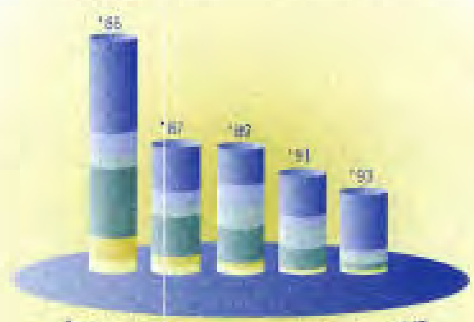
The Massachusetts Water Resources Authority

The State of Boston Harbor



Amounts of metals entering MWRA sewer system have decreased dramatically.

1993

The Role of Science

This report is a window into the world of scientific studies of Boston Harbor and the larger coastal ecosystem of Massachusetts and Cape Cod Bays. Though the MWRA conducts many of the studies, there are numerous other groups involved in monitoring these waters (see box). This report compiles, condenses, highlights, and presents this comprehensive body of knowledge in what is hoped to be an accessible form.

Studying a marine environment like the Massachusetts Bays system is not a simple task. Even the casual observer looking out over the harbor from the expressway, can see signs of immense variability: characteristics like waves, tides, and boat traffic are always changing. In order to understand these and other more complex aspects of the marine environment, scientists need information that captures the full range of this geographic and temporal variability. Collecting data requires extensive field and laboratory work. The data must then be evaluated using tools such as statistical analyses and computer modeling.

Studies of the Massachusetts Bays system serve two purposes: they (1) determine whether water quality standards are being met and (2) play an integral role in planning water quality improvements. Monitoring determines whether the water is safe both for the organisms that live in it and for the people who use it for fishing, recreation, transportation, and other activities. For example, water at beaches must be checked for bacteria to determine whether it is safe for swimming, and fish must be checked for disease to determine whether they are being harmed by pollution.

Scientific studies are also critical to improving future water quality. It was long thought that sewage contaminated waters could only be remedied with the most complex, state of the art treatment processes. While this approach had its successes, it did not always target the real problems. In the current approach, scientific studies determine which aspects of water quality need improvement, identify the cause of the problem, and help design cost effective solutions tailored to the specific problem. The studies may seem expensive in the short run, but in the long run they save time and money. As such, this report is not just an assessment of Boston Harbor and the bays; it helps form the basis for plans to improve water quality in the future.

Organizations Actively Monitoring Massachusetts Coastal Waters

- Boston College
- Boston University
- Harvard University
- Massachusetts Institute of Technology
- Northeastern University
- University of Massachusetts at Boston
- University of Massachusetts at Dartmouth
- University of Massachusetts at Lowell
- University of New Hampshire
- University of Rhode Island
- Woods Hole Oceanographic Institute
- Bigelow Laboratories
- The Center for Coastal Zone Studies
- Massachusetts Audubon Society
- Boston Water and Sewer Commission
- Massachusetts Bays Program
- Massachusetts Department of Marine Fisheries
- Massachusetts Highway Department
- National Oceanic and Atmospheric Administration
- U.S. Environmental Protection Agency
- U.S. Geological Survey

Massachusetts Water Resources Authority - 1993

The State of Boston Harbor

July 1994

Prepared under the direction of

Douglas B. MacDonald, Executive Director

John F. Fitzgerald, Director, Sewerage Division

Environmental Quality Department

Michael S. Connor

Kelly Coughlin

Paul Lavery

Margarete Steinhauer

Technical Report No. 94-0

Table of Contents

List of Figures

Executive Summary

Each year the State of Boston Harbor report documents changes in the environmental health of the harbor and Massachusetts Bay as MWRA's Boston Harbor Project progresses. It has been more than two years since improvements to the exisitng sewage treatment plants finally enabled MWRA to remove sludge from the discharges released every day into the harbor. With the forthcoming opening of the first phase of the new primary treatment plant at Deer Island in 1994, the MWRA is helping to further the restoration process in Boston Harbor. The following are examples of the extensive environmental resources the harbor now supports.

- One of the state's largest herring runs, more than 200,000 fish annually, travels through the harbor and up the Back River to spawn; more than double the numbers estimated in the 1970s.
- Each spring and fall, porpoises return to the Mystic/Chelsea Rivers in the inner harbor.
- Commercial and recreational fishing occurs throughout the harbor, including a lobster fishery valued at over $10.6 million per year and accounting for more than a third of all the state's lobster.
- The harbor is a winter refuge for more than 50 species of waterfowl, many of which migrate to the harbor before returning to Canada to breed.

Evidence of the improvements to the harbor's environmental health are harbingers of future restoration:

- Beach closures in 1993 remained below the incidence of the late 1980s, evidence of reduced bacterial contamination in the harbor.
- Toxic contamination of fish and shellfish has been greatly reduced compared to the late 1980s, and appears to be stabilizing at much lower levels.
- Along with the reduced contamination of fish, the incidence of disease in winter flounder has continued to decline rapidly.
- Increased biological diversity of species living in the seafloor, particularly in sites previously impacted heavily by sludge discharges, point to the first stages of sediment recovery.
- The harbor looks and smells cleaner: the amount of sewage-borne litter remains much lower than only a few years ago, and, in some areas, water clarity has improved by nearly two feet of visibility.

These improvements reflect effort to upgrade the existing sewage treatment system. However, monitoring results also indicate that improvements to treatment alone, even the inauguration of a new secondary treatment plant later this decade, will be insufficient to allow complete restoration of the harbor ecosystem. A large algal bloom last summer emphasizes the nutrient-rich status of the harbor and raises concerns regarding the harbor's ability to meet dissolved oxygen standards and the possibility of toxic algal blooms.

Moving the the treatment plant discharge outfall offshore is a cost-effective means of achieving further environmental benefits. Some are concerned, however, that an offshore outfall will act as a new source of nutrients to the Massachusetts and Cape Cod Bay system. While the MWRA discharge is the major source of nutrients to Boston Harbor, it represents only a small fraction of the total nutrient loads to the bays as a whole. Monitoring studies also show that the majority of discharges to the harbor are already transported to the bays. The concentration of distinct sewage effluent tracers are highest near the harbor, but the most sensitive tracer can be seen throughout Massachusetts and Cape Cod Bays. While evidence of contamination can be seen baywide, the monitoring studies show that the biological response to this contamination is mostly limited to the area within a few miles of the harbor. Even though the bays are not pristine, their overall environmental health is quite good. For instance, the animals living in the seafloor in Cape Cod Bay are found in the same kinds and numbers as were found more than twenty years ago.

In addition, moving the discharge offshore diminishes the potential impact of any remaining contaminants in the treated effluent because the dilution provided in deeper offshore waters will be about ten times greater than in the harbor. In these deep waters, nutrients will have less impact because the discharge will be trapped below the surface where there is less light for the growth of algae.

Rehabilitation of the sewer system has allowed the restoration process for the Boston Harbor ecosystem to begin. The benefits of this rehabilitation are limited and underscore the need for construction of new secondary treatment facilities for improved pollutant removal and a new effluent outfall tunnel for improved dilution offshore. The 1993 State of Boston Harbor Report explores these and other developments.

Introduction

The state of Boston Harbor in 1993, as described in this report, reflects about as much progress as can be made through interim improvements to the system's aging, outmoded sewage treatment plants. Over the past few years, the generally improved performance of the region's sewage treatment system has translated into a much healthier harbor showing many indicators of early ecosystem recovery. There remains, however, ample evidence that sewage effluent discharges are still damaging both the harbor and Massachusetts Bay. This reflects the limited nature of improvements that have been made and underscores the need for new treatment facilities to support the recovery process in both the harbor and the bay. With increasing awareness of the impact that Massachusetts Bay has suffered from the harbor's sewage-related pollution, the importance of the new treamtent facilities to the health of the entire bays system is now apparent.

Until this year, improvements to the existing sewage treatment system have been used to reduce pollution to the harbor and the bay. However, 1994 will see a shift in the project. Having completed improvements to the existing system, the MWRA now moves toward Phase One (start-up) of a new primary treatment facility, the first step toward introducing a modern secondary treatment system that will be the cornerstone of recovery for both waterbodies.

Effluent currently discharged into the MWRA system is conveyed to treatment facilities before it is discharged to Boston Harbor. From the harbor it is flushed to Massachusetts Bay. In addition, there are substantial discharges of untreated effluent which occur when the sewer system is overloaded. Past efforts have been directed at reducing these untreated discharges, while new facilities are about to be put into operation that will advance the quality of discharges from the treatment plants.

Abating Harbor Pollution

The approach being taken in the Boston Harbor Project relies on reducing pollutant flows to allow long-term improvement in the harbor. In Boston Harbor the major sources of pollution are treatment plant effluent, CSD discharges, and stormwater, and their amelioration is based on: 1) improving the quality of the effluent, and then 2) removing the effluent to Massachusetts Bay. Effluent entering the harbor already makes its way to Massachusetts Bay. Obviously, simply moving the pollution problem entirely to the bay is not an acceptable solution to the Boston Harbor problem. Therefore, the strategy involves substantially improving the quality of effluent entering the bay, by providing secondary treatment, and also designing an outfall that provides swift dilution and dispersion of the effluent. In this way the Boston Harbor Project will result in improvements not only to the harbor but also to the bay.

Pollutants Relevant to the Concerns in Boston Harbor

- **Safety for Swimming/Boating**
  Affected by: bacterial contamination of the water; toxic metal* and organic* pollutant concentrations in the water
- **Safety of Fish and Shellfish**
  Affected by: toxic levels of PAHs*, PCBs* and metals in fish and shellfish; microbial contaminants in fish and shellfish
- **Marine Resources**
  Affected by: bacterial, organic and metal contamination of sediments and biota*; suspended solids and other pollutants which consume oxygen and affect water clarity; nutrients which promote algal growth and possibly toxic algal blooms
- **Aesthetics**
  Affected by: suspended solids concentrations which reduce water clarity; floatable pollutants, noxious algal blooms

* See Glossary

The Process of Recovery

While reducing the pollutant loads will undoubtedly improve conditions in the harbor and bay, recovery will be gradual. Periods of obvious, short-term change will come with the successful completion of major milestones, such as the 1991 cessation of sludge discharges, and the planned ending of effluent discharges in the harbor when the new outfall tunnel is placed in service. However, incremental improvements will occur in years to come as the harbor's stored, or internal, pollutants are slowly flushed from the system.

Recovery will not only be a slow process, but it will proceed at varying rates in different parts of the harbor. Areas heavily impacted by sewage discharges will respond more noticeably to their cessation. Similarly, faster recovery is likely in well flushed areas of the harbor, or in areas initially less impacted. Change will be dramatic in some places; less so in others. There is also evidence in this report of temporary periods when pollution impacts seem to increase rather than decrease. This is all part of the nature of ecosystem recovery, a complex process that takes time.

Recovery of the harbor can be monitored by carefully studying the water, sediments, and plants and animals over an extended time period. The most tangible indicators of restoration will inevitably result at the point where user concerns meet environmental health. For the public, perhaps the two most significant indicators are the ability to swim safely in the harbor and to safely eat harbor fish and shellfish. Each of these concerns is closely linked to the health and restoration of at least one of the major facets of the harbor ecosystem, the water, the sediments or the plants and animals. The types of changes expected in each of these areas are summarized in the three boxes below.

This year's State of the Harbor Report has been structured to provide information in three sections. Ongoing improvements to the sewer system and their impact on the harbor are evaluated in the first chapter.

The second chapter examines the effects the improvements to the system have already had on Boston Harbor and the status of the recovery process.

Finally, the current state of Massachusetts Bay is examined in Chapter 3. As the final receiving place for much of the existing sewer system discharges, Massachusetts Bay has been gradually accumulating sewage-originated pollution. Monitoring has begun to reveal distinct patterns of pollution from the harbor to the bay. Knowing the nature of the current impacts, it is now possible to examine the benefits that the new treatment facilities and outfall will bring to the bay.

Water

Degraded
- Elevated concentrations of toxic pollutants and nutrients (can lead to aesthetic deterioration, deoxygenation, and toxic algal blooms and death of fish, shellfish and humans)
- Increased turbidity

Healthy
- Well oxygenated, low concentrations of toxic compounds and nutrients
- Algal blooms infrequent and not at densities which cause deoxygenation
- Relatively higher clarity

Rate of Recovery
- Depends on: degree of flushing, degree of contamination and behavior of sediments
- Well flushed waterbodies respond quickly

Sediments

Degraded
- Thin oxygenated layer caused by organic material, such as sewage, which stimulates bacterial activity and oxygen consumption
- Elevated pollutant concentrations cause disease in bottom dwelling animals
- Lack of plants and animals, or few species

Healthy
- Deep oxygenated layers
- Naturally occurring concentrations of metals and other potentially toxic compounds
- Supports a diverse assemblage of plants and animals

Rate of Recovery
- Slowest phase of ecosystem recovery
- Can determine the overall success of restoration efforts
- Sediments store pollutants and continue to release them, delaying the recovery

Plants and Animals

Degraded
- Individual animals and plants: less robust, disease-prone, low growth rate due largely to toxic contamination, reduced light and smothering by suspended particles
- The entire assemblage: low diversity, with only a few hardy or highly adapted species

Healthy
- Diverse range of species and individuals with little accumulation of toxic compounds, low incidence of disease, and high reproductive success
- Relatively higher clarity allows benthic plant growth in shallow areas

Rate of Recovery
- Species dependent
- Water column species recover most rapidly while those in contact with contaminated sediments recover more slowly
- Rapidly reproducing species become abundant quickly; slow breeding species recover slowly

Chapter One

Sewer System Update

When the MWRA assumed control of metropolitan Boston's sewer system in 1985, it inherited an aging collection of pipes and pumps, many of which had exceeded their useful lives. The treatment plants at the harbor's edge could no longer remove enough pollutants to meet federal and state standards. On rainy days the system was overwhelmed by volumes of flow it was not designed to handle, with breakdowns at one facility triggering a succession of backups and overflows throughout the system.

Today, as a result of repair and replacement work to many of its weakest links, the MWRA sewer system is capable of transporting and treating greater flows. Renovations in the collection system, reduction of toxic discharges, the end of scum and sludge dumping, increased pumping capacity, and more efficient disinfection of wastewater are among many efforts to operate and enhance the system in ways that will minimize the impact of its still considerable shortcomings. Ultimately, only replacement or expansion of most facilities will allow the system to provide an adequate level of service so that the waters affected by plant discharges can meet water quality standards.

The Metropolitan Sewer System

About 2.3 million people and 5,500 businesses in 43 communities in the metropolitan Boston area contribute wastewater to the MWRA's sewer system. With the addition of stormwater runoff and infiltrating groundwater, this amounts to an average flow of about 380 million gallons per day. Wastewater is collected from communities through an intricate network of local pipes that lead to MWRA interceptor pipes. It is then pumped to facilities where large debris is screened out before entering one of two MWRA treatment plants at Nut Island in Quincy or Deer Island off Winthrop.

Collection

Sewage travels through three different sets of pipes before reaching MWRA treatment plants. Wastewater from a home or business is flushed through a building's pipes until it reaches local sewers, which are owned and operated by city and town sewer departments. These 5,400 miles of local sewers connect to 230 miles of MWRA interceptor pipes, which lead to the sewage treatment plants.

When the MWRA took over the sewer system, many of the interceptors were in poor condition. Deterioration from age or lack of maintenance led to numerous backups and overflows. Currently, new interceptors are being built that will handle high volumes of flow and will prevent similar problems in the future. Upgrading is not a simple process, however, and will take several years to complete as it entails complex planning and construction and requires the involvement of many communities.

The high volume itself is an indicator of another problem. Sixty percent of the flow that reaches the treatment plants is a combination of infiltration and inflow (I/I)--infiltration of groundwater through cracks in pipes, and inflow from illegal connections and stormwater runoff. By itself, I/I requires little or no treatment. Once in the sewer system, however, it dilutes the raw sewage that does need treatment, increasing overall flow and further burdening the plants.

