for how conditions will be affected by various parts of the remediation plan. In addition, we expect that different aspects of environmental quality will respond at different rates. Changes in water quality, for example, should occur on a scale of months to years; changes in sediment quality and fish condition may take decades.

Cessation of Sludge Discharge

Halting of sludge discharge will improve water clarity and reduce concentrations of pathogens and toxic materials

Sludge is one of the most important sources of contaminants to the harbor. Thus, we can expect that plans to halt dumping of sludge into the harbor will also result in significant improvements in all contaminant groups. Sludge discharge will cease by the end of 1991, and the sludge will be made into fertilizer at the Fore River Staging Area.

Cessation of sludge discharge will reduce pathogen and toxic contaminant discharge into the harbor by 30%. The major beneficiary of pathogen reduction will be beaches in Winthrop and the outer islands. Because sludge contributes about 25% of the total load of solid material to Boston Harbor, water clarity is expected to improve with cessation of sludge discharge, making a significant aesthetic contribution to the harbor cleanup.

MWRA's Harbor Studies is monitoring the amount of sludge now in the harbor, and will compare the results to levels recorded after sludge is no longer discharged. This program is a joint effort with the New England Aquarium, the Massachusetts Audubon Society, and several universities and public agencies. These groups will examine data on fish, bottom-dwelling animals, and water circulation to measure the recovery of the harbor over time.

Effluent-Related Changes

In general, effluent from the MWRA primary treatment plants on Deer and Nut Islands is a major source of all groups of contaminants. As a result, parts of the remediation plan that affect effluent (i.e., construction of new plants to supply secondary treatment and construction

Cessation of sludge discharge is expected to make substantial improvements

The monitoring program designed to assess the effects of cessation of sludge discharge to the Harbor has made predictions about what will happen. These predictions are being used as scientific hypotheses to objectively analyze how much conditions have improved. These are some of the benefits expected as a result of the decrease in pathogen and toxic contamination associated with halting of sludge discharge into Boston Harbor:

Rapid Improvements (1 Year or Less)

- The concentrations of bacteria indicative of recent sewage contamination will decline in the clam beds near Deer Island and along Winthrop beaches.
- Turbidity will decrease as a result of the decrease in the particulate material discharged into the harbor from both sludge and effluent.

Long-Term Improvements (5 to 10 Years)

- Sources of toxic contaminants to sediment will be reduced.
- Incidence of pathological conditions in fish will decline, including fin erosion in winter flounder.
- Concentration of toxic contaminants in shellfish will decline.
- Benthic communities in areas now impacted by sludge will show improved conditions of species richness, abundance, and diversity.

Changes in effluent treatment will further reduce concentrations of pathogens and toxic materials

of the ocean outfall) will have a significant positive effect on all contaminants. By 1995, sewage effluent from the new Deer Island wastewater treatment plant will be discharged 15 km (9.5 miles) offshore in Massachusetts Bay, in water 33 m (110 ft) deep. This represents a major milestone in the rehabilitation of the harbor. Beneficial effects are a result of the improved capacity and efficiency of the new treatment plant and the increased dilution that all contaminants will experience. The concentration of pathogens and toxic materials will be 10 times less, thanks to the increased volume of water available for dilution. Because nutrients and organic particles will also be more dilute, the likelihood of oxygen depletion will be lower. On the other hand, it is possible that the area surrounding the new outfall may be more sensitive to reduced oxygen conditions.

The secondary treatment plant will benefit Massachusetts Bay, the site of the new outfall

By the end of the decade, new treatment facilities will have been constructed and the effluent discharged from the ocean outfall will be receiving secondary treatment. The main effect of the change from primary to secondary treatment will be an additional 30% reduction in the toxic materials discharged to the ocean. The change will be beneficial for Massachusetts Bay, but will have little effect on the harbor. There will be little change in pathogen or nutrient concentrations.

The MWRA Harbor Studies Department is conducting a long-term program to provide information about conditions at the outfall site. By determining conditions before and after the outfall is in operation, the impacts of effluent discharges can be determined.

CSO Control

The remaining pathogen and toxic contamination would be helped by CSO control; improvement would be most dramatic near individual overflows

In addition to effluent and sludge, CSOs are a significant source of contamination to Boston Harbor. Raw sewage released from CSOs is a major cause of environmental degradation in Boston Harbor. Because of the viruses and bacteria in untreated sewage, many areas in the harbor fail to meet microbial standards for swimming and shellfishing. If complete CSO control were implemented, the improvement in pathogen concentration near individual discharges would be 100-fold, and there would be a 25% reduction in beach closings harborwide. For toxic contaminants, the harborwide decrease would be about 5%, again with greater effects felt around individual overflows.

CSOs present a difficult problem in the remediation of Boston Harbor. MWRA has just completed a plan for addressing the CSO issue. The plan calls for installation of underground tunnels to store the overflow of combined sewage until the main plant is ready to receive it. Implementation of this plan will be difficult and expensive – the cost is estimated at $1.2 billion. Unfortunately, even complete control of CSO discharges will not totally eliminate the pathogen problem in the harbor because a significant number of pathogens also come from stormwater and rivers.

