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Review of Oceanographic and Geochemical Data Collected in Massachusetts Bay during a Large Discharge of Total Suspended Solids from Boston's Sewage-Treatment System and Ocean Outfall in August 2002

Open-File Report 2010–1050

U.S. Department of the Interior
U.S. Geological Survey

Cover. Deployment of a subsurface mooring in Massachusetts Bay from the U.S. Coast Guard Cutter *Marcus Hanna*. The yellow funnel-shaped instrument below the red subsurface float is the time-series sediment trap used to collect data shown in figures 3–9.

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By Michael H. Bothner, Bradford Butman, and Michael A. Casso

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square kilometer (km^2)	247.1	acre
square centimeter (cm^2)	0.001076	square foot (ft^2)
square meter (m^2)	10.76	square foot (ft^2)
	Volume	
liter (L)	0.2642	gallon (gal)
cubic meter (m^3)	0.0002642	million gallons (Mgal)
cubic centimeter (cm^3)	0.06102	cubic inch (in^3)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
	Density	
gram per cubic centimeter (g/cm^3)	62.4220	pound per cubic foot (lb/ft^3)
	Pressure	
millibar (mb)	0.0145038	pounds per square inch (lb/in^2)

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L). Concentrations of chemical constituents on dried sediment are given in parts per million (ppm), which are equivalent to micrograms of constituent per gram of dry sediment.

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Abstract

During the period August 14–23, 2002, the discharge of total suspended solids (TSS) from the Massachusetts Water Resources Authority sewage-treatment plant ranged from 32 to 132 milligrams per liter, causing the monthly average discharge to exceed the limit specified in the National Pollution Discharge Elimination System permit. Time-series monitoring data collected by the U.S. Geological Survey in western Massachusetts Bay were examined to evaluate changes in environmental conditions during and after this exceedance event. The rate of sediment trapping and the concentrations of near-bottom suspended sediment measured near the outfall in western Massachusetts Bay increased during this period. Because similar increases in sediment-trapping rate were observed in the summers of 2003 and 2004, however, the increase in 2002 cannot be definitively attributed to the increased TSS discharge. Concentrations of copper and silver in trapped sediment collected 10 and 20 days following the 2002 TSS event were elevated compared to those in pre-event samples. Maximum concentrations were less than 50 percent of toxicity guidelines. Photographs of surficial bottom sediments obtained before and after the TSS event do not show sediment accumulation on the sea floor. Concentrations of silver, *Clostridium perfringens*, and clay in surficial bottom sediments sampled 10 weeks after the discharge event at a depositional site 3 kilometers west of the outfall were unchanged from those in samples obtained before the event. Simulation of the TSS event by using a coupled hydrodynamic-wave-sediment-transport model could enhance understanding of these observations and of the effects of the exceedance on the local marine environment.

Introduction

From August 14 to 23, 2002, the discharge of total suspended solids (TSS) from the Deer Island Sewage Treatment Plant (DITP) through the Massachusetts Bay outfall exceeded the 30-mg/L limit (monthly average) specified in the National Pollution Discharge Elimination System (NPDES) permit granted by the U.S. Environmental Protection Agency. The event was caused by an upset in the secondary treatment process caused by "an overgrowth of filamentous bacteria" related to "discharge of sulfate-rich industrial effluent to the DITP through the Massachusetts Water Resources Authority (MWRA) Alford Street Pump station" (Michael Hornbrook, Massachusetts Water Resources Authority, written commun., 2002). The peak TSS concentration during the exceedance event was 132 mg/L on August 18, 2002. This report examines observations made by the U.S. Geological Survey (USGS) in Massachusetts Bay to document the effects of the exceedance event in the water column and on the sea floor.

Oceanographic and Geochemical Data

The USGS has carried out a long-term research program (1989–2006) to investigate the transport and fate of sediments in Massachusetts Bay (Bothner and Butman, 2007). As part of this program, time-series oceanographic observations and geochemical analyses of suspended and bottom sediments were made at locations near the Massachusetts Bay outfall (fig. 1). Measurements relevant to the August 2002 exceedance event include (1) sequential photographs of the sea floor; (2) observations of near-bottom light attenuation, pressure, and current speed; (3) sediment-trapping rates; (4) chemical analyses of trapped sediment; and (5) chemical analyses of surficial bottom sediment.

To provide a context for this review, we made an order-of-magnitude estimate of the concentration of suspended solids in the water column and the maximum amount that might accumulate on the sea floor at the site of the USGS time-series observations following the exceedance event. We used the dilution model results presented by Signell (2007) that predict that, on average, the concentration of effluent in the water 1.5 km from the outfall would be diluted to about 1 percent of the initial concentration. Concentrations would be higher nearer to the outfall and lower farther from the outfall. The TSS

