

# 2018 Outfall Monitoring Overview

Massachusetts Water  
Resources Authority  
Environmental Quality  
Department Report 2019-07



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Water column sampling in Massachusetts Bay  
*Alex Mansfield, Battelle*

Deer Island Treatment Plant staff celebrate receiving a Platinum Peak Performance award from the National Association of Clean Water Agencies  
*Massachusetts Water Resources Authority*

# **2018**

## **Outfall Monitoring Overview**

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**November 8, 2019**

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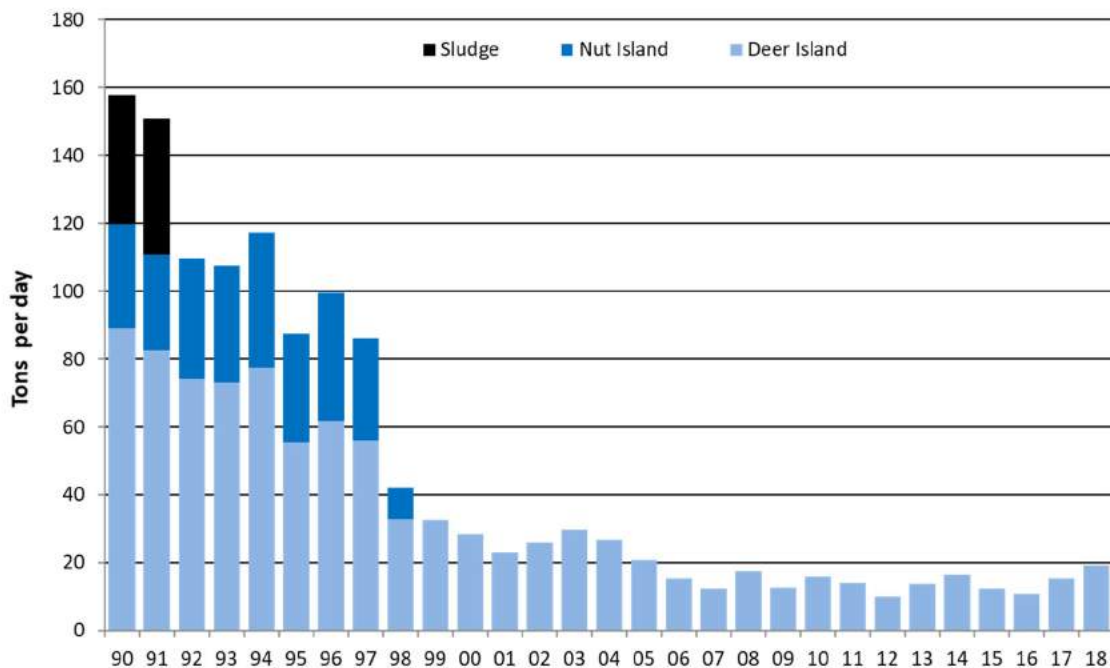
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# Executive Summary

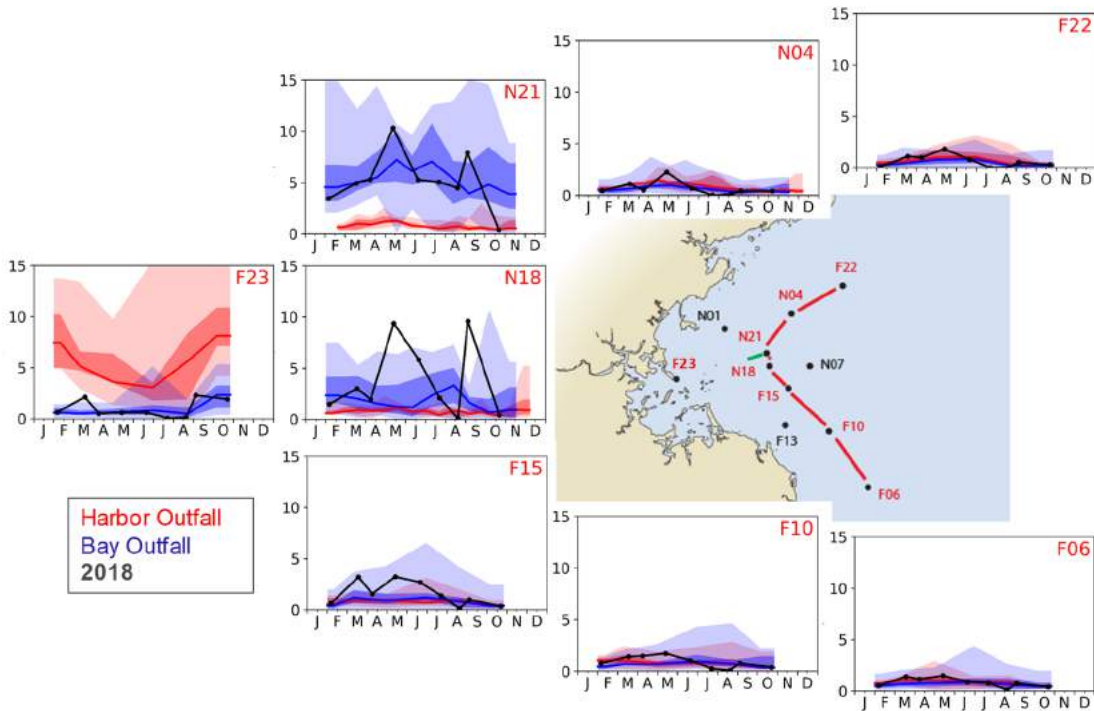
This outfall monitoring overview for 2018 marks the twenty-seventh year of the Massachusetts Water Resources Authority (MWRA) Massachusetts Bay monitoring program. More than eighteen years ago, in September 2000, municipal effluent discharge was diverted from the shallow, confined waters of Boston Harbor to the deeper, more open waters of Massachusetts Bay.

Through 2018, Deer Island Treatment Plant continued to operate as designed, earning MWRA the National Association of Clean Water Agencies Platinum 12 Peak Performance Award for facilities with 100% compliance with permit conditions over twelve consecutive years. Solids discharges, the portion of the municipal effluent that contains most of the persistent organic and inorganic contaminants, remained low, only a fraction of the discharges that had been made to Boston Harbor in the 1990s (Figure i).



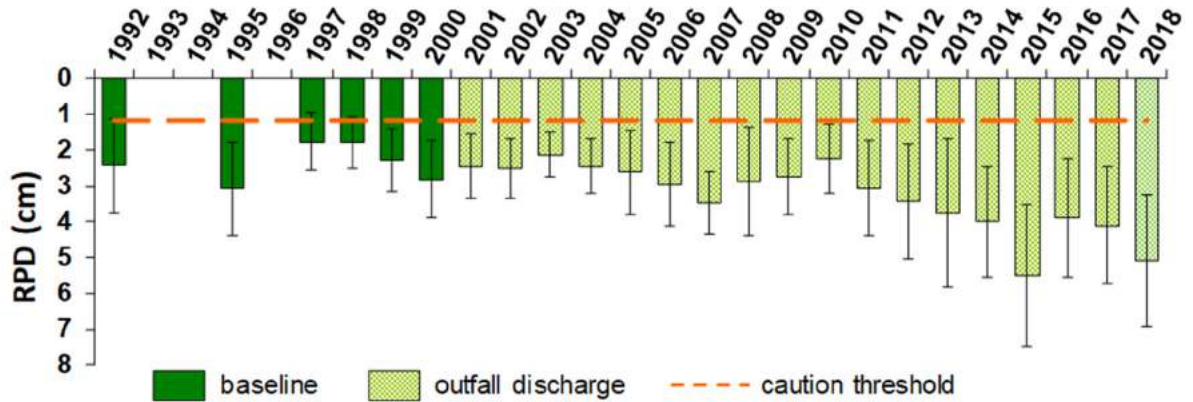
**Figure i. Annual solids discharges, 1990–2018.** Before December 1991, biosolids (sludge) removed during treatment were digested anaerobically and discharged into Boston Harbor. Ending biosolids disposal, ending effluent discharge to the southern portion of the harbor from Nut Island, implementing secondary treatment, and culminating in ending all discharges to the harbor in September 2000 were important steps for the Boston Harbor Project. Since 2006, variability in solids discharges to Massachusetts Bay can be attributed mostly to variation in effluent flow.

Water-column monitoring in Massachusetts Bay continued to confirm predictions that limited effects of the discharge would be detectable for some parameters, but only at stations located in close proximity to the outfall and not at levels that would cause environmental concern. Elevated concentrations of the nutrient ammonium can be detected close to the outfall, but those increases are limited in comparison to the large decreases in ammonium observed in Boston Harbor (Figure ii). The Massachusetts Bay outfall has not increased harmful phytoplankton blooms or lowered oxygen levels in the bay.



**Figure ii. Depth-averaged ammonium concentrations at selected stations in 2018 compared to prior years.** Black points and line are results from individual surveys in 2018. Red lines and shading show data from Boston Harbor discharge years. Results from September 2000–2017 are in blue. Line is the 50<sup>th</sup> percentile, dark shading spans the 25<sup>th</sup> to 75<sup>th</sup> percentile, and light shading spans the range.

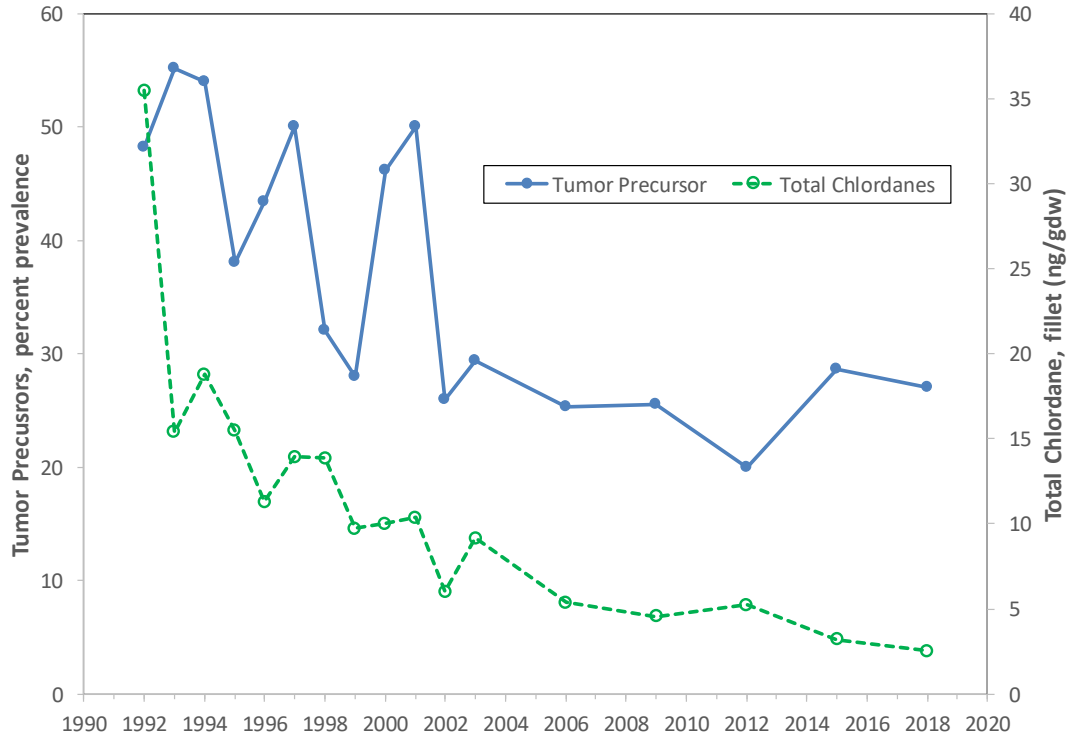
Healthy bottom-dwelling communities continue to thrive on the Massachusetts Bay sea floor, and the sediment oxygenated layer has deepened since the baseline period (Figure iii). In general, monitoring has shown that physical rather than biological processes, such as storms and storm-induced sediment transport, can be primary stressors on the Massachusetts Bay sea floor, lessening the chances of any effects of the Massachusetts Bay outfall.



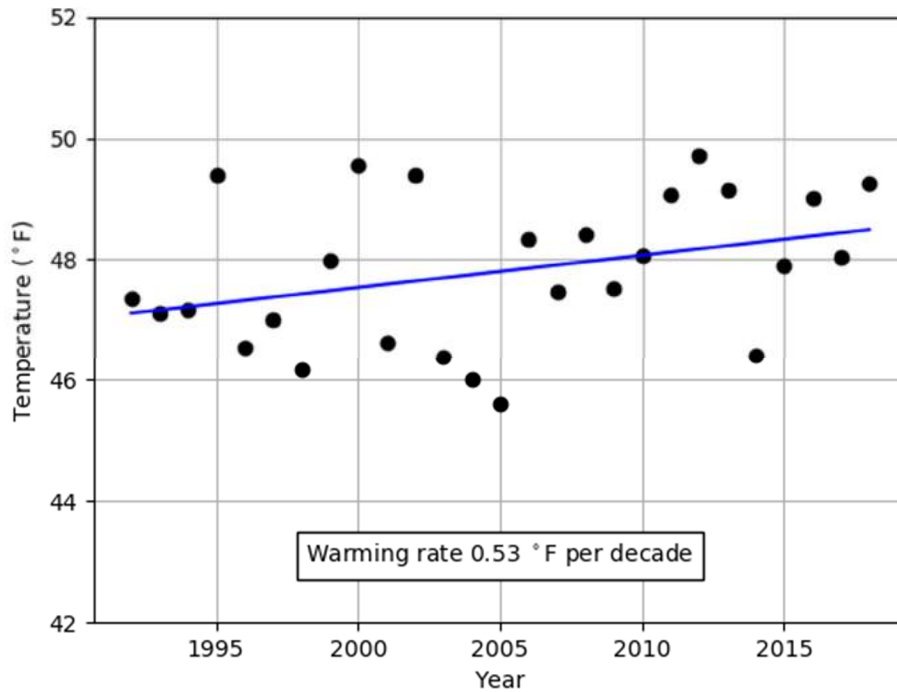
**Figure iii. Depth of the sediment oxygenated layer, 1992–2018.** The oxygenated layer in Massachusetts Bay sediments near the outfall has deepened since the baseline years, a strong indication of no adverse effect from the discharge.

Winter flounder remained healthy, without the widespread tumors and precancerous conditions that occurred in Boston Harbor in the 1980s and 1990s. MWRA monitoring has never detected tumors in fish taken from near the Massachusetts Bay outfall or tumors in fish from any location since 2004. Improvements in Boston Harbor flounder health began in the first years of the Boston Harbor Project and correlate well with declines in total solids discharges. Declines in cancer precursors also correspond to declines in organic contaminant concentrations in flounder livers, particularly declines of the banned organochlorine pesticide chlordane (Figure iv). Improving winter flounder health in Boston Harbor without degrading it in Massachusetts Bay has been one of the most notable successes of the Boston Harbor Project, validating the value of federal and state regulatory mandates, as well as the investments in facilities and management practices.

The 27 years that MWRA has monitored Massachusetts Bay have afforded an opportunity to examine longer-term trends than is possible for most coastal studies. Analyzing trends in temperature, dissolved oxygen concentrations, and the intensity and frequency of storms that can resuspend seafloor sediments can provide new insights into existing monitoring data and help to plan for the future. For example, analysis of depth-averaged February–October temperature data has shown an increase of about one-half degree Fahrenheit near the outfall per decade since 1992 (Figure v). Small declines in oxygen concentrations and increases in winter storm frequency and intensity have occurred over the same period.



**Figure iv. Incidence of tumor precursors in winter flounder livers and total chlordanes in fillets in Boston Harbor, 1991–2018.** Tumors and tumor precursors have dramatically declined in Boston Harbor, with no concurrent increase in Massachusetts Bay. These declines follow the stages of the Boston Harbor Project and correlate with concurrent declines in toxic contaminants in flounder fillets.



**Figure v. Annual average February–October temperatures at stations near the outfall, 1992–2018.** Temperatures have increased about one half degree Fahrenheit per decade over the course of the monitoring program.

MWRA remains committed to the mission it was given in 1984, to improve conditions in Boston Harbor without damage to Massachusetts Bay. The 27 years of Massachusetts Bay monitoring have confirmed predictions made before discharge began, verified continued good effluent treatment and operations at Deer Island Treatment Plant, and answered the monitoring questions posed at the beginnings of the program. Looking ahead, MWRA is working with regulators, managers, scientists, and the interested public to revise the monitoring plan.

# 1. Introduction

Boston Harbor was once known as one of the dirtiest in the nation, receiving discharges of both biosolids (sludge) and poorly treated wastewater. The Massachusetts Water Resources Authority (MWRA) was created by the state legislature in 1984 to clean up the harbor, a mission dubbed the “Boston Harbor Project.” That mission included reducing contaminants entering the wastewater; ending biosolids discharges; rebuilding failing treatment facilities; and sending highly treated effluent not to the shallow, confined harbor, but to the deeper, more open waters of Massachusetts Bay. MWRA has conducted long-term environmental monitoring in both the harbor and the bay, documenting the cleanup of the harbor, while ensuring no environmental harm to the bay. This report, required by the MWRA discharge permit, summarizes annual monitoring results.

MWRA ended all biosolids discharges in December 1991, ended effluent discharges to the southern part of the harbor in 1998, and upgraded Deer Island Treatment Plant during 1995–2001. The project reached a major milestone in September 2000, when all effluent discharge was diverted from Boston Harbor to Massachusetts Bay. The relocated outfall operates 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 (MassDEP). An independent Outfall Monitoring Science Advisory Panel (OMSAP) provides technical review to the regulatory agencies.

The NPDES permit requires monitoring of effluent and receiving waters, sediments, and marine life to assess compliance with permit conditions and with a permit-required Contingency Plan, designed to protect the environmental health of the bay. Background information about the monitoring program (Werme et al. 2012), the monitoring plan (MWRA 2010), the Contingency Plan (MWRA 2001), past plans and overviews, and study-specific technical reports are available at <http://www.mwra.state.ma.us/harbor/enquad/trlist.html>.

This year’s outfall monitoring overview presents results from 2018, marking the twenty-seventh year of Massachusetts Bay monitoring and more than eighteen years of discharge from the deep-water outfall. The report presents information relevant to permit and Contingency Plan requirements in the effluent, water column, sea floor, and fish and shellfish, as well as special studies conducted in response to permit conditions and environmental concerns. This year’s special studies section focuses on winter flounder health in Boston Harbor and long-term environmental trends in Massachusetts Bay. Results relevant to the Stellwagen Bank National Marine Sanctuary, located offshore from the outfall, are presented in sections covering the water column and the sea floor. The report also includes pertinent information derived from MWRA’s separate monitoring efforts in Boston Harbor.

## 2. Effluent

### 2018 Effluent Characterization

The Deer Island Treatment Plant continued to operate as designed through 2018, earning MWRA the National Association of Clean Water Agencies (NACWA) Platinum 12 Peak Performance Award. This NACWA award recognizes facilities with 100% compliance with effluent permit limits over twelve consecutive years.

Wastewater influent to Deer Island Treatment Plant includes not only municipal sewage but also groundwater infiltration and stormwater inflow. Consequently, rainfall is an important factor determining wastewater flows and contaminant loads in the MWRA effluent. The Boston area received 53.3 inches of rain in 2018, about 10 inches more than the average rainfall for 1990–2018, 43.5 inches (Figure 2-1). As rainfall was average or below average in 2012–2017, effluent flows and contaminant loads were expected to be somewhat higher in 2018 than in recent years.

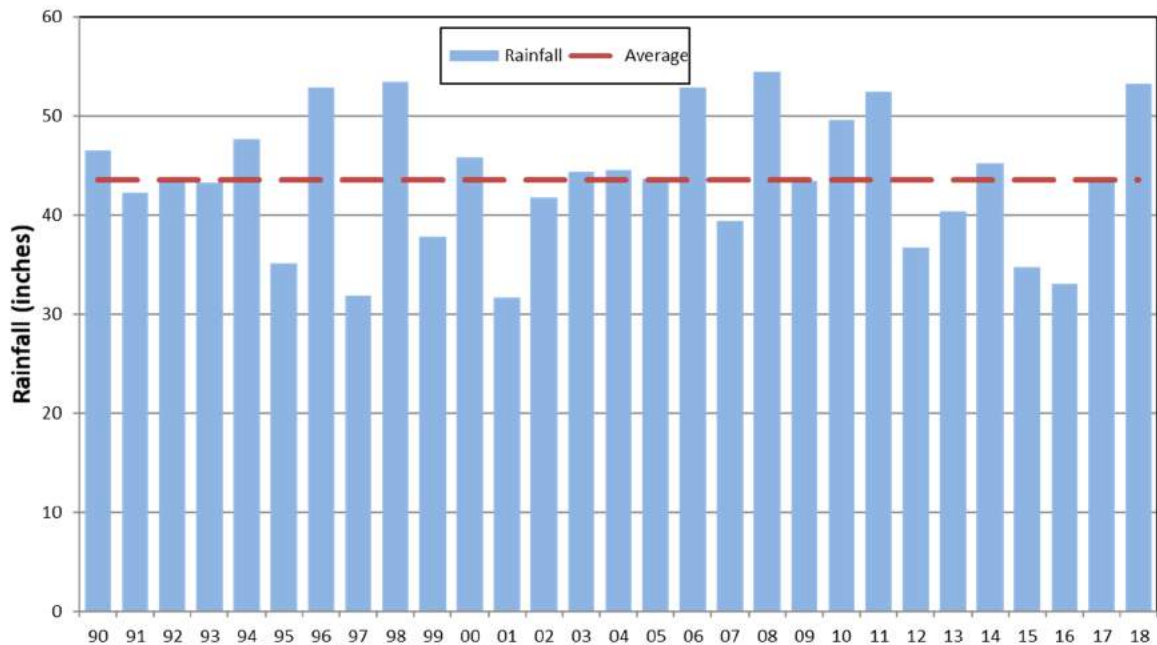
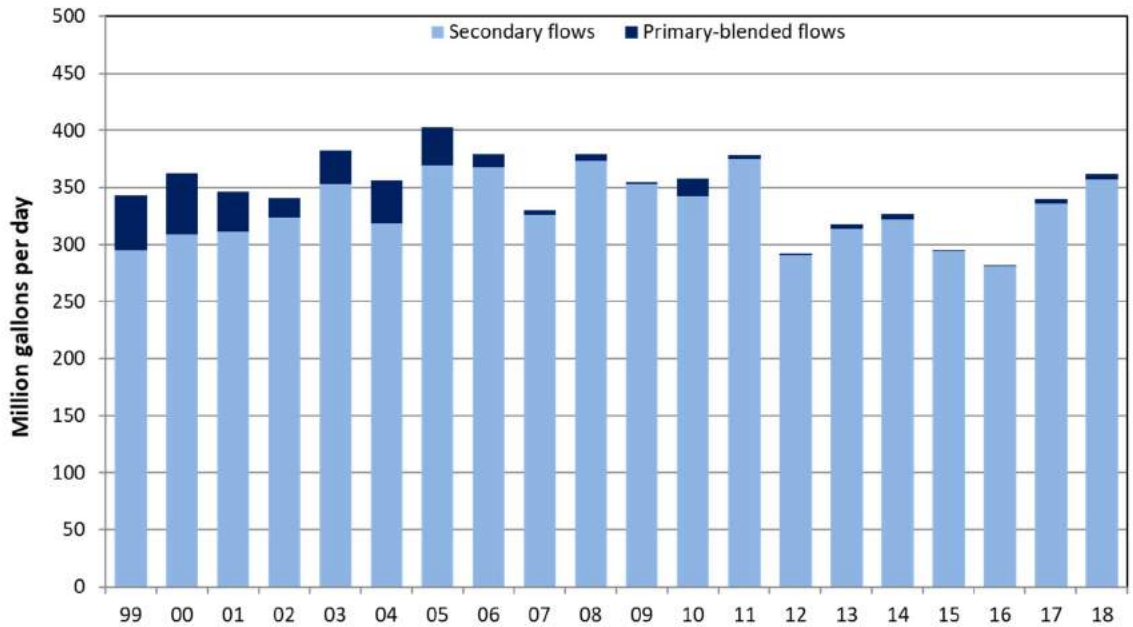
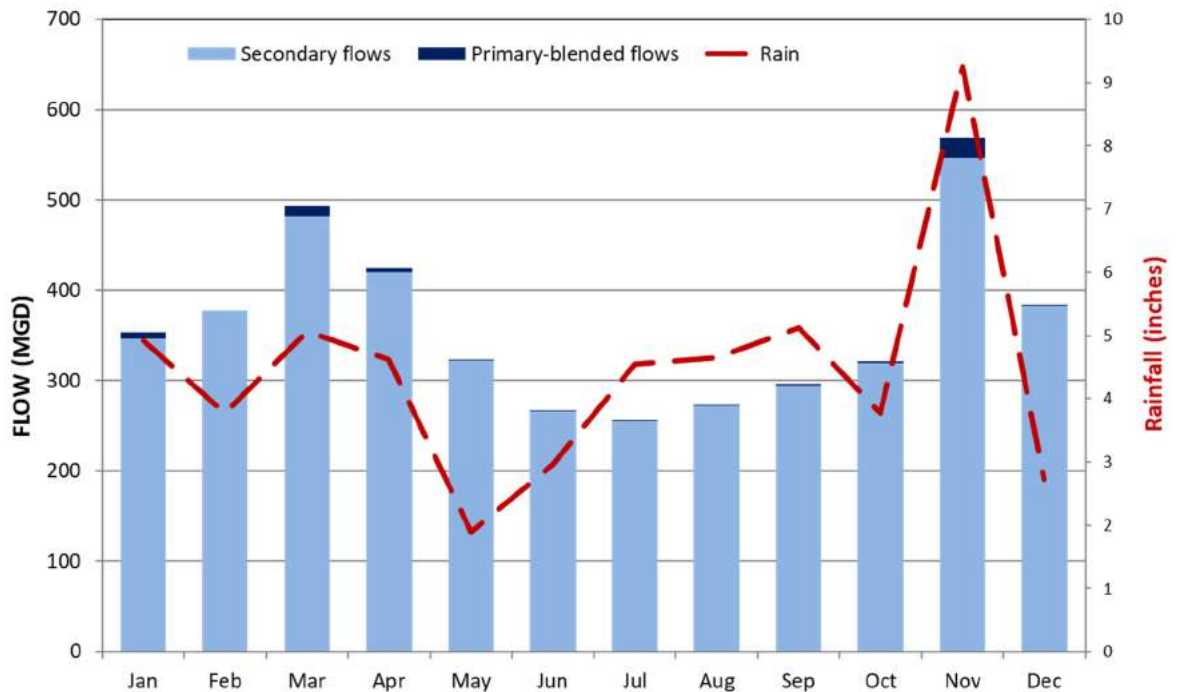