Removing sources of I/I is difficult because much of it originates in local systems. A $25 million MWRA I/I Local Financial Assistance Program has been launched to provide grants and interest-free loans to encourage I/I reduction. Other measures include the installation of meters which record flow at various points in the system, pointing to possible sources of I/I. Leaks in the system, once they are located and repaired, have a significant impact. Repair of an interceptor in Brookline, for example, removed 27,000 gallons per day of inflow.

Once pipes have been repaired and upgraded, regular inspections ensure they are maintained. Inspections, done primarily by pulling closed circuit TV cameras through pipes, enable crews to identify cracks and illegal connections. Inspections have continually increased each year, as shown in Figure 1.1.

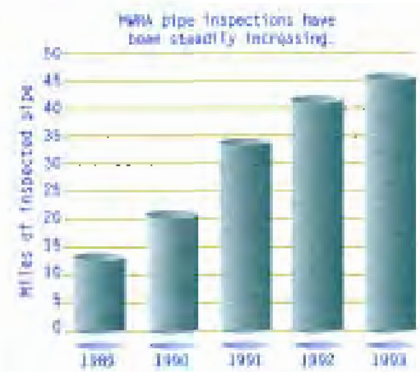


FIGURE 1.1 Miles of MWRA pipe inspected each year by closed circuit TV cameras

Pumping

While much of the interceptor system transports sewage from communities by gravity, eleven pumping stations help do the job. In the past, inadequate pumping capacity and equipment breakdowns at the pumping stations hindered the entire collection system.

Repairing, replacing, and maintaining pumping station equipment has generally increased efficiency and prevented costly breakdowns. Interim improvements, such as more powerful pumps, added "comminutors" which grind up solids and protect pumps from wear and tear, and stand-by generators, have greatly decreased the problems which have plagued the system. Most of the upgrades performed now are considered interim improvements until individual pumping facilities can be completely overhauled, which will yield dramatic results: when the 100-year-old Charlestown Pump Station was rebuilt in 1993, maximum daily pumping capacity at that site increased from 31 to 93 million gallons.

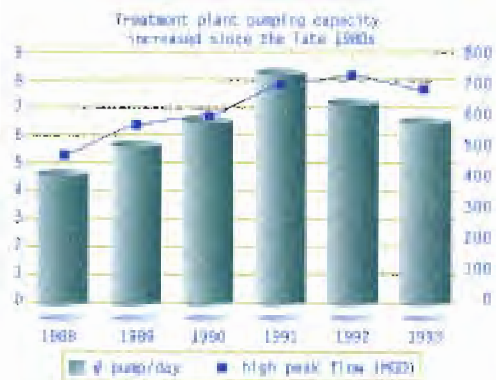


FIGURE 1.2 The average number of pumps operated per day and the highest daily flow recorded from 1988 to 1993 at the Deer Island Power and Pump Station.

At the system's largest pumping location, Deer Island itself, replacement of five of eight pumps and pump motors improved capacity and reliability, leading to better handling of high flows, as illustrated by Figure 1.2. A slight decrease in pumping capacity this year is due to the interruptions involved in equipment replacement as part of new plant construction.

Throughout the system, increased pumping capacity decreases "choking", a process by which flows that cannot be handled by existing pumps are 'choked back' into the sewer system, frequently leading to local overflows. Figure 1.3 shows the number of hours flow has been choked back each year at Deer Island. Increased choking in fiscal year 1993 resulted from Deer Island construction interruptions and particularly severe periods of wet winter weather.

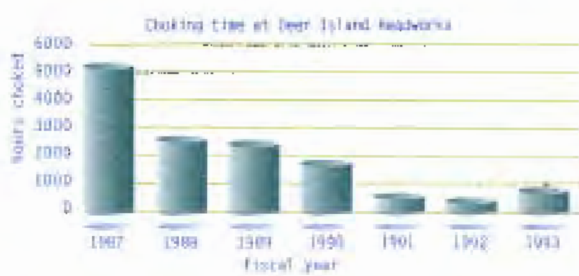


FIGURE 1.3 Total number of hours the headworks at Ward Street, Chelsea Creek and Columbus Park choked back flow between 1987 and 1993. A slight increase this year is primarily the result of construction related activity.

Screening

Sewage from interceptors passes first through headworks facilities, where grit and large objects like leaves and sticks, and hygiene products like tampon applicators and condoms are screened out. By the mid-1980s, shutdowns to repair obsolete equipment at the headworks caused frequent backups in the system. Inefficient grit removal resulted in increased wear and tear on treatment plant equipment. Now, less than a decade later, much of the equipment has been replaced or rehabilitated, increasing the volumes of grit and screenings removal and dramatically decreasing shutdowns.

Combined Sewer Overflows

Back in the 1800s, it seemed harmless enough to hook up backyard privies to nearby stormwater pipes—wastes were conveyed to a river or stream with enough dilution to make a smelly problem disappear. As the city's sewer system grew more complex, vestiges of this simple unsophisticated system remained. Because of the difficulty and high cost of modification, portions of Boston, Cambridge, Somerville and Chelsea still collect sewage in the same pipes used to collect stormwater runoff. Inconceivable as it seems, raw sewage still spills into nearby rivers and Boston Harbor itself dozens of times each year during wet weather through combined sewer overflow structures, or CSOs.

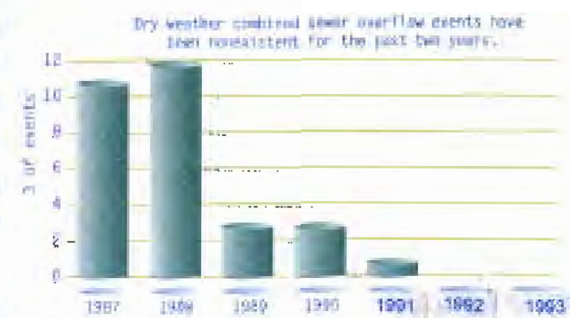


FIGURE 1.4a Number of dry weather overflow events at Cottage Farm, Prison Point, and Somerville Marginal CSOs. Overflows were designated "dry weather" if there was no rain during the previous 24 hours.

Combined sewer systems are extremely inefficient, as the combined volumes of sewage and stormwater in the system can compromise the quality of treatment either receives. There are 81 CSOs that can pollute beaches, boating areas, and shellfishing grounds of waterways including the Charles, Mystic, Chelsea and Neponset Rivers, Alewife Brook, and Boston Harbor.

Six treatment facilities that screen and disinfect wastewater have been built at CSO locations that receive particularly high flows or are located near recreational areas. Constructed or rehabilitated over the last decade, these six facili-

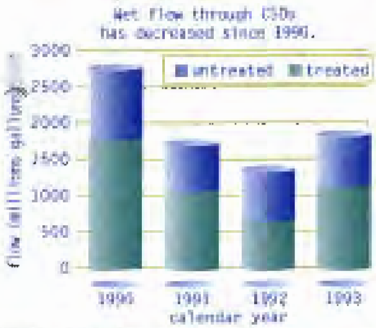


FIGURE 1.4b MWRA meter records were used to determine flow through the six CSO treatment facilities. Boston Water and Sewer Commission model data were used to estimate untreated flow. Treated flows consist of flows from the Constitution Beach, Fox Point, Commercial Point, Prison Point, Somerville Marginal and Cottage Farm CSOs.

ties provide treatment for approximately sixty percent of the CSO volume.

The dilapidation that until recently plagued the entire sewer system contributed to CSO activation even in dry weather. Today, the overall increase in the system pumping, storage capacity and regular maintenance of CSO structures reduce overflows and increase the percentage of sewage that reaches treatment plants. CSO activity during dry weather has been nonexistent for the past two years. While improvements in the system have generally reduced CSO flows even in wet weather, volume of flow is nevertheless dependent on rainfall and fluctuates accordingly (see Figures 1.4a and 1.4b).

Long term plans for CSO improvement include the development of a management and control plan which will seek to further reduce CSO discharge frequency and volume, to relocate CSOs to areas less vulnerable to degradation, and to eliminate CSO flow where possible. In the meantime, a variety of low cost, easily implemented short term projects (known as System Optimization Plans or SOPs) are being undertaken. Designed to maximize transport and treatment capacities, these projects include replacing tidegates, installing or raising weirs (small sewer dams that can hold overflow within existing sewers) and plugging and abandoning certain overflow pipes altogether. In addition to SOPs, intermediate projects will be implemented, improving CSO control through large-scale construction and modification. Work has also begun on the System Master Plan, which will address system-wide needs in an integrated manner.

The Treatment Plants

While construction of the new Deer Island treatment plant progresses, the existing Deer and Nut Island plants must be made to operate as effectively and reliably as possible until the new plant comes on line. There are limits, however, to the removal efficiencies the plants can attain. At present, federal and state standards which MWRA treatment cannot meet have been supplanted by reasonably achievable "interim" limits approved by Judge Mazzone as part of the federal court process which governs important aspects of the modernization program.

Table 1.1 lists the interim limit violations since 1987. As the table indicates, there has generally been a downward trend in the BOD (biochemical oxygen demand) and TSS (total suspended solids) violations over the past seven years. The increase in 1993 BOD violations at Deer and Nut Islands is most likely the result of variations in sludge processing and other construction-related impacts.

Neither plant has pH control capabilities. Violations in effluent pH are typically the result of naturally occurring but infrequent low incoming pH values like those at Nut Island during 1993's huge spring rains. Deer Island should be capable of meeting all applicable limits after construction of the new primary and secondary treatment plants.

Improvements that have already been made in the existing system include:

- Settling time of sewage in sedimentation tanks has increased, allowing for better separation and a decrease in the amount of solids and oxygen-consuming organic matter discharged into the harbor.
- Floatable material skimmed off the settling tanks, called scum, was discharged directly into the harbor prior to 1991. Now, a portion of that material is consumed through sludge digestion and the remainder is landfilled.
- Digested sludge (settled sewage solids) is barged from both treatment plants to a pelletizing plant, where it is dewatered and heat dried into fertilizer pellets. Prior to the opening of this facility in 1991, sludge was dumped on the outgoing tide.

MWRA Joins The Recycling Revolution With Bay State Organic

In March 1993, the Massachusetts Department of Environmental Protection granted MWRA pellets its "Approval of Suitability" rating as a Type I sludge product, the highest grade available. This means that the pellets can be used on lawns, gardens, agricultural crops, and in other settings. The only restriction is that it may not be used on pastures or hay crops because some grazing animals can be sensitive to certain metal levels in their diets. Currently, a demonstration program is under way to familiarize the public with the use of sludge-derived fertilizers, and the Authority is distributing its fertilizer as Bay State Organic, available to the public in 40 pound bags for lawn and garden use. The vast majority of fertilizer, however, will continue to be used in large-scale agriculture in other regions of the country.

Box 1.1

Violations of interim discharge limits

Deer Island					Nut Island				
Fiscal Year	BOD	TSS	Coliform	pH	Fiscal Year	BOD	TSS	Coliform	pH
1987	31	2	2	0	1987	0	0	0	1
1988	32	10	11	0	1988	0	0	0	0
1989	32	5	8	1	1989	1	0	0	0
1990	14	2	1	0	1990	2	0	1	0
1991	17	1	0	3	1991	0	0	2	2
1992	7	0	0	0	1992	0	0	0	0
1993	16	0	0	0	1993	6	0	0	10

TABLE 1.1 The number of Biochemical Oxygen Demand, Total Suspended Solids, Coliform and pH violations at Deer Island and Nut Island from 1987 to 1993.

Future Plant Developments

In late 1994, the largest and most comprehensive part of the MWRA's modernization program—the wholesale replacement of the system's sewage treatment plants—will reach its first phase of completion. After nearly a decade of planning, design and construction, the MWRA will enter the first start-up phase for a plant that will eventually double the amount and effectiveness of treatment provided for metropolitan Boston's wastewater.

Currently wastewater at both Deer and Nut Island does not receive secondary treatment; this addition will represent a major step forward. Unlike primary treatment, where solids are simply allowed to settle out of wastewater, secondary treatment combines a controlled environment to promote bacterial growth in addition to a physical settling process. This multi-step procedure improves both settling and decomposition of solids, which results in the removal of more organic matter and toxic pollutants: primary treatment removes only approximately 60 percent of solids, and 40 percent of toxins and reduces oxygen consuming material 35 percent; secondary treatment removes 85 percent of solids, 50 to 85 percent of toxins, and 85 percent of oxygen consuming material.

(Figure adapted from the Boston Globe.)

Box 1.2

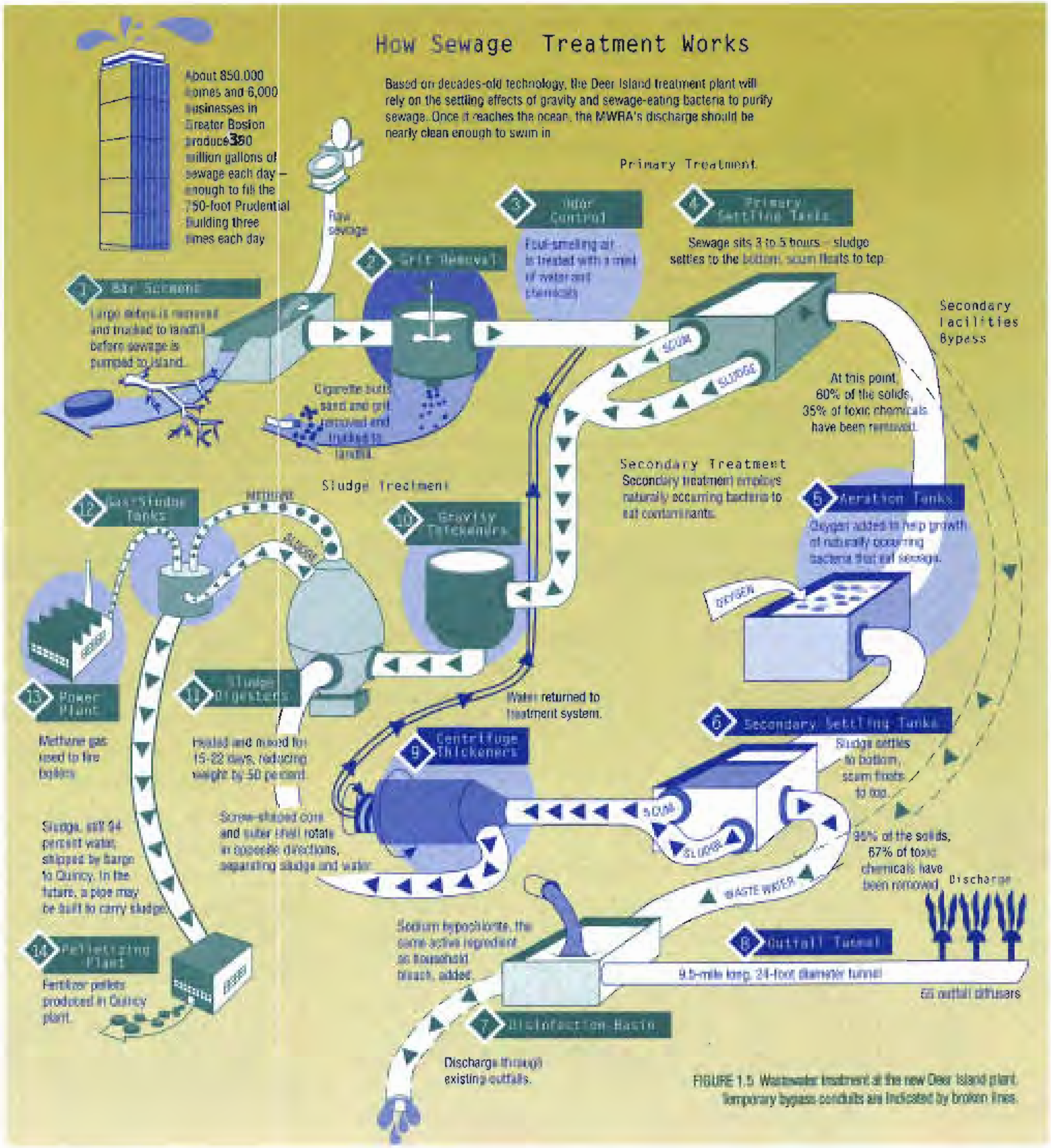


FIGURE 1.5 Wastewater treatment at the new Deer Island plant. Temporary bypass conduits are indicated by broken lines.

