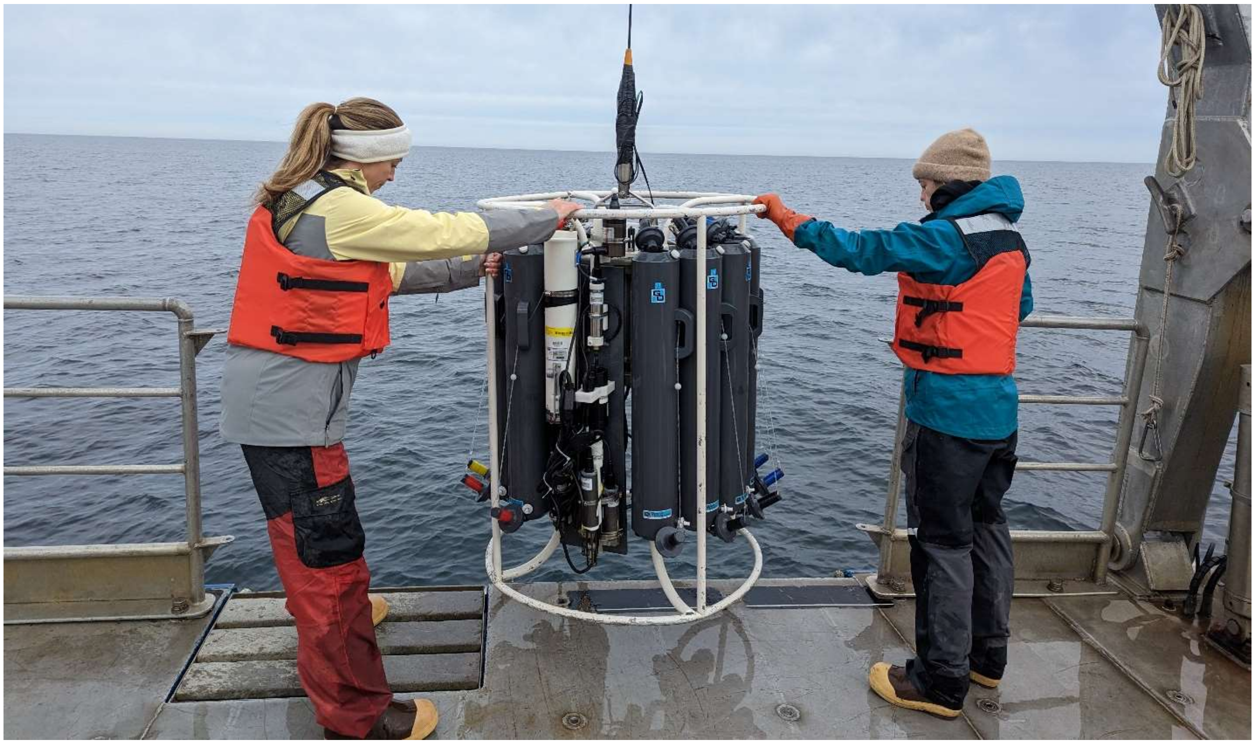

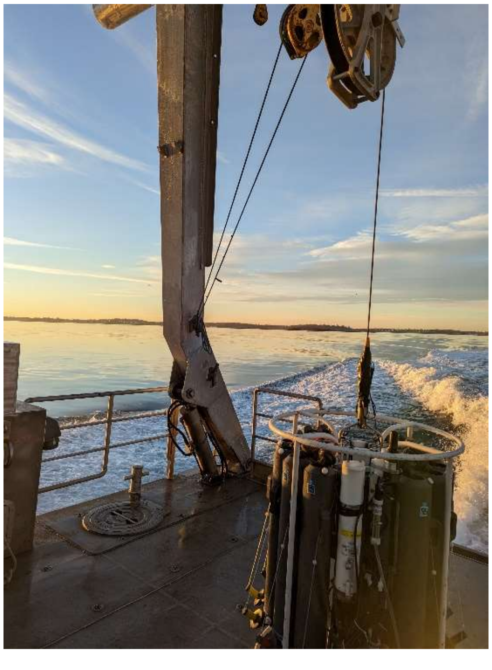

# 2022 Outfall Monitoring Overview

Massachusetts Water Resources Authority
Environmental Quality Department Report 2023-09

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**Cover photos:**
Photos courtesy of Battelle
Top: Battelle technicians deploying sampling rosette, February 2023.
Bottom: Stern view from February 2023 survey.

# 2022
# Outfall Monitoring Overview

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**November 8, 2023**

# 2022 Outfall Monitoring Panel and Committees

## Outfall Monitoring Science Advisory Panel

Judith Pederson, Massachusetts Institute of Technology Sea Grant (chair)
Robert Beardsley, Woods Hole Oceanographic Institution
Peter Burn, Suffolk University
Virginia P. Edgcomb, Woods Hole Oceanographic Institution
Loretta Fernandez, Northeastern University
Robert Kenney, University of Rhode Island
Mark Patterson, Northeastern University
Jeff Rosen, Corona Environmental Consulting
Juliet Simpson, Massachusetts Institute of Technology Sea Grant
Juanita Urban-Rich, University of Massachusetts, Boston

## Inter-Agency Advisory Committee

Massachusetts Bays National Estuary Partnership
Massachusetts Coastal Zone Management
Massachusetts Department of Environmental Protection
Massachusetts Division of Marine Fisheries
NOAA Fisheries
Stellwagen Bank National Marine Sanctuary
US Army Corps of Engineers
US Environmental Protection Agency
US Geological Survey

## Public Interest Advisory Committee

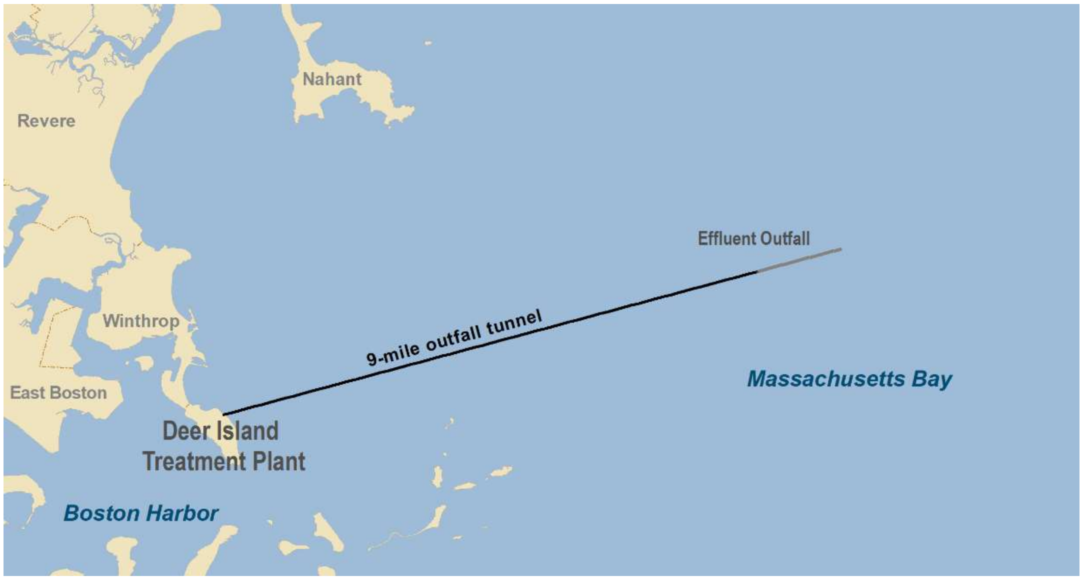
Association to Preserve Cape Cod
Boston Harbor Now
Cape Cod Commission
Center for Coastal Studies
Conservation Law Foundation
Massachusetts Audubon Society
Massachusetts Bays National Estuary Partnership
MWRA Advisory Board
MWRA Wastewater Advisory Committee
Safer Waters in Massachusetts
Save the Harbor/Save the Bay

# Plain Language Summary

*This overview is provided in plain language to make the technical information clearer to more readers.*

Every home uses water for washing dishes, flushing the toilet, taking showers, or watering the garden. Once the water goes down the drain of our sink, shower, or toilet, it is called **wastewater** or **sewage**. The wastewater from Boston and 42 other cities and towns flows through underground pipes that lead to the Deer Island Wastewater Treatment Plant. The treatment plant removes pollutants and kills disease-causing bacteria that are present in sewage.

The Massachusetts Water Resources Authority (MWRA) runs the Deer Island plant, which is located in Boston, near the town of Winthrop. The first step of sewage treatment separates solid material, known as **sludge**, from the liquid **effluent**. Sludge is turned into fertilizer for gardening and landscaping. Treated effluent is sent out into Massachusetts Bay through a nine-mile pipe and **outfall**.

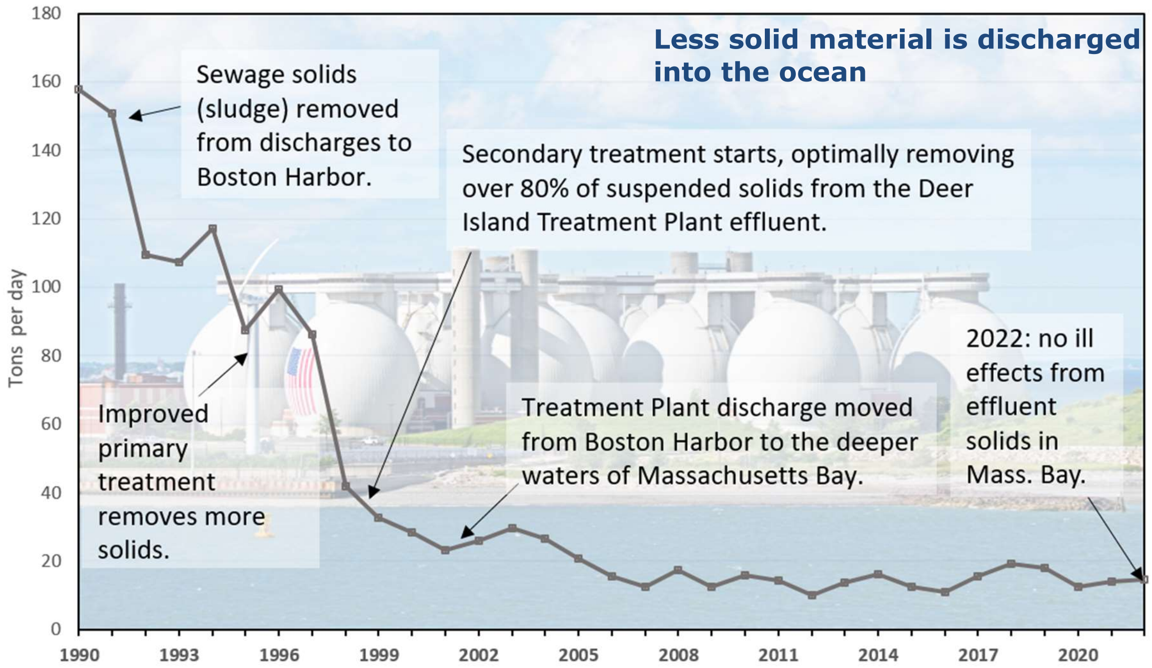


The Environmental Protection Agency, the federal governmental agency responsible for protecting air and water, allows the ocean outfall as long as MWRA tests the water, sediment, plants, fish, and shellfish to make sure they are not being harmed. For example, like people, marine animals need enough oxygen to live, and MWRA checks to make sure that there is enough oxygen in the water. MWRA also looks for harmful bacteria and pollutants that remain in the sewage effluent.

# What MWRA found out in 2022:

## Ten times fewer sewage solids go into the ocean than in 1990

While most solid material in sewage is removed as sludge, small particles remain in the effluent. Many pollutants that are toxic to marine life, such as lead and copper, are attached to these particles. The line in the graph below shows the decrease in the amounts of solids discharged from 1990 through 2022. Discharges of other pollutants have similarly declined.



## Ocean communities near the outfall are healthy

**Nutrients in sewage effluent have not caused too much phytoplankton to grow.**
Phytoplankton are small algae that float in ocean waters. If they get too many nutrients from sewage, they can grow too much and use up oxygen in the water when they die and decompose. As in other years, there was more of the nutrient called ammonium near the ocean outfall than before the discharge, but it did not increase phytoplankton growth or hurt marine life.

**Many types of animals continue to live on the sea floor near the outfall.** MWRA found more than 100 kinds of animals living on the ocean bottom near the outfall, one indicator of a healthy community. Tiny worms called bristle worms or polychaetes were the most common creatures. These animals live on the ocean floor and are affected more by the types of sand or sediments they live in and how deep the water is than by the effluent from the outfall.

**Fish and shellfish are healthier.** MWRA has been checking flounder, lobsters, and mussels in Massachusetts Bay and Boston Harbor since 1992. In the early years, some flounder had tumors, likely caused by pollutants in poorly treated sewage. No tumors have been found in any fish for nearly 20 years. Sometimes, fish show other signs of disease, but fish in 2022 were among the healthiest ever seen.

## Boston Harbor is a thriving urban harbor

After MWRA stopped sending effluent and sludge into Boston Harbor more than 20 years ago, the water and harbor sea floor got cleaner. MWRA still checks Boston Harbor to see how much better it has become.

MWRA tests the water at many locations in Boston Harbor.

# Report Highlights

**The Boston Harbor Project has been an environmental success**

Looking at Boston Harbor today, it is hard to imagine how polluted it was a generation ago. When the Massachusetts Water Resources Authority (MWRA) was created by the state legislature in 1984, the harbor was known as one of the dirtiest in the nation. Sewage from two failing treatment plants was separated into its liquid and solid components for treatment and disinfection, but then both the liquid effluent and solid sludge were discharged into the harbor. The Boston Harbor Project ended all discharge of sludge, converting it instead to fertilizer, and took steps to minimize the effects of effluent discharge.

**Source reduction** prevents pollutants from entering the waste stream. MWRA has championed projects to lessen household hazardous waste disposal and minimize mercury discharges from hospitals and dentists. The Toxic Reduction and Control department works to ensure that many pollutants never reach the treatment plant.

**Improved treatment** removes pollutants before discharge. A series of upgrades to MWRA's Deer Island Treatment Plant started with a new primary treatment plant, which separates the solid material from the liquid effluent. Batteries of secondary treatment, which greatly improves pollutant removal, began operation in 1997–2001. All effluent is disinfected before discharge. Most pollutants now meet federal and state standards when they are discharged, even before dilution.

**Better dilution** further protects the environment. In September 2000, the MWRA effluent discharge was diverted from Boston Harbor, through a 9.5-mile tunnel and diffuser system to Massachusetts Bay. The bay outfall's location and distance from shore ensure that sensitive resources are protected. Initial effluent dilution in the bay is about five times greater than that of the harbor outfall it replaced, and the greater depth ensures that summertime discharges are beneath the sunlit range where plant growth occurs, preventing the possible overstimulation of algal growth by effluent nutrients.

This 2022 Outfall Monitoring Overview summarizes results from the MWRA monitoring program in Massachusetts Bay and presents highlights from its companion program in Boston Harbor. MWRA began to monitor the harbor in 1991, when aging treatment plants were discharging wastewater effluent and sludge to the harbor. Monitoring in the bay began in 1992, in anticipation of September 2000, when effluent discharges were diverted from the shallow harbor to the deeper and more open waters of Massachusetts Bay.

A National Pollutant Discharge Elimination System (NPDES) permit regulates MWRA's Deer Island Treatment Plant discharge. The permit requires MWRA to monitor the effluent before discharge, as well as the receiving water, sea floor, and fish and shellfish in the bay to detect any unexpected or adverse effects. A Contingency Plan attached to the permit mandates responses by MWRA and the regulatory agencies in the event that monitoring detects a potential environmental concern.

It has been more than two decades since the Deer Island Treatment Plant first discharged treated wastewater into Massachusetts Bay. In 2022, MWRA earned a Platinum 16 award from the National Association of Clean Water Agencies for 16 consecutive years with no exceedances of effluent permit limits. The health of Boston Harbor has improved considerably over those past decades, without harming Massachusetts Bay. Monitoring has shown no unanticipated or meaningful effects of the treated wastewater on the water, the sea floor, or the fish and shellfish.

## Deer Island Treatment Plant produces cleaner effluent

Preventing pollutants from entering the wastewater system is the first step for ensuring "clean" effluent. MWRA has championed projects to lessen household hazardous waste disposal and minimize mercury discharges from hospitals and dentists. An industrial pretreatment/pollution prevention program works to ensure that many toxic contaminants never reach the treatment plant.

One of the most important measures of effluent quality is the suspended solids load, the total amount of solid material discharged over each year. Primary treatment removes most of the solid material ("solids") from sewage as sludge, but small particles remain in the liquid effluent. The 2022 effluent solids load was consistent with other recent years and far lower than amounts once discharged into the harbor (Figure i, top). Discharges of toxic metals have also greatly decreased, as most pollutants attach to the solids and are removed with them (Figure i, bottom).

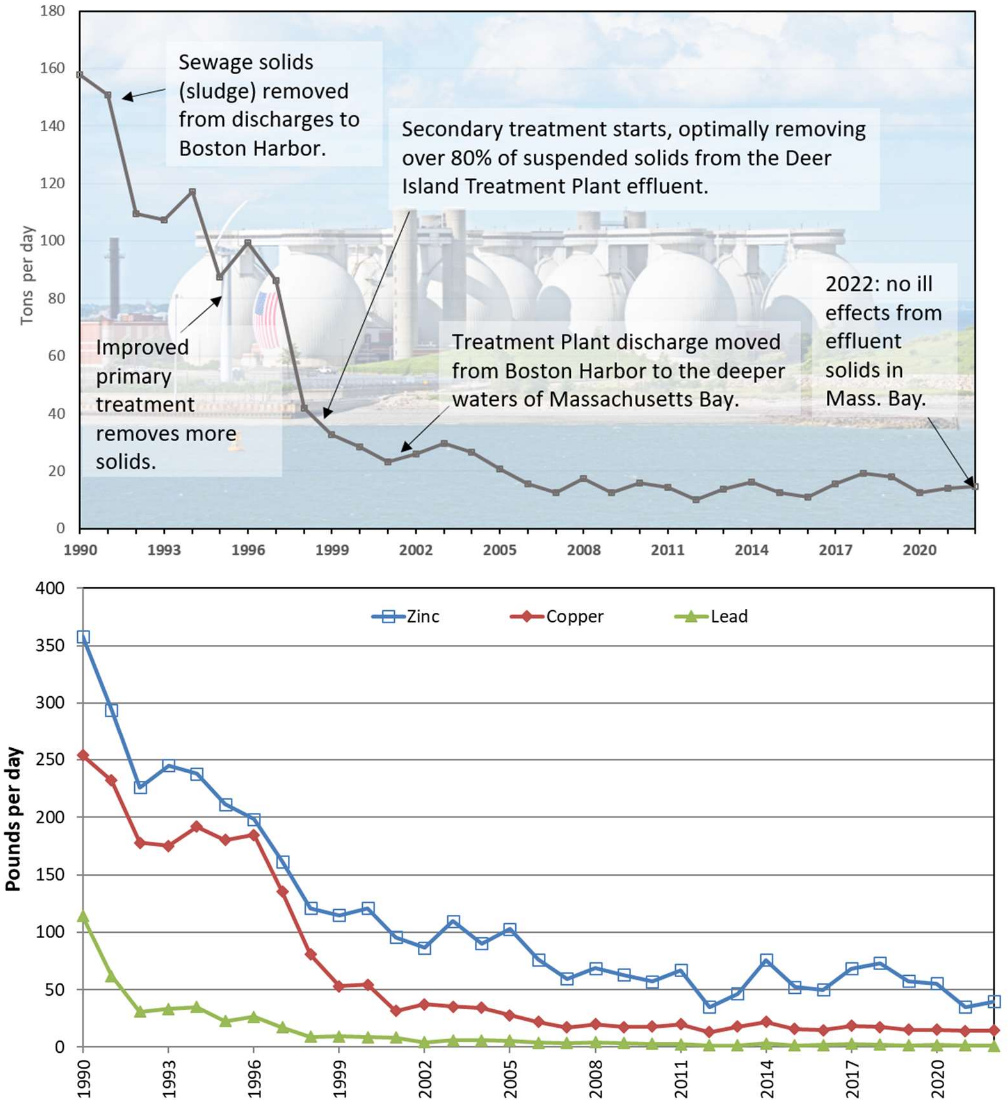


**Figure i. Annual effluent solids (top) and toxic metals (bottom) discharges, 1990–2022.** Source reduction, industrial pretreatment, and secondary treatment have dramatically decreased solids and metals discharges.

## MWRA's discharge has not affected oxygen in the bay

Primary and secondary treatment remove some, but not all, of the important nutrients in wastewater (nitrogen, phosphorus, and silica), so MWRA water-column monitoring focuses on potential nutrient effects. One concern for the bay discharge is that nutrient inputs could lead to eutrophication, a condition that results from the excessive growth and decay of phytoplankton, microscopic algae that live in the water column. Phytoplankton blooms are natural and necessary, but when excessive, their eventual die-off and decomposition depletes oxygen. Oxygen levels naturally decline in deep water during the late summer and fall, but in eutrophic waters, depleted oxygen can impair or even kill animal life near the sea floor.

Nitrogen is the main nutrient controlling phytoplankton growth in marine waters. The most abundant form of nitrogen in the MWRA discharge, ammonium, is a good effluent tracer. Increased ammonium concentrations have been frequently detected at stations closest to the outfall since the offshore discharge began (Figure ii). Variability has also increased at stations closest to the outfall, as sampling at those stations occurs before the discharge is fully mixed into surrounding water. Intermittent increases are sometimes also detected at greater distances. These increases were anticipated during planning for the outfall.

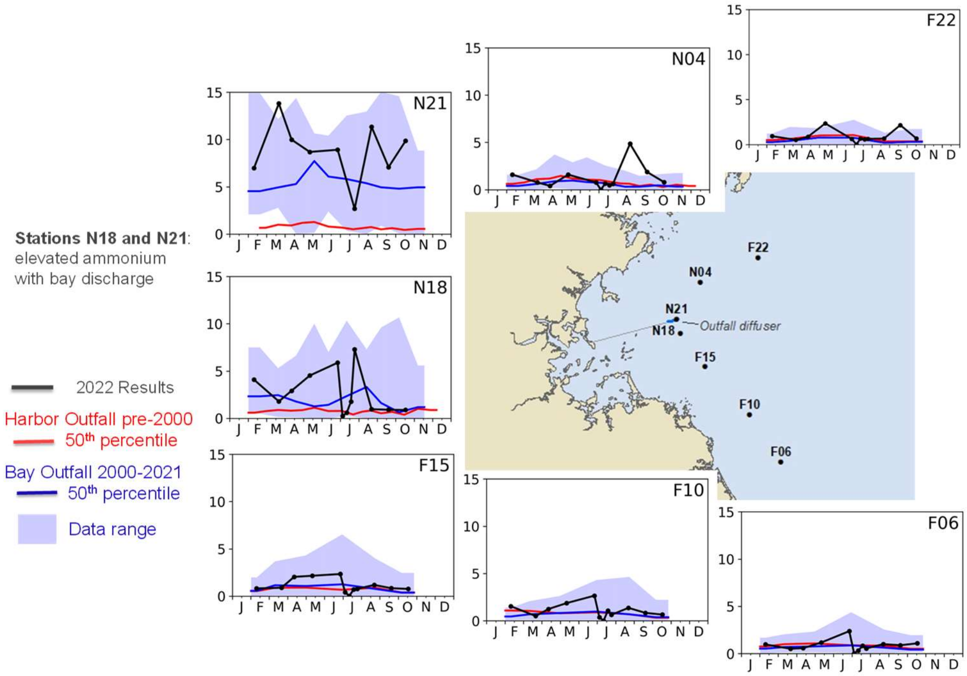


**Figure ii. Station-average ammonium concentrations (µM) at selected stations in 2022 compared to prior years.** Ammonium is a good sewage tracer, and elevated levels are frequently detected at stations closest to the outfall. Farther from the outfall, concentrations are similar to those before discharge began. The red lines show average results from pre-2000. The blue lines show results from after discharge was moved from the harbor to the bay. The "data range" spans all measurements through 2021.

The nutrients in the MWRA discharge have not increased phytoplankton growth or contributed to reduced dissolved oxygen levels in Massachusetts Bay, partially because the discharge is in deep water. During the summer months, warmer surface waters keep the discharge plume below the depth where most phytoplankton grow, and there has been no increase in phytoplankton biomass, even at the stations closest to the outfall.

In the fall of 2022, late summer, deepwater oxygen did reach low levels throughout the region, lower than some MWRA Contingency Plan thresholds. Because these declines in dissolved oxygen were also detected in areas outside the area of influence of the MWRA discharge, we know that those conditions resulted from physical factors, particularly unusually warm waters, rather than from the effluent discharge and eutrophication.

## Seafloor communities remain healthy and diverse

MWRA's studies of the sediments and animals at the sea floor have also shown little change related to the outfall. Bottom-dwelling animal communities are influenced by the seafloor sediment types and water depths rather than by the discharge. Concerns that the effluent might lead to low oxygen conditions, smother bottom-dwelling life, or increase sediment contaminants have been dispelled. The numbers of animals, numbers of species (Figure iii), and the species makeup of the communities have remained relatively constant, within the ranges of natural variability.

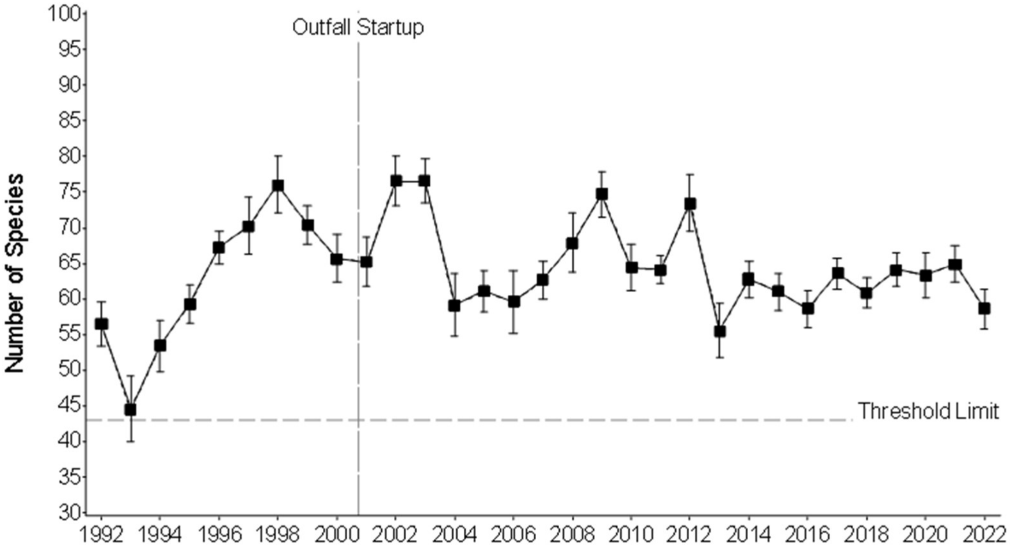


**Figure iii. Total number of seafloor species at Massachusetts Bay stations near the outfall, 1992–2022.** The number of species is one measure of community health, and it has been relatively stable since the outfall discharge began in 2000, remaining within the expected ranges. Abundance of invasive species, which are signs of degraded habitat, has declined. Falling below the "threshold limit" would indicate a decrease in the number of species that warranted further examination.