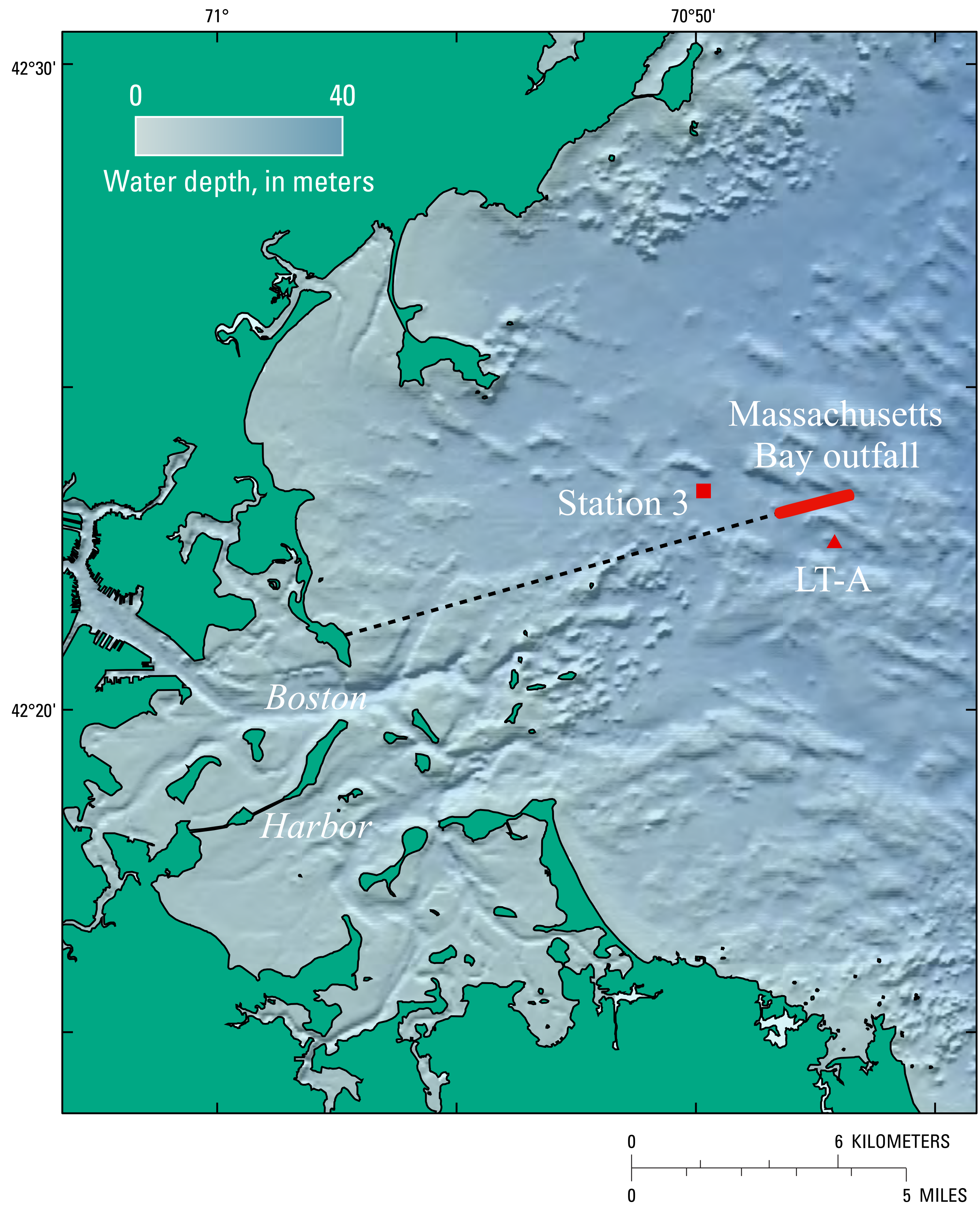

Figure 1. Location of the Massachusetts Bay outfall, U.S. Geological Survey long-term mooring station A (LT-A), and sediment sampling station 3.

concentration in effluent diluted to 1 percent would be about 0.7 mg/L and would be confined to the lower 15 m of the water column by the summer thermocline. If all of this material settled on the sea floor during the 10-day TSS event and remained there, the deposition near the USGS moorings would be a layer about 0.6 mm thick (if a wet bulk density of 1.2 g wet/cm^3 is assumed). This estimate is an upper limit because the effluent would be increasingly diluted farther from the outfall and because the dilution calculations are for a conservative tracer (that is, no settling). The estimate could be improved by running a coupled hydrodynamic-wave-sediment-transport model for the time period of the TSS event with a modification that allows TSS particles to sink at measured sinking rates. This approach would provide estimates of sediment concentration and accumulation throughout Massachusetts Bay associated with this event.

Bottom Photographs

Photographs of the sea floor were taken every 4 hours from a camera fixed about 2 m above the bottom at station LT-A (fig. 1) about 1.3 km south of the outfall site at a water depth of about 32 m (Butman and others, 2008). A comparison of photographs taken before and after the event (fig. 2) shows no obvious accumulation of fine sediment on the gravelly