Pollutant Source Reduction

Removing pollutants at their source, especially toxic substances, is far more effective than trying to remove them once they have collected in the wastewater stream. Primary treatment removes only a fraction of toxic pollutants. Hazardous chemicals and heavy metals entering the treatment plants can upset the balance of microorganisms used in the treatment process, pass through the treatment plants into Boston Harbor, or remain as residuals in the sludge and fertilizer end-products. In addition, some pollutants that enter the treatment facilities could pose a hazard to people in the plants and to the equipment they monitor.

Pollutants originate from industrial, commercial, and residential sources. MWRA Toxic Reduction and Control Department (TRAC) works to regulate the inflow of hazardous pollutants and heavy metals from industries, landfills, and septage haulers into the MWRA sewerage system. TRAC permits and regulates over 1,300 local industrial sewer users. MWRA personnel inspect facilities, monitor discharges to the system, enforce discharge regulations, and work with industries to reduce the flow of toxic pollution through pretreatment and source reduction programs. TRAC also assesses financial penalties against violators. Table 1.2 shows the type and number of penalties TRAC has imposed.

Households are also a significant source of toxic substances due to the careless dumping of toxic products. Pollutants go down the drain in the form of household cleaners, paints, motor oil, and pesticides. Ingredients of some soaps and detergents, known as surfactants, progress unchecked through the treatment system and are highly toxic to small marine organisms. By conserving water, reducing the use of toxic chemicals and ensuring their proper disposal, residents can make a significant difference in stopping harbor pollution.

The number of TRAC enforcement actions continued to increase in 1993.

Fiscal Year	1990	1991	1992	1993
Notice of Violation (a)	0	16	127	370
Noncompliance Notices (b)	23	99	171	132
Penalty Assessment Notices (c)	2	15	11	19
Penalties Assessed	$1,105,000	$611,000	$1,045,000	$800,000

TABLE 1.2 (a) Letter describing violation, asking user to identify reason for the violation and what steps will be taken to ensure it will not recur. (b) Formal notice of violation specifying requirements the user has violated and a schedule by which user must return to compliance. (c) Formal, written notice to user assessing civil monetary penalties.

The amounts of certain metals entering the system have decreased dramatically.

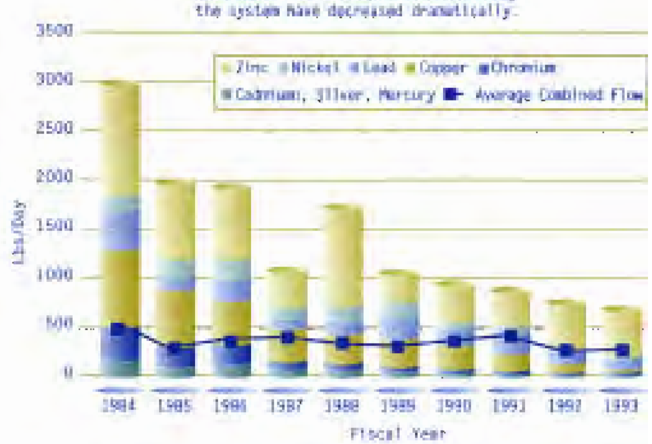


FIGURE 1.6 Combined loadings of all metals routinely monitored at Deer Island and Nut Island. Loadings based on average monthly flow through the two treatment plants. Average combined flow at the plants remained relatively unchanged during this period.

Other sources of pollutants are far more difficult to control, since they are beyond the regulatory capacity of TRAC and other organizations. Preexisting metal levels in drinking water, while safe for consumption, nevertheless contribute to levels which, in the wastewater stream, can be toxic to simple marine organisms. Contaminated groundwater can infiltrate the system through cracks and leaks in pipes. Stormwater runoff contains gasoline and other pollutants.

Nevertheless there are significant decreases in overall levels of pollutants entering the system. For example, over the past ten years, there has been a 75 percent decrease in the total amount of metals in MWRA effluent (see figure 1.6). This past year TRAC instituted a new fee program for regulated sewer users that recovers ratepayers costs and provides a better incentive for all industries to improve their discharge quality. During this first billing year, industries were billed for $1.7 million in fees. In addition to the efforts of TRAC, the federal government has banned the use of many hazardous materials and continues to refine regulations regarding industry-related discharge. Public awareness has increased, in part due to public outreach programs that have reduced illegal dumping, made it easier to dispose of toxic materials safely, and encouraged the use of nontoxic products.

the State of Boston Harbor

In 1993 definite signs of recovery were observed in all three components of the harbor ecosystem: the water, the sediments, and the plants and animals. These improvements were most obvious where they affected the way in which people use the harbor: for recreation, for fishing, and for enjoyment of its natural beauty.

Monitoring undertaken by the MWRA focuses on those natural resources which are key indicators of environmental change. In order to understand not only what changed, but also why it changed, the principal pollutants which affect the harbor are also monitored (see Box 2.1).

In the following sections, the monitoring data are used to address the environmental health of Boston Harbor in 1993 and to evaluate how far the recovery process has proceeded in the harbor. The monitoring data is presented in relation to the primary public concerns: swimming and recreation in the harbor; the edibility of the seafood; the health of the natural resources; and the aesthetic values of the harbor.

Swimming and Boating in the Harbor

The safety of the harbor for swimming and other contact recreation is affected by pathogens (bacteria and viruses) from undisinfected sewage in the water, mostly resulting from CSO discharges or from inadequately disinfected discharge from the sewage treatment plants. Healthy ecosystems typically have low to undetectable concentrations of sewage bacteria. State standards set the level of contamination that poses minimal health risk.

Bacterial counts in the outer harbor have declined dramatically since 1991, when sludge discharge ceased. More effective CSO controls and efforts to reduce sewage contamination from stormwater drains have improved water quality at beaches. The Metropolitan District Commission monitors bacterial counts at a number of beaches within the harbor and posts a beach as unsafe for swimming when the state standard is exceeded. For all beaches the percentage of days in violation of the standard fell between 1989 and 1993 (Figure 2.1).

The reductions in bacterial pollution have made the harbor a safer place to swim and boat than it has been in the recent past. Beach postings do still occur, however, and greater reductions will only be achieved through continued efforts to find and repair contaminated storm drains, and through the reduction of CSOs.

Monitoring and Pollutant Studies in Boston Harbor

Pollutant Sources and Characterization

- Studies on the nature of treatment plant effluent
- Studies on the sources and amounts of pollutants entering the harbor, including sources other than sewage effluent
- Monthly monitoring of the pollutant loads from the treatment plants and CSO entering the harbor and its tributaries

Pollutant Movement

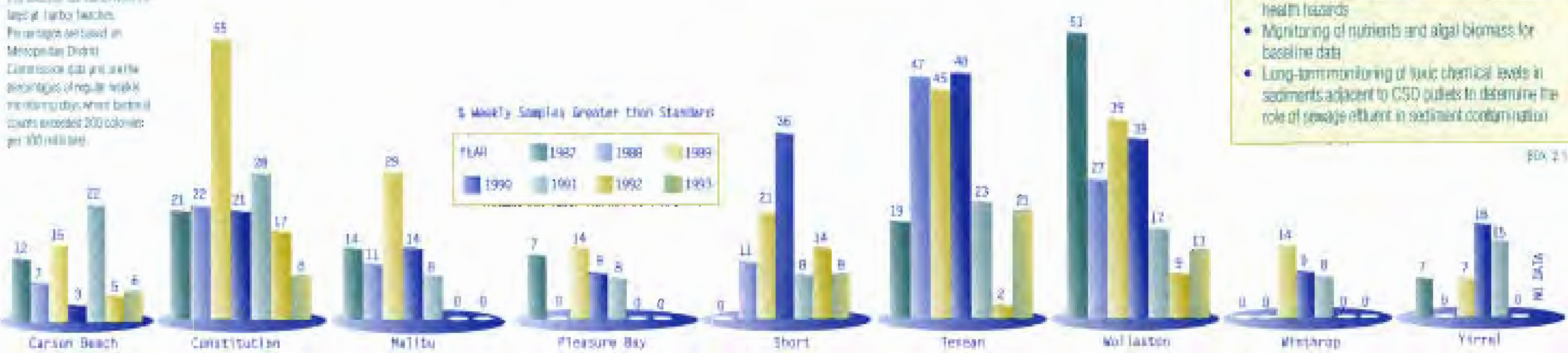
- Tracking discharge plumes from the treatment plants and CSOs
- Modeling studies to predict pollutant transport within the harbor
- Studies of sediment chemistry to determine the release of pollutants from sediments to the water column
- Monitoring bacterial numbers in sediments as a tracer for CSO and effluent plume contamination

Pollutant Effects

- Extensive monitoring of indicator bacteria, oxygen and other water quality parameters to assess water and sediment quality and potential health hazards
- Annual monitoring of sediment biota as an indication of the severity and extent of pollution
- Annual monitoring of PCB, PAH and metal concentrations in fish and shellfish tissue as a measure of the magnitude of pollution and potential health hazards
- Monitoring of nutrients and algal biomass for baseline data
- Long-term monitoring of toxic chemical levels in sediments adjacent to CSO outlets to determine the role of sewage effluent in sediment contamination

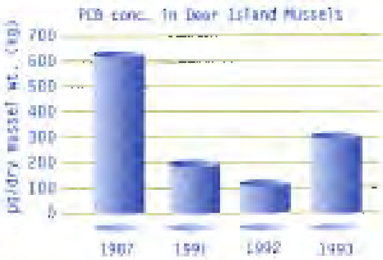
BOX 2.1

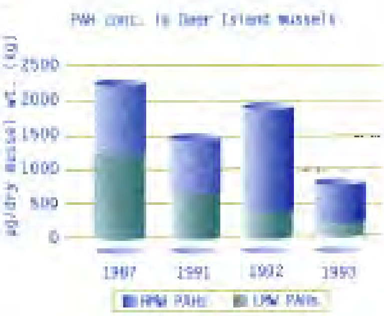
FIGURE 2.1 Percentage of days that bacterial standards were exceeded at harbor beaches. Percentages are based on Metropolitan District Commission data and are the percentages of regular weekly monitoring days when bacterial counts exceeded 200 colonies per 100 milliliters.



Edibility of Fish and Shellfish

The edibility of fish and shellfish from the harbor has improved since the 1980's. This improvement is a reflection of reduced pollution loads and the first stages of recovery of the sediments and water. However, while the levels of contamination generally meet the standards for safe eating, they are still high relative to seafood from other coastal areas.





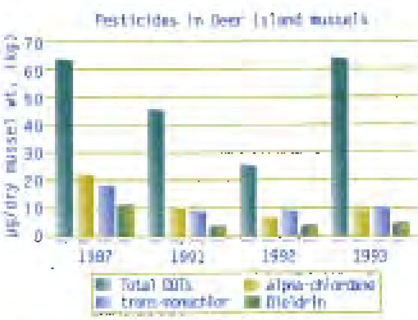
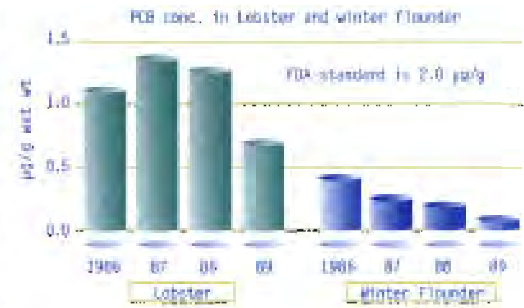


FIG.2.2 The concentration of most organic chemicals in mussels from Deer Island continued to remain below 1980s levels. Mussels were deployed for 50 days at Deer Island, except in the case of 1987 (30) days. No data were collected from 1988-1990.

Bacterial and toxic pollutant concentrations determine the safety of fish and shellfish for consumption. Since fish and shellfish live in contact with both the water and the sediments, restoration of both is necessary to reduce contaminant levels. So far, despite the long-term nature of recovery, some promising improvements are apparent. The concentrations of organic compounds in mussels at Deer Island appear to have reached steady state at levels noticeably lower than 1987 levels (see Figure 2.2). The increase in some concentrations from 1992 to 1993 is attributable to natural variability and not increased discharge to the harbor.

Monitoring of other fish and shellfish by the Massachusetts Division of Marine Fisheries (DMF) shows similar trends to those observed in mussels. PCB concentrations in winter flounder and lobster have fallen significantly since 1986 and are below the US FDA tolerance limit for consumption (see Figure 2.3). Mercury levels also fell and other metals showed no significant changes. As with mussels, contaminant levels in flounder and lobster were similar to, but a little higher than, those in other eastern marine areas (see Figure 2.4). On the basis of these trends MWRA concluded that management efforts were having an effect in reducing tissue concentrations of contaminants.

Bacteria and viruses are the major sources of shellfish contamination. Generally, chlorination of treatment plant effluent reduces bacterial counts to levels which avoid contamination above the health standard. Occasional chlorination failures in the treatment facilities can result in shellfish contamination. However, shellfish beds are also severely affected by contamination from storm drains and CSOs. While there has been some improvement to date, further dramatic changes are unlikely to occur until the continuing sources of pollution are further reduced.



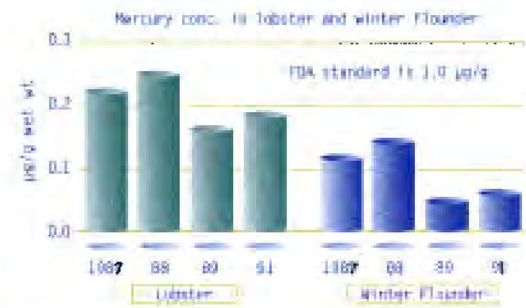


FIG.2.3. Contaminant concentrations in fish and shellfish have declined or remained at lower than previous levels. PCB and mercury concentrations in winter flounder (flesh) and lobster (composite tail and hepatopancreas). (Means are for three stations sampled several times each year. Data from Schwartz et al. 1991, 1993). Data are the most recently released results from the Mass. Division of Marine Fisheries.

Marine Resources

Determining how well the marine resources of an area are protected is more complicated than simply addressing concerns about the edibility of fish and shellfish or how safe it is to swim at public beaches. There are few regulatory standards for assessing the ecological health of an area. However, reliable indicators are provided by the state of the three principal components of marine systems: the sediments, the biota, and the water column. Cumulatively, the state of these three components provides a picture of the overall state of the marine resources.