## Fish and shellfish are healthier and safer than ever

MWRA monitors winter flounder, a popular commercial and recreational fish that lives and feeds on the bottom in contact with the sediment. Measurements include physical abnormalities and potential health risks, such as fin disease, ulcers, tumor precursors, and cancerous liver tumors. Flounder health has not declined in Massachusetts Bay, as some had feared before the outfall began to discharge. Rather, it has even improved near the Massachusetts Bay outfall and has greatly improved near the former outfall in Boston Harbor (Figure iv).

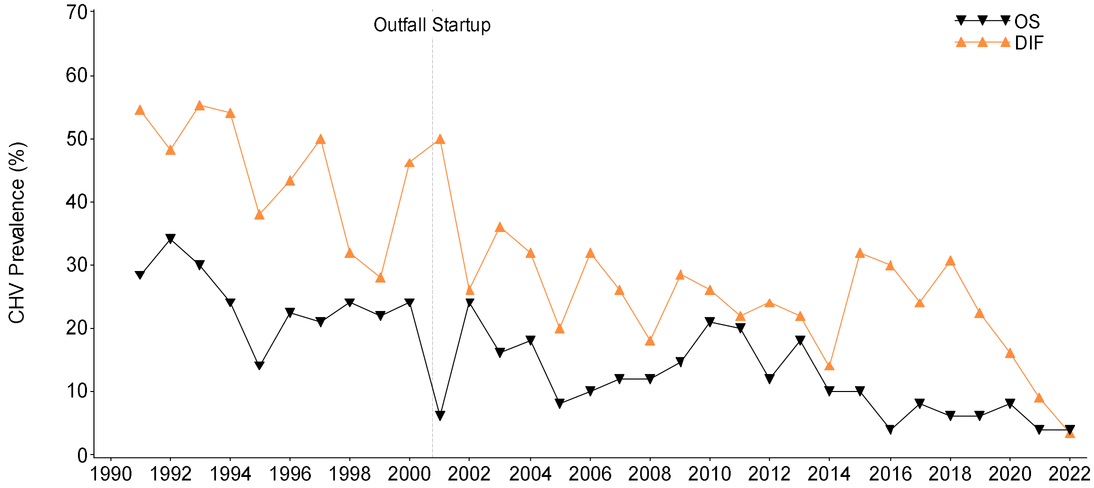


**Figure iv. Annual prevalence of the tumor precursor centrotubular hydropic vacuolation (CHV) in winter flounder near the Massachusetts Bay outfall site and at Deer Island Flats, 1991–2022.** Tumor precursors have declined over time at both locations. OS = Outfall Site, DIF = Deer Island Flats

In past years, most recently in 2021, MWRA also tested flounder, lobsters, and mussels for toxic metals and pesticides. Levels of toxic contaminants have declined in Boston Harbor and remained low or even declined in fish and shellfish sampled near the Massachusetts Bay outfall. Because there has been no evidence of effects of the discharge, the regulatory agencies have approved several reductions in the timing and geographic extent of monitoring.

## Effluent does not affect Stellwagen Bank Marine Sanctuary

There have been no measurable effects on the Stellwagen Bank National Marine Sanctuary, located offshore from the MWRA outfall. Stellwagen Bank supports rich recreational and commercial fisheries and is a major feeding ground for whales. Nutrients in the discharge are not detected in offshore waters, and the bottom communities have remained the same as before the discharge began.

Bottom-water dissolved oxygen concentrations in Stellwagen Basin, on the western side of the sanctuary, did reach unusually low levels in 2022. Oxygen concentrations naturally decrease through the summer before fall mixing restores the entire water column to well-oxygenated conditions. The low late-summer oxygen levels throughout the region in 2022 were the result of physical conditions, particularly warm waters, rather than an effect of the outfall.

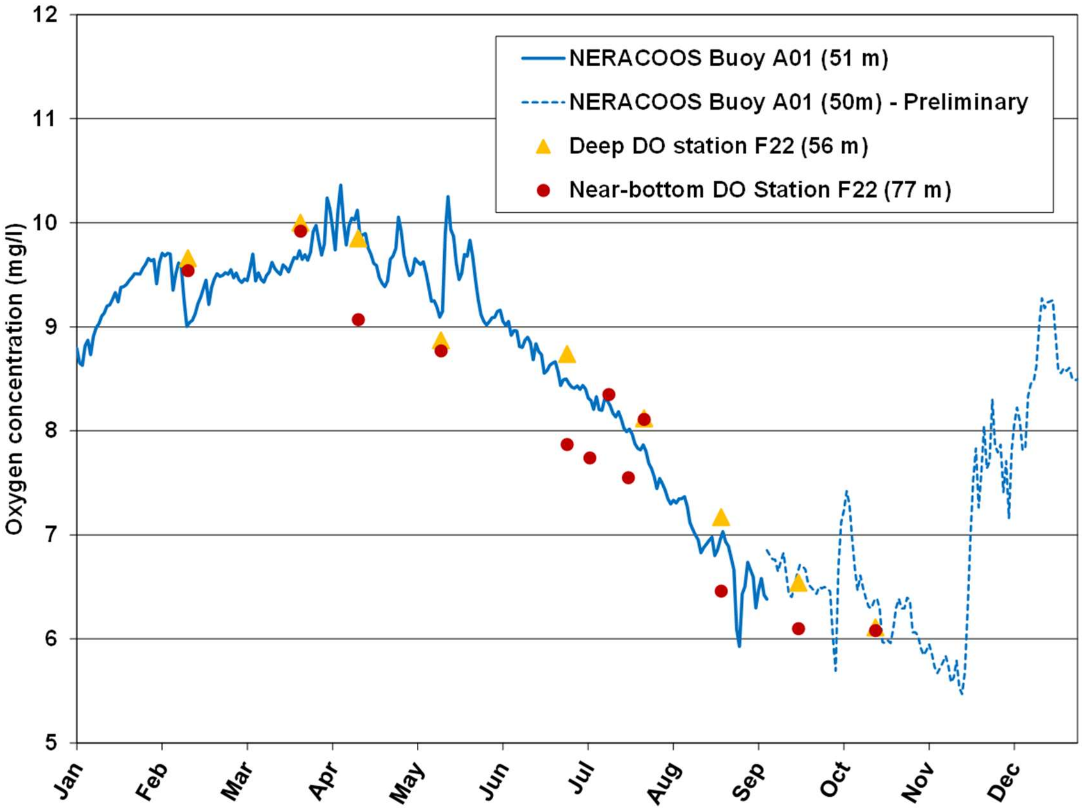


**Figure v. Dissolved oxygen concentrations at the NERACOOS Buoy A01 (lines) and at nearby deepwater MWRA survey Station F22 (symbols) in 2022**. Dissolved oxygen concentrations reached unusually low levels in 2022 but rapidly increased following early winter mixing events such as storms, after the final MWRA survey of the year.

## Boston Harbor is cleaner and still improving

While monitoring in Massachusetts Bay has shown that the outfall does not degrade the environment, Boston Harbor continues to improve since the effluent discharge was diverted from the harbor to the bay. Boston Harbor monitoring stations that had been subject to effluent discharge before September 2000 now exhibit healthy habitats, including thriving eelgrass, a sign of good seafloor conditions (Figure vi).

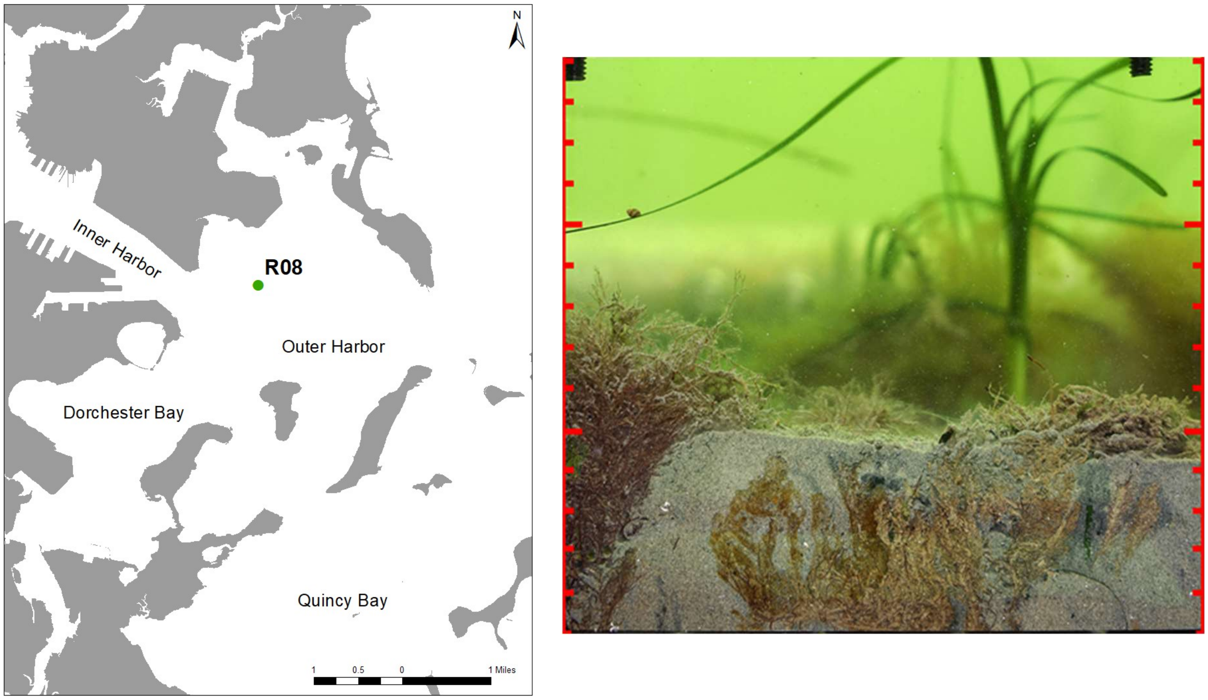


**Figure vi. An eelgrass bed continues to thrive near the former outfall location near Deer Island.** This sediment-profile image taken at Station R08 (red dot on the map) shows healthy eelgrass, well oxygenated sediment, and excellent water clarity.

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# 1. Introduction

Since 1984, the Massachusetts Water Resources Authority (MWRA) has worked to minimize adverse effects of municipal wastewater discharges on the marine environment through a vigorous pretreatment program, a carefully maintained treatment plant, and vigilant effluent and environmental monitoring. One of the most important steps in what is known as The Boston Harbor Project came in September 2000, when the regional effluent discharge was diverted from the shallow, enclosed waters of Boston Harbor to deeper, more open waters in Massachusetts Bay. Since then, the Massachusetts Bay outfall has operated under a National Pollutant Discharge Elimination System (NPDES) permit, jointly issued by the U.S. Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection. An independent Outfall Monitoring Science Advisory Panel has assisted EPA in addressing scientific questions about potential environmental effects of the outfall on Massachusetts Bay.

The NPDES permit requires MWRA to measure effluent quality before discharge and to monitor the water, sea floor, and marine life that could be affected in Massachusetts Bay. A Contingency Plan attached to the permit requires comparing measured conditions against "caution" and "warning" thresholds, developed from state standards and pre-2001 baseline monitoring data. If a caution threshold is exceeded, MWRA must investigate the issue, while a warning threshold is a higher level of concern that could require both investigation and responsive action. Background information about the monitoring program (Werme et al. 2012), the most current monitoring plan (MWRA 2021) and Contingency Plan (MWRA 2001), past plans and overviews, and study-specific technical reports are available on MWRA's technical report list at MWRA Environmental Quality Department Technical Reports.

This annual Outfall Monitoring Overview report fulfills a requirement of the NPDES permit that MWRA produce an annual summary of monitoring results for Massachusetts Bay. Annual overviews also report on special studies, conducted in response to permit conditions and environmental concerns, often in cooperation with other agencies. This year's report on special studies focuses on MWRA efforts under a new Massachusetts law requiring notifications to government agencies and the public of unanticipated or inadequately treated sewage discharges, MWRA's environmental data management system, and an update of the Bays Eutrophication Model, which simulates the processes affecting water quality throughout Massachusetts Bay and the surrounding waters.

This annual overview also reports on results relevant to the Stellwagen Bank National Marine Sanctuary, located offshore from the MWRA outfall, and presents some findings from MWRA's in-house Boston Harbor monitoring program. Harbor monitoring documents the success of the Boston Harbor Project, while Massachusetts Bay monitoring ensures that no new harm occurs offshore.

# 2. Effluent

**Treated effluent is the best way to protect Massachusetts Bay**
MWRA's vigorous pretreatment program and its secondary sewage treatment minimize the contaminants discharged into Massachusetts Bay. Effluent monitoring ensures that limits on pathogens, organic material, nutrients, and toxic contaminants are met.

Deer Island Treatment Plant continued to operate as designed through 2022, earning MWRA the National Association of Clean Water Agencies Platinum 16 Peak Performance Award for facilities with 100% compliance with effluent permit limits over 16 consecutive years.

## 2022 Effluent Characterization

Wastewater entering Deer Island Treatment Plant includes not only municipal sewage but also groundwater infiltration and stormwater inflow. Consequently, rainfall is an important factor in determining annual wastewater flow and contaminant concentrations in the treated effluent. The Boston area received only 31 inches of rain in 2022, almost 20 inches less than 2021 and well below the 2000–2022 average (Figure 2-1). The summer was especially dry, with the driest July ever recorded in Boston.

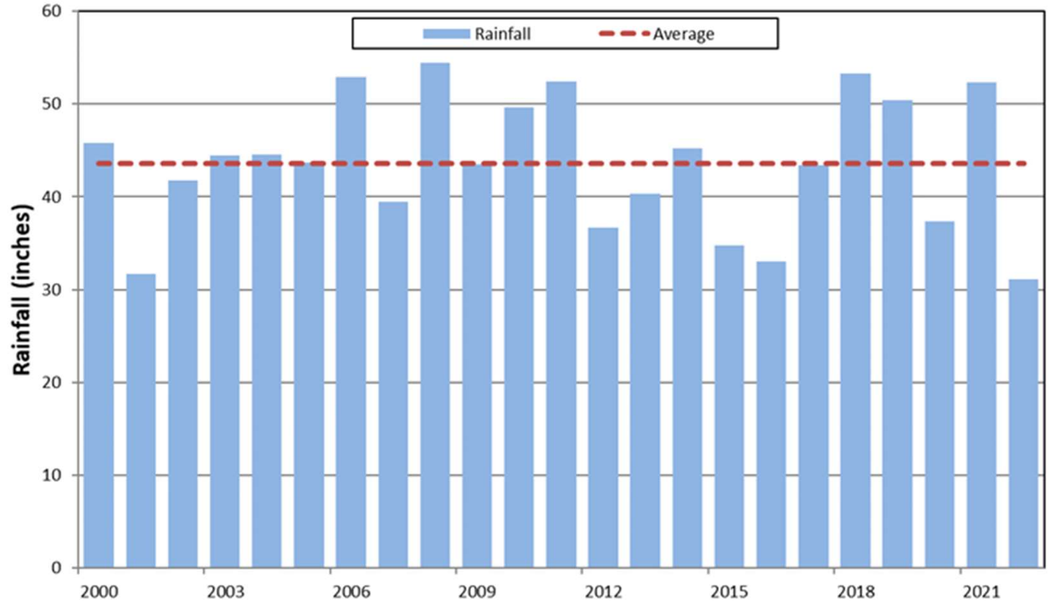

**Figure 2-1. Annual and average rainfall in Boston, 2000–2022.** Rain data are from the National Weather Service rain gauge at Boston Logan International Airport.

With low rainfall, annual total effluent flow in 2022 was substantially lower than the flows in 2021 and other wet years (Figure 2-2). Flow averaged 276 million gallons per day, less than 85% of the average 330 million gallons per day since 2000. Almost all the effluent in 2022 received full secondary treatment, with less than 1% of the total flow consisting of primary-only treated effluent blended into secondary-treated effluent prior to discharge (Figure 2-3). (Primary treatment is a physical process, which involves removal of solid material through settling; secondary treatment includes bacterial decomposition, which removes many more pollutants. All effluent is disinfected before discharge.)

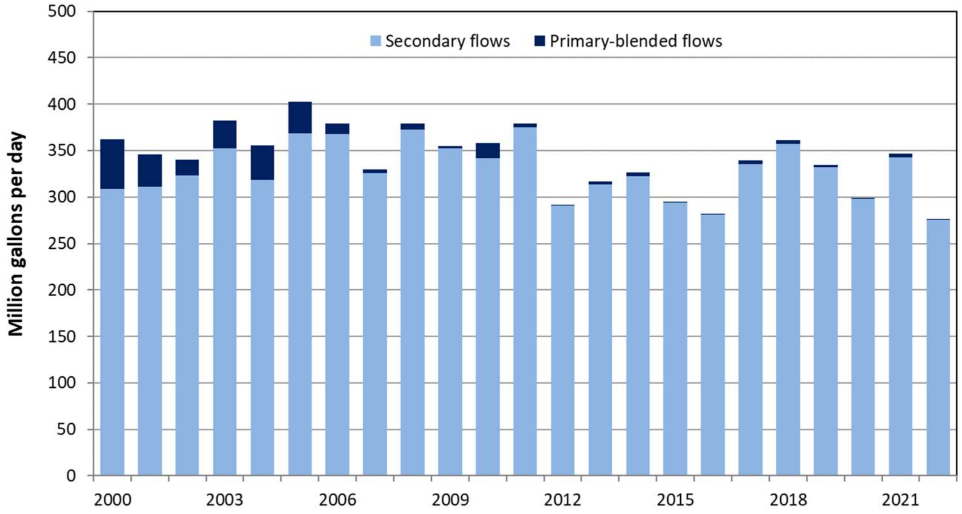

**Figure 2-2. Annual full secondary-treated effluent flows and primary-blended flows, 2000–2022**. During large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process; this primary-treated flow is blended with the fully treated flow before disinfection. and discharge. Blended flows meet all permit limits.

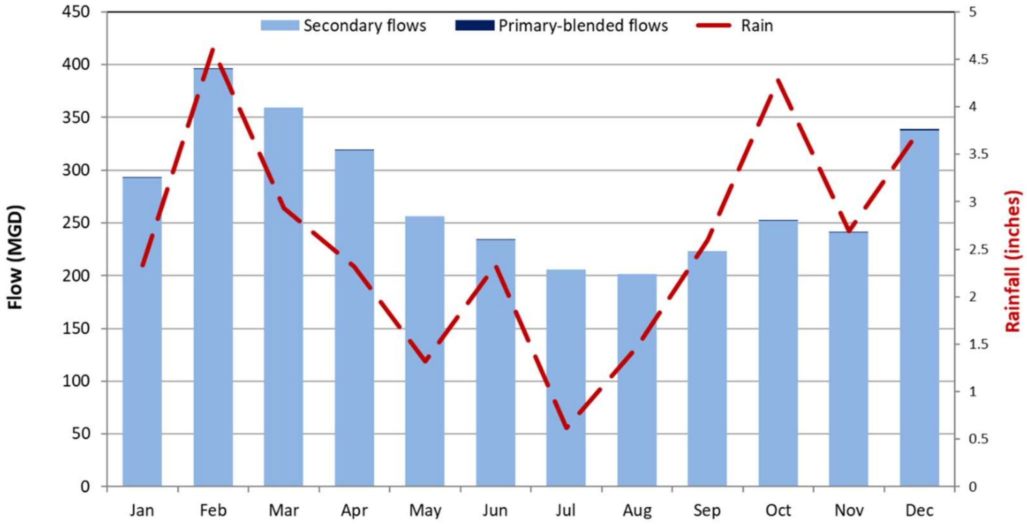

**Figure 2-3. Monthly full secondary-treated and primary-blended flows and rainfall during 2022.** In 2022, more than 99% of total flows received complete primary and secondary treatment.

Blending primary-treated effluent occurs when inflow to the treatment plant exceeds what the secondary treatment process is designed to handle. Blending occurs only during heavy rain, and blended flows fully meet permit limits. In 2022, blending events were so rare and amounts of blended flow so low that it is difficult to discern them in Figures 2-2 and 2-3. Massachusetts regulations require MWRA to notify regulators and the public whenever blending occurs. (See Section 6, Special Studies, for more information about notifications.)

In 2022, the total suspended solids load, those particles remaining after most of the solid material is removed as sludge, was about 14 tons per day, well below the amounts discharged into the harbor in the 1990s (Figure 2-4). In recent years, the total solids load has averaged only about 10% of what had been discharged to the harbor in 1990–1991.

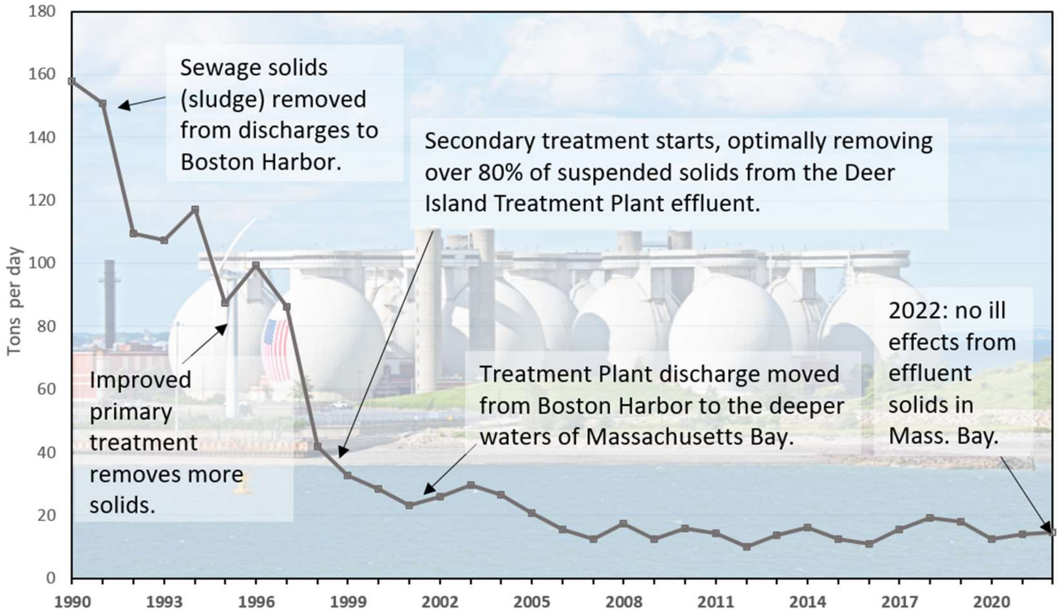

**Figure 2-4. Annual discharges of sewage solids, 1990–2022.** Solids discharges decreased with each accomplishment of the Boston Harbor Project and have remained low.

Biochemical oxygen demand (BOD), a measure of the amount of oxygen needed for decomposing organic material in effluent, remained well below levels that would be expected to affect dissolved oxygen in the environment. MWRA has consistently met its BOD permit limit.

**Organic material**, a major constituent of untreated sewage, consumes oxygen as it decays and can affect growth and productivity of phytoplankton. Treatment removes more than 80% of the biochemical oxygen demand, a measure of the amount of oxygen consumed by microorganisms as they break down the organic material.

MWRA monitors the effluent for fecal coliform bacteria, one indicator of a variety of pathogens that can make shellfish unhealthy for human consumption. Levels of fecal coliform bacteria in the effluent have always been well below permit limits. MWRA also monitors fecal coliform bacteria in Massachusetts Bay, and results at all locations, even those closest to the outfall, meet the stringent shellfishing limits set by the state.

**Pathogens,** including bacteria, viruses, and protozoa, are found in human and animal waste and some can cause disease. Human exposure to pathogens is unlikely in effluent discharged into Massachusetts Bay, as the outfall was sited to be far from shellfishing and swimming areas.

**Nutrients** control algal growth and, at too high concentrations, can lead to eutrophic conditions, which can cause or exacerbate low levels of dissolved oxygen, excess turbidity, and nuisance algal blooms.

MWRA's permit and monitoring plan do not have limits for nutrients, toxic metals and organic compounds, but do require reporting. Nutrient measurements include individual components of total nitrogen (ammonium, nitrate, and nitrite) and similar forms of other nutrients (such as total phosphorus and phosphate). Toxic metals with reporting requirements include lead, mercury, and other metals. Organic compounds include selected pesticides, polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs).

The total nitrogen load for 2022 was 11,888 metric tons, higher than in 2021 but remaining below the Contingency Plan caution threshold of 12,500 metric tons (Figure 2-5). This threshold was set conservatively at about 90% of the warning threshold, 14,000 metric tons, which was the level expected to be reached by 2020, based on population growth projections for the MWRA service area. Nitrogen loads have remained well below that anticipated amount. The caution threshold was exceeded once, in 2019; however, modeling has suggested that even loads much higher than the more stringent warning threshold would not harm the environment (Deltares 2022; see Section 6, Special Studies for further discussion). MWRA updates its report on potential nitrogen-removal strategies annually (most recently in Ellis-Hibbett et al. 2023).

