Battelle

CSO EFFECTS ON CONTAMINATION OF BOSTON HARBOR SEDIMENTS

MWRA Task Order No. 18

September 27, 1991

Prepared for

Massachusetts Water Resources Authority
Charlestown Navy Yard, 100 First Avenue
Boston, Massachusetts 02129

FINAL REPORT

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1.0 INTRODUCTION

During heavy rains, when the extra burden of storm runoff overloads wastewater-treatment systems, combined sewer overflows (CSO) may contribute significantly to the pollution of Boston Harbor and the tributaries flowing into the Harbor. CSO discharge may include pollutant debris of many types and sizes, as well as microbiological and chemical contaminants. Chemical contaminants may include those from lawn, park, agricultural, and street runoff and from raw sewage.

Massachusetts Water Resources Authority (MWRA) requested that Battelle Ocean Sciences study the impact of CSOs on sediment quality in certain areas of Boston Harbor. For this study, Battelle collected sediments close to and remote from known CSO outfalls to determine if the CSOs significantly impact the local sediment quality. Effluent and/or sludge were also collected from two CSOs and two wastewater treatment plants.

Battelle coordinated and carried out the field work, and conducted and/or coordinated analysis of sediment samples for chemical, microbiological, and physical parameters. The analytical data were compiled, statistically analyzed, and interpreted. Limited chemical analysis was performed on the effluent and sludge samples to characterize the composition of this source material. This report discusses the apparent impact of the studied CSOs on the local sediment quality.

Background Information and Regulatory Context

As part of their monitoring requirements for National Pollutant Discharge Elimination System (NPDES) permits, municipalities and agencies that own CSOs are required to measure the effects of the CSOs on receiving waters. MWRA is charged with the responsibility of overseeing NPDES monitoring of the local municipalities with CSOs (Boston, Cambridge, Somerville, and Chelsea). To facilitate an integrated approach to monitoring the quality of waters receiving CSO input from several different municipalities, MWRA has agreed to perform the receiving-water monitoring component of the NPDES permit (MWRA, 1989) for the entire CSO receiving-water area.

During the summers of 1989 and 1990, MWRA undertook intensive surveys of Boston Harbor and its tributary rivers (MWRA, 1990). The water-quality monitoring focused on measuring densities of sewage indicator bacteria as well as dissolved oxygen, water temperature, and salinity, during wet-

and dry-weather conditions. This approach was taken because data collected during 1988 for the MWRA CSO Facilities Plan and data previously collected by the Department of Environmental Protection (DEP) and the Metropolitan District Commission (MDC) indicated that the most severe CSO-caused pollution problem in the water column was contamination with human pathogens present in raw sewage, indicated by the high numbers of sewage indicator bacteria (fecal coliform and *Enterococcus*). MWRA has proposed focusing on sediments for the sampling and analysis of toxic metals and organic pollutants. MWRA and Battelle conducted a pilot study in May 1990 for which samples were collected from two sites in the Charles River and three sites in the Mystic River (Battelle, 1990a).

In the spring of 1990, MWRA and the Boston Water and Sewer Commission (BWSC) began a coordinated monitoring program to measure the flows and pollutant loadings from the BWSC CSOs and the effects of overflows on nearfield and farfield receiving waters (BWSC, 1990a,b). A portion of the sediment sampling proposed as part of the BWSC monitoring program was included in this study.

OBJECTIVES

The objective of this study was to determine the local effects of CSOs on contaminant concentrations in selected sediments of Boston Harbor. This was accomplished by measuring levels of selected contaminants in sediments at sites that were expected to be affected by CSOs and at sites in the same general area that were expected to be relatively free of CSO impact. In addition to assessing CSO impact on sediment quality, a number of sites were chosen for sampling and analysis primarily to provide status information and baseline data on sediment quality for future monitoring.

2.0 TECHNICAL APPROACH

To assess the impact of CSOs on sediment quality, sediment samples were collected from 14 sites in the Dorchester Bay region of Boston Harbor. Sample collection, transport, storage, and analysis procedures followed the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Mussel Watch Program sediment sample procedures (Battelle, 1990b), unless otherwise specified. Sediment samples were analyzed for a number of environmentally important chemical and microbiological parameters (Table 2-1).

The sample analysis was conducted using a stepwise approach, beginning with microbiological, total organic carbon (TOC), and grain-size analyses. Following these analyses, MWRA and Battelle selected samples for chemical analysis based on the results of microbiological, TOC, and grain-size analyses. The data were analyzed to determine the differences in sediment quality among sites predicted to have significant CSO input and sites remote from CSO sources. Additionally, the data were compared against Boston Harbor data from earlier studies. The sediment-quality data generated in this study are also useful baseline data for determining changes in future sediment quality.

2.1 SITE SELECTION — RATIONALE AND OBJECTIVES

The approximate locations of the 14 sampling sites selected for this study are indicated in Figure 2-1. These sites represent both areas expected to be impacted as well as areas unimpacted with respect to the CSOs chosen for investigation. In this study, the site identifiers were given the prefix DB for Dorchester Bay (i.e., DB01 is the same as site 1 in Figure 2-1).

The study focuses on the Old Harbor area of Dorchester Bay (sites 1 through 9) because little sediment-sampling work has been carried on there and because BWSC monitored CSOs in this area during summer 1990. Figure 2-2 shows the Old Harbor study area. The entire Old Harbor study area has a depth of less than 18 ft at low tide, and most of the Old Harbor has a depth of less than 10 ft. Carson Beach, on the northern side of Old Harbor in the Dorchester Bay region of Boston Harbor, has a number of CSOs that discharge into the intertidal zone after heavy rain. BOS-86 is the CSO in this area that has the largest discharge volume according to a recent sewer system modeling study (BWSC, 1991). The second largest discharge volume is from BOS-87 followed by BOS-82, BOS-84, BOS-81, BOS-85, and BOS-83. It is believed that BOS-87 discharges primarily stormwater

Table 2-1. Analysis Parameters and Their Respective Method Detection Limits in Sediment

Analyte	Method Detection Limit[a]
Polynuclear Aromatic Hydrocarbons (PAH) and Other Organic Compounds	
Naphthalene	0.47
2-methylnaphthalene	0.72
1-methylnaphthalene	0.63
Biphenyl	0.66
2,6-dimethylnaphthalene	1.08
Acenaphthylene	1.99
Acenaphthene	0.28
2,3,5,-trimethylnaphthalene	0.79
Fluorene	0.51
Phenanthrene	0.92
Anthracene	1.29
1-methylphenanthrene	1.27
Fluoranthene	1.47
Pyrene	1.44
Benz[*a*]anthracene	1.67
Chrysene	0.56
Benzo[*b*]fluoranthene	2.92
Benzo[*k*]fluoranthene	1.12
Benzo[*e*]pyrene	0.84
Benzo[*a*]pyrene	0.67
Perylene	0.39
Indeno[1,2,3-*c,d*]pyrene	1.51
Dibenz[*a,h*]anthracene	1.03
Benzo[*g,h,i*]perylene	1.10
Linear alkyl benzenes (LAB)	1.64
Coprostanol	2.5
Metals[b]	
Aluminum	190
Cadmium	0.003
Chromium	0.09
Copper	0.25
Lead	0.075
Manganese	2
Nickel	0.10
Iron	9.5
Zinc	1.5
Bacteriology	
Clostridium perfringens	Not applicable
Fecal coliform	Not applicable
Enterococcus	Not applicable
Other Analyses	
Total organic carbon (TOC)	100
Grain size	Not applicable

[a]PAH MDLs were determined in an earlier study. Organic MDLs are in nanograms per gram (ng/g) dry weight, and metals and TOC MDLs are in micrograms per gram (μg/g) dry weight.
[b]Metals MDLs are for total digestion; MDLs for partial digestion are generally 2-4 times higher.

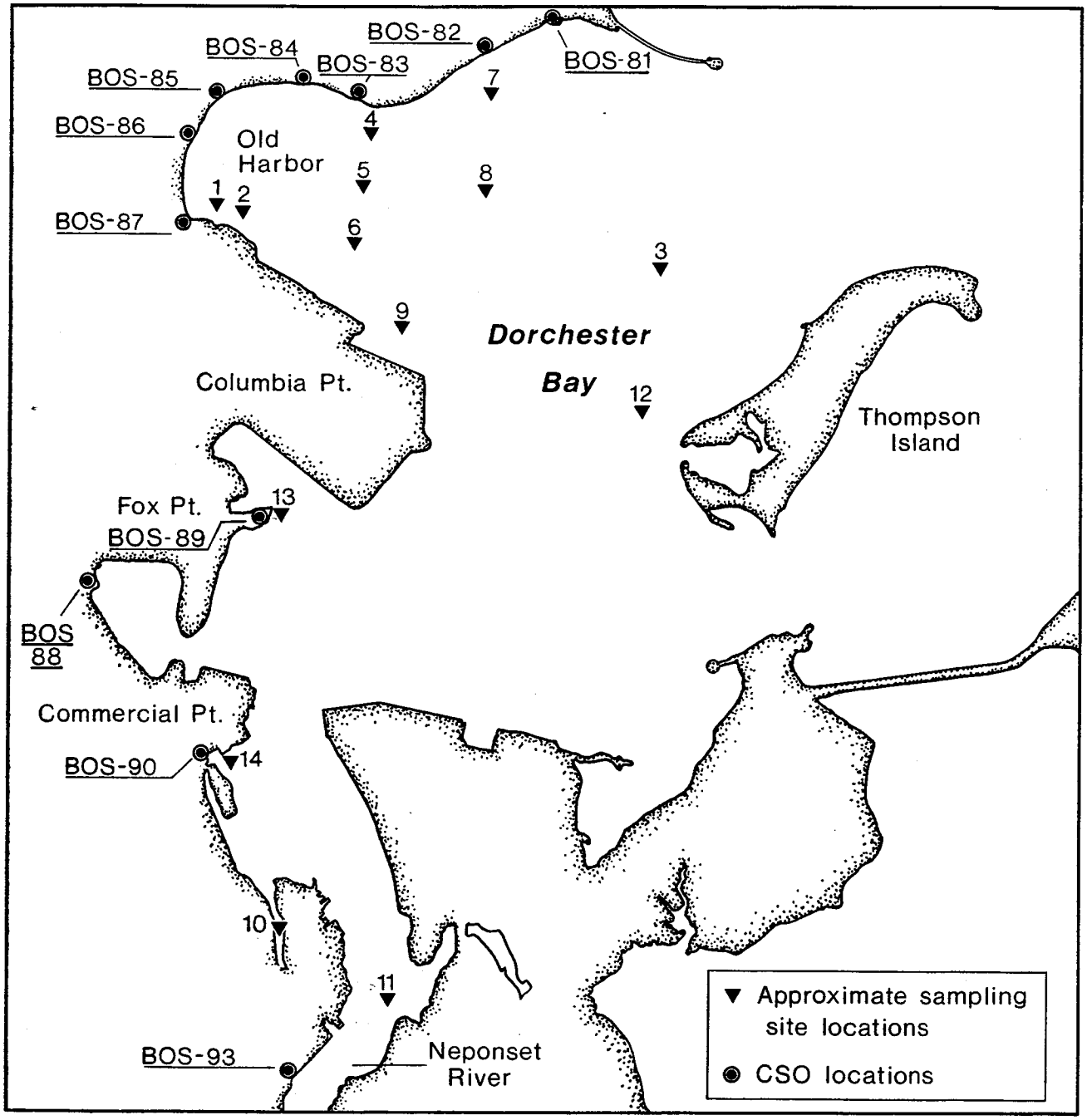

Figure 2-1. Dorchester Bay Study Area and Approximate Locations of Sampling Sites

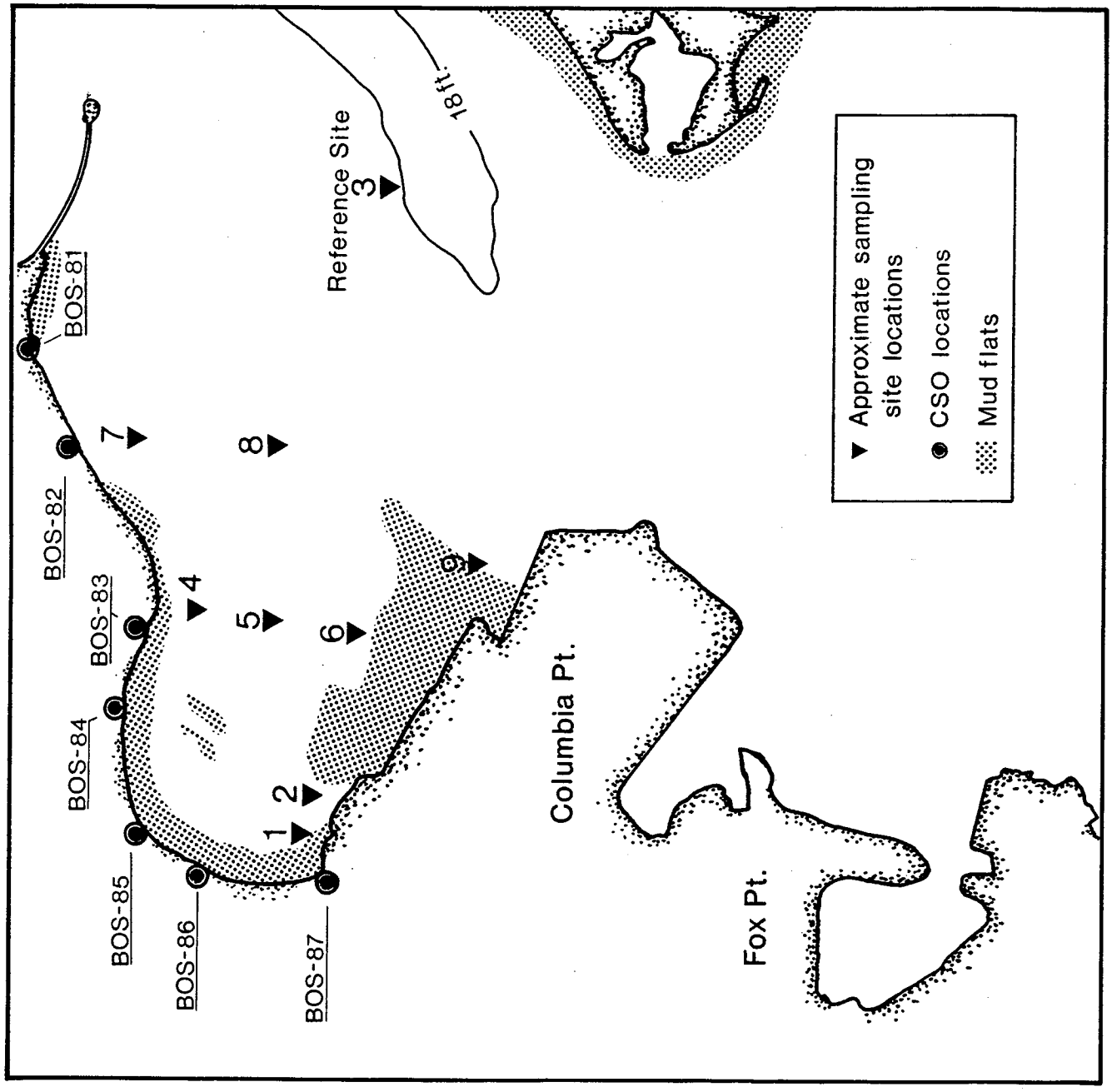

Figure 2-2. Old Harbor Study Area

runoff and little combined sewage (MWRA communication). The BOS-87 regulator is located on the west side of the highway (I-93), and it is relatively high in elevation and rarely allows sewage to overflow. It is therefore thought that most of the discharge from BOS-87 is stormwater runoff from the relatively large drainage area (including Day Boulevard and Columbus Park) between the CSO regulator and the point of discharge. The southern side of Old Harbor (sites DB06 and DB09) receives no CSO input, and was sampled, along with site DB03, to represent Boston Harbor areas relatively free of CSO impact.

The second area of Dorchester Bay that was studied was the Fox Point/Commercial Point area (sites DB10 through DB14). Figure 2-3 shows the Fox Point/Commercial Point study area, which, like the Old Harbor area, for the most part has a depth of less than 10 ft at low tide. This area is affected by two large CSOs: the Fox Point CSO (BOS-89) and the Commercial Point CSO (BOS-90) which discharged 91.7 and 86.2 million gallons in 1990, respectively (BWSC, 1991). Two smaller CSOs in this area (BOS-88 and BOS-93) discharge significantly lower volumes. The Fox Point/Commercial Point CSO area was, like the Old Harbor area, also sampled near (sites DB13 and DB14) and farther away from (sites DB11 and DB12) known CSO input. It was intended that sites DB10, DB11, and DB14 provide information on the effect of the effluent from BOS-90 (Commercial Point) on nearby sediments. A CSO treatment facility that screens and chlorinates the BOS-90 effluent became operational in the fall of 1990, but the samples collected for this study were collected prior to when the new facility went on line. Therefore, samples collected during this study will provide baseline data for comparison with samples collected after the facility began operation. As part of the monitoring study near Commercial Point, MWRA has located sites near Pine Neck Creek (site DB10) and the mouth of the Neponset River (site DB11) to assess the relative contributions of these potential sources of pollution to the Commercial Point/Tenean Beach area.

Sites DB12 and DB13 were used to determine if the results obtained from previous studies of the Fox Point CSO could be duplicated. Recent work near the Fox Point CSO (Eganhouse and Sherblom, 1990; Wallace *et al.*, 1990; Gallagher *et al.*, 1990) concluded that most of the sediment deposited adjacent to BOS-89 (Fox Point) did not come from that CSO. This conclusion was based on measured rates of deposition in that area which exceeded measured input of total suspended solids (TSS) from CSO BOS-89. In these studies, it was also observed that the total linear alkyl benzene (LAB)/coprostanol ratio in the sediments was characteristic of Nut Island sludge and effluent, and different from that found in the CSO BOS-89 effluent and Deer Island sludge and effluent.

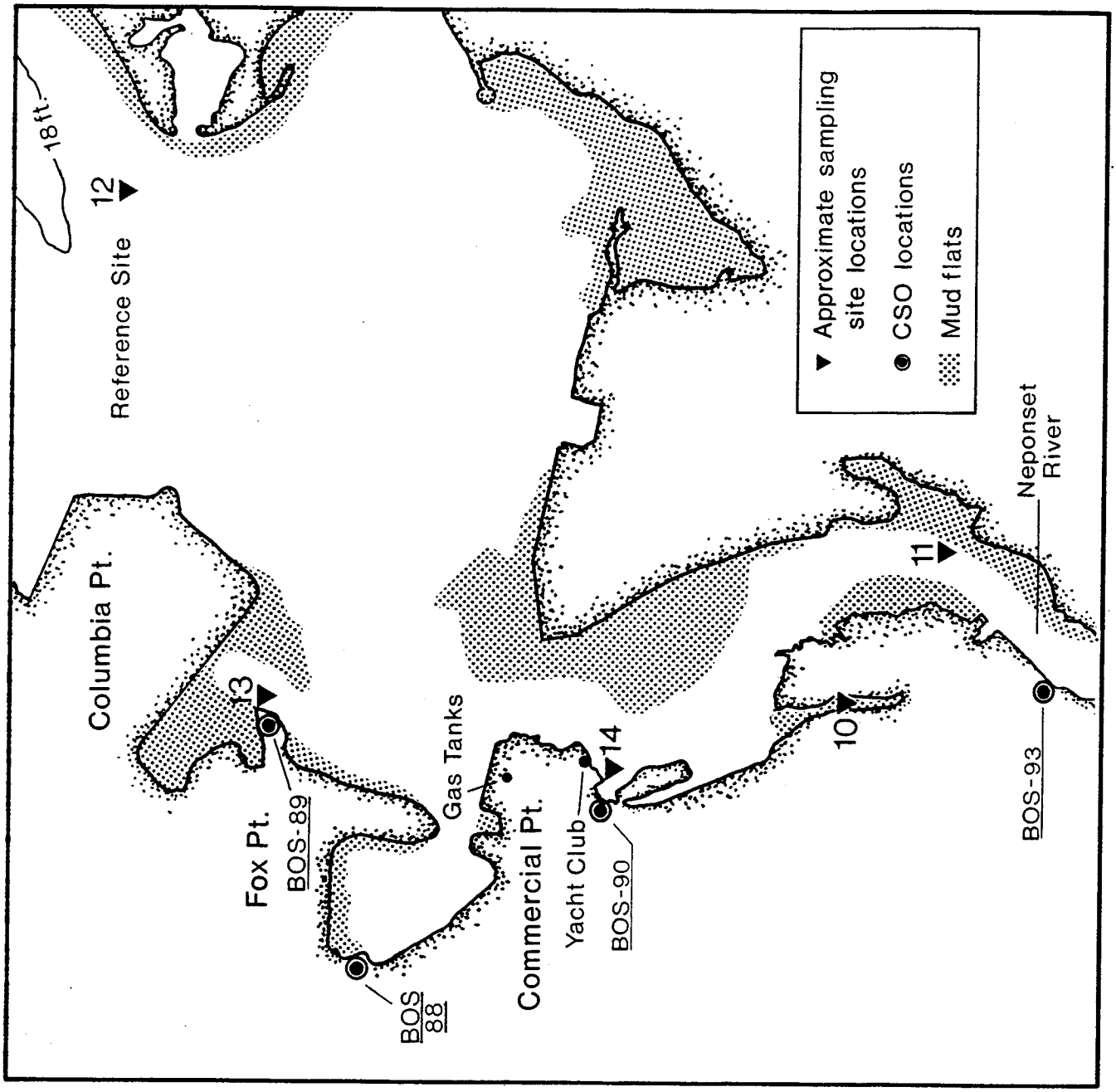

Figure 2-3. Fox Point/Commercial Point Study Area

The investigators hypothesized that the major source of contamination to nearby Savin Hill Cove was from Nut Island, and not from the nearby CSO.

Total LAB/coprostanol ratio measurements were made in an attempt to assess the sources of sediment contamination. The total LAB/coprostanol ratio was determined for Fox Point (BOS-89) and Commercial Point (BOS-90) to see how the results compare to previous work. As part of this study total LAB/coprostanol ratios in Nut Island sludge and effluent, Deer Island sludge and effluent, and the CSO effluent from BOS-89 and BOS-90 were also measured.

One of the most difficult problems in environmental monitoring is to measure the relative impact of different sources of pollution. In Boston Harbor, the effects of CSO input are confounded by input from treatment plants, upstream river sources, boats, stormwater (including street runoff), atmospheric deposition etc. In addition, all of these inputs can be dispersed and reconcentrated in depositional areas not necessarily near the original source. The intent of this study was to use microbial indicators and total LAB/coprostanol ratios to help to discriminate among some of these sources at sites near and distant from the CSOs, and to relate measured toxic pollutants to probable sources.

Table 2-2 lists indicator parameters and their possible sources in Dorchester Bay sediment. The microbiological parameters originate with human feces. Coprostanol is an organic compound that also originates with human feces. LABs are organic compounds that are major constituents of detergents, and originate where detergents are used or produced. The relative amounts of LAB to coprostanol (LAB/coprostanol ratio) have been used to determine possible sources of discharge (Eganhouse and Sherblom, 1990; Gallagher *et al.*, 1990).

2.2 SAMPLE COLLECTION AND FIELD PROCEDURES

Battelle coordinated the field effort for the collection of sediment samples for this study. This fieldwork was conducted on November 7 and 8, 1990. The field team consisted of a Battelle field scientist, one person from MWRA, and a boat captain. The boat and captain were provided by the Battelle subcontractor, TG&B Marine Services. MWRA coordinated the collection of effluent and sludge samples, and these samples were collected on January 7 and 8, 1991.

Table 2-2. Pollutant Indicator Parameters and Their Possible Sources

Indicator	Possible Source of Discharge to Dorchester Bay	Original Source
Fecal coliform and *Enterococcus*	CSO, storm drains, rivers, boats	Human feces
Clostridium perfringens	Sewage sludge and effluent, CSO, stormwater	Human feces
Coprostanol	CSO, sewage sludge and effluent	Human feces
Linear alkyl benzene (LAB)	CSO, sewage sludge and effluent	Detergent use and manufacturing
Total LAB/coprostanol ratio of approximately 0.2	Nut Island treatment plant	Domestic sewage and detergent manufacturing
Total LAB/coprostanol ratio of approximately 0.02	Deer Island treatment plant	Domestic sewage

The Dorchester Bay region of Boston Harbor was selected for this work. MWRA provided Battelle with the approximate locations for all sampling sites. Exact site locations were determined during the conduct of the field work by the MWRA field representative and the Battelle field scientist. Figures 2-1 through 2-3 show the approximate locations of the sampling sites. The exact location of each sampling site is shown in Table 2-3.

The field team collected surface sediment-grab samples from each of the 14 preselected sampling sites. To improve accuracy and evaluate the degree of intrasite variability in contaminant loading, three replicate sediment samples were collected at each site (for a total of 42 field sediment samples). The sediment samples were collected by using a clean Kynar®-coated 0.04-m^2 van Veen grab. The grab sampler and sampling scoops were cleaned by rinsing with dichloromethane, methanol, and deionized water prior to each sample collection. Sediment from the top 2 cm of the grab sampler was removed with a clean Teflon® scoop. Sediment in contact with the sides of the grab was not used. The samples for bacteriological analysis were removed directly from the grab and placed in sterilized, prelabeled containers. The sample to be used for grain-size and chemical analysis was placed in a wide-mouth glass jar (I-Chem, Inc.), cleaned and prepared specifically for the analysis to be performed. The sample was stirred with a Teflon spatula and subsampled for trace metals, organics, TOC, and grain-size analyses. Subsamples from this top 2-cm homogenate of the grab were removed using a clean Teflon scoop or spatula and placed in precleaned, prelabeled glass vials (TOC samples), glass jars [organics (I-Chem, Inc.)], Teflon jars (metals), and Whirl-Pack® bags (grain-size samples).

The samples were stored on ice in coolers while in the field. The fecal coliform and *Enterococcus* samples were transferred to the custody of a Toxikon representative at the end of the day. Toxikon, Woburn, Massachusetts, was the Battelle subcontractor used for fecal coliform and *Enterococcus* analysis. MWRA coordinated all aspects of the *C. perfringens* analysis, including provision of sample containers, sampling, storage, and transport of the samples to the analytical laboratory [Biological Analytical Laboratories (BAL), North Kingstown, Rhode Island].

The samples for grain-size and chemical analysis were stored on ice until delivery to Battelle later on the day of sampling. TOC and grain-size samples were later packaged and shipped, cold, for analysis by Battelle subcontractors. TOC analysis was performed by Global Geochemistry, Canoga Park, California. The grain-size analysis was performed by Geo/Plan Associates, Hingham, Massachusetts.