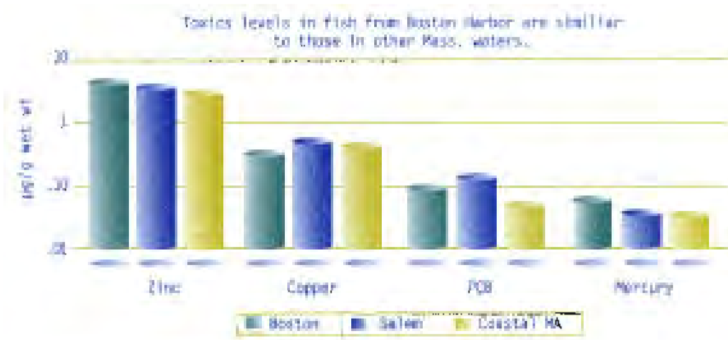
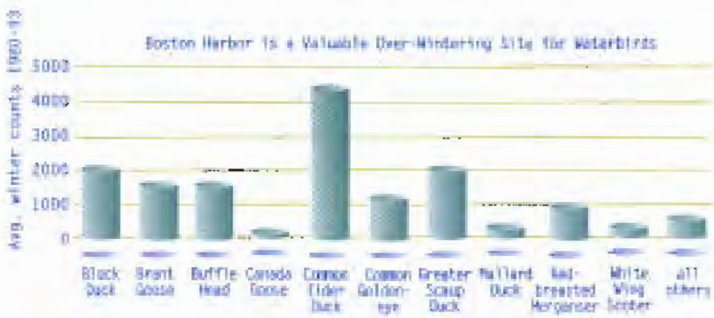
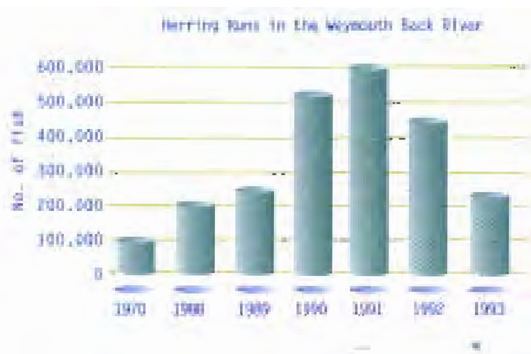


FIG.2.4. Contaminant concentrations in winter flounder tissue (muscle) from Boston and Salem Harbors and coastal waters of Massachusetts. (Data are from Schwartz et. al. 1991 and 1993 and are annual means of three sites in each area).





Waterbirds

Fifty-four different species of waterbird have been observed using the Harbor as an over-wintering site. An additional 22 species have been observed during late fall/early spring. In an average winter there are likely to be 39 different species using the harbor.

Commercial Cruise Operations

Harbor cruise operations are part of a large passenger boat industry in Boston Harbor with an estimated direct annual income of about $35 million. These cruise operations are dependent on the aesthetic health of the harbor.

Beaches

There are more than 8 miles of recreational beaches within Boston Harbor managed by the MDC and several more miles of walking paths, marinas and parks which abut the Harbor.

Herring and Smelt Runs

The Back River is the location of one of the largest annual runs in Massachusetts for both herring and smelt. The Mass Division of Marine Fisheries reports that over 200,000 of each fish navigate the Back River Ladder annually.

Resources of

Boston Harbor

Beach		1	Cod, Atlantic Mackeral
Shellfish		2	Harbor Seals
Fishing		3	Flounder
Effluent Outfall		4	Eelgrass
Cruise Boat Route		5	Scuba Diving
		6	Striped Bass
		7	Bluefish
		8	Harbor Porpoises

Boston Harbor: A Valuable Resource–Despite its past degradation, Boston Harbor remains a valuable economic, aesthetic and ecological resource. This map shows just some of the natural resources of the harbor and the activites they make possible. Among the most valued of these resources are the marine life that are harvested for food, sport and conservation-related values. On the water's surface, the aesthetic appeal of the harbor attracts boaters and waterfront users while also sustaining an array of tourism-related businesses. Consistently swimmable harbor waters are now providing beaches for the many city dwellers who are unable to reach more distant coastal communities. In communities throughout Massachusetts the direct and indirect economic benefits of the harbor are being realized, particularly the economic effects of harbor-based commerce. Even the present early stages of ecosystem recovery have shown the great potential of this long under utilized harbor.

Commercial Fishery

The fish and shellfishing industry is one of the largest commercial uses of Boston Harbor. In 1992 the Harbor provided 3.7 million pounds of lobster, over one-third of the total catch for the state, with a value of $10.6 million dollars.

Recreational Fishery

Boston Harbor supports a large recreational fishery. Among the species commonly fished inside the harbor are Bluefish, Flounder, Smelt and Striped Bass, and species caught just outside of Boston Harbor include Cod and Atlantic mackerel.

The MWRA tracks *Clostridium perfringens* spores (bacterial spores) as a tracer for sewage contamination in sediments (see 2.2). Since late 1991 there has been a dramatic reduction in spore counts at sites both near and distant from former sludge discharge sites (see Figure 2.5). The reductions are strong evidence of the positive impact of ceasing sludge disposal to the harbor. The rate of contamination reduction is much faster than expected and has probably been assisted by the recent series of severe storms which help to flush contaminated sediments from the harbor or cover them with clean sand from offshore.

Over the period that spore counts have declined, the diversity of benthic animals (animals living on or in the sea floor) has increased. Because these animals are largely sedentary and confined to one location throughout their lives, their numbers and diversity are good indicators of long-term pollution impacts on the biota of an area. Since sludge discharges ceased in 1991, the diversity of benthic animals has increased dramatically near the sludge discharge sites off Long Island (see Figure 2.6). Areas that were once lifeless are now inhabited by dense assemblages of shrimp-like amphipods. This improvement is due to reduced smothering by sewage solids and increased oxygen availability at the sediment surface. However, improvement is not uniform throughout the harbor; severely degraded areas such as those at Savin Hill Cove, as well as relatively healthy areas in Hingham Bay, have seen little change, other than normal seasonal fluctuations.

Clostridium perfringens

Clostridium perfringens is a bacterium found in great numbers in sewage effluent and sludge and which produces spores that survive for many years. The presence of high numbers of spores in marine systems is an indication of sewage contamination. The persistence of the spores makes them a more useful tracer of long-term pollution than many other bacteria found in effluent which tend to die within hours or a few days of contact with marine waters. Sampling must be designed carefully to include depositional areas where waterborne particles are likely to settle and accumulate in the sediments.

Box 2.2

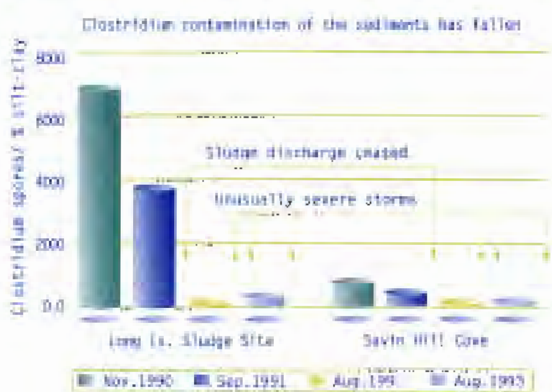


FIG 2.5 Counts of *Clostridium perfringens* spores in sediments of Boston Harbor. Counts are normalized to % silt-clay to account for differences in the depositional environment of different areas.

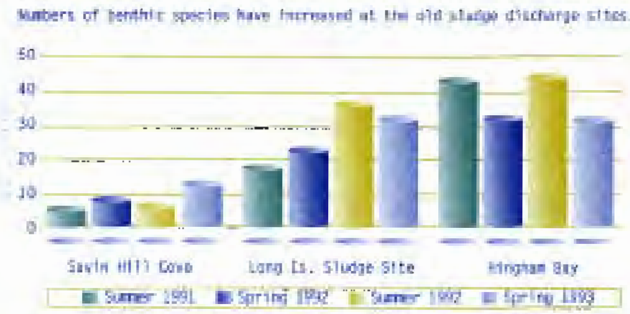


FIG 2.6 Number of species of benthic organisms at sites in Boston Harbor. Data are means of three grab samples on each sampling occasion.

The improvements in sediment animal life have caused changes in sediment chemistry which in the short-term appear detrimental but in fact have long-term benefits for harbor recovery. Increased benthic animal abundance has led indirectly to an increased release of nitrogen from the sediments. Over the period that animal abundance increased, the rate of nitrogen release from the sediments more than doubled (Giblin, unpublished). In the short term this acts as an additional source of pollution. In the long term, however, this activity is effectively acting as a nitrogen 'pump', driving nitrogen which has accumulated in the sediments into the water where it can be flushed from the system (see Figure 2.7). The combined action of the 'faunal pump' and reduced nitrogen loads from MWRA sources (see Figure 2.8) will eventually reduce the nitrogen store in the harbor as a whole.

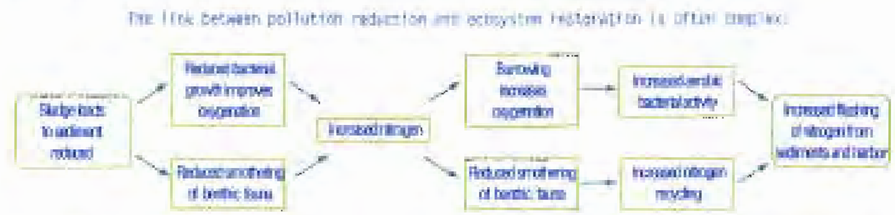


FIG 2.7 Schematic diagram of the effect of sludge abatement on sediment nitrogen flux. Stopping sludge discharges is the most likely cause of short-term increases in nitrogen release from harbor sediments. The effect, however, was not simple or direct but involved a complex interaction of chemical and biological processes.

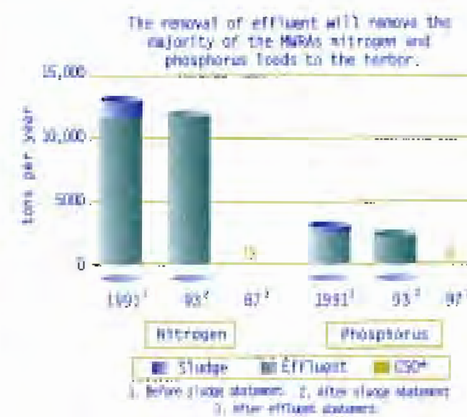


FIG 2.8 Nutrient loads to Boston Harbor from MWRA sources. Loads are based on estimates by Alber and Chan (1994) and CSO modeling by Metcalf and Eddy (1993). The 1997 loads are due entirely to CSOs.

Health of the Biota

The improvement in sediment quality is also reflected in the improved health of bottom-feeding fish, such as winter flounder, which live in contact with contaminated sediments and feed on small animals contaminated by sediment pollutants. The incidence of liver disease is monitored as an indicator of overall fish health. In 1993 the incidence of liver tumors discovered in winter flounder had fallen to zero, and the incidence of early liver disease indicators has stabilized at a lower level since about 1990 (see Figure 2.9).

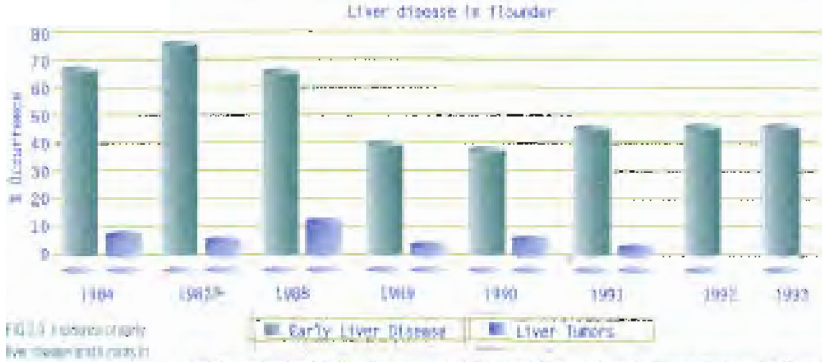


FIG 2.9 Incidence of early liver disease and tumors in winter flounder from Boston Harbor (Deer Island). Means of samples collected on a single occasion each year at Deer Island.

Other indicators suggest that the harbor continues to provide a valuable habitat for marine resources. The harbor has historically been the site of one of the largest herring runs in the region. The number of herring entering the Weymouth Back River each year has increased markedly since the early 1970s.

The harbor also provides an important over-wintering site for migratory birds (see Center Resource Map). Monitoring by the Massachusetts Audubon Society indicates that the bird populations have remained stable over recent years. It is likely, however, that improvements in the harbor will result in some changes in the bird community. Species such as the Common Black-Headed Gull, which tend to occur in the vicinity of effluent outfall or in nutrient enriched waterbodies, are likely to decline in number once the outfall is diverted offshore. These species may be replaced by others suited to better water quality.

State of Water Quality

Concentrations of algae and oxygen are two key determinants of water quality. Levels of chlorophyll (an algal pigment) are used to extrapolate a measure of algal mass. Boston Harbor has regular peaks in water column chlorophyll concentrations during spring and summer (see Figure 2.10). Apart from aesthetic considerations, the major concern with algal blooms is the effect of their death and decay on reducing the concentration levels of dissolved oxygen in the water. Oxygen is consumed by bacteria in the decay of dead algal cells. In extreme cases, this bacterial decay process can deplete oxygen from the water. During the summer of 1993 there was a dense algal 'bloom' in the inner harbor which collapsed and was washed into the outer harbor in early September. Oxygen levels during the bloom were well above the state standard but, coinciding with the death and decay of the algae, concentrations later fell below the standard (see Figure 2.10).

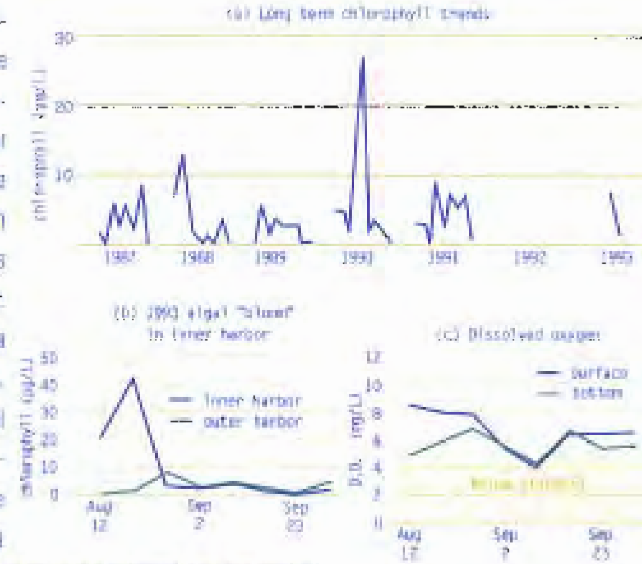


FIG 2.10 (a) Mean monthly chlorophyll concentration in the inner harbor since 1987. (b) The 1993 summer bloom can be seen expanded to show weekly concentrations and (c) concurrent dissolved oxygen concentrations at the site.

The algal mass in Boston Harbor is lower than that found in other estuaries with similar levels of nutrients (see Figure 2.11). This is probably due to the turbidity of the water, which reduces the amount of light available to support algal growth, and the high flushing rate in the harbor. The removal of nutrients from the harbor when the discharge is moved should reduce algal growth. However, the removal of effluent will also improve light penetration. The net effect on algal growth is still unclear and is dependent on

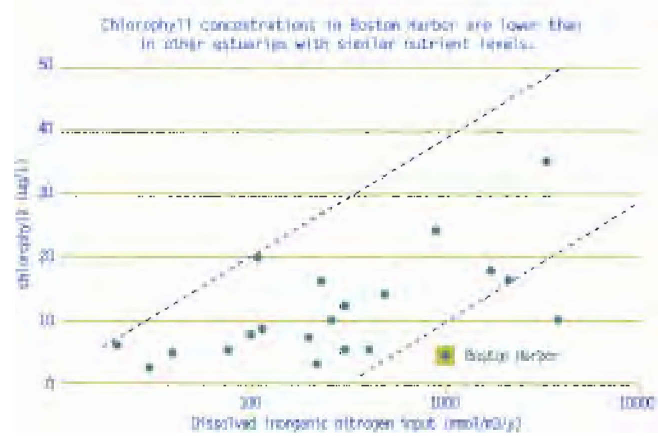
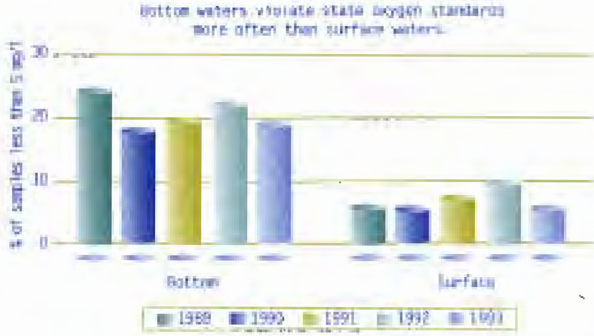


FIG 2.11 The relationship between dissolved inorganic nitrogen loads and chlorophyll concentrations in North American estuaries. Data for other estuaries is from Nixon and Pilson (1983) and Nixon (1991). The box for Boston Harbor covers the range of annual DIN loads and mean chlorophyll concentrations for 1987-1993.