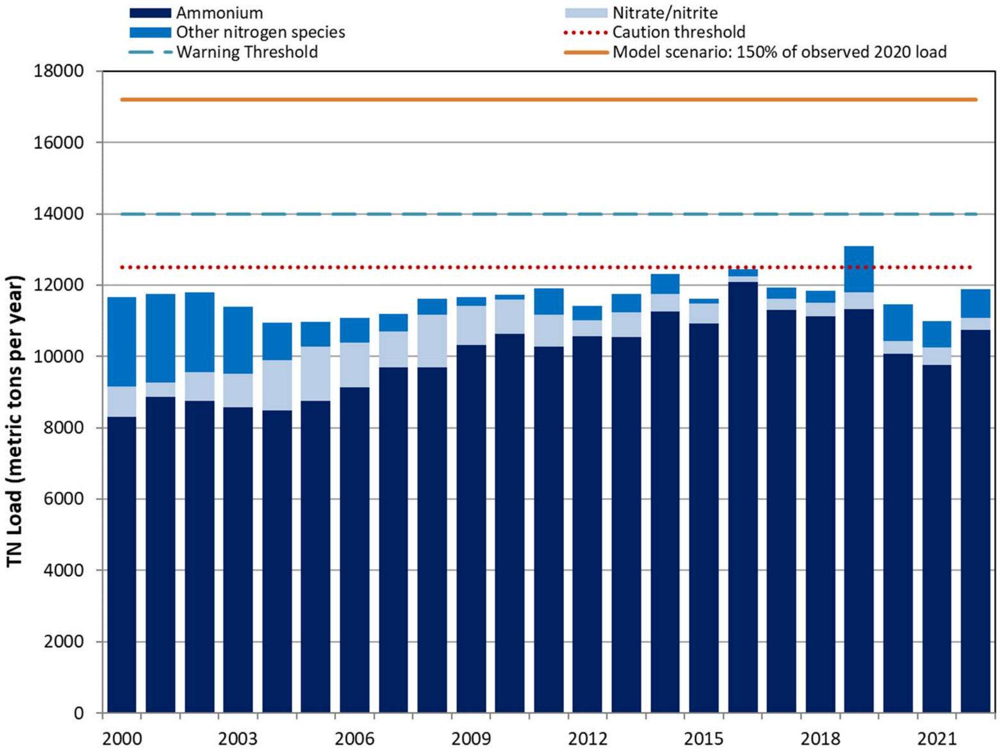

**Figure 2-5. Annual nitrogen discharges, 2000–2022.** The warning threshold, 14,000 metric tons per year, was set as the load anticipated for 2020; the caution threshold was set at 90% of the warning threshold. Actual loads have remained lower than anticipated. A model run simulating inputs that were 150% of the actual 2020 load predicted no adverse effects on the environment.

The portion of the effluent total nitrogen load composed of ammonium, a form of nitrogen readily taken up by phytoplankton (microscopic algae and other plant-like organisms) and a good effluent tracer, increased in comparison to 2021 after two years of decreases. Steady increases in ammonium discharges through most years of monitoring had been a result of the treatment processes for both sewage sludge and effluent; reasons for the recent decreases are unclear and may simply reflect sampling variability.

Metals loads remained low in 2022 (Figure 2-6). Zinc continued to be the most abundant metal, followed by copper. Both are present in water pipes and fixtures. Other notable sources of zinc to wastewater include beauty shops, automobile-repair shops, and hospitals; residential household products, such as shampoos, ointments, and laundry detergent; and street runoff (MWRA, unpublished data).

**Toxic contaminants** include heavy metals, such as copper and lead, and organic compounds, including now-banned pesticides and polychlorinated biphenyls. Elevated levels of toxic contaminants could directly affect marine communities or could bioaccumulate, eventually affecting human health.

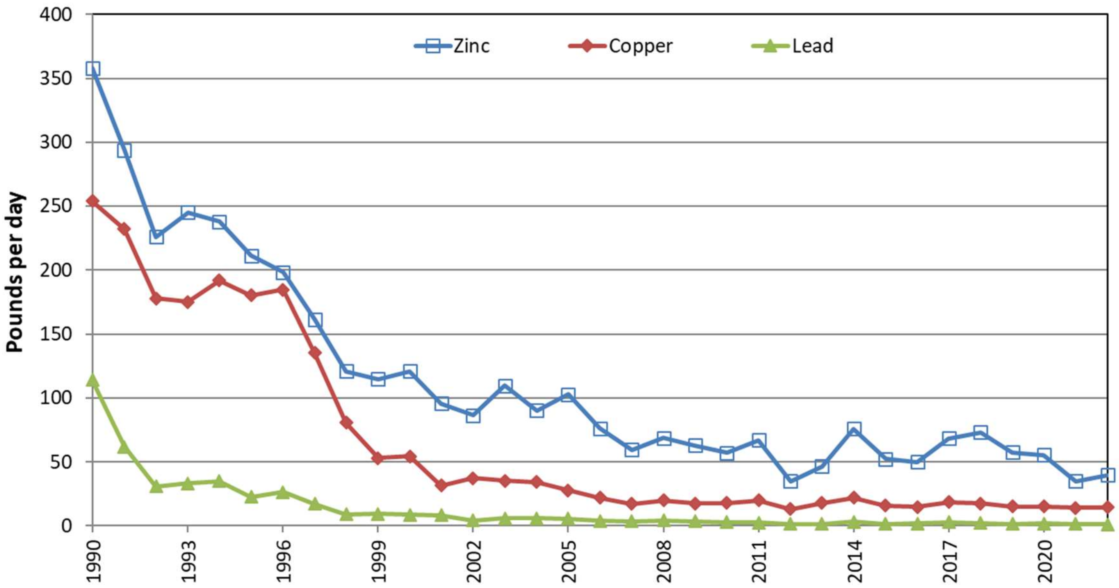

**Figure 2-6. Annual metals discharges, 1990–2022.** Source reduction, industrial pretreatment, and secondary treatment have dramatically decreased metals loads in the effluent.

Total loads of all metals remained small percentages of what had been anticipated during planning for the Massachusetts Bay outfall. Copper discharges were less than 20% of what had been predicted, and all other metals discharges were less than 10% of the predictions (Werme et al. 2021). Except for copper, all metals meet water quality standards prior to discharge. In the receiving water initial dilution (the amount of mixing within a strictly defined area near the outfall) further reduces concentrations. Copper discharges meet the standard after initial dilution and have declined over time, a result of drinking-water corrosion control, which decreases leaching from water pipes, and other source-reduction efforts. Corrosion control, as well as secondary treatment, have also significantly reduced lead levels in the effluent discharge.

Mercury discharges were only 1% of what had been anticipated during planning for the outfall. Silver, once considered a good effluent tracer, is now often at levels below detection limits, a result of the decline in film-based photography, as well as good removal efficiencies with secondary treatment.

Discharges of organic contaminants have varied slightly from year to year but have been well below loads historically discharged into Boston Harbor. Annual polycyclic aromatic hydrocarbon (PAH) loads, for example, were only 74 kilograms in 2022, compared to the more than 3,000 kilograms of PAHs estimated to have been discharged in wastewater effluent into Boston Harbor in 1991 (Rex et al. 1992). PAH concentrations now meet water quality standards at discharge. For some other organic compounds, such as 4,4’-DDE, one of the most prevalent breakdown products of the pesticide DDT, the effluent data show evidence of the very slow declines anticipated in the 1970s when it was banned along with other pesticides and toxic chemicals.

# Effluent Contingency Plan Thresholds

There were no effluent Contingency Plan exceedances in 2022 (Table 2-1). Exceedances of effluent permit limits have been rare, and none have occurred since 2006. The total nitrogen caution level, which is not a permit limit but set in the Contingency Plan, was not exceeded in 2022.

**Table 2-1. Contingency Plan threshold values and 2022 results for effluent monitoring.**

| Parameter | Baseline | Caution Level | Warning Level | 2022 Results |
|---|---|---|---|---|
| **Permit Condition and Contingency Plan Thresholds** | | | | |
| pH | NA | None | <6 or >9 | Not exceeded |
| Fecal coliform | NA | None | >14,000 fecal coliforms/100 mL | Not exceeded |
| Chlorine, residual | NA | None | >631 µg/L daily,<br>>456 µg/L monthly | Not exceeded |
| Suspended solids | NA | None | >45 mg/L weekly<br>>30 mg/L monthly | Not exceeded |
| cBOD | NA | None | >40 mg/L weekly,<br>>25 mg/L monthly | Not exceeded |
| Acute toxicity | NA | None | LC50 <50% | Not exceeded |
| Chronic toxicity | NA | None | NOEC <1.5% effluent | Not exceeded |
| PCBs | NA | Aroclor>0.045 ng/L | None | Not exceeded |
| Plant performance | NA | 5 violations/year | Compliance <95% of the time | 100% compliance |
| Flow | NA | None | >436 MGD average dry days | Not exceeded |
| Oil and grease | NA | None | >15 mg/L weekly | Not exceeded |
| **Contingency Plan Thresholds** | | | | |
| Total nitrogen load | NA | >12,500 mtons/year | >14,000 mtons/year | 11,888 mtons |

NA = not applicable
cBOD = carbonaceous biological oxygen demand
LC50 = 50% mortality concentration
NOEC = no observable effect concentration
PCB = polychlorinated biphenyl
Plant performance = compliance with permit conditions

# 3. Water Column

**Water-column monitoring looks for signs of eutrophication in the bay**
MWRA's effluent contains nitrogen and other nutrients, which at high concentrations could overstimulate phytoplankton growth and lead to low levels of dissolved oxygen or increased severity of nuisance algal blooms. Monitoring assesses physical conditions, water quality (nutrients, phytoplankton biomass measured as chlorophyll, and dissolved oxygen), and phytoplankton and zooplankton communities to detect signs of eutrophication.

MWRA's water-column monitoring program evaluates physical oceanographic processes, water quality, and phytoplankton and zooplankton communities at stations in Massachusetts Bay, at the mouth of Boston Harbor, and in Cape Cod Bay (Figure 3-1). Ship-based field surveys are augmented by instrumented buoys and satellite imagery. Water-column monitoring is primarily focused on nutrients, as inputs of other pollutants present in the effluent, such as organic material, pathogens, and toxic contaminants, are more completely removed in wastewater treatment and are unlikely to have any harmful effects.

Excess nutrient levels can cause eutrophication, which occurs when nutrients overstimulate phytoplankton growth, leading to lower levels of dissolved oxygen or promoting nuisance or toxic algal blooms. One nuisance phytoplankton species, *Phaeocystis pouchetii*, was a focus in past years but has been shown to vary in response to physical conditions rather than the outfall and is no longer considered a concern. Potentially toxic species include *Alexandrium catenella*, which occurs regularly in Massachusetts Bay, and *Pseudo-nitzschia*, a species group that occurs in Massachusetts Bay, but usually in low numbers and in its nontoxic forms.

Nine ship-based surveys are completed between February and October of each year. Five stations are in the "nearfield," a 12- by 10-kilometer area centered on the outfall, where some effects of the effluent were expected and have been observed. Nine are in the more distant "farfield," including the mouth of Boston Harbor, Cape Cod Bay, and near Stellwagen Bank National Marine Sanctuary offshore from the outfall.

Additional surveys may be triggered by elevated abundance of the potentially toxic phytoplankton species *Alexandrium catenella*. These *Alexandrium* Rapid Response Study surveys (Libby et al. 2013) provide in situ hydrographic data and water samples for measuring nutrients and *Alexandrium* abundance at up to 19 stations. Three of these additional surveys were conducted in July 2022.

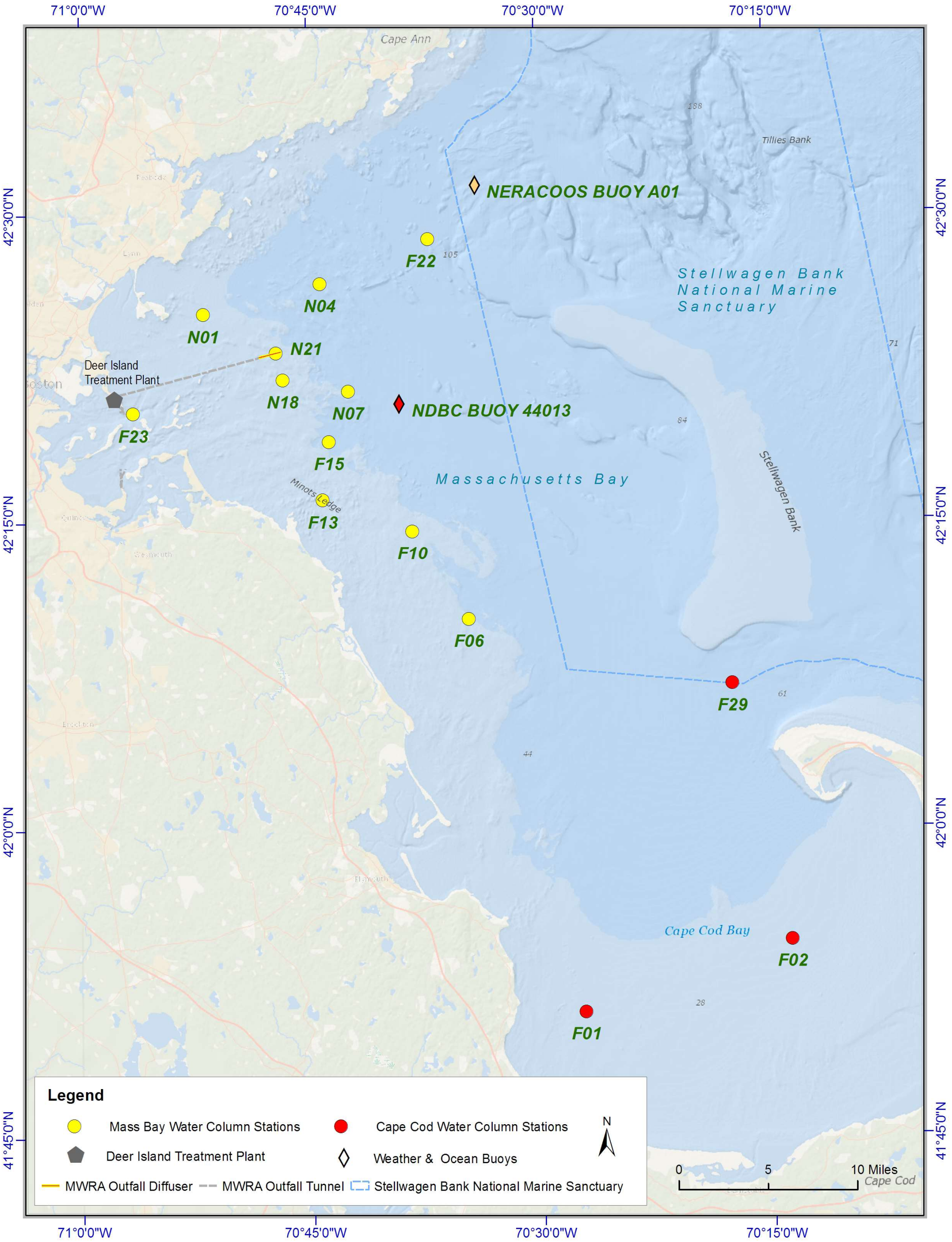

**Figure 3-1. Water-column monitoring stations and instrumented buoys in Massachusetts and Cape Cod Bays.** Data are obtained from surveys, the NERACOOS A01 and NDBC 44013 buoys, and satellite imagery. Also shown are the outfall and the Stellwagen Bank National Marine Sanctuary.

The monitoring program benefits from collaboration with the Center for Coastal Studies in Provincetown, Massachusetts, which samples the three water-column stations in Cape Cod Bay and near Stellwagen Bank National Marine Sanctuary. Regulators have set a target that, whenever possible, sampling in Cape Cod Bay should occur within 48 hours of the Massachusetts Bay survey. In 2022, the October Cape Cod Bay sampling occurred three days after the Massachusetts Bay survey; all other surveys were within the 48-hour window.

Surveys are supplemented by measurements at two instrumented buoys: the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Buoy A01 off Cape Ann at the northern limit of Massachusetts Bay, and the National Oceanic and Atmospheric Administration’s National Data Buoy Center (NDBC) Buoy 44013 in central Massachusetts Bay. The National Aeronautics and Space Administration provides Moderate Resolution Imaging Spectroradiometer satellite imagery of chlorophyll fluorescence, a measure of phytoplankton biomass.

## Physical Conditions

**Circulation and physical properties in Massachusetts Bay are driven by the larger pattern of water flow in the Gulf of Maine.** Water enters Massachusetts Bay from the north, circulates in a counter-clockwise direction, and exits by Race Point, at the tip of Cape Cod. Water flows vary from week-to-week and depend on the strength of the current and on wind speed and direction. The coastal current is strongest during spring runoff from rivers and streams.

In the winter, the water column is well mixed, and nutrient levels are high. As surface waters warm, the water column stratifies, separating surface from bottom waters and leading to lowered bottom-water dissolved oxygen levels in late summer and fall. Inputs of freshwater, which is lighter than seawater, can contribute to stronger stratification. Cooling surface waters and strong winds in the fall promote mixing, ending the stratified season and re-oxygenating bottom waters.

Following a relatively rainy 2021, with the highest summer river flows measured in the past 30 years, 2022 was dry. River flows from the Merrimack and Charles Rivers were high in the winter and early spring, but later spring, summer, and early fall flows were among the lowest of the monitoring program (Figure 3-2; Libby et al. 2023). While there has been no discernable long-term trend in river flow, year-to-year variability in rainfall and the influx of freshwater in river discharges can exert large effects on conditions in Massachusetts Bay, such as increasing stratification, which separates surface from bottom waters during summer months.

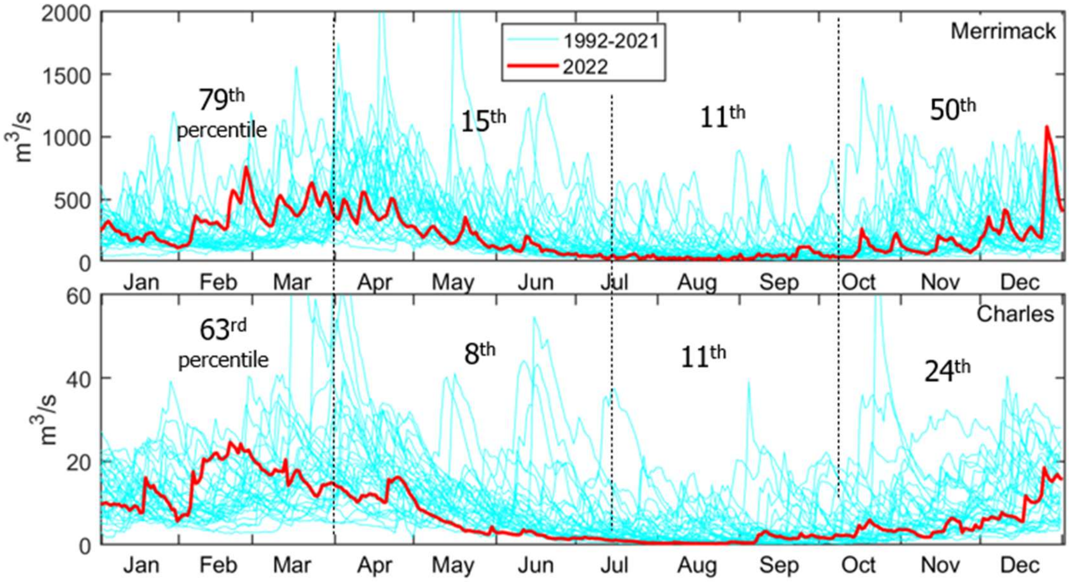

**Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) Rivers.** The Charles River flows into Boston Harbor. The much larger Merrimack River flows into the Gulf of Maine just south of the New Hampshire border, but greatly influences Massachusetts Bay. Low river flow, which occurred in 2022, leads to high salinity in Massachusetts Bay. Red lines are 2022 data. Results from 1992–2021 are in light blue. The quarterly percentiles represent the 2022 flows in comparison to the entire record.

Surface- and bottom-water temperatures were warm during most survey months, for example, at Station N18 just south of the outfall (Figure 3-3, top two panels). Temperatures dipped during the July *Alexandrium* surveys, when air temperatures remained high, but upwelling brought cooler waters to the surface. Water temperatures rose quickly after the upwelling subsided.

Surface- and bottom-salinities at Station N18 were very high throughout most of the year, a result of the low river inflows (Figure 3-3, bottom panels). Warm waters and high salinities correlate with low late-summer dissolved oxygen conditions in Massachusetts Bay.

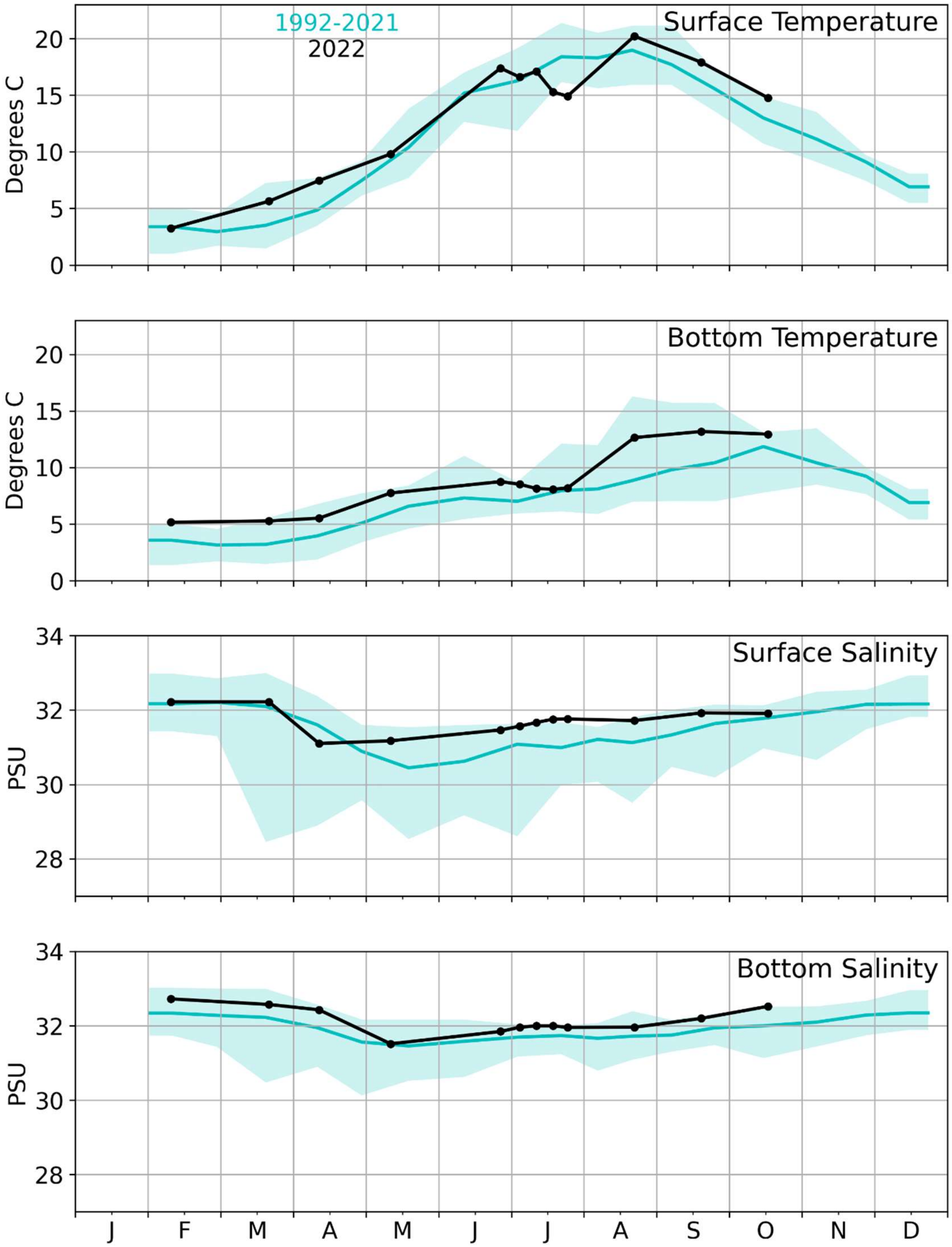

**Figure 3-3. Surface- and bottom water temperature and salinity at Station N18 just to the south of the outfall in 2022 compared to prior years.** The black points and lines are results from 2022; the blue lines and shading are results from 1992–2021. PSU = practical salinity units or parts per thousand.

Wind speeds and directions, which can exert large effects on conditions in the bay, were typical through 2022, with no storm producing large waves capable of resuspending and transporting bottom sediments, as occurs in some years. Two wind events in April were conducive to bringing cells of the nuisance algal species *Alexandrium catenella* into Massachusetts Bay from the Gulf of Maine. Such wind events have frequently triggered *Alexandrium* blooms in past years; however, in 2022, a bloom did not begin until later in the season.

# Water Quality

Water quality measurements include quantification of nutrients (nitrogen, phosphorus, and silica), phytoplankton biomass (measured as chlorophyll), and dissolved oxygen. These measurements address the concern that excess nutrients could stimulate phytoplankton growth (increase biomass) and exacerbate low bottom-water oxygen conditions. Results for 2022 continued to confirm measurable outfall influence on some nutrient concentrations at stations near the outfall, but no resulting increase in phytoplankton biomass (Libby et al. 2023). Bottom-water dissolved oxygen levels, which typically begin the year relatively high and steadily decline during the summer, stratified season, reached lower levels than in past years. Those conditions were a result of high temperature and salinity rather than a response to nutrients in the outfall discharge.

## Nutrients

Concentrations of most forms of dissolved inorganic nutrients near the outfall stayed within the ranges measured in previous years, with many measurements at the historic medians. Prevalent forms of the nutrients, including nitrate, phosphate, and silicate, continued to show the typical seasonal patterns that were present before the bay outfall began to discharge. Nutrient levels naturally vary with phytoplankton uptake, exchange with the Gulf of Maine, and river flow.

Nitrogen, including its dissolved forms of nitrate and ammonium, is the most important nutrient for phytoplankton growth in marine waters. Ammonium is also the largest fraction of the total nitrogen in wastewater (see Figure 2-5, page 6), making it a good effluent tracer. Since the discharge was relocated from the harbor to the bay in late 2000, variable and elevated levels of ammonium have been detected at stations near the outfall (Figure 3-4).

Especially high ammonium concentrations at stations closest to the outfall are sometimes a result of a sample being taken directly in the effluent plume before it is completely mixed into the surrounding water. For example, for most of the year, ammonium levels were particularly high at Station N21, located right at the outfall. However, during one July survey, ammonium levels were lower at Station N21 and higher at Station N18, immediately to the south. These results indicate a possible shift in water flows, pushing the plume to the south as it mixed into the water column.