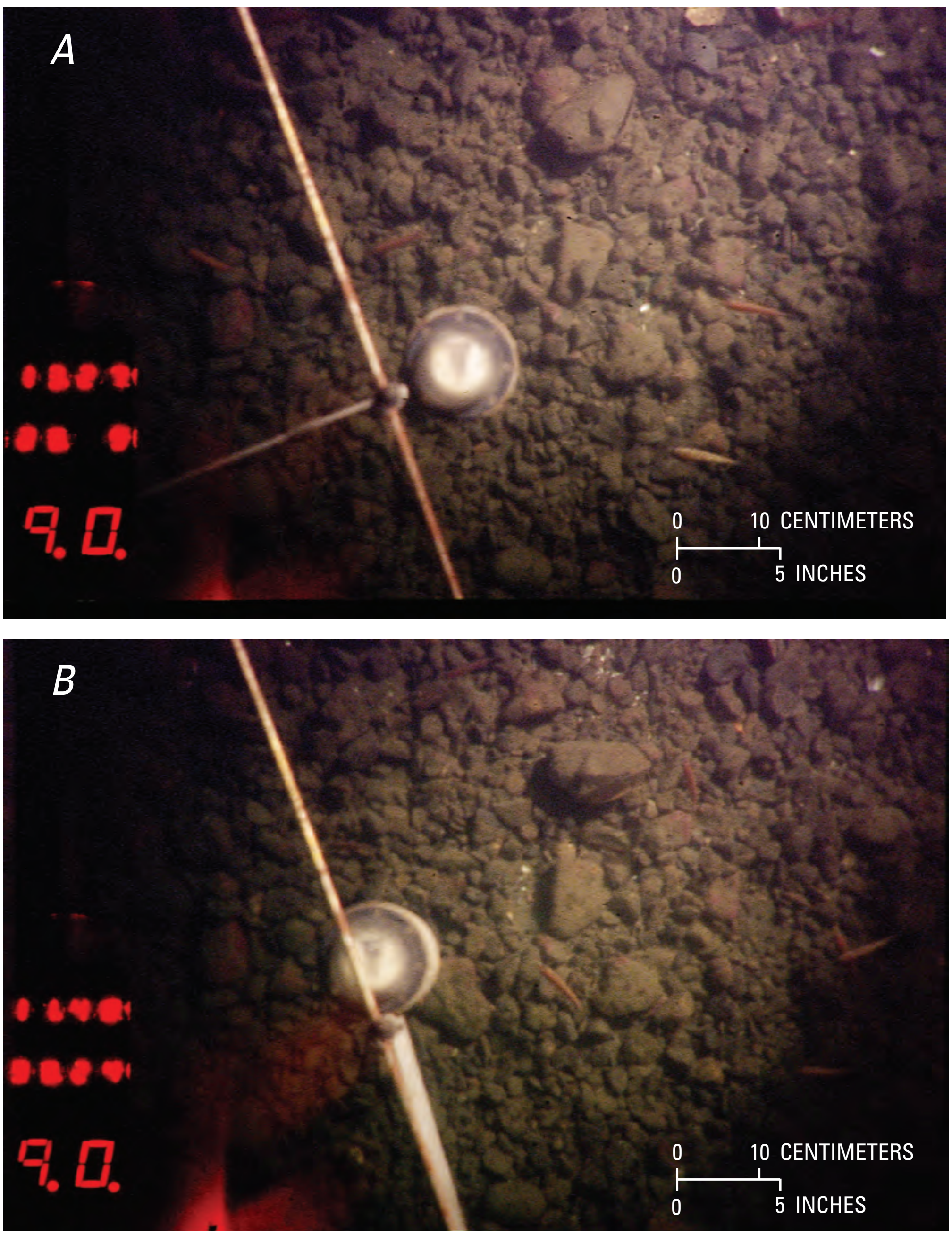

Figure 2. Photographs of the sea floor from an instrumented tripod (U.S. Geological Survey mooring number 690) on (*A*) August 10, 2002, 1840 GMT; and (*B*) August 25, 2002, 1704 GMT. The original photographs were tinged red and underexposed, especially in the periphery; the bright spot reflects the strobe light that illuminated the sea floor. No change in sediment cover is apparent. (From Butman and others, 2008.)

bottom or on the compass mounted on the tripod; however, the sea floor is poorly illuminated because the instrument was near the end of a deployment and the strobe was most likely fouled or losing battery power. Even with improved illumination, the maximum predicted accumulation of about 0.6 mm would be difficult to observe in these photographs.

Near-Bottom Time-Series Observations

The continuous record of beam attenuation (a measure of suspended-sediment concentration) at approximately 2 m above bottom (in a water depth of about 32 m) shows an increase that began on August 18 and reached about 0.5 m^{-1} on August 23 (figs. 3, 4). There is no calibration of the beam transmissometer appropriate for this period, but a 0.5-m^{-1} increase in beam attenuation is equivalent to about 1 mg/L suspended sediment using the calibration in Harris and others (2003) from the middle Atlantic Bight. Beam attenuation continued to rise gradually from August 23 to about September 5. From August 18 to about August 23 the currents were less than 0.1 m/s and there was no surface wave activity, so the increase is unlikely to have been caused by sediment resuspension (although a single spike in current speed reached 0.2 m/s just prior to this event). The increase in beam attenuation could be associated with the TSS event, but also could have been caused by advection of different water masses past the tripod or occasional resuspension by internal waves that occur throughout Massachusetts Bay in summer (Butman and others, 2006). The gradual increase in attenuation after August 23 is associated with a period of surface waves and likely reflects some sediment resuspension from the sea floor.

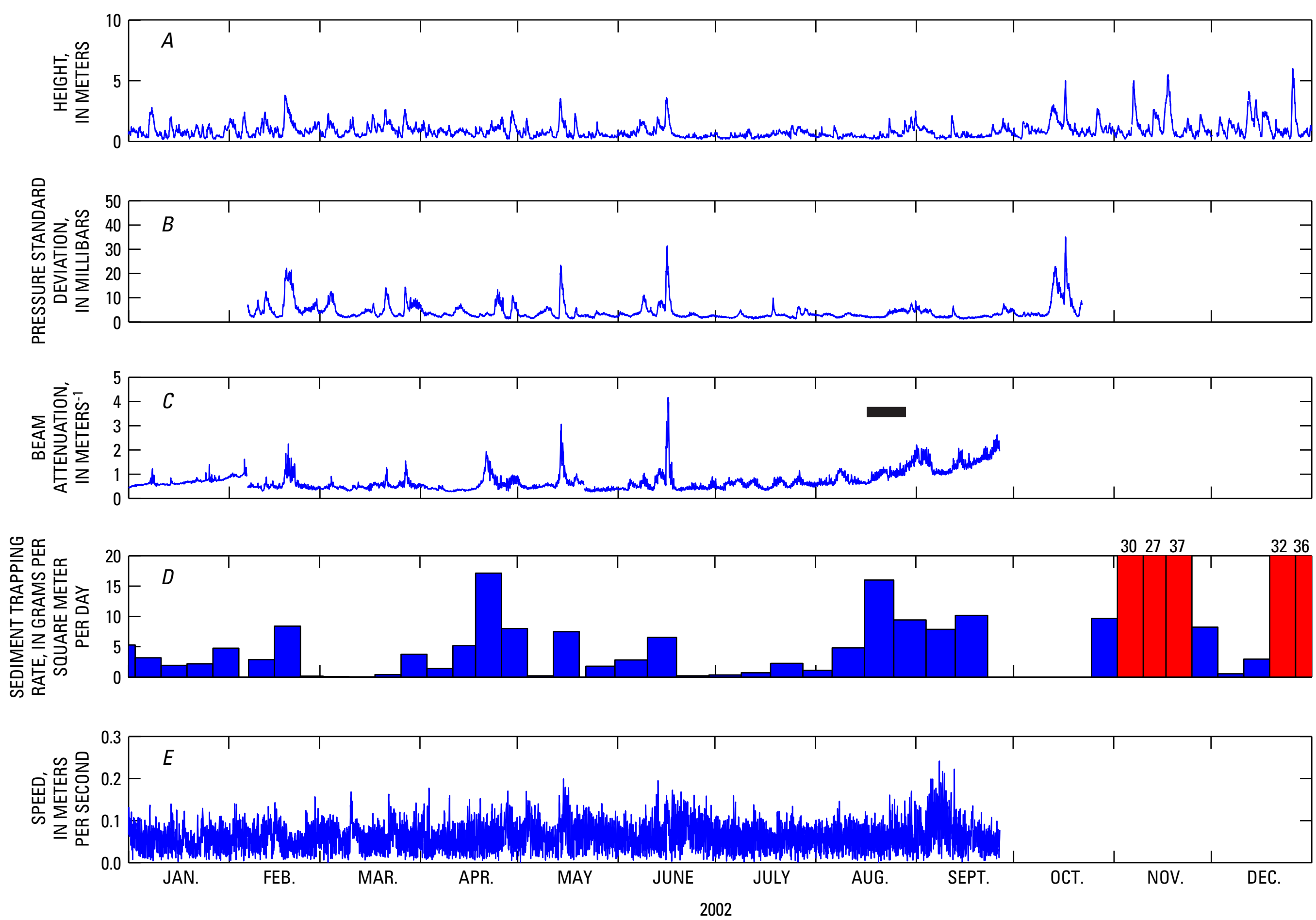

Figure 3. (*A*) Significant wave height at National Oceanic and Atmospheric Administration buoy 44013; (*B*) standard deviation of burst pressure; (*C*) beam attenuation; (*D*) sediment-trapping rate at 10-day intervals from time-series sediment trap; and (*E*) current speed at a depth of 31 meters (~1 meter above bottom), 2002. (Trapping rates greater than 20 grams per square meter per day are shown in red; the trapping rate, rounded to an integer, is shown at the top of the bar. The period of total suspended solids exceedance is indicated by the solid black line in (*C*). Modified from Butman and others, 2009. See figure 4 for period August 1 to September 15, 2002.)