Figure 2-1. Annual and average rainfall in Boston, 1990–2018.

Corresponding to the higher rainfall, effluent flow in 2018 was 357 million gallons per day (MGD), slightly higher than flow in 2012–2017 and higher than the longer-term 1999–2018 average of 330 MGD (Figure 2-2). Almost all the flow, 99%, received full primary and secondary treatment, with only trace discharges of primary-treated effluent blended with fully treated effluent prior to discharge in any month (Figure 2-3).



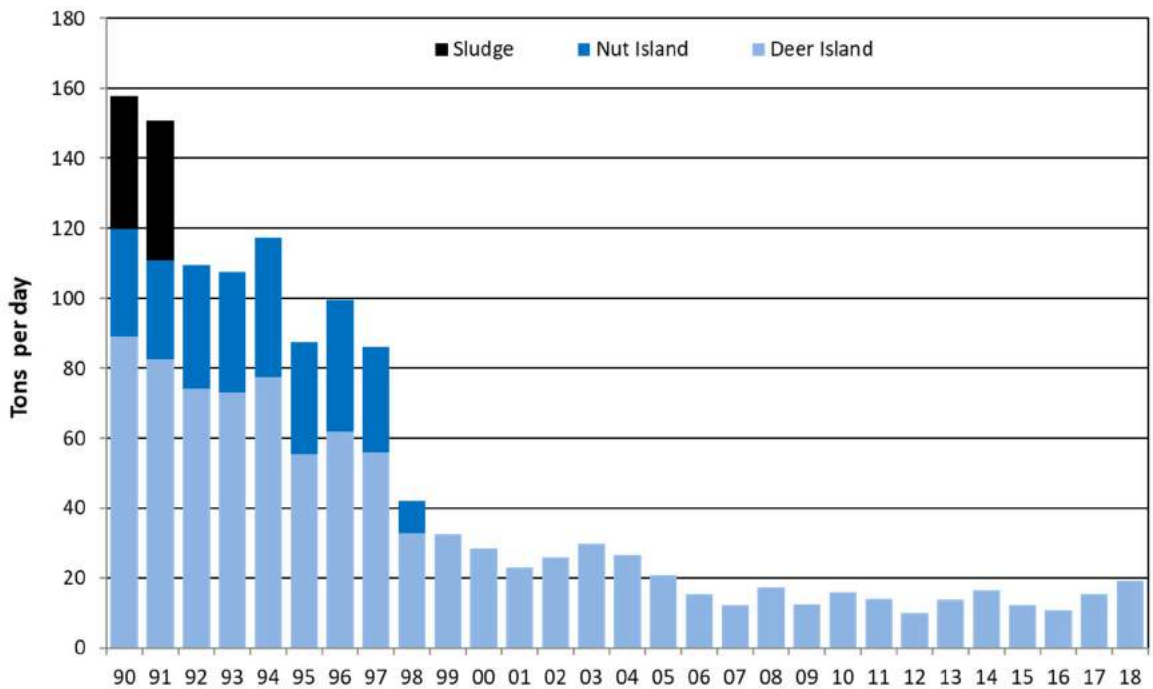
**Figure 2-2. Annual full secondary and primary-blended effluent flows, 1999–2018.** During some large storms, flow exceeding the secondary capacity of the plant is diverted around the secondary process. Primary-treated flows are blended into secondary-treated effluent and disinfected before discharge.



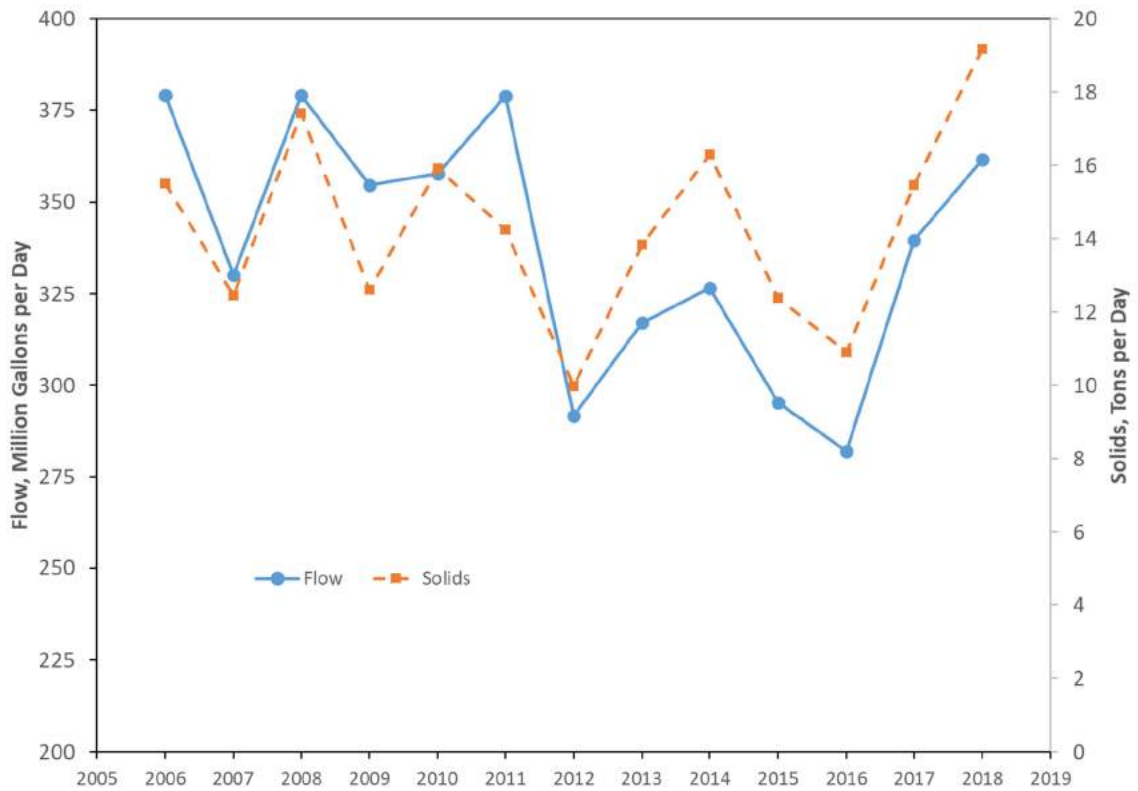
**Figure 2-3. Monthly full secondary and primary-blended flows and rainfall during 2018.**



The total suspended solids load to Massachusetts Bay, about 19 tons per day, was higher than in recent years, but below levels measured before 2005 and far below the levels discharged into Boston Harbor before the outfall diversion in 2000 (Figure 2-4). In recent years, variability in the suspended solids load has corresponded to variability in rainfall and effluent flow (Figure 2-5). For example, 2015 and 2016 were drought years, with correspondingly low flows and extremely low solids loading compared to 2018, which was rainier and had higher loading. Carbonaceous biochemical oxygen demand, a measure of the amount of oxygen consumed by microorganisms, also remained low, well below levels that would be expected to affect dissolved oxygen concentrations at the discharge (not shown).

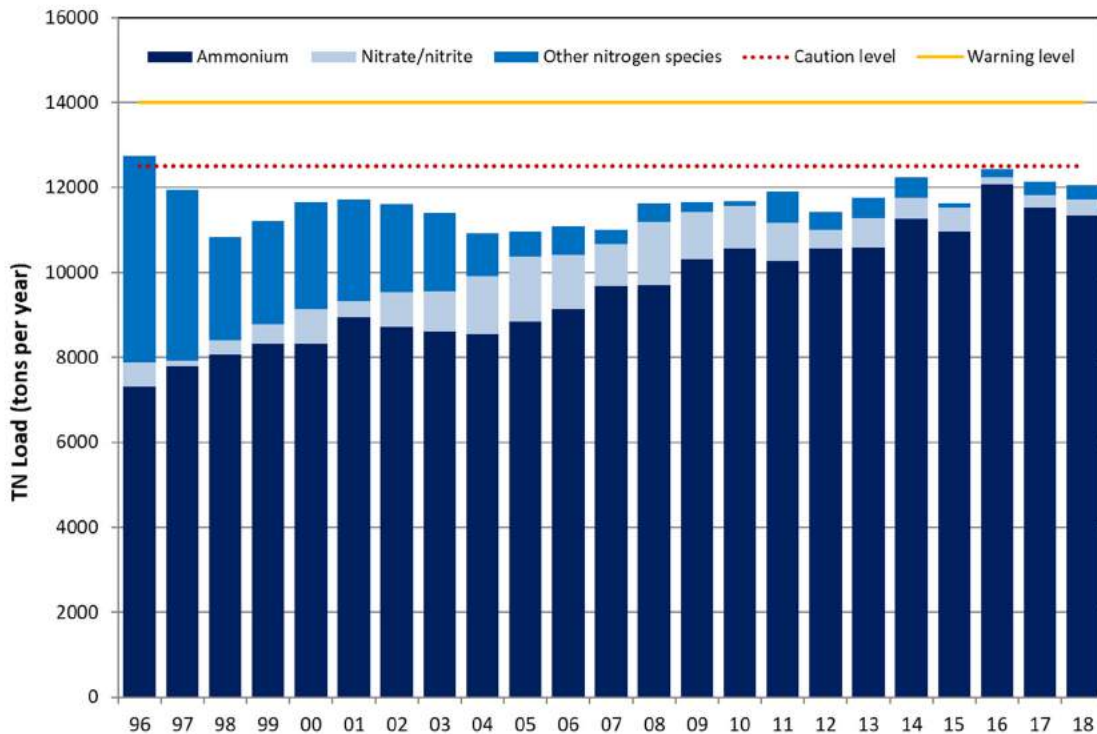


**Figure 2-4. Annual solids discharges, 1990–2018.** Before December 1991, biosolids (sludge) removed during treatment were digested anaerobically and discharged into Boston Harbor. Ending biosolids disposal, ending effluent discharge to the southern portion of the harbor from Nut Island, implementing secondary treatment, and culminating in ending all discharges to the harbor in September 2000 were important steps in the Boston Harbor Project.



**Figure 2-5. Annual solids discharges and flows, 2006–2018.** Since 2006, variability in solids discharges to Massachusetts Bay can be attributed mostly to variation in effluent flow.

Despite the increased flow, the total nitrogen load was lower than in recent years, remaining just under its Contingency Plan caution-level threshold (Figure 2-6) and well below the warning-level threshold, 14,000 metric tons per year. The caution level was somewhat arbitrarily set as 90% of the warning level; the warning level was the anticipated total nitrogen load for the year 2020, projected during design of the treatment plant. Since 2000, when discharges to the harbor ended, total nitrogen loads have been lower than were predicted at the start of the Boston Harbor Project.



**Figure 2-6. Annual nitrogen discharges, 1996–2018.** The caution threshold is set at 90% of the warning level, which was the anticipated discharge for the year 2020, 14,000 tons per year.

Total effluent nitrogen loads reflect variability in nitrogen levels in the influent reaching Deer Island, with about 30% of the nitrogen removed during treatment. Total nitrogen loads have increased modestly since the Massachusetts Bay outfall began to discharge, most likely due to population increases in the MWRA service area. There have been no observed unexpected or adverse environmental effects due to nitrogen discharge into Massachusetts Bay, and water-quality modeling has suggested that even large increases to the nitrogen discharge would have no adverse effect on the environment. The portion of the nitrogen load made up of ammonium declined for a second year after a record high in 2016. Increased ammonium loads are a consequence of the biological treatment process and addition of ammonium-rich liquids from the biosolids pelletizing plant, which converts biosolids to fertilizer.

Metals loads remained low in 2018, with little evidence of increases associated with increased flow. Zinc and copper continued to be the most abundant metals in the annual discharge (Figure 2-7), and total loads of all metals remained a small fraction of what had been anticipated during planning for the Massachusetts Bay outfall (Table 2-1). Except for copper, metals meet water quality standards prior to discharge, where initial dilution at the Massachusetts Bay outfall reduces concentrations further. Even copper discharges, which meet the standard after initial dilution, have declined over time, a result of drinking-water corrosion control, which limits leaching from water pipes, the major source of copper in the influent.

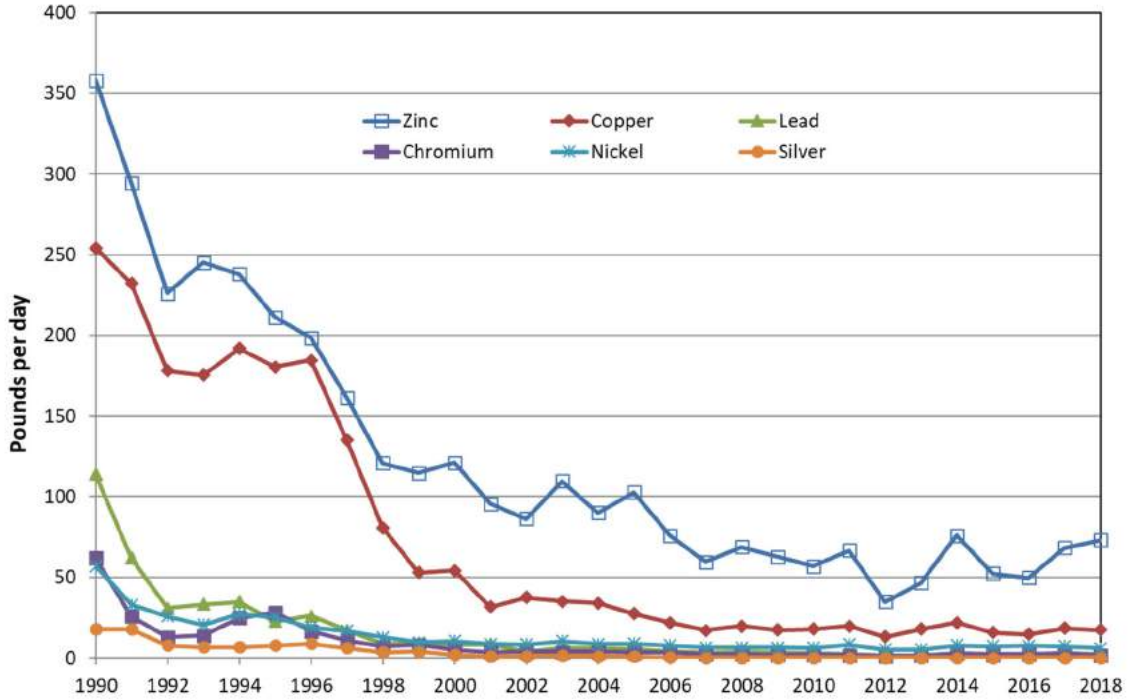


Figure 2-7. Annual metals discharges, 1990–2018.

Table 2-1. Projected and actual loads of metals in MWRA effluent. Loads of metals and organic contaminants are far below those projected during the planning and permitting process.

Parameter	SEIS Projected Load (kg/year)	2018 Load (kg/year)	Percent Projected Load
Chromium	3,517	313	8.9%
Copper	11,945	2,880	24%
Lead	4,961	387	7.8%
Mercury	216	2.0	9.3%
Nickel	8,926	387	4.3%
Silver	290	25	8.6%

SEIS = Supplemental Environmental Impact Statement (EPA 1988)

Polycyclic aromatic hydrocarbon (PAH) and other organic contaminant loads (not shown) were also low, only a small fraction of what had been anticipated during planning for the outfall, as they have been throughout the monitoring program. Discharges of organic contaminants have varied slightly from year to year but have been well below levels historically discharged into Boston Harbor.

## Contingency Plan Thresholds

There were no permit violations in 2018 and no exceedances of the Contingency Plan effluent thresholds (Table 2-2). Effluent threshold exceedances have been rare throughout the duration of the monitoring program, and none have occurred over the past twelve years.

**Table 2-2. Contingency Plan threshold values and 2018 results for effluent monitoring.**

Parameter	Baseline	Caution Level	Warning Level	2018 Results
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, >456 µg/L monthly	Not exceeded
Suspended solids	NA	None	>45 mg/L weekly >30 mg/L monthly	Not exceeded
cBOD	NA	None	>40 mg/L weekly, >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	Not exceeded
Flow	NA	None	>436 MGD average dry days	Not exceeded
Total nitrogen load	NA	>12,500 mtons/year	>14,000 mtons/year	Not exceeded
Oil and grease	NA	None	>15 mg/L weekly	Not exceeded

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 evaluates relevant 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). Field monitoring is augmented by measurements from instrumented buoys and satellite imagery.

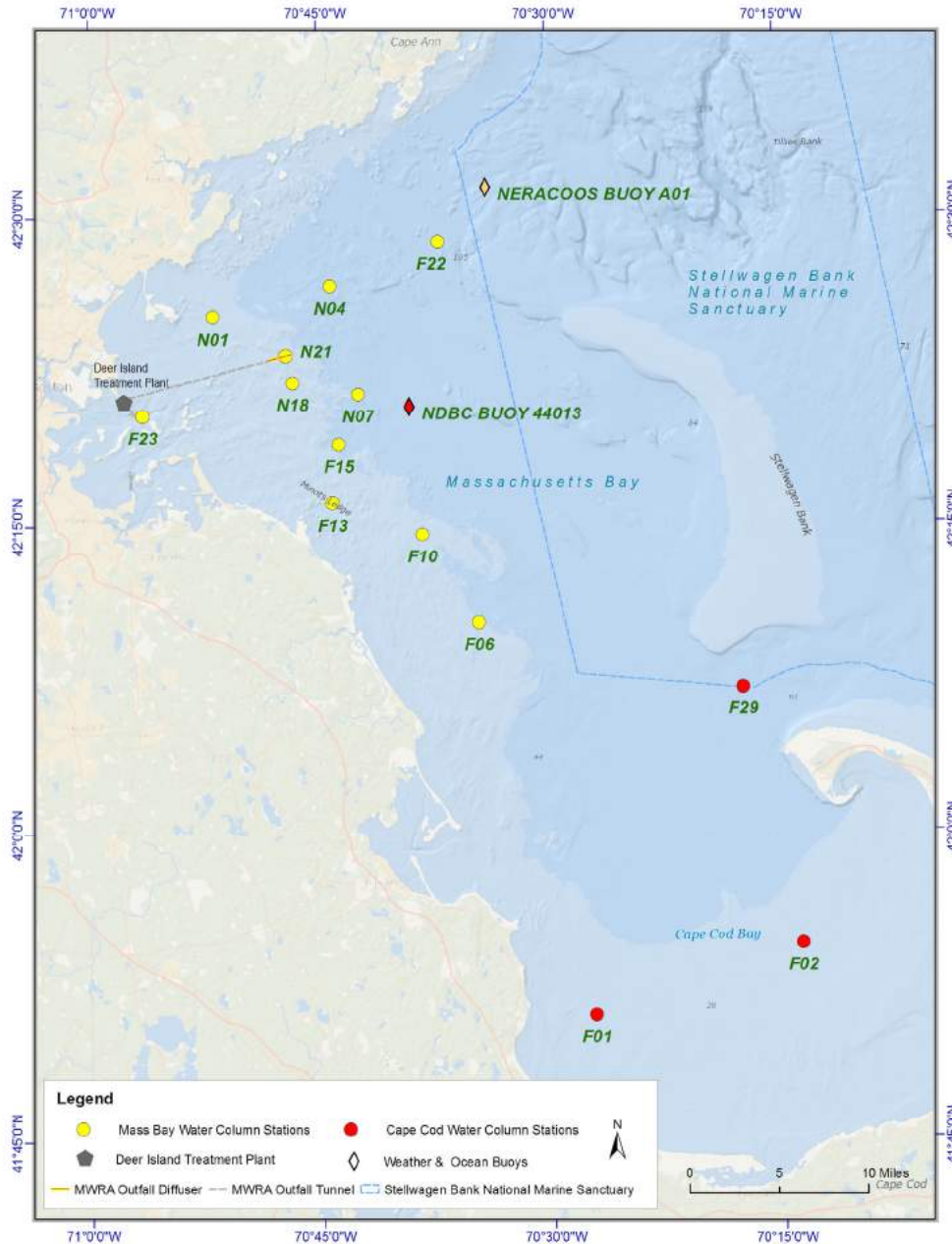


Figure 3-1. Water-column monitoring stations and instrumented buoys in Massachusetts and Cape Cod bays.