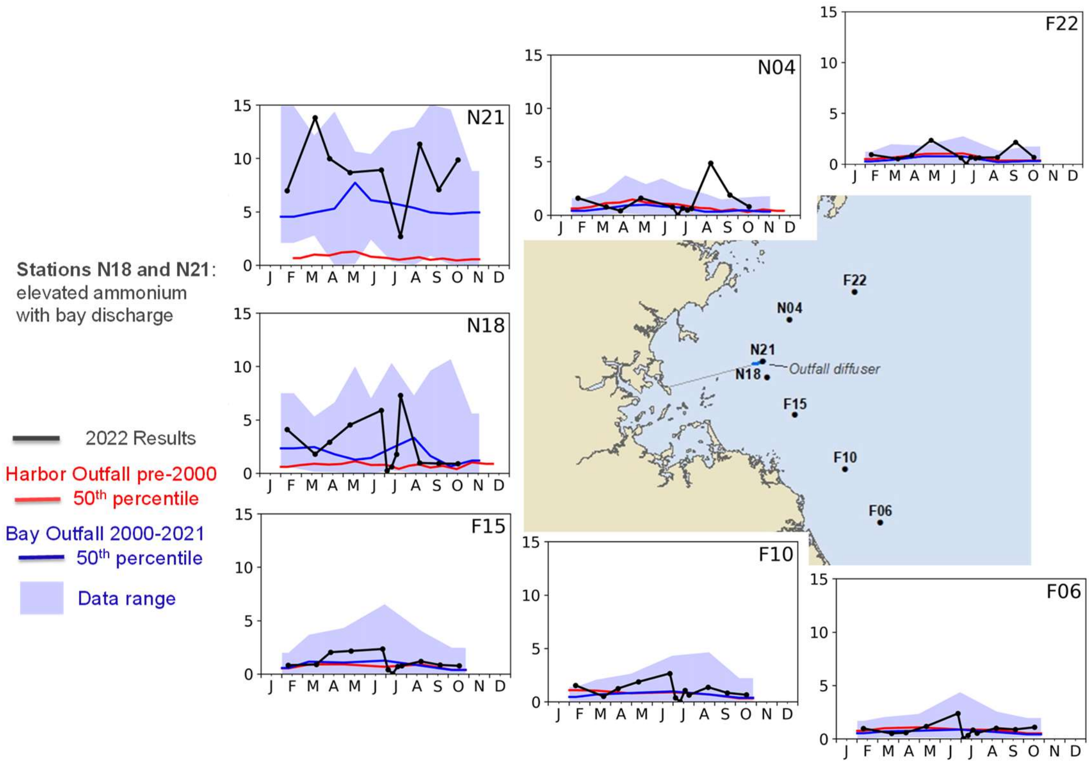

**Figure 3-4. Ammonium concentrations (µM) at selected stations in 2022 compared to prior years.** Increased concentrations of the sewage tracer ammonium are found at stations closest to the outfall, while stations further away have maintained concentrations simitar to pre-outfall levels. The "data range" spans all measurements.

As is typical, the effluent plume's ammonium signature was evident in surface waters at stations closest to the outfall during the winter surveys, when the water column was relatively well-mixed (Figure 3-5). During the summer stratified season, the plume was confined beneath the pycnocline, below depths where maximum phytoplankton growth occurs (Figure 3-6). During the June survey, the ammonium signature was detected at greater distance from the outfall than sometimes occurs. Similar to past years, this extended plume signal is intermittent and was absent during the July survey.

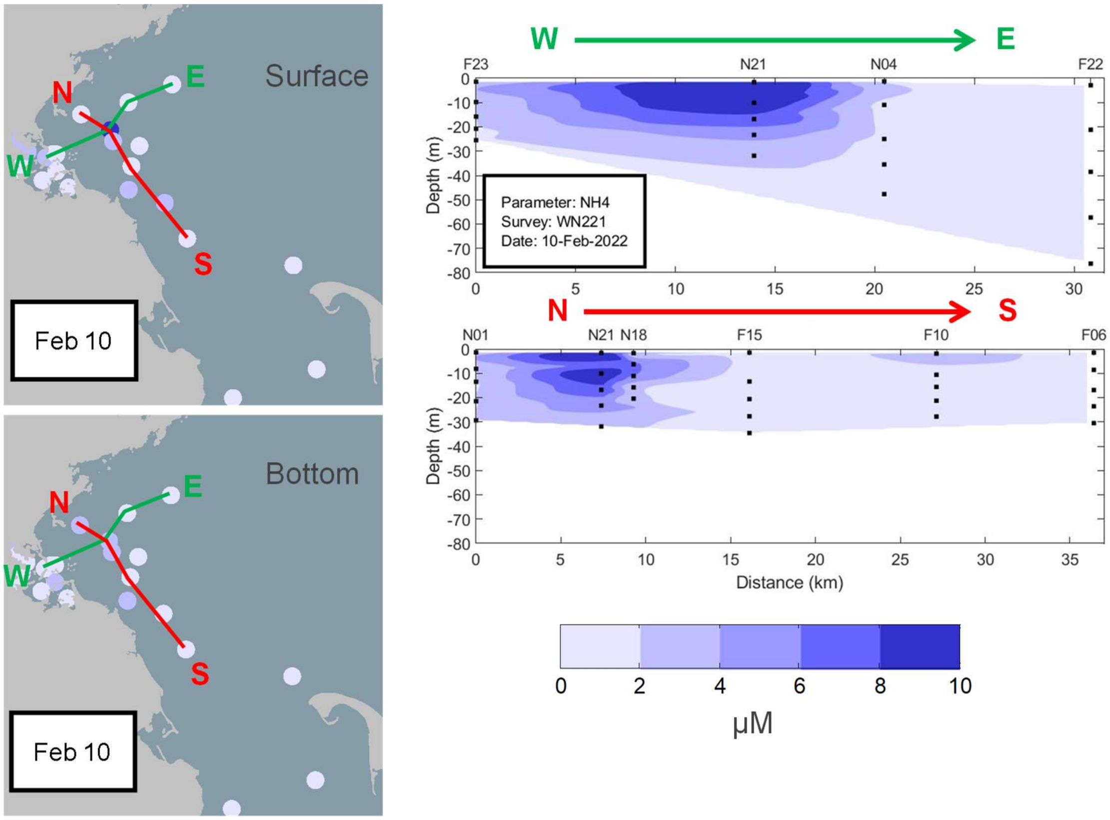

**Figure 3-5. (Left) Surface- and bottom-water ammonium on February 10, 2022, during mixed (non-stratified) conditions. (Right) Cross-sections of concentrations through the water column along transects connecting selected stations**. Station N21 is directly over the outfall. During winter, well-mixed conditions, the plume is evident in surface waters. Detectable elevated ammonium concentrations were found along west to east as north to south transects. Dots include results from MWRA's in-house Boston Harbor monitoring program.

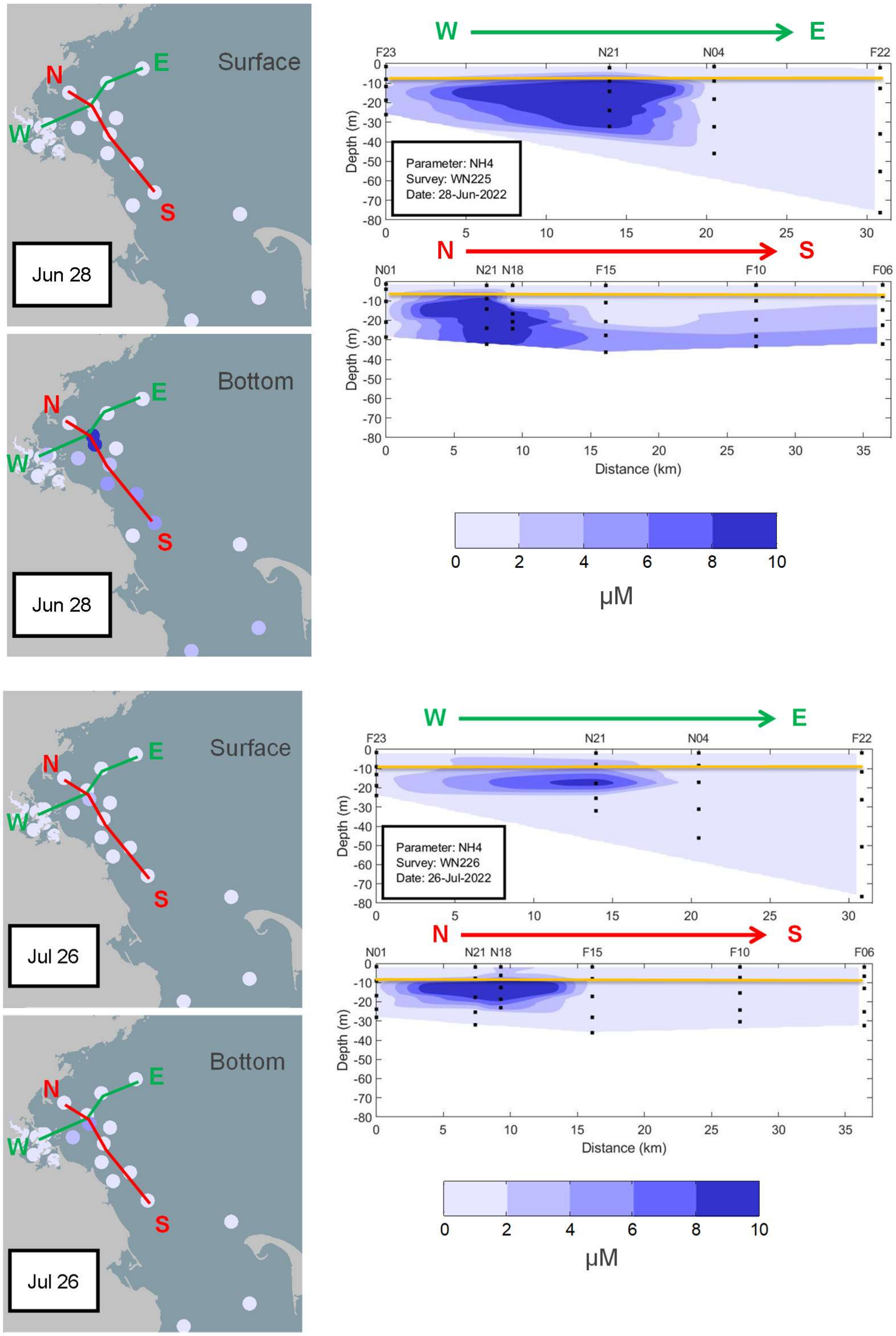

**Figure 3-6. (Left) Surface- and bottom-water ammonium on June 28 and July 26, 2022 during stratified conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations**. On both dates, the plume was confined below the pycnocline, below the depth of most phytoplankton growth. The distance that the plume could be detected was greater in June than in July, reflecting natural variability in oceanographic conditions. The yellow lines denote the pycnocline. Dots include results from MWRA's in-house Boston Harbor monitoring program.

## Phytoplankton Biomass (Chlorophyll)

The localized ammonium concentration increases have not stimulated phytoplankton growth or resulted in increased phytoplankton biomass at any station, even those closest to the outfall (Figure 3-7). Survey phytoplankton biomass is reported as vertically summed (areal) chlorophyll from measurements collected throughout the water column from the surface to the sea floor. Seasonal peaks often occur in the winter or spring and again in the fall, corresponding to typical spring and fall phytoplankton blooms, although timing and magnitude vary from year to year. During the 2022 survey season, areal chlorophyll levels peaked during March at many stations, particularly those in shallow water and to the south of the outfall. There was no indication of any increase in chlorophyll levels compared to the years before the Massachusetts Bay outfall began to discharge.

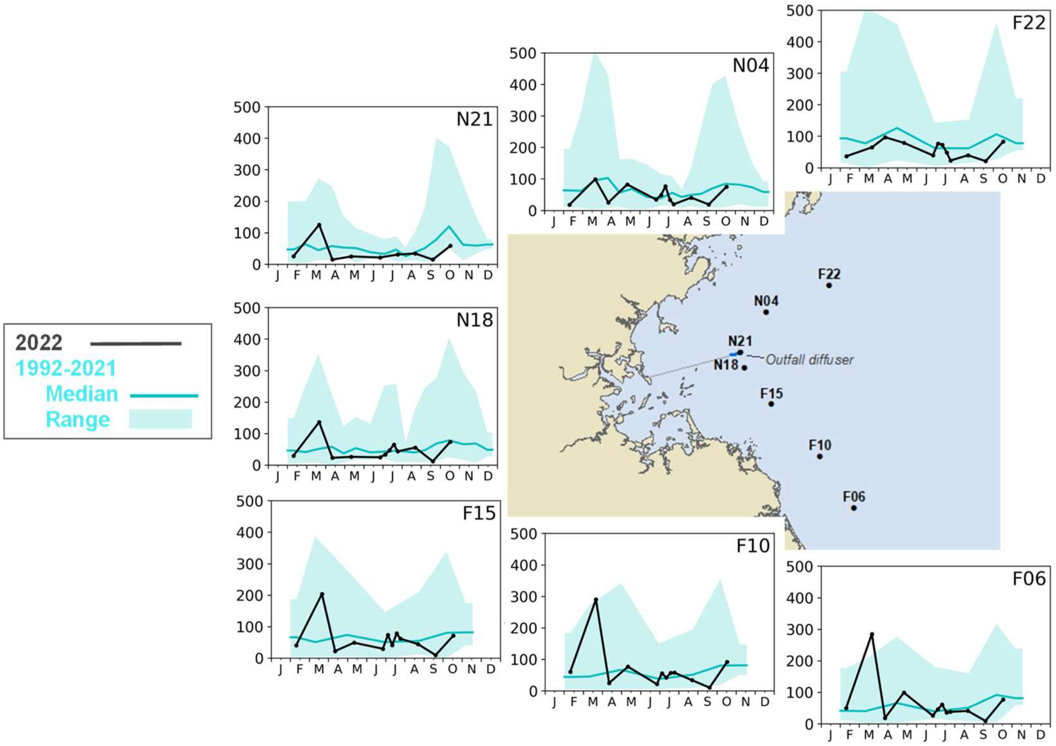

**Figure 3-7. Areal chlorophyll concentrations (milligrams per square meter) at selected stations in 2022 compared to prior years.** For some stations, historic data (shaded areas) extend later in the year than the current survey schedule.

Satellite imagery, which helps fill in the gaps between survey dates, showed moderate chlorophyll concentrations in January and early February, prior to the start of the survey season (Figure 3-8). Similar to the survey data, chlorophyll levels increased in March, likely the result of a spring phytoplankton bloom, typical of healthy coastal waters. Increased phytoplankton biomass in May often signals a bloom of a nuisance species, *Phaeocystis pouchetii*, but survey measurements did not confirm a bloom in 2022. The satellite imagery also showed elevated levels in the fall, reflecting another bloom, also typical of coastal waters and consistent with past observations.

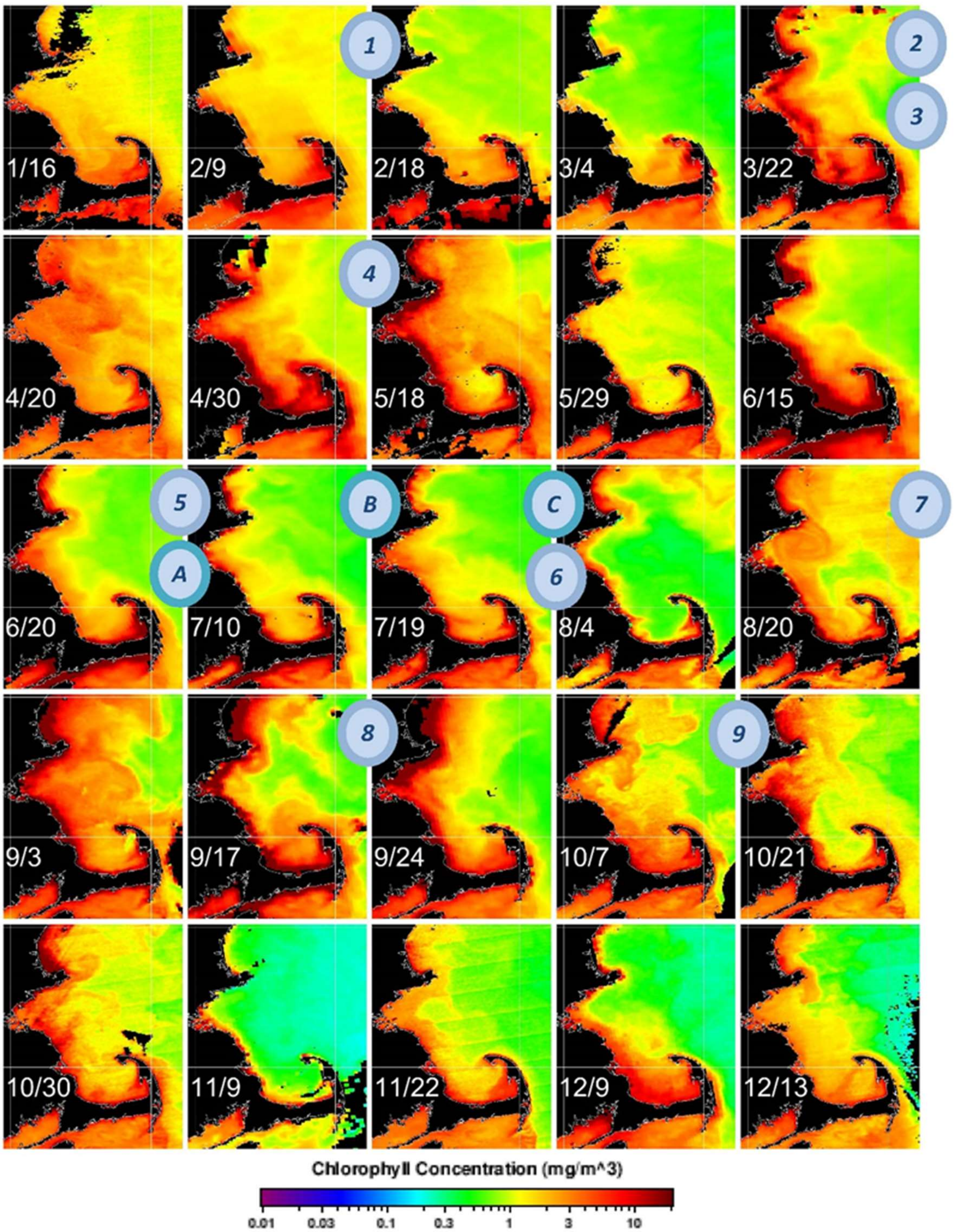

**Figure 3-8. Moderate-Resolution Imaging Spectroradiometer satellite imagery of surface chlorophyll concentrations in 2022**. The dates (marked in each frame) are highly weather-dependent and do not represent consistent intervals of time. The numbers 1–9 show the timing of the routine MWRA surveys; and the letters A–C show additional surveys conducted in response to elevated abundance of the potentially toxic dinoflagellate *Alexandrium catenella*. The imagery helps fill the temporal gaps between surveys.

## Dissolved Oxygen

In general, dissolved oxygen levels (concentration and percent saturation) in bottom water begin the year relatively high and steadily decline throughout the summer, when warm temperatures stratify the water column into distinct layers. (The boundary between layers is called the thermocline, based on temperature measurements, or the pycnocline, based on density which reflects changes in both temperature and salinity.) Stratification prevents exchange between the atmosphere and bottom waters, so dissolved oxygen levels naturally decline at depth, as animals and microbes respire.

Dissolved oxygen concentrations in Massachusetts Bay bottom water declined steadily from March through the end of the survey season, with some rebounds during the notable July upwelling event, which temporarily disrupted stratification (Figure 3-9). The steady decline spanned the monitoring area, reaching the lowest levels observed by the monitoring program at some stations, and also detected at the NERACOOS Buoy A01. Percent oxygen saturation, a measure of how much oxygen is dissolved in the water compared to how much oxygen the water could hold at a given temperature and salinity, also reached low levels throughout the region. Low concentrations and percent saturation resulted in Contingency Plan caution and warning threshold exceedances in the nearfield and in Stellwagen Basin. These exceedances are discussed on page 29.

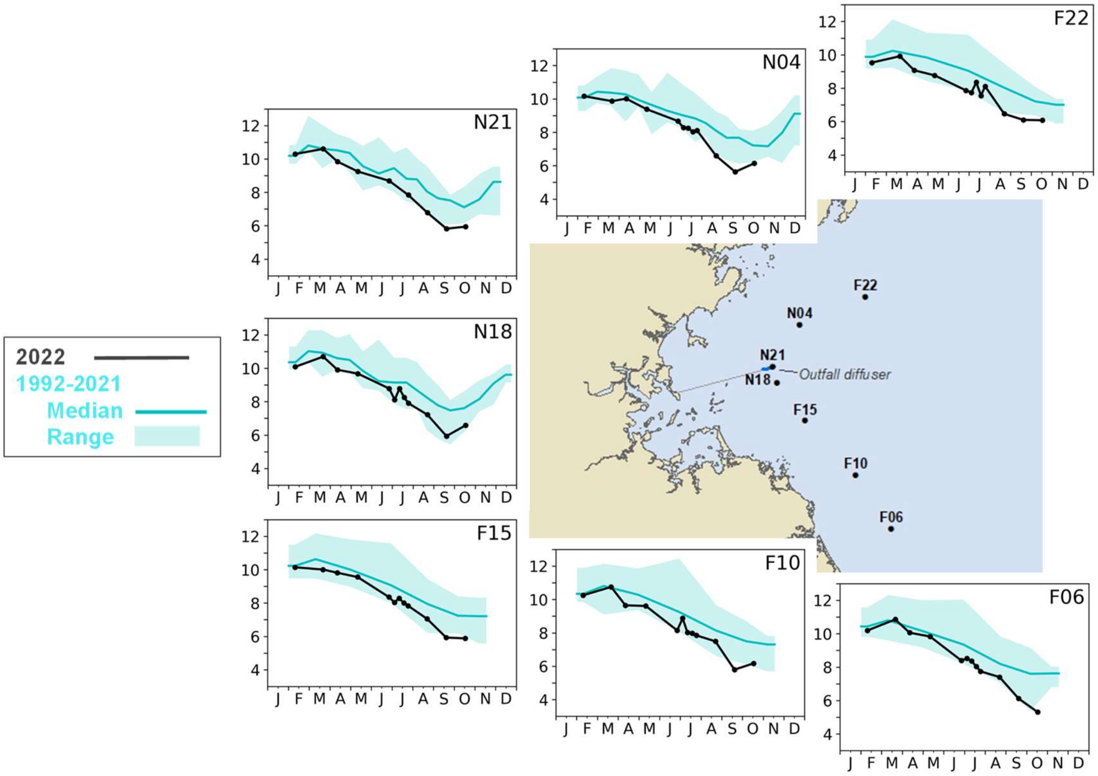

**Figure 3-9. Near-bottom water dissolved oxygen concentrations (milligrams per liter) in 2022 compared to prior years.** For some stations, historic data (shaded ranges) extend later in the year than the current survey schedule.

Low dissolved oxygen concentrations also occurred in Cape Cod Bay, but unlike some recent years, there was no hypoxia or anoxia (extremely low- or no-oxygen conditions that can kill fish, lobsters, and other marine life). Researchers in Cape Cod Bay had noted a number of factors contributing to the hypoxia in those years, including upwelling-unfavorable winds, a strong and deep thermocline, and abundance of a phytoplankton species *Karenia mikimotoi*, which is well-suited to shallow waters with deep thermoclines (Scully et al. 2022). In 2022, winds more typically favored upwelling, and although *Karenia* was present, there was no large bloom.

## Plankton Communities

MWRA monitors phytoplankton and zooplankton abundance and species composition to detect any changes that might be associated with the outfall discharge (Cibik et al. 1998). A focus on potentially toxic or nuisance phytoplankton species further ensures environmental and human health.

Massachusetts Bay phytoplankton includes small algae and other plant-like organisms, such as microflagellates, centric (rounded) and pennate (elongated) diatoms, and dinoflagellates. Microflagellates are extremely small and are typically the most abundant phytoplankton type in Massachusetts Bay. Centric and pennate diatoms have silica-rich cell walls and often dominate spring blooms. The potentially toxic dinoflagellate *Alexandrium catenella* often blooms in Massachusetts Bay and the wider Gulf of Maine region and is the species known in New England as causing "red tide." Other geographic areas designate different species, usually other dinoflagellates, as red tides, and many types of phytoplankton can, when abundant, color the water column.

Zooplankton communities in Massachusetts Bay include animal species that live their entire lives as plankton, such as copepods, and those that live in the plankton only a part of their life cycles, such as barnacle and other larvae. Most species are small, but larger animals, such as jellyfish, are also part of the zooplankton community. Zooplankton abundance and species composition are highly variable through the seasons and between years.

### Phytoplankton Communities

Total phytoplankton abundance increased in 2022 after a period of comparatively low numbers (Figures 3-10 and 3-11, Libby et al. 2023). The 2022 annual abundance in the nearfield (the five stations closest to the outfall) was 1,127,147 organisms per cubic meter, ranking 18th out of 31 years of monitoring, about the middle of the long-term range, and more than one and a half times the 2019–2021 average, when numbers were relatively low.

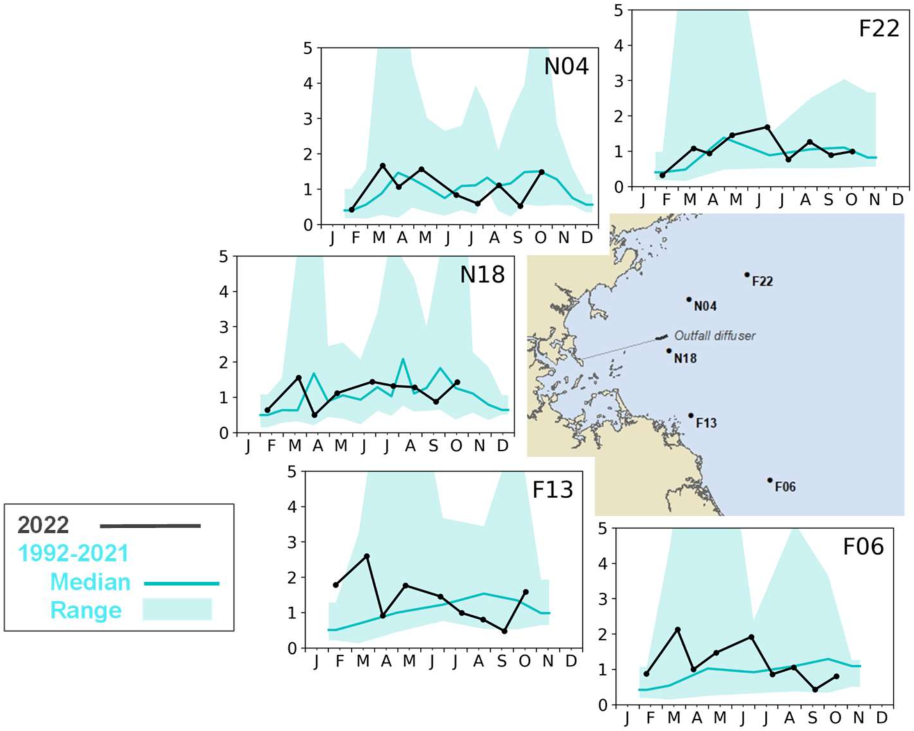

**Figure 3-10. Total phytoplankton abundance (million cells per liter) at selected stations in 2022 compared to prior years**. For some stations, historic data (shaded ranges) extend later in the year than the current survey schedule.