FIG 2.12 The percentage of surface and bottom water dissolved oxygen samples in violation of the 5 mg/L (Class SB) standard. Data are for all sites monitored in the harbor between May and October, 1989-1993.



the interaction of nutrient levels and light. Resolving the likely impact on Algal growth is the objective of a current MWRA study.

Because dissolved oxygen is a key component of many ecological processes and is essential to maintaining a healthy marine resource system, it is a useful measure of the overall water quality. The biota, chemical processes and the decomposition of organic matter (such as sewage) all consume oxygen. Despite these consuming processes, surface waters tend to maintain high oxygen concentrations through mixing with air, whereas bottom waters may become isolated from the air during periods of stratification (see Box 3.3) with subsequent depletion of oxygen. This pattern of bottom water oxygen depletion is common in the harbor; 5-10% of surface water samples violate the standard compared with about 20% of bottom water samples (see Figure 2.12). Most of the violations occur in semi-enclosed areas, like the inner harbor, that not only become stratified over summer but are also highly depositional, with oxygen consuming matter accumulating in the bottom waters. Many of these inner harbor areas are also in the vicinity of CSOs, where untreated sewage effluent dramatically increases oxygen consumption (see Figure 2.13).

The percentage of oxygen violations throughout the harbor in 1993 has fallen compared to 1989, however there is no consistent trend of improvement (see Figure 2.12). This is largely due to the influence of rainfall – in wet years there tend to be more CSO flows and more violations of the oxygen standard. Reductions in the number of oxygen violations should occur as the capacity of the sewage system to handle effluent is improved and the number of CSO discharges decline. At present, however, areas of the harbor around CSO overflows continue to suffer from oxygen depletion.

A final measure of marine resource protection is the growth of eelgrasses in the harbor. These plants are important nursery areas for many of the estuarine and oceanic fishes and shellfish and their survival is dependent on light penetrating to the bottom of the water column. Measurements show that light penetration in the harbor is generally poor. Historical information suggests that seagrasses were once distributed throughout the harbor. Today however seagrasses grow only in the Hingham Bay area, which is an area of relatively high light penetration (see Figure 2.14). Elsewhere during the summer, light sometimes reaches the bottom at low tide, but never at high tide. Reductions in suspended solids loads to the harbor (see next section) will improve the clarity of the water. The likelihood of restoring some of the seagrasses communities, either through natural re-colonization or through replanting schemes such as those being investigated by the Department of Environmental Protection, will be enhanced with improved water clarity.

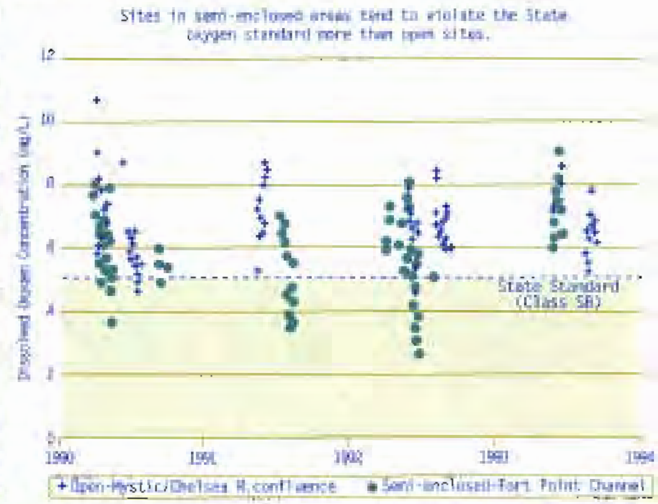


FIG 2.13 Dissolved oxygen concentrations in bottom waters of semi-enclosed and open water sites of the Harbor. Data are bottom water concentrations between May and October the period of most oxygen violations.

In summary, there is strong evidence of an improvement in the state of the marine resources in the harbor. The sediments throughout the harbor show increased faunal diversity and the incidence of disease in bottom-feeding fish has been significantly reduced. The harbor continues to serve a role as habitat for large fish and bird populations. Dissolved oxygen levels are generally high in the outer harbor and water clarity appears to be improving. However, there continue to be areas in which significant improvements can still be made: oxygen standards are still being violated in some areas; it appears that fish disease could be further reduced; and the restricted distribution of eelgrass meadows indicates that turbidity is higher than it was a century ago. While it appears that the harbor has reached a new equilibrium, it is unlikely that further significant improvements will be visible only as pollutant loads are dramatically reduced by virtue of the operation of the new treatment plant outfall and furthering improvements in CSO controls.

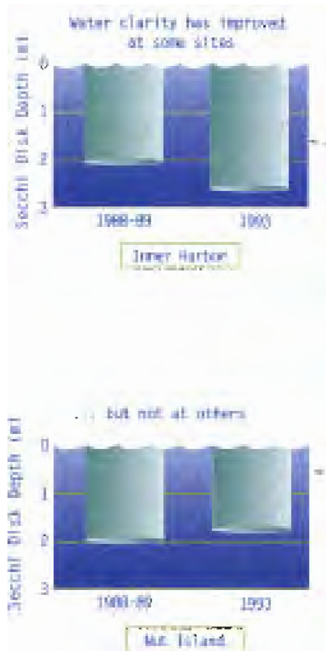


FIG 2.14. a. Difference in May-October water clarity between 1988-89 and 1993. Deeper secchi disk measurements correlated with clearer water.

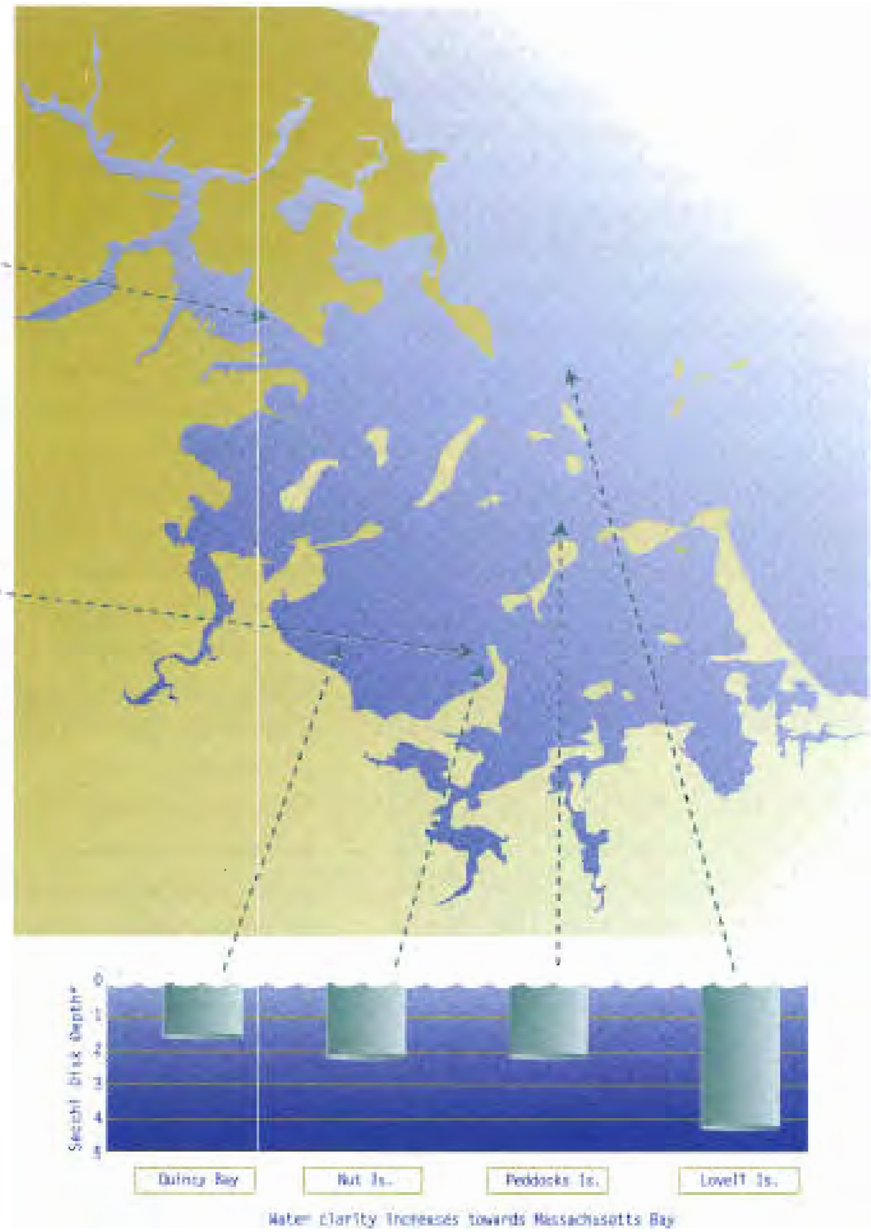


FIG 2.14 b. Example of typical changes in water clarity from the inner harbor to the outer harbor (secchi disk depth). Measurements taken 9/3/93.

FIG 2.14. How deep can you see? The depth of light penetration in four locations on a single day in 1993 are shown on the graph at bottom. The increase in water clarity towards Massachusetts Bay is typical. Differences in May-October water clarity between 1988-89 and 1993 are shown on the left. (Deeper secchi disk measurements correlate with clearer water.)

Aesthetic Appeal

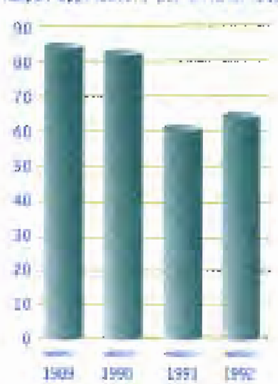
The clarity of the water column is an important aesthetic consideration, as is the frequency of algal blooms which can discolor water and cause foul odors. Other aesthetic considerations include the amount of floating debris from the sewer system which enters the water and accumulates on beaches.

The process of ecosystem restoration should improve water clarity. Water clarity is affected principally by the amount of suspended material in the water. Major sources of suspended solids include sewage (effluent, CSOs and sludge), rivers, resuspension of sediments, and algae. The suspended solids load to the harbor has fallen by over 25% since sludge discharge ceased in 1991, and more significant further reductions are expected once the new outfall is operational. The control of CSO, sludge and effluent discharge not only reduces the external load of suspended matter but also reduces the nutrient load entering theharbor which would otherwise stimulate algal growth.

Water transparency is generally insufficient to see the bottom of the harbor during summer (see Figure 2.14). It is in the order of only 1-2 meters in the harbor, increasing to about 4 meters in areas adjacent to Massachusetts Bay. Although clarity improves during winter when algal mass is low, it is still poorer in the harbor than in the bay. There is very little past information on water clarity in the harbor but the little that there is suggests that the removal of sludge from the harbor has improved water clarity (see Figure 2.14). The future reductions in solids loads, which will occur when the new outfall is operational, should see further improvements in water clarity.

Another major source of aesthetic deterioration in the harbor has been floating pollutants which pass through the sewer system. These include floatable objects such as condoms, tampon applicators and plastics. A decline in the amount of sewage-related debris washing up on harbor beaches, like tampon applicators, reflects a continuing improvement in treatment system effectiveness (see Figure 2.15).

FIG. 2.15: Tampon applicators per mile of beach are based on the most recently released counts from Mass. Coastal Zone Management's annual Cleansweep. Tampon applicators reach beaches via a variety of routes including effluent, CSOs, and sludge discharge (now ceased). Because these tampon applicators from a given year wash up on beaches over several following years, improvements in treatment system effectiveness do not appear in full immediately. Further decline is expected as treatment improvement continues.



Current and Future State of the Harbor

The state of the harbor has improved markedly over the past few years. Violations of the bacterial standard for swimming are fewer, and the concentrations of toxic substances in fish and shellfish **edible tissue has decreased**, well below the FDA standard. The detected incidence of fish disease has continued to fall, and benthic faunal diversity is increasing throughout the harbor. Bird and fish populations continue to use the harbor and the number of violations of the state oxygen standard are decreasing.

However, the improvements to date must not be overstated. There continue to be violations of state and federal standards for water quality. Oxygen levels occasionally fail the state standard, particularly in bottom waters. Fish and shellfish have contaminant levels well within the standard for edibility, however the concentrations in fish from the harbor continue to be higher than in many other eastern estuaries. The occurrence of a large algal bloom in the harbor in summer 1993 emphasized the nutrient-enriched status of the harbor and raises concerns regarding oxygen depletion and the possibility of toxic algal blooms.

We also need to be aware that ecosystem recovery is not a straight-forward or predictable process. Short-term changes, such as the increased release of nitrogen from the sediments at some sites, may not appear at first to be an improvement. However, these intermediate phases often result in a long-term improvement.

FIG. 2.16: State of Harbor Ecosystem Recovery in 1994: yellow = Poor Health, blue = Good Health

Currently, therefore, the harbor is at an intermediate level of recovery (see Figure 2.16). The signs of recovery have resulted from improved quality of sewage effluent, improved management of CSOs and cessation of sludge disposal to the harbor. The harbor is obviously not at the 'poor' end of the recovery scale. However, further improvements are necessary before the harbor approaches the 'healthy' end of the recovery scale. The commissioning of the new outfall and further improvements in CSO controls will effect the drastic reductions in pollutant loadings that are necessary for further significant improvements in the health of the harbor.

Chapter Three

Monitoring Massachusetts & Cape Cod Bays

Boston Harbor is part of a larger coastal ecosystem: the Massachusetts and Cape Cod Bays. Although the degraded condition of Boston Harbor is widely recognized, the environmental health of the bays has received much less public attention. The MWRA's Outfall Monitoring Program, an outgrowth of the decision to site the new treatment plant outfall 9.5 miles into Massachusetts Bay, is shedding significant new light on both the state of these two bays and on their interaction with each other and with Boston Harbor.

Facilities now under construction will change two important aspects of MWRA effluent discharges: (1) the quality of the treated effluent will be greatly improved as poor treatment levels at the current facilities are replaced by modern primary and secondary treatment processes and (2) the location of effluent entering the bay will change from a surface plume originating in the harbor to a discharge point 100 feet below the water's surface and 9.5 miles out into the bay. Moving the effluent outfall to Massachusetts Bay is not simply a case of moving the problem. Rather, the improvements in the quality of the effluent and increased dilution at the offshore location will improve the overall environmental health of both Boston Harbor and Massachusetts Bay.

Monitoring and Modeling the Bays

In researching current and potential pollution impacts in Massachusetts and Cape Cod Bays, the scientific focus differs from that taken in Boston Harbor. In the bays, two issues dominate: the possible effects of nutrients from discharged effluent, and the health of the bays' food chain, including fish and shellfish intended for human consumption. These issues are at the core of an MWRA bays-wide monitoring program designed to enhance overall understanding of how the bays currently function; to help predict any potential effects from the new outfall; and to understand whether the outfall is affecting the highest levels of the food chain: the humpback and right whales that visit Stellwagen Bank, the eastern boundary of Massachusetts Bay, and Cape Cod Bay.

The Outfall Monitoring Program has two key elements: long-term monitoring and research and water quality modeling. Environmental changes can only be detected and measured by comparison of known environmental conditions. The long-term monitoring plan (see Figure 3.1) is designed to provide a baseline record of conditions in the bays, including the best obtainable understanding of the ecosystems' natural variations.

The second element is the development of a water-quality model, a mathematical, computerized tool which uses information about the physics, chemistry and biology of a water body to understand interactions and predict changes; for example, how changes in the location of the outfall would affect phytoplankton (algae) growth. As the monitoring program progresses, the model is fine-tuned by comparing its output with data collected in the monitoring program. In turn, the model is able to assimilate and interpret the great volume of data collected through monitoring and to focus future efforts in the most important areas.