A gradual increase in background is also typical of biological fouling of the optical windows on the transmissometer; the reduction around September 5 is hypothesized to reflect removal of material from the transmissometer windows by the bottom currents, which increase to more than 0.15 m/s on a tidal cycle. The August 18–23 increase in beam attenuation is of the same order as the short-term increases observed prior to the TSS exceedance event that correlate with small increases in wave-induced bottom stress, and is much smaller than the peak in attenuation (which exceeded 4 m^{-1}) during the resuspension event on June 16, 2002, associated with surface waves (fig. 3). Simulation of the TSS event using a coupled hydrodynamic-wave-sediment-transport model could provide estimates of the distribution of suspended sediments associated with the TSS event that could be compared to these observations. The hydrodynamics have been modeled (for example Signell and others, 2000), but the sediment-transport calculations would require information on particle-settling velocity of the introduced material, which is presently unavailable.

Sediment Traps

The sediment-collection rate in a time-series sediment trap deployed at 4.3 m above bottom at station LT-A (fig. 1) increased from about 5 $g/m^2/d$ to more than 15 $g/m^2/d$ during the August 16–25 period (bottle 10 of 13), which is nearly synchronous with the discharge event (fig. 5A). Because the highest collection rate coincides with a period during which little bottom-sediment resuspension was expected (low wave heights and bottom current speeds), it would not be unreasonable to consider other sources of settling particulate matter,

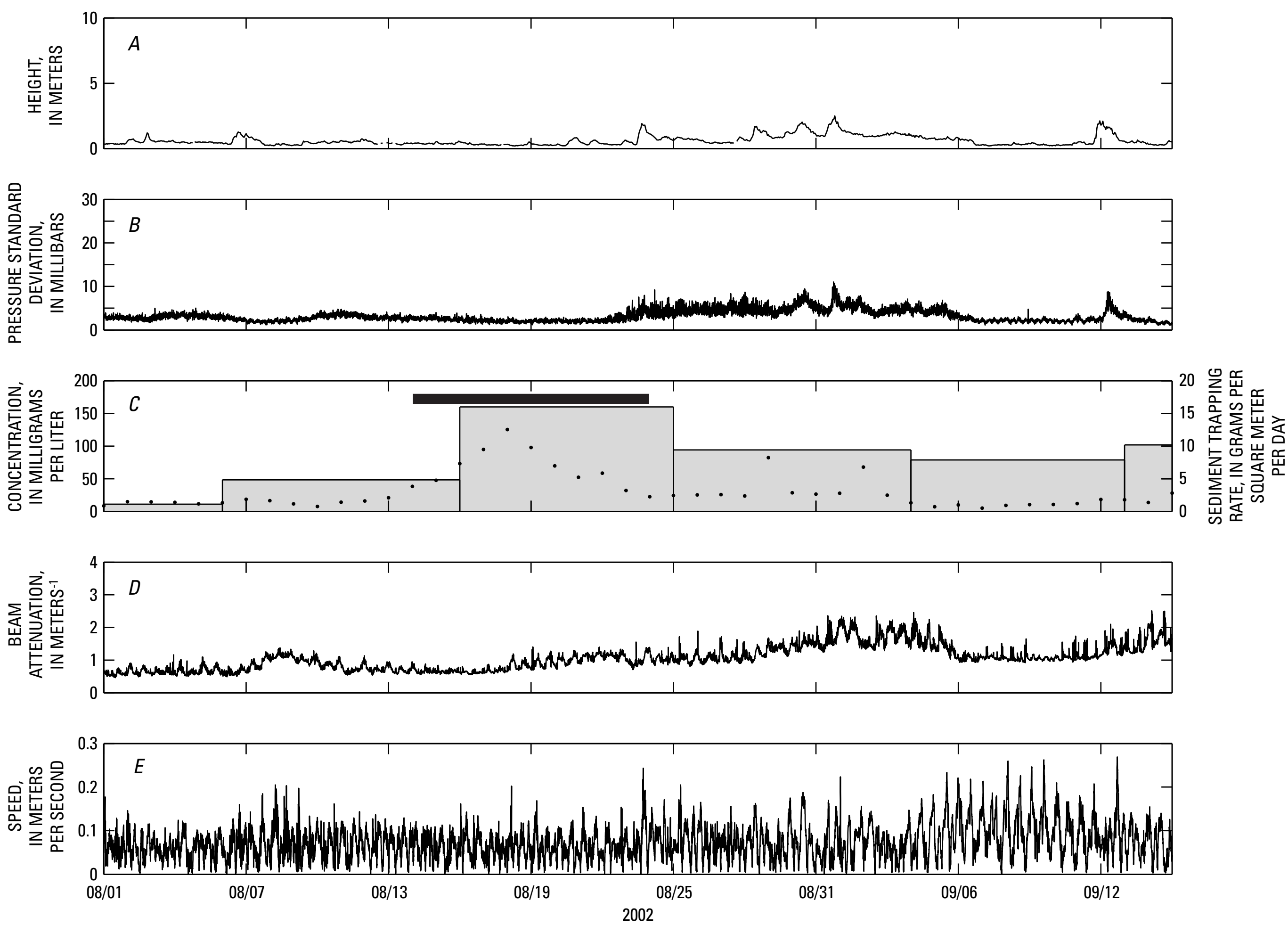

Figure 4. (*A*) Significant wave height at National Oceanic and Atmospheric Administration buoy 44013; (*B*) standard deviation of burst pressure; (*C*) sediment-trapping rate from time-series sediment trap at 4 meters above bottom (histogram) and total suspended solids (TSS) concentration from the Deer Island Sewage Treatment Plant (dots); (*D*) beam attenuation; (*E*) current speed at a depth of 31 meters (~1 meter above bottom) at station LT-A for August–September 2002. (The period of TSS exceedance (August 14–23) is indicated by the heavy black line in (*C*). Time-series data for station LT-A from Butman and others, 2009; TSS data from Massachusetts Water Resources Authority.)