Nine water-column surveys of fourteen stations in 2018 sampled the nearfield (the 10- by 12-kilometer area around the outfall where some effects of the effluent were expected and have been observed) and farfield reference stations, including stations at the mouth of Boston Harbor, in Cape Cod Bay, and near the Stellwagen Bank National Marine Sanctuary. Data from ten additional stations, sampled as part of MWRA's Boston Harbor water-quality monitoring program were included in analyses when sampling dates were within a few days of the outfall-monitoring surveys.

The program continued to benefit from collaboration with the Center for Coastal Studies at Provincetown, Massachusetts, which conducts a monitoring program in Cape Cod Bay and, as part of the MWRA monitoring program, samples the water-column stations in Cape Cod Bay and near the 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 sampling. All 2018 surveys were completed within that target.

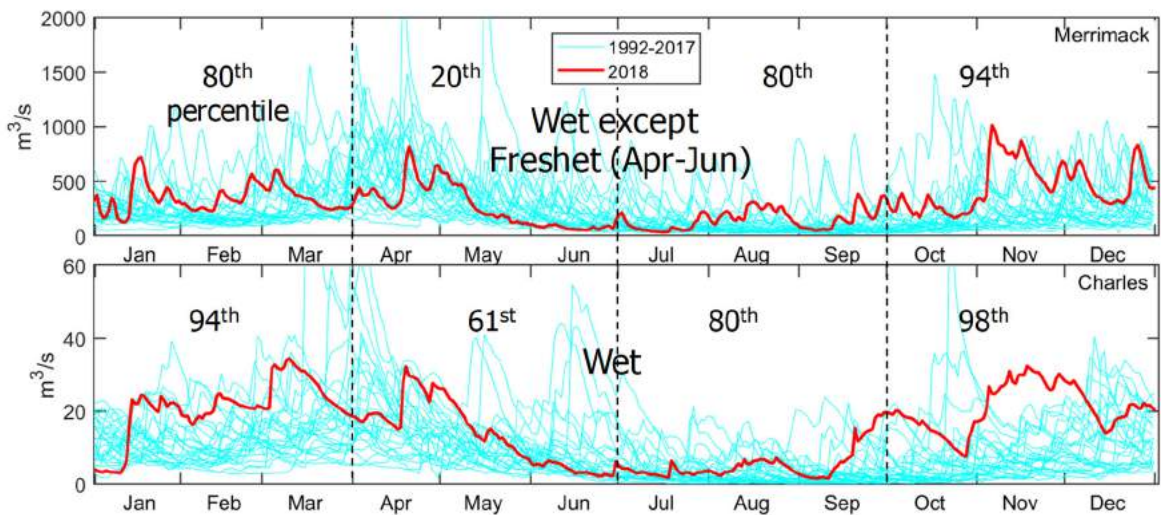
As in past years, the field monitoring program was supplemented by measurements on two instrumented buoys: the Northeastern Regional Association of Coastal and Ocean Observing Systems (NERACOOS) Buoy A01 and the National Oceanic and Atmospheric Administration's National Data Buoy Center Buoy (NDBC) 44013. The National Aeronautics and Space Administration provided Moderate Resolution Imaging Spectroradiometer satellite imagery of chlorophyll and sea-surface temperature.

## **Physical Conditions**

Monitoring has shown that the water quality in the vicinity of the outfall and throughout Massachusetts and Cape Cod bays is heavily influenced by weather, river inflows, and other physical factors. Information about physical conditions has proven key to interpreting the annual water-column monitoring data.

The Boston area experienced heavier than average rainfall in 2018 (see Figure 2-1 in Section 2, Effluent) and two major storms. An early March blizzard with sustained 45 miles per hour winds from the northeast and 32-foot waves was the largest storm since Massachusetts Bay monitoring began in 1992. Time-integrated bottom stress, an indicator of wave-induced erosion of the sea floor, was higher during this storm than for any storm in the region over the past 30 years. Late August brought a rare summer storm with winds from the northeast, which mixed warm water to the near bottom waters at shallower locations, such as Station N18 just south of the outfall. Such "Nor'easters" more typically occur during the fall, winter, or spring. Wet weather continued from October through December. (See Section 6, Special Studies, for additional discussion of storms in Massachusetts Bay.)

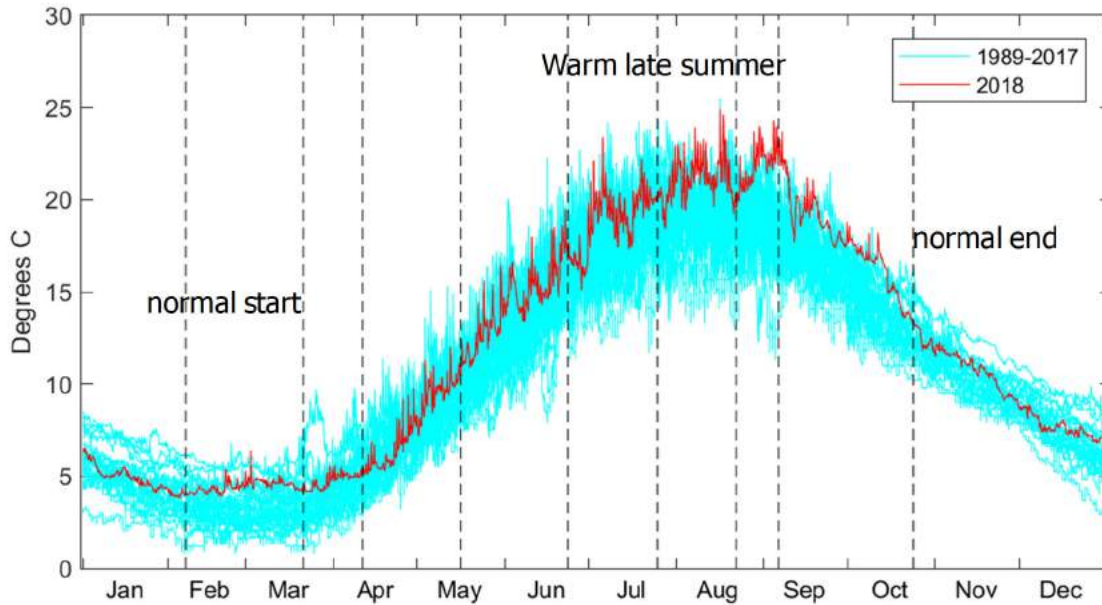
Corresponding to the rainy year, discharges from the Merrimack and Charles rivers were also higher than average, among the highest flows since monitoring began in 1992. Flows were especially high in the late winter, summer, and fall, but the spring snow and ice melt, the “freshet,” was not especially robust, particularly in the Merrimack River, where April–June flows were only in the twentieth percentile of the long-term average (Figure 3-2). Such lower than average spring flow from the Merrimack River can result in relatively high salinities and seawater moving slowly through Massachusetts Bay, factors that may lead to low dissolved oxygen concentrations.



**Figure 3-2. Flows of the Merrimack (top) and Charles (bottom) rivers.** Dark red lines are 2018 data. Results from 1992–2017 are in light blue. The quarterly percentiles represent the 2018 flows in comparison to the entire 27-year record.

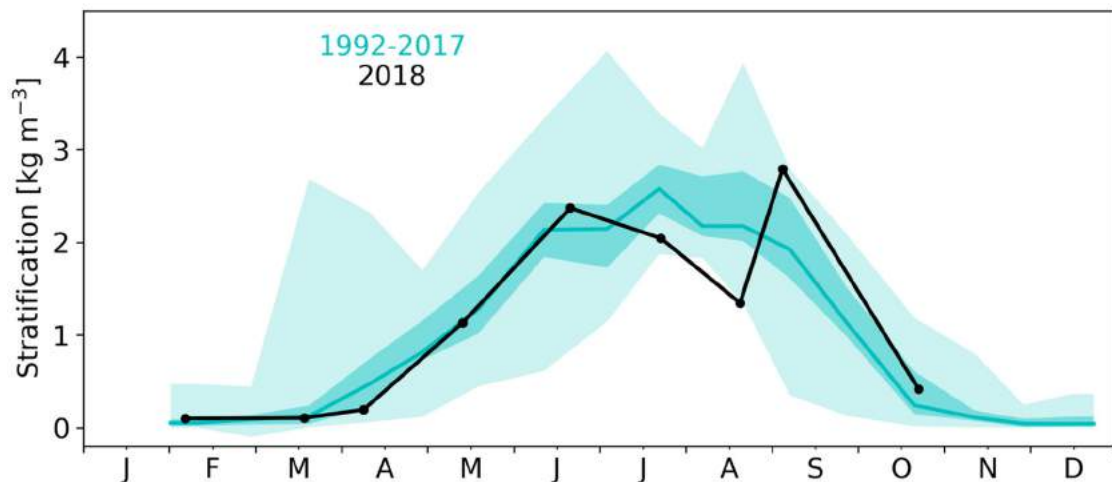
Warm temperature is another factor that can contribute to low dissolved oxygen levels. Surface-water temperatures, measured at Buoy 44013 (Figure 3-3) were average at the beginning and end of the year, but especially warm in the late summer, a result of warm air and oceanographic conditions (Libby et al. 2019). At nearby Station N18 (not shown), surface and bottom temperatures similarly began the year at the approximate median for the monitoring program and remained close to average through June, were higher than usual in July and August, and then returned to average in September. The August bottom temperature at Station N18 was the highest measured at that station over the years of monitoring, above 15°C.





**Figure 3-3. Surface-water temperature at Buoy 44013 in 2018 compared to prior years.** Vertical dashed lines denote timing of MWRA surveys.

Typically, waters in Massachusetts Bay stratify into distinct shallow and deep layers during the spring, as surface temperatures warm, and freshwater flows reduce surface salinities. In 2018, that usual pattern was disrupted during the summer, particularly by the unusual August storm, which mixed warm surface water downward at Station N18 (Figure 3-4). The water column re-stratified following the storm, and then destratified with the typical cooling and mixing events during the fall.



**Figure 3-4. Stratification at nearfield Station N18 in 2018 compared to prior years.** Black points and line are results from 2018. Results from 1992–2017 are in blue: line is 50<sup>th</sup> percentile, dark shading spans the 25<sup>th</sup> to 75<sup>th</sup> percentile, light shading spans the range.

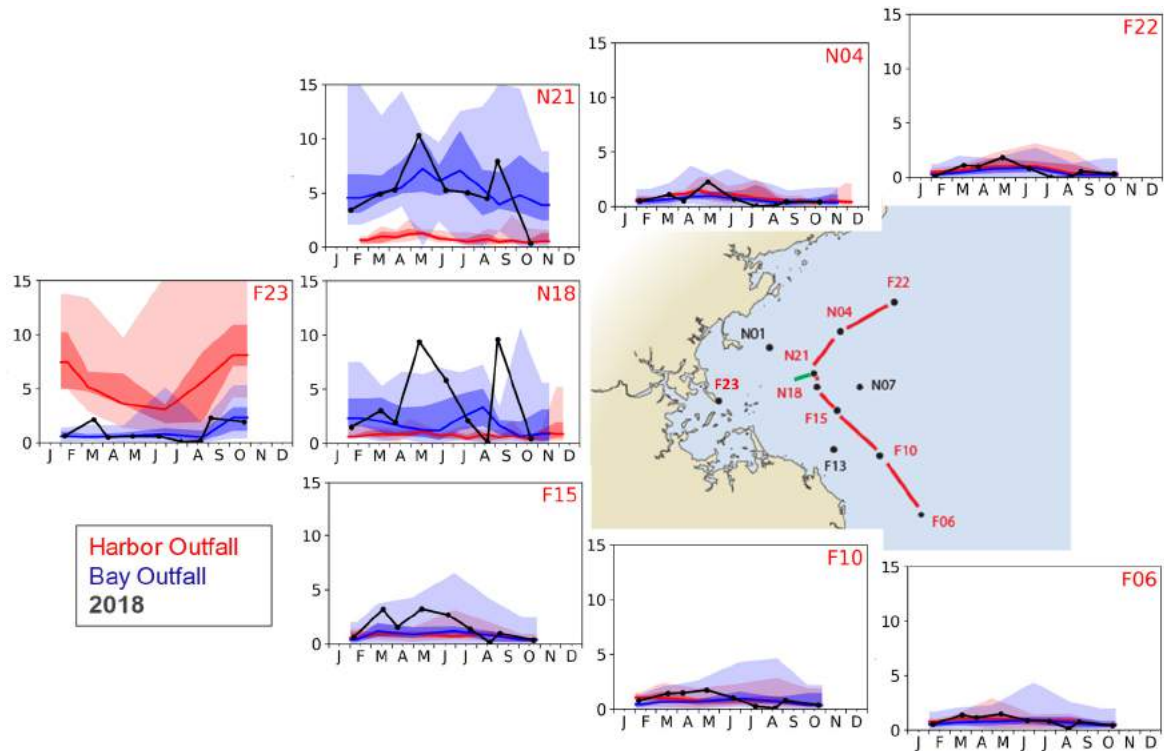
## **Water Quality**

Water quality measurements for 2018 included quantification of nutrients, phytoplankton biomass, and dissolved oxygen. Results continued to confirm predictions of measurable outfall influence in some parameters, but only at stations very near the outfall. There were no unexpected or environmentally adverse effects (Libby et al. 2019).

### **Nutrients**

Dissolved inorganic nutrient concentrations (nitrogen, phosphorus, and silica) in the nearfield fell mostly within the ranges measured in previous years. Ammonium is the largest fraction of the total nitrogen in wastewater (see Figure 2-5, above) and provides a tracer that could identify possible adverse effects of the outfall, if they were to occur. During 2018, as in other years since the Massachusetts Bay outfall startup, elevated ammonium concentrations were detected at Station N21, located just 60 meters from the outfall, at Station N18, 2.5 kilometers to the south, and during some surveys, at Station F15, nine kilometers to the southeast.

The ammonium signature in 2018 was especially apparent during the May and September surveys (Figure 3-5). Concentrations were consistently low at Station F23 at the mouth of Boston Harbor, at other Massachusetts Bay stations, and in Cape Cod Bay. Concentrations at Station F23 at the mouth of Boston Harbor remained well below baseline levels, as they have been since the discharge was diverted from the harbor to Massachusetts Bay in 2000. Overall, the ammonium signature of the outfall was typical of the years since the discharge relocation.



**Figure 3-5. Depth-averaged ammonium concentrations at selected stations in 2018 compared to prior years.** Black points and line are results from individual surveys in 2018. Red lines and shading show data from Boston Harbor discharge years. Results from September 2000–2017 are in blue. Line is the 50<sup>th</sup> percentile, dark shading spans the 25<sup>th</sup> to 75<sup>th</sup> percentile, and light shading spans the range.

As in previous years, the plume’s ammonium signature was evident in surface waters during the winter and spring when the water column was relatively well-mixed (Figure 3-6) but was confined beneath the pycnocline during the summer, stratified season (Figure 3-7). The distances where the ammonium signature could be detected during both stratified and unstratified seasons remained consistent with predictions made during planning for the outfall.

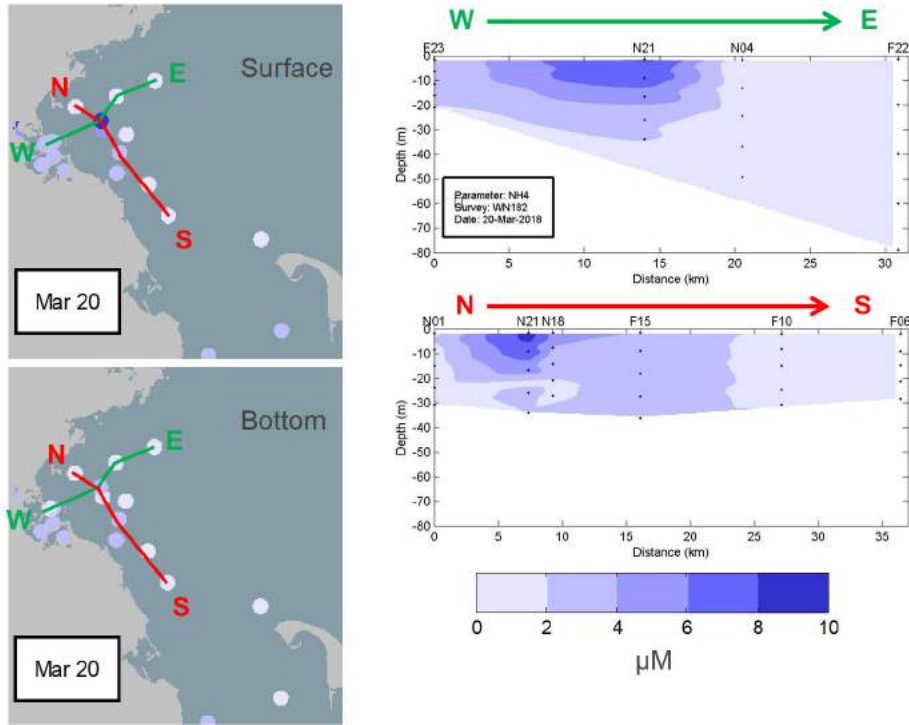


Figure 3-6. (Left) Surface- and bottom-water ammonium on March 20, 2018 during mixed conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations. Station N21 is directly over the outfall.

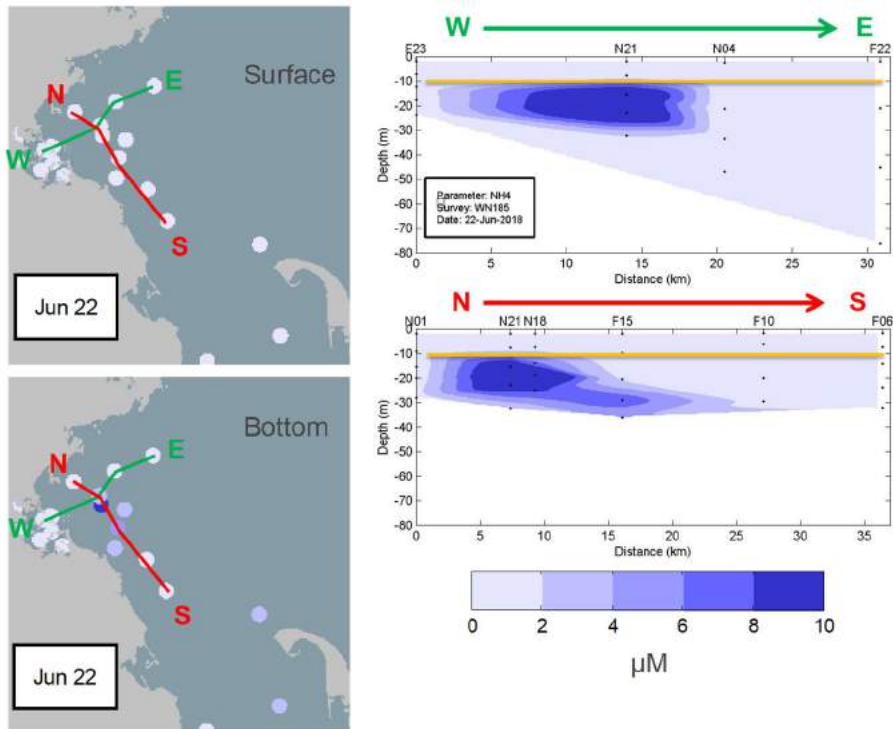


Figure 3-7. (Left) Surface- and bottom-water ammonium on June 22, 2018 during stratified conditions. (Right) Cross-sections of concentrations throughout the water column along transects connecting selected stations. The orange line indicates the approximate depth of the pycnocline.

## Phytoplankton Biomass

Despite the elevated ammonium levels, no increase in phytoplankton biomass (measured as chlorophyll and particulate organic carbon), has been evident since the discharge began, even at stations closest to the outfall, and none was measured in 2018 (Figure 3-8). Satellite imagery and data from Buoy A01 (not shown) suggested that moderate chlorophyll levels in the fall of 2017 persisted through the winter but decreased abruptly with the March 2018 storm. Chlorophyll levels increased in April in Boston Harbor, in offshore waters northeast of the outfall, and in Cape Cod Bay. The increases corresponded to blooms of diatoms *Skeletonema* spp. in the harbor, the large, chlorophyll-rich diatom *Rhizosolenia herbetata* offshore to the northeast, and the colonial flagellate *Phaeocystis pouchetii* in Cape Cod Bay. Typical healthy blooms of the diatoms *Skeletonema* spp. were responsible for the elevated concentrations in the fall. Satellite imagery further showed that these fall blooms persisted until October and November, after the end of the survey season.