Monitoring stations are located throughout
Boston Harbor, Massachusetts Bay and Cape Cod Bay.

Figure 3.1 The MWRA's monitoring plan is one of the most extensive marine monitoring projects ever undertaken in the United States. Nearfield stations provide a detailed description of water quality in the area expected to be affected by the new outfall. Farfield stations monitor large scale trends across the bays and will identify any unexpected impacts of the new outfall.

Early Baseline Monitoring Results

Under way since February 1992, baseline data gathering programs for Massachusetts and Cape Cod Bays have provided the basis for drawing some broad generalizations about the bays:

- Massachusetts and Cape Cod Bays are not pristine environments.

Massachusetts and Cape Cod Bays have received pollutants from a variety of sources for many years. The primary contributors are Boston Harbor (25-50% of most heavy metals and organic contaminants), rivers, the atmosphere, and other sources. Data from nutrient, plankton, dissolved oxygen and fish/shellfish studies offer evidence of these impacts.

- There is transport of pollutants from Boston Harbor to Massachusetts Bay and some evidence of associated biological impacts.

Distribution of sewage tracers documents the export of solids from Boston Harbor.

Figure 3.2 Clostridium spore concentrations in sediments of Mass Bay. Clostridium perfringens spores are a useful indicator of sewage contamination of sediments. 1991 data revealed a strong gradient of contamination with highest concentrations in and near the Harbor and declining into Mass Bay.

Concentrations of pollutants provide evidence that pollutants travel from Boston Harbor to Massachusetts Bay. Figure 3.2 shows that concentrations of *Clostridium Perfringens* spores, a bacterial indicator of sewage pollution, are high in the harbor and more dilute in Massachusetts Bay. The gradients of chemical pollutants such as metals and pesticides correspond closely to the gradient of effluent-associated bacteria. In some instances there are corresponding gradients in biological impacts, such as liver disease and toxic contamination of fish and shellfish. Data from nutrient, plankton, dissolved oxygen, fish/shellfish and benthic community studies all offer evidence to support this observation. However, other biological indicators, such as the type of sediment faunal community, do not show similar gradients.

- Cape Cod & Massachusetts Bays are distinct ecosystems (see Box 3.1).

Evidence is mounting which supports earlier suggestions that the two bays function, in many respects, as distinct waterbodies. Some of the differences between the bays may be related to hydrodynamic features or nutrient availability. Whatever the causes, recognizing these differences now will greatly enhance later efforts to monitor change throughout the bays. Data from chlorophyll, plankton, and benthic community studies all offer evidence to support this observation.

The following detailed sections present and explain the data which support these general conclusions. Descriptions of other findings are also included.

Nutrients

Two years of water quality monitoring have demonstrated the consistent presence of a nutrient concentration gradient (a gradient is a decrease or increase in the amount of a substance across a specified distance) decreasing from the harbor to western Massachusetts Bay (Figure 3.3). This gradient has the same general configuration shown for *Clostridium perfringens* spore concentrations (Figure 3.1), suggesting that much of this nitrogen probably originated from effluent discharge into the harbor. The rapid flushing of the harbor – harbor water is completely replaced approximately every 5 to 10 days – transports 85 to 90% of the harbor's total nitrogen to Massachusetts Bay where it is rapidly diluted. This gradient illustrates the extent to which Massachusetts Bay has already been impacted by nutrient transport from Boston Harbor. Similar gradients have been observed for silver and other chemical pollutants which are typically found in effluent (Bothner et al. 1993).

How Similar Are Massachusetts & Cape Cod Bays?

Data from the Massachusetts Bay Monitoring Program support earlier suggestions that Massachusetts and Cape Cod Bays function as distinct coastal systems. This is illustrated by differences in both the benthic faunal community and chlorophyll concentrations in the Bays. Cape Cod Bay has an unusual sea cucumber-polychaete worm assemblage which dominates the sediment fauna. This assemblage is not found in Massachusetts Bay and probably reflects the differences in the physical nature of the bays: Cape Cod Bay is relatively sheltered and low energy; Massachusetts Bay is a higher energy environment.

Cape Cod Bay also has higher winter-spring chlorophyll concentrations, higher levels of primary production, an intense dinoflagellate bloom, and then a summer phytoplankton population with a lower diatom component than found at most Massachusetts Bay stations. These characteristics are usually typical of nutrient enriched waters and it is possible that Cape Cod Bay is influenced by an unquantified source of nutrients or by efficient recycling of nutrients made possible by its shallowness. Seasonal differences in the phytoplankton species between the Bays (see text) may also be related to differences in the nutrient dynamics of the Bays. Alternatively, surface water temperatures, which are distinctly different in Cape Cod and Massachusetts Bays, may be responsible for initiating the phytoplankton successional trend.

Box 3.1

Figure 3.3 Total Nitrogen concentrations [illegible] in Mass. Bay. Contours are based [illegible] nitrogen concentrations from [illegible] surveys in 1992 and show a similar pattern [illegible] highest in the harbor and declining into the bays. This suggests that the source of both the [illegible] discharged to the harbor.

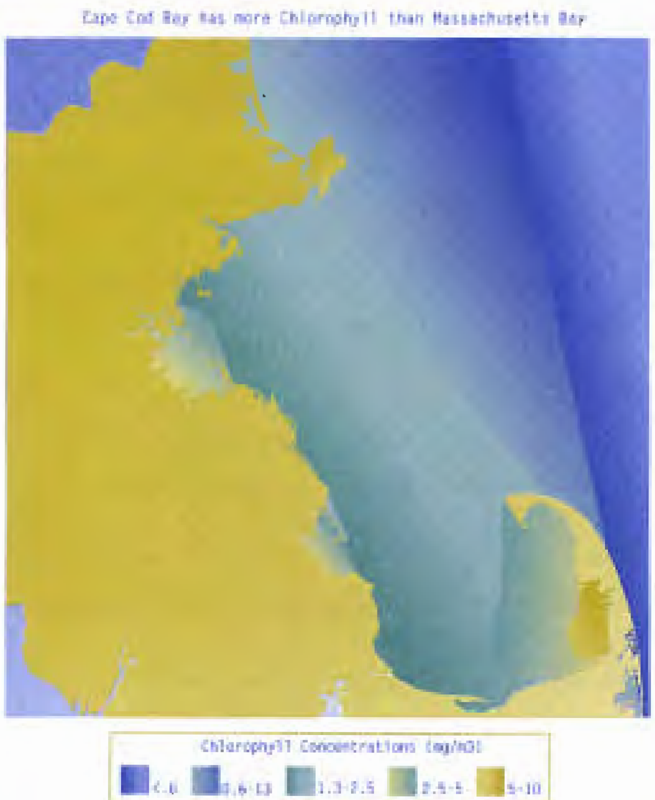


Figure 3.4 Mean chlorophyll concentrations in Massachusetts and Cape Cod Bays in 1979-81. Data are based on the mean of 12 CZCS satellite images [illegible] and processed by Mathewson (1995).

Chlorophyll Concentrations

Because the cells of phytoplankton (microscopic marine algae) are small, and difficult to count and measure directly, the total amount of chlorophyll (the green photosynthetic pigment in plants) is measured as an estimate of how much plant material is in the water. Increased nutrients in the water can result in increased phytoplankton growth, detected as increased levels of chlorophyll. "Blooms" of phytoplankton occur as part of the natural seasonal cycle in Massachusetts Bay, with chlorophyll levels increasing rapidly in February and remaining high through early spring.

Monitoring has revealed that chlorophyll concentrations vary markedly at three distinct scales: daily, seasonally, and regionally (between Massachusetts and Cape Cod Bays). Chlorophyll concentrations can change from near-zero to bloom concentrations in a matter of hours or days. Satellite imagery from fifteen years ago has revealed that the average chlorophyll levels were higher in Cape Cod Bay than in Massachusetts Bay (see Figure 3.4). Over the 1992 annual cycle, the chlorophyll peak due to the winter-spring bloom occurred earlier, was more intense, and lasted longer in Cape Cod Bay than in Massachusetts Bay, presenting new evidence of the different natures of the two bays.

Plankton Population

Analyses of large numbers of plankton samples during baseline monitoring indicate that the phytoplankton communities are generally similar throughout Massachusetts and Cape Cod Bays. Plankton communities in the bays include dozens of species, ranging from large (diatoms) to small (microflagellates). Similar communities of phytoplankton are found in other east coast embayments (e.g., Narragansett Bay and Long Island Sound). The phytoplankton population in both Massachusetts and Cape Cod Bays has included periodic blooms of the nuisance species such as *Phaeocystis pouchetti*, and *Alexandrium tamarense*, a red tide species which causes paralytic shellfish poisoning. Nuisance algal blooms are natural phenomena that have been observed for many decades.

Monitoring of Massachusetts Bay will enable scientists to determine if the new effluent outfall has any effect on the pattern of nuisance blooms.

Calanus Copepods and Right Whales

Several kinds of whales including fin, right, and humpback are frequently sighted in the coastal waters of Massachusetts and Cape Cod Bays. The north Atlantic right whales are regular seasonal residents, actively feeding in this region from spring through fall. These baleen whales feed almost exclusively on Calanus copepods and actively seek out dense swarms of these zooplankton throughout their feeding grounds. Although the Calanus copepods occur commonly in the right whale's summer feeding grounds, their abundance is highly variable and dependent on many factors, including the availability of the phytoplankton they feed on. This patchy distribution is also influenced by physical factors such as wind, waves, and currents which aid or enhance the formation of dense Calanus patches at the surface. When feeding on the surface patches, right whales actually skim the water's surface with their open mouths, efficiently drawing in the dense swarms of Calanus.

III-37

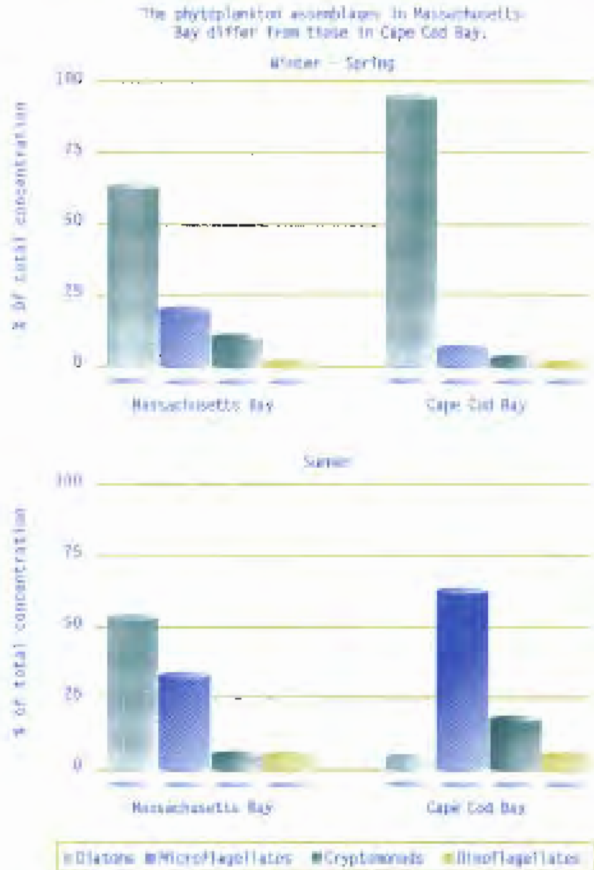


Figure 3.5 Phytoplankton assemblages in Massachusetts and Cape Cod Bays. The winter communities are similar, with diatoms dominating. Summer communities are dominated by diatoms in Massachusetts Bay but by microflagellates in Cape Cod Bay.

Although total phytoplankton cell counts can vary widely among the sampling locations within Massachusetts Bay, the monitoring program has allowed the identification of major seasonal bloom events, and seasonal patterns distinguishing Massachusetts and Cape Cod Bay. Figure 3.5 compares the dominant phytoplankton at the future outfall site in Massachusetts Bay and at a Cape Cod Bay site during winter and summer. During the winter-spring bloom at both locations, the phytoplankton population is dominated by diatoms, especially species of Thalassiosira. This is a pattern typical of coastal waters throughout New England. During the summer, the community structure changes to one dominated by microflagellates in Cape Cod Bay and to a more mixed population in Massachusetts Bay. Another important difference is that in winter microflagellates are twice as abundant in Cape Cod Bay as in Massacusetts Bay. These differences may be due to variations in the nutrient cycling processes or the mixing and circulation patterns of the bay but, whatever the cause, they highlight the distinctiveness of each bay.

Dissolved Oxygen Concentrations

Over the last two years, baseline monitoring has shown that dissolved oxygen concentrations in Massachusetts Bay vary seasonally but are consistently within the state standard. High oxygen concentrations are typical in the winter season when the water column is well mixed and aerated (Figure 3.6). Beginning in August and lasting until about October, there is a continuous decline in bottom water dissolved oxygen, caused mainly by the onset of stratification (See Box 3.3) and by lower oxygen solubility at higher water temperatures. However, the lowest concentration measured during this period was generally around 7 mg/L, well above the 6 mg/L standard that the state considers safe for marine organisms. The lowest concentrations of dissolved oxygen are characteristically measured in Stellwagen Basin, where water is deeper than 150 feet and there is little exchange with adjacent waters. In general, dissolved oxygen levels in Massachusetts Bay generally reflect seasonal and depth-related variations rather than pollution-related impacts.

Figure 3.6 Dissolved Oxygen concentrations measured in 1992 at the future outfall site. Concentrations were well within the State standard for marine waters, although there was a decline in levels over summer and autumn.

Health of Fish and Shellfish

The MWRA has dramatically reduced the loads of bacteria and toxic contaminants to Boston Harbor and in turn to Massachusetts Bay by various interim improvements to the sewer system, particularly the end of sludge discharges in 1991. While this MWRA reduction will no doubt continue to have positive impacts, there are still significant inputs of contaminants from other sources (Figure 3.7). There is still concern that despite the increased dilution and improved quality of MWRA effluent discharged at the future outfall site, the combined effect of all pollutant sources could have an adverse impact on the Massachusetts Bay ecosystem.

Stratification

Stratification is the process whereby the water column becomes divided into layers of different density. In Massachusetts Bay, this commonly occurs over summer when warming of the water causes a layer of warm, less dense, surface water to overlay a cooler, denser, bottom layer. If the stratification is strong enough it can prevent winds and tides from mixing surface waters and oxygen down into the deeper waters. Meanwhile, however, the normal oxygen consuming processes continue to occur in the bottom waters with the result that oxygen levels may gradually fall, not increasing again until the water column mixes in fall or winter.

Box 3.3

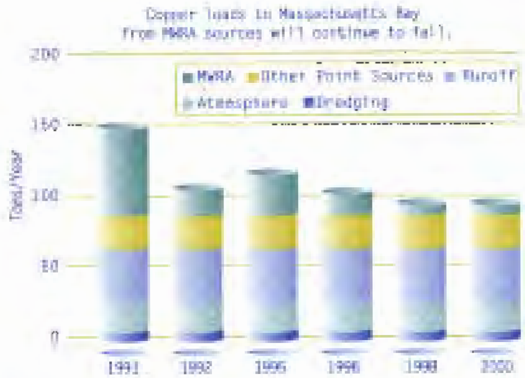
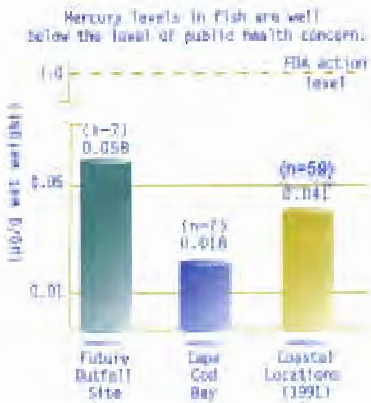


Figure 3.7. Copper loads from [illegible]



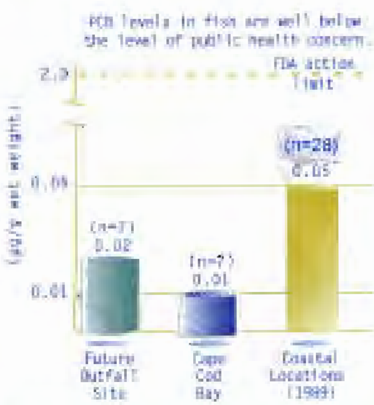


Figure 3.8. Mean PCB and Mercury concentrations in fish samples. [illegible] Data from Schwartz et al. (1991, 1993) and MWRA unpublished.