Table 2-3. Sampling-Site Locations

Site ID	Loran Coordinates[a]		Lat/Long Coordinates[b]		Depth[c]
	TD1	TD2	N	W	(ft)
DB01	14061.23	25870.88	42 19.48	71 02.75	5
DB02	14060.56	25870.08	42 19.45	71 02.64	6
DB03	14049.37	25856.19	42 19.30	71 00.86	17
DB04	14056.75	25868.36	42 19.68	71 02.22	9
DB05	14057.59	25867.96	42 19.52	71 02.23	4
DB06	14058.34	25866.87	42 19.39	71 02.25	NR[d]
DB07	14053.29	25865.79	42 19.80	71 01.78	4
DB08	14054.01	25863.63	42 19.53	71 01.69	7
DB09	14058.74	25864.53	42 19.14	71 02.12	8
DB10	14069.35	25857.78	42 17.46	71 02.54	4
DB11	14066.64	25853.57	42 17.32	71 02.05	8
DB12	14053.78	25857.48	42 18.97	71 01.29	21
DB13	14063.45	25864.15	42 18.60	71 02.50	18
DB14	14068.16	25861.96	42 17.92	71 02.73	4

[a]Loran calibration point was Sunken Ledge Light, Boston Harbor. Calibration-point coordinates at point of calibration (just north of light) are N42 17.67 and W70 57.43, according to United States Coast Guard/NOAA Boston Harbor chart 13270 (June 10, 1989).
[b]Lat/long coordinates are given in degrees and minutes (e.g., W71 02.86 is 71° 02.86'W).
[c]Depth at time of sampling.
[d]NR: Not recorded.

The organic and metals samples were placed in a freezer and stored at, or below, —20 °C until laboratory processing could begin. Effluent from the Fox Point and Commercial Point CSOs (BOS-89 and BOS-90), and effluent and sludge from Deer Island and Nut Island were collected by MWRA for LAB and coprostanol analyses. These samples were collected in glass containers with Teflon-lined caps (I-Chem, Inc.), provided by Battelle. MWRA coordinated the sampling and transport of these samples to Battelle. These samples were stored at 4 °C, and extracted within 24 h of receipt.

Navigation

The precise site locations were determined using a shipboard Loran C system. Positioning was accomplished with a Micrologic Explorer Loran C unit aboard the R/V *Surveysa*. During survey operations, the latitude/longitude positions as well as Loran time delays (TD) of the sampling sites were recorded on site log forms. On both days, the Loran was calibrated against a point of known coordinates, the Sunken Ledge Light. The Loran readings of the calibration point were recorded in the field. All measured sampling-site coordinates were later corrected for the offset by using the true calibration-point coordinates. Loran signal strength was monitored, and the signal-to-noise ratio ranged from 73 to 90 on the two sampling days.

2.3 LABORATORY SAMPLE-ANALYSIS PROCEDURES

The surface-sediment samples were analyzed for selected physicochemical and environmentally important organic, trace-metal, and microbiological parameters (Table 2-1). Battelle was responsible for coordinating the analysis of samples selected for organics, metals, *Enterococcus*, fecal coliform, TOC, and grain-size analyses. MWRA coordinated the *C. perfringens* analyses. The method detection limits for the Battelle conducted chemical analyses (Table 2-1) were determined either in other recent studies (PAH) or in this study (metals, LAB, and coprostanol).

Sample analysis was conducted in a stepwise fashion. Microbiology, TOC, and grain-size analyses were conducted on all 42 field sediment samples. Based on the microbiological, TOC, and grain-size analysis results, MWRA and Battelle jointly decided which sediment samples would be processed for organic and metals analysis so that as much valuable information as possible could be generated with the funds available. In this site/analysis-selection process, sites with similar locations and characteristics (microbiological, TOC, and grain size) were identified and, in some cases, eliminated from the list of sites for chemical analysis.

The chemical analyses performed on the sediment samples are identified by site in Table 2-4. Effluent from the Fox Point and Commercial Point CSOs (BOS-89 and BOS-90) and effluent and sludge from Deer Island and Nut Island wastewater treatment plant outfall were analyzed for LAB and coprostanol only.

2.3.1 Sample Analysis for Organic Analytes

Analysis for PAHs and LABs was performed by gas chromatography/mass spectrometry (GC/MS). Analysis for coprostanol was performed by gas chromatography/flame ionization detection (GC/FID), which generally is more sensitive for this analyte. The PAH analytes include the 24 PAHs used in the NOAA National Status and Trends Mussel Watch Program (Battelle, 1990b, 1990c, 1991) and in a previous pilot study on CSOs (Battelle, 1990a). The LABs were quantified as the five major LAB groups, as designated by the number of carbons in the alkyl chain (i.e., the individual phenyl decanes were summed and reported as C_{10}-LABs). The C_{10}-, C_{11}-, C_{12}-, C_{13}-, and C_{14}-LABs were determined and reported separately, and the total LAB concentration was calculated as the sum of the five LAB groups.

In addition, Battelle attempted to analyze for benzthiazole as part of the PAH analytical method. Benzthiazole is a polycyclic organic compound originating in synthetic rubber and has been used as an indicator of street runoff (Spies *et al.*, 1987). This was an "extra" and experimental analysis and, as agreed upon with MWRA, was to be performed only if it could be performed without any significant additional effort (and at no extra cost). Because no commercial standards are available, the parent compound Delac® MOR [2-(morpholinothio)-benzthiazole] was artificially degraded to form the three primary degradation products benzthiazole, 2-(4-morpholinyl)-benzthiazole, and 2-methyl-mercapto-benzthiazole. These degradation products are the main compounds originating in Delac MOR that occur in the environment. However, the degradation is very slow and could not be completed during this project. Without these analytical standards (the degradation products), reliable analysis could not be performed, and therefore no benzthiazole data are reported for this study.

Organic samples were spiked with the PAH surrogates d_8-naphthalene, d_{10}-acenaphthene, d_{12}-perylene, d_{14}-dibenz[*a,h*]anthracene, the LAB surrogate 1-phenyl nonane, and the coprostanol surrogate androstanol. Samples were solvent-extracted, purified using either high-performance liquid

Table 2-4. Analysis Parameters by Sampling Site

Site	Metals	PAH	LAB/ Coprostanol	Bacteriology/ TOC/Grain-size
Sediment				
DB01	X	X	X	X
DB02	X	X		X
DB03	X	X		X
DB04	X	X	X	X
DB05	X	X		X
DB06	X	X		X
DB07				X
DB08				X
DB09				X
DB10	X	X		X
DB11				X
DB12	X	X	X	X
DB13	X	X	X	X
DB14	X	X	X	X
Sludge				
Deer Island			X	
Nut Island			X	
Effluent				
Deer Island			X	
Nut Island			X	
Fox Point (CSO)			X	
Commercial Point (CSO)			X	

chromatography (HPLC) or traditional liquid chromatography column cleanup, and analyzed by GC/MS and/or GC/FID. Samples for which only PAH were to be determined were purified by HPLC (using a size-exclusion chromatography column), and then analyzed by GC/MS. Samples for which LAB and coprostanol (and PAH for some samples) were to be determined were purified by traditional liquid chromatography cleanup, fractionated into a PAH/LAB fraction and a coprostanol fraction, and then analyzed by GC/MS (PAH/LAB) and/or GC/FID (coprostanol). Samples were quantified based on the surrogates (i.e. corrected for surrogate recovery). D_{10}-phenanthrene was added as an internal standard for determination of PAH and LAB surrogate recoveries, and androstane was added as an internal standard for the determination of coprostanol surrogate recovery.

2.3.2 Sample Analysis for Metal Analytes

All metals, except cadmium, were initially analyzed by flame atomic absorption spectroscopy (FAAS). Cadmium analysis was performed by graphite-furnace atomic absorption spectroscopy (GFAAS). A few samples had analyte concentration levels below the detection limit of FAAS and were reanalyzed by GFAAS, for a lower detection limit. Table 2-1 lists the detection limits determined in this study. The samples for metal analysis were processed by an aqua regia/hydrofluoric acid digestion ("total digestion") procedure. The aqua regia/hydrofluoric acid extraction/digestion and sample-preparation scheme will quantitatively recover all metals, including the aluminum in the sample, allowing normalization of the concentration of other metals to aluminum. Three samples (the replicates from site DB01) were processed by the partial-digestion method (aqua regia only) used in a previous pilot study on CSOs (Battelle, 1990a). This allows comparison of the two digestion methods and provides estimates of relative differences in recovery of each metal from sediment. This will facilitate comparison of data from studies in which the two different digestion methods were used.

2.3.3 Sample Analysis for Microbiological Parameters

Enterococcus and fecal coliform were analyzed by Battelle's subcontractor, Toxikon, Inc. This analysis was conducted using the membrane filtration method. *Enterococcus* was analyzed as fecal streptococcus, using an agar medium relatively selective for *Enterococcus*. *C. perfringens* analysis was coordinated by MWRA and performed by BAL, using a sonication and membrane filtration

method. All *C. perfringens* analyses were performed in duplicate. MWRA provided Battelle with the *C. perfringens* data for inclusion in this report.

2.3.4 Sample Analysis for TOC and Grain Size

TOC analysis was performed by Battelle's subcontractor, Global Geochemistry, Inc., using a LECO carbon analyzer. TOC measurements were based on the measurement of oxidized carbon (the procedure does not measure any inorganic carbon that may be present).

Grain-size analysis was performed by Battelle's subcontractor, Geo/Plan Associates. The standard sieve/pipette method was utilized to determine the percent gravel/sand/silt/clay distribution by weight of the sample. This method includes the use of a deflocculant and mechanical disaggregation of the wet sample, and wet sieving to separate the coarse (gravel/sand) portion from the fine (silt/clay) portion.

2.4 LABORATORY QUALITY CONTROL PROCEDURES

Data quality is assessed by comparability, representativeness, completeness, accuracy, and precision in field and laboratory activities. Comparability between this project and earlier studies was ensured by using standard methods consistent with those used in other Battelle - MWRA studies. Representativeness was addressed through the design of the field sampling program, and by the proper preservation and storage of samples to ensure that the samples analyzed accurately represent the materials collected. In the field, representativeness and precision were addressed by collecting three site replicates. Completeness, which is defined as the measure of data collected versus the amount expected under ideal conditions, was 100%. The Quality Control (QC) samples and data requirements for accuracy and precision are summarized below.

The QC program for organic analysis included the processing of one procedural blank, one matrix (or blank) spike, and one matrix (or blank) spike duplicate sample for each batch of no more than 20 field samples. The procedural blanks (containing all reagents used in sample processing, carried through all steps and treated as samples) ensures that there are no significant levels of laboratory contamination. The matrix spike (field sample spiked with the respective analytes) and matrix-spike

sample duplicates were used to demonstrate laboratory accuracy and precision. Internal standard recoveries were monitored for every sample to provide data on the efficiency of the sample extraction and other sample-processing manipulations. For metals analysis, the QC program included the processing of a sediment standard reference material (SRM), one sample duplicate, one matrix spike, and one procedural blank as a minimum for every 20 samples.

Quality control for the *Enterococcus* and fecal coliform analyses included ensuring the media quality by conducting growth promotion and sterility analyses on all lots of media prepared and used. Positive and negative controls were also included with each set of samples. Positive control involved the inoculation of media to verify its ability to support characteristic growth. Sterile, blank filters placed on medium plates were negative controls used to indicate contamination in the filter or media. The contracting laboratory neglected to perform the two laboratory duplicate analyses that were to be performed with the field samples, which made it impossible to measure variability.

Quality control of TOC analysis was monitored by tracking instrument calibration accuracy by analyzing one standard material every 10 samples (within 5% of true value), precision by performing duplicate analyses every 10 samples (within 10% of each other), and by analyzing one procedural blank every 50 samples (no significant levels of interference or contamination).

Sediment grain-size QC included determination of precision by performing two duplicate analyses with the 42 field samples. The percent difference between the two replicate determinations was to be less than 20% for sand, silt, and clay.

The following are the laboratory QC accuracy and precision criteria goals that were in effect for the chemistry analyses.

PAH Analysis	
Surrogate recovery	50%-150%
Matrix spike analyte recovery	50%-150%
Matrix spike/matrix-spike duplicate quantification reproducibility	30% difference
Procedural blanks	<5× detection limit
Metals Analysis	
SRM accuracy	50%
Matrix spike analyte recovery	50%-150%
Sample duplicate quantification reproducibility	30% difference
Procedural blanks	<5× detection limit
TOC Analysis	
Standard Material accuracy	5%
Sample duplicate quantification reproducibility	10% difference

2.5 DATA ANALYSIS PROCEDURES

Battelle analyzed the data, using appropriate statistical techniques to determine if there were significant differences in contaminant loading among CSO-impacted sites and sites expected to be relatively unimpacted by CSOs (reference sites). Three main types of statistical analysis were performed. These were (1) determination of the intrasite variability, (2) determination of contamination differences among individual sites (potentially impacted) compared to a reference site, and (3) determination of contamination differences among sites within each of the two areas sampled. For the statistical analysis, the sampling sites were separated into two areas: Old Harbor (sites DB01 through DB09) and Fox Point/Commercial Point (sites DB10 through DB14).

Summary statistics were generated to test the intrasite variability, using the data for the three stations from each site. These include means, standard deviation, minimum and maximum station values, standard error, variance, and coefficient of variation for each study parameter. Two-sample *t*-tests were performed to compare differences in concentrations between potentially CSO-impacted sites and reference sites. Multiple comparisons of test sites were performed using a one-way analysis of variance (ANOVA) and the Student-Newman-Keuls Range test to determine differences in concentra-

fuels or as principal components of creosote formulation and are primarily the heavier-molecular-weight PAHs. The Group 1 PAHs are: naphthalene, 1-methylnaphthalene, 2-methylnaphthalene, 2,6-dimethylnaphthalene, 2,3,5-trimethylnaphthalene, fluorene, and 1-methylphenanthrene. The Group 2 PAHs are: fluoranthene, pyrene, benz[*a*]anthracene, chrysene, benzo[*b*]fluoranthene, benzo[*k*]-fluoranthene, benzo[*e*]pyrene, benzo[*a*]pyrene, indeno[1,2,3-*cd*]pyrene, dibenz[*a,h*]anthracene, and benzo[*g,h,i*]perylene.

Six of the 24 individual PAHs (biphenyl, acenaphthylene, acenaphthene, phenanthrene, anthracene, and perylene) are not included with either the Group 1 or Group 2 PAHs because they cannot be clearly categorized as belonging to only one of these two defined groups. Total PAH is defined as the sum of the 24 individual PAHs, and does not include any PAHs other than these 24 compounds. This grouping of PAHs, for purposes of analyzing the data, is identical to the method used in the NOAA Status and Trends Mussel Watch Program. Although the PAH data are presented in the text only by these three categories, the analytical results for all samples and all 24 PAH analytes are given in Appendix A (Organics Data for Sediments, Effluent, and Sludge Field Samples).

A summary of the sediment organics concentration data is presented in Table 3-1(a). These sediment concentration data were normalized to TOC and are presented in Table 3-1(b). The LAB and coprostanol data are presented in more detail in Section 3.1.1.2.

As indicated in Table 3-1(a), PAH concentrations in the sediment samples varied greatly, with total PAH concentrations ranging from 0.55 (site DB06) to 65.84 μg/g (site DB01). The Group 1 PAH (the low-molecular-weight petroleum-related PAHs) range in concentration from 0.03 to 4.48 μg/g and the Group 2 PAH (higher-molecular-weight combustion- and creosote-related PAHs) cover a concentration range of 0.45 to 46.77 μg/g. The concentration of the Group 2 PAH was, on average, approximately 10 times higher than the concentration of the Group 1 PAH.

The sediment PAH concentrations are less variable once the PAH data are normalized to sediment TOC content [Table 3-1(b)]. The TOC-normalized total PAH concentrations ranged from 2.00 (site DB05) to 10.54 μg/g/%TOC (site DB01), a factor of 5 difference. The difference in concentration for raw PAH data from the highest to lowest sites was a factor of approximately 100. Much of the variability in the sediment PAH concentration can thus be attributed to the variability in the TOC content.

Table 3-1. Sediment Organics Data Summary
(a) PAH, Total LAB, and Coprostanol Concentrations (μg/g dry weight)

Site ID	Group 1 PAH[a]	Group 2 PAH[b]	Total PAH	Total LAB	Coprostanol
DB01	4.48	46.77	65.84	1.35	4.22
DB02	0.07	1.19	1.46	NA[c]	NA
DB03	0.18	1.93	2.44	NA	NA
DB04	0.55	6.03	8.03	1.17	5.16
DB05	0.03	0.46	0.56	NA	NA
DB06	0.03	0.45	0.55	NA	NA
DB10	0.84	14.64	18.14	NA	NA
DB12	0.33	3.40	4.49	1.23	4.86
DB13	0.62	6.96	9.01	2.43	16.77
DB14	1.87	27.48	35.72	3.21	31.03

[a]Group 1 PAH: Low molecular weight, primarily petroleum-related PAH.
[b]Group 2 PAH: High molecular weight, primarily combustion-related PAH.
[c]NA: Not applicable; sample was not analyzed for this parameter.

Table 3-1. Sediment Organics Data Summary
(b) PAH, Total LAB, and Coprostanol Concentrations — Normalized to TOC (μg/g/% TOC)

Site ID	Group 1 PAH[a]	Group 2 PAH[b]	Total PAH	Total LAB	Coprostanol
DB01	0.69	7.54	10.54	0.22	0.65
DB02	0.17	2.89	3.54	NA[c]	NA
DB03	0.19	2.04	2.57	NA	NA
DB04	0.17	1.91	2.54	0.37	1.64
DB05	0.11	1.64	2.00	NA	NA
DB06	0.12	1.76	2.16	NA	NA
DB10	0.18	3.23	4.00	NA	NA
DB12	0.18	1.87	2.47	0.67	2.56
DB13	0.16	1.84	2.38	0.64	4.44
DB14	0.43	6.39	8.30	0.75	7.24

[a]Group 1 PAH: Low molecular weight, primarily petroleum-related PAH.
[b]Group 2 PAH: High molecular weight, primarily combustion-related PAH.
[c]NA: Not applicable; sample was not analyzed for this parameter.

3.1.1.2 LAB and Coprostanol Results

LABs were determined as the five major environmentally important LAB groups: phenyldecanes (C_{10}-LABs), phenylundecanes (C_{11}-LABs), phenyldodecanes (C_{12}-LABs), phenyltridecanes (C_{13}-LABs), and phenyltetradecanes (C_{14}-LABs). The individual phenyl-substituted alkanes in each LAB group were determined together as one analyte and reported as one value for the LAB group. The total LAB, defined as the sum of the C_{10}-, C_{11}-, C_{12}-, C_{13}-, and C_{14}-LABs, was also determined.

LAB and coprostanol analysis was performed on sediments from five sites. These samples were collected near two CSO outfalls in the Old Harbor area (sites DB01 and DB04), near the Fox Point (site DB13) and Commercial Point CSOs (site DB14), and from a reference site for the Fox Point/Commercial Point area near Thompson Island (site DB12). The total LAB concentrations in the sediment samples ranged from 1.17 (site DB04) to 3.21 μg/g (site DB14), and the coprostanol concentrations ranged from 4.22 (site DB01) to 31.03 μg/g (site DB14). When normalized to TOC, the concentrations ranged from 0.22 (site DB01) to 0.75 μg/g/%TOC (site DB14) and from 0.65 (site DB01) to 7.24 μg/g/%TOC (site DB14) for total LAB and coprostanol, respectively. The site with the highest PAH levels (site DB01) has the lowest TOC-normalized LAB and coprostanol levels.

Tables 3-1(c) and (d) present the LAB concentrations in the five sediment samples by the five individual LAB-groups. Table 3-1(c) presents the raw data, and Table 3-1(d) presents the data normalized to TOC. All five LAB groups were identified in every sample, and the C_{12}-LABs were generally the most abundant (except for sediment from DB01, which had slightly higher levels of the C_{11}-LABs). Figure 3-1 shows a typical GC/MS extracted ion chromatogram (*m/z* 91) of the chromatographic region where LABs elute. This particular chromatogram is from a sample of Deer Island sludge, but similar GC/MS profiles were obtained for samples with lower concentrations of LABs.

LAB and coprostanol concentrations were also determined in two CSO effluent, two wastewater treatment plant effluent, and two wastewater treatment plant sludge samples. These samples were all liquid samples, and concentrations were therefore determined in micrograms per liter (μg/L). The LAB and coprostanol concentration data for these six samples as well as the LAB to coprostanol ratio

Table 3-1. Sediment Organics Data Summary
(c) Individual LAB-Group and Total LAB Concentrations (μg/g dry weight)

Site ID	C10-LAB	C11-LAB	C12-LAB	C13-LAB	C14-LAB	Total LAB
DB01	0.11	0.39	0.37	0.24	0.24	1.36
DB04	0.06	0.23	0.37	0.27	0.24	1.17
DB12	0.06	0.27	0.38	0.28	0.24	1.23
DB13	0.14	0.54	0.77	0.53	0.46	2.43
DB14	0.30	0.81	1.00	0.60	0.51	3.21

Table 3-1. Sediment Organics Data Summary
(d) Individual LAB-Group and Total LAB Concentrations — Normalized to TOC (μg/g/% TOC)

Site ID	C10-LAB	C11-LAB	C12-LAB	C13-LAB	C14-LAB	Total LAB
DB01	0.02	0.06	0.06	0.04	0.04	0.22
DB04	0.02	0.07	0.12	0.09	0.07	0.37
DB12	0.03	0.14	0.20	0.14	0.13	0.67
DB13	0.04	0.14	0.20	0.14	0.12	0.64
DB14	0.07	0.19	0.23	0.14	0.12	0.75

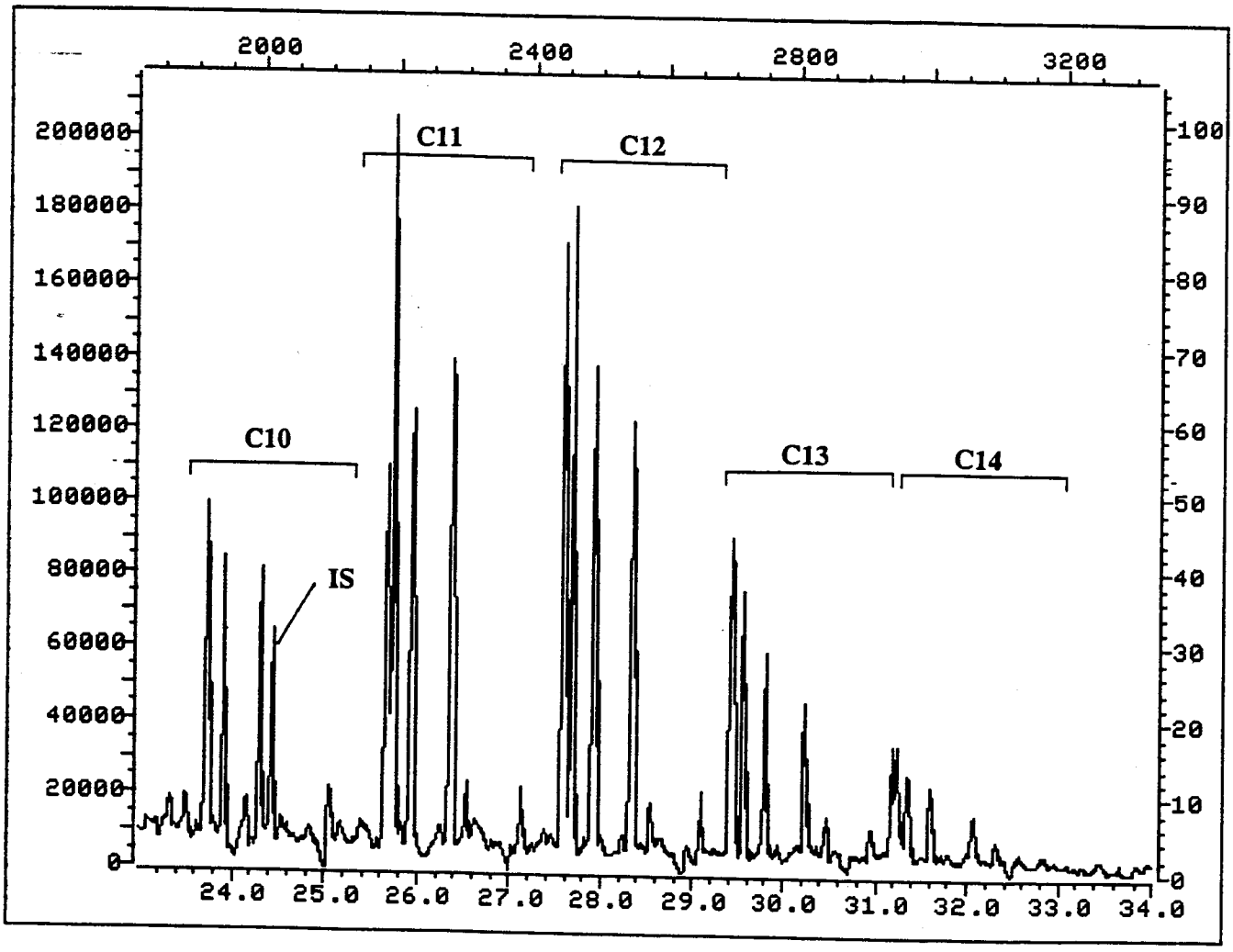

Figure 3-1. GC/MS Extracted Ion Chromatogram (m/z 91) for LABs of a Deer Island Sludge Sample Extract

are presented in Table 3-2. It must be pointed out that the effluent samples were one-time grab samples, and as such do not represent time-integrated data. This is particularly important for these samples because, by their nature, effluent vary greatly in composition, depending on factors such as treatment plant operation schedule and procedures, weather and overflow, and the composition of the influent. Additionally, the CSO "effluent" samples were collected at the actual CSO facilities during a dry period and are not true effluent from an overflow event. These samples were collected from the surface of the CSO interceptor, and most solids had probably settled. The sludge samples were 24 h composite samples.

No LABs were detected in the Fox Point and Commercial Point CSO effluent samples. The coprostanol concentrations were 6.31 and 1.75 μg/L for Fox Point and Commercial Point, respectively. The total LAB concentration in the wastewater treatment plant effluent samples was approximately 16 and 23 μg/L and the coprostanol levels were approximately 126 and 192 μg/L for Deer Island and Nut Island effluent, respectively. The LAB and coprostanol concentrations in the sludge were significantly higher, with total LAB concentrations of approximately 980 and 1705 μg/L, and coprostanol concentrations of approximately 43,400 and 22,700 μg/L for Deer Island and Nut Island, respectively. The C_{12}-LABs were the most abundant LABs in all effluent and sludge samples, with the exception of Deer Island where C_{11}-LABs were slightly higher, accounting for approximately one-third of the total LAB.