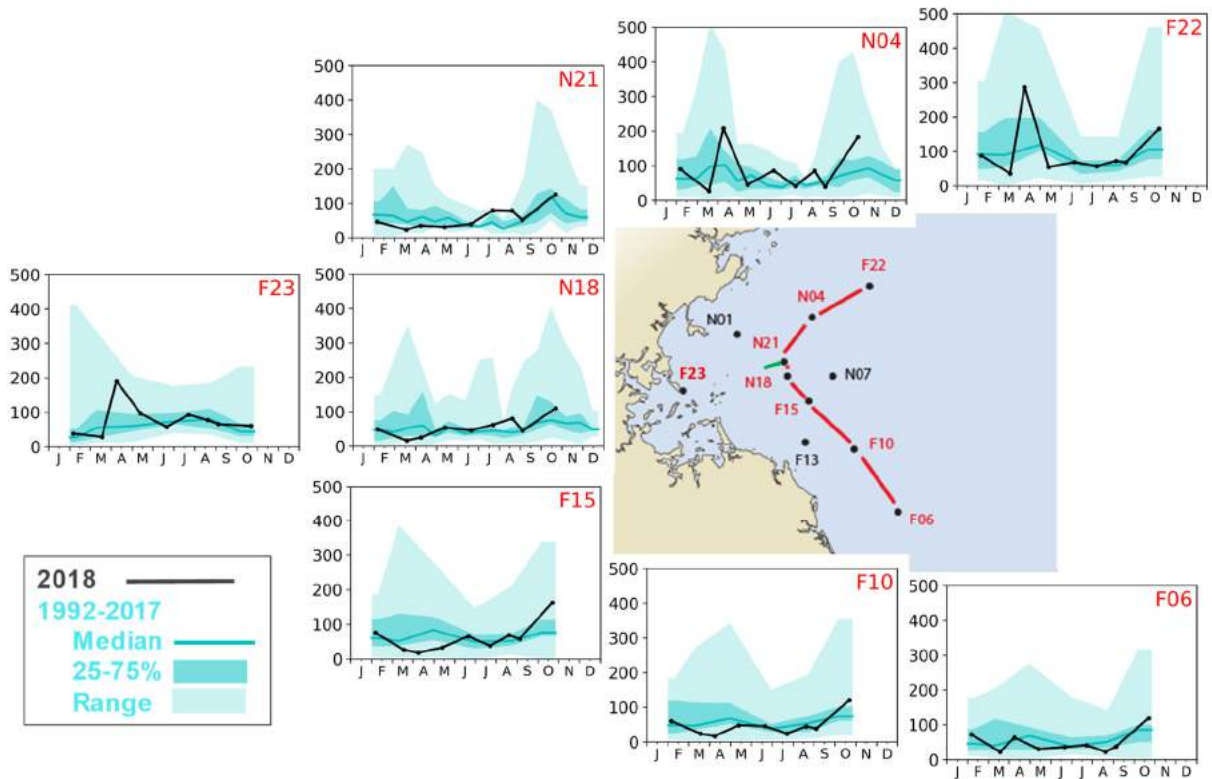
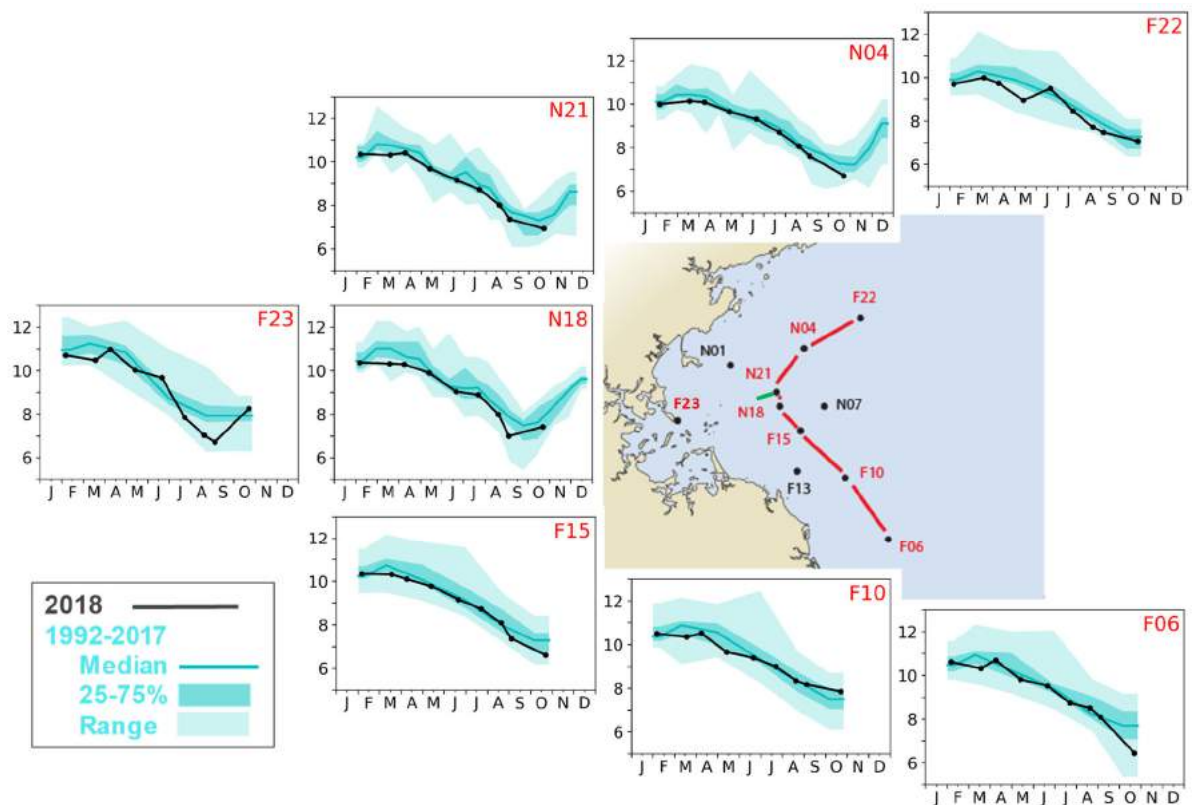


Figure 3-8. Station average areal chlorophyll concentrations (milligrams per square meter) at selected stations in 2018 compared to prior years. (For some stations, historic data extend later in the year than the current survey schedule.)

## Dissolved Oxygen

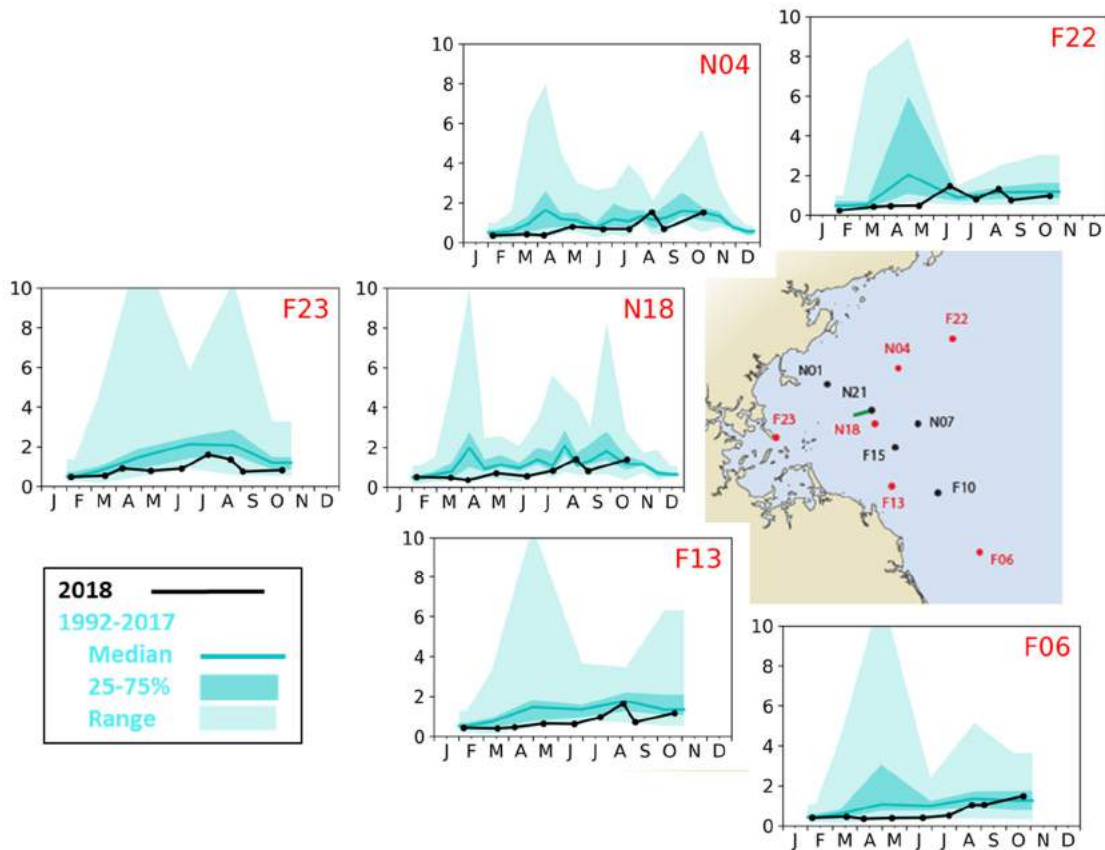
Based on spring salinity and temperature measurements, late summer dissolved oxygen concentrations were expected to be relatively low in 2018. As in 2017, levels of dissolved oxygen in near-bottom waters were lower than average during the early months of the year (Figure 3-9). Typically, concentrations of dissolved oxygen in bottom waters of Massachusetts Bay fall steadily from highest concentrations in the spring to lowest in the fall, with recovery after the breakdown of stratification in the fall, but this pattern can be disturbed by storms or other mixing events. Field and buoy data in 2018 confirmed that upwelling in June and the storm in August slowed the rate of decline, and minimum levels were higher than had been predicted at the start of the year. Mixing in the fall re-aerated the water column, after the end of the survey season but shown by data from the instrumented buoys (see results from Stellwagen Bank National Marine Sanctuary, below). Measurements remained well above the 6 milligrams per liter water quality standard, with minimum levels considered moderate for the region.



**Figure 3-9. Near-bottom water dissolved oxygen concentrations (milligrams per liter) in 2018 compared to prior years.** (For some stations, historic data extend later in the year than the current survey schedule.)

## Phytoplankton Communities

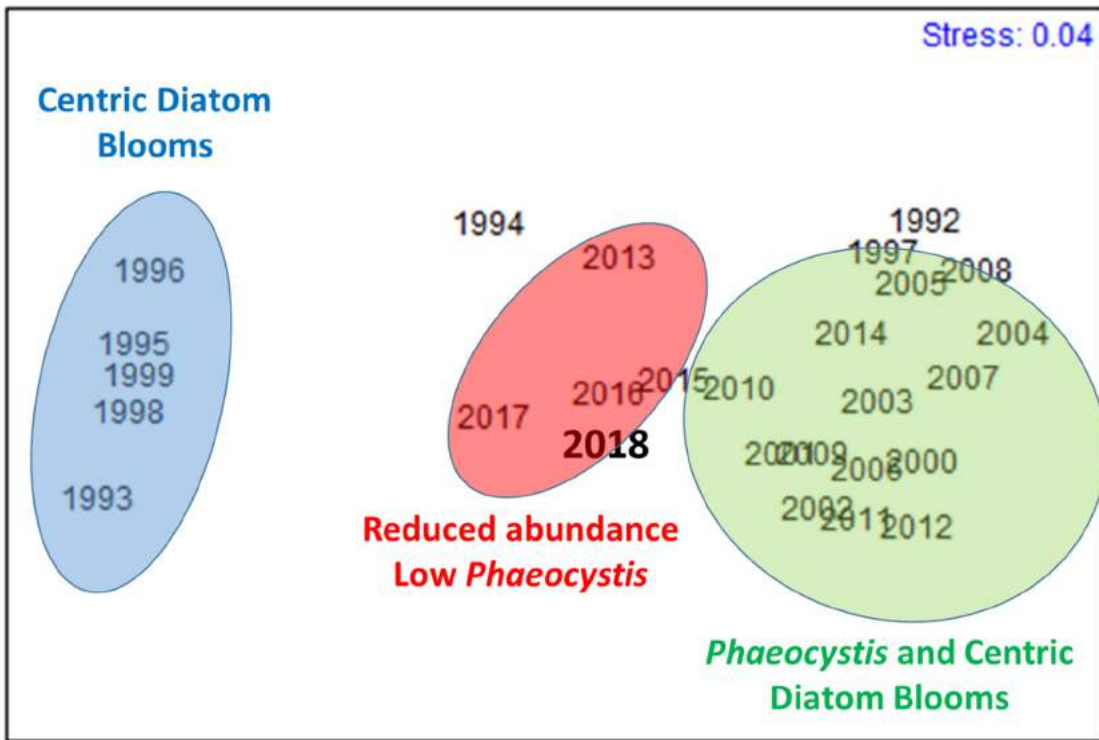
As in recent years, total observed phytoplankton abundances were somewhat low throughout the year and throughout Massachusetts Bay (Figure 3-10, Libby et al. 2019). In the nearfield, overall abundance was 56% of the long-term mean, ranking 23 out of 27 years of monitoring. The relatively low abundance can be partially explained by a lack of a winter-spring diatom bloom during the survey season and also by the absence of a bloom of the nuisance colonial flagellate *Phaeocystis pouchetii* in Massachusetts Bay, as has occurred in some monitoring years.



**Figure 3-10. Total phytoplankton abundance (million cells per liter) at selected stations in 2018 compared to prior years.** (For some stations, historic data extend later in the year than the current survey schedule.)

Microflagellates continued to be the most abundant species group, comprising about 63% of the total abundance, but were present at only 72% of their long-term average, another factor in the low overall phytoplankton abundance. Diatom abundance was moderately low, with some centric diatoms occurring in numbers that approximated the long-term average and other species occurring at lower levels. Dinoflagellate abundance was also below the long-term mean.

Ordination analysis suggests that there have been three phytoplankton abundance patterns over the course of monitoring (Figure 3-11). During many of the baseline years, the community was dominated by centric diatoms. In other baseline years, there were both diatom and spring *Phaeocystis* blooms, and this pattern continued after the outfall relocation, for most of 2000–2012. Since 2013, total phytoplankton and *Phaeocystis* abundances have been relatively low, both in the nearfield and throughout Massachusetts Bay. These regional patterns have not been associated with the outfall but are likely controlled by natural physical and biological conditions.



**Figure 3-11. Ordination plot of phytoplankton abundance by year, 1992–2018.** Similarity of species composition is indicated by proximity of points on the plot. Stress is a measure of how well the ordination results represent the raw; a stress of 0.04 indicates excellent representation.



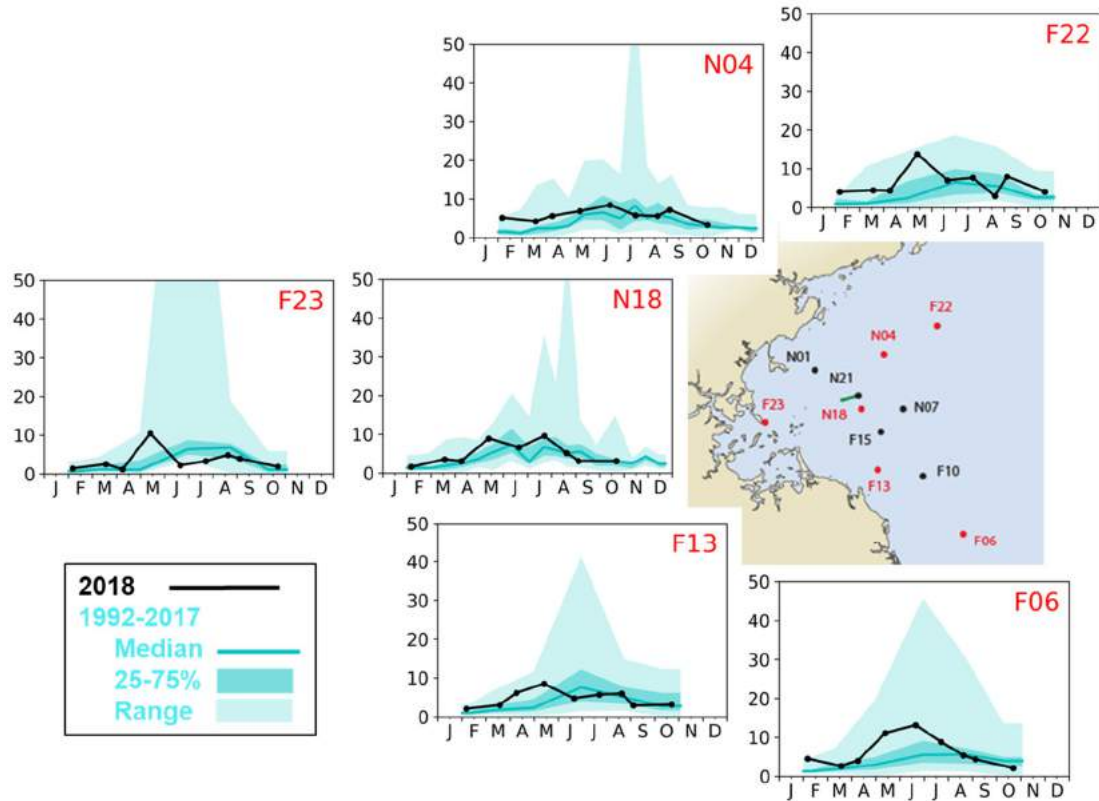
The potentially toxic genus of pennate diatoms, *Pseudo-nitzschia*, was present in 2018, but only in very low numbers. At high abundance, domoic acid produced by some species of *Pseudo-nitzschia* can cause amnesic shellfish poisoning (ASP), a life-threatening illness. *Pseudo-nitzschia* spp. abundance in Massachusetts Bay in 2018 was well below levels that could cause ASP.

Abundance of the toxic dinoflagellate *Alexandrium catenella* was also low in 2018, essentially absent and not reaching a level that would trigger special surveys, as occurs in some years. *Alexandrium catenella* blooms cause paralytic shellfish poisoning (PSP), another life-threatening condition. In 2018, there were no new PSP-related shellfish closures in Massachusetts Bay or north of Cape Ann. In years when blooms have occurred in Massachusetts Bay, they have originated from cells from established cyst beds off the coast of Maine.

For a second consecutive year, an unusual dinoflagellate *Karenia mikimotoi* was detected but in lower abundance than it was found in 2017. *Karenia mikimotoi* has been classified as potentially harmful, but its toxicity is not well understood. (It is not the same species of *Karenia* that was responsible for persistent harmful algal blooms in Florida and Texas in 2018.)

## **Zooplankton Communities**

Zooplankton communities continued to be dominated by the typical mix of copepod nauplii, copepodites, and adults and by meroplankton, those animals that are planktonic for only a portion of their lives. The small copepod *Oithona similis* continued to dominate most samples, with *Acartia* spp. dominating in Boston Harbor and the much larger *Calanus finmarchicus* sometimes dominating in offshore samples. Annual peak abundances of total zooplankton were higher than many years of the monitoring period, in the upper 75<sup>th</sup> percentile at many stations (Figure 3-12, Libby et al. 2019). There were no extreme peaks, such as the bivalve veliger larvae that drove total abundance peaks to record highs in July and August of 2015.



**Figure 3-12. Total zooplankton abundance (10,000 animals per square meter) at selected stations in 2018 compared to prior years.** (For some stations, historic data extend later in the year than the current survey schedule.)

Trend analysis has shown a sustained decrease in total copepodite and adult copepod abundance during 2000–2006, followed by an increase in 2006–2017, and a possible leveling off in 2018. Opposite trends in phytoplankton abundance suggest zooplankton grazing may be an important factor for both phytoplankton and zooplankton communities (Figure 3-13). The trend analysis also supports the results of the ordination analysis (Figure-3-11, above), which identified lower abundance assemblages in 2013–2018.

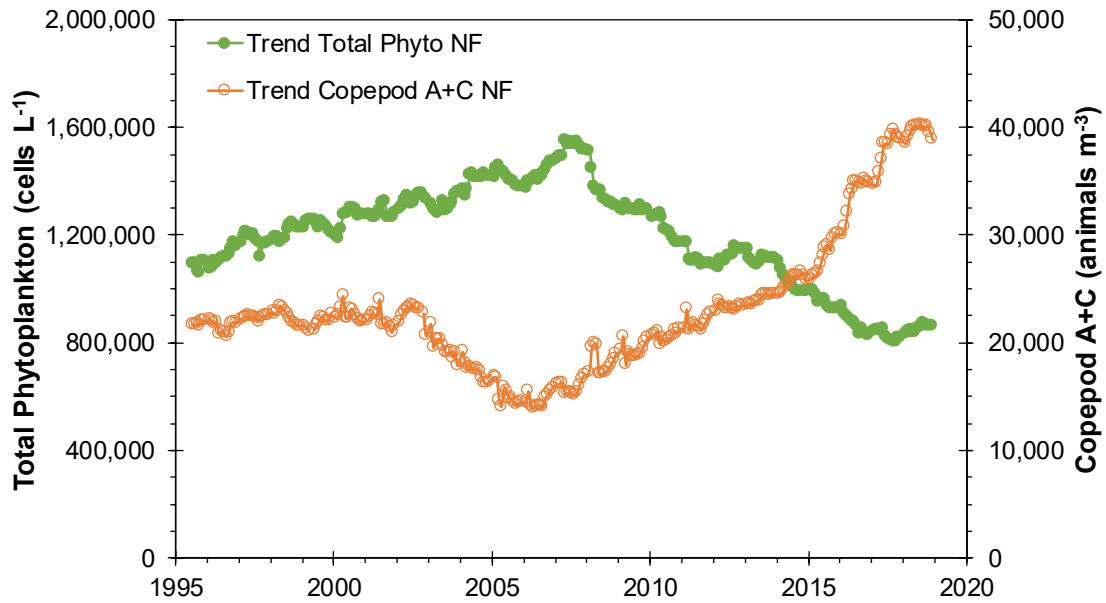


Figure 3-13. Trends in abundance of total phytoplankton (green, solid dots) and copepod adults and copepodites (orange, open circles) in the nearfield.

## 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 the Stellwagen Bank National Marine Sanctuary. Water column Station F22 is in Stellwagen Basin, just to the west of the sanctuary and is considered to be representative of northern, offshore conditions.

Ammonium levels have remained low at Station F22 since the outfall began to discharge (see, for example, Figure 3-5, above). Levels have also remained low at Station F06, located 29 kilometers to the southeast and offshore from the outfall and to the west of the sanctuary.

Sampling at Station F22, as well as data from Buoy A01 and satellite imagery, detected no unusual chlorophyll levels in offshore regions in 2018. No effects on chlorophyll levels in the offshore, including the sanctuary, were predicted and none have been measured.

Deep and near-bottom dissolved oxygen concentrations at Station F22 in Stellwagen Basin were healthy throughout 2018. Both survey observations and data from Buoy A01, located within the sanctuary, showed the typical decline during the stratified season (Figure 3-14). Data from the buoy documented the return to oxygenated conditions following fall mixing events.

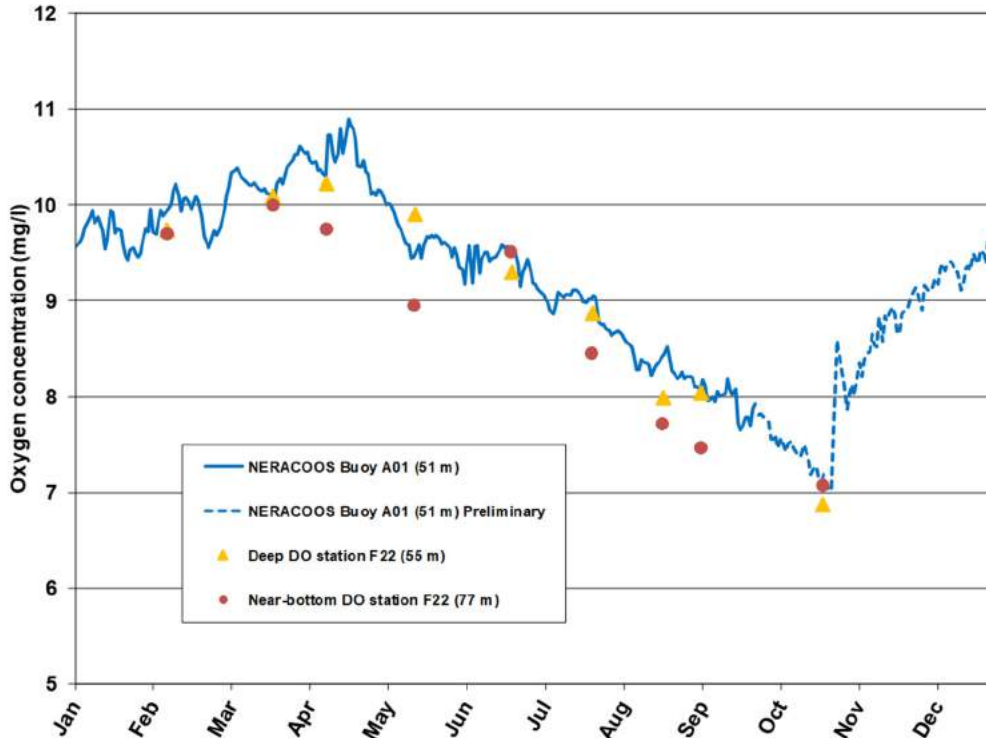


Figure 3-14. Dissolved oxygen at Buoy A01 and at Station F22 in Stellwagen Basin. NERACOOS = Northeastern Regional Association of Coastal and Ocean Observing Systems DO = dissolved oxygen

## Boston Harbor Water Quality

Water quality in Boston Harbor has greatly improved during the past 20 years, and those improvements were sustained in 2018. MWRA’s in-house Boston Harbor monitoring program confirmed that harbor-wide concentrations of total nitrogen and phosphorus remained low, as they have since effluent discharges to the harbor ended.