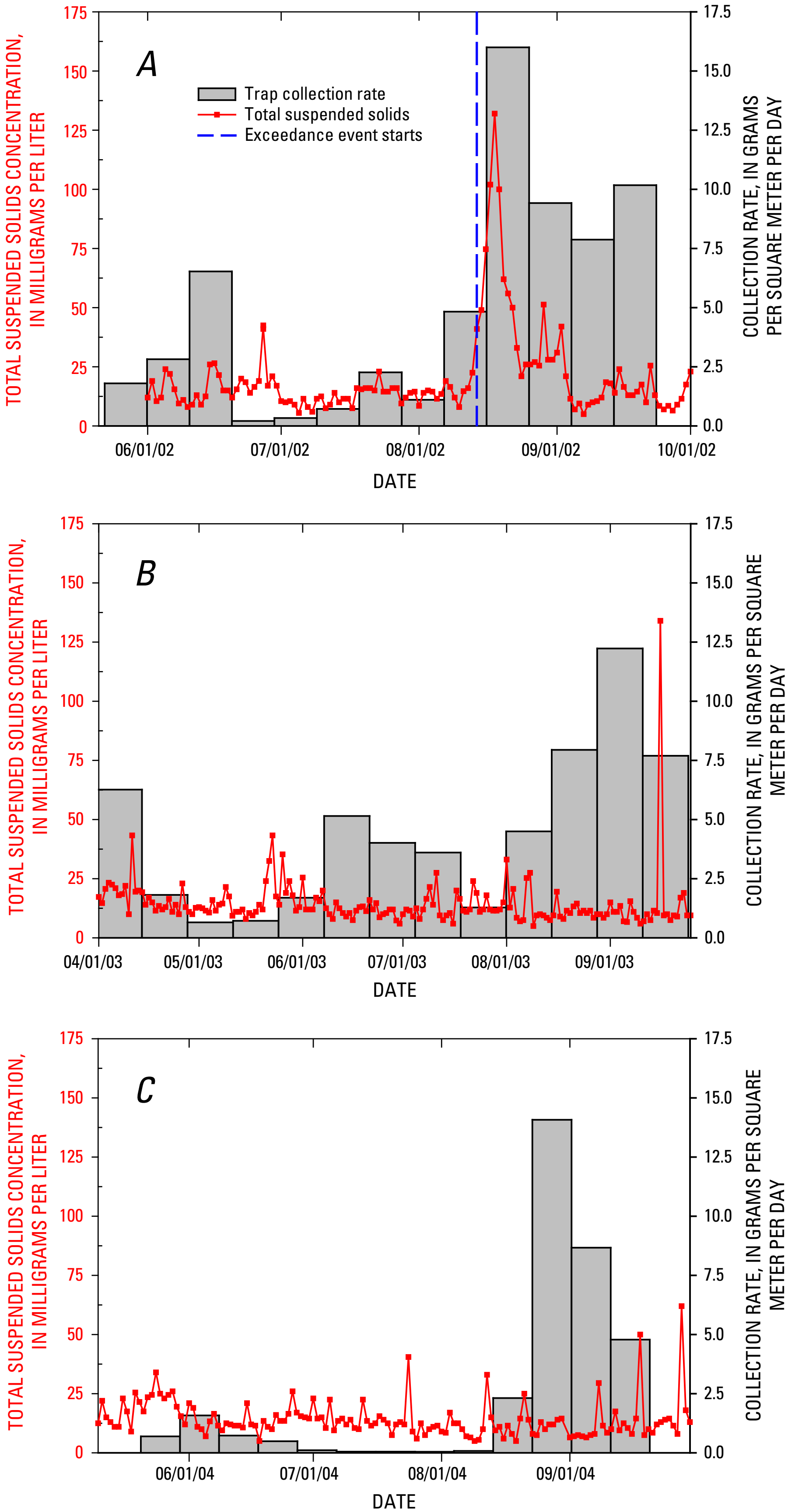

Figure 5. Total suspended solids (TSS) concentrations from Massachusetts Water Resources Authority records and sediment-collection rate in a time-series sediment trap deployed at station LT-A during (*A*) summer 2002, (*B*) summer 2003, and (*C*) summer 2004. The dashed blue line in (*A*) shows the start of the exceedance event, August 14–23, 2002. Plots (*B*) and (*C*) illustrate that increases in sediment-trap collection rate can occur in late summer with no correspondence to the concentrations of TSS leaving the Deer Island Sewage Treatment Plant. Higher sediment-trap collection rates have often been observed during periods of low wave-induced bottom stress, and the full explanation of the high rates has been elusive.

such as the TSS event, to account for the observed increase. However, the high collection rates continued for 30 days past the TSS event and increases in trapping rate were also observed during August and September of 2003 and 2004, which also were periods of low waves and currents (figs. 5B and 5C) when TSS discharges were low. We have hypothesized that these recurring late-summer increases in sediment-trapping rate may be related to decomposition of biological mucus that binds sediments, releasing fine sediments into the water column even under very low current stress, but this hypothesis remains to be fully explored. In addition, the concentration of organic matter in the trap did not increase during the high collection rate, which would have been expected from the filamentous bacteria that reportedly caused the exceedance event. Because of the recurring seasonal increase in sediment-collection rate and the absence of expected chemical signal, the increase in collection rate recorded in bottle 10 (fig. 5A) cannot be uniquely attributed to the pulse of high TSS discharge.

Sediment-Trap Sample Analysis

Analysis of the time-series sediment-trap samples revealed that concentrations of *Clostridium perfringens* (fig. 6), a chemically resistant bacterium spore found in sewage (Buchholz ten Brink and others, 2000), increased from July to mid September and there was no change in this gradual increase at the time of the exceedance event. The consistent slope of the increase and the observation that the concentration was greatest (50,000 spores/g) about a month after the exceedance event make it difficult to conclude that the highest *Clostridium perfringens* concentrations are directly related to the event.

The metals copper (Cu) and silver (Ag) (fig. 7), also tracers of sewage particles, reached their maximum concentrations (61 and 1.7 ppm, respectively) in a sample obtained 10 days (one trapping interval) following the TSS event. These values are about 0.5 and 2 times higher, respectively, than the average concentrations in pre-event samples (June–mid August). From a toxicity perspective, these maximum concentrations are below the warning levels set by the NPDES permit for bottom sediment (Cu, 270 ppm; Ag, 3.7 ppm). Although the increase in the concentrations of these metals is consistent with an increase in sewage discharge, running the hydrodynamic-wave-sediment-transport model would help to determine whether such a delay in the signal reaching the sediment trap is reasonable.