To determine whether fish and shellfish in Massachusetts Bay are safe for human consumption, contaminants are now being measured in winter flounder and lobster. In the first two years of monitoring, few of the analyzed muscle tissue samples have exceeded FDA action levels for contaminants (Figure 3.8). "Action levels" are the concentrations of contaminants presumed, on the basis of risk assessments, to cause potential health effects. Only polychlorinated biphenyls (PCBs) and mercury have occasionally exceeded the FDA limits in samples of liver and hepatopancreas (organs that are not normally consumed by humans except in the case of lobster tamale).

Despite the generally low concentrations of metals and PCBs in fish tissue, there is a strong gradient in the level of contamination decreasing from the harbor to Cape Cod Bay (Figure 3.9). Fish caught near Boston Harbor have higher levels of tissue contamination and liver disease than those caught in Cape Cod Bay. This gradient is similar to the *Clostridium* spores gradient, indicating that effluent is a source of this contamination, albeit at a level well below that of public health concerns.

Benthic Community

The types of animal communities living on the bottom (benthic fauna) of Massachusetts and Cape Cod Bays vary greatly. This variation is largely due to the variety of sediment types (Blake et al 1993). The area around the new outfall is primarily coarse gravel and boulder fields. Bottom currents are sometimes strong, rapidly eroding effluent-borne contaminants that might be deposited there. Therefore, future impacts on the benthic community from effluent discharge will be minimal at the outfall site (see Figure 3.10). Instead, effluent will disperse over a larger area of Massachusetts Bay, by which time it will be highly diluted with other sedimenting materials. By contrast, Boston Harbor is an environment where sediments accumulate rapidly. Thus, effluent-borne contaminants build up in the harbor sediments, degrading the benthic community and contaminating fish and shellfish. In Massachusetts Bay, the nearest depositional, soft bottom (sandy to muddy) area is more than a kilometer from the outfall. Impacts on the fauna from effluent discharge will therefore be sharply limited by the nature of the environment these species inhabit.

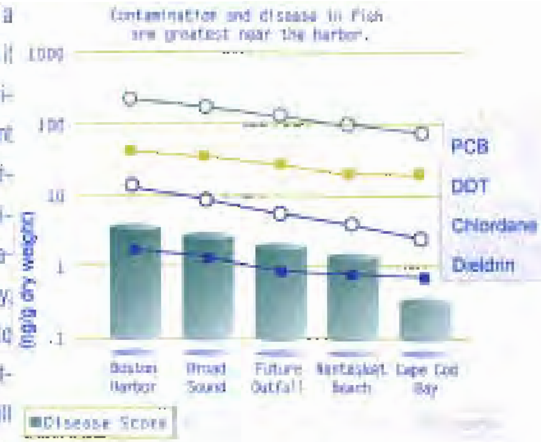


Figure 3.9. Mean contaminant levels in winter flounder (n=?) from five sites in Mass Bay collected in April, 1992. Contamination and disease decreased with distance from the harbor. This pattern is similar to the mapping of *Clostridium perfringens* as a tracer for sewage contamination from the harbor. Source of data: Shea (1993).

On another level, the variation in benthic communities provides a striking example of the differences between Cape Cod and Massachusetts Bays. Cape Cod Bay is characterized by an unusual sea cucumber-polychaete worm assemblage which is not found at any of the Massachusetts Bay sites. The

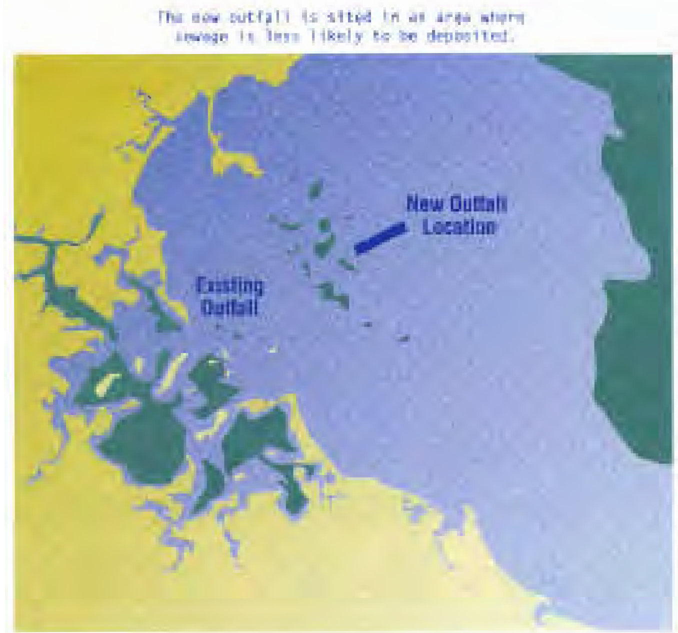


Figure 3.10. Depositional sediment areas in western Massachusetts Bay. The depositional sediment areas were mapped by the U.S. Geological Survey (Butman et al., 1992) using sonar images. The map shows that there is less depositional area and it is farther removed from the new outfall than is the case at the existing outfall.

presence of this assemblage was first noted in the late 1960s (Young and Rhoads, 1971) and, despite its susceptibility to disturbance, it appears to have remained relatively unchanged (Blake et al., 1993). This persistence suggests that the last 20 years of effluent discharge into the bays, via the harbor, has not had noticeable affects on the benthos of Cape Cod Bay. The presence of this assemblage will continue to serve as an indicator of environmental conditions once the new outfall is operational.

Modeling: Dilution Patterns in Mass & Cape Cod Bays

Moving the effluent outfall to Massachusetts Bay will not only change the location (9.5 miles out) but also the depth (100 feet) at which the effluent enters the receiving water. The surface dilution pattern, as well as the vertical distribution of the effluent in the water column, will change. Through modelling, Figure 3.11 shows the surface summer dilution patterns for effluent discharged from the existing and the future outfalls. As shown by the cross-sectional patterns, the existing nearshore discharge results in nearly all of the effluent entering the surface water where there is a greater potential to influence the growth of phytoplankton. However, when discharged from the future site in Massachusetts Bay, the effluent will be released from diffuser pipes well below the surface layer (see stratification box, page 16) where it is less available to the phytoplankton community for stimulating algal blooms.

These differences in the current and future effluent dilution patterns are vividly illustrated in the aerial dilution maps showing the absence of effluent in the surface waters during summer. During the winter when the water column is well mixed, the model predicts that the effluent discharged from the diffuser will dilute rapidly throughout the water column resulting in a one-half square-mile area of least-diluted effluent compared to an area of about 77 square miles under existing conditions. If the model is accurate, the future outfall should have much less of an impact on Massachusetts and Cape Cod Bays than the existing discharge.

Future Monitoring and Modeling

With the new outfall due to be commissioned soon, it is important to build a strong catalogue of baseline information on the bays. The data collected so far have confirmed two important features of the bays which underscore the importance of the monitoring program -the differences between Massachusetts and Cape Cod Bays and the degree of existing impacts on the water quality of the bays.

The variation between Massachusetts and Cape Cod Bays has long been suspected, but is only now being confirmed. These differences have two-fold importance. First, they imply that the two bays may respond differently to environmental changes. Second, they may mean that Cape Cod Bay is more isolated from processes occurring in Massachusetts Bay than was initially suspected.

The gradients of sewage-borne chemical contamination in the bays indicate that sewage discharged into Boston Harbor currently reaches Massachusetts Bay. The presence of toxic "red tides" which are poisonous to marine life and to people consuming contaminated shellfish have also been documented. Red tides appear, to some extent, to be natural occurrences in New England waters. Documenting these current environmental features of the bays will allow a more accurate assessment of whether environmental occurrences in the future are due to the new outfall or are the result of natural variability and past pollution. It will also help determine the extent to which the Boston Harbor Project benefits the bays, as well as the harbor.

Existing conditions (surface)

Future conditions (surface)

The New Outfall will increase dilution of the effluent and, in summer, prevent it from reaching the surface.

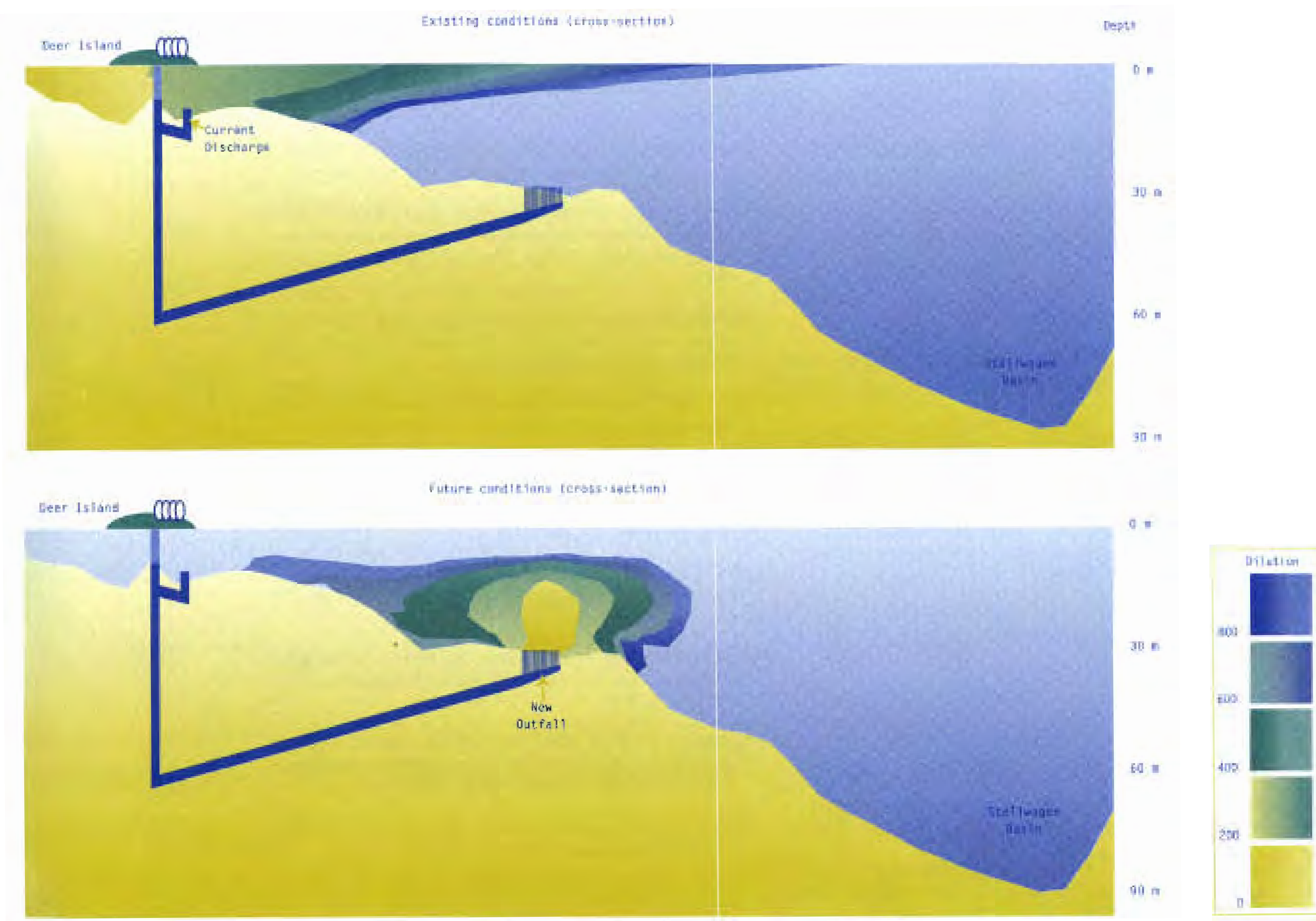


Figure 3.11: Modeled effluent dilution patterns at the existing and new outfall sites (surface and cross-section views). Model by the U.S. Geological Survey shows the predicted summer average dilution patterns of the future and existing outfalls. The shading represents the areas of each dilution range in the surface waters. Dashed line in surface view indicates location of cut for cross-section views. The new outfall will more effectively dilute effluent and will prevent it reaching the surface waters during summer.

Kelly, J. 1993. Nutrients and Massachusetts Bay: an update of eutrophication issues. MWRA ENQUAD no. 93-17. 94 pp., plus appendices.

Blake, J.A. D.G. Rhoads, and I.P. Williams. 1993. Boston Harbor sludge abatement monitoring program: soft bottom benthic biology and sedimentology 1991-92 surveys. MWRA ENQUAD no. 93-11. 65pp. + 3 appendices.

For Further Reading:

Aubrey, D.G. and M.S. Connor. 1993. Boston Harbor: fallout over the outfall. Oceanus 36: no. 1 pp. 61-70.

Bigornia-Vitale, G. and M.J. Sullivan. 1993. NPDES compliance summary report, fiscal year 1992. MWRA ENQUAD no. 93-14. 196 pp.

Blumberg, A.F., R.P. Signell, and H.L. Jenter. 1993. Modeling transport processes in the coastal ocean. ASCE Journal of Environmental Engineering 119.

Buchsbaum, R., ed. 1992. Turning the tide: toward a livable coast in Massachusetts. Massachusetts Audubon Society. 121 pp.

Butman, B., et. al. 1992. Contaminant transport and accumulation in Massachusetts Bay and Boston Harbor: a summary of U.S. Geological Survey Studies. U.S. Geological Survey Open-file Report 92-202, Woods Hole, MA. 42 pp.

Chin, Y.-P. and P.M. Gschwend. 1991. The abundance, distribution and configuration of porewater organic colloids in recent sediments. Geochim. Cosmochim. Acta, 55: pp. 1308-1317.

Chin, Y.-P. and P. M. Gschwend. 1992. Partitioning of polycyclic aromatic hydrocarbons to marine porewater organic colloids. Environ. Sci. Technol. 26: 1621-1626.

Downey, P.C., J.K. Comeau, R.C. Binkerd, and J.W. Williams. 1993. Bioaccumulation of selected organic compounds in mussels deployed near Deer Island discharge and Massachusetts Bay, 1992. MWRA ENQUAD no. 93-6. 64 pp.

ENSR Consulting and Engineering. 1993. Spectacle Island water quality monitoring report. Prepared for the Massachusetts Highway Department. 35 pp.

Geyer, W.R, et al. 1992. Physical oceanographic investigation of Massachusetts and Cape Cod Bays. Massachusetts Bays Program Technical Report No. MBP-92-03. 445 pp. plus figures and appendices.

Irish, J.D. and R.P. Signell. 1992. Tides of Massachusetts and Cape Cod Bays. Woods Hole Oceanographic Institution Tech. Report WHOI-92-35. 62 pp.

Johnson, L.L., et. al. 1992. Bio-indicators of contaminant exposure, liver pathology, and reproductive development in pre-spawning female winter flounder (Pleuronectes americanus) from urban and non-urban estuaries on the northeast Atlantic coast. NOAA Technical Memorandum NMFS-NWFFC-1. 76 pp.

Massachusetts Bays Program. 1991. Massachusetts Bays 1991 comprehensive conservation and management plan. 99 pp.

Nowicki, B.L. 1994. The effect of temperature, oxygen, salinity, and nutrient enrichment on estuarine denitrification rates measured with a modified nitrogen gas flux technique. Estuarine, Coastal and Shelf Science 38: pp. 137-156.

Parmenter, C.M., and M.H. Bothner. 1993. The distribution of Clostridium perfringens, a sewage indicator, in sediments of coastal Massachusetts. U.S. Geological Survey Open-file Report 93-8. 45 pp.