Perhaps the most dramatic improvement in Boston Harbor has been the decrease in ammonium levels (see Figure 3-5, above). Ammonium concentrations dropped precipitously when the effluent discharge was diverted from the harbor to Massachusetts Bay in 2000 and have remained low. The decreases in nutrient inputs have been accompanied by decreases in primary production and phytoplankton biomass, an abatement of the historic high level of eutrophication that is typical from over-stimulation of phytoplankton growth in urban bays (reviewed in the 2017 outfall monitoring overview, Werme et al. 2018).

## Contingency Plan Thresholds

There were no water-column threshold exceedances in 2018 (Table 3-1). All water quality parameters remained within normal ranges, and there were no nuisance algal blooms.

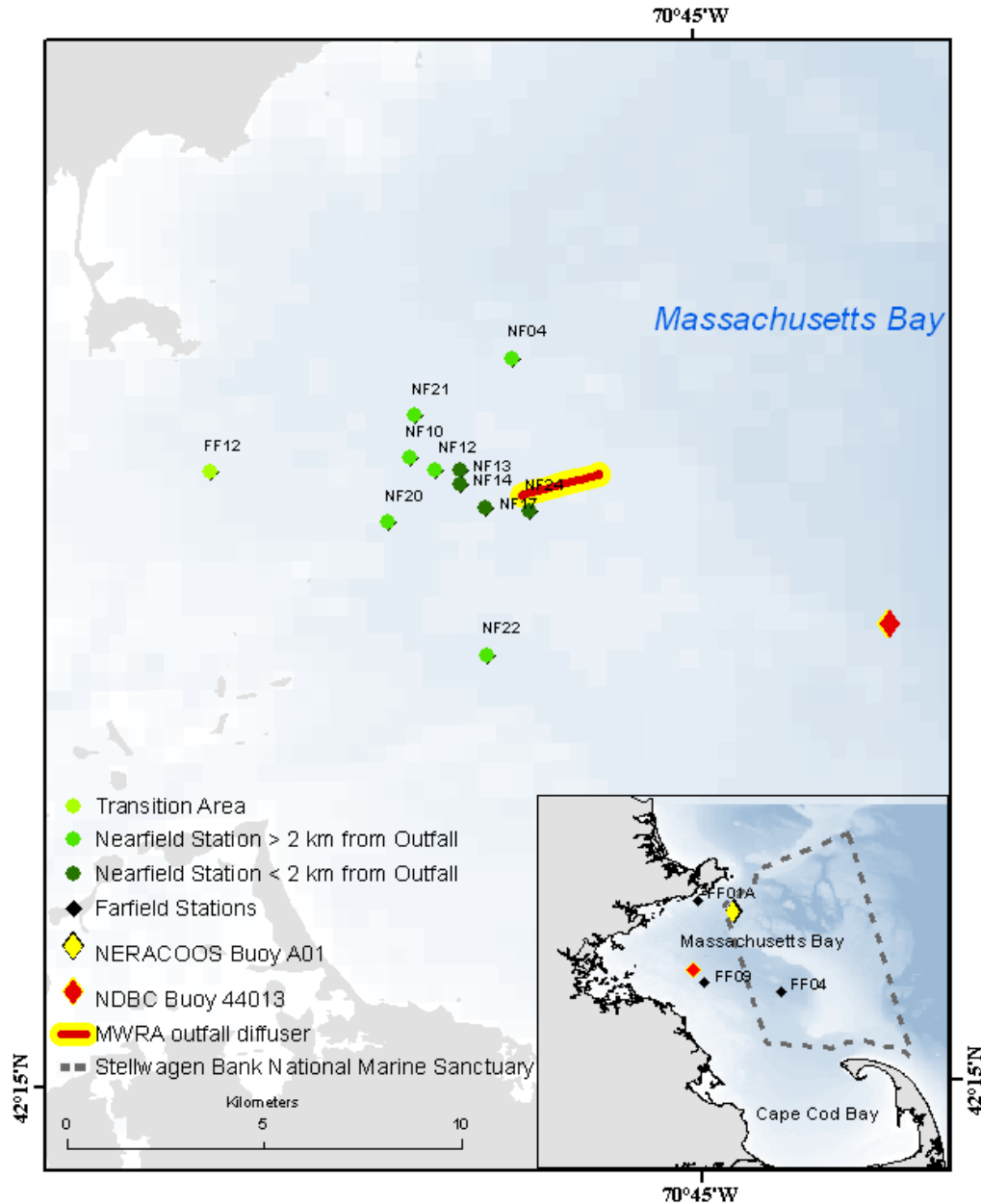
**Table 3-1. Contingency Plan threshold values and 2018 results for water-column monitoring.**

Parameter	Baseline	Caution Level	Warning Level	2018 Results
<b>Dissolved oxygen*</b>				
Nearfield concentration	6.05 mg/L	<6.5 mg/L	<6.0 mg/L	6.83 mg/L
Nearfield percent saturation	65.3%	<80%	<75%	75.5%
Stellwagen concentration	6.23 mg/L	<6.5 mg/L	<6.0 mg/L	7.07 mg/L
Stellwagen percent saturation	67.2%	<80	<75%	76.3%
Nearfield depletion rate	0.024 mg/L/d	>0.037 mg/L/d	>0.049 mg/L/d	0.020 mg/L/d
<b>Chlorophyll</b>				
Annual	72 mg/m <sup>2</sup>	>108 mg/m <sup>2</sup>	>144 mg/m <sup>2</sup>	71 mg/m <sup>2</sup>
Winter/spring	51 mg/m <sup>2</sup>	>199 mg/m <sup>2</sup>	None	73 mg/m <sup>2</sup>
Summer	50 mg/m <sup>2</sup>	>89 mg/m <sup>2</sup>	None	58 mg/m <sup>2</sup>
Autumn	90 mg/m <sup>2</sup>	>239 mg/m <sup>2</sup>	None	95 mg/m <sup>2</sup>
<b>Nuisance algae nearfield <i>Pseudo-nitzschia</i></b>				
Winter/spring	6,735 cells/L	>17,900 cells/L	None	122 cells/L
Summer	14,635 cells/L	>43,100 cells/L	None	245 cells/L
Autumn	10,500 cells/L	>27,500 cells/L	None	518 cells/L
<b>Nuisance algae nearfield <i>Alexandrium catenella</i></b>				
Any nearfield sample	Baseline maximum 163 cells/L	>100 cells/L	None	4 cells/L
PSP toxin extent	NA	New incidence	None	No new incidence

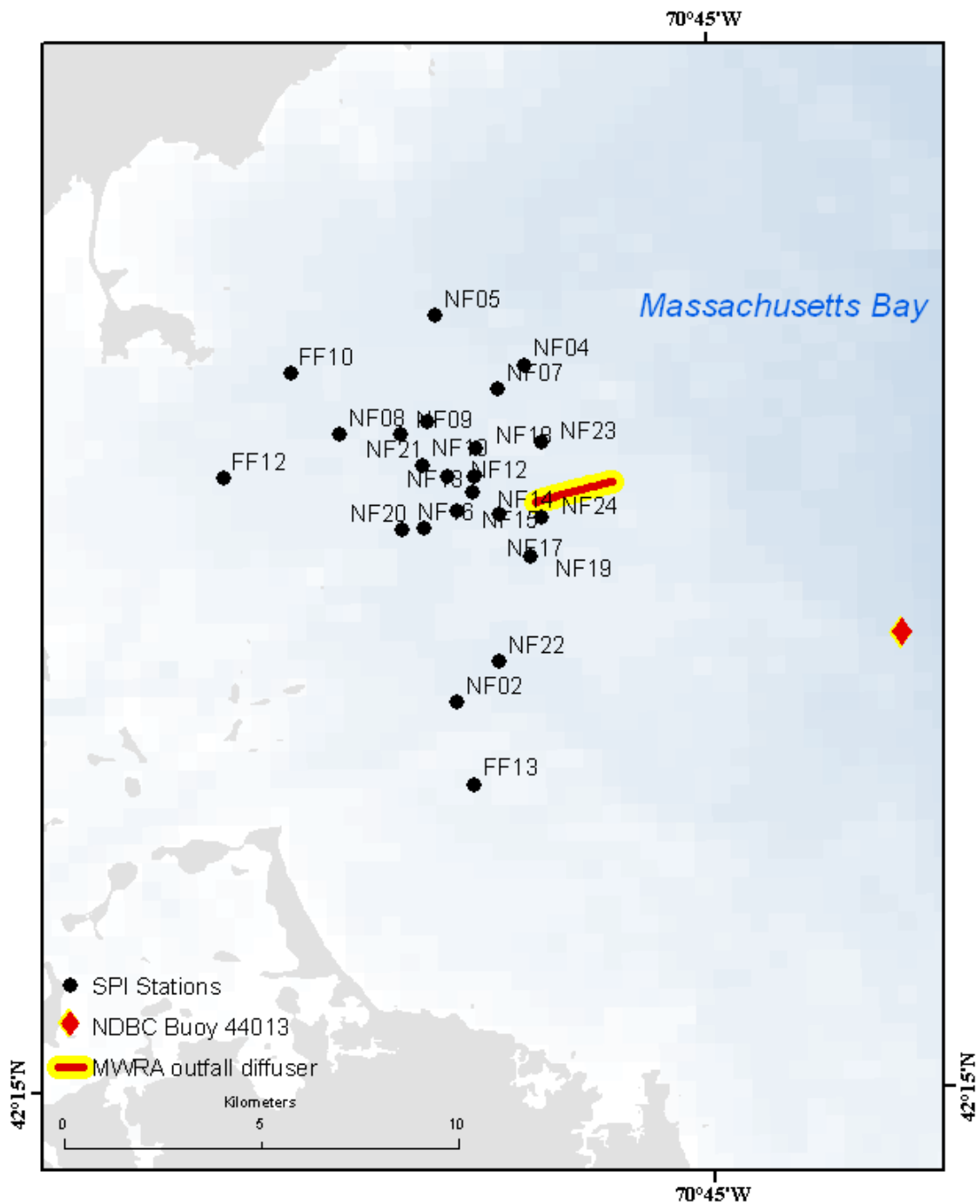
\*Dissolved oxygen caution and warning levels represent numerical criteria, with the caveat “unless background conditions are lower.” Results are therefore compared to the baseline rather than to the caution and warning levels. PSP = paralytic shellfish poisoning NA = not applicable

## 4. Sea Floor

Seafloor monitoring in 2018 included sampling and analysis of soft-bottom sediment conditions, effluent tracers, and infauna at 14 stations and sediment-profile imaging at 23 stations (Figures 4-1 and 4-2). Anthropogenic contaminants analyses and video assessment of 23 hard-bottom stations occur at three-year intervals, most recently in 2017.



**Figure 4-1. Soft-bottom monitoring stations.** Also shown are the instrumented buoys, the MWRA outfall diffuser, and the Stellwagen Bank National Marine Sanctuary. NERACOOS = Northeastern Regional Association of Coastal and Ocean Observing Systems NDBC = National Data Buoy Center



**Figure 4-2. Sediment-profile imaging stations.** Also shown are Buoy 44013 and the MWRA outfall diffuser. SPI = sediment-profile imaging

Soft-bottom sediment sampling was completed in August 2018, with samples analyzed for grain-size distribution, the effluent tracer *Clostridium perfringens* spores, total organic carbon, and benthic infauna. The 14 stations included four nearfield stations located within two kilometers of the outfall (NF13, NF14, NF17, NF24); six nearfield stations located within western Massachusetts Bay but farther than two kilometers from the outfall (NF04, NF10, NF12, NF20, NF21, NF22); one station in the “transition” area, located between Boston Harbor and the nearfield stations (FF12); and three farfield reference stations located in Massachusetts Bay and Cape Cod Bay (FF01A, FF04, and FF09). For the purposes of threshold testing, “nearfield” includes the transition station, as well as both nearfield groups, for a total of eleven stations.

Sediment-profile imaging was also completed in August 2018. Triplicate images from 23 stations were used to measure the apparent reduction-oxidation (redox) potential discontinuity (RPD) depth, an approximation of the depth that oxygen penetrates the sediments, and to assess the status of the bottom community.

## **Sediment Characteristics and Tracers**

As in past years, sediment grain-size distributions in 2018 varied broadly among stations, ranging from silt and clay at some stations to almost entirely sand at others (Rutecki et al. 2019). Sediment grain-size distributions have remained generally consistent at individual stations over the years of the monitoring program. When changes do occur, they have been mostly associated with large storms with wave-driven currents sufficient to resuspend bottom sediments. The 2018 samples, however, showed no changes that could be attributed to the intense March storm described in Section 3.

As in past years since the offshore outfall began to discharge, it was possible to detect elevated levels of the effluent tracer *Clostridium perfringens* spores at some stations located closest to the outfall (Figures 4-3). *Clostridium* are anaerobic bacteria found in mammalian (including human) digestive tracts and that form persistent spores in oxygen-rich conditions. In 2018, the average *Clostridium* abundance at stations located within two kilometers of the outfall remained elevated above what was observed in the late 1990s, but was relatively low compared to other recent years. Statistical analyses have shown that the increases close to the discharge are consistent with predictions made during planning for the outfall.

Percent organic carbon content analyses were also consistent with past results, with no increased organic carbon in any area, even the station group closest to the outfall (Figure 4-5). In general, stations with finer sediments, such as Station FF04 within Stellwagen Basin, have higher mean total organic carbon concentrations, while stations with coarser sediments have lower concentrations. There was an increase in organic carbon levels at Station NF17 just to the south of the outfall in 2018 (not shown), but the concentrations were not consistently higher than baseline conditions. Total organic carbon concentrations continue to show no signs of organic enrichment.



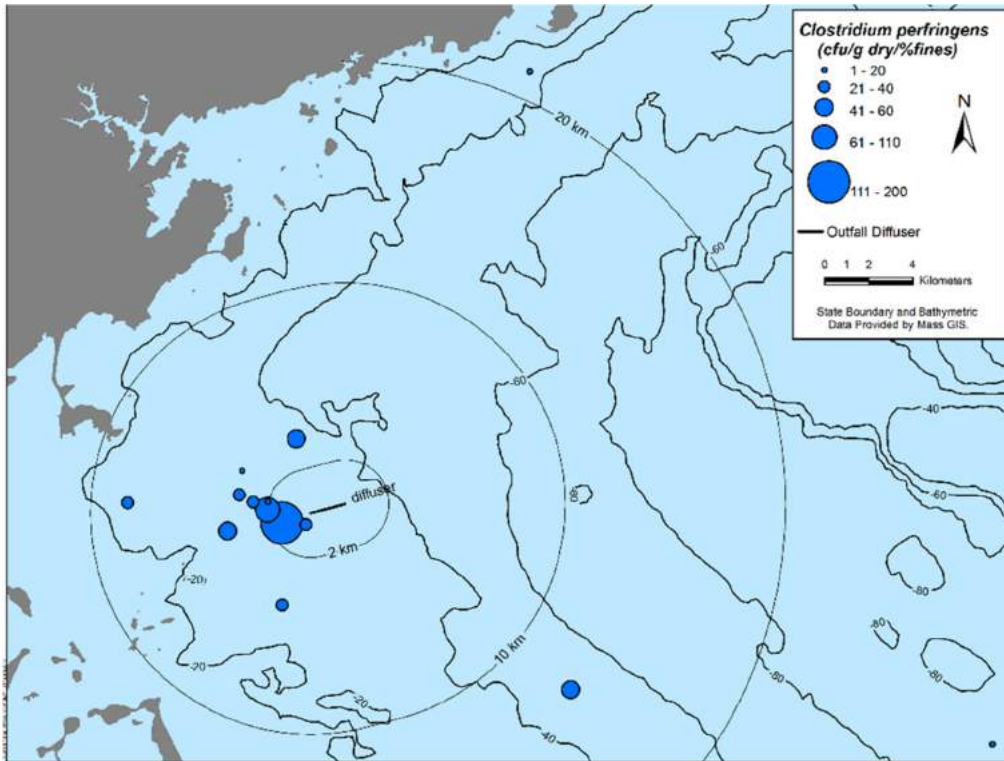


Figure 4-3. Concentrations of *Clostridium perfringens* spores, corrected for sediment grain size, in 2018.

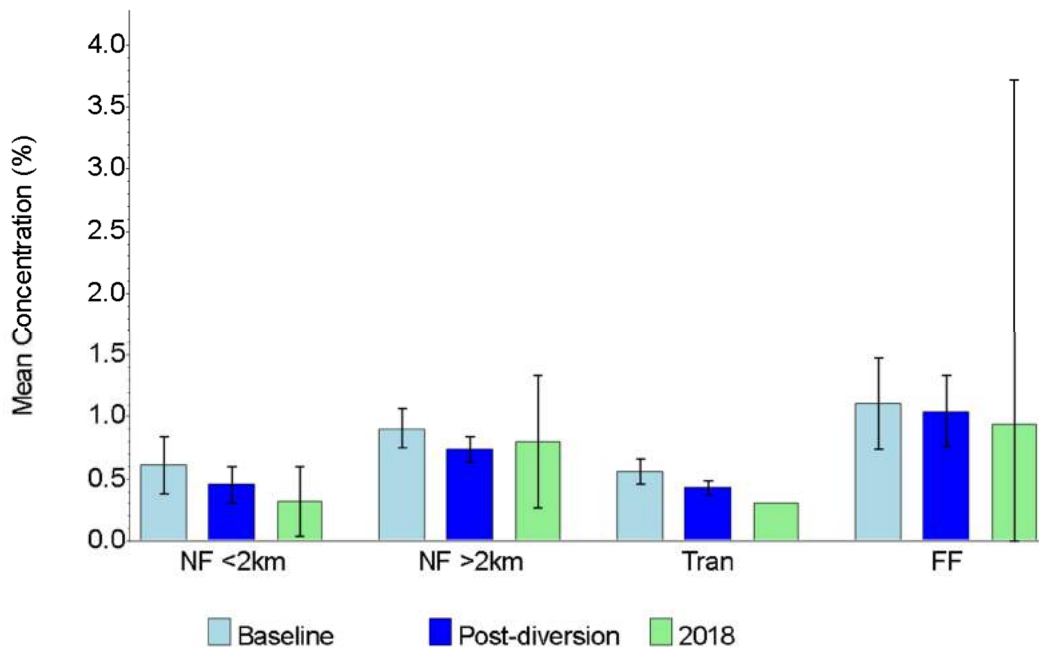
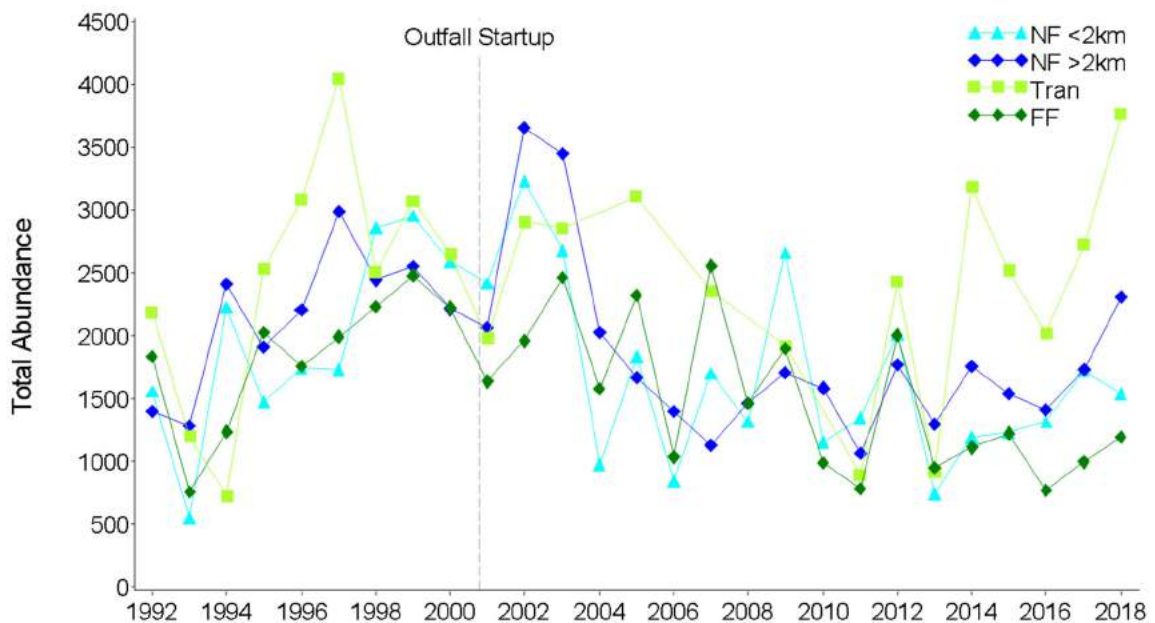


Figure 4-4. Percent total organic carbon (with 95% confidence intervals) by location during baseline (Boston Harbor discharge), post-diversion years (Massachusetts Bay discharge), and 2018 by region. NF <2km = nearfield within two kilometers of the outfall; NF >2km = nearfield farther than two kilometers from the outfall; Tran = area between Boston Harbor and the outfall; FF = farfield. The 2018 results have wider confidence intervals than baseline and post-diversion data, because they represent fewer samples.

## Soft-bottom Communities

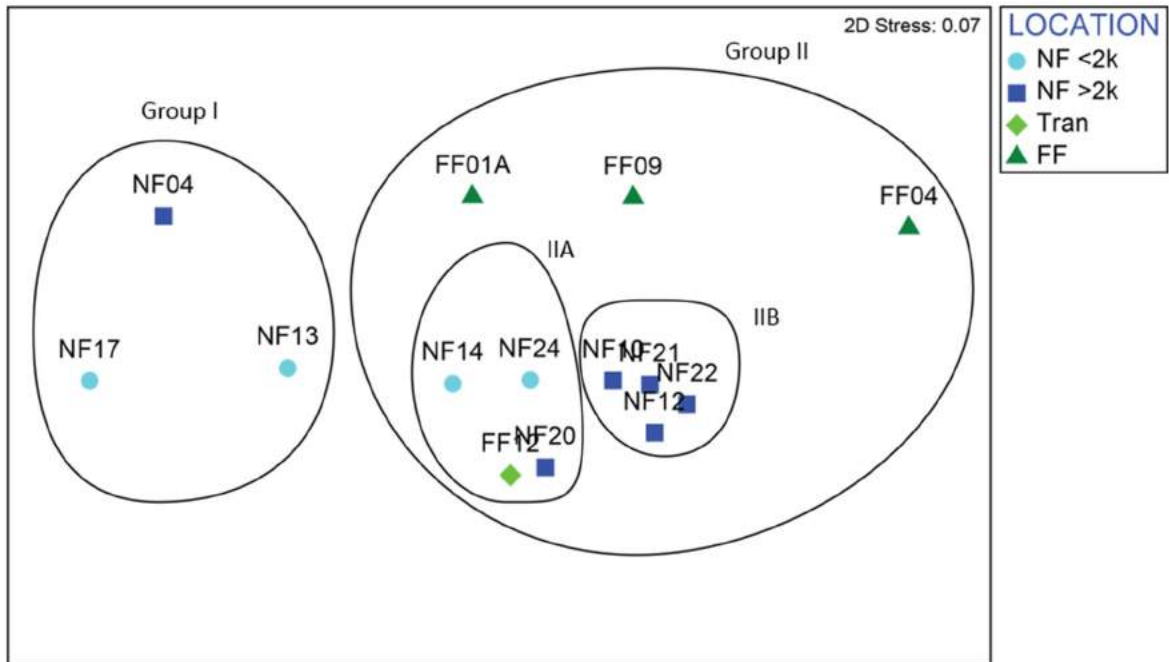
The 14 soft-bottom samples collected and analyzed in 2018 yielded 27,352 organisms, classified into 175 species and 20 other discrete taxonomic groups (Rutecki et al. 2018). Total abundance of organisms was higher in 2018 than in 2017 at many stations, and as in recent years, the highest measured abundance was at the only station within the transition area located between the harbor and the nearfield (Figure 4-5). The numbers of species per sample and diversity measures (not shown) were lower than in 2017 and other recent years but remained within the range measured throughout the monitoring program. The relatively low diversity at nearfield stations could be attributed to high numbers of two dominant polychaete species, *Aricidea catherinae* and *Tharyx acutus*. The apparent variability in total abundance and diversity over time reflects broad regional patterns.