There was no difference between the pre- and post-event range in concentrations of organic carbon (C), iron (Fe), and arsenic (As) (fig. 8), or of cadmium (Cd), mercury (Hg), lead (Pb), and zinc (Zn) (fig. 9). There were no chemical analyses of the TSS samples that were collected from the effluent stream during the exceedance event. Such data would assist in identifying chemical parameters and chemical ratios that would link the particles from the treatment plant to those in the sediment traps. Would the “overgrowth of filamentous bacteria” dilute the signal of Ag and Cu in the TSS, for example? Analyses for additional components of a bacteria-rich discharge, such as isotopes of sulfur (S), C, and nitrogen (N), could be useful as well.

Surficial Sediments

The concentrations of Ag, *Clostridium perfringens*, and clay in a sample of surficial (0–0.5 cm) sediment collected at station 3 (fig. 10) about 10 weeks after the TSS exceedance event were not appreciably different from those in samples collected before the event. This station is about 3 km west of the Massachusetts Bay outfall, in a slight depression where sediments are muddy. The site is thought to be a sink for fine sediments and associated contaminants (Bothner and others, 2007).

Summary

Oceanographic and geochemical observations in western Massachusetts Bay near the MWRA ocean outfall have been examined for evidence of the August 2002 high-TSS discharge event. The collection rate in a sediment trap at the USGS mooring station LT-A, located 1.3 km from the Massachusetts Bay outfall, increased at the same time as the maximum TSS discharge and could be directly related; however, such increases in trap collection rate also were observed in late summer 2003 and 2004 when TSS discharge was low and constant, indicating that other natural factors may be responsible for the high collection rates observed in 2002. A small increase in concentrations of the typical biochemical tracers of sewage particles (Ag, Cu, and *Clostridium perfringens*) was observed in the suspended matter trapped following the exceedance event. Chemical analyses of the TSS at the DITP during the event are not available and, therefore, direct chemical comparisons between TSS and trapped sediment are not presently possible. On the basis of simple calculations and a number of assumptions, it is estimated that about 0.6 mm of sediment could have been deposited on the sea floor in the vicinity of station LT-A in association with the increased discharge. Although no accumulation is apparent in the time-series bottom photographs, an accumulation on the order of 0.6 mm would be difficult to quantify from these photographs. Near-bottom measurements of light attenuation show a small increase consistent with increased concentrations of suspended sediments between August 14 and August 23. Concentrations of sewage-particle indicators in the surface sediment (0–0.5 cm) collected at station 3 about 10 weeks after the TSS discharge event were not greater than those in the surface sediment collected before the discharge event. Simulation of the TSS event using a coupled hydrodynamic-wave-sediment-transport model may provide additional insight about the fate of sewage-derived particulates and facilitate further interpretation of the observations presented here.

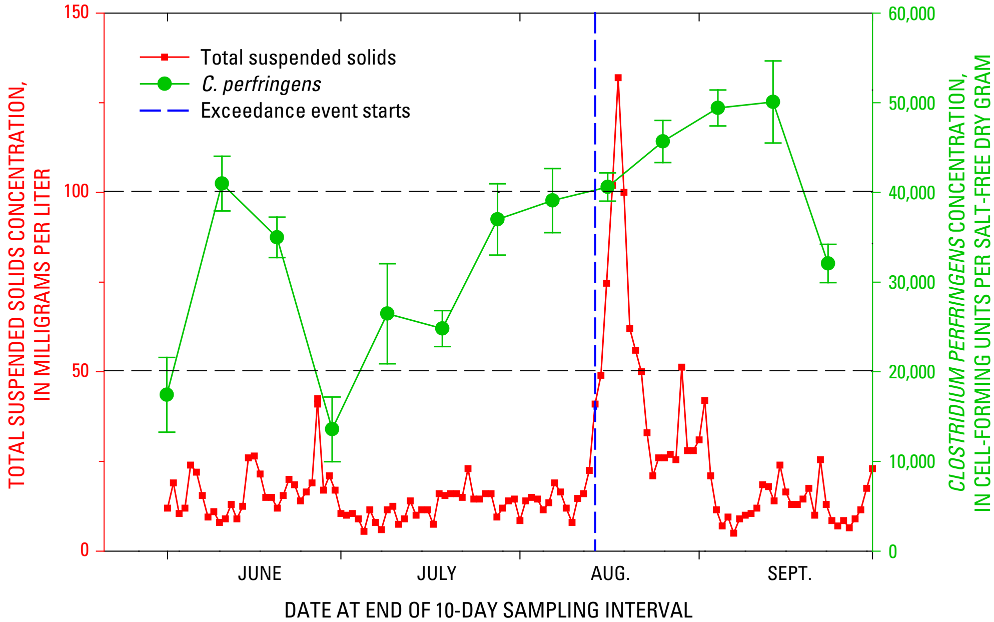

Figure 6. Concentration of *Clostridium perfringens* (salt-free) in sediment-trap samples at the end of each 10-day sampling interval and concentration of total suspended solids in the waste steam at the Deer Island Sewage Treatment Plant on the day of collection, summer 2002.