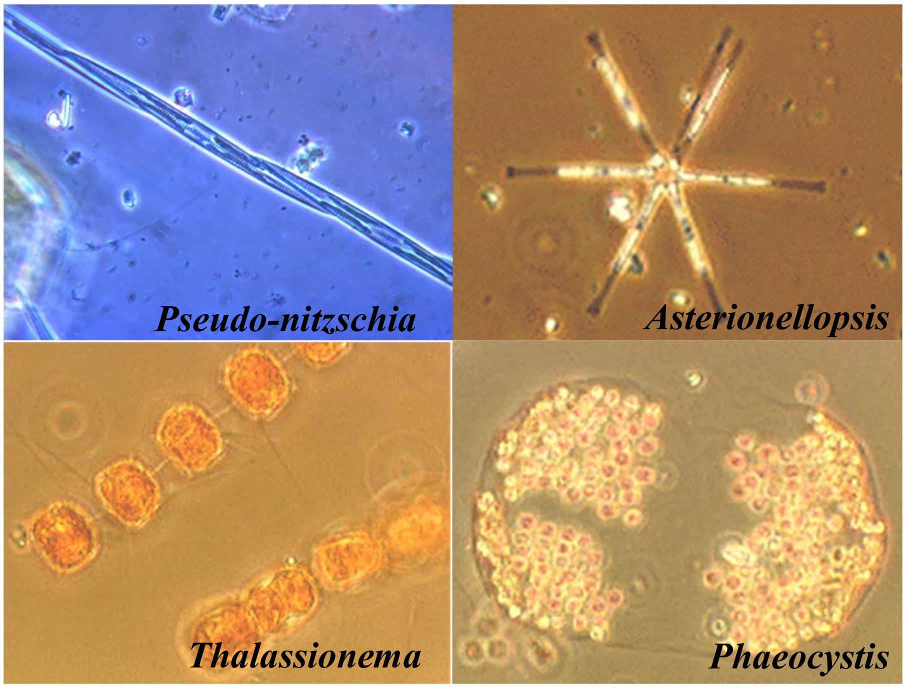

**Figure 3-11. Phytoplankton species typical of Massachusetts Bay.** *Pseudo-nitzschia* and *Asterionellopsis* are groups of pennate diatoms, *Thalassionema* are centric diatoms, and *Phaeocystis* is a flagellate. Some species of *Pseudo-nitzschia* produce toxins, and *Phaeocystis* can be a nuisance if it grows into large, chain-forming colonies. Photo credits David Borkman, Rhode Island Department of Environmental Management, Providence, Rhode Island

One reason for the overall increase in abundance was a centric diatom bloom in March. Winter and spring diatom blooms are common in coastal waters, but the March 2022 bloom was the largest measured by the monitoring program since 1999 (Figure 3-12). This bloom was dominated by *Skeletonema* species, a worldwide genus found across a broad range of physical conditions. Although *Skeletonema* has been present throughout the monitoring program, its abundance in 2022 far exceeded any prior year. Other species groups, such as *Thalassiosira*, have dominated in the past. None of the dominant centric diatom species is potentially toxic, and the results pose no environmental concern. The unprecedented early *Skeletonema* bloom may, however, signal a shift in physical conditions in Massachusetts Bay.

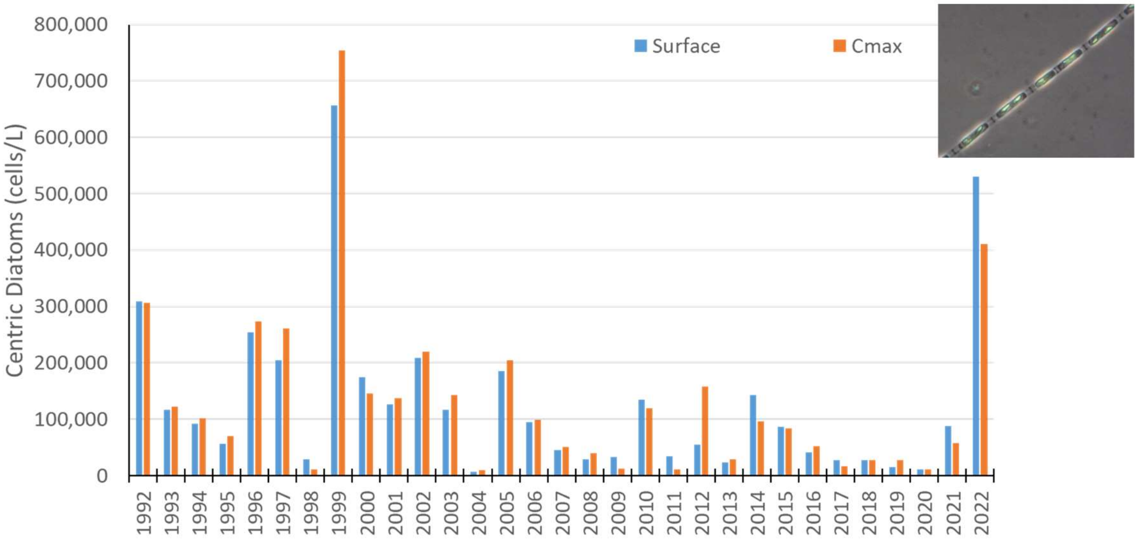

**Figure 3-12. Total abundance of centric diatoms, 1992–2022.** Blue bars are abundances near the surface; orange bars art abundances at the depth of maximum chlorophyll concentrations (Cmax). The large peak in 1999 was primarily *Thalassiosira*; the peak in 2022 was largely *Skeletonema*. Photo credit David Borkman, Rhode Island Department of Environmental Management, Providence, Rhode Island.

Pennate diatoms also bloomed in March, including the potentially toxic genus *Pseudo-nitzschia*. Some *Pseudo-nitzschia* species produce domoic acid, a neurotoxin that causes amnesic shellfish poisoning (ASP), a life-threatening illness in seabirds, marine mammals, and humans that consume contaminated shellfish. Historically, ASP has not caused shellfish closures in Massachusetts or Cape Cod Bays, and there were no closures in 2022. *Pseudo-nitzschia* was particularly numerous at coastal stations, reaching a maximum abundance of 680,000 cells per liter at Station F13 off Scituate, Massachusetts, but it was not found at the mouth of Boston Harbor or at Cape Cod Bay stations. Maximum abundance at some coastal and nearfield stations was the highest measured by the monitoring program. However, the species found was *Pseudo-nitzschia delicatissima*, which is not known to be a major toxin-producing species, and the Massachusetts Division of Marine Fisheries, which monitors shellfish, detected no ASP toxin.

Dinoflagellates were also more abundant in 2022 than in recent years, dominated by the genus *Prorocentrum*, the genus *Tripos* (formerly *Ceratium)*, and *Karenia mikimotoi*. Throughout the monitoring program, dinoflagellate abundance has been cyclic, increasing and decreasing on approximately 11-year natural cycles. The small species *Prorocentrum minimum* bloomed in May. This species has been known to produce toxins but has not been considered a nuisance species in Massachusetts Bay. *Tripos* species were present in the summer and fall. *Karenia mikimotoi* was present for a sixth year, after first being detected in 2017, but at lower abundance than in past years. The drivers for the cycles in dinoflagellate abundance are not yet understood.

Abundance of the potentially toxic dinoflagellate *Alexandrium catenella* was higher than in many years during the spring. Its toxin causes paralytic shellfish poisoning (PSP), a potentially deadly poison to people who consume shellfish. In 2022, the Massachusetts Department of Marine Fisheries detected PSP toxicity in Massachusetts Bay mussels on June 22. Northern Massachusetts shellfishing had already been closed by PCP toxicity, so the closure area was extended south to Plymouth, Massachusetts. The presence of toxicity also triggered *Alexandrium* Rapid Response Study surveys. Two stations were added to the already-scheduled regular June survey, which was completed on June 28, and three additional surveys of 19 stations were conducted in July.

*Alexandrium* abundance exceeded the Contingency Plan caution threshold (Figure 3-13). The highest *Alexandrium* cell count for 2022 was found at one of the additional stations added to the June survey, 10,180 cells per liter. Overall abundances during that survey were comparable to previous large blooms and decreased during the subsequent July surveys. Additional information on the Contingency Plan exceedance is presented on page 33.

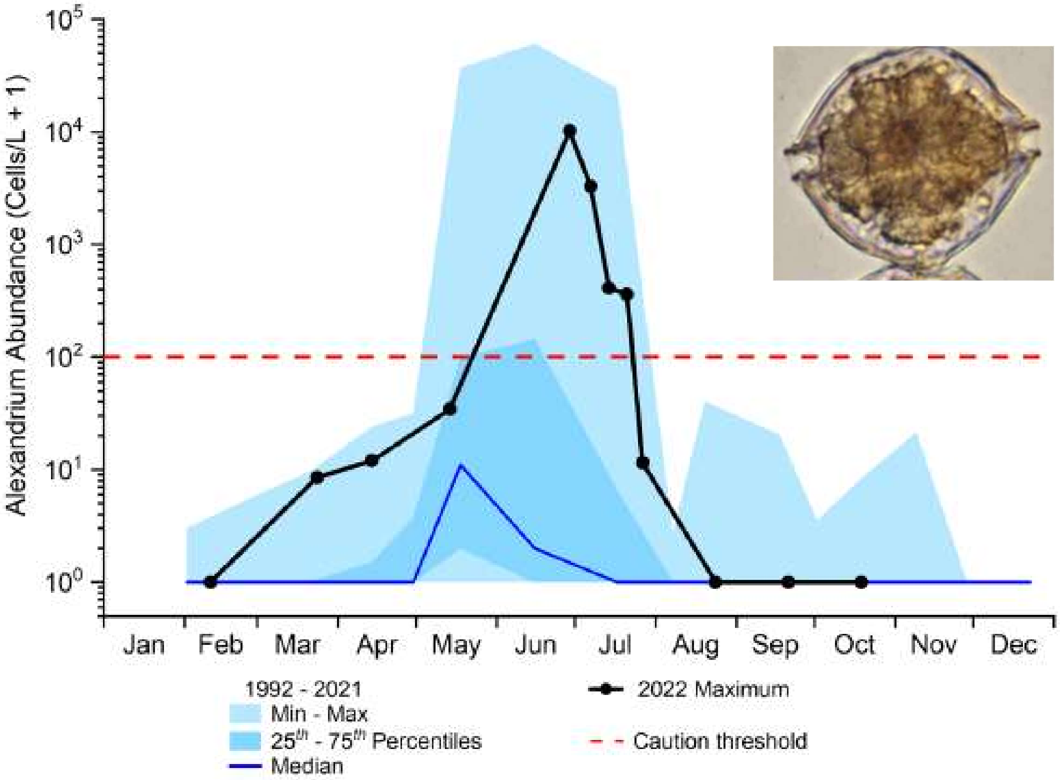

**Figure 3-13. Maximum nearfield *Alexandrium* abundance for 2022 surveys compared to prior years.** Photo credit Don Anderson, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

## Zooplankton Communities

Total zooplankton abundance and seasonal patterns were mostly typical in 2022 (Figure 3-14, Libby et al. 2023). As in past years, copepod adults and younger life stages dominated in every survey. The small copepod species *Oithona similis* continued to dominate the zooplankton community. Early life stages of copepods were particularly abundant at offshore stations in March and July.

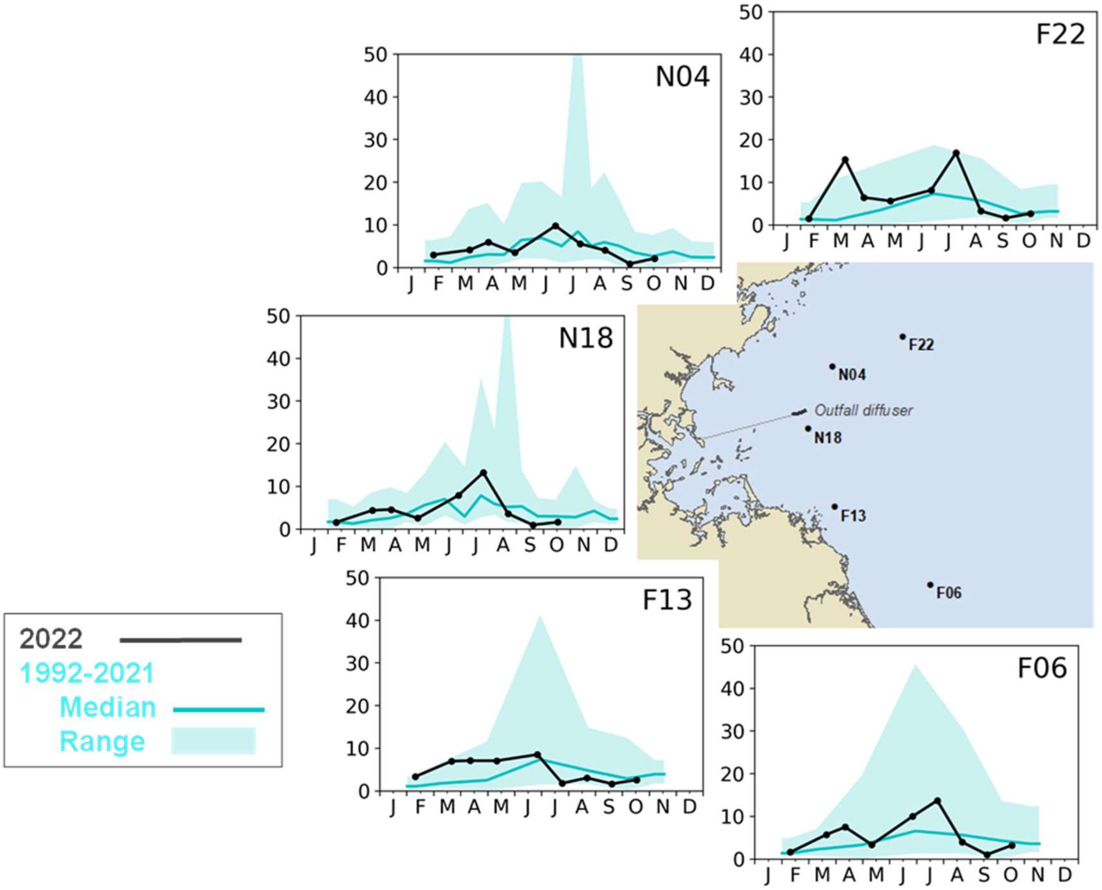

**Figure 3-14. Total zooplankton abundance (10,000 individuals per cubic meter) at selected stations in 2022 compared to prior years.** For some stations, historic data (shaded regions) extend later in the year than the current survey schedule. The high historic values in July, including those that extend beyond the y-axis, occurred in July 2015 when larval bivalves were especially abundant, as sampling took place after a major spawning event. Abundances in 2022 were close to average.

As in 2020 and 2021, July 2022 samples included high numbers of radiolarians, single-celled protozoans that build ornate silica exoskeletons. Radiolarians are more typically found in offshore waters, and their presence since 2020 appears to reflect an influx of water masses from offshore. Another group, called doliolids, which are planktonic tunicates (often called sea squirts), occurred for the first time, providing further evidence of intrusion of water from offshore.

## Stellwagen Bank National Marine Sanctuary

The NPDES permit requires MWRA to report on results relevant to Stellwagen Bank National Marine Sanctuary. Water-column Station F22 is just north of Stellwagen Basin, to the west of the sanctuary, and is representative of offshore conditions. The instrumented NERACOOS Buoy A01 is located within the sanctuary.

Ammonium levels have not increased at Station F22 since the outfall began to discharge (see Figure 3-4, page 15). Phytoplankton biomass has also not increased. There were no unusual chlorophyll levels in offshore water samples, measurements at the NERACOOS Buoy A01, or satellite imagery in 2022. No effects on chlorophyll levels in the offshore areas of Massachusetts Bay, including the sanctuary, were predicted as a result of moving the discharge from Boston Harbor to the bay, and none have been measured.

Dissolved oxygen concentrations and percent saturation in the deep water at Station F22 in Stellwagen Basin did reach low levels in the fall, failing to meet the Contingency Plan warning thresholds. These results have not been attributed to the outfall and are discussed further on page 30, below. Data from the NERACOOS Buoy A01 (which are not used to calculate Contingency Plan threshold parameters) showed the decline during the stratified season and also documented the rapid return to oxygenated conditions following fall mixing events (Figure 3-15).

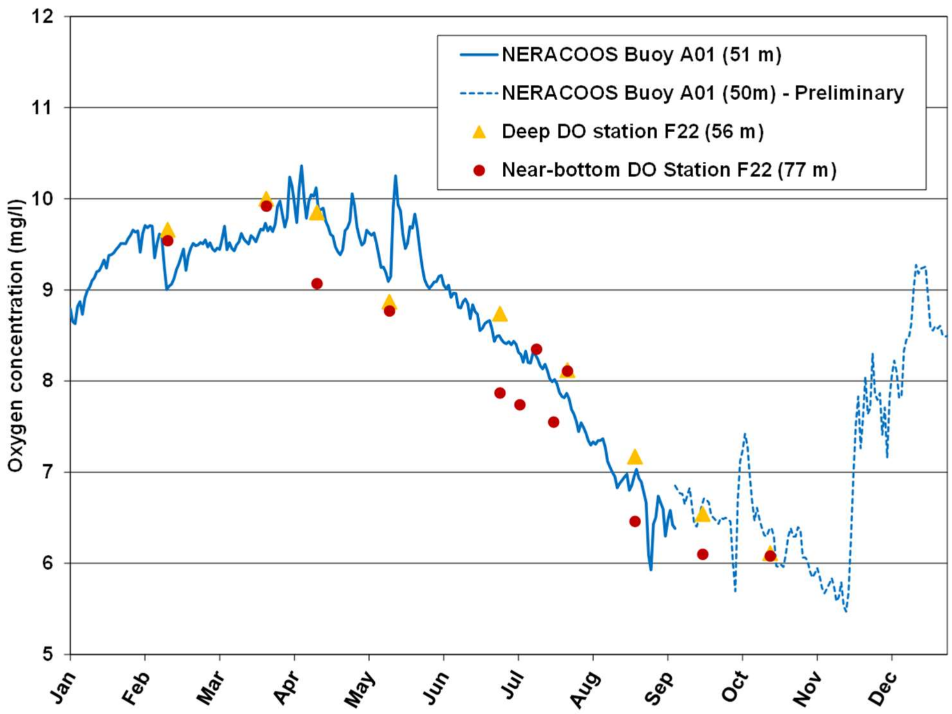

**Figure 3-15. Dissolved oxygen concentrations at the NERACOOS Buoy A01 (lines) and at nearby deepwater MWRA survey Station F22 (symbols) in 2022**. Dissolved oxygen concentrations reached low levels in 2023 but rapidly increased following the late fall and early winter mixing events, after the final MWRA survey of the year. The state water quality standard for dissolved oxygen is 6.0 mg/L.

# Boston Harbor Water Quality

Water quality in Boston Harbor greatly improved during the decades of the Boston Harbor Project, and those advances remained evident in 2022. Perhaps the most dramatic improvement in Boston Harbor was the immediate decrease in ammonium levels, which dropped precipitously in 2000 after the effluent discharge was diverted from the harbor to the bay, and have remained low. The decreases in nutrient inputs have been accompanied by decreases in primary production and phytoplankton biomass, an abatement of the harbor's historic high level of eutrophication (Werme et al. 2018, Taylor et al. 2020).

Sewage-related bacterial contamination has also declined, no longer spiking during years with heavy rain (Figure 3-16). Concentrations of the sewage-indicator bacteria *Enterococcus* began to decline when sludge discharges to the harbor ended in 1991. Subsequent upgrades to Deer Island Treatment Plant and the stormwater system have continued improvements. While bacteria concentrations remain routinely higher in the western part of the harbor, which is closer to river and stormwater runoff than the western harbor, all parts of the harbor meet state standards for swimming.

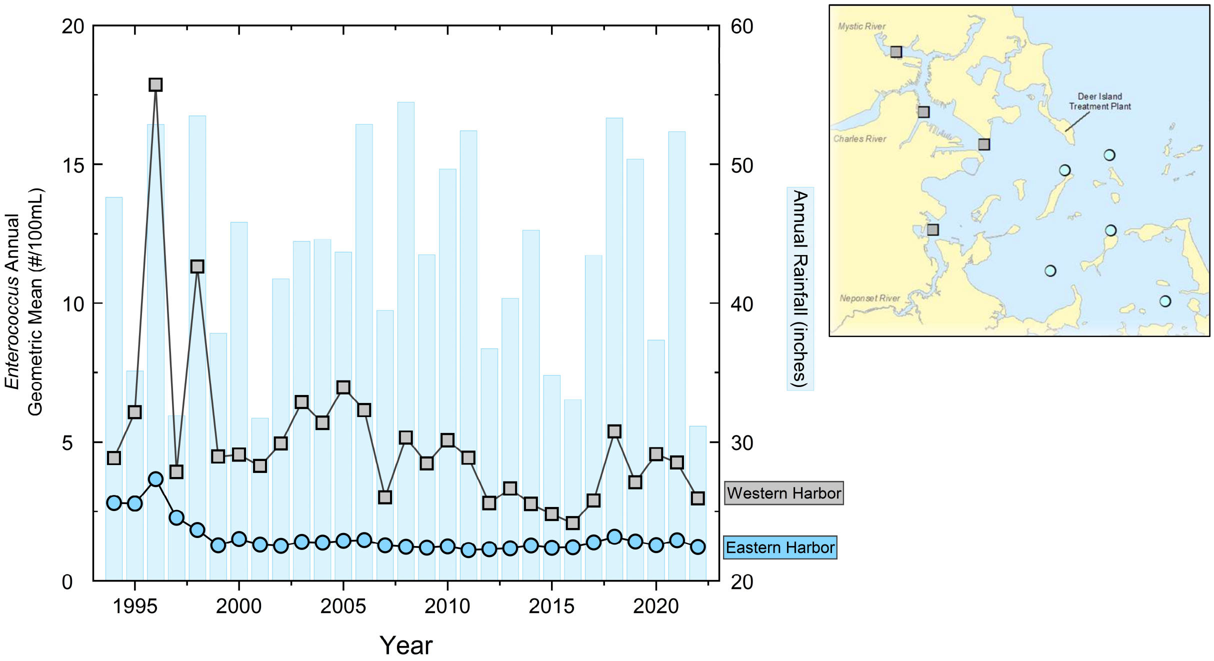

**Figure 3-16. *Enterococcus* in Boston Harbor, 1994–2022.** Western Harbor stations are close to river mouths and urban stormwater. High *Enterococcus* concentrations in 1996 and 1998 correlated with high rainfall. Subsequent high-rainfall years have not had similar spikes, and Boston Harbor meets state standards for swimming.

## Water-Column Contingency Plan Thresholds

There were exceedances of four water-column thresholds in 2022, including exceedances for dissolved oxygen parameters in September and October and exceedance of the abundance threshold for the nuisance algal species *Alexandrium catenella* in June and July (Table 3-1). Oxygen threshold exceedances included nearfield dissolved oxygen concentration and Stellwagen Basin concentration and percent saturation. *Alexandrium* presence was first noted by measurements of PSP toxicity by the Massachusetts Department of Marine Fisheries on June 22, and the threshold exceedance was determined by cell counts in eight of ten nearfield samples on June 28.

**Table 3-1. Contingency Plan threshold values and 2022 results for water-column monitoring.** "Nearfield" refers to the five stations closest to the outfall, where effects might be detected, if they were to occur.

| Parameter | Baseline | Caution Level | Warning Level | 2022 Results |
|---|---|---|---|---|
| **Dissolved oxygen*** | | | | |
| Nearfield concentration | 6.05 mg/L | <6.5 mg/L | <6.0 mg/L | 5.85 mg/L |
| Nearfield percent saturation | 65.3% | <80% | <75% | 66.6% |
| Stellwagen concentration | 6.23 mg/L | <6.5 mg/L | <6.0 mg/L | 6.08 mg/L |
| Stellwagen percent saturation | 67.2% | <80% | <75% | 65.4 % |
| Nearfield depletion rate | 0.024 mg/L/d | >0.037 mg/L/d | >0.049 mg/L/d | 0.027 mg/L/d |
| **Chlorophyll** | | | | |
| Annual | 72 mg/m$^2$ | >108 mg/m$^2$ | >144 mg/m$^2$ | 52.5 mg/m$^2$ |
| Winter/spring | 50 mg/m$^2$ | >199 mg/m$^2$ | None | 623.3 mg/m$^2$ |
| Summer | 51 mg/m$^2$ | >89 mg/m$^2$ | None | 42 mg/m$^2$ |
| Autumn | 90 mg/m$^2$ | >239 mg/m$^2$ | None | 50.6 mg/m$^2$ |
| **Nuisance algae nearfield *Pseudo-nitzschia*** | | | | |
| Winter/spring | 6,735 cells/L | >17,900 cells/L | None | 502 cells/L |
| Summer | 14,635 cells/L | >43,100 cells/L | None | 5,770 cells/L |
| Autumn | 10,050 cells/L | >27,500 cells/L | None | 1,280 cells/L |
| **Nuisance algae nearfield *Alexandrium catenella*** | | | | |
| Any nearfield sample | Baseline maximum 163 cells/L | >100 cells/L | None | 10,180 cells/L |
| PSP toxin extent | NA | New incidence | None | No new incidence |

*Dissolved oxygen caution and warning levels represent numerical criteria, with the caveat "unless background conditions are lower." Results are therefore compared to the baseline rather than to the caution and warning levels.

PSP = paralytic shellfish poisoning

NA = not applicable

## Dissolved Oxygen Exceedances

The Contingency Plan includes caution and warning thresholds for concentrations, percent saturation, and the rate of oxygen depletion during the summer months at the nearfield stations close to the outfall and in Stellwagen Basin. Those stations close to the outfall would be most likely to show an effect of the outfall, while the thresholds in Stellwagen Basin ensure that there are no adverse effects on the Stellwagen Bank National Marine Sanctuary.

The thresholds were developed in the mid-1990s and were based on the established Massachusetts regulatory standards of the time. For example, the warning threshold for concentration was set at the state standard, 6.0 milligrams per liter, and the caution threshold somewhat higher, 6.5 milligrams per liter. However, for some parameters, baseline levels were lower than the standards, so in those cases, the Contingency Plan directs that monitoring results be compared to the baseline rather than the standards. Baseline oxygen concentrations in both the nearfield and Stellwagen Basin were lower than the 6.5 milligram per liter caution threshold.