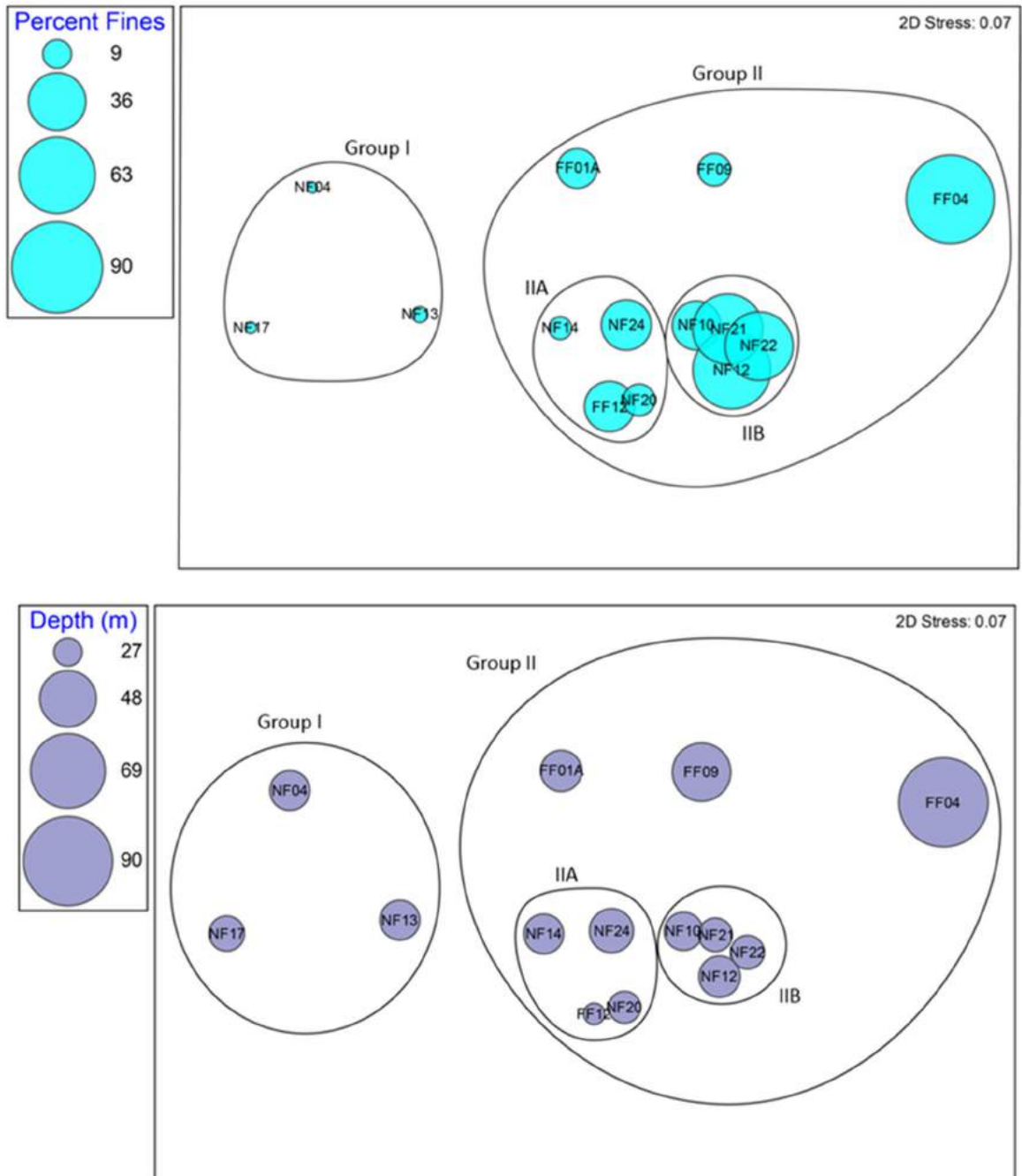
**Figure 4-5. Total abundance of soft-bottom organisms by region, 1992–2018.** NF <2km = nearfield within two kilometers of the outfall; NF >2km = nearfield farther than two kilometers from the outfall; Tran = area between Boston Harbor and the outfall; FF = farfield.

Community analyses showed no effects of the outfall on relative abundance or community composition. A series of multivariate analyses assessed spatial and temporal patterns in the soft-bottom benthic communities and found no particular species or type of community specifically associated with the outfall.

As in past years, a cluster analysis identified two main infauna assemblages, both dominated by polychaete worms. Ordination analysis continued to show no indication of any relation of species composition to proximity to the outfall, with stations closest to the outfall represented in both main assemblages (Figure 4-6). Analyses further continued to demonstrate that variations in species distributions largely followed differences in sediment grain size and depth (Figure 4-7).



**Figure 4-6. Ordination plot of 2018 Massachusetts Bay infauna by location.** Each point on the plot represents one of the 14 stations; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) identified by cluster analysis are circled on the plot. NF <2km = nearfield within two kilometers of the outfall; NF >2km = nearfield farther than two kilometers from the outfall; Tran = area between Boston Harbor and the outfall; FF = farfield. Stress is a measure of how well the ordination results represent the raw; a stress of 0.07 indicates excellent representation.

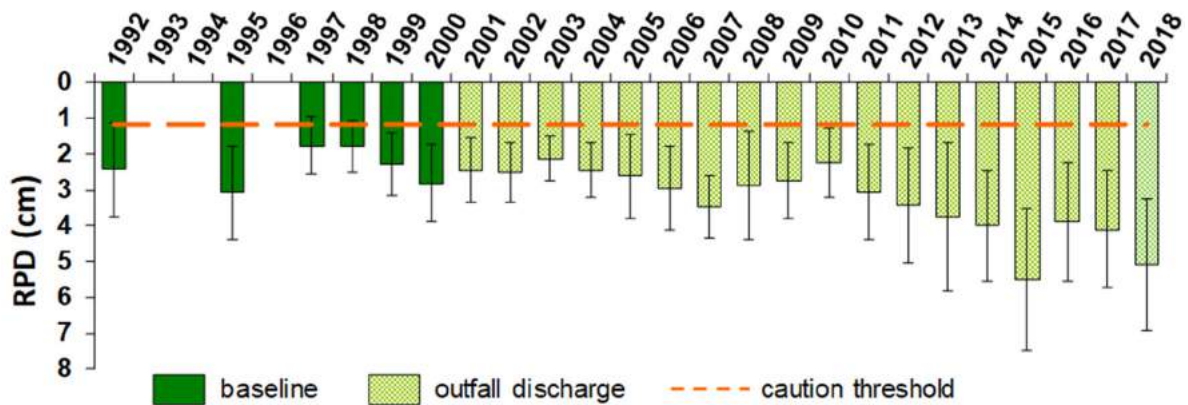


**Figure 4-7. Percent fine sediments (top) and depth (bottom) superimposed on the ordination plot of the 2018 infauna samples.** Each point on the plot represents one of the 14 stations; similarity of species composition is indicated by proximity of points on the plot. Faunal assemblages (Groups I-II, and sub-groups) were identified by cluster analysis. Circles smaller than those in the legend represent proportionally smaller grain size or shallower depth. Stress is a measure of how well the ordination results represent the raw; a stress of 0.07 indicates excellent representation.

## Sediment-profile Imaging

Sediment-profile images continued to show no adverse effects of the outfall (Rutecki et al. 2019). Rough topography and physical processes in the nearfield remained the more important factors in determining benthic habitat quality.

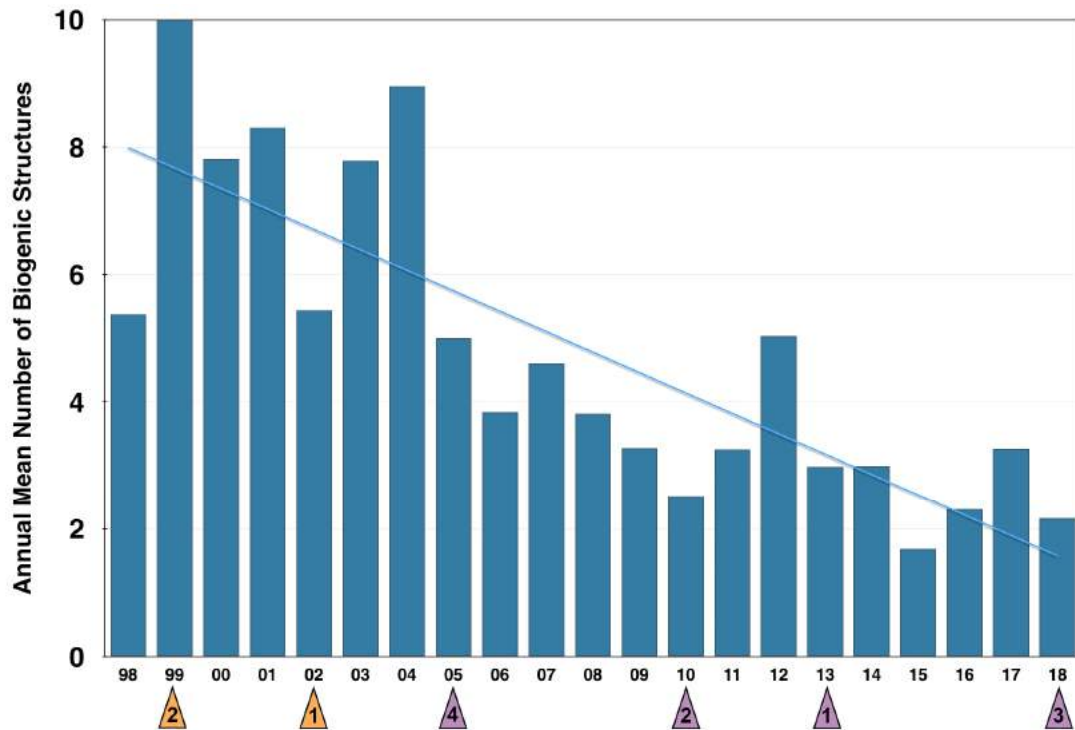
As in past years, the average redox potential discontinuity (RPD) depth (the depth to which oxygen penetrates into sediments as determined by color changes) was deeper than the average RPD measured during the baseline period (Figure 4-8), with a mean depth of 4.8 cm for all stations where RPDs could be measured. At eleven of the 23 stations, the RPD was deeper than the bottom of the images, either because of sandy sediments or sediment compaction. The environmental concern before the outfall began to discharge was that the RPD would become shallower, due to increases in sediment organic matter causing stress on sensitive sediment-dwelling organisms. A deeper RPD in 2018 continued to indicate there have been no adverse effects from the discharge.



**Figure 4-8. Annual apparent color RPD depth for nearfield stations.** The mean RPD has been deeper than in baseline years, a strong indication of no adverse effect from the discharge.

Along with the deepening RPD, nearfield stations have shown an increase in the organism sediment index (OSI, not shown), a measure that integrates RPD depth with the successional stage of the infauna community. Since 2004, the OSI has documented increasingly good habitat quality throughout the nearfield.

While the integrated OSI has increased over time, the number of biogenic structures, such as organisms, burrows, and voids, has decreased (Figure 4-9). The decline appears to be related to the number of winter storms occurring within the year.



**Figure 4-9. Annual mean total biogenic structures, 1998–2018.** The four stormiest years, in terms of number of storms, are indicated by numbered purple triangles. The two least stormy years are indicated by numbered orange triangles.

In general, monitoring has shown that physical rather than biological processes, such as storms and storm-induced sediment transport, can be primary stressors on the Massachusetts Bay sea floor, lessening the chances of any effects of the Massachusetts Bay outfall (see Section 6, Special Studies, for further analysis of storms using wind and wave measurements). At Station FF13 to the southwest of the outfall, for example, biological processes were evident in 1997 and 1998, prior to outfall startup, while physical processes have been particularly evident in recent years (Figure 4-10).

Not all storms resuspend and redistribute sediments, or if they do, the patterns can be unpredictable. For example, as was also evident from the infauna results, sediment-profile imaging showed no obvious effects of the intense March 2018 storm. Sediments sampled after three other stormy years (2005, 2010, and 2013) became finer at some stations and coarser at others.

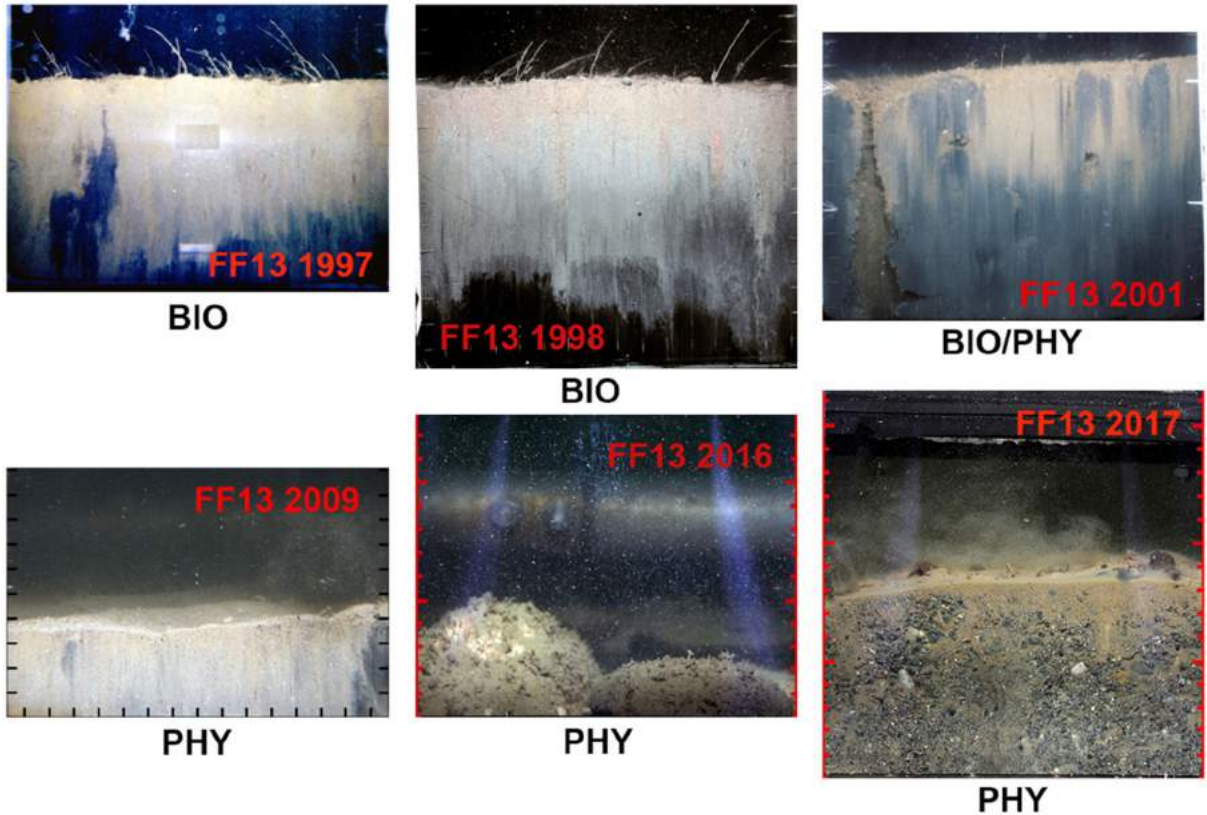


Figure 4-10. Physical and biological forces structuring sediments shown in sediment-profile images from Station FF13, southwest of the outfall, 1997–2017. BIO = biological dominance, PHY = physical dominance. Scales on sides of images are centimeters.

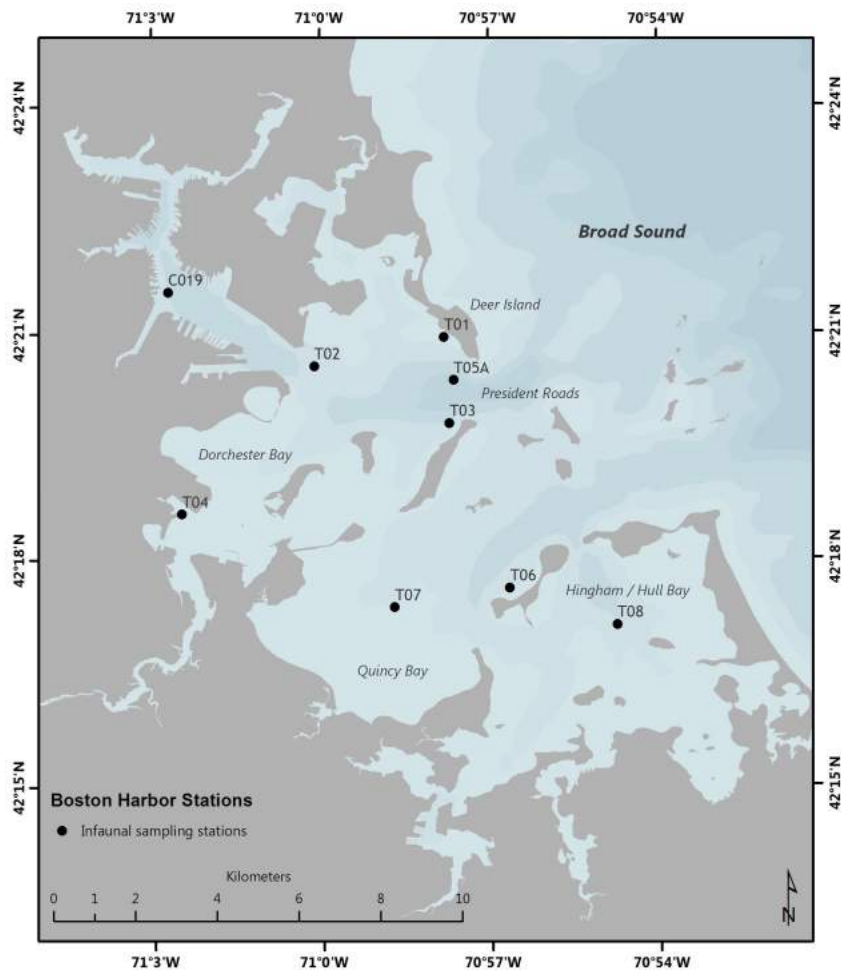
## Stellwagen Bank National Marine Sanctuary

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

Station FF04 is typical of the deep waters offshore from the outfall, representative of a number of stations monitored in earlier years of the program, and it continues to support an infauna community typical of what had been found at the larger suite of deep-water stations. The deep-water stations, including Station FF04, have always shown distinct differences from those found at shallower stations, probably due to their depth, their fine-grained sediments, and their distance from shore. Superimposing percent grain size and depth on the ordination plot for 2018 infauna samples continued to show these natural differences (see Figure 4-7, above).

## Boston Harbor Seafloor Monitoring

While the chemistry and biology of the Massachusetts Bay sea floor have not been adversely affected by the relocated outfall, conditions have greatly improved and continue to improve in Boston Harbor, a result of the Boston Harbor Project, more recent enhancements to treatment, and remediation of combined sewer overflows. MWRA has conducted ongoing seafloor monitoring in Boston Harbor since 1991. Annual sediment and infauna samples are taken from nine stations (Figure 4-11), and sediment-profile imaging is conducted at 61 stations throughout the inner and outer harbor.



**Figure 4-11. Soft-bottom sampling stations in Boston Harbor.** Nine stations are sampled each year for sediment characteristics and infauna analyses.

Concentrations of total organic carbon (not shown) and *Clostridium perfringens* spores (Figure 4-12) in harbor sediments have declined over time. Infauna diversity (not shown) has increased, reflecting continued improvement in habitat conditions. An ordination plot of Boston Harbor infauna samples (Figure 4-13) shows two related communities at stations in the outer harbor and two related communities at stations in the inner harbor and Quincy Bay, including a unique fauna at persistently polluted Station T04 at the mouth of Savin Hill Cove.



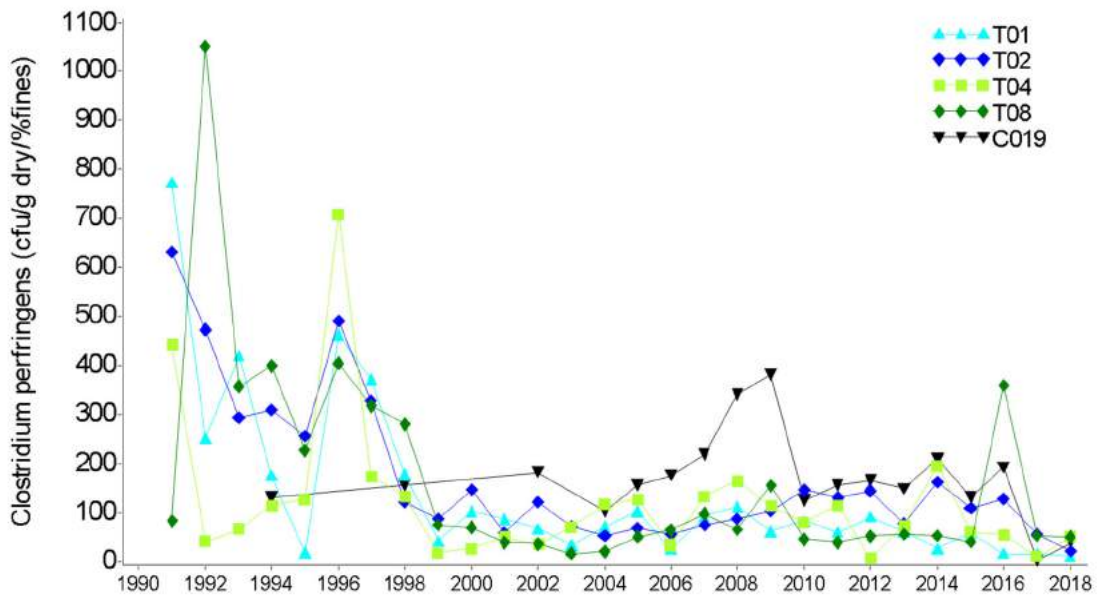


Figure 4-12. Mean concentrations of *Clostridium perfringens* spores at selected harbor stations, 1991–2018.