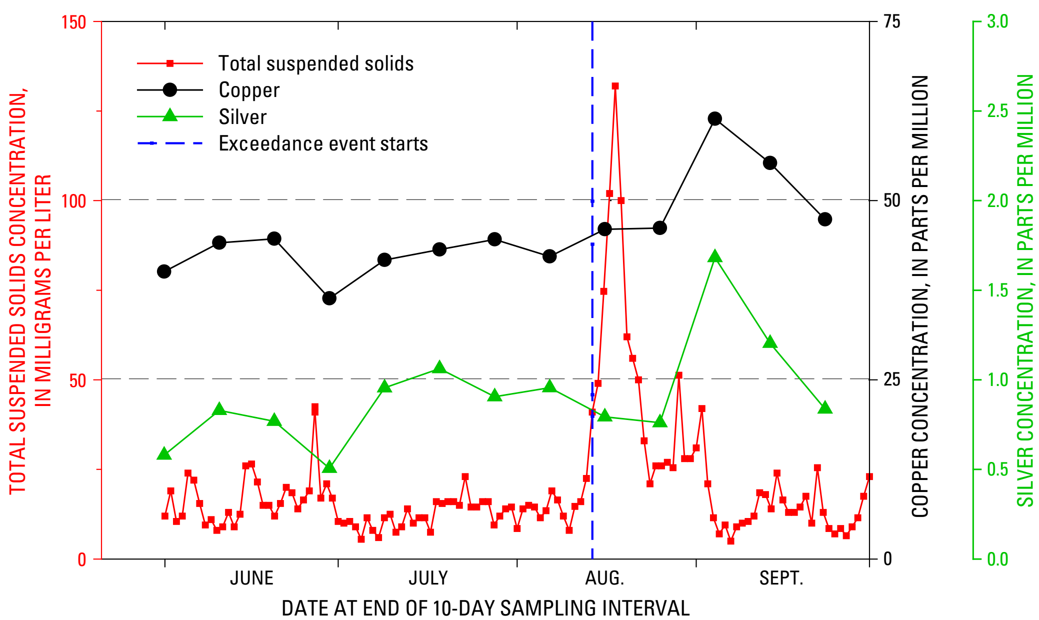

Figure 7. Concentrations of silver and copper (salt-free) in sediment-trap samples at the end of each 10-day sampling interval and concentration of total suspended solids in the waste steam at the Deer Island Sewage Treatment Plant on the day of collection, summer 2002.

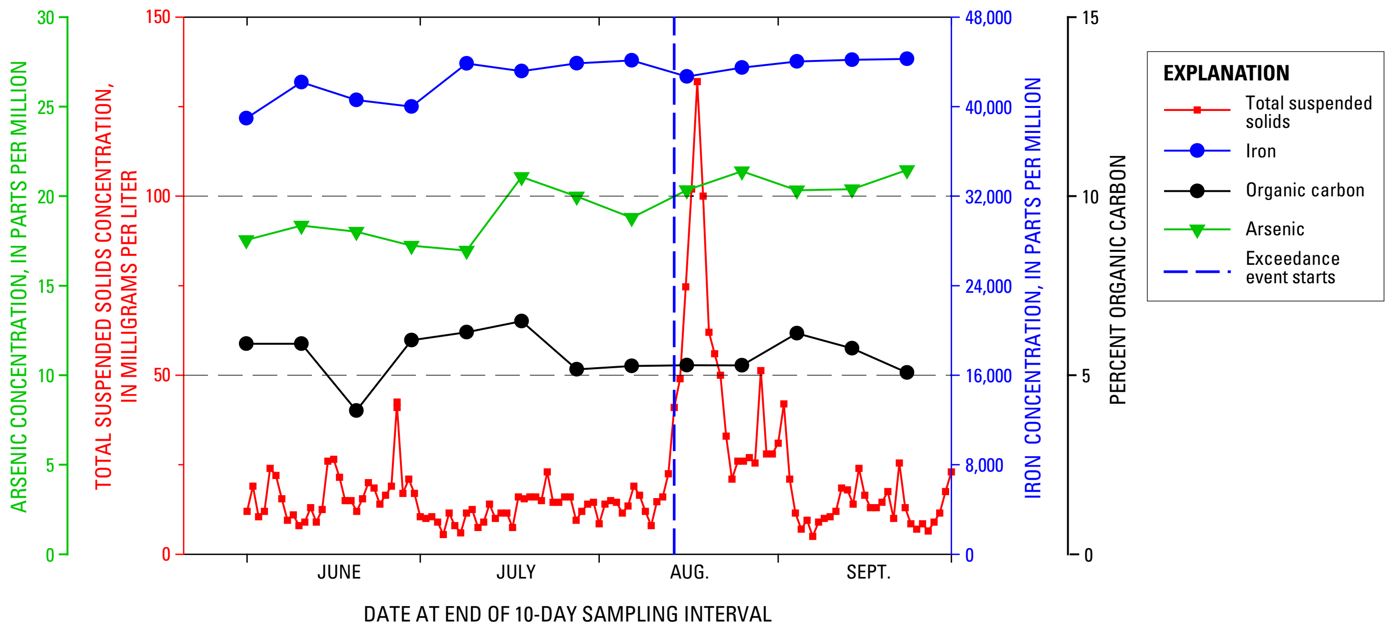

Figure 8. Concentrations of organic carbon, iron, and arsenic (salt-free) in sediment-trap samples at the end of each 10-day sampling interval and concentration of total suspended solids in the waste steam at the Deer Island Sewage Treatment Plant on the day of collection, summer 2002.