In the intervening years, regulators have recognized that marine organisms remain fully protected at lower oxygen levels than the stringent standards of the 1990s. Some New England states (but not Massachusetts) and New York have relaxed their regulatory standards, and standards for oxygen concentrations now range from 4.8 to 5.0 milligrams per liter.

Percent saturation levels were also based on the Massachusetts standard of the 1990s, but measurements were lower than the caution levels in seven of eight baseline years, 1992–1999, and also in 2000, the year that the Massachusetts Bay outfall began to discharge. No further excursions below the caution thresholds occurred until 2021 (Figure 3-16). Massachusetts dropped percent oxygen saturation from its state standards in 2008, after research showed that percent saturation was not strongly associated with ecosystem health.

The 2022 exceedances have not been attributed to the outfall, but instead appear to be the result of widely recognized regional physical conditions, particularly warming waters, which have been broadly documented in the Gulf of Maine, and high salinity, which is also correlated with lower dissolved oxygen levels. There is no evidence that increased nutrient inputs, either from the outfall or other sources, have fueled algal blooms that could result in lower dissolved oxygen measurements.

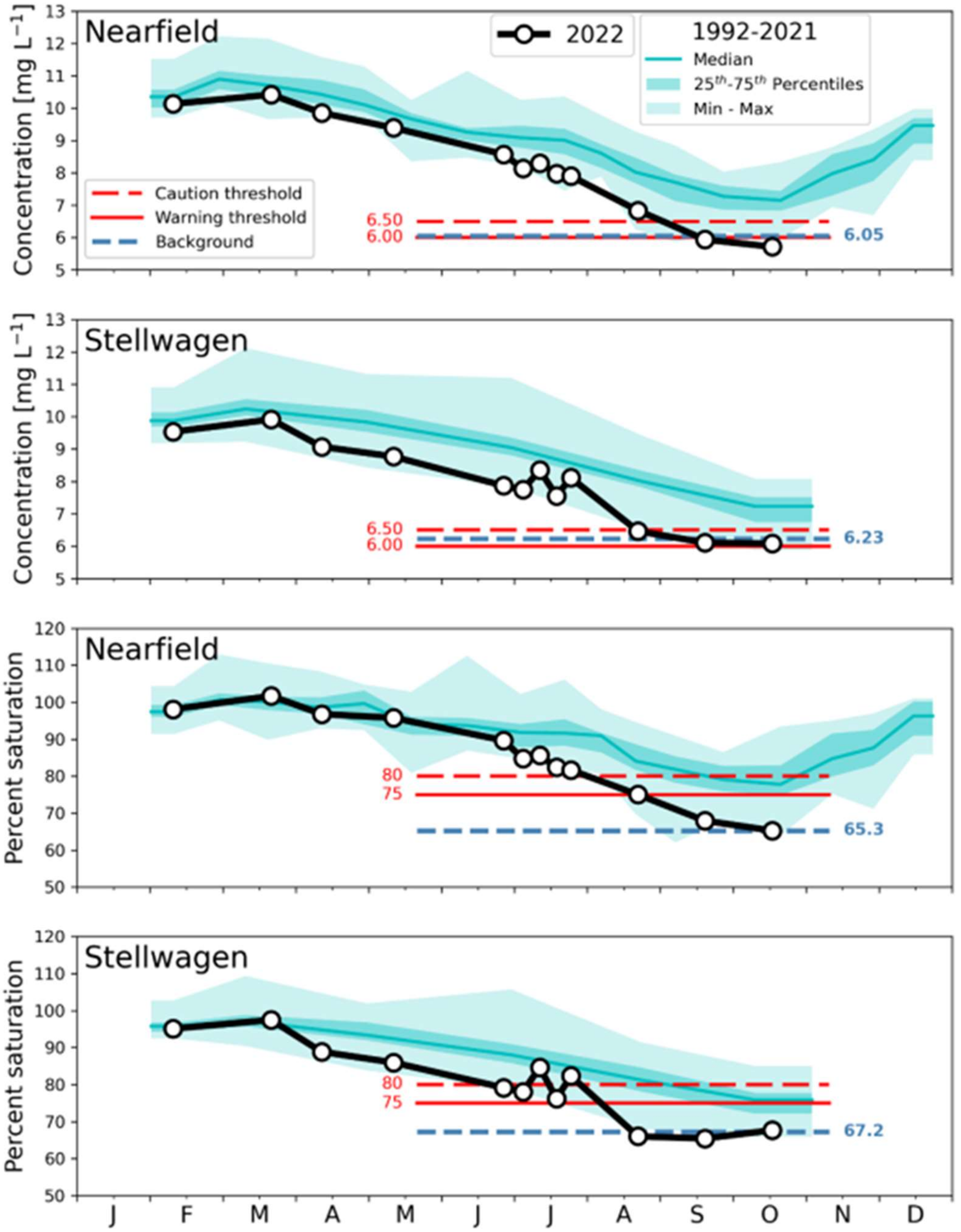

**Figure 3-16. Bottom dissolved oxygen concentrations (top) and percent saturation (bottom) in the nearfield and Stellwagen Basin, 2022**. Nearfield = the five stations closest to the outfall where effects might be expected to occur.

A simple regression model developed during baseline monitoring shows the relationship between temperature, salinity, and dissolved oxygen minima in nearfield bottom waters (Geyer et al. 2002). For 2022, the model predicted even lower dissolved oxygen concentrations than were measured, based on both the high temperatures and high salinity (Figure 3-17). The model had good agreement with observed minima during the baseline and the first years after the Massachusetts Bay outfall began to discharge. Discrepancies between the observed and modeled results in 2015–2018 were likely due to changes in wind patterns. The upwelling-favorable winds in 2022 were more similar to those earlier monitoring years, and the agreement with the model was comparable to those earlier years.

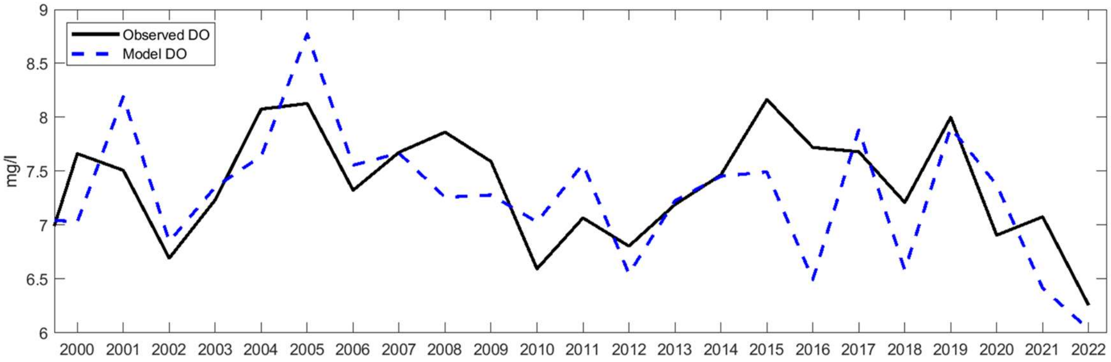

**Figure 3-17. Results of a simple regression model using temperature and salinity data to predict dissolved oxygen minima in the nearfield.** Because both temperature and salinity were high in 2022, the model predicted an even lower dissolved oxygen minimum than was observed.

Many scientists both within and outside the MWRA monitoring program are studying increasing water temperatures in Massachusetts Bay and have found an apparent shift to earlier warming in April and May. No long-term trends in river inflow and resulting variations in salinity have been detected. MWRA is paying close attention to the ongoing research into understanding effects of climate changes on ocean water quality in the region and will continue to evaluate results in that context.

### *Alexandrium catenella* Abundance Exceedance

*Alexandrium catenella* occurs regularly in Massachusetts Bay, typically peaking in abundance in May and June. *Alexandrium* blooms were first documented in Maine in the 1950s and in Massachusetts Bay in the early 1970s. Blooms were common in the 1970s and 1980s, followed by a lull in the 1990s and early 2000s.

When the water-sample threshold for *Alexandrium* abundance was set at 100 cells per liter, the Outfall Monitoring Science Advisory Panel recognized that blooms were patchy and unpredictable, so the panel also endorsed an alternative threshold based on new geographic extent of PSP toxin in shellfish. The cell-count caution threshold (there is no warning threshold) was not exceeded in the first five years after the outfall began to discharge to Massachusetts Bay, but it has been exceeded ten times since 2005, including in 2022 (Figure 3-18). The threshold for new incidence of PSP toxin, has never been exceeded.

Massachusetts Bay blooms have typically originated from cyst beds found to the north of Massachusetts Bay, along the coast of Maine (Anderson et al. 2014). Cysts are the dormant overwintering life stage of *Alexandrium*. Blooms in Massachusetts Bay have occurred when wind patterns are suitable for bringing water and phytoplankton into the bay from the Gulf of Maine. This pattern persisted in 2022. Cysts have, however, been detected in Massachusetts Bay as well as in coastal Maine, and in one prior year, 2021, wind patterns suggest that the bloom could have originated from a more local source. This hypothesis and its implications are being investigated by MWRA and its consultants.

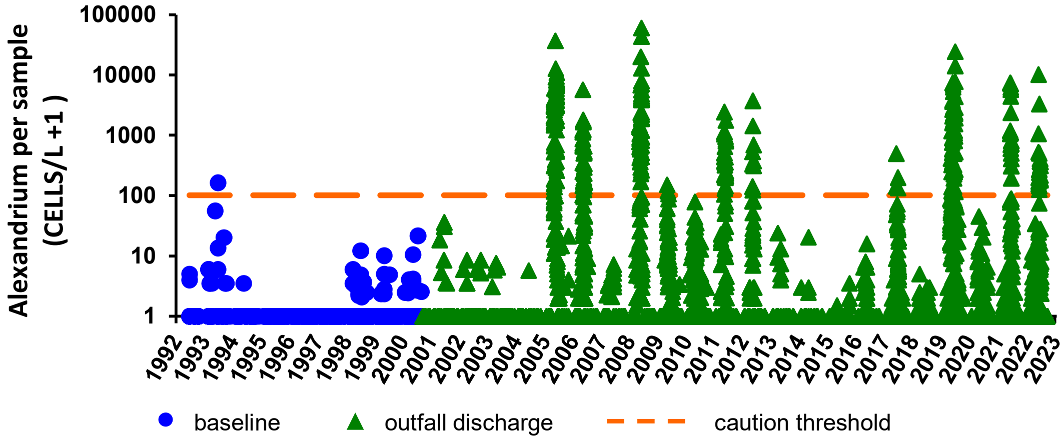

**Figure 3-18. *Alexandrium catenella* abundance, 1992–2022.** Alexandrium blooms were common in the 1970s and 1980s, less frequent in the 1990s and early 2000s, and have exceeded the caution threshold ten times since 2005.

# 4. Sea Floor

**Seafloor monitoring assesses the health of habitats and communities**
MWRA's continued seafloor monitoring includes assessments of sediment characteristics and animals living in soft- and hard-bottom communities. The initial concerns for the sea floor ecosystem, such as potential eutrophication or accumulations of toxic contaminants in the sediments have been disproven by years of monitoring. There have not been any changes to the seafloor animal communities outside natural and typical cycles.

Seafloor monitoring assesses potential outfall effects on the health of the sandy and finer-grained soft-bottom and rocky hard-bottom habitats of Massachusetts Bay. Soft-bottom surveys are conducted annually, while photographic and video assessments of the hard-bottom areas occur at three-year intervals, most recently in 2023. (Those 2023 results are currently being analyzed and will be presented in next year's outfall monitoring overview.) A separate program in Boston Harbor includes annual soft-bottom surveys and photographic sediment-profile imagery.

In August 2022, MWRA sampled 14 soft-bottom stations for the analysis of grain-size distribution, the effluent tracer *Clostridium perfringens* spores, total organic carbon, and infauna (animal) abundance and species composition (Figure 4-1). The stations included four "inner nearfield" stations located within two kilometers of the outfall; a second set of six "outer nearfield" stations in western Massachusetts Bay somewhat farther from the outfall; one station in the "transition" area between Boston Harbor and the nearfield; and three "farfield" reference stations in Massachusetts and Cape Cod Bays. For the purposes of testing Contingency Plan thresholds for the sea floor, "nearfield" includes both nearfield groups and the transition station, for a total of 11 stations. (Note that water-column and seafloor monitoring sample different stations and have somewhat different definitions of near- and farfield.)

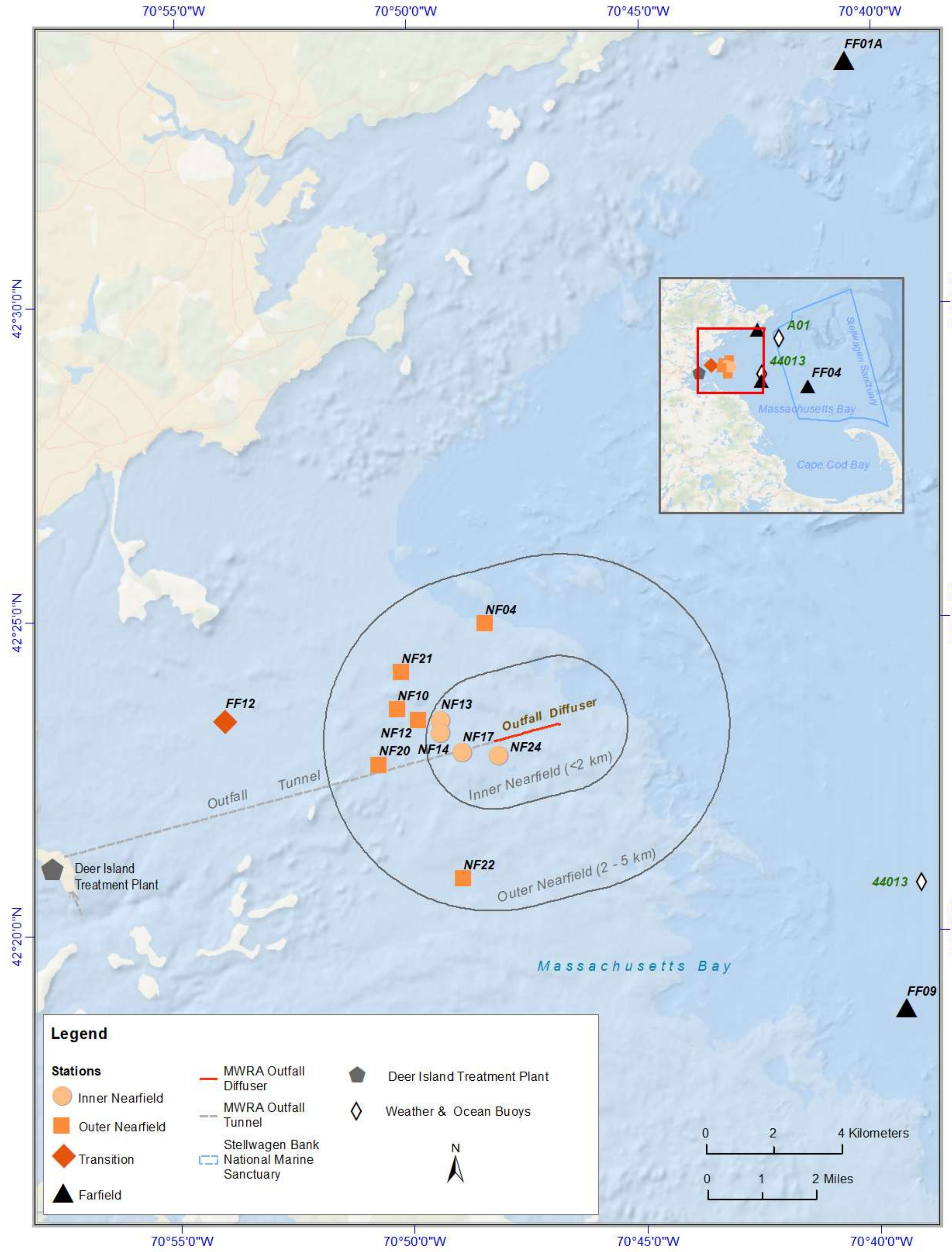

**Figure 4-1. Soft-bottom monitoring stations.** The inset shows the three farfield stations, located at distance from the outfall. Also shown are the instrumented buoys, the MWRA outfall diffuser, and Stellwagen Bank National Marine Sanctuary.

## Sediment Characteristics and Tracers

As in past years, sediment grain-size distributions in 2022 varied broadly, ranging from silt and clay at some stations (particularly Station FF04 within Stellwagen Basin offshore from the outfall) to almost entirely sand at others (Nestler et al. 2023). Within individual stations, sediment textures have remained generally stable over the years of monitoring, with occasional changes following large storms.

*Clostridium perfringens* is an anaerobic bacteria species found in the digestive tracts of humans and other mammals. In the presence of oxygen, it forms persistent resting spores, and those spores provide a sensitive tracer of sewage effluent. In 2022, as in other years, it was possible to detect elevated abundance of *Clostridium* spores at some stations located closest to the outfall (Figure 4-2). In most years, *Clostridium* spore concentrations have been elevated at stations located within two kilometers of the outfall. Unusually, spore concentrations were also higher at two of the reference stations quite far from and out of range of potential outfall influence, as much as four times higher than past measurements. A review of field and laboratory procedures found no anomalies in sample handling or analysis, and these unexpectedly higher concentrations remain under investigation.

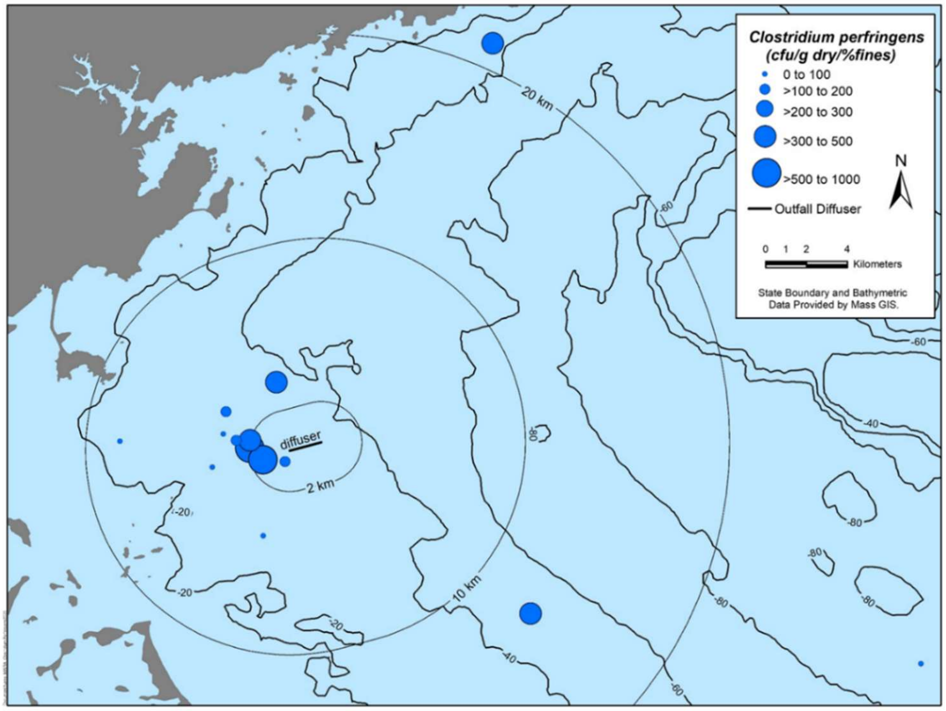

**Figure 4-2. Concentrations of the effluent tracer *Clostridium perfringens* spores in 2022.** Concentrations represent spore counts (cfu, colony forming units) normalized to the percent of the sediment made up of fine silts and clays. As anticipated during outfall planning, *Clostridium* spore concentrations are elevated at stations closest to the outfall.

Percent total organic carbon content was consistent with past results, with no increased organic carbon from sewage effluent at stations near the outfall (Figure 4-3). In general, stations with finer sediments, such as Station FF04, offshore from the outfall in Stellwagen Basin, have higher mean total organic carbon concentrations, while stations with coarser sediments, such as Station NF17 just to the south of the outfall have lower concentrations. Overall, the total organic carbon data continue to show no signs of organic enrichment from the discharge, consistent with predictions made before the outfall began to discharge and also consistent with a detailed special study of sediment metabolism, which was completed in 2010 (Tucker et al. 2010, Tucker et al. 2014).

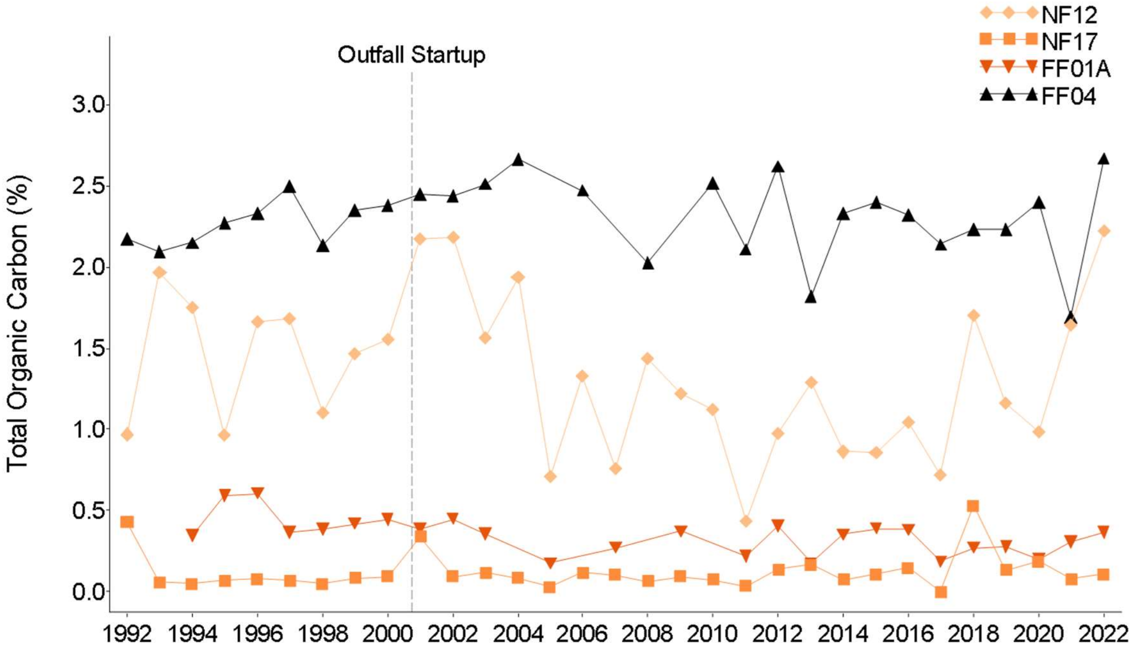

**Figure 4-3. Total organic carbon at selected stations, 1992–2022.** Station NF12 is more than two kilometers northwest of the outfall; and NF17 is in close proximity (less than two kilometers) and southwest of the outfall, where the effects of the discharge might be expected but have not been found. Station FF01A is the northern reference station and FF04 is in Stellwagen Basin; both are farther than 20 kilometers from the outfall. No effects of the discharge have been observed at any station; total organic carbon content is correlated with sediment type rather than distance from the outfall.

# Soft-bottom Communities

A variety of small animals live in the sediments, including segmented polychaete worms, mollusks, and crustaceans. MWRA monitors abundance and species composition of animals living within soft-bottom communities to document any changes that might be associated with the outfall discharge. Effluent discharges have been known to change species makeup and decrease biodiversity.

The 14 soft-bottom samples collected and analyzed in 2022 yielded 22,538 organisms, classified into 173 species and 22 other discrete taxonomic groups of animals that could not be identified to the species level (Nestler et al. 2023). Total abundance of organisms was slightly lower in 2022 than in 2021 in both nearfield station groups and at the transition station between Boston Harbor and the outfall (Figure 4-4). Most of the several diversity measures calculated for the samples were also slightly lower than in 2021, but all measurements remained within the ranges found throughout the monitoring program. Minor changes and cycles are characteristic of seafloor communities in the region.

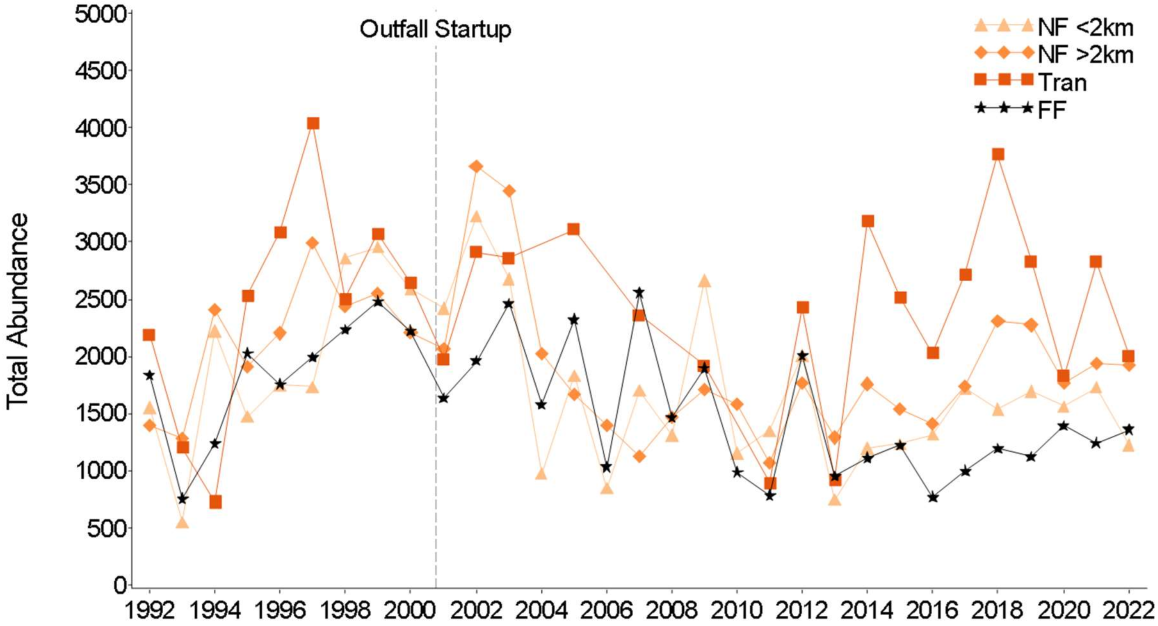

**Figure 4-4. Total abundance of soft-bottom organisms by region, 1992–2022**. Regions include the nearfield within two kilometers of the outfall, the outer nearfield farther than two kilometers from the outfall, the transition area between Boston Harbor and the outfall, and the farfield.