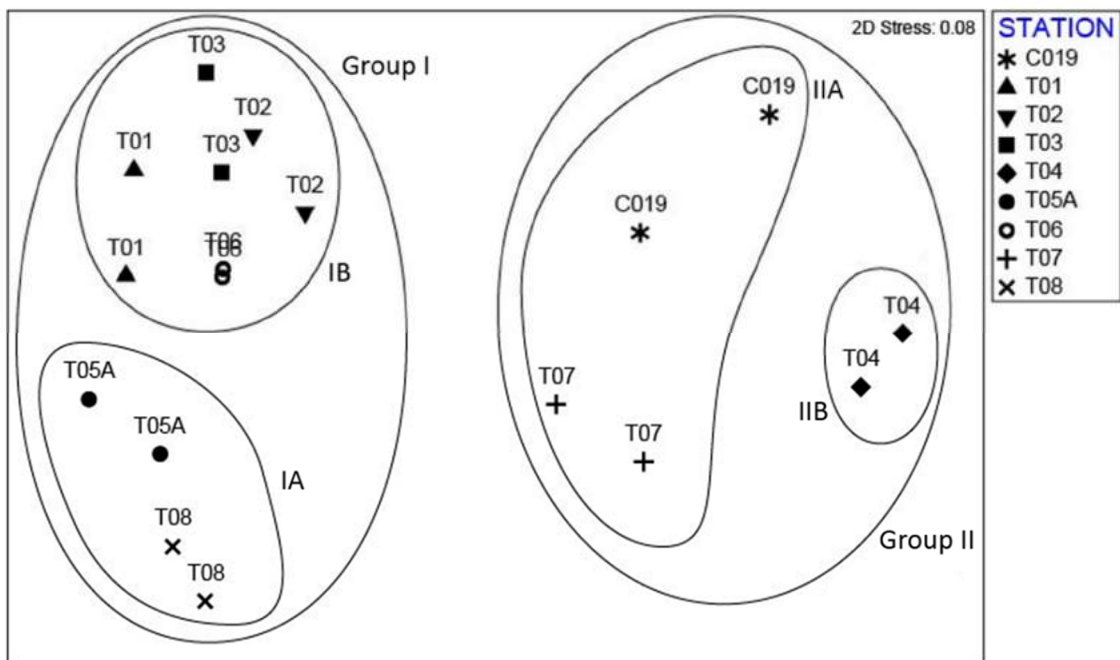


Figure 4-13. Ordination plot of 2018 Boston Harbor infauna samples. Two samples are collected per station. Group I comprises stations from the outer harbor; Group II includes Station C019 in the inner harbor, Station T07 in Quincy Bay, and Station T04, at the mouth of Savin Hill Cove, in Dorchester Bay. Stress is a measure of how well the ordination results represent the raw; a stress of 0.08 indicates excellent representation.

Sediment-profile imaging has also confirmed an inner- to outer-harbor gradient and clearly documented the effects of winter storms on the surface sediments. Including the intense March storm, 2018 was the third stormiest year of the monitoring program, and it was a record year for sediment changes in the harbor. More than half of the 61 sediment-profile stations demonstrably changed from coarse to fine or fine to coarse sediments.

Sediment-profile imaging studies have also documented presence of eelgrass at Deer Island Flats, another sign of recovery of the harbor following the outfall diversion. An eelgrass bed was first detected in 2008 and persisted in 2018.

The 2018 studies showed evidence of the dredging that was underway at the time of the survey, part of a channel-deepening project by the U.S. Army Corps of Engineers. Because of this disturbance, the OSI at Deer Island Flats, located within the dredging project area, was far lower than in 2017, reflecting the removal of the seafloor community by the dredges. Dredging continued in the area after the 2018 MWRA survey concluded.

## Contingency Plan Thresholds

There were no Contingency Plan threshold exceedances for seafloor parameters in 2018 (Table 4-1). The average RPD was deeper than the thresholds and also deeper than baseline values. Diversity and other benthic community parameters were higher than Contingency Plan limits, and the percent opportunistic species remained far below any level of concern.

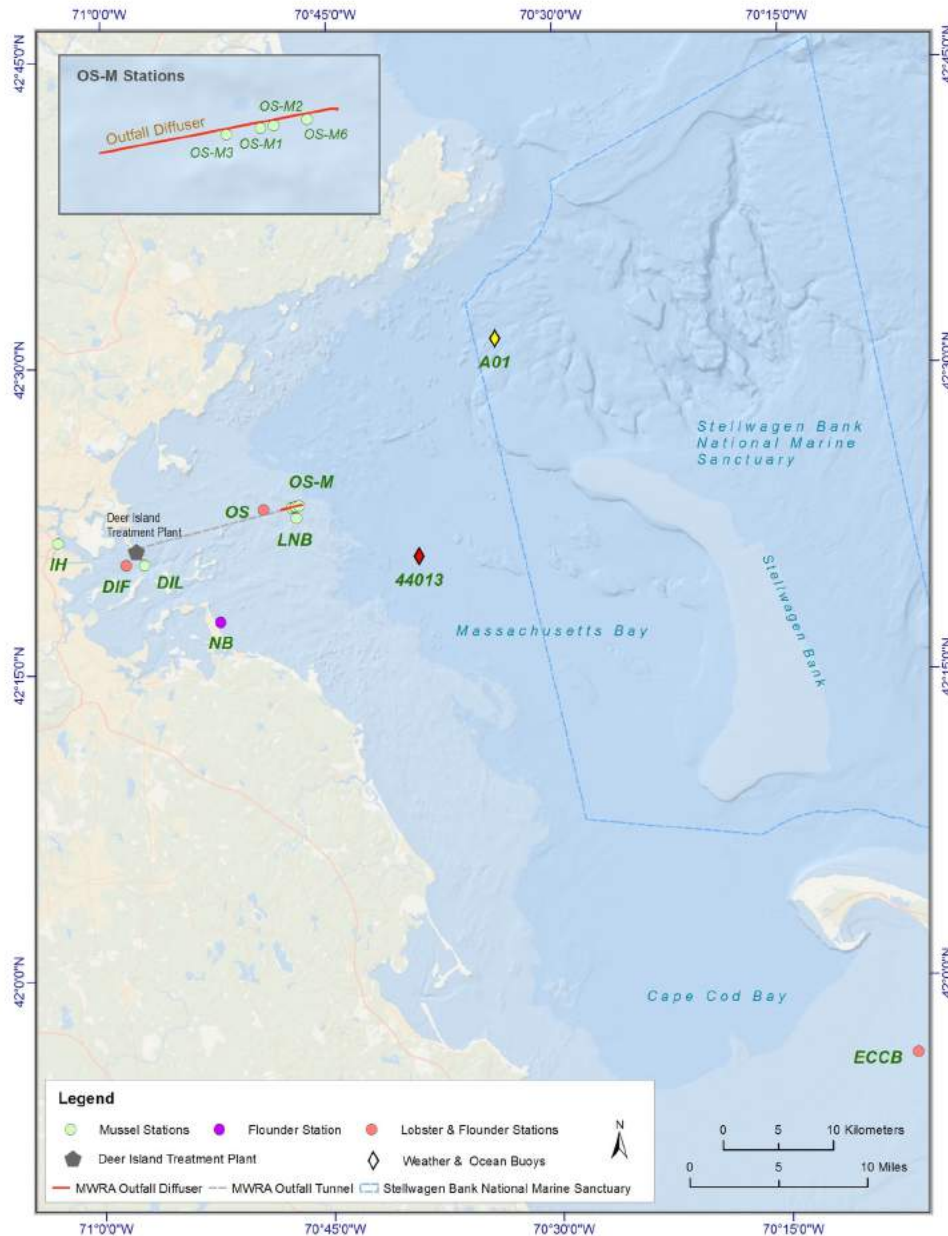
**Table 4-1. Contingency Plan threshold values and 2018 results for seafloor monitoring.**

Parameter	Baseline	Caution Level	Warning Level	2018 Results
<b>Sediment parameters</b>				
RPD depth	NA	<1.18 cm	None	5.09 cm
<b>Benthic community parameters</b>				
Species per sample	NA	<42.99	None	60.8
Fisher's log-series alpha	NA	<9.42	None	12.1
Shannon diversity	NA	<3.37	None	3.65
Pielou's evenness	NA	<0.57	None	0.62
% opportunists	NA	>10%	>25%	1.79%

NA = not applicable; RPD = redox potential discontinuity

# 5. Fish and Shellfish

MWRA monitors winter flounder health each year and conducts chemical contaminant analyses of flounder fillets and liver, lobster meat and hepatopancreas (the digestive gland or tomalley), and cage-deployed blue mussels every three years, including 2018. Sampling and deployment sites vary by species (Figure 5-1). This section includes results for 2018; Section 6, Special Studies, further discusses improved health and decreased chemical contamination in Boston Harbor flounder.



**Figure 5-1. Fish-and-shellfish monitoring stations.** Also shown are the two instrumented buoys, the MWRA outfall diffuser, and the boundaries of the Stellwagen Bank National Marine Sanctuary.

## Flounder Health

Annual flounder monitoring focuses on external condition and the presence of liver disease and tumors (neoplasia). In April and May 2018, 50 sexually mature flounder were collected from each of four sites: Deer Island Flats near the former Boston Harbor outfall, off Nantasket Beach, the Massachusetts Bay outfall site, and eastern Cape Cod Bay (Moore et al. 2018a). Catch per unit effort was higher at eastern Cape Cod Bay and Nantasket Beach than at the other sites. Abandoned fishing gear, sometimes referred to as “ghost gear,” continued to interfere with catches, particularly in muddy depressions at the outfall and at Deer Island Flats (Figure 5-2).

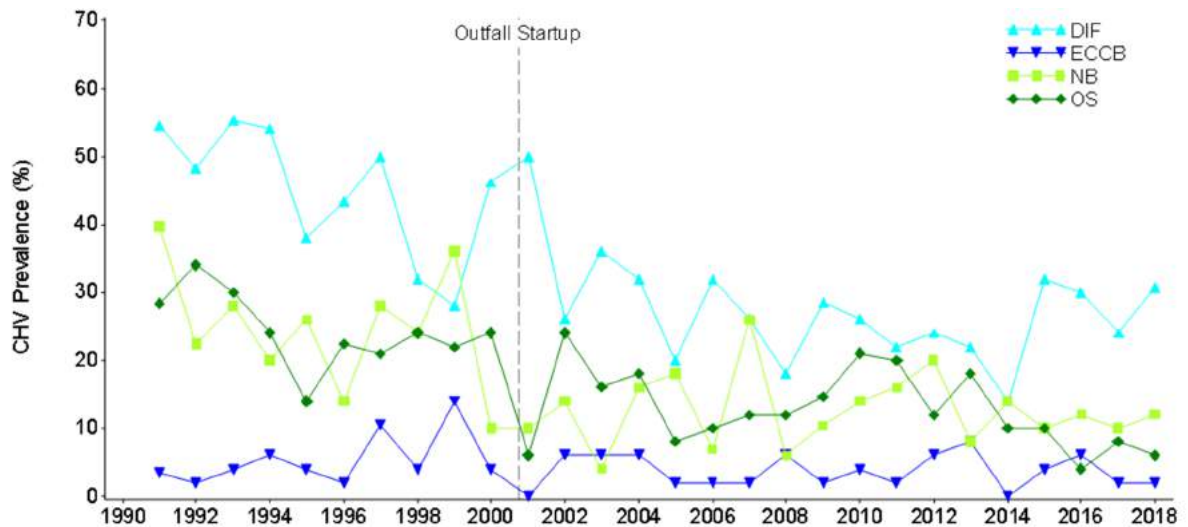


**Figure 5-2.** “Ghost” lobstering gear coming up in an MWRA flounder trawl. Photo credit Michael Moore, Woods Hole Oceanographic Institution

Across the sites, mean age of fish ranged from 3.8 to 4.2 years, and standard length ranged from 270 to 285 millimeters, within the ranges for the monitoring program (Moore et al. 2018a). As in past years and as is common throughout northeast coastal populations (Moore et al. 2016), the catches were dominated by females.

Measures of external condition (such as occurrence and severity of fin erosion) continued to suggest improved conditions since the 1980s and 1990s, and there continued to be no evidence of neoplasia. Tumors have not been observed by the monitoring program since 2004 and have never been found in fish taken from the outfall site. Incidence of fin erosion, often an indicator of ammonium and other pollutants, was highest in fish from Deer Island Flats and lowest in fish from eastern Cape Cod Bay and the outfall site. Incidence of fin erosion has been highly variable at all sites, with no obvious long-term trend and no correlation with liver conditions. Two fish collected at the outfall site in 2018 had blind-side ulcers, a condition that has been investigated but remains poorly understood.

The incidence of centrotubular hydropic vacuolation (CHV), a mild condition associated with exposure to contaminants and a tumor precursor, remained lower than the baseline observations (Figure 5-3). CHV incidence remained low in fish from the outfall site and somewhat elevated in fish from Deer Island Flats, although at lower levels than were found prior to the Boston Harbor Project (see Section 6, Special Studies). Average severity of CHV (not shown) also remained highest at Deer Island Flats but at lower than baseline levels.



**Figure 5-3. Annual prevalence of centrotubular hydropic vacuolation (CHV), 1991–2018.**  
DIF = Deer Island Flats, ECCB = Eastern Cape Cod Bay, NB = Nantasket Beach, OS = Outfall Site

## Fish and Shellfish Tissue Chemistry

Samples for chemical analyses were taken from the same winter flounder collections made for health assessments in April and May. Samples of winter flounder fillet from each site were analyzed for PCBs, pesticides, and mercury. Liver samples from the same fish were analyzed for PCBs, pesticides, PAHs, and selected metals.

Lobsters were collected over a one-week period in July from near Deer Island, eastern Cape Cod Bay, and the outfall site. Samples of lobster meat from each site were analyzed for PCBs, pesticides, and mercury. Hepatopancreas samples from the same animals were analyzed for PCBs, pesticides, PAHs, and selected metals.

Reference mussels were sourced from a commercial grower in Trenton, Maine and deployed at Boston Inner Harbor, Deer Island Flats, and several locations at or near the outfall. Over the years of the monitoring program, decreasing abundances of wild mussels from Massachusetts to Maine have complicated the collection of sufficient mussels for deployment. In 2015, mussels were for the first time obtained from a commercial grower. They were thin-shelled and had low survival rates. The commercial mussels deployed in 2018 were hardier, with appreciable mortality evident only in mussels deployed in Boston Inner Harbor.

Overall, concentrations of banned organochlorine pesticides and PCBs remained low in flounder and lobster meat and mussel tissues, with the highest concentrations in flounder and lobster tissues found in samples from near Deer Island and lowest in samples from Cape Cod Bay. Slow declines in banned pesticides and PCBs continued across all flounder and lobster tissue types and locations and were particularly evident in samples from fish taken from near Deer Island.

For example, slow declines in concentrations of the banned pesticide chlordane in flounder fillets (Figure 5-4) have persisted throughout the monitoring program, and have been evident even in fish from the relatively pristine eastern Cape Cod Bay. Similarly, long-term declines in concentrations of the banned pesticide DDT and its breakdown products have been observed in lobster meat from all three locations (Figure 5-5).

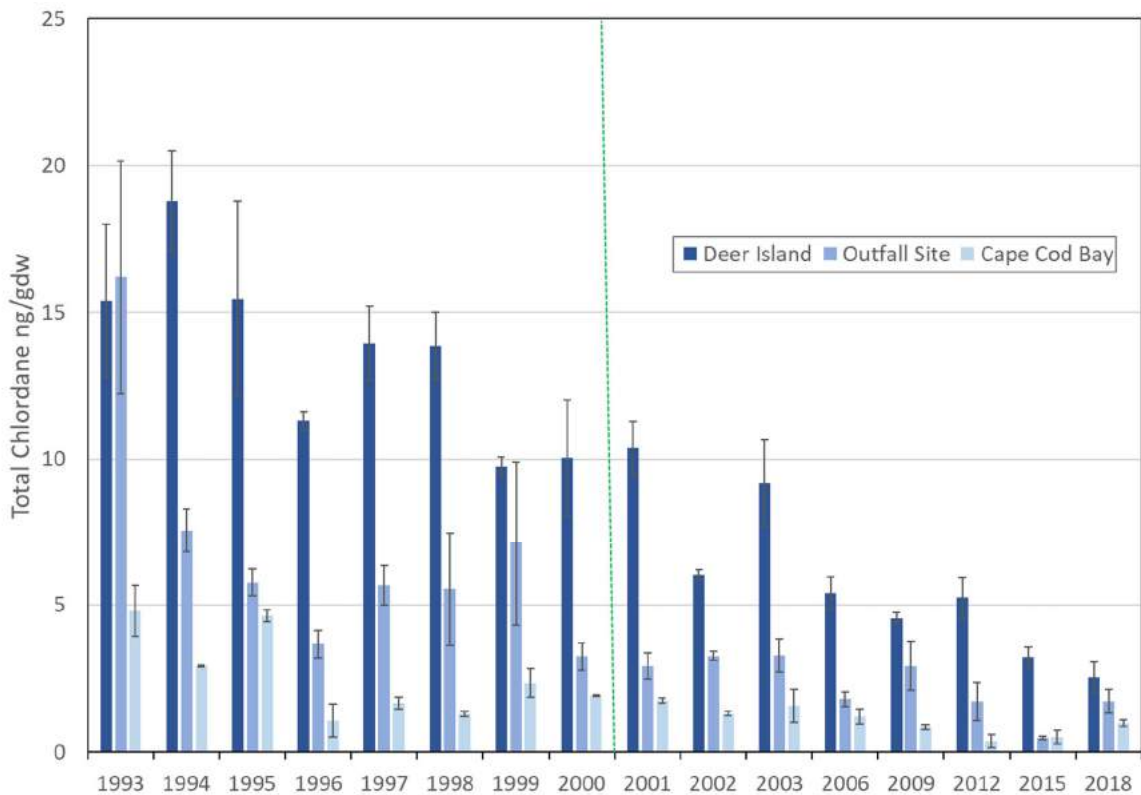
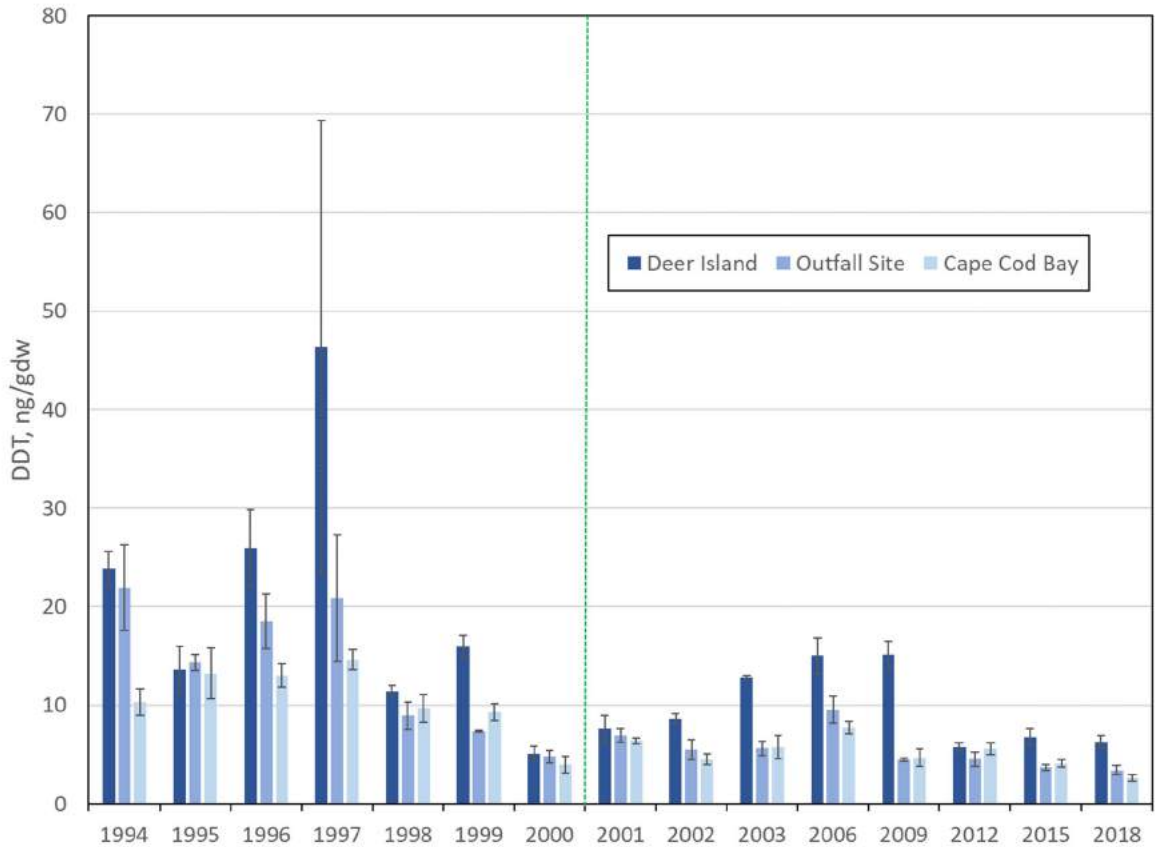
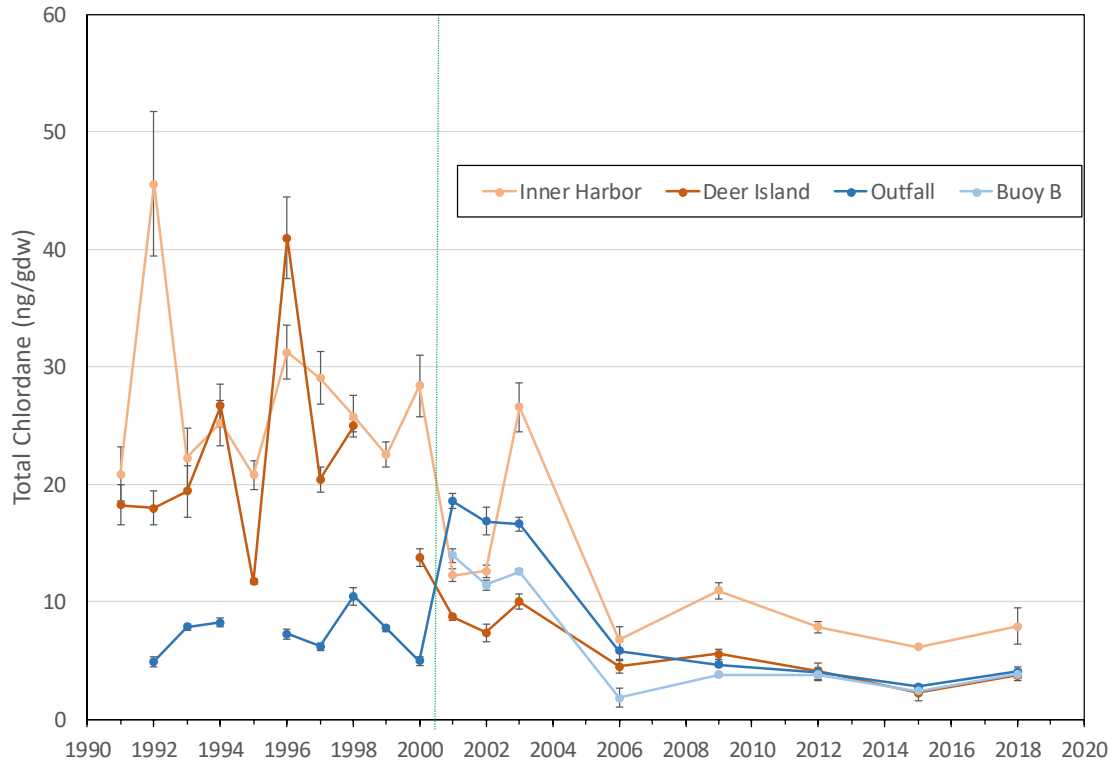


Figure 5-4. Total chlordanes in flounder fillets, 1992–2018.