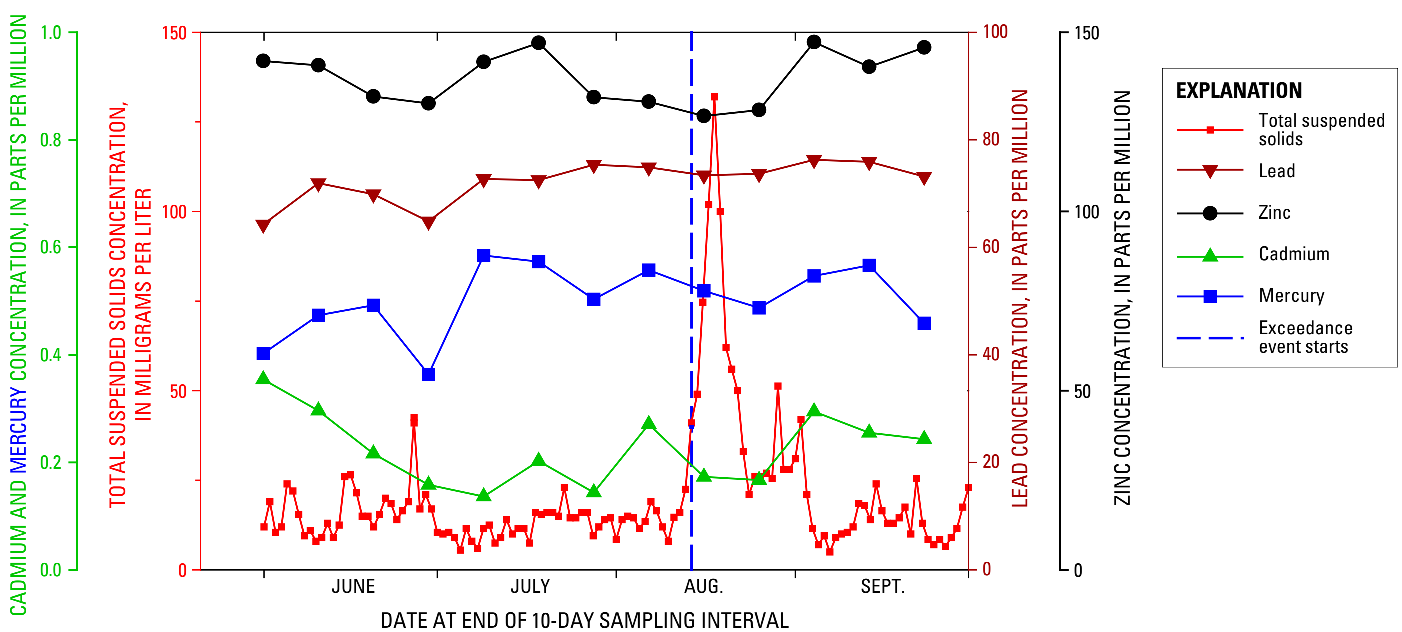

Figure 9. Concentrations of cadmium, mercury, lead, and zinc (salt-free) in sediment-trap samples at the end of each 10-day sampling interval and concentration of total suspended solids in the waste steam at the Deer Island Sewage Treatment Plant on the day of collection, summer 2002.

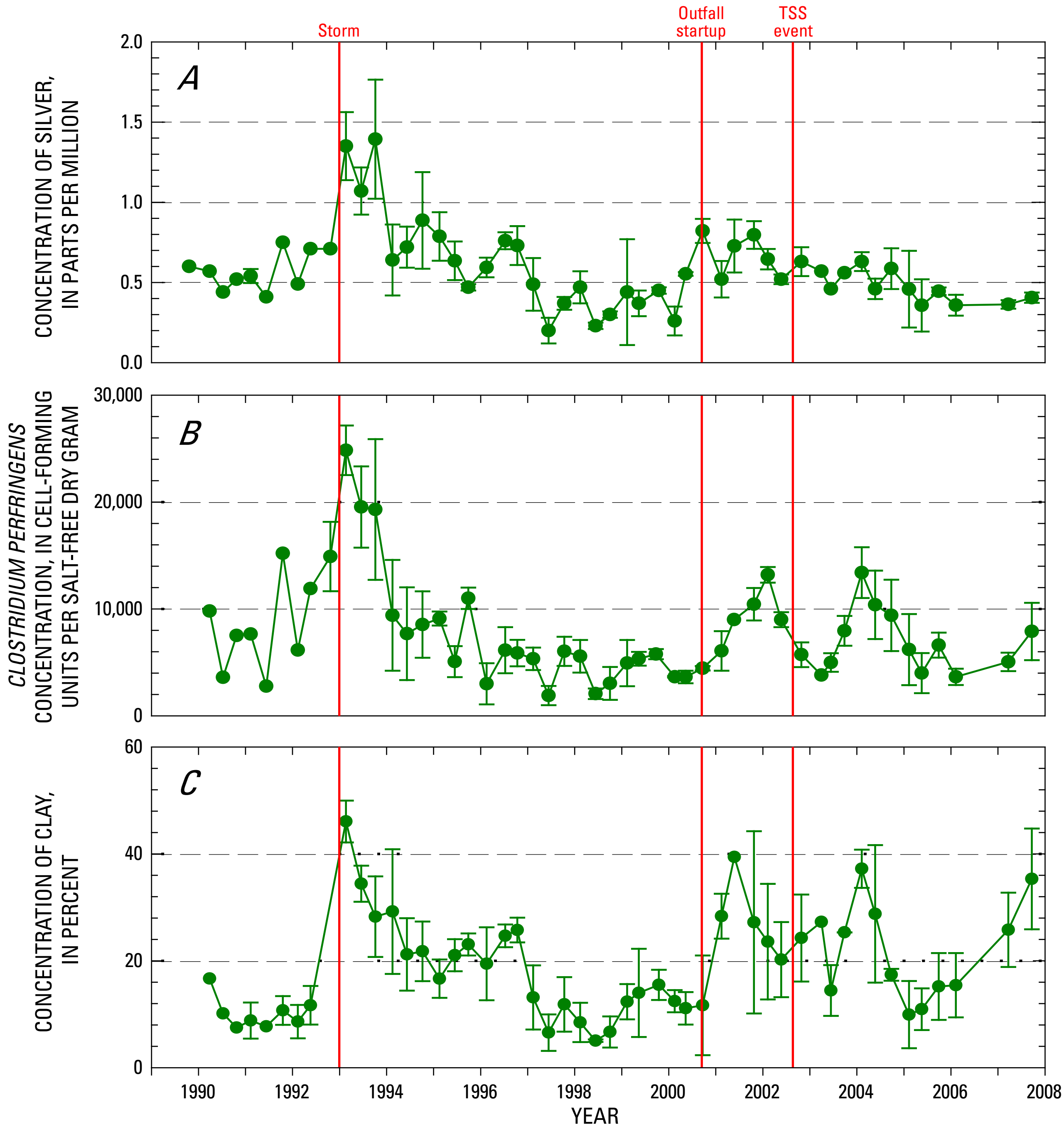

Figure 10. Concentrations of (*A*) silver (Ag), (*B*) *Clostridium perfringens*, and (*C*) clay in surface sediments (0–0.5 centimeters) at station 3, 1989–2007. There is no significant change in the concentrations of Ag, *C. perfringens*, or clay that could be attributed to the total suspended solids (TSS) event in samples of surface sediment that were collected 10 weeks after the August 2002 event. The highest Ag concentrations were observed in 1993 and are attributed to the transport of fine-grained sediment bearing Ag from near the shore to this location during the intense storm of December 11–16, 1992. Average post-outfall concentrations of Ag at station 3 are not statistically different from average pre-outfall concentrations (even with storm-related values removed from pre-outfall average). The post-outfall concentrations of Ag are not increasing with time. Error bars are defined by analysis of two or more replicate samples. Highest concentrations of *C. perfringens* and clay, like those of Ag, follow the storm of December 11–16, 1992. Average post-outfall concentrations of *C. perfringens* at station 3 are not statistically different from average pre-outfall concentrations (even with storm-related values removed from the pre-outfall average). The post-outfall concentrations of *C. perfringens* are not increasing systematically with time. Post-outfall clay content in the 4 years following outfall startup (September 2000) were on average higher and more variable than during the 3-year period prior to outfall startup. Variations in the clay content of the surface sediment may account for the similar patterns observed in Ag and *C. perfringens* concentrations during the period. (From Bothner and Butman, 2007, fig. 7.3)

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