Small polychaete worms (sometimes known as bristle worms; for example, Figure 4-5), dominated at most stations, as they have for the duration of the monitoring program. These segmented worms are among the most common marine organisms. The polychaete *Prionospio steenstrupi*, which was the numerically dominant species in 1997–2005, was slightly less abundant in 2022 than in the past several years, but remained among a group of dominant species. Other common polychaetes, including *Aricidea catherinae* and *Mediomastus californiensis*, were present in numbers comparable to those of other recent years.

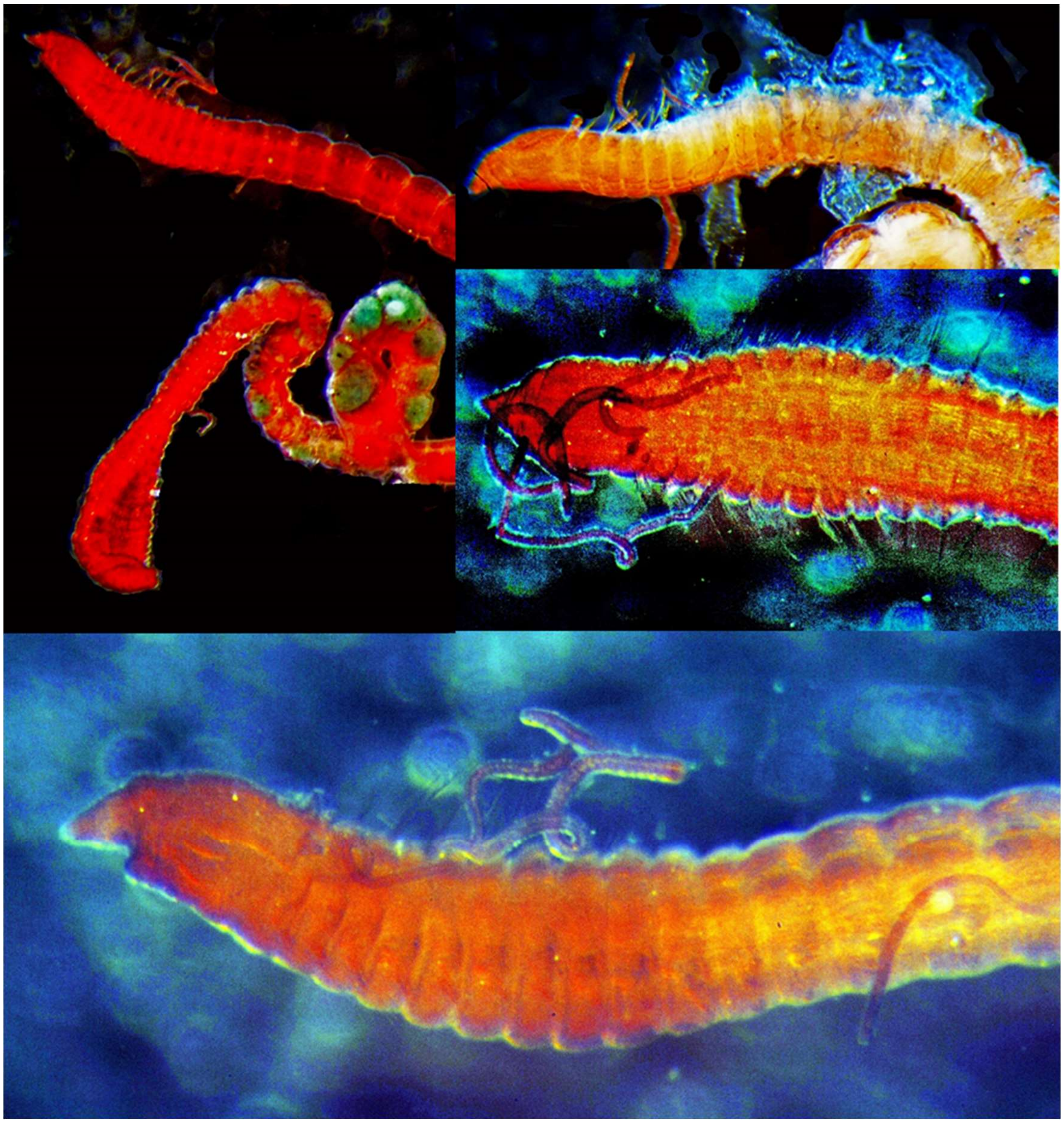

**Figure 4-5. Polychaete worms dominate the soft-bottom habitats in Massachusetts Bay.** Polychaetes can range in size from less than a millimeter to several meters; most are very small. This species, *Kirkegaardia baptistae*, is about 14 millimeters long and frequently found in fine-grained, offshore sediment. MWRA samples were used in its original description. Photo credits James A. Blake, Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts.

Community analyses continued to show no effects of the outfall on relative abundance of animals or community composition. A series of analyses assessed patterns in the soft-bottom communities over space and time and found no particular species or type of community specifically associated with the outfall.

One type of community analysis, called cluster analysis, groups stations by similarity in species composition and abundance, designating groups by numbers, which are used in further analyses and shown in the figures below. Similar to prior years, cluster analysis of the 2022 samples identified two main groups (I and II) and one “outlier” group (III). Group I was dominated by crustaceans and polychaete worms. Group II included a greater abundance of polychaetes and also mollusks; it could be further subdivided into three subgroups (IIA, IIB, and IIC). As in past years, the outlier group occurred only the offshore station located within Stellwagen Basin, which has consistently supported a unique polychaete community, typical of a larger number of deepwater, offshore stations sampled in the past.

Further analysis, called ordination analysis, provides a picture of how closely the bottom communities identified in the cluster analysis relate to each other. The 2022 ordination analysis continued to show no indication of any relation of community composition to proximity to the outfall (Figure 4-6). Both main groups I and II included stations located at various distances and directions from the outfall. Group II included stations in both nearfield station groups, the transition station between the harbor and the outfall, and farfield stations to the northeast and southeast of the outfall.

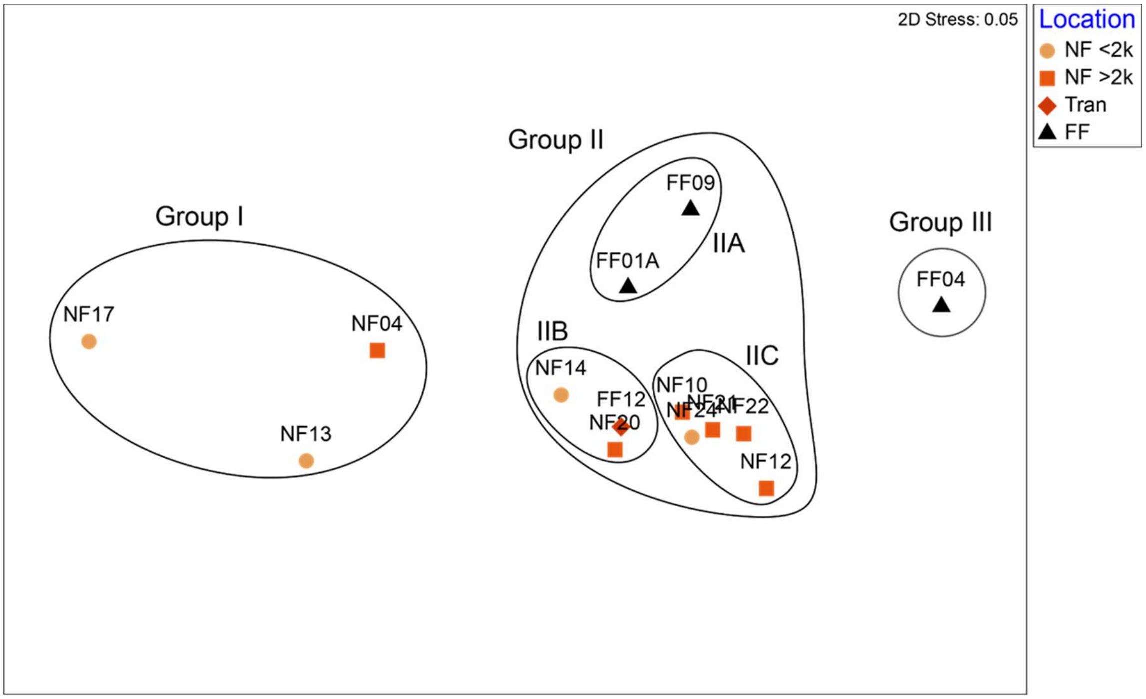

**Figure 4-6. Ordination plot of 2022 Massachusetts Bay samples by location.** The ordination analysis shows that the distance from the outfall does not correspond with bottom community composition. Each point on the plot represents one of 14 stations, and varying colors and shapes depict locations. Placement of the points indicates similarity of the communities—the nearer two points are to each other, the more similar their seafloor communities. NF<2k = stations within two kilometers of the outfall; NF >2k = stations near but more than two kilometers from the outfall; Tran = the one station between Boston Harbor and the outfall; FF = stations far from the outfall. (The 2D Stress value noted in the upper right is a measure of good confidence in the analysis.)

As in past years, further assessment of the ordination analysis demonstrated that variations in species distributions largely followed differences in sediment grain size (Figure 4-7). Water depth was another important factor in determining community structure. That is, seafloor animal communities at stations with similar sediment textures or water depths tended to be more closely related, as shown by closer proximity on the ordination plots. These results continued to validate past findings that the Massachusetts Bay sea floor is dominated by physical factors rather than by the discharge. The strong physical forces in the bay, as well as the low pollutant levels in the effluent discharge, have helped to maintain healthy soft-bottom habitats throughout Massachusetts Bay.

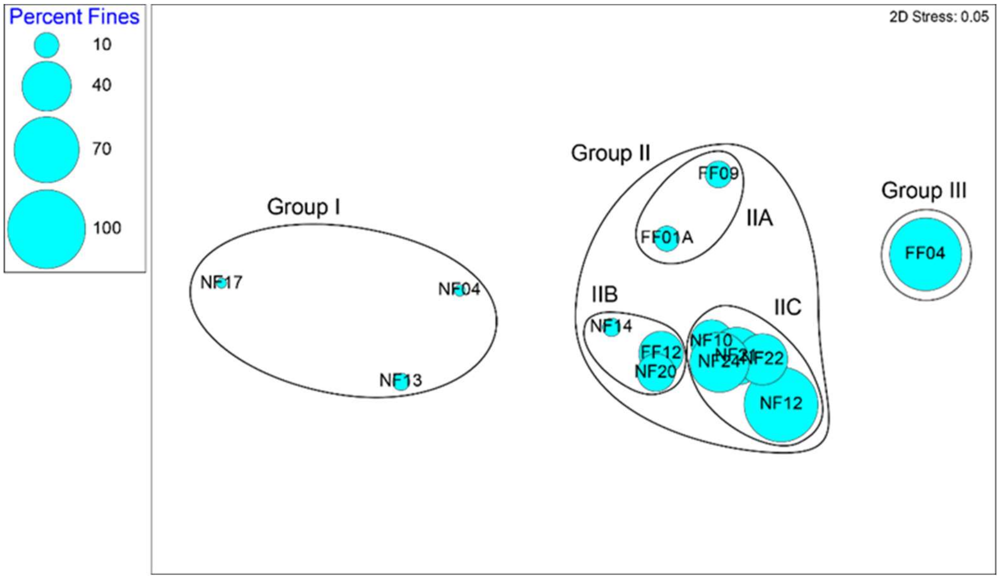

**Figure 4-7. Percent fine sediments superimposed on the ordination plot of the 2022 samples.** Combining the ordination analysis with sediment grain-size data shows that sediment texture is likely a strong driver of community composition. Data are shown as in Figure 4-6, with the size of each station marker indicating the percentage of fine sediments (percent fines). Stations with similar “percent fines” tend to be represented in the same groups. Group I included only stations with coarser sediments, and Group II subgroups reflected a range of finer-grained sediments. (The 2D Stress value noted in the upper right is a measure of good confidence in the analysis.)

Examining data over the past 31 years of monitoring, another ordination analysis demonstrated the temporal stability of the seafloor communities in Massachusetts Bay. Samples collected from selected stations in 1992–2022 showed relatively high levels of similarity within each station over the 31-year period, with individual stations remaining grouped over time (Figure 4-8).

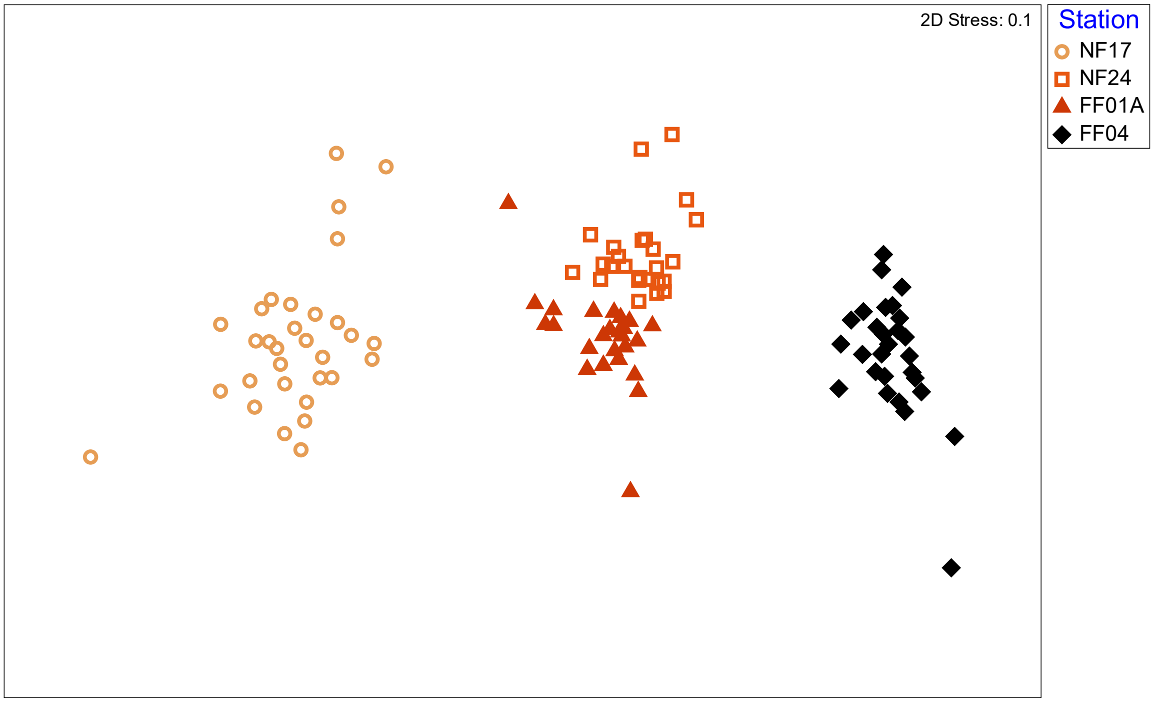

**Figure 4-8. Ordination plot of soft-bottom communities at selected stations over time, 1992–2022.** Closer proximity of the data points indicates greater similarity of the communities; each station grouped relatively closely over the 31-year period, demonstrating the stability of Massachusetts Bay sediments over time. NF17 is near (less than two kilometers) and southwest of the outfall, where the effects of the discharge might be expected but have not been found. Station NF24 is just to the south of the outfall. Station FF01A is the northern reference station. FF04 is in Stellwagen Basin. (The 2D Stress value noted in the upper right is a measure of good confidence in the analysis.)

## Stellwagen Bank National Marine Sanctuary

The NPDES permit to discharge from Deer Island Treatment Plant into Massachusetts Bay requires annual reporting on results relevant to Stellwagen Bank National Marine Sanctuary. MWRA's deepwater reference Station FF04 lies within the depositional part of the sanctuary, Stellwagen Basin, where long-term accumulation of pollutants and their effects would be expected if they were to occur.

Station FF04 is typical of the deepwater sites offshore from the outfall, representative of a larger group of stations that were monitored in earlier years of the program, and it continues to support a soft-bottom community typical of what had been found at the larger suite of deepwater stations. Communities at those stations have always shown distinct differences from those found at shallower areas, probably due to their distance from shore, as well as their depth and their fine-grained sediments (Figures 4-6 through 4-8, above). Superimposing percent grain size on the ordination plot for 2022 samples continued to show those natural differences, and the ordination plot using data from 1992–2023 further demonstrated the temporal consistency of the seafloor community at that station.

## Boston Harbor Seafloor Monitoring

While the chemistry and biology of the Massachusetts Bay sea floor have not been harmed by the outfall, conditions are much better and continue to improve in Boston Harbor, which received sewage sludge discharge until 1991 and effluent discharge until September 2000. MWRA has conducted ongoing seafloor monitoring in Boston Harbor since 1991. Each year, sediment samples are taken from nine stations, and sediment-profile images are taken at 61 stations throughout the harbor.

Sediment textures within individual harbor stations have been generally stable over time, but have ranged from mostly sand at some stations to silt and clay at others. Concentrations of total organic carbon in harbor sediments have declined over time, reflecting the lowered inputs associated with each milestone of the Boston Harbor Project.

Over the past decade, the total abundance of organisms and number of species per sample have stabilized (Figure 4-9), responses to continued and sustained improvement in seafloor habitat conditions. In 2022, samples yielded 34,325 specimens, classified into 139 species and 14 other discrete taxonomic groups. When the harbor received wastewater inputs, the bottom fauna was dominated by opportunistic species, animals that respond to inputs of nutrients and organic matter and are typical of degraded habitats. Abundances varied greatly from year to year, another characteristic of opportunistic species.

As in past years, the communities in 2022 varied along an outer-to-inner harbor gradient, reflecting the greater stream and river inputs to the inner harbor and greater tidal flushing at the outer harbor stations. Sediment-profile imaging has also confirmed the gradient and clearly documented improvements to habitat conditions throughout the harbor, showing sustained responses to each phase of the Boston Harbor Project.

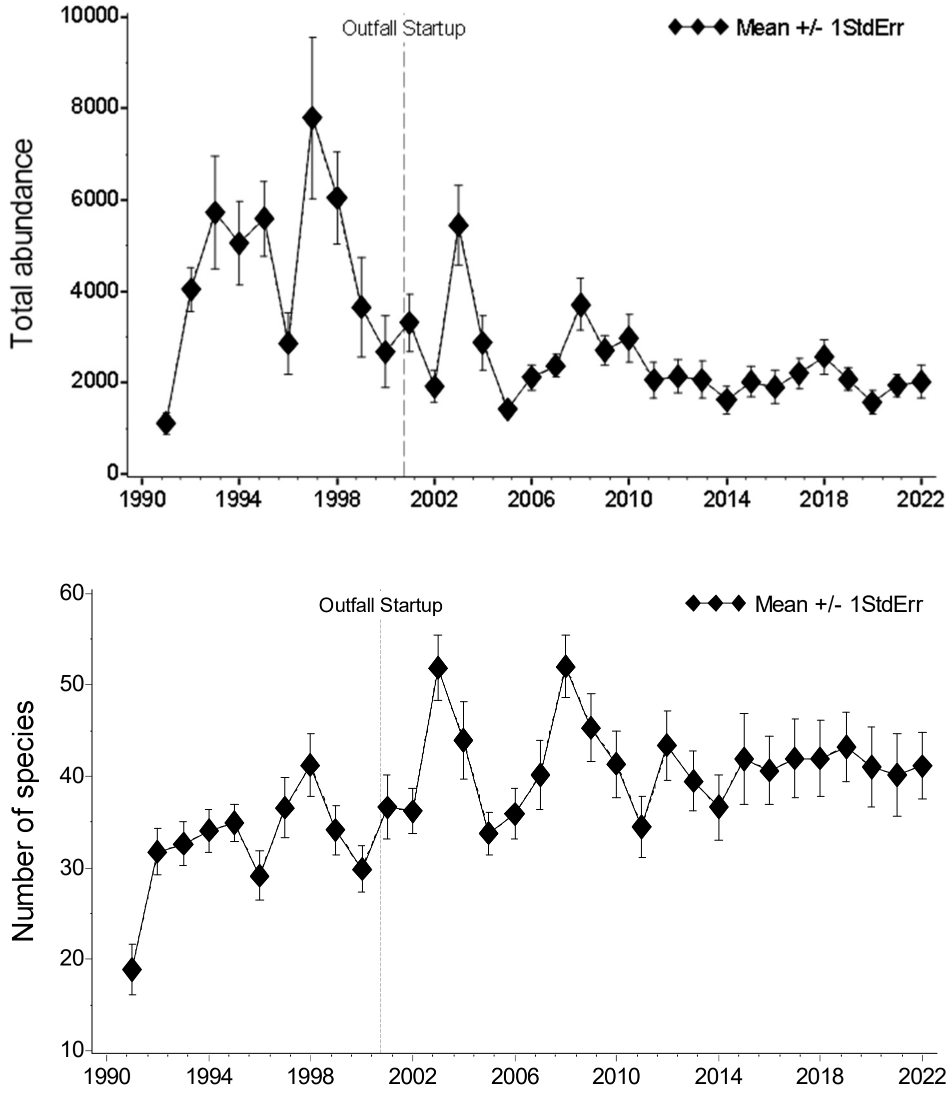

**Figure 4-9. Total abundance of soft-bottom animals (top) and number of species (bottom) per sample in Boston Harbor samples, 1991–2022.** Both numbers of organisms and numbers of species have stabilized as the harbor has recovered. Data are from eight harbor stations that have been consistently monitored since 1991. "Outfall startup" refers to the beginning of discharge through the Massachusetts Bay outfall and the end of discharge to the harbor.

Sediment-profile images depicted the continuing good conditions in 2022. There were few storms in 2021 and 2022, but physical processes continued to dominate over biological processes in shaping the shallow sediments (Figure 4-10). Prior to the mid-2000s, biological processes, such as burrows and tube mats, had a greater role, likely due to the past inputs of sewage-derived organic matter, which fueled growth of the animals that built the burrows and mats. In 2022, none of the 61 sediment-profile stations were dominated by biological processes. Sediments continued to be well-oxidized, with no evidence of excess organic matter. Eelgrass, a sign of a healthy sea floor, continued to be present at Station R08 in Deer Island Flats, near the location of the former effluent outfall.

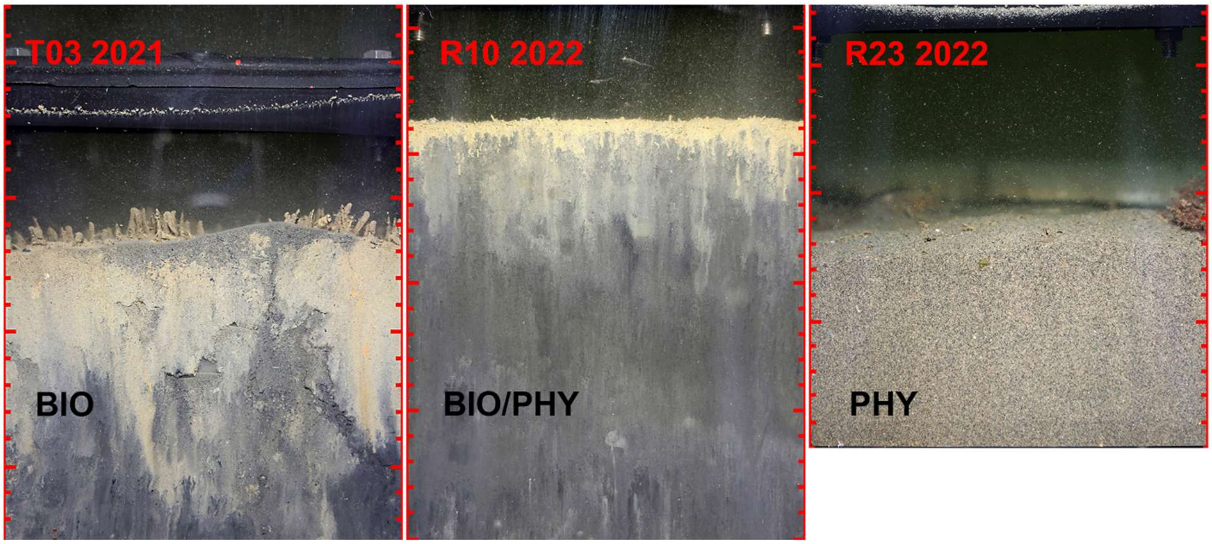

**Figure 4-10. Sediment profiles depicting biologically (BIO), physically (PHY), and mixed (BIO/PHY) dominated sediment surfaces at three stations in 2021 and 2022.** No examples of biologically dominated sediments were found in 2022. The transition from light to darker sediments in the left-most pictures reflects the transition from oxygenated sediments with depth. The right-most picture, showing sediments fully dominated by physical conditions was oxygenated throughout its depth. The red markings on the photo edges are centimeters of depth. Station T03 is south of Deer Island in President Roads; Station R10 is in the Inner Harbor; and Station R23 is in Nantasket Roads, offshore from Quincy, Hingham, and Hull Bays.

# Seafloor Contingency Plan Thresholds

There were no threshold exceedances for the seafloor Contingency Plan thresholds in 2022 (Table 4-1). For the purposes of threshold testing, "nearfield" includes stations from both nearfield groups (both nearer and farther than two kilometers from the outfall) and the station in the transition area between Boston Harbor and the Massachusetts Bay outfall.

All threshold parameters continued to confirm that Massachusetts Bay maintains persistently healthy seafloor habitats, unaffected by the outfall discharge. Number of species per sample and the diversity and evenness indices remained higher than Contingency Plan limits, while the percent opportunistic species remained far below any level of concern, only 0.02% compared to caution and warning thresholds of 10% and 25%.

**Table 4-1. Contingency Plan threshold values and 2022 results for seafloor monitoring.**

| Parameter | Baseline | Caution Level | Warning Level | 2022 Results |
|---|---|---|---|---|
| Species per sample | NA | <42.99 | None | 58.5 |
| Fisher's log-series alpha | NA | <9.42 | None | 12.2 |
| Shannon diversity | NA | <3.37 | None | 4.05 |
| Pielou's evenness | NA | <0.57 | None | 0.69 |
| % opportunists | NA | >10% | >25% | 0.02% |

NA = not applicable

# 5. Fish and Shellfish

**Fish and shellfish monitoring highlights animal health and safe seafood**

In planning for the Massachusetts Bay effluent discharge, the main concern for fish and shellfish was that chemical contaminants could directly affect bottom feeders like flounder and lobster or filter feeders such as mussels.