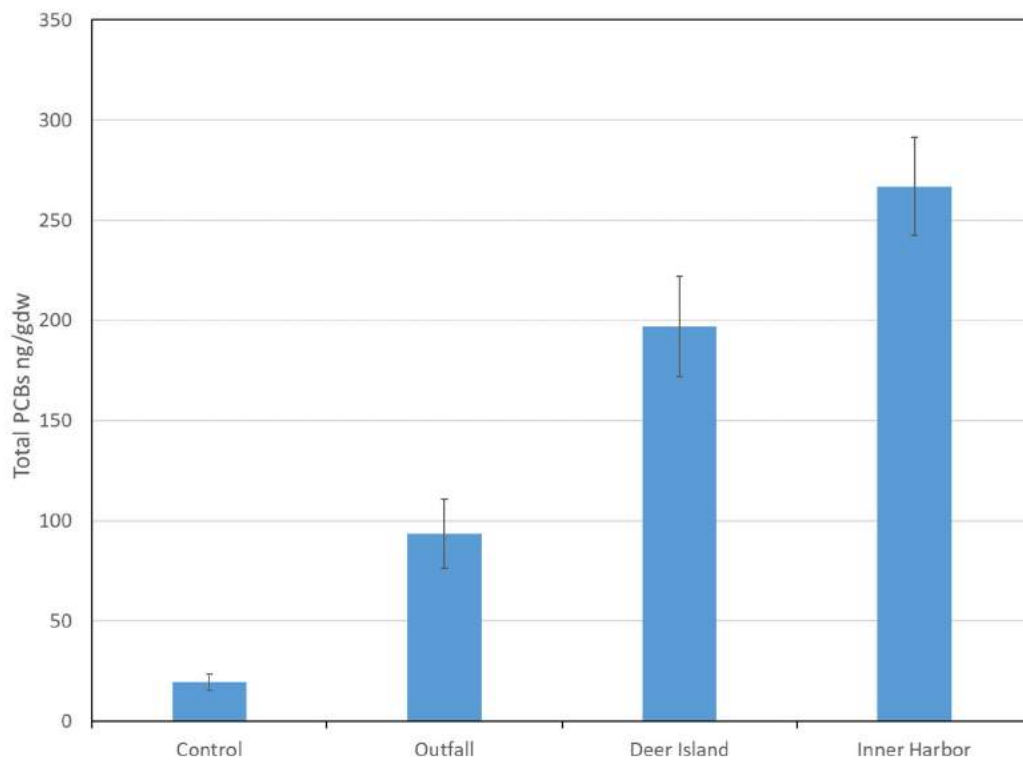


**Figure 5-5. DDTs in lobster meat, 1992–2018.**

Chlordane concentrations in deployed mussels have also declined over time (Figure 5-6), a result not only of their ban, but also due to improved treatment at Deer Island Treatment Plant and the outfall relocation. Results from 2018 demonstrated that contamination in Boston Harbor remains greater than inputs at the Massachusetts Bay outfall (Figure 5-6, 5-7). Consistent with past years, total PCBs accumulation was greatest in mussels from the inner harbor, intermediate in mussels from Deer Island, and lowest in mussels from the Massachusetts Bay outfall. Other contaminants showed similar patterns.



**Figure 5-6. Total chlordanes in deployed mussels, 1991–2018.** Buoy B (labeled LNB in Figure 5-1) is one kilometer south of the outfall.



**Figure 5-7. Total PCBs in control and deployed mussels in 2018.**



## Contingency Plan Thresholds

There were no fish-and-shellfish Contingency Plan threshold exceedances for 2018 (Table 5-1). Incidence of CHV, the most common indicator of liver disease in winter flounder of the region, was 6% in fish taken from the vicinity of the outfall, much lower than the 44.9% caution threshold or 24.4% baseline average. All chemical contaminant measures remained far below caution and/or warning levels.

**Table 5-1. Contingency Plan threshold values and 2018 result for fish-and-shellfish monitoring. \***

Parameter	Baseline	Caution Level	Warning Level	2018 Results
<b>Flounder disease</b>				
Liver disease (CHV)	24.4%	44.9%	None	6%
<b>Flounder meat</b>				
PCB	0.033 ppm	1 ppm wet weight	1.6 ppm wet weight	0.036 ppm
Mercury	0.074 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.0573 ppm
<b>Flounder meat, lipid normalized</b>				
Chlordane	242 ppb	484 ppb	None	27 ppb
Dieldrin	63.7 ppb	127 ppb	None	0 ppb
DDT	775.9 ppb	1552 ppb	None	107 ppb
<b>Lobster meat</b>				
PCB	0.015 ppm	1 ppm wet weight	1.6 ppm wet weight	0.009 ppm
Mercury	0.148 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.170 ppm
<b>Lobster meat, lipid normalized</b>				
Chlordane	75 ppb	150 ppb	None	2.6 ppb
Dieldrin	161 ppb	322 ppb	None	0 ppb
DDT	341.3 ppb	683 ppb	None	28.5 ppb
<b>Mussel tissue</b>				
PCB	0.011 ppm	1 ppm wet weight	1.6 ppm wet weight	0.0013 ppm
Lead	0.415 ppm	2 ppm wet weight	3 ppm wet weight	0.14 ppm
Mercury	0.019 ppm	0.5 ppm wet weight	0.8 ppm wet weight	0.01 ppm
<b>Mussel tissue, lipid normalized</b>				
Chlordane	102.3 ppb	205 ppb	None	33 ppb
Dieldrin	25 ppb	50 ppb	None	0 ppb
DDT	241.7 ppb	483 ppb	None	71 ppb
PAH	1080 ppb	2160 ppb	None	726 ppb

\* Exceedances are values greater than (>) all thresholds.  
CHV = centrotubular hydropic vacuolation

## 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 special studies section celebrates the improved health of winter flounder in Boston Harbor and examines long-term trends found in MWRA's years of monitoring in Massachusetts Bay.

### Winter Flounder in Boston Harbor

Winter flounder (Figure 6-1) have long been popular recreational sport fish in Massachusetts, and even in the 1970s, when the harbor was extremely polluted, they were the most abundant sport fish.

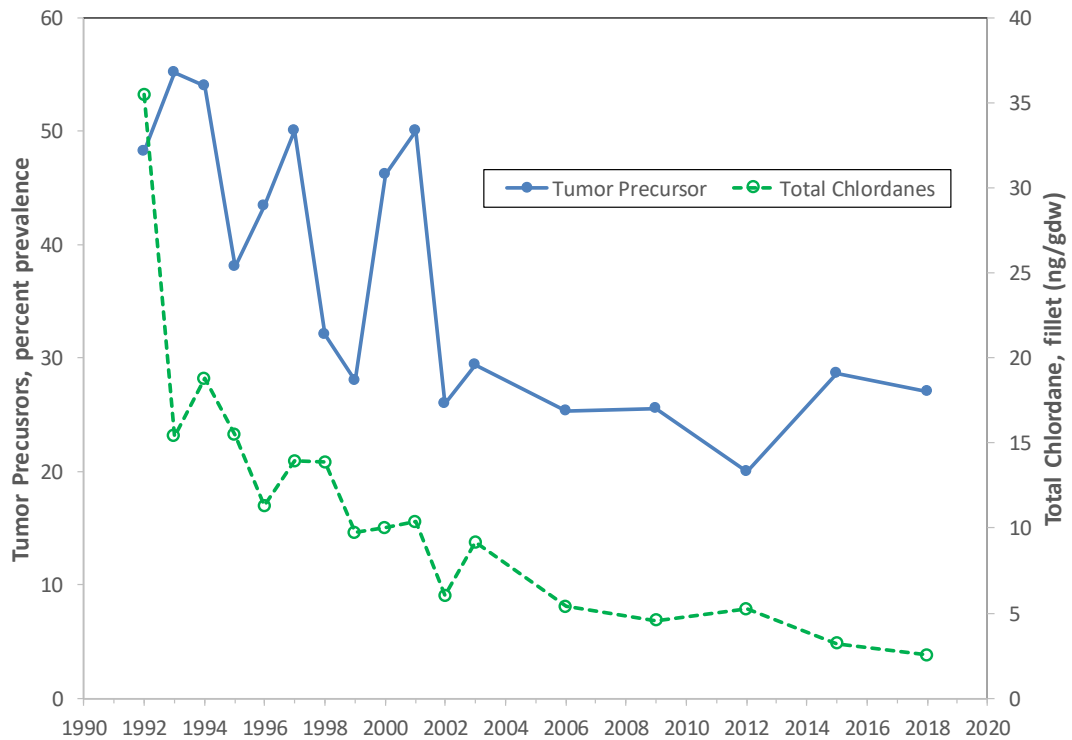


**Figure 6-1. Eelgrass in Boston Harbor provides habitat for flounder and other fish and shellfish.**  
Photo credit Phil Colarusso, EPA.

Despite their abundance, a 1978–1979 survey by MWRA’s predecessor, the Metropolitan District Commission, found that more than 40% of the winter flounder had fin erosion, often called fin rot because of its ragged and decayed appearance. Worse, a 1984–1985 study by the National Marine Fisheries Service found that 15% of fish taken from Deer Island Flats near the Boston Harbor outfall had cancerous liver tumors, and almost 80% had pre-cancerous liver conditions (including CHV, see Section 5, Fish and Shellfish). Neither the liver disease nor the fin erosion represented a health risk for people eating the fish, but these conditions were a major factor in Boston Harbor’s label as the “dirtiest harbor in America.”

MWRA began routine sampling and analysis of winter flounder livers in 1991. Since then, MWRA, with Woods Hole Oceanographic Institution scientists, has documented substantial declines in tumors and precancerous conditions. In fact, no tumors have been observed in any fish since 2004, and CHV incidence has declined to half of the 1980s levels. Other liver cancer precursors have similarly declined.

These improvements in flounder health began in the first years of the Boston Harbor Project, prior to relocating the outfall from Boston Harbor to Massachusetts Bay, and correlate well with declines in total solids discharges, that portion of the municipal effluent that contains most of the persistent organic and inorganic contaminants (Moore et al. 2018b). The declines in tumor precursors also correspond to declines in organic contaminant concentrations in flounder tissues, particularly declines in the banned organochlorine pesticide chlordane (Figure 6-2).



**Figure 6-2. Incidence of tumor precursors in winter flounder livers and total chlordanes in fillets in Boston Harbor, 1991–2018.**

The improvements to winter flounder health in Boston Harbor were not accompanied by any degradation in Massachusetts Bay. No tumors have ever been observed in fish from the Massachusetts Bay outfall site, and tumor precursors have declined there as well. Contaminant levels in fish tissues have also declined. Improving winter flounder health in Boston Harbor without degrading it in Massachusetts Bay has been one of the most notable successes of the Boston Harbor Project, validating the value of federal and state regulatory mandates, as well as the investments in facilities and management practices.

## Long-term Trends in Massachusetts Bay

MWRA's long-term monitoring program has afforded an opportunity to examine longer-term trends than is possible for most coastal studies. Analyzing trends in temperature, dissolved oxygen concentrations, and the intensity and frequency of storms that resuspend seafloor sediments can provide new insights into existing monitoring data and help to plan for the future.

MWRA has found that average February–October water temperatures at all depths have warmed by about half a degree Fahrenheit per decade during 1992–2018 (Figure 6-3). Calculations suggest that the length of time required to detect a trend such as this one is more than 20 years, so it would not have been detected over a shorter monitoring period. The degree of warming is consistent with other studies and appears to be region-wide. Thus far, the warming has not affected summertime water-column stratification.

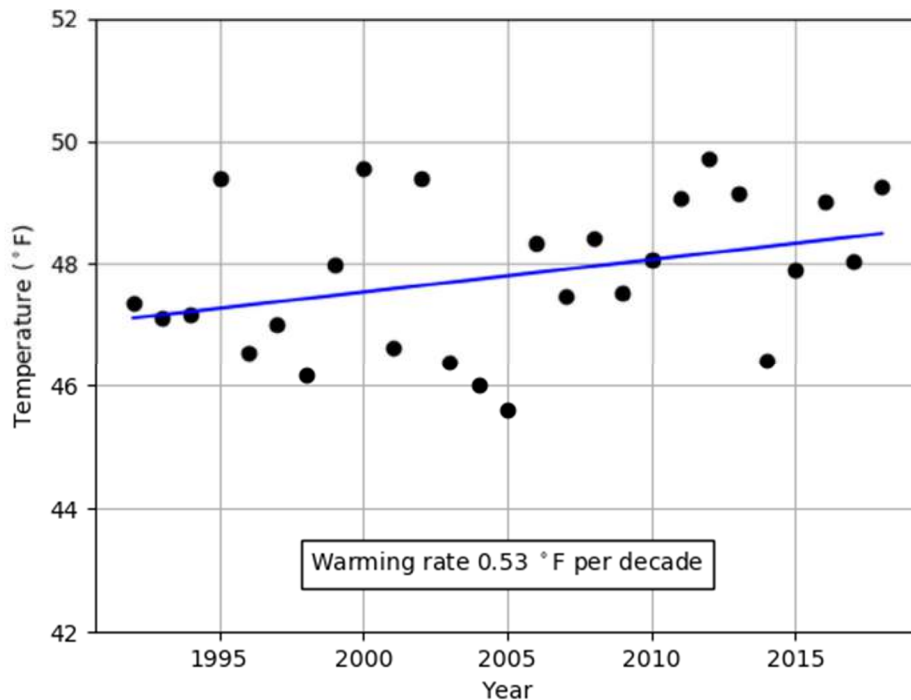


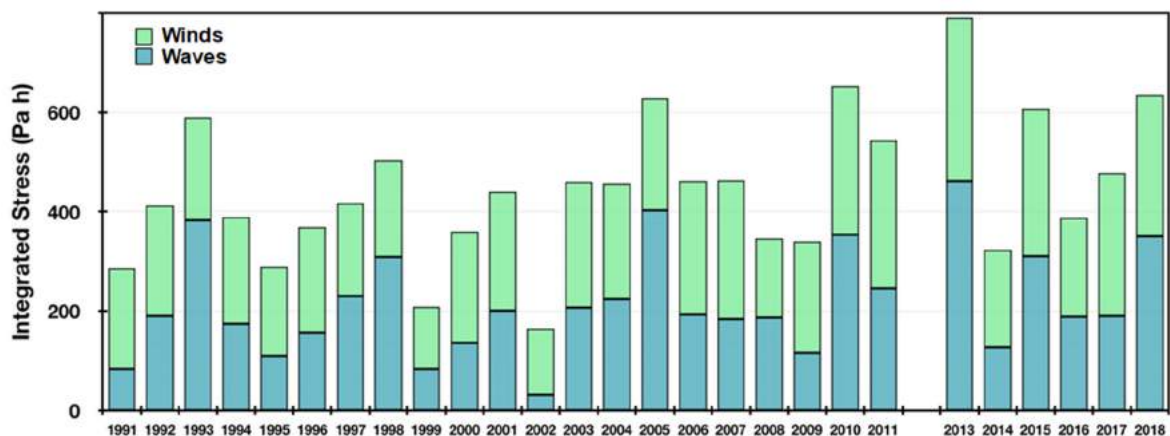
Figure 6-3. Annual average February–October temperatures, 1992–2018.

Over the same time span, MWRA has found that dissolved oxygen concentrations have declined 0.16 milligrams per liter per decade. About half that decline can be attributed to the warmer temperatures. Available measurements did not span long enough periods to determine long-term trends in plankton biomass (chlorophyll) or abundance, as those parameters have greater inter-annual variability than temperature and oxygen.

The principal factors affecting the bottom habitats in the nearfield and throughout Massachusetts Bay appear to be storms and storm-driven sediment transport. To better understand these influences on the sea floor, MWRA recently analyzed long-term trends in storm characteristics, as derived from wind and wave observations. Storms were defined by wind stress and by wave stress at 30 meters, about the depth of the nearfield stations (Butman et al. 2008).

Storms defined by wind stress had 25 miles per hour winds, producing a stress of 0.2 Pascals at the sea surface, for at least six hours. Storms defined by wave stress exerted a stress of 0.1 Pascals on the sea floor, the amount of stress necessary to resuspend and move fine-grained sediments. The analysis showed that during 1990–2018, 832 storms met the wind-stress definition, and 575 storms met the wave-stress definition.

Since 1990, most storms and the strongest storms have occurred during the broad winter period, October–May (Rutecki et al. 2019). Integrated measures of those winter wind and wave stresses showed long-term increases over the course of the monitoring program (Figure 6-4). Both wind and wave data showed increases in duration of individual storms and increases in the total number of storms each year. Five of the stormiest winters occurred during 2005–2018, and four of the least stormy occurred during 1991–2002.



**Figure 6-4. Integrated stress from wind- and wave-driven storms, October–May, 1991–2018.**

(Missing data from 2012 kept that year from being included in the analysis.)

Overall, the long-term increase in storminess has increased the likelihood that bottom sediments will be dominated by physical rather than biological forces (see Section 4, Sea Floor). At some stations, stronger storms have correlated with changes in sediment grain size, decreased numbers of biogenic structures such as burrows, and decreased abundance of amphipods and isopods, animals that dwell at or just above the sediment-water interface, where they are susceptible to wave action.

## 7. Looking Ahead

Boston Harbor and Massachusetts Bay are healthier today than when baseline monitoring began. Effluent contaminant concentrations have decreased and stayed low. Concentrations of contaminants such as PCBs and banned pesticides have declined in the sediments and biota, and the sediment oxygenated layer has deepened. Blooms of nuisance and potentially toxic algae have not intensified in response to the outfall discharge, and even the outfall diffusers are covered with lush and healthy sea anemones, barnacles, and mussels. After nine years of baseline monitoring and more than 18 years of data collection and analysis since the Massachusetts Bay outfall began to discharge, it is clear that the outfall has not damaged the environment.

In November 2018, OMSAP hosted a large group of scientists, regulators, public interest groups, and interested private citizens to review past monitoring results and the ongoing monitoring program. This workshop, “2300 Days at Sea: Monitoring the Impacts of the Outfall on Massachusetts Bay,” also began to look ahead to new issues. There are new challenges not only for MWRA, but for all who treasure and benefit from the healthy marine environment in Massachusetts Bay.

The goals of the workshop were to (1) examine the public concerns and monitoring questions (Table 7-1), posed by the monitoring plan which was developed during the planning and siting process for the outfall (routinely updated, most recently MWRA 2010); (2) identify remaining or new issues to be addressed, including new chemical compounds or microplastic debris that could be present in the discharge; (3) question the role that climate change may have on Massachusetts Bay and the outfall discharge; and (4) compare the MWRA monitoring program with those in other regions.

Workshop participants agreed that the more than a quarter century of monitoring has shown that the outfall has not adversely affected Massachusetts Bay. They expressed concern for new contaminants that might become environmental problems, recognizing a need to understand sources and potential effects. They also recognized potential difficulties in distinguishing effects of climate change from effects of the outfall and speculated that climate-related changes to species ranges might introduce new organisms of interest or concern. Participants noted that, although the initial monitoring questions have been answered, some concerns, such as for endangered species, will persist. They endorsed continued and new special studies and collaborative efforts to address broad regional issues.

Moving forward after the workshop, MWRA has worked with OMSAP and other stakeholders to revise the monitoring plan and refine monitoring questions to address emerging issues. A report on the status of monitoring provides detailed answers to the monitoring questions (MWRA 2019).

**Table 7-1. Public concerns and monitoring questions presented in the original monitoring plan.**

<p><b>Public Concern: Is it safe to eat fish and shellfish?</b></p> <ul style="list-style-type: none"> <li>▪ Will toxic chemicals accumulate in the edible tissues of fish and shellfish, and thereby contribute to human health problems?</li> <li>▪ Will pathogens in the effluent be transported to shellfishing areas where they could accumulate in the edible tissues of shellfish and contribute to human health problems?</li> </ul>
<p><b>Public Concern: Are natural/living resources protected?</b></p> <ul style="list-style-type: none"> <li>▪ Will nutrient enrichment in the water column contribute to an increase in primary production?</li> <li>▪ Will enrichment of organic matter contribute to an increase in benthic respiration and nutrient flux to the water column?</li> <li>▪ Will increased water-column and benthic respiration contribute to depressed oxygen levels in the water?</li> <li>▪ Will increased water-column and benthic respiration contribute to depressed oxygen levels in the sediment?</li> <li>▪ Will nutrient enrichment in the water column contribute to changes in plankton community structure? (Such changes could include stimulation of nuisance or noxious algal blooms and could affect fisheries.)</li> <li>▪ Will benthic enrichment contribute to changes in community structure of soft-bottom and hard-bottom macrofauna, possibly also affecting fisheries?</li> <li>▪ Will the water column near the diffuser mixing zone have elevated levels of some contaminants?</li> <li>▪ Will contaminants affect some size classes or species of plankton and thereby contribute to changes in community structure and/or the marine food web?</li> <li>▪ Will finfish and shellfish that live near or migrate by the diffuser be exposed to elevated levels of some contaminants, potentially contributing to adverse health in some populations?</li> <li>▪ Will the benthos near the outfall mixing zone and in depositional areas farther away accumulate some contaminants?</li> <li>▪ Will benthic macrofauna near the outfall mixing zone be exposed to some contaminants, potentially contributing to changes in community structure?</li> </ul>
<p><b>Public Concern: Is it safe to swim?</b></p> <ul style="list-style-type: none"> <li>▪ Will pathogens in the effluent be transported to waters near swimming beaches, contributing to human health problems?</li> </ul>
<p><b>Public Concern: Are aesthetics being maintained?</b></p> <ul style="list-style-type: none"> <li>▪ Will changes in water clarity and/or color result from the direct input of effluent particles or other colored constituents, or indirectly through nutrient stimulation of nuisance plankton species?</li> <li>▪ Will the loading of floatable debris increase, contributing to visible degradation?</li> </ul>



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# List of Acronyms

ASP	Amnesic shellfish poisoning
cBOD	Carbonaceous biochemical oxygen demand
CHV	Centrotubular hydropic vacuolation
DDT	Dichlorodiphenyltrichloroethane
DIF	Deer Island Flats
DO	Dissolved oxygen
ECCB	Eastern Cape Cod Bay
EPA	U.S. Environmental Protection Agency
FF	Farfield
IAAC	Inter-Agency Advisory Committee
LC50	50% mortality concentration
MassDEP	Massachusetts Department of Environmental Protection
MGD	Million gallons per day
MWRA	Massachusetts Water Resources Authority
NA	Not analyzed/not applicable
NACWA	National Association of Clean Water Agencies
NB	Nantasket Beach
NDBC	National Data Buoy Center
NERACOOS	Northeastern Regional Association of Coastal and Ocean Observing Systems
NF	Nearfield
NOEC	No observed effects concentration
NPDES	National Pollutant Discharge Elimination System
OMSAP	Outfall Monitoring Science Advisory Panel
OS	Outfall site
OSI	Organism sediment index
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PIAC	Public Interest Advisory Committee
PSP	Paralytic shellfish poisoning
RPD	Redox potential discontinuity
SEIS	Supplemental environmental impact statement
SPI	Sediment-profile imagery





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