3.1.2 Metals Analysis Results

Sediment was the only sample matrix analyzed for metals in this study. Analysis was completed for nine metals in sediment samples collected from 10 sites. These analytical parameters are presented in Table 2-1, and the analyses are summarized by site in Table 2-3. All sediment metals-concentration data are presented in micrograms per gram (μg/g) dry weight. In Section 3.1.2, the data are presented as the average site data. The complete metals data set, with results for individual stations, is presented in Appendix B (Metals Data for Sediment Field Samples).

The analytical data from the metals analyses of sediment samples are summarized in Tables 3-3(a) through (d). Table 3-3(a) presents the raw data. Tables 3-3(b) and (c) present the sediment metals-concentration data normalized to grain size and aluminum, respectively. Table 3-3(d) presents the

Table 3-2. CSO Effluent, Treatment Plant Effluent, and Sludge LAB and Coprostanol Data Summary (μg/L)

Sample	C10-LAB	C11-LAB	C12-LAB	C13-LAB	C14-LAB	Total LAB	Coprostanol	LAB\Coprostanol Ratio
Fox Point CSO effluent[a]	ND[b]	ND	ND	ND	ND	ND	6.31	NA
Commercial Point CSO effluent[a]	ND	ND	ND	ND	ND	ND	1.75	NA
Deer Island effluent	1.47	4.56	5.01	3.08	1.73	15.8	126	0.13
Nut Island effluent	1.50	6.21	7.83	4.50	2.63	22.7	192	0.12
Deer Island sludge	123	319	299	125	113	980	43400	0.02
Nut Island sludge	105	400	638	330	232	1705	22700	0.08

[a]Dry weather sample; *not* sampled during an overflow event.
[b]ND: Not Detected.

Table 3-3. Sediment Metals Data Summary
(a) Metals Concentrations (μg/g dry weight)

Site ID	Al	Cd[a]	Cr[a]	Cu	Fe	Pb	Mn	Ni[a]	Zn
DB01	65200	8.28	116.3	215.1	28233	468.7	430	73.4	1472.0
DB02	48767	0.33	24.8	15.7	9877	35.8	238	10.2	42.3
DB03	53133	0.60	82.8	48.5	20867	59.7	338	19.3	97.6
DB04	74367	1.50	195.8	156.3	36967	149.7	570	47.9	275.2
DB05	44967	0.19	30.3	15.8	12367	33.4	307	11.3	32.7
DB06	51133	0.25	34.2	18.6	13867	36.7	386	13.8	46.7
DB10	71433	2.29	217.7	215.2	46233	427.4	557	51.5	472.6
DB12	64433	1.06	168.2	103.2	30733	110.0	536	34.0	155.5
DB13	74067	2.01	212.1	181.7	40133	191.6	591	44.3	342.3
DB14	69700	2.46	160.3	183.1	37033	522.6	520	44.3	433.4

[a]Concentrations are blank-corrected.

Table 3-3. Sediment Metals Data Summary
(b) Metals Concentrations — Normalized to Grain Size (μg/g/% mud)

Site ID	Al	Cd[a]	Cr[a]	Cu	Fe	Pb	Mn	Ni[a]	Zn	% Mud[b]
DB01	2208	0.278	3.93	7.29	956	15.86	14.50	2.39	49.86	30.1
DB02	6733	0.045	3.36	2.12	1350	4.87	32.23	1.39	5.77	7.4
DB03	3003	0.033	4.53	2.66	1168	3.28	18.68	1.06	5.46	18.5
DB04	1189	0.024	3.14	2.51	592	2.39	9.12	0.77	4.42	63.8
DB05	6226	0.026	4.17	2.17	1708	4.61	42.40	1.56	4.51	7.2
DB06	8428	0.042	5.60	3.04	2279	6.04	63.37	2.27	7.63	6.1
DB10	1142	0.037	3.48	3.43	738	6.81	8.91	0.82	7.53	62.7
DB12	1459	0.024	3.81	2.34	697	2.49	12.15	0.77	3.52	44.1
DB13	954	0.026	2.74	2.35	518	2.48	7.64	0.57	4.42	77.7
DB14	1088	0.038	2.51	2.86	578	8.15	8.12	0.69	6.77	64.1

[a]Concentrations are blank-corrected.
[b]Actual percent mud value (% silt + % clay).

Table 3-3. Sediment Metals Data Summary
(c) Metals Concentrations — Normalized to Aluminum[a]

Site ID	Cd[b]	Cr[b]	Cu	Fe	Pb	Mn	Ni[b]	Zn
DB01	1.27e-04	0.00179	0.00330	0.433	0.00719	0.00661	0.00114	0.02257
DB02	6.85e-06	0.00051	0.00032	0.202	0.00074	0.00487	0.00021	0.00088
DB03	1.12e-05	0.00154	0.00090	0.391	0.00111	0.00635	0.00036	0.00183
DB04	2.03e-05	0.00264	0.00210	0.498	0.00201	0.00766	0.00065	0.00367
DB05	4.14e-06	0.00068	0.00035	0.276	0.00075	0.00686	0.00025	0.00073
DB06	4.98e-06	0.00066	0.00036	0.270	0.00072	0.00749	0.00027	0.00091
DB10	3.21e-05	0.00305	0.00302	0.649	0.00600	0.00781	0.00072	0.00663
DB12	1.64e-05	0.00262	0.00161	0.479	0.00171	0.00835	0.00053	0.00242
DB13	2.72e-05	0.00287	0.00246	0.543	0.00259	0.00800	0.00060	0.00463
DB14	3.55e-05	0.00230	0.00263	0.531	0.00750	0.00746	0.00064	0.00622

[a]Values are unitless (μg/g metal X per μg/g aluminum).
[b]Concentrations are blank-corrected.

Table 3-3. Sediment Metals Data Summary
(d) Metals Concentration for Site DB01 - Total vs Partial Digestion (μg/g dry weight)

	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn[a]
Partial Digestion									
MWRA096P[b]	8130	8.59	83.3	193	19000	514	179	26.5	1500
MWRA097P	8480	8.53	82.5	212	19500	707	173	29.1	1700
MWRA098P	7820	10.1	80.0	199	18200	554	160	26.3	1530
Total Digestion									
MWRA096T	63700	7.77	110	196	29200	460	445	138	1480
MWRA097T	69100	8.20	121	232	29700	492	432	41.6	1560
MWRA098T	62800	8.87	119	217	25800	454	414	40.7	1380
Total/Partial Ratio									
MWRA096	7.84	0.90	1.32	1.02	1.54	0.89	2.49	5.20	0.98
MWRA097	8.15	0.96	1.46	1.09	1.52	0.70	2.50	1.43	0.92
MWRA098	8.03	0.88	1.48	1.09	1.42	0.82	2.58	1.55	0.90
Average	8.00	0.91	1.42	1.07	1.49	0.80	2.52	1.49[c]	0.93
STD	0.13	0.04	0.07	0.04	0.05	0.08	0.04	0.06	0.04
%RSD	1.6	3.8	5.1	3.3	3.6	10.2	1.7	4.0	3.8

[a]Blank: corrected (partial digestion value)
[b]Mean of replicate analyses
[c]Sample MWRA096 was not used in determining the average ratio for nickel.

data from the comparison of the total-and partial-digestion procedure, which was conducted on the three sediment samples collected at Site DB01. The data presented in Tables 3-3(a) through (c) are from analyses using the total-digestion procedure. The aluminum-normalized data [Table 3-3(c)] are unitless because they are a ratio of one concentration to another (micrograms per gram metal / per micrograms per gram aluminum).

The concentrations of the nonanthropogenic metals, aluminum and iron, were the highest, ranging from approximately 45,000 (site DB05) to approximately 74,000 μg/g (sites DB04 and DB13) and from approximately 10,000 (site DB02) to approximately 46,000 μg/g (site DB10), respectively. Manganese, another metal that rarely has anthropogenic origin, was detected at levels ranging from 238 (site DB02) to 591 μg/g (site DB13). Chromium, copper, lead, and zinc were present at intermediate levels with respective concentration ranges of 25 (site DB02) to 218 μg/g (site DB10), 16 (sites DB02 and DB05) to 215 μg/g (sites DB01 and DB10), 33 (site DB05) to 523 μg/g (site DB14), and 33 (site DB05) to 1,472 μg/g (site DB01). Nickel and cadmium were the two metals with the lowest concentrations, ranging from 10 (site DB02) to 73 μg/g (site DB01) and from 0.2 (site DB05) to 8.3 μg/g (site DB01), respectively.

The sediment metals concentrations are less variable once the data are normalized to sediment grain size [Table 3-3(b)]. For instance, the grain-size normalized copper concentration in the sediment samples ranged from 2.12 to 7.29 μg/g/% mud, a factor of approximately 3.4 difference in concentration between the high and the low sites. The raw copper data showed a high-to-low site concentration difference of a factor of 13.7. Similar reductions in variability, by normalizing to grain size, were observed for all metals.

The sediment metals concentrations are somewhat less variable when normalized to sediment aluminum concentrations [Table 3-3(c)]. For instance, the aluminum-normalized copper concentration in the sediment samples ranged from 0.00032 to 0.00330 (unitless), a factor of approximately 10.3 in concentration range as compared to the raw copper data, which had a factor of 13.7 difference between the high and the low concentrations. Similar reductions in variability, by normalizing to aluminum, were observed for all metals.

A comparison of total and partial digestion procedures was also performed in this study. The three DB01 site replicates (three station samples) were analyzed separately by both total- and partial-digestion procedures. The data from these analyses are presented in Table 3-3(d). As expected, significantly higher levels of aluminum are measured in the samples that were processed by the total-digestion procedure than in the samples that were processed by the partial-digestion procedure.

3.1.3 Microbiological Analyses Results

The microbiology data are summarized in Table 3-4. Microbiological analyses were completed on the sediment samples from all 14 sites. Analyses were performed for *Clostridium perfringens, Enterococcus,* and fecal coliform. The *Clostridium perfringens* data are presented as spores per gram dry weight, and the *Enterococcus* and fecal coliform data are presented as colony-forming units (cfu)/g dry weight. In Section 3.1.3, as in all of Section 3.1, the data are presented as the average site data (i.e., the average of the three stations that were the site replicates), and the complete microbiology data set, with results for each individual station, is presented in Appendix C (Microbiology Data for Sediment Field Samples).

The densities of the microorganisms determined were quite variable even when presenting the data by site averages. The sediment densities of *C. perfringens* ranged from approximately 2000 (site DB06) to approximately 115,000 spores per gram (site DB14). The densities of *Enterococcus* and fecal coliform in the sediment ranged from 1.7 (site DB09) to 190 cfu/g (site DB14), and from 3.2 (site DB01) to 57 cfu/g (site DB11), respectively. The data were also $\log_{10}$-transformed for data analysis and interpretation, and these data are presented in Table 3-4.

3.1.4 TOC and Grain-Size Analyses Results

The total organic carbon (TOC) and grain-size data are presented in Table 3-5. TOC and grain-size analyses were completed on the sediment samples from all 14 sites. The TOC data are presented as weight percent, dry weight. The grain-size data are presented as percent distribution of gravel, sand, silt, and clay. The percent mud was determined by adding the percent silt and clay and was used to normalize the metals data to grain size. In Section 3.1.4, the data are presented as the average site data. The complete TOC and grain-size data set, with results for each individual station, is presented in Appendix D (Moisture Content, TOC, and Grain-Size Data for Sediment Field Samples).

Table 3-4. Microbiology Data Summary

Site ID				Log_{10} Transformed		
	C. perfringens Spores/gram dry weight	*Enterococcus* cfu/gram dry weight	Fecal coliform cfu/gram dry weight	*C. perfringens* Spores/gram dry weight	*Enterococcus* cfu/gram dry weight	Fecal coliform cfu/gram dry weight
DB01	27033	15.35	3.15	4.43	1.19	0.50
DB02	3360	5.14	8.16	3.53	0.71	0.91
DB03	12963	4.91	7.97	4.11	0.69	0.90
DB04	45533	4.70	9.30	4.66	0.67	0.97
DB05	3743	1.79	31.22	3.57	0.25	1.49
DB06	1990	6.25	16.41	3.30	0.80	1.22
DB07	3503	9.50	14.66	3.54	0.98	1.17
DB08	14410	3.24	8.78	4.16	0.51	0.94
DB09	2203	1.68	6.74	3.34	0.23	0.83
DB10	34567	27.13	33.31	4.54	1.43	1.52
DB11	25400	31.81	56.91	4.40	1.50	1.76
DB12	27800	5.38	8.46	4.44	0.73	0.93
DB13	53400	46.17	22.36	4.73	1.66	1.35
DB14	115400	189.98	35.14	5.06	2.28	1.55

Table 3-5. TOC, Grain Size, and Moisture-Content Data Summary

Site ID	TOC Weight %	Grain-Size Distribution				
	Dry Weight	% Gravel	% Sand	% Silt	% Clay	% Water
DB01	6.3	13.6	56.3	23.9	6.2	55.3
DB02	0.4	2.2	90.5	5.3	2.1	27.3
DB03	1.0	15.5	66.0	12.2	6.2	35.7
DB04	3.2	0.3	35.9	51.1	12.7	72.3
DB05	0.3	0.0	92.7	5.1	2.1	25.3
DB06	0.3	0.5	93.5	4.3	1.8	23.7
DB07	0.7	23.0	70.2	4.7	2.1	28.3
DB08	1.0	11.0	72.7	11.8	4.5	44.3
DB09	0.2	11.0	85.9	2.3	0.9	24.7
DB10	4.5	14.1	23.2	48.3	14.4	69.7
DB11	3.1	1.3	24.0	58.6	16.0	67.0
DB12	1.9	1.1	54.8	32.8	11.3	58.7
DB13	3.8	0.0	22.3	55.8	21.9	75.3
DB14	4.3	0.0	35.9	53.4	10.7	64.0

The TOC content of the sediment samples varied greatly, ranging from 0.2 (site DB09) to 6.3% dry weight (site DB01). The grain size was also quite variable, with five of the 14 sites having a composition of more than 90% as sand and gravel, and five of the 14 sites had more than 60% mud (silt plus clay). As expected, the coarse sediments generally had a low TOC content. The five sediment sites with more than 90% sand plus gravel had TOC levels below 1%. Table 3-5 also lists the moisture content of the sediments, which ranged from 24% (site DB06) to 75% water (site DB13).

3.2 DATA ANALYSIS RESULTS

The results of the statistical analyses are presented in Section 3.3. These data are presented as site data. However, for all of the statistical analyses, the individual station data ($n=3$; the three replicates from each site) were used to perform the analysis. The data presented in this Section are a summary of the statistical analysis. A copy of the complete statistical analysis data set, which is several hundred pages of SAS computer-generated printout, will be presented to MWRA and a copy will be maintained at Battelle.

For the statistical analysis, the sites were placed in one of two site areas. The Old Harbor area included sites DB01 through DB09, with DB03 as the reference site. The Fox Point/Commercial Point area included sites DB10 through DB14, with DB12 as the reference site.

3.2.1 Organics and Microbiology Data Analysis Results

Organics and microbiology intrasite variability analyses were performed and the data were subsequently used for two other statistical analyses: (1) comparison of test sites with a reference site (t test) to determine if there are differences and associated significance levels (p values) and (2) multiple comparison test of difference among sites within an area.

The intrasite variability in organics and microbiological concentrations differed considerably from parameter to parameter and from site to site. In general, the variability was smaller for the organics parameters (PAHs, LABs, and coprostanol) than for the microbiology parameters (*C. perfringens*, *Enterococcus*, and fecal coliform). For some sites (e.g., DB01, DB10, and DB12) the percent relative standard deviation (%RSD) in the average, raw, value for the organics parameters was

greater than 30%, but for most sites the variability was less, with the RSD for the most part being less than 20% for the organics values. The variability in the TOC-normalized organics data was significantly smaller than in the non-normalized data. The intrasite variability was highly variable for the microbiological parameters, with some sites and parameters having an RSD average value of less than 10%, but for many sites the RSD was greater than 50% for the microbiology values.

Tables 3-6(a) and (b) present the results of the *t* test of difference among test sites and a reference site for the Old Harbor and Fox Point/Commercial Point areas, respectively. The probability values (*p* values) are presented for comparisons that resulted in a *p* value ≤ 0.10 ($\geq 90\%$ probability of difference in the means of the test site and the reference site). This statistical analysis considers the variability in each site value, in addition to comparing the means, for determination of significant differences. The results indicate that there are relatively few sites with concentrations of the organic and microbiology parameters that are significantly higher than those of the reference site.

Tables 3-7(a) and (b) present the results of the multiple comparison test (an ANOVA) of difference among sites within the Old Harbor and Fox Point/Commercial Point areas, respectively. These data were generated using a probability of difference criterion of 95% or greater ($\alpha = 0.05$). The results indicate that there are relatively few concentration "groupings" of significant difference for the sites and parameters tested, in particular for organics and the Old Harbor area sites.

3.2.2 Metals Data Analysis Results

Metals intrasite variability analyses were performed and the data were subsequently used for two other statistical analyses: (1) comparison of test sites with a reference site (*t* test) to determine if there are differences and associated significance levels (*p* values) and (2) multiple comparison test of difference among sites within an area.

The intrasite variability in metals concentrations differed considerably from parameter to parameter, and from site to site. In general, the variability was smaller for the metals parameters than for the organics and microbiology parameters. For some sites, in particular those with the lowest metals concentrations (e.g., DB02, DB03, DB05, and DB06), the RSD in the average, raw, value for the metals parameters was greater than 20% for several analytes. However, for most sites and most metals, the RSD was less than 20% and frequently less than 10%. The variability in the grain-size

Table 3-6. Observed Significance Levels (p Values) for Statistical Comparison of Test Sites with a Reference Site for Selected Organic and Microbiological Parameters. (a) Old Harbor Area — Site DB03 as the Reference Site

Parameter	Probability of Difference (p value)[a]							
	DB01	DB02	DB04	DB05	DB06	DB07	DB08	DB09
Nonnormalized								
Group-1 PAH	NSD[b]	NSD	0.0161	0.0618[c]	0.0618[c]	na[d]	na	na
Group-2 PAH	0.0190	0.0210[c]	0.0050	0.0139[c]	0.0013[c]	na	na	na
Total PAH	0.0285	0.0248[c]	0.0060	0.0181[c]	0.0021[c]	na	na	na
Normalized to TOC								
Group-1 PAH	0.0731	NSD	NSD	0.0467[c]	NSD	na	na	na
Group-2 PAH	0.0003	NSD	NSD	NSD	NSD	na	na	na
Total PAH	0.0003	NSD	NSD	NSD	NSD	na	na	na
Nontransformed								
C. perfringens	NSD	0.0390[c]	0.0119	0.0951[c]	0.0698[c]	0.0439[c]	NSD	0.0731[c]
Enterococcus	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD
Fecal coliform	0.0914[c]	NSD	NSD	NSD	NSD	NSD	NSD	NSD
Log-transformed								
C. perfringens	NSD	0.0130[c]	0.0092[c]	0.0081[c]	0.0030[c]	0.0193[c]	NSD	0.0022[c]
Enterococcus	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD
Fecal coliform	NSD	NSD	NSD	NSD	NSD	NSD	NSD	NSD

[a]The p value indicates the level of certainty in the site value being different from the reference-site value, but does not indicate the probability of observing a difference in reanalysis. $p=0.01$ and $p=0.10$ indicate a 99% and 90% level of certainty in a difference, respectively. All reported probability of difference data are for an elevated value relative to the reference site, except for sites noted with [c].

[b]NSD: No significant difference ($p>0.1$).

[c]Site value was lower than reference site value and the statistical data are for the significance in the value being *lower* than reference site.

[d]NA: Not applicable; sample was not analyzed for this parameter.

Table 3-6. Observed Significance Levels (p Values) for Statistical Comparison of Test Sites with a Reference Site for Selected Organic and Microbiological Parameters. (b) Fox Point/Commercial Point Area — Site DB12 as the Reference Site

Parameter	Probability of Difference (p value)[a]			
	DB10	DB11	DB13	DB14
Nonnormalized				
Group-1 PAH	0.0979	na[b]	0.0089	0.0001
Group-2 PAH	0.0155	na	0.0169	0.0001
Total PAH	0.0201	na	0.0196	0.0001
Total LAB	na	na	0.0247	0.0066
Coprostanol	na	na	0.0049	0.0302
Normalized to TOC				
Group-1 PAH	NSD[c]	na	NSD	0.0040
Group-2 PAH	NSD	na	NSD	0.0010
Total PAH	NSD	na	NSD	0.0011
Total LAB	na	na	NSD	NSD
Coprostanol	na	na	0.0581	0.0197
Nontransformed				
C. perfringens	NSD	NSD	0.0047	0.0922
Enterococcus	0.0011	0.0073	NSD	NSD
Fecal coliform	NSD	0.0565	NSD	0.0305
Log-transformed				
C. perfringens	NSD	NSD	0.0100	0.0079
Enterococcus	0.0043	0.0047	0.0183	0.0196
Fecal coliform	NSD	0.0239	NSD	0.0358

[a]The p-value indicates the level of certainty in the site value being different from the reference-site value, but does not indicate the probability of observing a difference in reanalysis. $p=0.01$ and $p=0.10$ indicate a 99% and 90% level of certainty in a difference, respectively.
[b]NA: Not applicable; sample was not analyzed for this parameter.
[c]NSD: No significant difference ($p>0.1$).

Table 3-7. Multiple Comparisons among Test Sites for Selected Organic and Microbiological Parameters
(a) Old Harbor Area

Parameter	Significant Difference Test Results (α=0.05)[a]							
	DB01	DB02	DB04	DB05	DB06	DB07	DB08	DB09
Nonnormalized								
Group-1 PAH	A	B	B	B	B	na[b]	na	na
Group-2 PAH	A	B	B	B	B	na	na	na
Total PAH	A	B	B	B	B	na	na	na
Total LAB	A	na	A	na	na	na	na	na
Coprostanol	A	na	A	na	na	na	na	na
Normalized to TOC								
Group-1 PAH	A	B	B	B	B	na	na	na
Group-2 PAH	A	B	B	B	B	na	na	na
Total PAH	A	B	B	B	B	na	na	na
Total LAB	B	na	A	na	na	na	na	na
Coprostanol	B	na	A	na	na	na	na	na
Nontransformed								
C. perfringens	B	C	A	C	C	C	C	C
Enterococcus	A	A/B	A/B	B	A/B	A/B	B	B
Fecal coliform	A	A	A	A	A	A	A	A
Log-transformed								
C. perfringens	A/B	C	A	C	C	C	B	C
Enterococcus	A	A	A	A	A	A	A	A
Fecal coliform	A	A	A	A	A	A	A	A

[a]The data in the above table should be interpreted within each row only. The multiple comparison test divides the sites into groups (labeled by A, B, and C) that have similar responses (i.e., sites with the same letter are not significantly different from each other). Group A encompasses those sites with the highest level of that parameter. Sites with A/B are not significantly different from those with A or B, although sites with A and B alone are significantly different from each other. α=0.05.
[b] na: Not applicable; sample was not analyzed for this parameter.

Table 3-7. Multiple Comparisons among Test Sites for Selected Organic and Microbiological Parameters
(b) Fox Point/Commercial Point Area

Parameter	Significant Difference Test Results (α=0.05)[a]			
	DB10	DB11	DB13	DB14
Nonnormalized				
Group-1 PAH	B	na[b]	B	A
Group-2 PAH	B	na	C	A
Total PAH	B	na	C	A
Total LAB	na	na	A	A
Coprostanol	na	na	A	A
Normalized to TOC				
Group-1 PAH	B	na	B	A
Group-2 PAH	B	na	C	A
Total PAH	B	na	B	A
Total LAB	na	na	A	A
Coprostanol	na	na	A	A
Nontransformed				
C. perfringens	B	B	B	A
Enterococcus	A	A	A	A
Fecal coliform	A	A	A	A
Log-transformed				
C. perfringens	B/C	C	B	A
Enterococcus	A	A	A	A
Fecal coliform	A	A	A	A

[a]The data in the above table should be interpreted within each row only. The multiple comparison test divides the sites into groups (labeled by A, B, and C) that have similar responses (i.e., sites with the same letter are not significantly different from each other). Group A encompasses those sites with the highest level of that parameter. Sites with A/B are not significantly different from A or B, although sites with A and B alone are significantly different from those with each other. α=0.05.
[b]NA: Not applicable; sample was not analyzed for this parameter.

normalized metals data was significantly smaller than in the raw data. Some individual analyses yielded values that appeared to be the result of isolated contamination or an otherwise nonrepresentative site sample. For instance, the raw nickel levels in the three DB01 station samples were 40.7, 41.6, and 137.9 μg/g, and the chromium concentrations for the DB03 site replicates were 59.5, 64.5, and 124.6 μg/g.

Tables 3-8(a) and (b) present the results of the t test of difference among test sites and a reference site for the Old Harbor and Fox Point/Commercial Point areas, respectively. The probability values (p values) are presented for comparisons that resulted in a p value ≤ 0.10 ($\geq 90\%$ probability of difference between the means of the test site and the reference site). This statistical analysis considers the variability in each site value, in addition to comparing the means, for determination of significant differences. The results indicate that there are relatively few sites with normalized concentrations of more than one metal that are significantly higher than those of the reference site.

Tables 3-9(a) and (b) present the results of the multiple comparison test (an ANOVA) of differences among sites within the Old Harbor and Fox Point/Commercial Point areas, respectively. These data were generated using a probability of difference criterion of 95% or greater ($\alpha = 0.05$). The results show more concentration "groupings" of significant difference, for the sites and metals parameters tested, than do the organics and microbiological data.

3.3 QUALITY CONTROL RESULTS

3.3.1 Organics QC Results

A summary of the organic analysis quality control (QC) results is presented in Table 3-10. The complete organics QC data set is presented in Appendix E (Organics Quality Control Data). The field and QC sample analyses were broken up into three batches: two sediment batches and one water batch. Sediment batch 1 was analyzed for PAH; sediment batch 2 included PAH, LAB; and coprostanol analyses; and water batch 1 (the effluent and sludge samples) was analyzed for LABs and coprostanol only.