Winter flounder health has improved not only in Boston Harbor, but also near the Massachusetts Bay effluent outfall. Contaminant levels in flounder liver and fillet, lobster meat and digestive gland, and mussels have not increased since the outfall began to discharge. In fact, levels of many contaminants have declined, particularly near the former harbor outfalls. The good results have allowed for reductions in fish and shellfish monitoring.

Fish and shellfish are important to the regional identity and economy of Massachusetts. Fish and shellfish can also be good indicators of overall environmental health. Monitoring protects fish health and ensures safe seafood. Monitoring focuses on winter flounder, lobster, and cage-deployed blue mussels. Flounder and lobster are two important commercial and recreational species that live on the sea floor and feed on bottom-dwelling animals, likely sources for contaminant exposure. Mussels filter large volumes of water and can concentrate toxic metals and organic compounds in their tissues. Sampling locations vary by species (Figure 5-1).

MWRA monitors winter flounder health each year and conducts chemical contaminant analyses of flounder, lobster, and mussel tissues every three years, most recently in 2021. Flounder health assessment was the only monitoring activity in 2022. It measured external conditions of the fish and the presence of liver disease, including precancerous conditions and tumors.

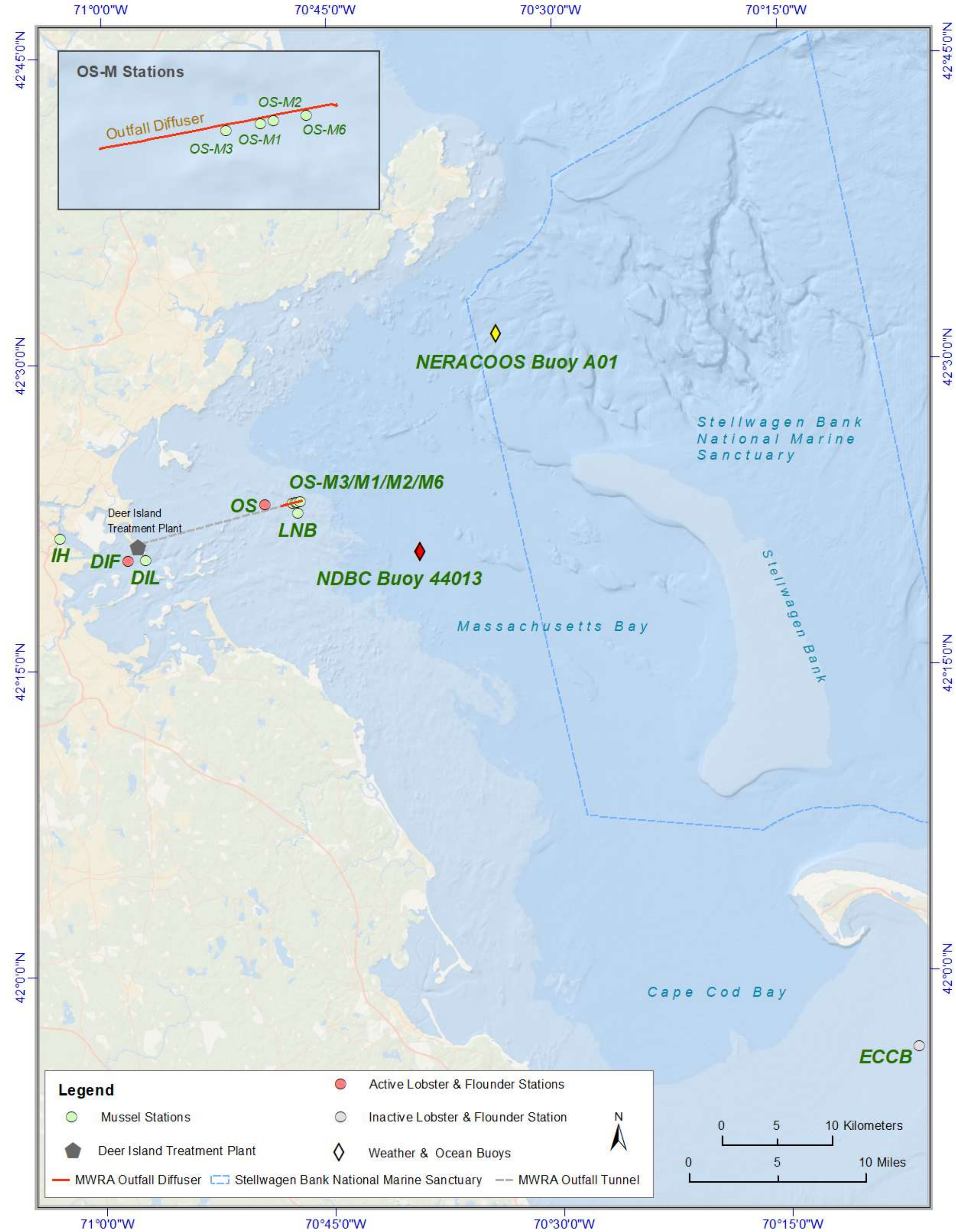

**Figure 5-1. Fish-and-shellfish monitoring stations.** IH = Inner Harbor; DIF = Deer Island Flats; DIL = Deer Island Light; OS = Outfall Site; OS-M = Outfall Site, Mussels; LNB = Large Navigation Buoy (buoy south of the outfall); ECCB = Eastern Cape Cod Bay. Also shown are the outfall, the instrumented buoys, and the Stellwagen Bank Marine Sanctuary.

In 2022, for the first time, flounder monitoring was conducted at only two sites, at the Massachusetts Bay outfall and at Deer Island Flats, near the former Boston Harbor outfall. Through 2021, fish were also collected from eastern Cape Cod Bay, which was considered a relatively pristine control site. In past years, other locations provided a greater geographic representation of the area. That past monitoring concluded that there have been no adverse effects of the relocated outfall and that instead, conditions have improved throughout the region. Consequently, a formal study with a control site was deemed no longer necessary. However, the regulatory agencies asserted a continued interest in documenting flounder health in Massachusetts Bay and sustained improvements in Boston Harbor, so MWRA continues to sample and evaluate sites at the bay outfall and Deer Island Flats.

All sampling was completed on one day in April 2022. As in past years, scientists completed external health assessments at sea and preserved livers for laboratory analysis (Moore et al. 2023; Figure 5-2).

**Figure 5-2. External assessments are made at sea, and livers are removed for laboratory analysis.** Photo credit Eric Rydbeck, Normandeau Associates, Bedford, New Hampshire.

## Flounder Characteristics

A full complement of 50 fish was collected from near the Massachusetts Bay outfall site, where the catch per unit effort was among the highest of the monitoring program. Catches at Deer Island Flats in Boston Harbor were somewhat higher in 2022 than in 2021, but despite more than three hours of trawling, the time limit designated in the work plan, only 29 fish were taken. Catches have been relatively low throughout the region for the past several years. Southern New England winter flounder populations have declined since the 1980s, possibly a result of overfishing (for example, Frisk et al. 2018). MWRA survey trawls at Deer Island Flats have also been compromised by abandoned lobstering gear and algal growth clogging the trawl net, and both those conditions hampered the 2022 catch.

Mean age of fish in 2022 ranged from 4.7 to 5.6 years, and standard length (length from the tip of the head to the base of the tail fin) ranged from 271 to 280 millimeters, within the values observed in past years. Weights were also within the typical range for the program. As is common throughout northeast coastal populations (Moore et al. 2016), the catches were dominated by females.

## Flounder Health

Measures of external condition, such as bent fin rays and occurrence and severity of fin erosion, remained variable but continued to suggest improved conditions since the 1980s and 1990s. Incidence of fin erosion, which has been associated with excess ammonium and other pollutants, remained low at both the Massachusetts Bay outfall site and Deer Island Flats. Ulcers, which are poorly understood but are observed on the bottom or "blind side" of the fish in some years, were not present in 2022.

**Winter flounder disease was a main indicator of harbor pollution in the 1990s.** Ensuring that there was no increase in disease in Massachusetts Bay was a major goal of the Boston Harbor Project, and that has been successful.

The incidence of centrotubular hydropic vacuolation (CHV), a key tumor precursor and mild liver condition associated with exposure to contaminants, was the lowest ever measured at both sites, only 4% at the Massachusetts Bay outfall (similar to 2021) and only 3.4% at Deer Island Flats (Figure 5-3). The decrease in CHV incidence at Deer Island Flats is especially impressive, as more than 75% of Boston Harbor flounder had CHV in the late 1980s. CHV incidence has been lower across all age groups in both the harbor and the bay, alleviating the concern prior to the outfall relocation that there could be increased liver disease in Massachusetts Bay. In the few fish where CHV has been found, severity of the condition has also declined.

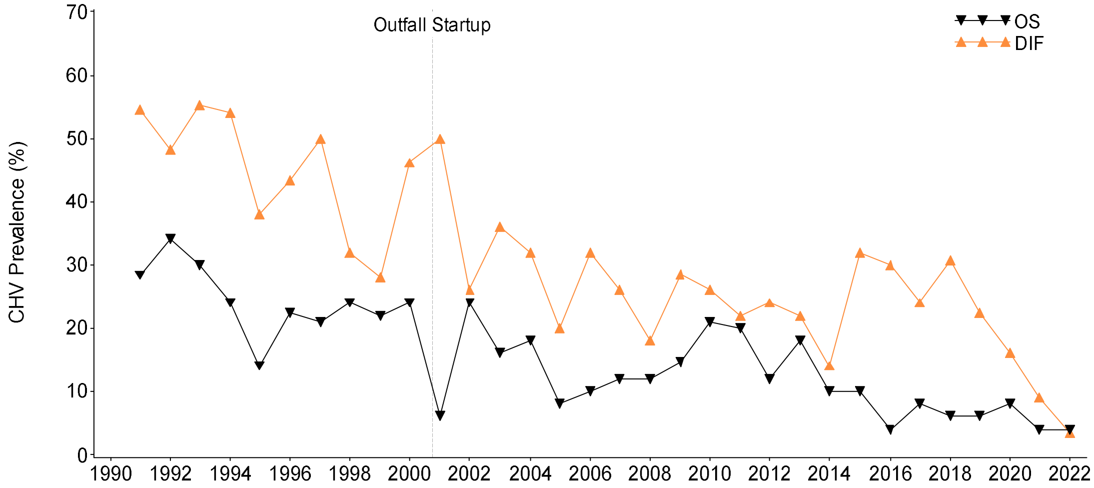

**Figure 5-3. Annual prevalence of the tumor precursor centrotubular hydropic vacuolation (CHV) in winter flounder near the Massachusetts Bay outfall site and at Deer Island Flats, 1991–2022.** CHV incidence has declined throughout the region. OS = Outfall Site, DIF = Deer Island Flats

Liver tumors or neoplasia, which were present in up to 10% of flounder from Boston Harbor in the 1980s, remained absent, as they have since 2004. Tumors have never been found in fish taken from near the Massachusetts Bay outfall site (Figure 5-4; see also Moore et al. 2018).

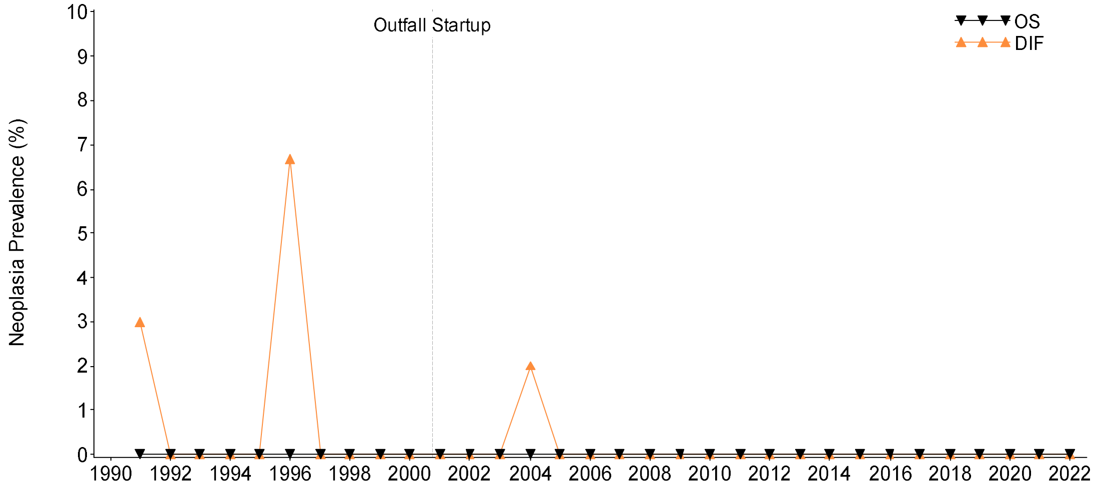

**Figure 5-4. Annual prevalence of neoplasia (liver tumors) in winter flounder, 1991–2022.** OS = Massachusetts Bay Outfall Site; DIF = Deer Island Flats. No tumors have ever been recorded in fish taken from near the Massachusetts Bay outfall.

## Winter Flounder Contingency Plan Thresholds

There was no Contingency Plan threshold exceedance for the only parameter measured in 2022, flounder liver disease, measured as prevalence of CHV, in fish caught near the Massachusetts Bay outfall (Table 5-1). CHV incidence remained less than 10% of the caution threshold and also far less than levels found during the baseline period before the Massachusetts Bay outfall began to discharge.

**Table 5-1. Contingency Plan threshold values and 2022 results for winter flounder**

| Parameter | Baseline | Caution Level | Warning Level | 2022 Results |
|---|---|---|---|---|
| **Flounder disease** | | | | |
| Liver disease (CHV) | 24.4% | >44.9% | None | 4% |

CHV = centrotubular hydropic vacuolation, a liver tumor precursor associated with degraded habitats

# 6. Special Studies

Besides monitoring the effluent and the water column, sea floor, and fish and shellfish in Massachusetts Bay, MWRA conducts special studies in response to specific permit requirements, scientific questions, and public concerns. This year's report focuses on both specific studies and other ongoing activities, including MWRA notifications of unanticipated or partially treated sewage discharges, data quality control and management, and the most recent update of the Bays Eutrophication Model, a permit-required water quality and hydrodynamics model that simulates the processes affecting water quality throughout Massachusetts Bay and the surrounding waters.

## Notification of Sewage Discharges

In January 2021, Massachusetts passed "an Act promoting awareness of sewage pollution in public waters, ensuring public notification of unanticipated or inadequately treated sewage discharges." Under this law and regulations issued by the Massachusetts Department of Environmental Protection in 2022, MWRA must make public notifications of "blending events," combined sewer overflows (CSOs), and sanitary sewer overflows (SSOs).

Blending occurs when partially treated effluent (primary-treated flow) is blended into fully treated effluent (primary- and secondary-treated flow) before rejoining at the disinfection basin, where all effluent is disinfected and dechlorinated before discharge. Blending occurs only during heavy rainfall, when inflow to the treatment plant exceeds what the secondary treatment process is designed to handle. Diverting some flow around secondary treatment prevents street flooding and backups into homes and businesses. Blending also protects the secondary treatment system, preventing washout of the beneficial bacteria that are part of that process.

CSOs occur in sewer systems where storm sewers connect to sanitary sewers. In the MWRA service area, these combined systems are found in Boston, Cambridge, Chelsea, and Somerville. During especially large rainstorms, the stormwater and sewage flow that exceeds the sewer capacity is discharged through designated outfalls in the stormwater system. These local municipal and MWRA CSO discharges prevent overloading the treatment plant and avoid backups to streets, homes, and businesses. Controlling and eliminating CSO discharges has been a major part of MWRA's Boston Harbor Project.

SSOs include any unintended or unauthorized discharge from the sewage system. SSOs can occur from a blocked pipe, a break in a sewer line, or from excess rainwater leaking into the sewers. Common dry-weather causes of SSOs are buildups of grease and bathroom wipes. MWRA has worked to inform the public about improper disposal of grease, wipes, and other items that can cause pipe blockages, and created a website page, It's a Toilet, not a Trash Can! Household Waste Disposal.

MWRA began providing website notifications of SSOs in late 2015 and of treated CSOs in 2016, in advance of the sewage notification law. Email and text notifications of untreated CSOs and blending events were added in 2022. Within two hours of confirming a blending event or discharge, MWRA issues notifications to relevant local, state, and federal government agencies, as well as interested members of the public. News agencies that report on local issues and organizations that serve affected environmental justice communities also receive the notifications. In 2023, MWRA began working with local communities to post warning signs at public access points located near CSOs.

More information about MWRA's notifications and how to sign up for them can be found at the Rapid Notifications page on the MWRA website. The page also has links to historical blending events, CSOs and SSOs.

## Data Management

Data management is as important to the success of marine monitoring programs as the collection of data (National Research Council 1990). Since its inception, MWRA has prioritized attention to data quality and management (Figure 6-1). Automated systems, including web-based applications for sending data to MWRA, make it easy to gather and check data at the collection point, where it is easiest to correct errors. Further automated checking occurs when data are loaded into the MWRA database, and MWRA data management staff work with data providers to resolve issues flagged by those checks. Data checks include a variety of tools, such as statistical summaries, checks for station locations and sampling times, and visual presentations to identify suspicious results (for example, Figure 6-2).

Each portion of the monitoring program is governed by a Quality Assurance Project Plan (QAPP). QAPPs ensure that all project participants understand the goals, the work to be done, and the data quality standards that apply to their individual tasks. Specific field and laboratory work elements follow approved standard operating procedures. Quality assurance officers at MWRA's Department of Laboratory Services and within the MWRA contractor organizations ensure that QAPPs and standard operating procedures are followed.

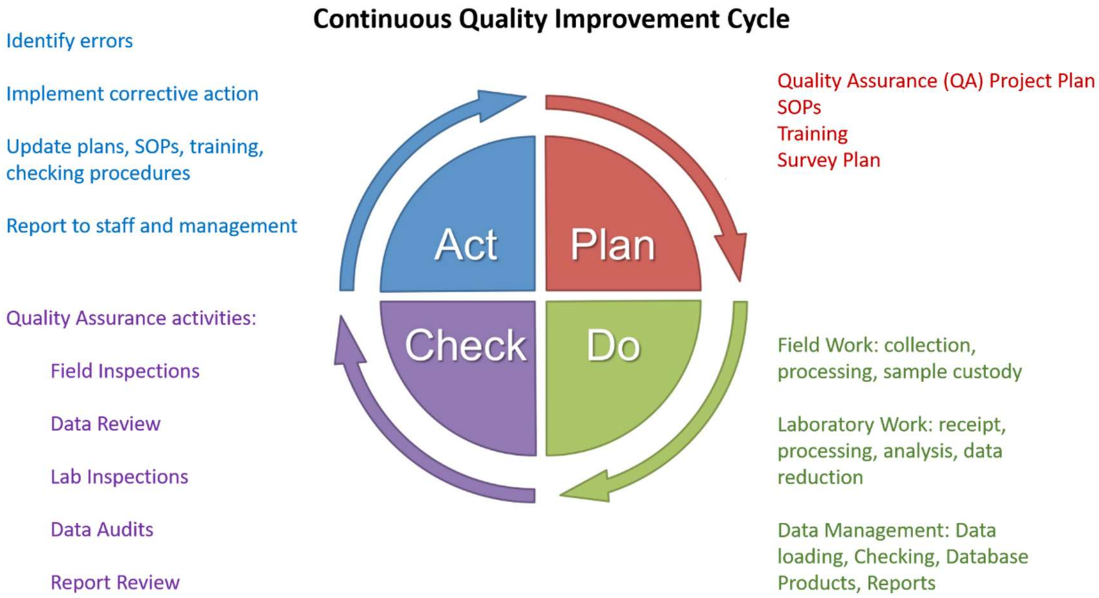

**Figure 6-1. Monitoring data are collected by MWRA and its consultants under stringent quality assurance and quality control, following the Plan-Do-Check-Act cycle for continuous quality improvement.**

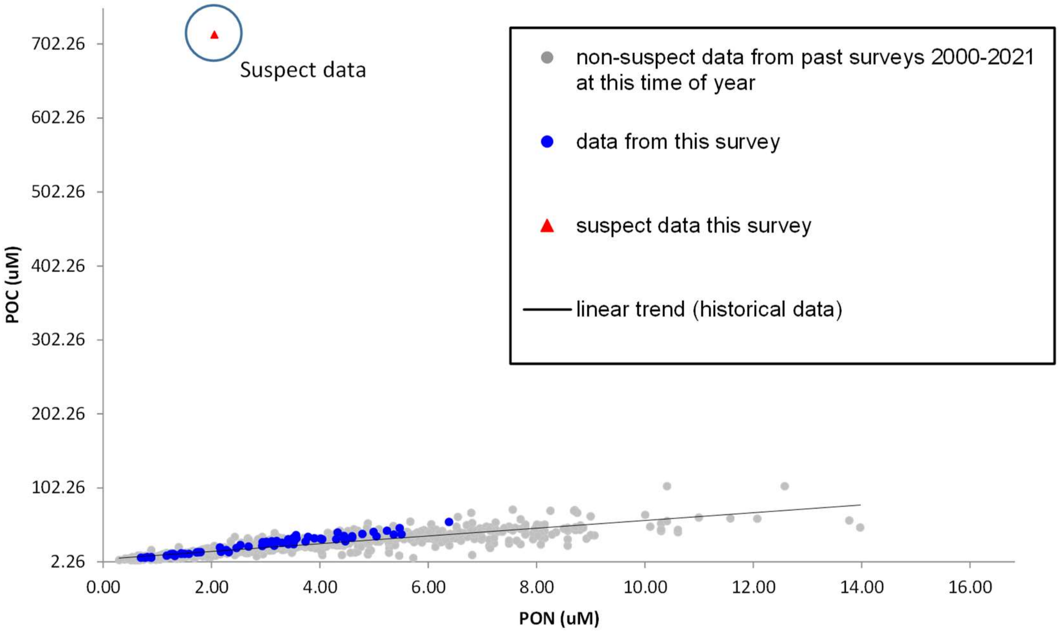

**Figure 6-2. Example of a presentation used to identify suspicious data.** This plot depicts particulate organic carbon (POC) and particulate organic nitrogen (PON) at one station compared to historic data. The suspect data point is flagged for review.

MWRA follows a four-step corrections process to address data errors: (1) verify with the data collector that a correction is necessary; (2) correct the error in the database; (3) implement automated procedures to ensure that similar errors will be detected in the future, and (4) look for and correct similar errors in the historical data. Seasonal and annual data are not considered "final" until they have been reviewed by the monitoring team.

All MWRA technical reports, including this annual overview, draw on data from the central database, which is also used for compliance with the NPDES permit and court orders. MWRA also provides data to academic, scientific, and community members interested in the environmental health and physical characteristics of Boston Harbor and Massachusetts Bay. All QAPPs and study-specific technical reports are available on the MWRA Environmental Quality Department Technical Reports List.

## Bays Eutrophication Model Update

MWRA's permit to discharge wastewater effluent to Massachusetts Bay requires maintenance and annual runs of the Bays Eutrophication Model (BEM), a combined circulation and water quality model, which simulates the parameters and processes affecting potential eutrophication and subsequent low dissolved oxygen levels in Massachusetts Bay, Boston Harbor, and Cape Cod Bay. Parameters include water temperature, salinity, circulation, nutrients, and phytoplankton biomass. A precursor to the BEM was instrumental in siting the outfall, and annual simulations have continually confirmed the early predictions that the nutrient inputs from the outfall would not lead to eutrophication in Massachusetts or Cape Cod Bays. Annual runs complement MWRA's field program.

The most recent BEM simulation, for the year 2021, successfully captured many of the seasonal and geographic conditions measured by the survey team (Deltares 2023). For example, the model accurately simulated late spring nutrient depletion as phytoplankton began to bloom and the typical drop in dissolved oxygen levels in the late summer. Results were consistent with previous years' model runs, continuing to confirm field monitoring observations that nutrient inputs from the outfall discharge did not influence phytoplankton biomass or dissolved oxygen.

MWRA has run a scenario in which effluent nitrogen loads were set to 50% higher than the actual 2020 load (equivalent to 24% higher than the warning threshold). Even with those additional nutrients, the outfall discharge did not adversely affect the environment (Deltares 2022). At the simulated high load, the model predicted increases in dissolved inorganic nitrogen concentrations throughout Massachusetts Bay. Significant increases in ammonium levels (larger than one micromolar, a concentration unit based on molecular weight) were limited to within ten kilometers of the outfall. The model simulation also predicted minor localized increases in chlorophyll and decreases in dissolved oxygen concentrations, but no effects beyond the immediate vicinity of the outfall.

# 7. Update on the NPDES Permit

MWRA's permit to discharge treated sewage effluent into Massachusetts Bay became effective in August 2000. While EPA issues permits with an effective period of five years, the permit has been administratively continued since its first approval.

EPA issued a new draft permit, NPDES Permit No. MA0103284, on May 31, 2023, with public comments due by November 28, 2023. After the close of the public comment period, EPA will review, respond, and issue a final permit. This period of moving from draft to final permit issuance can take months to years. The Massachusetts Department of Environmental Protection has also issued a companion Surface Water Discharge permit which incorporates by reference the EPA NPDES permit requirements.

**Figure 7-1. Deer Island staff in front of the sludge digesters.**

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# List of Acronyms

| | |
|---|---|
| ASP | Amnesic shellfish poisoning |
| BOD | Biochemical oxygen demand |
| cBOD | Carbonaceous biochemical oxygen demand |
| cfu | Colony forming units |
| CHV | Centrotubular hydropic vacuolation |
| CSO | Combined sewer overflow |
| DDT | Dichlorodiphenyltrichloroethane |
| DIF | Deer Island Flats |
| ECCB | Eastern Cape Cod Bay |
| EPA | U.S. Environmental Protection Agency |
| IAAC | Inter-Agency Advisory Committee |
| LC50 | 50% mortality concentration |
| LNB | Large navigation buoy |
| MGD | Million gallons per day |
| MWRA | Massachusetts Water Resources Authority |
| NA | Not analyzed/not applicable |
| NDBC | National Data Buoy Center |
| NERACOOS | Northeastern Regional Association of Coastal and Ocean Observing Systems |
| NOEC | No observed effects concentration |
| NPDES | National Pollutant Discharge Elimination System |
| OS | Outfall site |
| OS-M | Outfall site mussels |
| PAH | Polycyclic aromatic hydrocarbon |
| PCB | Polychlorinated biphenyl |
| PIAC | Public Interest Advisory Committee |
| POC | Particulate organic carbon |
| PON | Particulate organic nitrogen |
| PSP | Paralytic shellfish poisoning |
| PSU | Practical salinity units |
| QAPP | Quality assurance project plan |
| SSO | Sanitary sewer overflow |

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