Harbor Studies has also developed a monitoring program to determine the effects of CSOs on the environment. The baseline data on microbial contamination from current sampling will be compared to measurements made after completion of each stage of CSO control.

Remaining Problems

Some sources of contamination will remain

Unfortunately, even when the MWRA remediation plans are completed, all sources of contamination to the harbor will not be eliminated. Stormwater and rivers carry pollution in amounts that seem generally unimportant in comparison to effluent and sludge, but which can be significant when these other sources are reduced. In addition, contaminants accumulated in Boston Harbor sediments are a major concern, as discussed in Section 5.

Stormwater contributes to contamination, especially from pathogens

Stormwater: Stormwater—water from rain or other precipitation—picks up contaminants as it flows across the ground. Much of this water eventually drains into surface waters, either by being collected in ditches and drains and directed there, or by natural flow over the land until it encounters a body of water. Depending upon what the land that it flows over is used for, stormwater may become contaminated with materials such as oil from roadways; pesticides and fertilizers from cropland and gardens; and pathogens from sewage or from feces of domestic, agricultural, or wild animals. In Boston Harbor, as in many other coastal areas, pathogens in stormwater are a major issue. MWRA has estimated that beach closings around the harbor would be reduced by 40% if stormwater discharges were eliminated. In some localized areas near discharges, the improvement would be 100-fold. This suggests that after the remediation plans are complete, unless stormwater discharges are reduced, there may still be some beach and shellfish closures for short periods after rains in areas within a few hundred yards of stormwater discharges.

Rivers contribute significant amounts of metals and pathogens

Rivers: Rivers are also known sources of pollutants. In Boston Harbor, flow from rivers is about half that from the sewage treatment plants. The Charles is the largest river in the area, and discharges 7.5 m^3 of water into the Inner Harbor each second. This compares to a flow of 20 m^3/s for the treatment plants and 10 m^3/s for all rivers combined. The remaining large river discharges are the Neponset, Mystic, Chelsea, Weymouth Fore, Weymouth Back, and Weir rivers, all in the southern part of the harbor. In Boston Harbor, rivers are significant sources of metals such as mercury and zinc and of fecal coliform bacteria.

Contaminated sediments are a source of toxic materials

Sediment: The problem of materials accumulated and stored in the sediment at the bottom of the harbor is primarily a significant issue for toxic contaminants. After the MWRA remediation projects are complete, Boston Harbor waters probably will meet water quality standards for these contaminants. However, the contaminants remaining in the sediments will continue to provide some risk to fish and shellfish living in these sediments. In addition, there is the danger that materials could be released from the sediment to recontaminate the overlying water. Sediment contamination is most likely to be a problem in areas where sediment is deposited at a high rate. Such *depositional* areas where contamination with toxic materials has been found include Deer Island Flats, the Inner Harbor, and the portion of Dorchester Bay bounded by Moon, Thompson's, Long, and Spectacle islands.

Leaching from hazardous waste sites remains a problem

Leaching of Hazardous Waste: A number of hazardous waste sites are found in the Boston area. Leaching of materials from these sites is yet another source of continued contamination to the harbor.

The Boston Harbor Report Card

Boston Harbor conditions are summed up in a report card

As we looked at different aspects of the condition of Boston Harbor, we gave each one a grade. As an overview of the contents of this report on the status of the harbor, we present a complete report card covering all the factors and all the grades (Figure 7.1). Some may think our grades are too high; others that they are too low. We look to the future to provide the answer.

KEY TO GRADES

A **Excellent:** Consistently maintains conditions characteristic of other clean coastal sites.

B **Good:** Frequently exceeds Federal water quality standards and expectations for an urban estuary.

C **Satisfactory:** Complies with Federal water quality standards and meets expectations for an urban estuary.

D **Poor:** Sometimes fails to comply with existing standards or meet expectations for an urban estuary; some uses of the harbor are maintained.

F **Failing:** Consistently fails to comply with Federal water quality standards or meet expectations for an urban estuary; there is obvious environmental degradation, and uses of the harbor are lost.

REPORT CARD FOR *Boston Harbor*

	NOW	1992	1995	2000	2005
IS IT SAFE TO SWIM?					
Swimming beaches	D	D+	C	C	B
IS IT SAFE TO EAT FISH AND SHELLFISH?					
Shellfish: Pathogens	D-	D	C-	C-	B-
Fish: Organic contamination	C-	C-	C-	C+	B-
Fish: Metal contamination	B-	B-	B-	B	B+
ARE MARINE RESOURCES PROTECTED?					
Sediment contamination	D-	D	D	C-	C-
Water quality: Oxygen	C-	C	B	B	B
Water quality: Toxic contamination	B-	B	B+	B+	A-
Fish disease	D-	D	D+	C-	C+
Benthic communities	D-	D	D	C-	C-
HOW DOES THE HARBOR RATE AESTHETICALLY?					
Aesthetics	D	C-	B-	B-	B+
OVERALL GRADE	D+	C-	C	C+	B-

Figure 7.1. The Boston Harbor Report Card sums up our knowledge of present conditions and our hopes for the future.

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