In general, the organics QC results were good in this study, although some sample-specific deviations from the QC goals were observed. All deviations from QC goals were reviewed by the Task

Table 3-8. Observed Significance Levels (p Values) for Statistical Comparison of Test Sites with a Reference Site for Selected Metals Parameters.
(a) Old Harbor Area — Site DB03 as the Reference Site

Parameter	Probability of Difference (p Value)[a]				
	DB01	DB02	DB04	DB05	DB06
Nonnormalized					
Aluminum	0.0454	NSD[b]	0.0124	NSD	NSD
Cadmium	0.0001	0.0461[c]	0.0009	0.0105[c]	0.0378[c]
Chromium	NSD	NSD	0.0061	0.0682[c]	0.0848[c]
Copper	0.0005	0.0517[c]	0.0011	NSD	0.0741[c]
Iron	0.0547	0.0136[c]	0.0039	0.0305[c]	0.0775[c]
Lead	0.0001	NSD	0.0024	NSD	NSD
Manganese	NSD	NSD	0.0140	NSD	NSD
Nickel	NSD	0.0838[c]	0.0032	NSD	NSD
Zinc	0.0001	0.0132[c]	0.0094	0.0079[c]	0.0413[c]
Normalized to Grain Size					
Cadmium	0.0006	0.0580[c]	NSD	NSD	NSD
Chromium	NSD	NSD	NSD	NSD	NSD
Copper	0.0150	NSD	NSD	NSD	NSD
Iron	NSD	NSD	0.0445[c]	0.0612	0.0200
Lead	0.0030	NSD	NSD	NSD	0.0170
Manganese	NSD	0.0319	0.0305[c]	0.0027	0.0089
Nickel	NSD	NSD	NSD	NSD	0.0143
Zinc	0.0180	NSD	NSD	NSD	NSD
Normalized to Aluminum					
Cadmium	0.0001	0.0606[c]	0.0048	0.0074[c]	0.0319[c]
Chromium	NSD	0.0309[c]	0.0257	0.0546[c]	0.0502[c]
Copper	0.0003	0.0298[c]	0.0023	0.0364[c]	0.0418[c]
Iron	NSD	0.0020[c]	0.0133	0.0299[c]	0.0204[c]
Lead	0.0001	NSD	0.0341	NSD	0.0887[c]
Manganese	NSD	NSD	NSD	NSD	NSD
Nickel	NSD	0.0500[c]	0.0117	NSD	NSD
Zinc	0.0001	0.0038[c]	0.0078	0.0021[c]	0.0257[c]

[a]The p Value indicates the level of certainty in the site value being different from the reference-site value, but does not indicate the probability of observing a difference in reanalysis. $p=0.01$ and $p=0.10$ indicate a 99% and 90% level of certainty in a difference, respectively. All reported probability of difference data are for an elevated value relative to the reference site, except for sites noted with [c].
[b]NSD: No significant difference ($p>0.1$).
[c]Site value was lower than reference-site value and the statistical data are for the significance in the value being *lower* than that for the reference site.

Table 3-8. Observed Significance Levels (p Values) for Statistical Comparison of Test Sites with a Reference Site for Selected Metals Parameters.
(b) Fox Point/Commercial Point Area — Site DB12 as the Reference Site

Parameter	Probability of Difference (p Value)[a]		
	DB10	DB13	DB14
Nonnormalized			
Aluminum	0.0916	0.0477	NSD[b]
Cadmium	0.0001	0.0002	0.0006
Chromium	0.0013	0.0146	NSD
Copper	0.0001	0.0001	0.0002
Iron	0.0007	0.0001	0.0100
Lead	0.0030	0.0001	0.0001
Manganese	0.0802	0.0033	0.0531[c]
Nickel	0.0002	0.0027	0.0006
Zinc	0.0035	0.0001	0.0001
Normalized to Grain-size			
Cadmium	0.0022	NSD	0.0042
Chromium	NSD	0.0062[c]	0.0027[c]
Copper	0.0001	NSD	0.0267
Iron	NSD	0.0035[c]	0.0088[c]
Lead	0.0001	NSD	0.0001
Manganese	0.0018[c]	0.0004[c]	0.0002[c]
Nickel	NSD	0.0016[c]	0.0644[c]
Zinc	<0.0001	0.0209	0.0001
Normalized to Aluminum			
Cadmium	0.0001	0.0009	0.0017
Chromium	NSD	NSD	NSD
Copper	0.0005	0.0028	0.0007
Iron	0.0199	NSD	NSD
Lead	0.0003	0.0025	0.0001
Manganese	NSD	NSD	0.0939[c]
Nickel	0.0105	NSD	0.0749
Zinc	0.0005	0.0005	0.0001

[a]The p Value indicates the level of certainty in the site value being different from the reference-site value, but does not indicate the probability of observing a difference in reanalysis. $p=0.01$ and $p=0.10$ indicate a 99% and 90% level of certainty in a difference, respectively. All reported probability of difference data are for an elevated value relative to the reference site, except for sites noted with [c].
[b]NSD: No significant difference ($p>0.1$).
[c]Site value was lower than reference-site value and the statistical data are for the significance in the value being *lower* than that for the reference site.

Table 3-9. Multiple Comparisons among Test Sites for Selected Metals Parameters
(a) Old Harbor Area

Parameter	Significant-Difference Test Results (α=0.05)[a]				
	DB01	DB02	DB04	DB05	DB06
Nonnormalized					
Aluminum	B	C	A	C	C
Cadmium	A	C	B	C	C
Chromium	B	C	A	C	C
Copper	A	C	B	C	C
Iron	B	C	A	C	C
Lead	A	C	B	C	C
Manganese	B	C	A	B/C	B
Nickel	A	A	A	A	A
Zinc	A	C	B	C	C
Normalized to Grain Size					
Cadmium	A	B	B	B	B
Chromium	B	B	B	B	A
Copper	A	B	B	B	B
Iron	C/D	B/C	D	B	A
Lead	A	B	B	B	B
Manganese	C	B	C	B	A
Nickel	A	A	A	A	A
Zinc	A	B	B	B	B
Normalized to Aluminum					
Cadmium	A	C	B	C	C
Chromium	B	C	A	C	C
Copper	A	C	B	C	C
Iron	B	D	A	C	C
Lead	A	C	B	C	C
Manganese	A/B	B	A	A/B	A
Nickel	A	A	A	A	A
Zinc	A	C	B	C	C

[a]The data in the above table should be interpreted within each row only. The multiple comparison test divides the sites into groups (labeled A, B, C, and D) that have similar responses (e.g., sites with the same letter are not significantly different from each other). Group A encompasses those sites with the highest level of that parameter. Sites with A/B are not significantly different from those with A or B, although sites with A and B alone are significantly different from each other. α=0.05.

Table 3-9. Multiple Comparisons among Test Sites for Selected Metals Parameters
(b) Fox Point/Commercial Point Area

Parameter	Significant-Difference Test Results (α=0.05)[a]		
	DB10	DB13	DB14
Nonnormalized			
Aluminum	A	A	A
Cadmium	A	B	A
Chromium	A	A	B
Copper	A	B	B
Iron	A	B	B
Lead	B	C	A
Manganese	B	A	C
Nickel	A	B	B
Zinc	A	B	A
Normalized to Grain Size			
Cadmium	A	B	A
Chromium	A	B	B
Copper	A	C	B
Iron	A	B	B
Lead	B	C	A
Manganese	A	A	A
Nickel	A	C	B
Zinc	A	C	B
Normalized to Aluminum			
Cadmium	A/B	B	A
Chromium	A	A	B
Copper	A	B	B
Iron	A	B	B
Lead	B	C	A
Manganese	A	A	A
Nickel	A	B	B
Zinc	A	B	A

[a]The data in the above table should be interpreted within each row only. The multiple comparison test divides the sites into groups (labeled by A, B, and C) that have similar responses (e.g., sites with the same letter are not significantly different from each other). Group A encompasses those sites with the highest level of that parameter. Sites with A/B are not significantly different from those with A or B, although sites with A and B alone are significantly different from each other. α=0.05.

Table 3-10. Organics Quality Control Results[a]

QC Parameter	Sediment Batch 1	Sediment Batch 2	Water Batch 1
PAH			
Procedural blank	NSL[b]	NSL	NA[c]
Surrogate recovery — overall average (%)	68	68	NA
Surrogate recovery — range of average (%)	38-103	41-93	NA
MS/MSD recovery — overall average (%)	107	93	NA
MS/MSD recovery — range of average (%)	58-191	64-114	NA
MS/MSD precision — overall average (%RPD)	15	5	NA
MS/MSD precision — range (%RPD)	0-45	1-13	NA
LAB			
Procedural blank	NA	ND[d]	ND
Surrogate recovery — overall average (%)	NA	89	91
Surrogate recovery — range (%)	NA	57-102	70-148
MS/MSD recovery — overall average (%)	NA	93	106
MS/MSD recovery — range of average (%)	NA	90-99	100-113
MS/MSD precision — overall average (%RPD)	NA	3	1
MS/MSD precision — range (%RPD)	NA	0-7	0-3
Coprostanol			
Procedural blank	NA	ND	ND
Surrogate recovery — overall average (%)	NA	82	65
Surrogate recovery — range (%)	NA	51-107	58-73
MS/MSD recovery — overall average (%)	NA	96	15
MS/MSD recovery — range (%)	NA	91-101	6-24
MS/MSD precision (%RPD)	NA	6	38

[a]Surrogate recovery data are for field samples. Surrogate recovery ranges are range of average recoveries for the four surrogates (PAH) or range of recovery of the one surrogate (LAB and coprostanol). MS/MSD recovery ranges are range of average recoveries for the 24 analytes (PAH), five analytes (LAB), or one analyte (coprostanol). MS/MSD precision ranges are range of relative percent difference (%RPD) in the determined concentrations for the 24 analytes (PAH) or five analytes (LAB), or one analyte (coprostanol) in the MS and MSD samples.
[b]NSL: No significant levels.
[c]NA: Not applicable; samples were not analyzed for this parameter.
[d]ND: None detected.

Leaders, and the analyses were accepted only if the deviation was judged not to significantly impact the quality of the field sample analysis data.

No significant levels of PAH were detected in the procedural blank samples. The average PAH surrogate recovery was 68% for both batches of sediment samples, and ranged from 38% to 103% for these two batches. The average d_8-naphthalene surrogate recovery in sediment batch 1 and the average d_{12}-perylene recovery in sediment batch 2 were approximately 40%, which was below the recovery goal of 50%, but sample quantification was not expected to have been significantly affected. Surrogate recoveries could not be determined in six samples in sediment batch 2, because the samples were diluted to determine the high PAH analyte concentrations in these samples. Individual PAH analyte recoveries averaged 107% and 93% for the matrix spike/matrix-spike duplicate (MS/MSD) samples in sediment batches 1 and 2, respectively. Low d_8-naphthalene surrogate recovery for the MSD sample in sediment batch 1, resulted in high quantification results for five of the six PAH analytes that were quantified versus this surrogate. This in turn resulted in artificially high recoveries that skew the data to reflect average MS/MSD recoveries of up to 191% and precision of up to 45% RPD for these analytes. The MS/MSD recovery data for sediment batch 2 excludes six of the 24 PAH analytes because background levels of these analytes were more than 80% of the levels in the spiked MS/MSD samples, making them unsuitable for recovery determinations.

No LABs were detected in the procedural blank samples. The average LAB surrogate (1-phenylnonane) recovery was approximately 90%, and individual sample surrogate recoveries ranged from 57% to 148% for the two batches in which LABs were analyzed. The analyte recoveries in the MS and MSD samples (recovery of 1-phenyldecane, 1-phenylundecane, 1-phenyldodecane, 1-phenyltridecane, and 1-phenyltetradecane) averaged 93% and 106% in the two batches analyzed for LABs, and ranged from 90% to 113% for the individual analytes. The precision was also excellent, with average RPDs of 3% and 1% for the MS/MSD samples in the two batches. The RPD in MS/MSD quantification ranged from 0% to 7% for the individual LAB analytes.

No coprostanol was detected in the procedural blank samples. The average coprostanol surrogate (androstanol) recovery was 82% and 65% in sediment batch 2 and water batch 1, respectively, and individual sample surrogate recoveries ranged from 51% to 107%. The analyte recoveries in the MS and MSD samples averaged 96%, and ranged from 91% to 101%, in the sediment batch and averaged 15% in the water batch. The precision was also excellent in the sediment batch, with an RPD of 6%.

The water batch had an RPD of 38% for the MS/MSD sample duplicate quantification. The poor recovery/precision in the MS/MSD sample analyses for the water batch appeared to be an isolated, sample-specific occurrence. The recovery of the surrogate was also poor in this sample. The coprostanol quantification was not compromised because the surrogate recovery was good in all field samples, and the recovery of the surrogate and the analyte (coprostanol) are generally comparable. One explanation for the isolated poor recoveries is that the MS/MSD samples were actually "blank" spiked samples. Deionized water was used and spiked instead of one of the field samples because the field water samples were expected to have very high levels of coprostanol, making suitable spiking and background correction difficult. Polar compounds, like coprostanol, are often recovered with lower efficiency from a sample with low salinity (like deionized water) than from samples with higher salinity, suspended solids, and other matrix constituents (like the field samples).

3.3.2 Metals QC Results

The metals-analysis quality control (QC) results are summarized in Table 3-11. The complete metals QC data set is presented in Appendix F (Metals Quality Control Data). In general, the metals QC results were very good in this study. All deviations from QC goals were reviewed and the analyses accepted only if the deviation was judged to not significantly impact the quality of the field-sample analysis data.

No significant levels of analytes were detected in the procedural-blank samples. However, the total-digestion data have been corrected for low levels of cadmium, chromium, and nickel detected in the procedural blank replicates, and the partial-digestion data have been corrected for low levels of zinc found in procedural-blank replicates. The average matrix-spike recovery was 103% and 94% for the total and partial digestion samples, respectively. The matrix spike recovery ranged from 87% to 113% for individual metal analytes in individual samples. The precision in sample duplicate analyses averaged 22% and 7% RPD for duplicate analyses by the total- and partial-digestion procedure, respectively. The precision ranged from 1% to 49% RPD for individual metal analytes, with three metals falling outside the QC criteria goal of 30% RPD for a set of duplicates processed by the total-digestion procedure. The elevated precision values may be the result of the analyte concentrations being quite low for the affected metals; the sample chosen for the duplicate analysis had some of the lowest analyte levels measured in this study. The analysis of certified marine sediment SRM showed excellent analytical accuracy. The two SRM samples processed by the total digestion procedure

Table 3-11. Metals Quality Control Results[a]

QC Parameter	QC Value
Total Digestion Samples	
Procedural blank — PB-1	NSL[b]
Procedural blank — PB-2	NSL
Matrix spike recovery — average (%)	103
Matrix spike recovery — range (%)	98-113
Sample duplicate precision — average (%RPD)	22
Sample duplicate precision — range (%RPD)	1-49
SRM-1 accuracy — overall average (%recovery)	105
SRM-1 accuracy — range (%recovery)	88-122
SRM-2 accuracy — overall average (%recovery)	104
SRM-2 accuracy — range (%recovery)	85-135
Partial Digestion Samples	
Procedural blank — PB-1	NSL
Procedural blank — PB-2	NSL
Matrix spike recovery — average (%)	94
Matrix spike recovery — range (%)	87-105
Sample duplicate precision — average (%RPD)	7
Sample duplicate precision — range (%RPD)	3-17
SRM-1 accuracy — overall average (%recovery)	77[c]
SRM-1 accuracy — range (%recovery)	43-103[c]

[a]Two procedural blanks (PB-1 and PB-2) were processed for each of the total- and partial-digestion sets of samples. Matrix-spike data do not include aluminum or iron, which were present at such high levels in the matrix that spiking at significant levels above background could not be performed. Two SRMs were processed in the total-digestion sample set and one SRM in the partial-digestion sample set. The SRM accuracy (recovery) is the determined value relative to the certified/expected value.

[b]NSL: No significant levels. However, the total-digestion data have been corrected for low levels of cadmium, chromium, and nickel detected in the procedural-blank replicates, and the partial digestion data have been corrected for low levels of zinc found in procedural-blank replicates.

[c]Excludes recovery data for aluminum, which is incompletely recovered by the partial-digestion procedure (18% recovery was obtained for aluminum on this SRM).

yielded an average accuracy (determined value relative to certified and expected value) of 105% and 104% and ranged from 88% to 135% for individual analytes. The SRM value for copper (249%) in SRM-1 for the total digestion sample was not included in the QC data summary in Table 3-11 because this outlier value was most likely due to isolated contamination. An average accuracy of 77% and a range of 43% to 103% were obtained for the SRM that was processed by the partial-digestion procedure. The lower average and some lower individual analyte accuracy values are the result of incomplete digestion and recovery of some metals by the partial-digestion method. The partial digestion method by definition only partially (incompletely) digests sediment for analysis of some metals. This difference in recovery and quantification results between the two digestion methods was investigated as part of the scope of this study.

3.3.3 Microbiology QC Results

Quality control for the *Enterococcus* and fecal coliform analyses included ensuring the media quality by conducting growth promotion and sterility analyses on all lots of media prepared and used. Positive and negative controls were also included with each set of samples. Positive control involved the inoculation of media to verify its ability to support representative growth. Sterile, blank filters placed on media plates were negative controls used to indicate contamination in the filter or media. The quality of the media used in this study was ensured, and no significant levels of contamination were detected. The laboratory that performed the *Enterococcus* and fecal coliform analyses neglected to perform replicate sample analyses as had initially been intended. MWRA was responsible for the *C. perfringens* analyses, and QC data were reported to MWRA by the laboratory that conducted these analyses (BAL). The *C. perfringens* QC data have not been included in this report.

3.3.4 TOC and Grain-Size QC Results

The TOC and grain-size quality control (QC) results are summarized in Section 3.2.4. The complete QC data are presented in Appendices G (TOC Quality Control Data) and H (Grain-Size Quality Control Data), respectively.

The TOC QC results were all good. No significant levels of organic carbon were detected in the procedural-blank samples. However, the sample data have been corrected for the low levels of TOC that were detected in the blanks. The accuracy of the analysis was also excellent, with an average

RPD of 2.1% between the determined and true TOC value of a standard material. The RPD ranged from 0% to 5.9% for 23 analyses of standard TOC material. The average precision in duplicate analyses was 3.7% RPD between the determined values of the two sample duplicates. The RPD in the determined TOC concentration ranged from 0.4% to 11.2% for 13 sample duplicate analyses.

Two sets of sample duplicates were processed for quality control in the grain-size analyses. For one of the two samples the RPDs in the determined grain-size fractions for the duplicate analyses were 0.9%, 0.0%, and 5.9% for the sand, silt, and clay fractions, respectively. The gravel fraction, because of its nature, is generally not included in precision determinations. The precision was not quite as good for the other duplicate analysis, with RPDs of 24.0%, 19.0%, and 23.1% for the sand, silt, and clay fractions, respectively. This lower precision can be attributed to large variability in the amount of gravel in these duplicates.

4.0 DISCUSSION

The primary goal of this study was to assess the impact of specific CSOs on contamination of sediments in the Dorchester Bay area. The discussion presented in this Section is based on the data (concentration and statistical) generated in this study, along with relevant historical data where appropriate. Historical data are summarized in Section 4.1, followed by a discussion of the effects of CSOs on the organic (Section 4.2), metal (Section 4.3), and microbiological (Section 4.4) contamination of the sediments in the Dorchester Bay area.

4.1 HISTORICAL DATA

There are limited amounts of data from other studies for comparison with this study. Sediment, water-column, and CSO and treatment-plant discharge data from a variety of studies and monitoring programs were reviewed. Most of this work was not useful for comparison either because of the lack of site, parameter, and/or sample-matrix overlap with this study, or because the analytical methods were not comparable or documented well enough. Studies that were considered useful are discussed below.

4.1.1 Studies of Contaminant Fate and Transport in Boston Harbor

Transport and deposition of pollutants has been shown to be important in regulating contaminant levels in Boston Harbor (Gallagher *et al.*, 1990; MDC, 1979; Wallace *et al.*, 1988). Studies have shown levels for most metals to be relatively uniform in the water column within much of Boston Harbor. However, Wallace *et al.* (1988) found that the Dorchester Bay sites generally had among the highest particulate-phase water-column metals concentrations, and had dissolved-phase concentrations that were comparable with most other Harbor sites. Wallace *et al.* (1990) determined the metals concentrations in Fox Point CSO discharge and in water and sediment samples collected near the Fox Point CSO. They concluded that, although the CSO effluent elevates the levels of several metals in the water column near the point of discharge during and shortly after the time of discharge, the elevated levels found in the sediment were due primarily to transport from elsewhere in the Harbor, and not from the Fox Point discharge. Similar conclusions were drawn by Eganhouse and Sherblom (1990) with respect to organic pollutants in the Fox Point area.

Deer Island and Nut Island wastewater treatment plants discharge their effluent and sludge into Boston Harbor. The sludge discharges occur predominantly with outgoing tides, while the effluent discharges are continuous. The sewage outfall from these two plants accounts for approximately 46% of the total freshwater input into Boston Harbor (Wallace *et al.*, 1988). Other sources of fresh water to the Harbor are the Mystic, Charles, and Neponset Rivers. The sewage discharges do not completely disperse into Massachusetts Bay, but reenter the Harbor through President Roads and other routes such as Nantasket Roads. Transport back into the Harbor by either of these routes is supported by known tidal-current patterns and measured water and sediment contaminant distribution patterns (Gallagher *et al.*, 1990; MDC, 1979; MDEQE, 1986; Wallace *et al.*, 1988). The data from these studies suggest that there is a plume of elevated contaminant concentrations that extends from the Deer Island/President Roads area up into the Fox Point/Commercial Point area of Dorchester Bay. These historical chemistry data suggest that this may be the main route of transport into Dorchester Bay for most toxic chemicals, and that most of the chemicals originate in Deer Island and Nut Island discharges.

4.1.2 Contaminant Levels in Boston Harbor and Massachusetts Bay

The NOAA Mussel Watch Program is one source of Massachusetts Bay data that were generated using analytical methods comparable to the ones used in this study. Table 4-1 lists metal and PAH concentrations found in sediment samples collected between 1985 and 1990 at eight Mussel Watch sites from Cape Ann to Cape Cod. Two sites, the Deer Island and Dorchester Bay sites, are of particular interest for comparison purposes because of their proximity to the area investigated in this study. These data will be used as reference data in the discussion sections that follow.

PAH

The mean sediment concentration for the Deer Island and Dorchester Bay Mussel Watch sites (sampled 1985-1989) were 1.1 and 4.5 μg/g for Group 1 (petroleum-related lighter-molecular-weight) and Group 2 (combustion-related heavier-molecular-weight) PAH, respectively (Battelle, 1990c). The total PAH concentrations measured in the Mystic and Charles River sediment ranged from 30 to 99 μg/g for the five sites sampled in an earlier study conducted by Battelle for MWRA (Battelle, 1990a). Although other work on levels of PAH in Boston Harbor and Massachusetts Bay sediment were reviewed (e.g., Shiaris and Jambard-Sweet, 1986; EPA, 1988a, 1988b; MDEQE, 1986), they were found to not be useful for comparison purposes for a variety of reasons, such as noncomparable

Table 4-1. Massachusetts Bay Reference Sediment Data from the Mussel Watch Program

	Analyte Concentration[a]								
	Cu	Pb	Cd	Cr	Ni	Zn	PAH-1[b]	PAH-2	ΣPAH
Site Location									
Cape Ann, Gap Head	9.0	28.3	0.13	33.7	10.9	40.3	0.32	1.35	—
Salem Harbor, Folger Point	58.0	133.3	1.95	6.0	31.7	150.0	1.17	3.48	—
Massachusetts Bay, Nahant Bay	7.5	24.1	0.11	52.0	—	—	—	—	0.88
Boston Harbor, Deer Island	103.3	109.8	1.13	190.7	29.2	145.2	0.88	3.43	—
Boston Harbor, Dorchester Bay	118.0	132.3	1.43	191.8	30.8	182.8	1.31	5.66	—
Boston Harbor, Hingham Bay	25.0	35.5	0.27	56.8	14.5	58.5	0.14	0.60	—
Massachusetts Bay, North River	13.3	32.5	0.24	26.9	—	—	—	—	1.23
Duxbury Bay, Clarks Island	4.8	11.1	0.04	18.5	6.5	19.7	0.03	0.08	—

[a] Concentration in sediment samples collected between 1985 and 1990. Mean concentration if site was analyzed more than one time. All concentrations are in μg/g dry weight. Data for Massachusetts Bay, Nahant Bay and Massachusetts Bay, North River are from (Battelle, 1991). All other data are from (Battelle, 1990c).

[b] PAH-1; Group 1 PAHs, PAH-2 are the Group 2 PAHs, and ΣPAH is the sum of the 24 individual PAH analytes.

analytical methods, high detection limits, insufficient overlap in analyte lists, noncomparable site locations, and insufficient information on how data were generated and what they represented.

LAB and Coprostanol

Linear alkylbenzenes (LAB) are aromatic compound byproducts produced during industrial synthesis of LAB sulfonates, which are widely used anionic surfactants in detergents (Eganhouse and Sherblom, 1990; Takada and Ishiwatari, 1990). Sources of LABs in Boston Harbor include waste from industrial production and household and commercial cleaning activities. Coprostanol (5β-cholestan-3β-ol) is a sterol that is found in human feces and can be used as an indicator of sewage-derived organic material (Brown and Wade, 1984; Hatcher and McGillivary, 1979). It is particularly useful as a tracer because its concentration is unaffected by chlorination and aeration and it persists in anoxic sediments (Vankatesan and Kaplan, 1990).

In a previous study in Dorchester Bay, Eganhouse and Sherblom (1990) found that total LAB concentrations in the sediment ranged from 0.28 to 2.34 μg/g (eight stations) and that coprostanol concentrations ranged from 0.26 to 11.5 μg/g (seven stations). The LAB/coprostanol ratios for five sites located in Savin Hill Cove, near Thompson Island, and at the mouth of the Neponset River ranged from 0.20 to 0.55. They also report coprostanol values from a six station survey of Boston Harbor in which a mean sediment concentration of 4.80 μg/g were determined. In an earlier study, Eganhouse *et al.* (1988) reported LAB concentrations of 3220 and 821 μg/L in Nut Island and Deer Island sludge, respectively. In the same study, coprostanol levels were determined to be 15.3 and 38.6 mg/L in Nut Island and Deer Island sludge, respectively. This yielded an LAB/coprostanol ratio of 0.21 for Nut Island sludge, and 0.021 for Deer Island sludge.

Metals

Several studies have been conducted for the determination of metals concentrations in Boston Harbor waters (MDEQE, 1986; Wallace *et al.*, 1988) and sediment (MDC, 1979; MDEQE, 1986; Battelle, 1990a; Wallace *et al.*, 1990). Although some of these data were useful, much of the data could not be used for comparison for the same reasons stated above.

The concentrations of cadmium, chromium, copper, lead, nickel, and zinc at the eight Massachusetts Bay Mussel Watch sites are given in Table 4-1. The Dorchester Bay and Deer Island sites, the sites closest to the two areas studied in this work, generally have, along with the Salem Harbor site, the

highest metals concentrations. The metals concentrations averaged approximately 1.3 μg/g for cadmium, 190 μg/g for chromium, 110 μg/g for copper, 120 μg/g for lead, 30 μg/g for nickel, and 160 μg/g for zinc for the Dorchester Bay and Deer Island sites.