Rex, A. 1993. Combined sewer overflow receiving water monitoring: Boston Harbor and its tributary rivers. MWRA ENQUAD no. 93-4. 210 pp.

Rhoads, D.C. and L.F. Boyer. 1992. The effects of marine benthos on physical properties of sediments; a successional perspective. In: McCall, P.L. and M.J.S. Tevesz (eds.), Animal-Sediment Relations, pp 3-52. Geobiology series, v. 2, Plenum Press, New York.

Shea, D. and J. Kelly. 1992. Transport and fate of toxic contaminants discharged by MWRA into Massachusetts Bay. MWRA ENQUAD no. 92-4. 78 pp.

Signell, R.P., H.L. Jenter and A.F. Blumberg. 1992. Modeling the mean flow in Massachusetts Bay. EOS, Transactions, American Geophysical Union, vol. 73, no. 43. p. 298 ff.

Stolzenbach, et. al. 1993. Boston Harbor study of sources and transport of Harbor sediment contamination, Part I; transport of contaminated sediments in Boston Harbor. MWRA ENQUAD no. 93-12. 80 pp.

Wong, C.S., Y.-P. Chin and P.M. Gschwend. 1992. Sorption of radon-222 to natural sediments. Geochim. Cosmochim. Acta. 56: pp. 3923-3932.

Acknowledgements

Many people have contributed information and advice to this report. The authors would like to thank Amy Barad, Grace Bigornia-Vitale, Ed Caruso, Dan Cushing, Ben Davis, Susan Curran Ford, Maury Hall, Mike Hornbrook, Ken Keay, Dave Kubiak, Hayes Lamont, Wendy Smith Leo, Carl Leone, Charlie Lombardi, Kevin McManus, Mike Mickelson, Dan O'Brien, Carl Pawlowski, Peter Ralston, Andrea Rex, John Riccio, Elisa Speranza, Liz Steele, Mark Sullivan, Rick Trubiano, Dede Vittori, and Nancy Wheatley. The authors would like to acknowledge especially the help of those not affiliated with the MWRA: E. Bruce Berman Jr., Brad Chase, Ann Giblin, David McCarron, and Ken Reback.

Graphics and layout:
Rita Berkeley, Carolynn DeCillo, and Jennifer Siegel

Editors:
Tim Watkins, Mari Sullivan, and Leo Sommaripa

Printing:
Town Printing

The Massachusetts Water Resources Authority

Charlestown Navy Yard
100 First Avenue
Boston, MA 02129
(617) 242-6000

State of the Harbor: 1993
Errata

N.B.: a.x under location refers to column a (the left hand column), x tenths of the way down; column b is the right hand column.

LOCATION		CURRENT	CORRECTED
list of figures		Wet weather combined sewer overflow events	Wet weather combined sewer overflow v
list of figures		1.7 The amounts . . .	*fig 1.7 does not exist*
list of figures		*fig 2.16 not mentioned*	2.16 State of harbor ecosystem recov
1	a.8	It is then pumped to facilities where large debris is screened out before entering one of two MWRA treatment plants at Nut Island in Quincy or Deer Island off Winthrop	*Deer Island has headworks; Nut Island sc facilities*
2	fig 1.4a	3 of events	number of events
2	fig 1.4a	1992 1990 1992	1991 1992 1993
3	fig 1.4b	flow (millions gallons/day)	volume (million gallons)
4	fig 1.5	About 850,000 homes and 6,000 businesses in Greater Boston produce 480 million gallons of sewage each day	. . . 380 million gallons of sewage each
5	fig 1.6	Average Combined Flow	*add units,* (MGD)
6	b.5	For five beaches the percentage of days in violation of the standard fell between 1989 and 1993	For all beaches the . . . . *see fig 2.1*
7	a.9	On the basis of these trends the DMF concluded that management efforts were having an effect in reducing tissue concentrations of contaminants	On the basis of these trends MWRA conc
7	fig 2.3	1986 88 89 91 1986 88 89 90	1987 88 89 91 1987 8
7	fig 2.4 caption	annual means of three sites in each area	annual means of three sites in the most re each area
7	fig 2.4 key	*the color next to "Boston" is blue and should be green and the color next to "Salem" is green and should be blue*	
Centerspread		*The "Hull Bay" identifier is in Hingham Bay*	
Centerspread		*the beach umbrella directly to the left of the label "Neponset R." should be moved to Wollaston Beach, below and slightly to the left of the label "Quincy Bay"*	
Centerspread		*the arrow for the Back River points to the Fore River*	
8 *adjacent to the yellow box*	fig 2.5 key	Aug. 1993	Aug. 1992

8	fig 2.6	µg/g wet wt	number of species
8	fig 2.7	Increased nitrogen -> Reduced smothering of benthic fauna	Increased Fauna -> Consumption of organic matter
9	fig 2.9	the color next to "Early Liver Disease" is blue and should be green and the color next to "Liver Tumors" is green and should be blue	
9	a.6	The number of herring entering the Weymouth Back River each year has increased markedly since the early 1970s (see Center Resource Map).	*The referenced figure shows a decline after 1991. The reference should be to the "Centerspread" in stead of the "Center Resource Map." Delete the word "markedly"*
12	b.1	concentrations of toxic substances in fish and shellfish edibility has decreased	concentrations of toxic substances in fish and shellfish edible tissue has decreased
12	fig 2.16	*referenced in the text, but has no figure number, title, or key*	FIG. 2.16; State of Harbor Ecosystem Recovery in 1994; *yellow* = Poor Health, *blue* = Good Health
14	fig 3.2 key	*The shading of the colors within each box is backwards (e.g. it goes dark blue to light blue, left to right, and it should go light blue to dark blue).*	
15	fig 3.3	Mean total Nitrogen (M)	Mean total Nitrogen (µM)
15	fig 3.4	*The shading of the colors within each box is backwards (e.g. it goes dark blue to light blue, left to right, and it should go light blue to dark blue).*	
17	a.9	rapidly eroding deposition of effluent-borne contaminants	rapidly eroding effluent-borne contaminants
17	fig 3.8	*colors of first and second columns are switched between the first and second graphs*	*in the second graph, the color of the first column is blue and should be green and the color of the second column is green and should be blue*
17	fig 3.8 caption	fish samples taken from Georges Bank, Boston Harbor and Salem Harbor.	fish samples taken from the future outfall site, Eastern Cape Cod Bay, and Massachusetts coastal locations (average).
17 *mercury graph, above coastal locations*	fig 3.8	n=7	n=59
17 *PCB graph, above coastal locations*	fig 3.8	n=7	n=28
17	fig 3.8 caption	Data from Schwartz et al. (1991, 1993) and MWRA unpublished.	Coastal data are from Schwartz et al. (1991, 1993); other data are from MWRA unpublished
17	fig 3.9 key	*color of the box to the left of Chlordane is green and should be yellow*	
17	fig 3.9 key	*all four line id's are incorrectly labeled*	*from top to bottom, the lines are PCB, DDT, Chlordane, and Dieldrin*
17	fig 3.9	*there is no y-axis ID*	*y-axis ID should be "ng/g dry weight"*
17	fig 3.10 caption	(Bothner et al., 1991)	(Knebel, 1993)

For Further Reading:

Aubrey, D.G. and M.S. Connor. 1993. Boston Harbor: fallout over the outfall. *Oceanus* 36: no. 1 pp. 61-70.

Bigornia-Vitale, G. and M.J. Sullivan. 1993. NPDES compliance summary report, fiscal year 1992. MWRA ENQUAD no. 93-14. 196 pp.

Blumberg, A.F., R.P. Signell, and H.L. Jenter. (in press). Modeling transport processes in the coastal ocean. *ASCE Journal of Environmental Engineering* .

Buchsbaum, R., ed. 1992. Turning the tide: toward a livable coast in Massachusetts. Massachusetts Audubon Society. 121 pp.

Butman, B., et. al. 1992. Contaminant transport and accumulation in Massachusetts Bay and Boston Harbor: a summary of U.S. Geological Survey Studies. U.S. Geological Survey Open File Report 92-202, Woods Hole, MA. 42 pp.

Chin, Y.-P. and P.M. Gschwend. 1991. The abundance, distribution and configuration of porewater organic colloids in recent sediments. *Geochim. Cosmochim. Acta.* 55: pp. 1308-1317.

Chin, Y.-P. and P. M. Gschwend. 1992. Partitioning of polycyclic aromatic hydrocarbons to marine porewater organic colloids. *Environ. Sci. Technol.* 26: 1621-1626.

Downey, P.C., J.K. Comeau, R.C. Binkerd, and J.W. Williams. 1993. Bioaccumulation of selected organic compounds in mussels deployed near Deer Island discharge and Massachusetts Bay, 1992. MWRA ENQUAD no. 93-8. 64 pp.

ENSR Consulting and Engineering. 1993. Spectacle Island water quality monitoring report. Prepared for the Massachusetts Highway Department. 35 pp.

Geyer, W.R. et al. 1992. Physical oceanographic investigation of Massachusetts and Cape Cod Bays. Massachusetts Bays Program Technical Report No. MBP-92-03. 445 pp.

Irish, J.D. and R.P. Signell. 1992. Tides of Massachusetts and Cape Cod Bays. Woods Hole Oceanographic Institution Tech. Report WHOI-92-35. 62 pp.

Johnson, L.L., et. al. 1992. Bio-indicators of contaminant exposure, liver pathology, and reproductive development in pre-spawning female winter flounder (*Pleuronectes americanus*) from urban and non-urban estuaries on the northeast Atlantic coast. NOAA Technical Memorandum NMFS-NWFFC-1. 76 pp.

Massachusetts Bays Program. 1991. Massachusetts Bays 1991 comprehensive conservation and management plan. 99 pp.

Nowicki, B.L. 1994. The effect of temperature, oxygen, salinity, and nutrient enrichment on estuarine denitrification rates measured with a modified nitrogen gas flux technique. *Estuarine, Coastal and Shelf Science* 38: pp. 137-156.

Parmenter, C.M., and M.H. Bothner. 1993. The distribution of *Clostridium perfringens*, a sewage indicator, in sediments of coastal Massachusetts. U.S. Geological Survey Open File Report 93-8. 45 pp.

Rex, A. 1993. Combined sewer overflow receiving water monitoring: Boston Harbor and its tributary rivers. MWRA ENQUAD no. 93-4. 210 pp.

Rhoads, D.C. and L.F. Boyer. 1992. The effects of marine benthos on physical properties of sediments: a successional perspective. In: McCall, P.L. and M.J.S. Tevesz (eds.), Animal-Sediment Relations, pp 3-52. Geobiology series, v. 2, Plenum Press, New York.

Shea, D. and J. Kelly. 1992. Transport and fate of toxic contaminants discharged by MWRA into Massachusetts Bay. MWRA ENQUAD no. 92-4. 78 pp.

Signell, R.P., H.L. Jenter and A.F. Blumberg. 1992. Modeling the mean flow in Massachusetts Bay. EOS, Transactions, American Geophysical Union, vol. 73, no. 43. pp. 298 ff.

Stolzenbach, et. al. 1993. Boston Harbor study of sources and transport of Harbor sediment contamination. Part I: transport of contaminated sediments in Boston Harbor. MWRA ENQUAD no. 93-12. 80 pp.

Wong, C.S., Y.-P. Chin and P.M. Gschwend. 1992. Sorption of radon-222 to natural sediments. *Geochim. Cosmochim. Acta.* 56: pp. 3923-3932.

MWRA ENQUAD reports can be ordered by contacting the MWRA Environmental Quality Department, (617) 242-6000.

State of the Harbor: 1993 Supplemental Information

Glossary:

biota: the living organisms of a region.

CSO (combined sewer overflow): 1) sewage that must be discharged from the sewer system before reaching a treatment plant, in a sewer system that collects both stormwater and domestic/industrial wastewater. Overflows usually happen when the sewer system is unable to handle increased flow caused by stormwater runoff. 2) a facility that allows for the discharge of such overflow.

organic: 1) relating to or derived from living organisms. 2) containing carbon, in reference to a chemical compound .

PAH (polyaromatic hydrocarbon): a set of chemical compounds found in petroleum products and as a byproduct of most combustion processes. Some PAHs are known carcinogens and accumulate in animal tissue, particularly in fish and shellfish.

PCB (polychlorinated biphenyl): a set of banned chemical compounds formerly used in many industrial processes and still present in the environment at significant concentrations. PCBs are suspected carcinogens and accumulate in animal tissue, particularly in fish and shellfish.

Secchi disk depth: the depth below the water's surface at which a black and white disk cannot be seen from above the water's surface. Secchi disk depth is a standard measure of water clarity.

toxic metal: a metal that causes disease when present in a living organism at certain concentrations (e.g. copper, silver, mercury).

Bibliography:

Alber, M. and A. Chan. 1994. Sources of contaminants to Boston Harbor: revised loading estimates. MWRA ENQUAD no. 94-1.

Blake, J.A., B. Hilbig, and D.C. Rhoads. 1993. Massachusetts Bay outfall monitoring program: soft-bottom benthic biology and sedimentology, 1992 baseline conditions in Massachusetts and Cape Cod Bays. MWRA ENQUAD no. 93-10. 108 pp.

Blake, J.A, D.C. Rhoads, and I.P. Williams. 1993. Boston Harbor sludge abatement monitoring program: soft bottom benthic biology and sedimentology, 1991-92 surveys. MWRA ENQUAD no. 93-11. 65 pp.

Bothner, M.H., et. al. 1993. The distribution of silver and other metals in sediments from Massachusetts and Cape Cod Bays - an interim compilation. U.S. Geological Survey Open File Report 93-725.

Giblin, A. (unpublished). Unpublished benthic nitrogen flux studies. Marine Biological Laboratory, Woods Hole, MA.

Kelly, J. 1993. Nutrients and Massachusetts Bay: an update of eutrophication issues. MWRA ENQUAD no. 93-17. 94 pp.

Kelly, J. and R.K. Kropp. 1992. Benthic recovery following sludge abatement to Boston Harbor. MWRA ENQUAD no. 92-7.

Knebel, H.J. 1993. Sedimentary environments within a glaciated estuarine-shelf system: Boston Harbor and Massachusetts Bay. *Marine Geology* 110: pp. 7-30.

McCarron, D. and T.B. Hoopes. 1992. 1992 Massachusetts lobster fishery statistics. Massachusetts Division of Marine Fisheries. Technical Series 27.

Metcalf and Eddy. 1993 . Baseline CSO flows. Report to MWRA, December 1993.

Metropolitan District Commission. 1984. Application for a waiver of secondary treatment for Nut Island and Deer Island Treatment Plants.

Michelson, A. 1990. Analysis of the spatial and temporal variability of primary production in the Boston Harbor, Massachusetts and Cape Cod Bays. Masters Thesis. Department of Geography, Boston University. Sept., 1990.

MWRA. 1993 . Interim CSO report. Submitted to: US Environmental Protection Agency, Conservation Law Foundation. Prepared by Metcalf and Eddy, February 1993.

Schwartz, J., N. Dunstan, and C. Batdorf. 1991. PCBs in winter flounder, american lobster, and bivalve mollusks from Boston Harbor, Salem Harbor and coastal Massachusetts: 1984-1989. Massachusetts Division of Marine Fisheries. Report no. 16, 966-63-250-10-91-C.R.

Schwartz, J., N. Dunstan, and C. Batdorf. 1993. Metal concentrations in winter flounder, american lobster, and bivalve mollusks from Boston Harbor, Salem Harbor and coastal Massachusetts: 1986-1991. Massachusetts Division of Marine Fisheries.

Shea, D. (1993). Draft annual review of toxic contaminants discharged by MWRA: 1992. MWRA ENQUAD no. 93 -18.

Young, D.K. and D.C. Rhoads. 1971. Animal-sediment relations in Cape Cod Bay, Massachusetts. I. A transect study. *Marine Biology* 11: pp. 242-254.