Wallace *et al.* (1990) determined that the Savin Hill Cove overall intertidal and subtidal surface sediment metals concentrations ranged from approximately 1.6 to 2.2 μg/g for cadmium, 190 to 220 μg/g for chromium, 130 to 180 μg/g for copper, 210 to 230 μg/g for lead, 32 to 38 μg/g for nickel, and 190 to 280 μg/g for zinc. The metals concentrations were slightly lower at reference sites near Thompson Island, and lower yet at sites near the mouth of the Neponset River.

Microbiology

A limited amount of data are available on the microbiology of Boston Harbor sediment. Site-to-site variability has been high for total and fecal coliform levels measured in the water column within Boston Harbor, with sites in the Inner Harbor generally having the highest levels, but with highly elevated densities occasionally being measured in the mouth of the Neponset River, and other scattered sites (MDEQE, 1984, 1986). The levels at individual sites were found to be highly variable from one sampling time to another, with the same sites having among the highest densities on one survey and among the lowest densities of coliforms in a survey that was conducted only a few weeks later. Sediment levels of microbiological pollutants were not measured in these studies. There are only limited data on CSO discharge, and the density data from these analyses are of limited value because of the large variability in the few data that are available. There are particularly few data on the Dorchester Bay CSOs relevant to this study. However, some of these data suggest that the Old Harbor CSOs do not frequently overflow (BWSC, 1990a). CSO BOS-85 has a history of occasionally discharging, and high fecal coliform levels have been measured at such times, with densities over 100,000 col/100 mL being measured in the discharge (BWSC, 1990a). However, because elevated levels of fecal coliform generally are obtained only with recent pollution, and their longevity/survivability is highly variable and dependent on the local environment, data on "background," or even elevated, harbor densities are not particularly useful because they can vary dramatically within a small area without necessarily indicating significant pollution differences. *Enterococcus* has longer survivability than fecal coliform, and *Clostridium perfringens* has the longest survivability of the three indicators. *C. perfringens* is therefore the better indicator of long-term, chronic, sewage pollution.

4.2 ORGANIC CONCENTRATION LEVELS DETERMINED IN THIS STUDY

In Section 4.2.1, the sediment organic concentration and statistics data are discussed with respect to the Dorchester Bay CSOs that were sampled near in this study. Other possible sources of the measured pollutants are also discussed where appropriate. In Section 4.2.2, the measured sediment concentrations of organic are compared to concentrations measured in other studies.

4.2.1 Fate and Transport

4.2.1.1 PAH Concentrations

Figures 4-1(a) and (b) represent the raw PAH concentration data and normalized for TOC, respectively, for all sites analyzed. The highest PAH concentrations in the Old Harbor area were measured for site DB01, located near CSO BOS-87. This observation holds true even when the data are normalized to TOC. The statistical data show that DB01 is significantly different in PAH concentration from background site DB03 [Table 3-6(a)] as well as the other Old Harbor sites [Table 3-7(a)] for both raw and TOC-normalized PAH data. The data indicate that there may be a point source of PAH contamination at or near site DB01. Site DB01 appears to have been impacted by localized input of PAH as evidenced by the background levels found at site DB02, which is the site nearest DB01. However, without more information on the hydrodynamics of the area one cannot exclude the possibility of these pollutants being transported from other parts of the Harbor and deposited at this location. Site DB04, located near CSO BOS-83, also has higher and significantly different raw PAH concentrations than does the background site, DB03. The TOC-normalized concentrations at site DB04 are not significantly elevated. The levels at DB02, 05, and 06 are consistently relatively low both non- and TOC-normalized and none of these is significantly different either one from another or from the reference site.

The average total PAH concentration of the Fox Point/Commercial Point area is slightly higher than that of the Old Harbor area. Site DB14, near the Commercial Point CSO, has the highest concentration of PAH (raw and TOC-normalized) in the Fox Point/Commercial Point area. These levels are significantly higher than those of the reference site (DB12) and the other sites in the Fox Point/Commercial Point area [Tables 3-6(b) and 3-7(b)]. As with site DB01, this may be due to point-source pollution or deposition of contaminated sediment transported from another area. Site DB10, a site expected to be relatively nonimpacted by CSOs, also has significantly elevated PAH

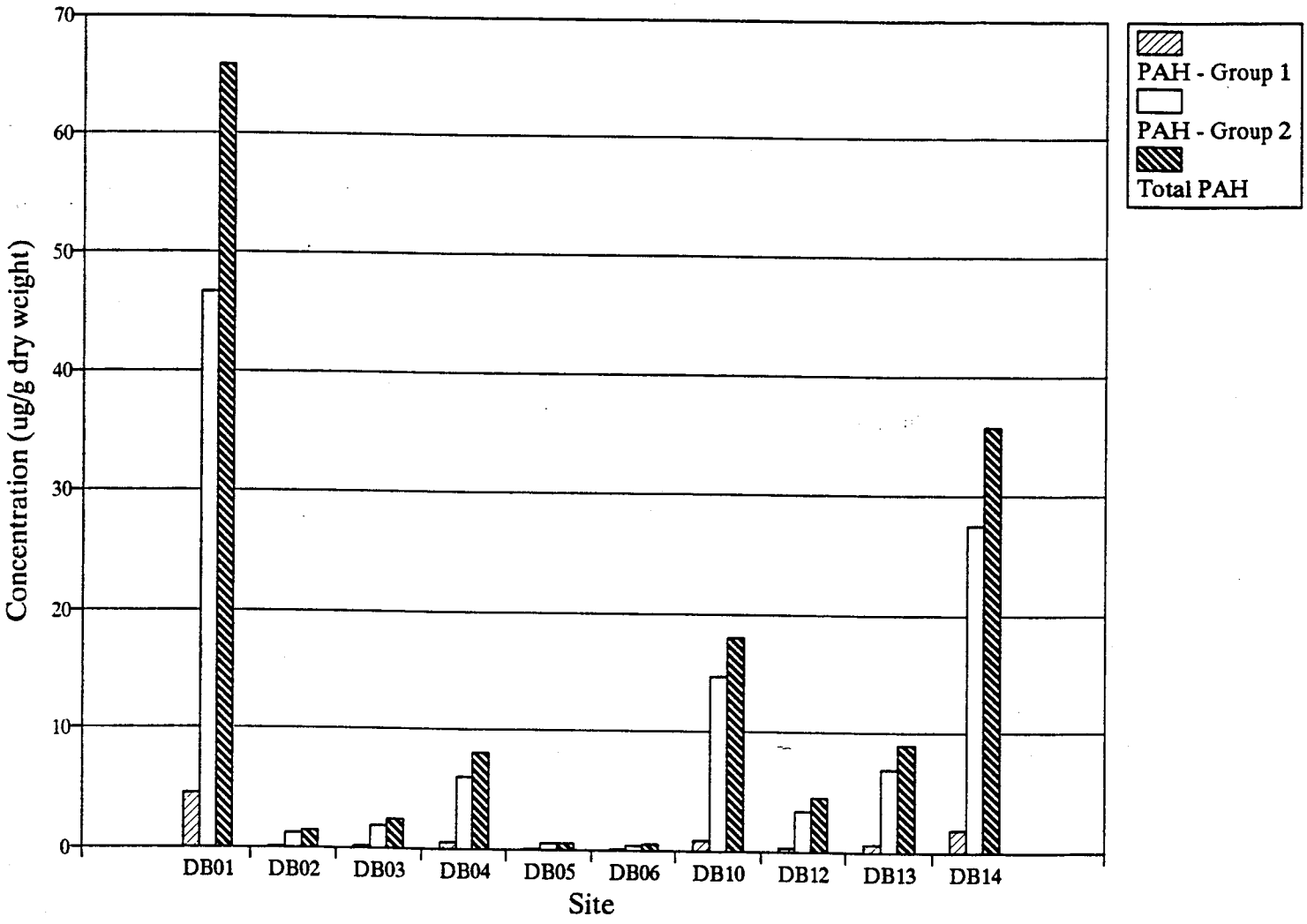

Figure 4-1. Sediment PAH Concentrations
(a) Nonnormalized

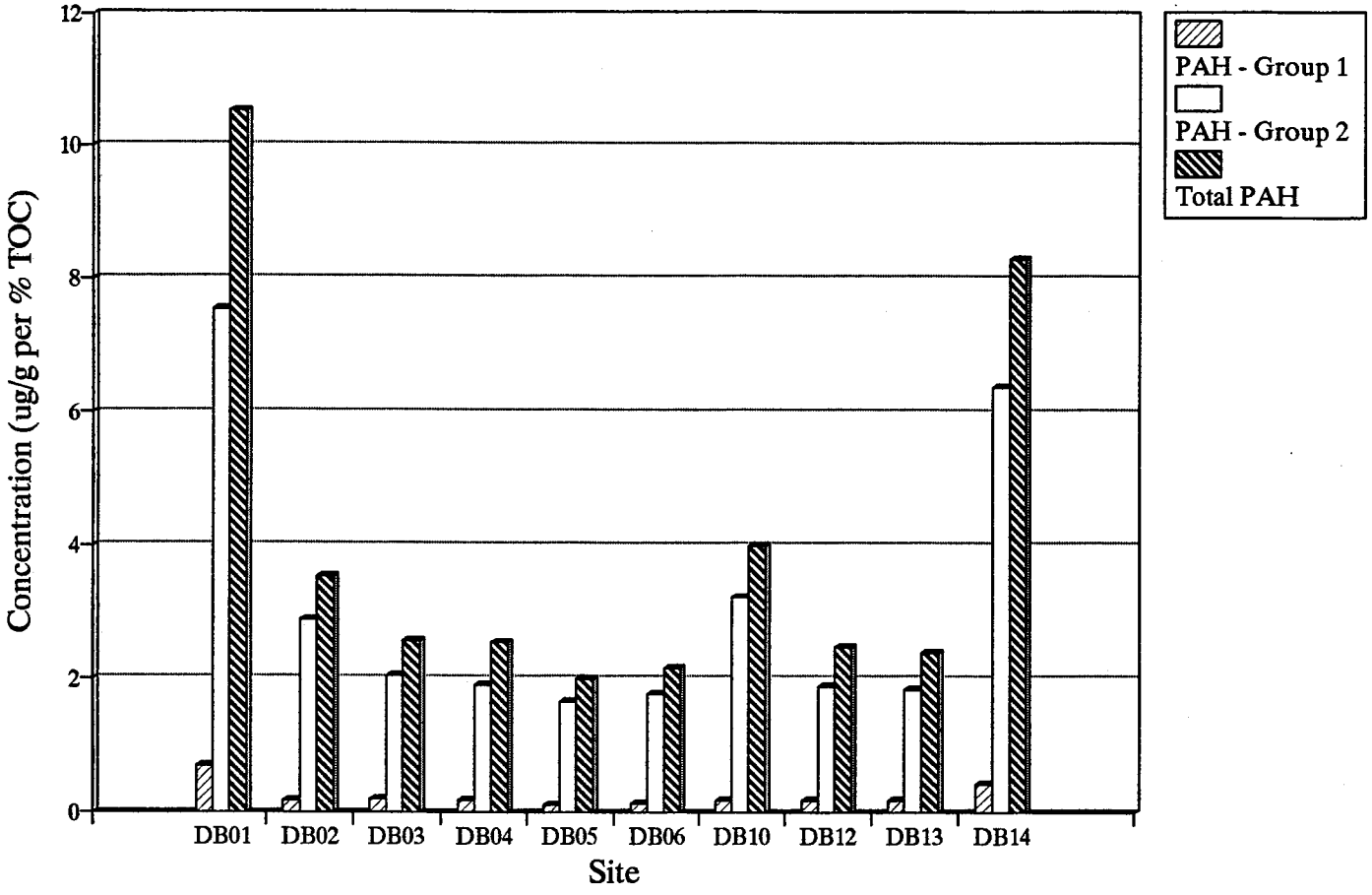

Figure 4-1. Sediment PAH Concentrations
(b) Normalized to TOC

levels as compared to the background site. However, these lie closer to the background level when normalized to TOC and are no longer significantly different. The PAH levels at DB10 are higher than at DB12 and 13, which may be due to impact from the Commercial Point CSO, BOS-90, from other localized point sources [there may be an active storm drain upstream of DB10 in Pine Neck Creek (BWSC/MWRA communication)], or deposition. Site DB13 (near Fox Point CSO) PAH levels (Group 2 and total PAH) are approximately one-fourth those of site DB14 (near Commercial Point CSO) but are twice as high as the levels at the background site for this area. The TOC and percent mud at sites DB10, DB13, and DB14 are among the highest of all the sites in this study. This may be due to CSO discharge from the Fox Point and Commercial Point CSOs, but cannot be easily explained for site DB10 (unless indeed there is an active storm drain in Pine Neck Creek near DB10), which is expected to receive minimal CSO impact. However, it is possible that site DB10 is in a different depositional environment than DB13 and DB14.

It should be cautioned that it may be inappropriate to focus strictly on TOC-normalized data in this analysis. It is possible, and likely, that along with the discharge from a CSO the sediment TOC and percent mud content will increase because sewage (and most CSO) waste is high in organic carbon content and the solids are of small particulate size as compared to most Harbor sediments. For instance, sites DB01 and DB04 have the highest TOC and mud content in the Old Harbor area. This suggests that these are either areas of CSO discharge or depositional areas. Sites DB02 and DB05, which are the sites nearest DB01 and DB04, respectively, have among the lowest TOC and mud content. This significant difference in TOC and mud content in very a short distance may suggest that DB01 and DB04 are not in depositional areas, and indeed are impacted by CSO discharge, but this can be confirmed only by hydrodynamic data.

These data suggest that CSO BOS-87 has been and/or is contributing significant amounts of PAH to the sediment in Old Harbor. The PAH may be originating in stormwater, which can include street runoff, from the drainage area served by this CSO. The data suggest that the elevated PAH concentrations measured at DB14 are due to discharges from the Commercial Point CSO. Other possible sources of PAH to site DB14 include the nearby yacht club and runoff from activities on Commercial Point. However, the relatively uniform concentrations in the Fox Point/Commercial Point area, along with the historical data, indicate that this is an area that may receive significant pollutant deposition originating from elsewhere in the Harbor, and it is possible that a significant

proportion of the PAH in the sediment at DB14 originates elsewhere in the Harbor and not with the Commercial Point CSO. Reliable information on the erosional and depositional conditions for both the Old Harbor and Fox Point/Commercial Point areas are needed to accurately interpret the data. Unfortunately, this area has not been thoroughly studied in the past, and it is not possible to completely assess the impact of the CSOs without comprehensive sediment transport and hydrodynamic data.

4.2.1.2 LAB and Coprostanol Concentrations

Sediment

Figures 4-2(a) and (b) present the raw and TOC-normalized sediment LAB and coprostanol concentrations. Figure 4-2(a) shows that the LAB concentrations were uniformly low, although DB13 and DB14 are statistically significantly higher than DB12, which is the background site. Sites DB13 and DB14 also had significantly elevated coprostanol concentrations. In contrast, the TOC-normalized LAB in Figure 4-2(b) shows that DB12, DB13, and DB14 are similar, and DB01 and DB04 fall to lower concentrations relative to the reference site (DB12). The overall similarity in LAB concentrations throughout Dorchester Bay indicates that the primary source is probably remote, and that LABs are likely transported into the Bay from the source. It is possible that the discharge from the Deer Island and Nut Island treatment plants is responsible for maintaining the evenly distributed background levels of LAB. The coprostanol levels show a trend of decreased concentration away from DB14 going north through the Bay where the lowest level occurs at site DB01. Although the coprostanol levels at DB13 and DB14 are significantly different from the reference site (DB12), sites DB13 and DB14 are not significantly different from each other [Tables 3-6(b) and 3-7(b)].

The pollutant distribution suggests that CSO BOS-90 may be a source of coprostanol through domestic-waste input to the area, and tidal flushing may be responsible for disbursing coprostanol to the other sites. One might expect the LAB concentrations to be elevated similarly to coprostanol if BOS-90 contributes domestic waste to the area, unless there is (or has been) a remote discharge of significantly higher levels of LAB. Nut Island sludge has been implicated as a source of LAB (and coprostanol) in other studies (Eganhouse and Sherblom, 1990; Gallagher *et al.*, 1990). Although the data suggest that the Commercial Point CSO may be contributing coprostanol, and domestic sewage, to the area, this cannot be stated conclusively, given the relative magnitudes of the measured concentrations and the limited data on pollutant transport for the area.

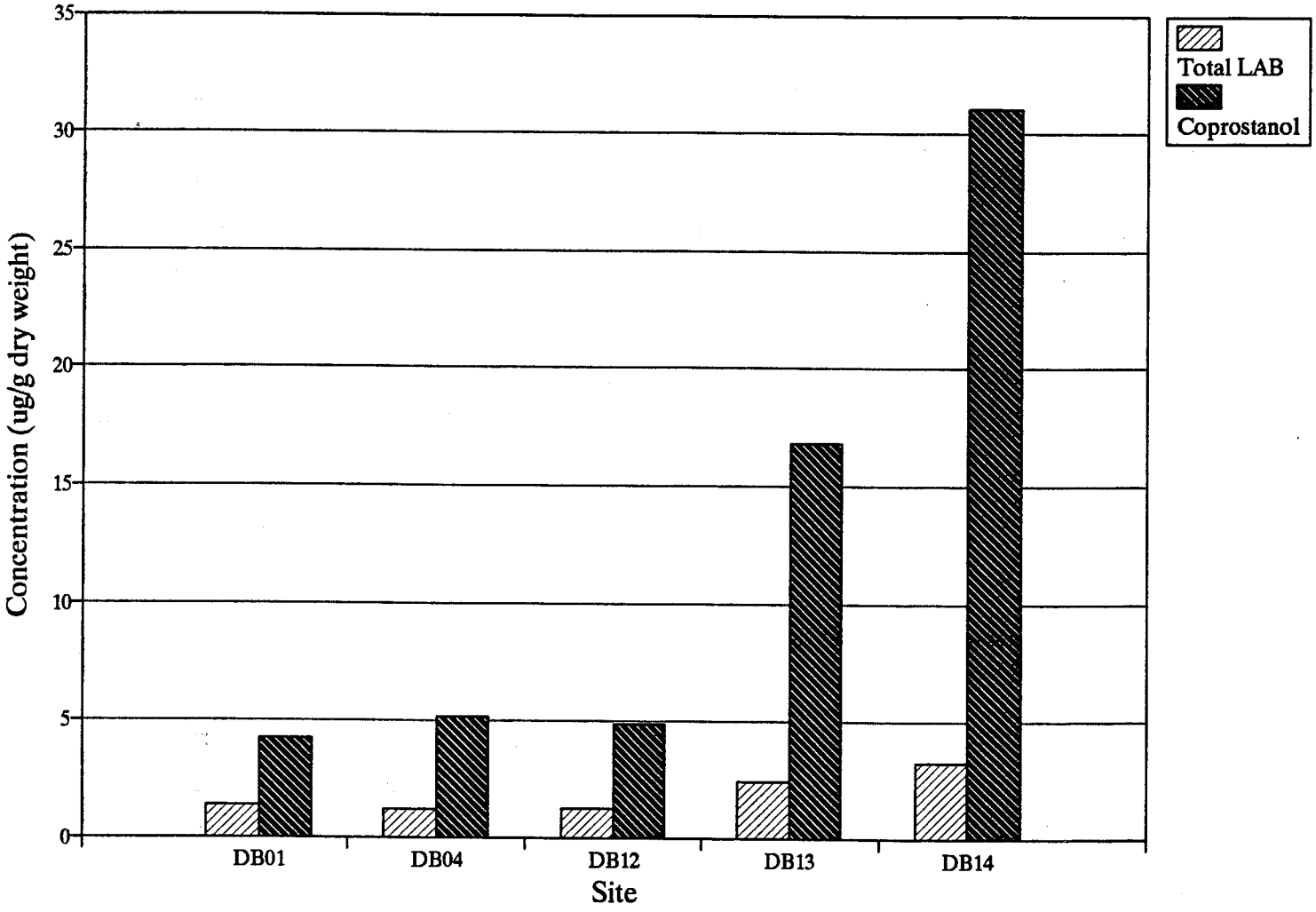

Figure 4-2. Sediment Total LAB and Coprostanol Concentrations
(a) Nonnormalized

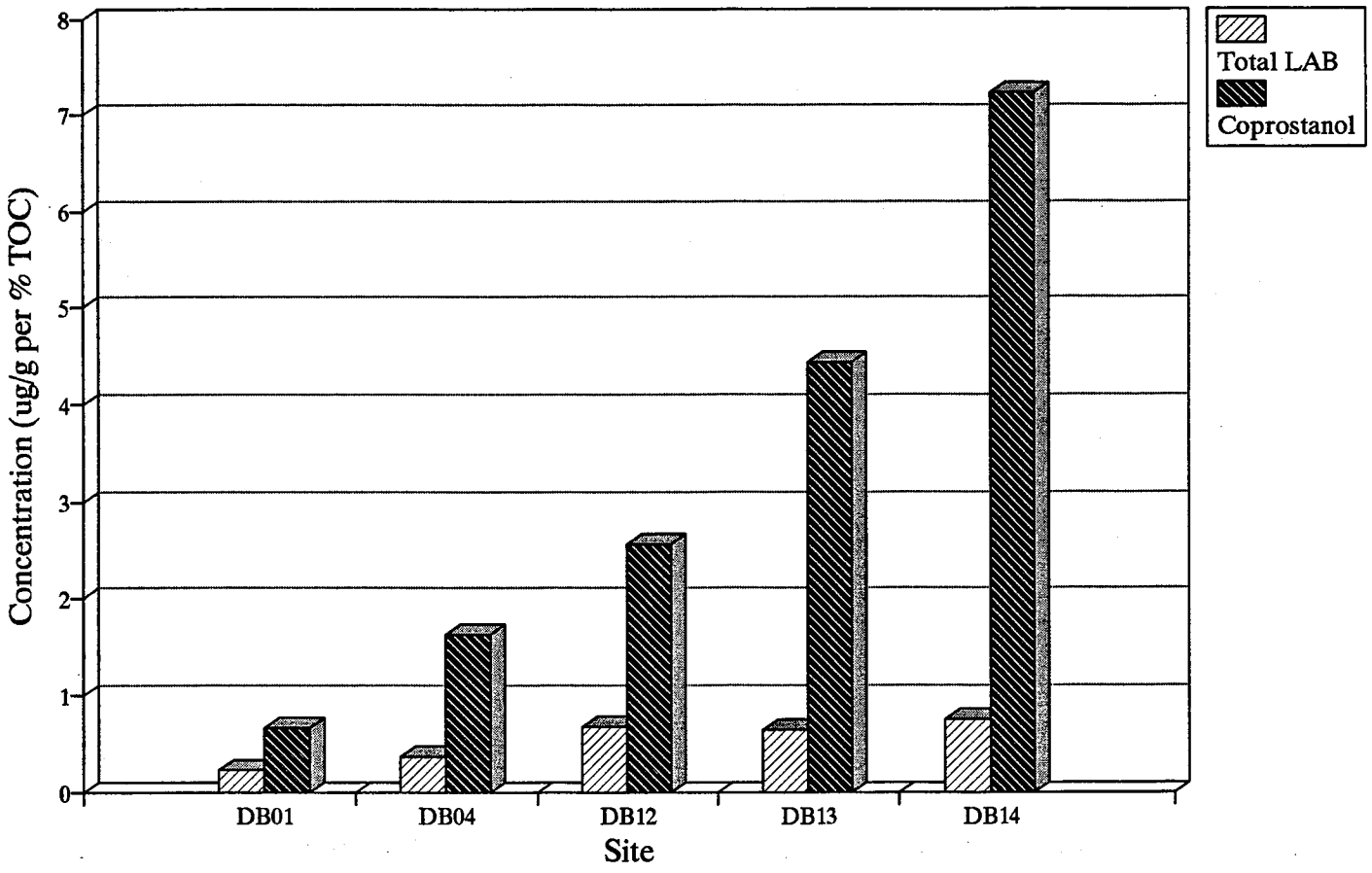

Figure 4-2. Sediment Total LAB and Coprostanol Concentrations
(b) Normalized to TOC

Wastewater and Sludge as Potential LAB and Coprostanol Pollution Sources

When discussing the effluent (CSO and treatment-plant) sample data, it is important to remember that these samples were collected as one-time grabs, and not as composite samples, which may bias the data since treatment-plant and CSO discharge activities vary greatly over time. The sludge samples were 24-h composites. Additionally, the CSO samplings were made during a dry period, and the resultant LAB and coprostanol concentrations are not representative of an overflow event (e.g., no LABs were detected in the two CSO effluent samples). Thus, the CSO effluent data in this study are not useful for comparison with other samples and/or for assessing the possibility of local CSO source inputs.

Figures 4-3 and 4-4 show the Deer Island and Nut Island treatment-plant concentrations of LAB and coprostanol for effluent and sludge, respectively. Figure 4-5 presents the LAB/coprostanol ratios for the sediment sites analyzed for these parameters, in addition to ratios for the treatment-plant waste streams. Nut Island effluent concentrations are slightly higher than those at Deer Island, although it is clear that the LAB/coprostanol ratios are approximately equal. The concentration of LAB in Nut Island sludge is approximately twice as high as Deer Island sludge, and the Nut Island sludge coprostanol concentration is about half that of Deer Island. As expected, the sludge LAB/coprostanol ratios differ between the two sources; Deer Island has a ratio of 0.02 and Nut Island has a ratio of 0.08. The ratios determined in this study are the same for Deer Island sludge and lower for Nut Island sludge than the ratios of approximately 0.02 and 0.2, respectively, that had been observed in earlier studies (Eganhouse *et al.*, 1988; Eganhouse and Sherblom, 1990).

The two treatment plant sludge LAB/coprostanol ratios measured in this study are not as different from each other as reported in an earlier study. This could be because (1) there is greater variability in LAB/coprostanol ratios than earlier thought, or (2) the ratios indeed are more similar today than they were a few years ago. In any case, these data suggest that the LAB/coprostanol ratio may not be as useful as previously suggested in identifying sources in Boston Harbor. The difference in LAB/coprostanol ratios in this study, as compared to earlier work, appears to be due primarily to lower LAB concentration in the Nut Island sludge. Eganhouse measured LAB and coprostanol concentrations of 3.2 and 15.3 mg/L, respectively, in Nut Island sludge. In this study, the LAB and coprostanol concentrations were determined to be 1.7 and 22.7 mg/L, respectively. This reduction in LAB concentration in Nut Island sludge could indicate changes in treatment-plant influent (and at the

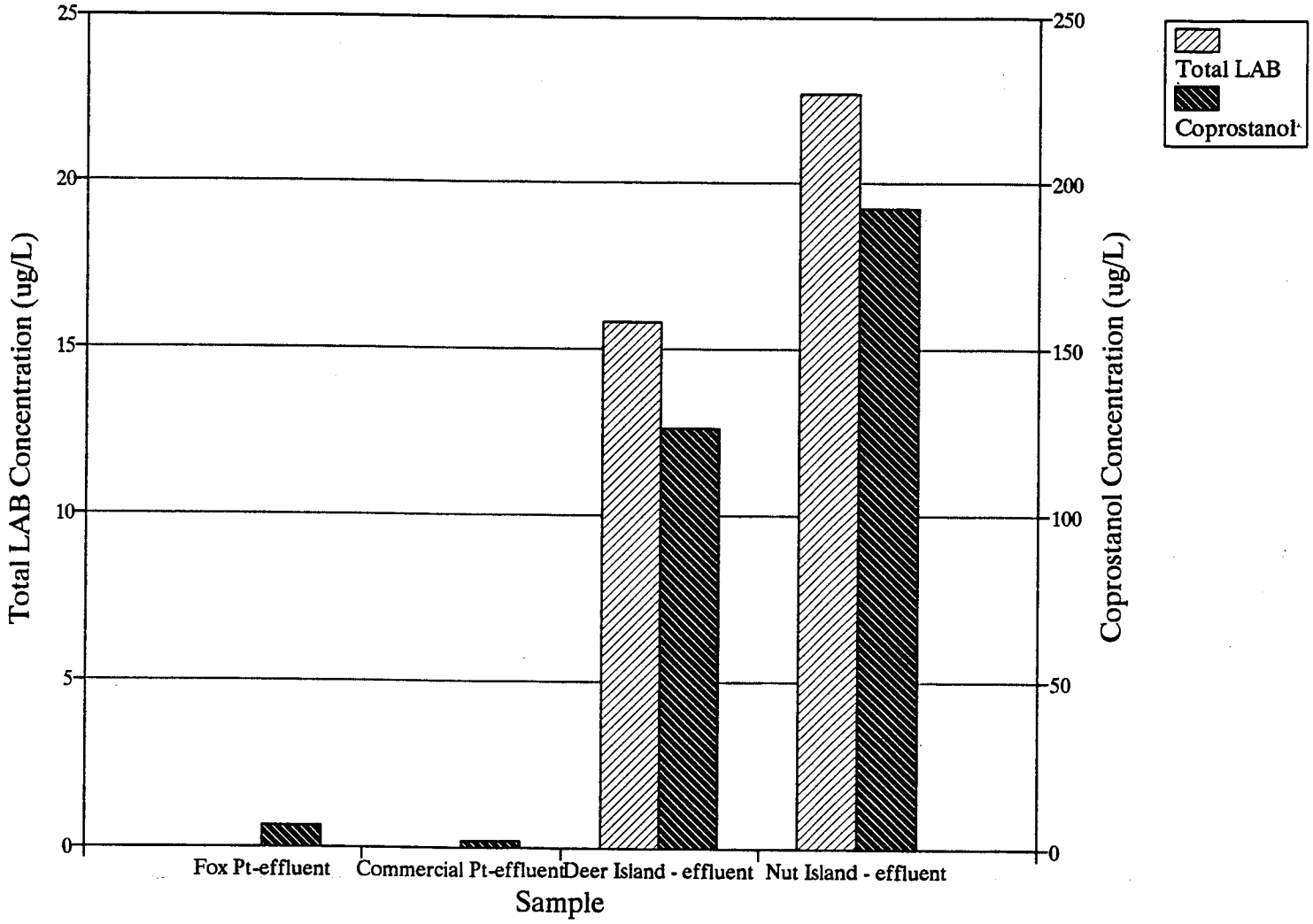

Figure 4-3. CSO and Treatment-Plant Effluent Total LAB and Coprostanol Concentrations

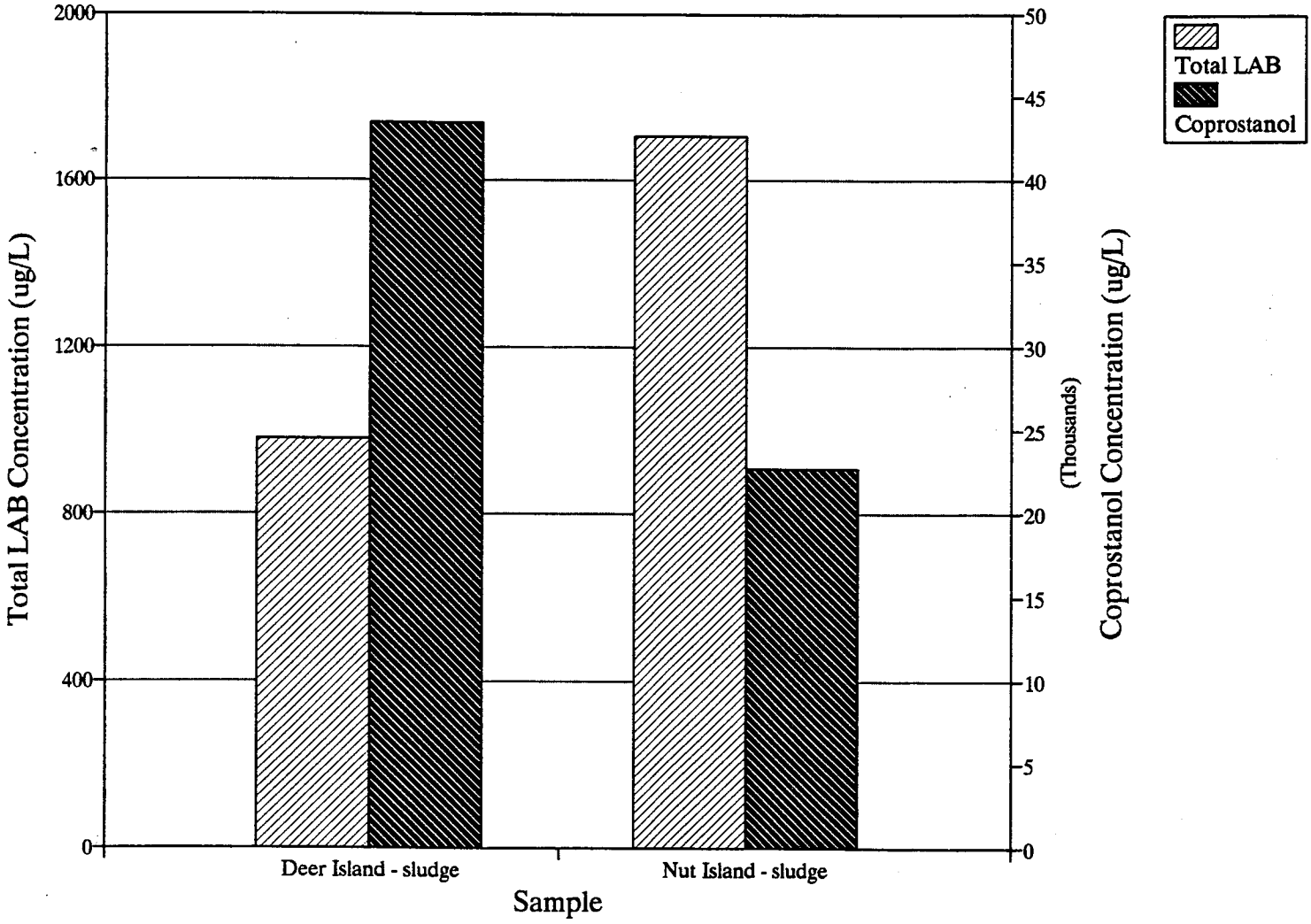

Figure 4-4. Treatment-Plant Sludge Total LAB and Coprostanol Concentrations

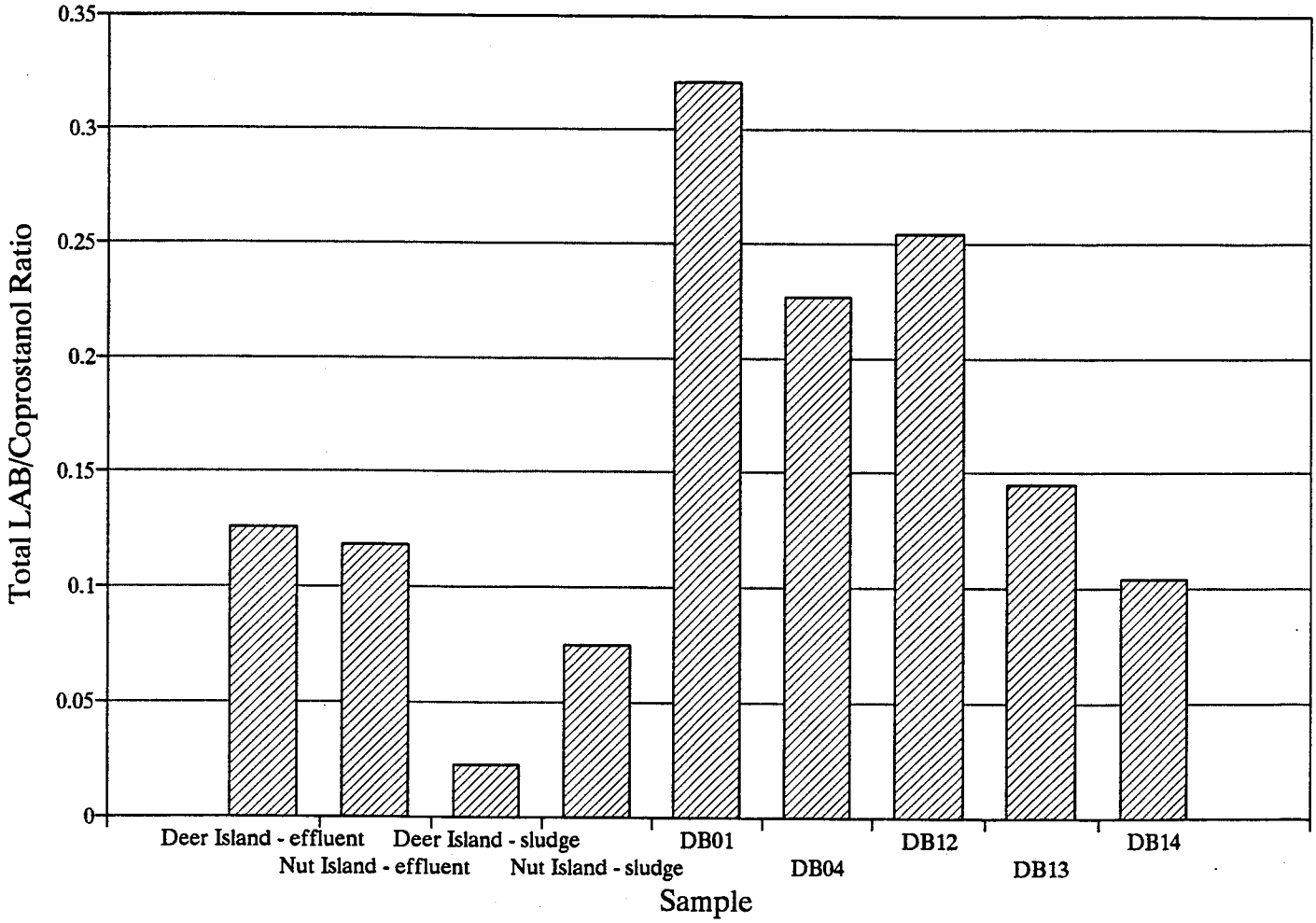

Figure 4-5. Sediment and Treatment-Plant Effluent and Sludge Total LAB-to-Coprostanol Ratios

original source) or treatment-plant operation. Although we do not have information on treatment-plant influent LAB and coprostanol levels, or treatment-plant removal efficiency, the LAB and coprostanol data suggest that Deer Island receives relatively more domestic waste than does Nut Island, and that Nut Island receives more waste from industrial detergent use and/or production than does Deer Island.

Sites DB13 and DB14 had sediment LAB/coprostanol ratios slightly higher than those of the Nut Island treatment-plant sludge (approximately 0.14 and 0.11, respectively), and an LAB/coprostanol ratio lower than the ratio of approximately 0.2 previously determined by Eganhouse and Sherblom (1990) for sediment in this area (near Fox Point). This gradual reduction in LAB/coprostanol ratio is consistent with Eganhouse's data suggesting Nut Island to be the primary source of these pollutants in this area. The sediment LAB/coprostanol ratio can be expected to slowly decrease if the LAB/coprostanol ratio at the source has decreased. The LAB/coprostanol ratios at sediment sites DB01 and DB04 are relatively high, 0.32 and 0.23, respectively. These data for DB01 and DB04 support the earlier suggestion that these sites might be in areas of significant deposition. These elevated ratios relative to the source suggests that either (1) LABs degrade or partition significantly slower in the local environment than does coprostanol, thus increasing the LAB/coprostanol ratio with time, or (2) there is differential transport and deposition between LAB and coprostanol because of chemical- and/or physical-property differences, or a combination of these possibilities. However, without additional LAB and coprostanol data for the Dorchester Bay CSOs, and other possible local sources, these sediment LAB/coprostanol data cannot be fully interpreted.

4.2.2 Comparison with Historical Concentration Data

PAH

The total PAH concentration ranged from 0.55 to 65.84 μg/g for the 10 sediment sites in this study. This can be compared to a range from 30 to 99 μg/g for five Mystic River and Charles River sites sampled and analyzed in an earlier study by Battelle for MWRA (Battelle, 1990a). The respective average Group 1 (petroleum-related lighter-molecular-weight) and Group 2 (combustion-related higher-molecular-weight) PAH concentrations determined in this study for the two areas of Dorchester Bay are 0.89 and 9.47 μg/g in Old Harbor and 0.92 and 13.12 μg/g in the Fox Point/Commercial Point area. Both study areas had Group 1 PAH concentrations that are similar to each other and the nearby Mussel Watch sites (averaged 1.1 μg/g for the Deer Island and Dorchester Bay Mussel Watch

sites). However, the average Group 2 PAH concentration determined for the two study areas is at least twice as high as that of the nearby Mussel Watch sites (averaged 4.5 μg/g). This discrepancy may be because the sites sampled in this study are closer to the source of Group 2 PAH (e.g., urban fossil fuel combustion, street runoff, creosote from wood pilings) than the two Mussel Watch sites. The higher Group 2 PAHs in both areas of Dorchester Bay, as compared to the Mussel Watch sites, imply a higher mean pyrogenic PAH input in this part of Boston Harbor than that of the Massachusetts Bay region in general. The Group 1 PAHs comprise approximately one-tenth of the total PAH at the sites sampled. This would indicate that there is relatively little petrogenic input to the total PAH, and therefore most of the input is pyrogenic. Urban combustion from both industrial, home heating, and automobile sources can accumulate over time. Therefore, high PAH concentrations do not necessarily reflect recent input; Group 2 PAHs, for instance, are slower to dissipate and break down than are Group 1 PAHs owing to the lower water-solubility and slower rates of biodegradation of Group 2 PAHs.

LAB and Coprostanol

In a previous study in Dorchester Bay, Eganhouse and Sherblom (1990) determined sediment total LAB concentrations ranging from 0.28 to 2.34 μg/g and coprostanol concentrations ranging from 0.26 to 11.5 μg/g (seven stations). They also report coprostanol values from a six-station survey of Boston Harbor in which a mean sediment concentration of 4.80 μg/g was determined. Comparable concentrations were determined in this study with total LAB concentrations ranging from 1.2 to 3.2 μg/g for the five sediment sites, and coprostanol levels ranging from 4.2 to 31.0 μg/g. The sediment LAB/coprostanol ratios determined in this study were also comparable to those determined by Eganhouse and Sherblom (1990) for sediment samples from the same general area.

Figure 4-6 shows the concentrations of the individual LAB groups for nonnormalized sediment data. The 12 carbon alkyl chain length LABs predominate at all sites but site DB01, where the C_{11} LABs are slightly higher. The C_{12} predominance is evident in both Deer Island and Nut Island effluent samples and Nut Island sludge as well (Table 3-2). In Deer Island sludge, the C_{11} and C_{12} are approximately equivalent. C_{12} predominance in municipal effluent and sludge has been documented in several municipalities worldwide (Eganhouse and Sherblom, 1990) and is likewise expected in coastal sediments (Takada and Ishiwatari, 1990).

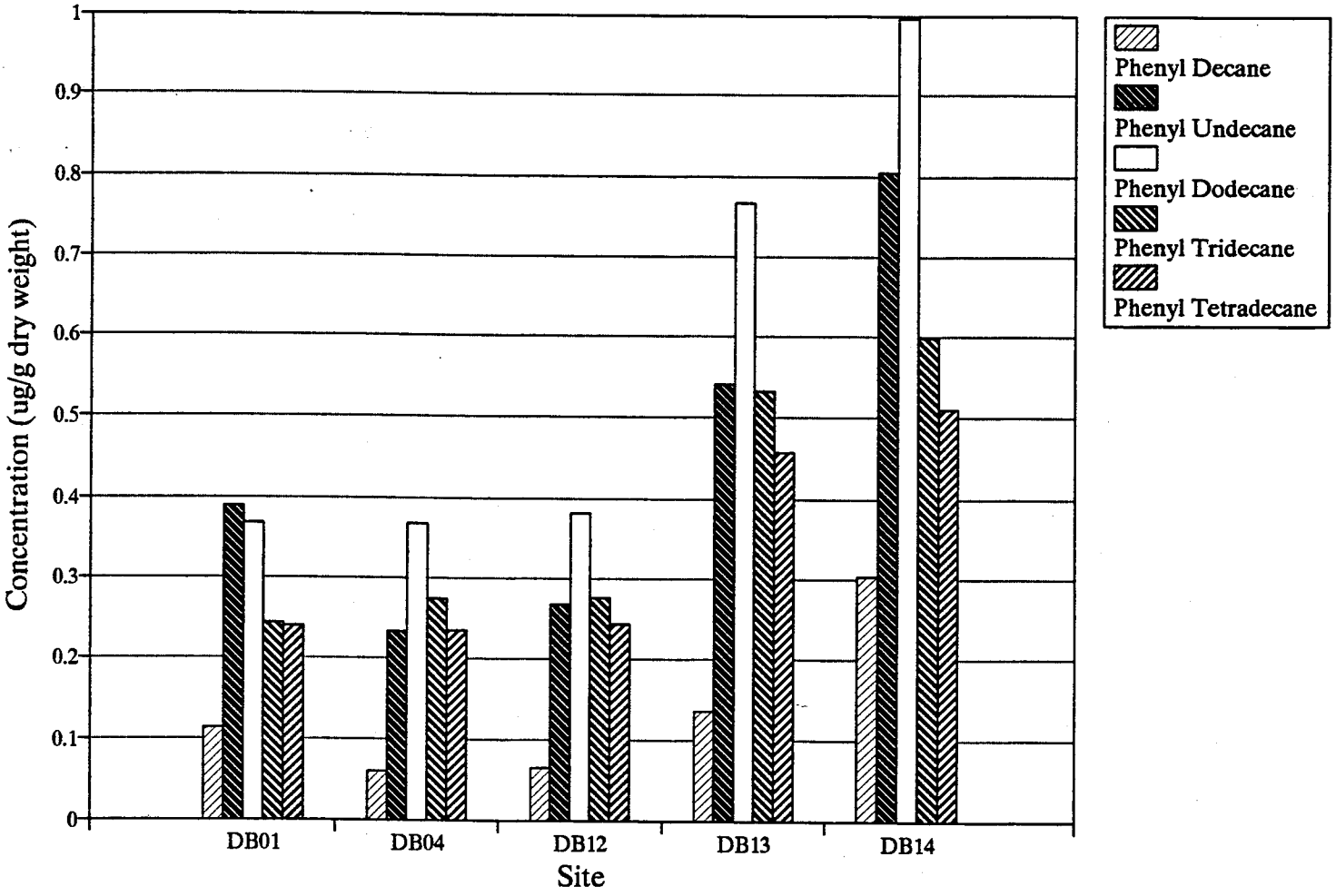

Figure 4-6. Sediment LAB Concentration Distribution by LAB Group

4.3 METAL CONCENTRATION LEVELS DETERMINED IN THIS STUDY

In Section 4.3.1, the sediment metals concentration and statistics data are discussed with respect to the Dorchester Bay CSOs sampled near in this study. Other possible sources of the measured pollutants are also discussed where appropriate. In Section 4.3.2, the measured sediment concentrations of metals are compared to concentrations measured in other studies.

4.3.1 Fate and Transport

The sediment metals concentrations are presented nonnormalized, normalized to grain-size, and normalized to aluminum in Figures 4-7, 4-8, and 4-9, respectively. Figures 4-7(a), 4-8(a), and 4-9(a) present the data for the nonanthropogenic originating metals (aluminum, iron, and manganese); these data are presented for completeness, and are not considered pollutants. Figure 4-10 shows the relationship between the concentrations of aluminum and iron (upper plot) and cadmium and zinc (lower plot) versus grain size, with each data point representing one site. The relationship shows a slight linear increase in the aluminum and iron concentration with an increase in fines (percent mud) in the sediment. The same relationship was observed for manganese. This is the expected relationship for metals concentrations that represent the crustal abundance of the area and confirms that these three metals indeed are not of anthropogenic origin. The cadmium and zinc plot, on the other hand, does not show the same linearity, and one site (DB01) is significantly elevated relative to the other sites. Similar plots for the other four metals showed at least one incidence of an outlier per metal, suggesting that there might be anthropogenic sources of these metals.

Figures 4-7(b)-(c), 4-8(b)-(c), and 4-9(b)-(c) present the data for the six metals for which the data suggest there may be anthropogenic sources. Although data are presented as nonnormalized, normalized to grain size, and normalized to aluminum, the data that have been normalized to aluminum will be used primarily for assessing possible sources of pollution. This is the most appropriate normalization method for eliminating sample matrix effects and providing data for identifying and interpreting metal concentrations above regional background levels. Normalizing to grain size often provides a similar concentration profile as normalizing to aluminum, but it is generally considered a surrogate for aluminum normalization.

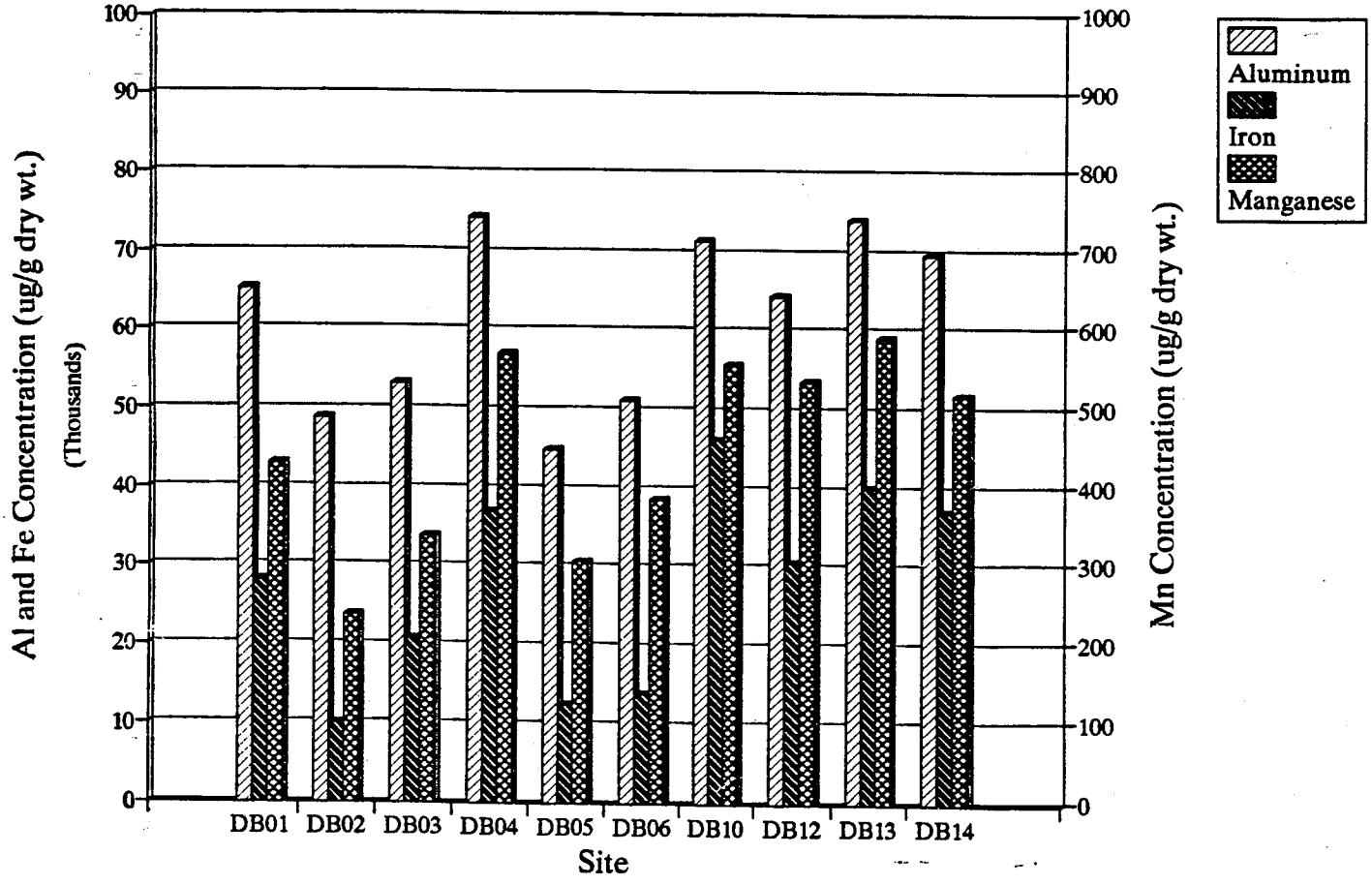

Figure 4-7. Sediment Metals Concentrations — Nonnormalized
(a) Aluminum, Iron, and Manganese

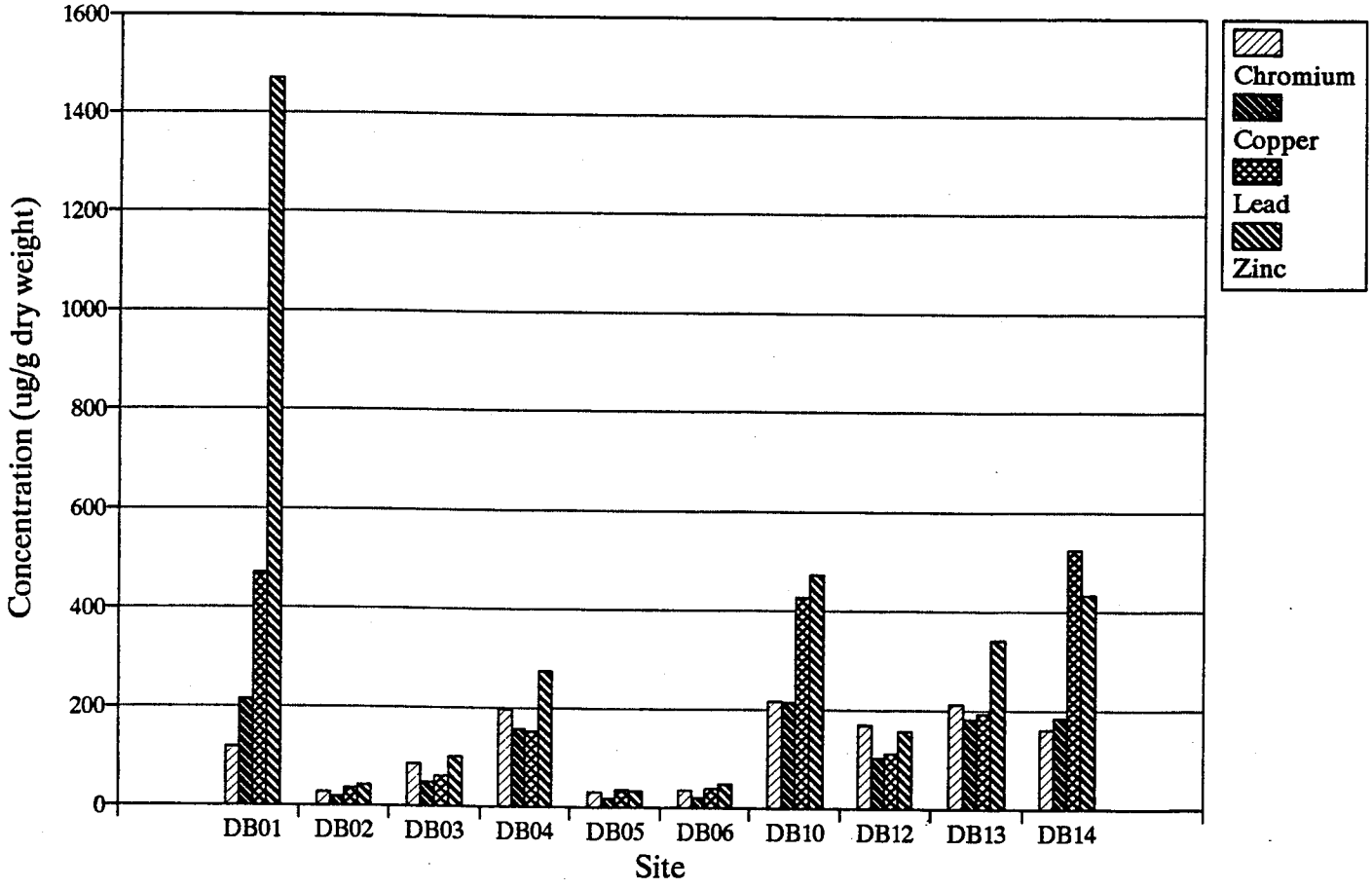

Figure 4-7. Sediment Metals Concentrations — Nonnormalized
(b) Chromium, Copper, Lead, and Zinc

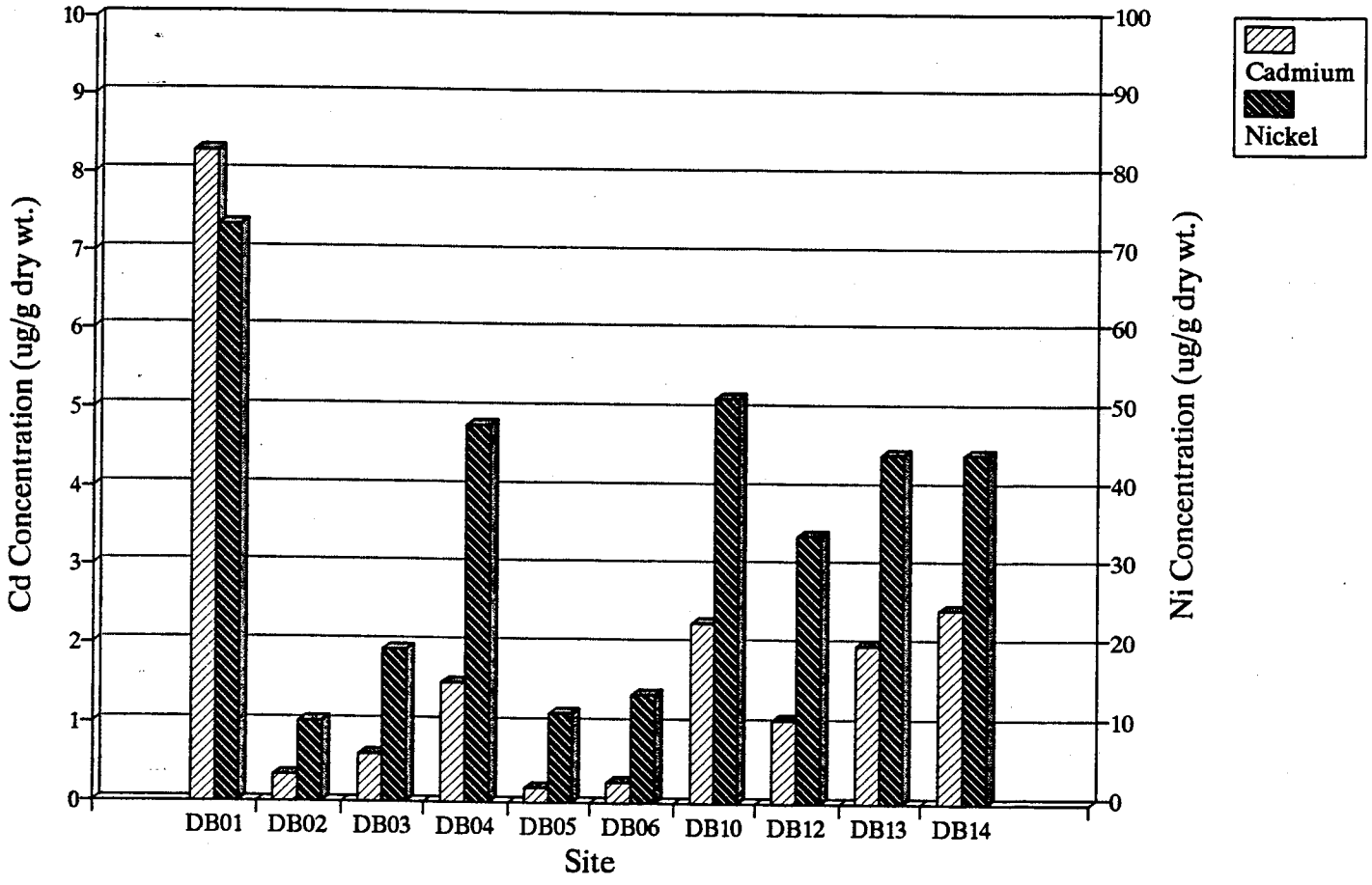

Figure 4-7. Sediment Metals Concentrations - Nonnormalized
(c) Cadmium and Nickel

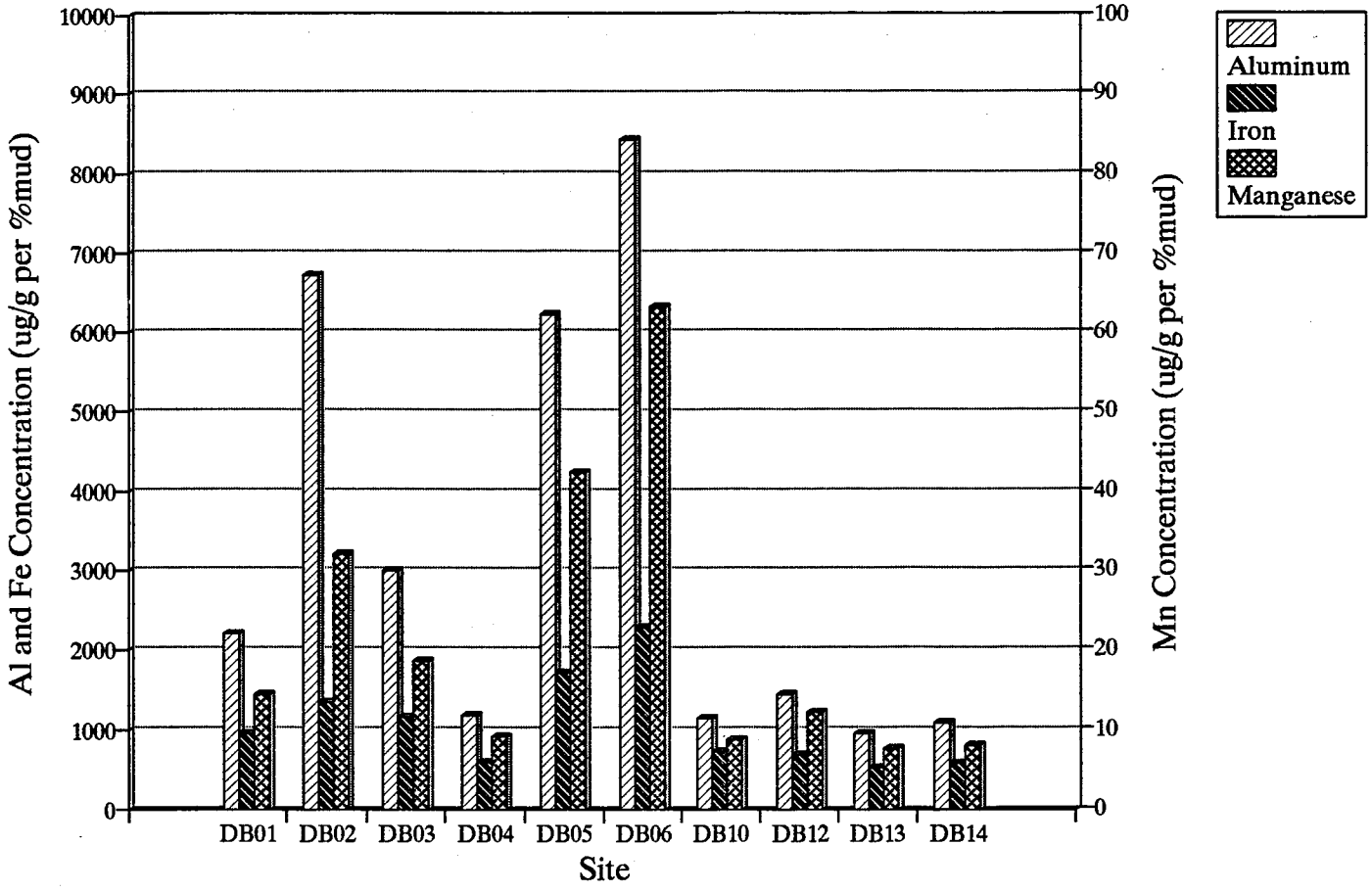

Figure 4-8. Sediment Metals Concentrations — Normalized to Grain Size (% Mud)
(a) Aluminum, Iron, and Manganese

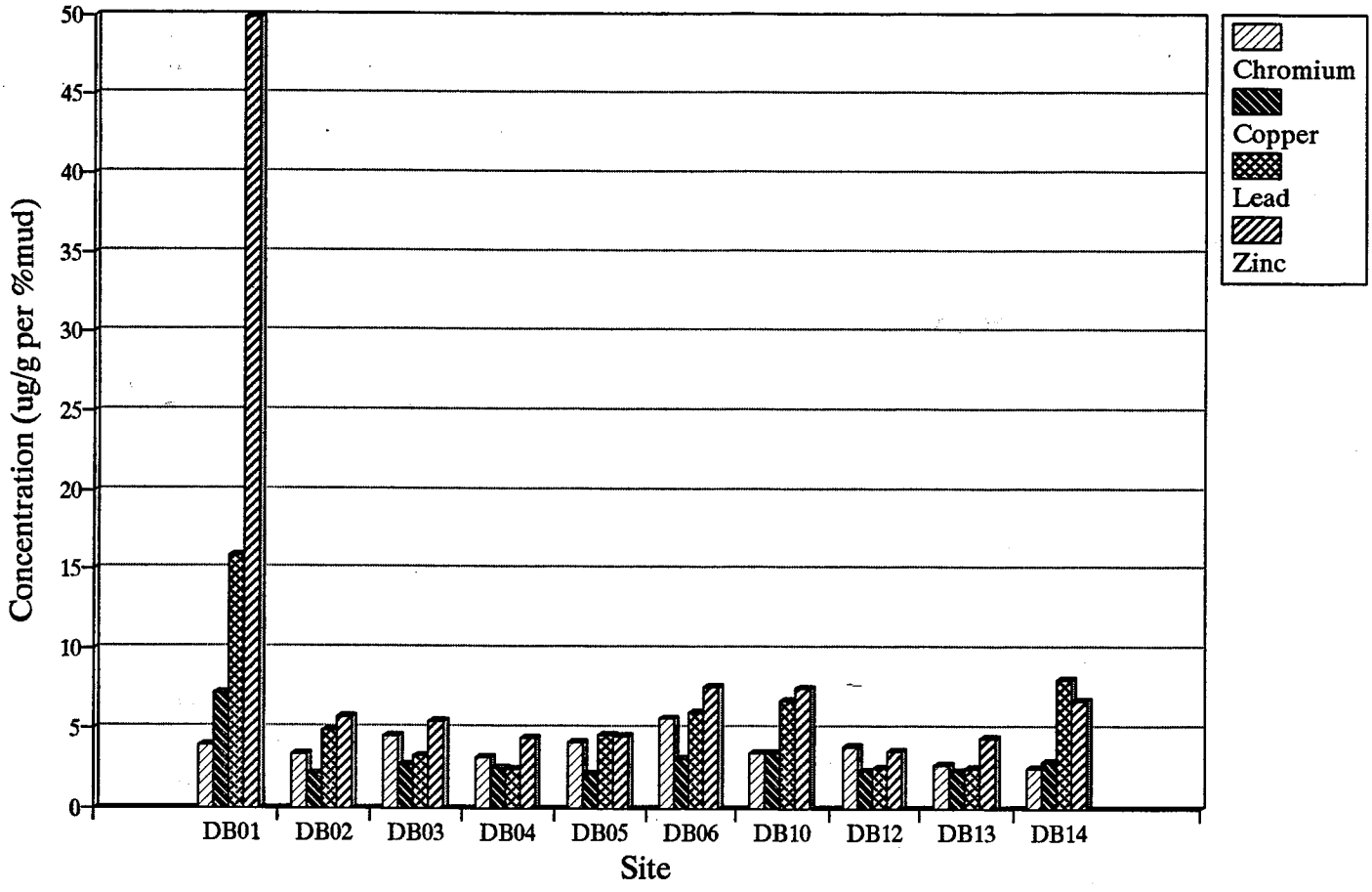

Figure 4-8. Sediment Metals Concentrations — Normalized to Grain Size (% Mud)
(b) Chromium, Copper, Lead, and Zinc

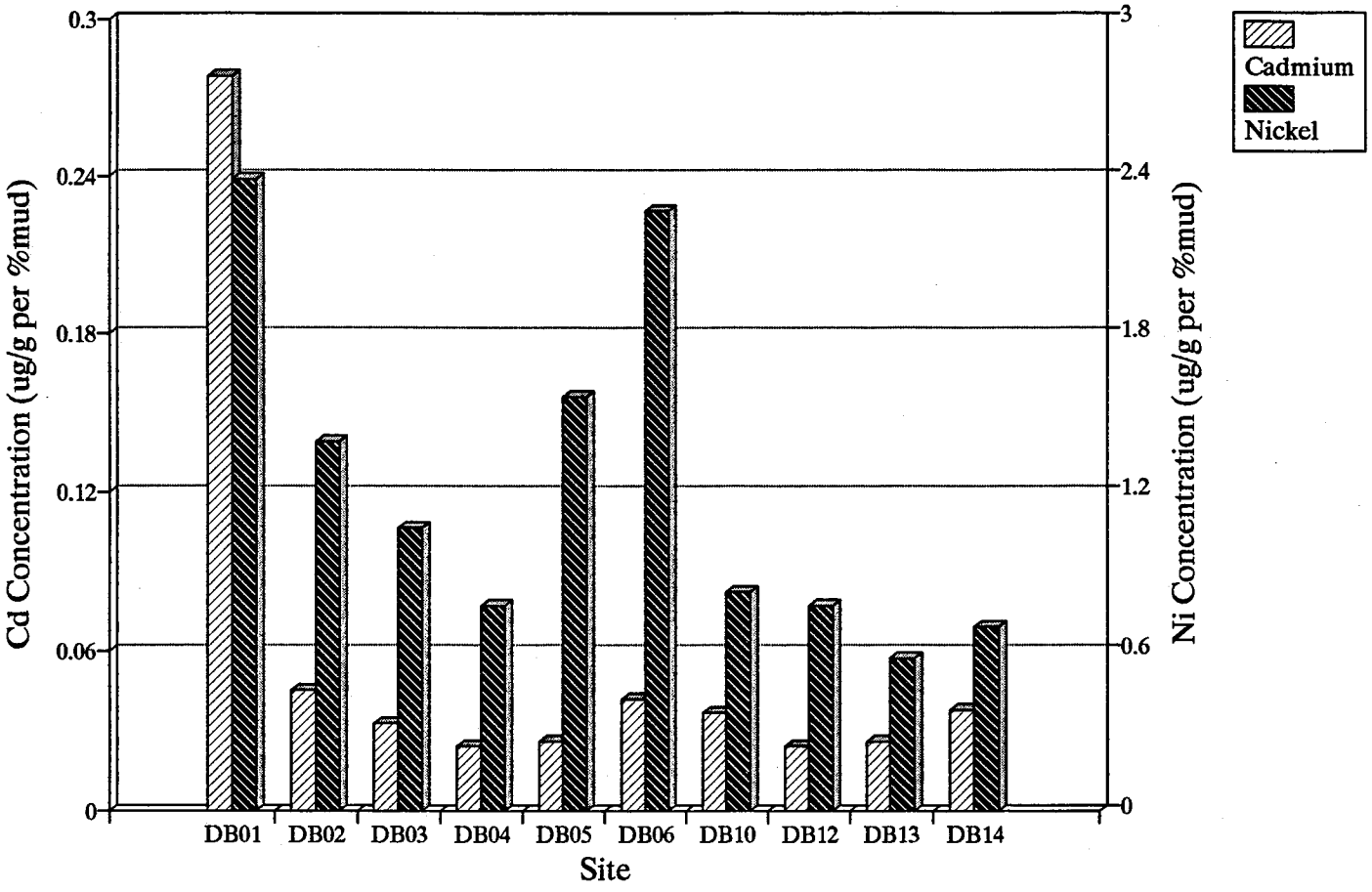

Figure 4-8. Sediment Metals Concentrations — Normalized to Grain Size (% Mud)
(c) Cadmium and Nickel

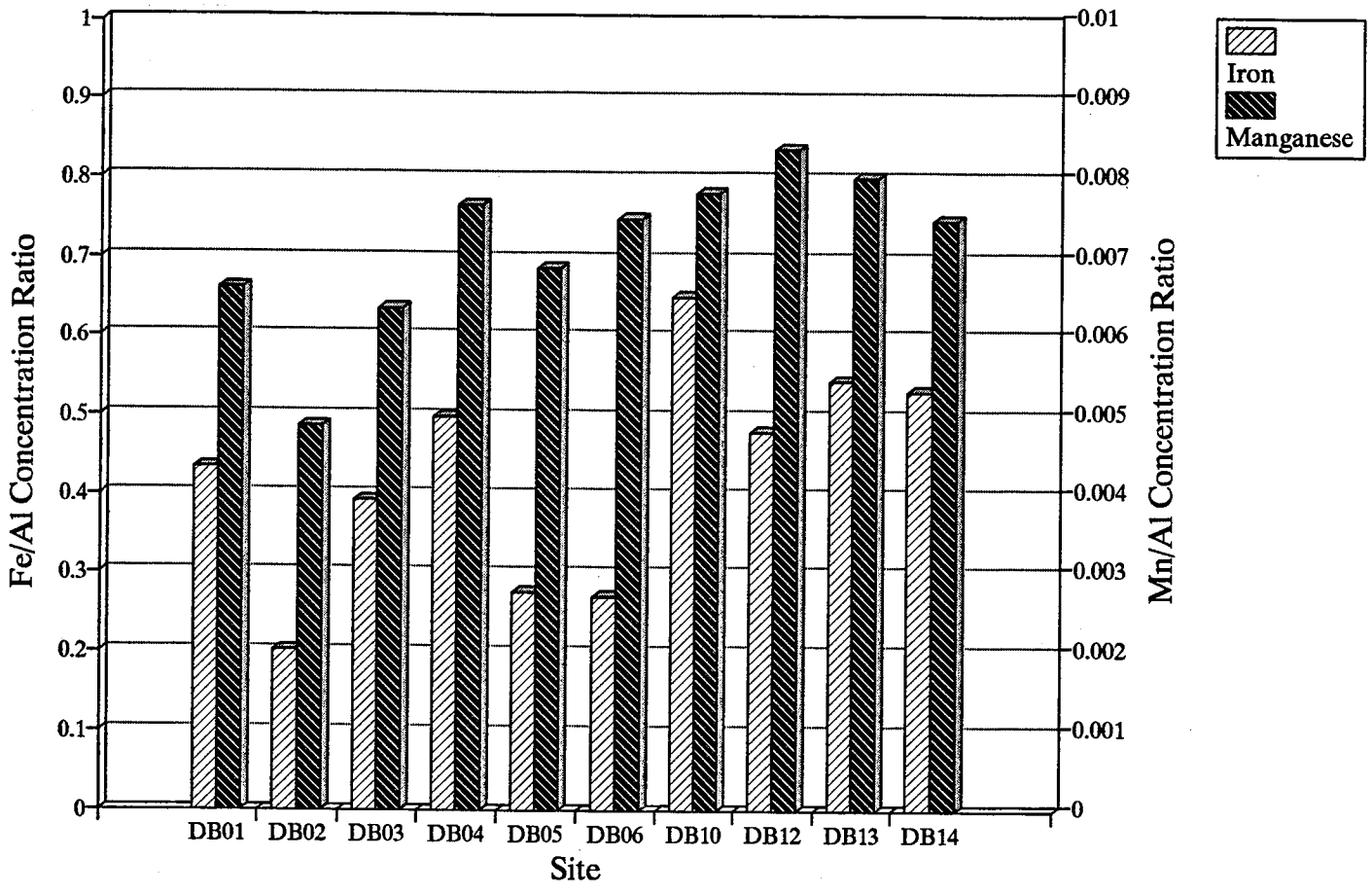

Figure 4-9. Sediment Metals Concentrations — Normalized to Aluminum
(a) Iron and Manganese

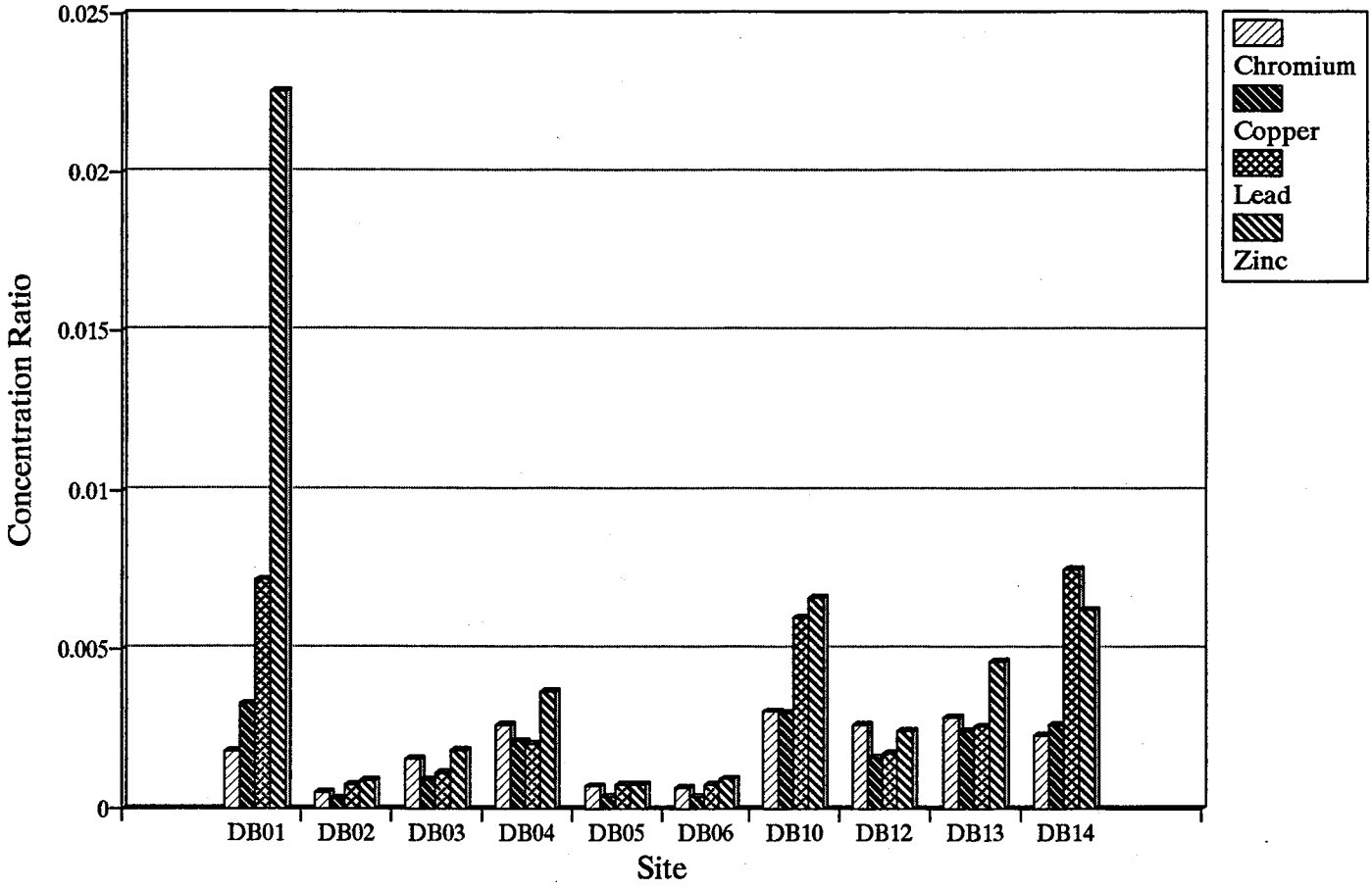

Figure 4-9. Sediment Metals Concentrations — Normalized to Aluminum
(b) Chromium, Copper, Lead, and Zinc

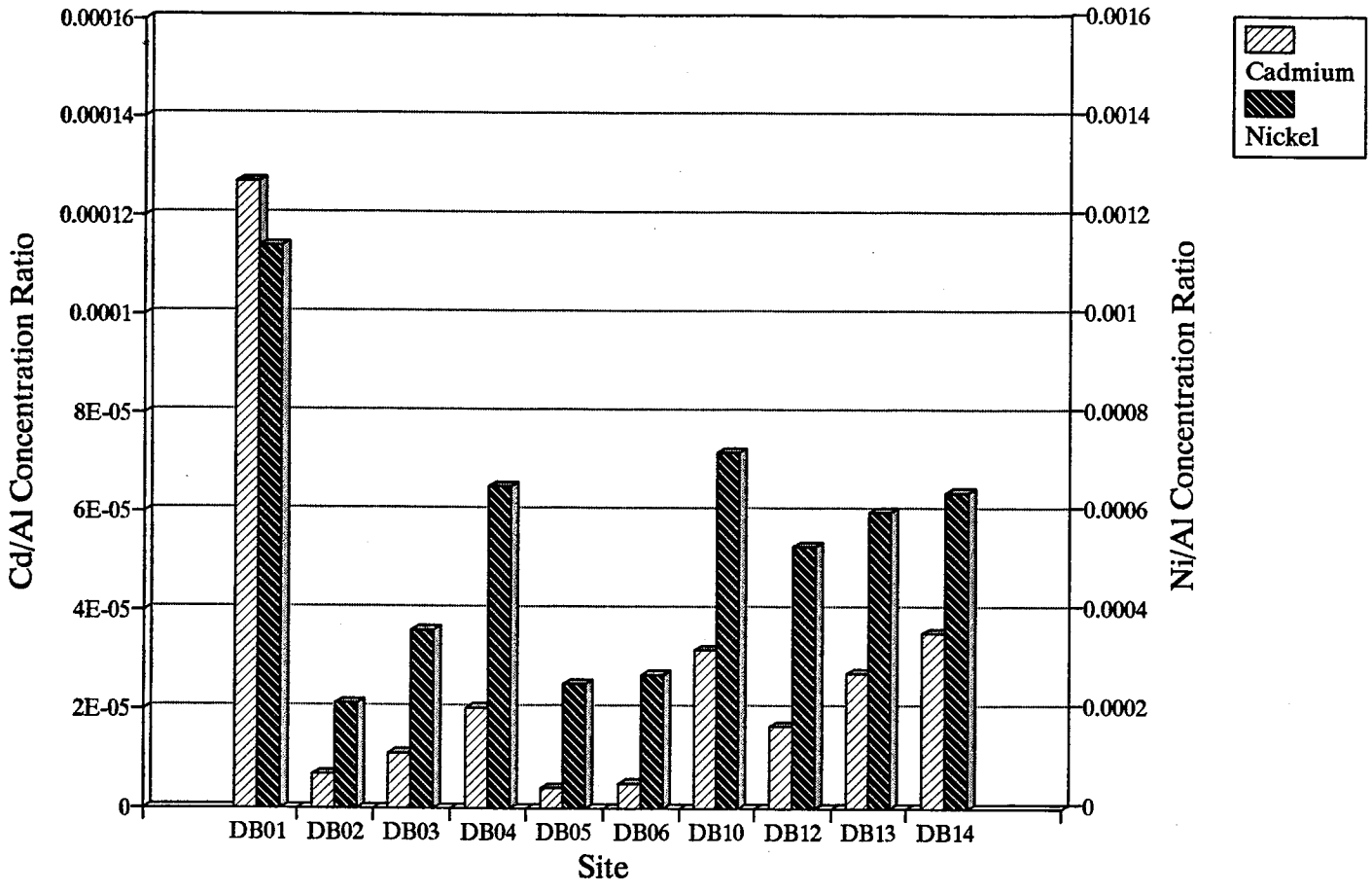

Figure 4-9. Sediment Metals Concentrations — Normalized to Aluminum
(c) Cadmium and Nickel

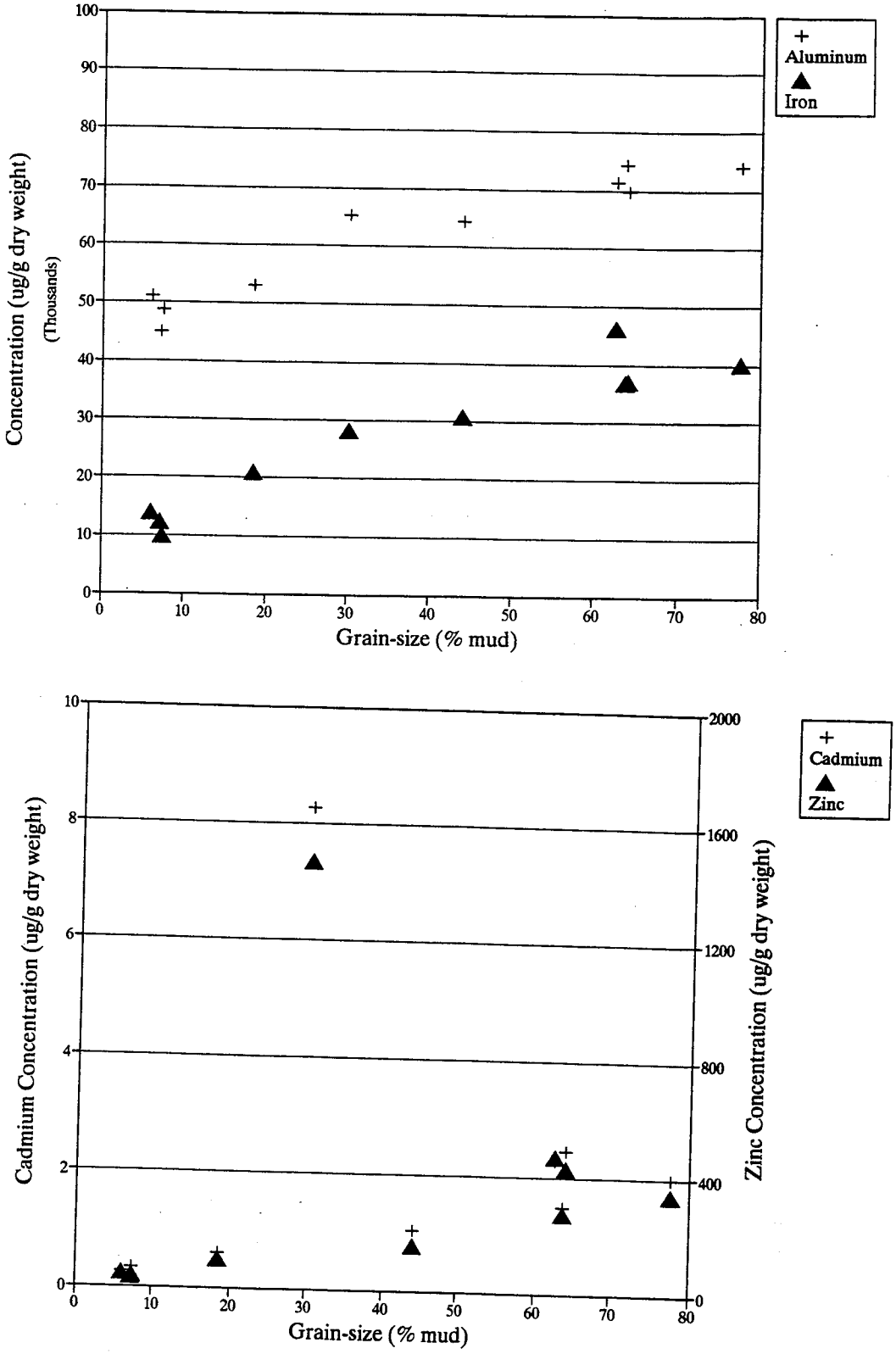

Figure 4-10. Sediment Metals Concentrations — Concentrations of Aluminum and Iron (upper) and Cadmium and Zinc (lower) versus Grain Size

Chromium and Nickel

Site DB04 was the only site in the Old Harbor area with nonnormalized and aluminum-normalized chromium concentrations, and sites DB01 and DB04 were the only sites with aluminum-normalized nickel concentrations that were statistically significantly higher than the reference site (DB03). Using both nonnormalized and aluminum-normalized data, site DB04 had chromium concentrations that were significantly higher than the other sites in the Old Harbor area. Site DB01 had the next highest levels of chromium, which were significantly higher than the remaining sites in the Old Harbor area [Table 3-9(a)]. None of the Old Harbor sites was significantly elevated in nickel than the other sites. The aluminum-normalized chromium concentrations at sites DB01 and DB04 were less than two times the levels at the reference site. When removing what appeared to be an isolated incidence of contamination for nickel for site DB01 (the concentrations determined for the three site replicates were 41, 41, and 138 μg/g), sites DB01 and DB04 had aluminum-normalized nickel concentrations that were less than two times that of the reference site.

The chromium and nickel concentrations in the Fox Point/Commercial Point area were generally slightly higher than in the Old Harbor area. The normalized chromium concentrations in the Fox Point/Commercial Point area were not significantly above the levels at the reference site [Table 3-8(b)]. The nickel concentrations at sites DB10 and DB14 were statistically significantly above the levels at the reference site. The data suggest that the chromium levels are significantly higher at DB10 and DB13 than at DB14 [Table 3-9(b)], and that the nickel levels are higher at DB10 than at DB13 or DB14 but this is more a reflection of good precision in the site replicate analyses than an indication of large differences in concentration levels.

Chromium and nickel levels do not appear to be significantly elevated at the test sites in the study areas. The data suggest that there may be one or more minor sources of nickel in the Fox Point/Commercial Point area, or possibly in Pine Neck Creek [where there may be an active storm drain (BWSC/MWRA communication)] or up the Neponset River. Alternatively, nickel may be transported from elsewhere in the Harbor and deposited in the Fox Point/Commercial Point area. None of the data indicates that CSOs in the study areas significantly contribute chromium or nickel to these areas or to Boston Harbor as a whole.

Cadmium, Copper, Lead, and Zinc

Sites DB01 and DB04 were the only sites in the Old Harbor area with measured nonnormalized and aluminum-normalized cadmium, copper, lead, and zinc concentrations significantly higher than those of the reference site [Table 3-8(a)]. Using both nonnormalized and aluminum-normalized data, these two sites showed cadmium, copper, lead, and zinc concentrations that were significantly higher than those of the reference site (DB03) and the other sites in the Old Harbor area, with site DB01 having significantly higher levels than did DB04 [Table 3-9(a)]. The aluminum-normalized cadmium, copper, lead, and zinc concentrations at DB01 are approximately 11, 4, 7, and 12 times higher than the levels at the reference site, respectively. The aluminum-normalized cadmium, copper, lead, and zinc concentrations at DB04 are approximately two times higher than the levels at the reference site.

The cadmium, copper, lead, and zinc concentrations in the Fox Point/Commercial Point area were, on average, slightly higher than in the Old Harbor area. The cadmium, copper, lead, and zinc concentrations for the Fox Point/Commercial Point sites were all statistically significantly above the levels at the reference site (site DB12) [Table 3-8(b)]. However, the aluminum-normalized cadmium, copper, lead, and zinc concentrations were no more than twice (copper), three times (cadmium and zinc) or four times (lead) the concentration determined for the reference site. The data indicate that the copper levels are statistically significantly higher at DB10 than at DB14 or DB13 [Table 3-9(b)], and that the zinc levels are significantly higher at DB10 and DB14 than at DB13. The aluminum normalized data indicate that the cadmium levels are significantly higher at DB14 than at DB13, and that the levels at DB10 are not significantly different from those at DB13 or DB14. The data suggest that the lead levels are significantly higher at DB14 than at DB10, which in turn has levels that are significantly higher than at DB13.

The data suggest that there may have been significant contributions of cadmium, lead, and zinc from BOS-87 (near DB01) and possibly some contribution from BOS-83 (near DB04) in the Old Harbor area, but the elevation in levels at DB04 is so small that the BOS-83 CSO cannot be confidently identified as a source. However, pollutant transport from other parts of the Harbor is a possibility that must be considered and without complete hydrodynamic information for the area BOS-87 cannot be conclusively identified as a significant source of these pollutants. The data suggest that there may have also been small contributions of copper from BOS-87 (near DB01) and BOS-83 (near DB04) in the Old Harbor area, but the elevation in levels at these sites is so small that the CSOs cannot be confidently identified as the source. Transport and deposition from other parts of the Harbor may

also account for the measured copper concentrations. The data suggest that the Fox Point and Commercial Point CSOs do not contribute significantly to the cadmium, copper, lead, or zinc levels in the area, because the concentrations at site DB10 (a site in this area that was expected to be relatively nonimpacted by CSOs) are consistently high relative to the other sites. However, the data do suggest that there may be one or more significant sources in the Fox Point/Commercial Point area, or possibly in Pine Neck Creek [where there may be an active storm drain (BWSC/MWRA communication)] or up the Neponset River, that contribute cadmium, copper, lead, and zinc to this area. Alternatively, significant amounts of these metals may be transported from elsewhere in the Harbor and deposited in the Fox Point/Commercial Point area which other investigators have suggested is an area significantly impacted by pollutant transport and deposition.

4.3.2 Comparison with Historical Concentration Data

In this study, the concentrations of chromium ranged from 25 (site DB02) to 218 μg/g (site DB10). These levels were close to or below the approximately 190 μg/g determined at the two Boston Harbor Mussel Watch sites closest to the study area, and the 190 to 220 μg/g determined by Wallace *et al.* (1990) for Savin Hill Cove sites.

The concentrations of copper ranged from 16 (sites DB02 and DB05) to 215 μg/g (sites DB01 and DB10) in this study. These levels were up to twice the average concentration of 110 μg/g determined for the two Deer Island and Dorchester Bay Mussel Watch sites, but generally not significantly higher than the Savin Hill Cove levels (130 to 180 μg/g) determined by Wallace *et al.* (1990). Five of the 10 sites had copper concentrations that were below both the average for the two Mussel Watch sites and the levels determined for Savin Hill Cove.

The concentrations of lead ranged from 33 (site DB05) to 523 μg/g (site DB14). These levels are up to approximately four times higher than the mean of 120 μg/g determined at the two Boston Harbor Mussel Watch sites, but only three sites had concentrations that were higher than the Savin Hill Cove levels (210 to 230 μg/g) determined by Wallace *et al.* (1990). Five of the 10 sites had lead concentrations that were below both the average for the two Mussel Watch sites and the levels determined for Savin Hill Cove.

The concentrations of zinc ranged from 33 (site DB05) to 1472 μg/g (site DB01). Five sites had

levels that were higher than the average of approximately 160 μg/g determined for the two Boston Harbor Mussel Watch sites, and four sites had higher levels than the Savin Hill Cove levels (190 to 280 μg/g) determined by Wallace *et al.* (1990). Five of the 10 sites had zinc concentrations that were below both the average for the two Mussel Watch sites and the levels determined for Savin Hill Cove.

The concentrations of cadmium ranged from 0.2 (site DB05) to 8.3 μg/g (site DB01). Except for site DB01 no sites had levels that were more than two times higher than the average of approximately 1.3 μg/g determined for the two nearby Boston Harbor Mussel Watch sites, and all except DB01 were comparable to or below the Savin Hill Cove levels (1.6 to 2.2 μg/g) determined by Wallace *et al.*, (1990). Five of the ten sites had cadmium concentrations that were below both the average for the two Mussel Watch sites and the levels determined for Savin Hill Cove.

The concentrations of nickel ranged from 10 (site DB02) to 73 μg/g (site DB01). These levels were, with the exception of site DB01, close to or slightly above the approximately 30 μg/g determined at the two Boston Harbor Mussel Watch sites and the Savin Hill Cove levels (32 to 38 μg/g) determined by Wallace *et al.* (1990). Four of the 10 sites had cadmium concentrations that were below both the average for the two Mussel Watch sites and the levels determined for Savin Hill Cove.

4.4 MICROBIOLOGICAL DENSITIES DETERMINED IN THIS STUDY

In Section 4.4.1, the sediment microbiological density and statistics data are discussed with respect to the Dorchester Bay CSOs sampled for this study.

4.4.1 Fate and Transport

The sediment microbiology data are presented in Figures 4-11(a) and (b). These data are also summarized in Table 3-4. The data are presented nontransformed as well as log-transformed, but for evaluating relative differences in microbiological pollution log-transformed data are most commonly used.

Clostridium perfringens

The densities of *C. perfringens* in the Old Harbor area ranged from approximately 2000 (site DB06) to 46,000 spores per gram dry weight (site DB04). DB04 was the only site in the Old Harbor area

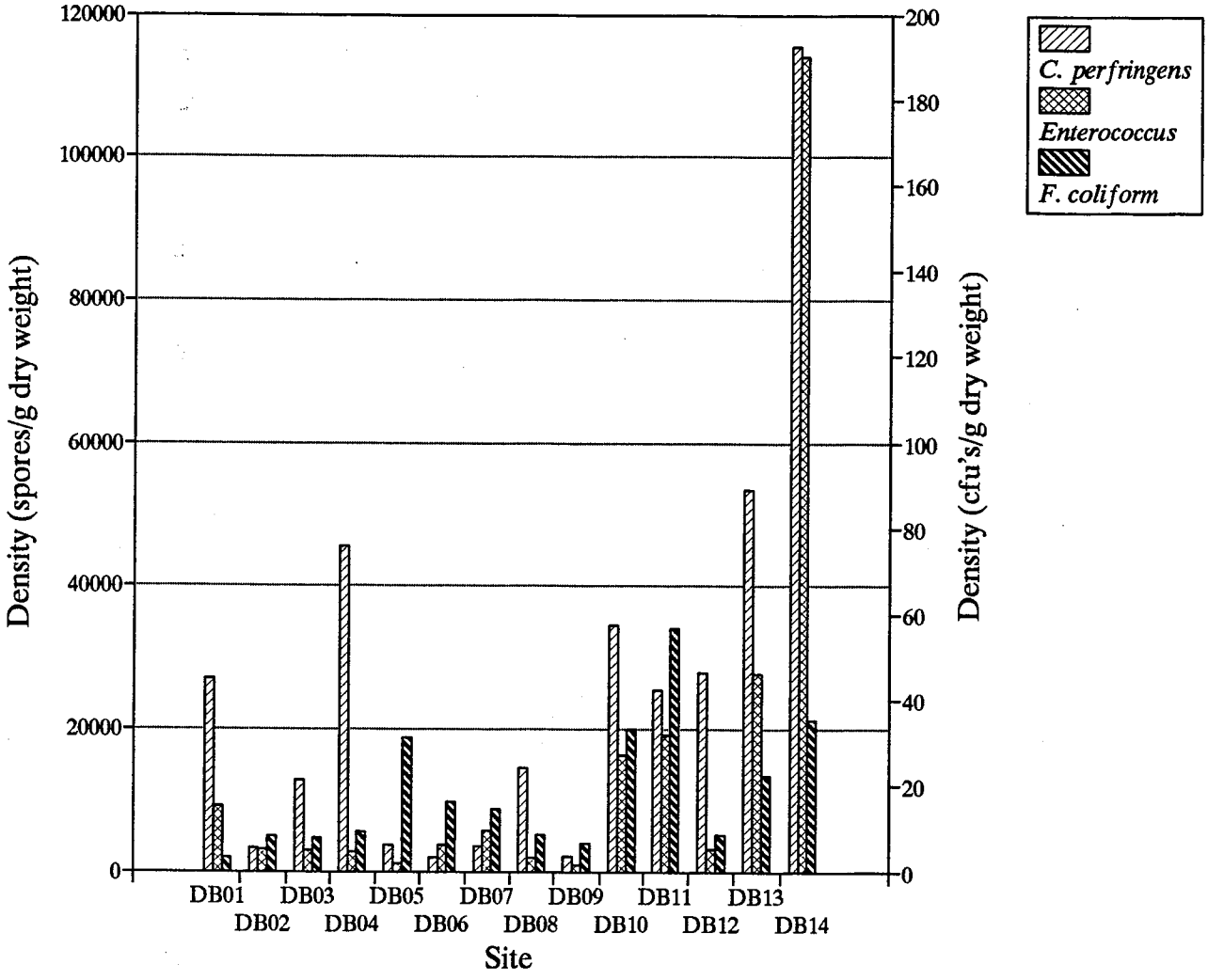

Figure 4-11. Sediment Microbiological Density Data
(a) Nontransformed
Clostridium perfringens **reported in spores/g dry weight;** ***Enterococcus*** **and fecal coliform reported in cfu/g dry weight.**

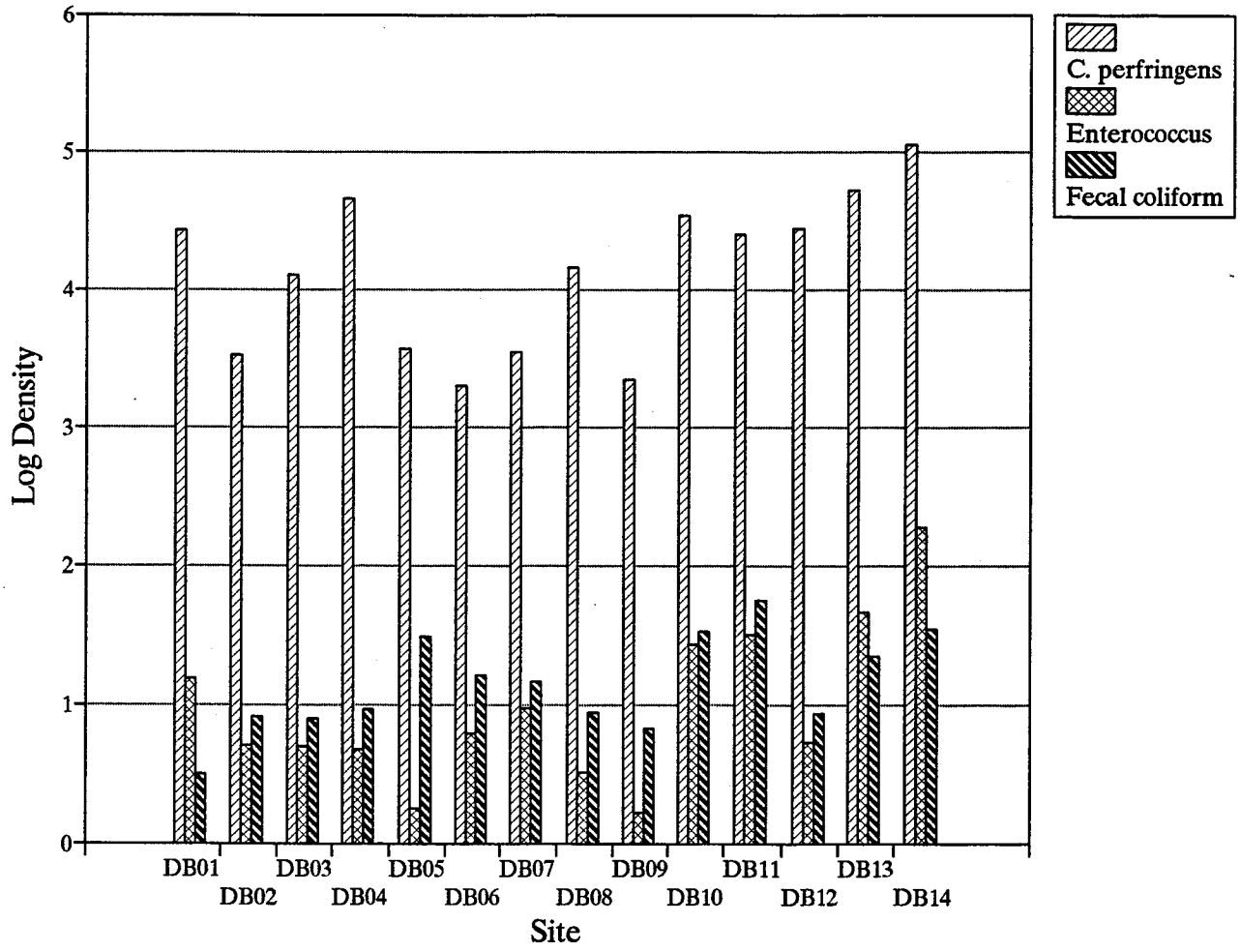

Figure 4-11. Sediment Microbiological Density Data
(b) Log-transformed
Clostridium perfringens **reported in log spores/g dry weight;** ***Enterococcus*** **and fecal coliform reported in log cfu/g dry weight.**

with nontransformed *C. perfringens* levels significantly higher than the reference site [Figure 4-11(a) and Table 3-6(a)]. However, the log-transformed data do not indicate any site in the Old Harbor area with levels significantly above those at the reference site. The multiple comparison statistics data [Table 3-7(a)] show site DB04 to have significantly higher *C. perfringens* densities than have the other sites in the Old Harbor area, with site DB01 having the next highest. However, the non-transformed densities at DB04 and DB01 are no more than three times the densities at the reference site, and the data show overall small relative density differences between the Old Harbor sites.

The densities of *C. perfringens* in the Fox Point/Commercial Point area ranged from approximately 25,000 (site DB11) to 115,000 spores per gram dry weight (site DB14). The *C. perfringens* levels in this area were, in general, higher than in the Old Harbor area. Sites DB13 and DB14 had non-transformed and log-transformed *C. perfringens* levels significantly higher than did the reference site [Table 3-6(b)]. The multiple comparison statistics data [Table 3-7(b)] show site DB14 to have significantly higher *C. perfringens* log-transformed levels than do the other sites in the Fox Point/Commercial Point area, and site DB13 to be the next highest with levels significantly higher than those at DB11 but not significantly different from those at site DB10. However, the non-transformed densities at DB14 and DB13 are less than four times the density at the reference site, and the data show overall small relative density differences among the sites.

Figure 4-12 shows the *C. perfringens* density versus the coprostanol concentration for the five sediment samples (three at each site) for which both of these parameters were determined. These parameters are generally considered good indicators of long-term, chronic, sewage input. These data suggest that site DB14 may have been impacted by sewage pollution. The elevated levels of *C. perfringens* (and coprostanol) at DB14 in the Fox Point/Commercial Point area may originate from CSO BOS-90 (Commercial Point) CSO effluent. The levels at DB13 were slightly elevated, and may be contributed to by CSO BOS-89 (Fox Point), CSO BOS-90, or a combination of the two. However, the elevation in density at DB13 was so small that CSOs cannot be confidently identified as the source. The data indicate that the *C. perfringens* level is slightly elevated at DB04 in the Old Harbor area, although the coprostanol level was low. The *C. perfringens* level may have been contributed to by CSO BOS-83, but the elevation in density was so small that the CSO cannot be confidently identified as the source. The *C. perfringens* levels at the sites with the highest densities in each area (DB14 and DB04) were only two to four times higher than those at the respective reference sites, a

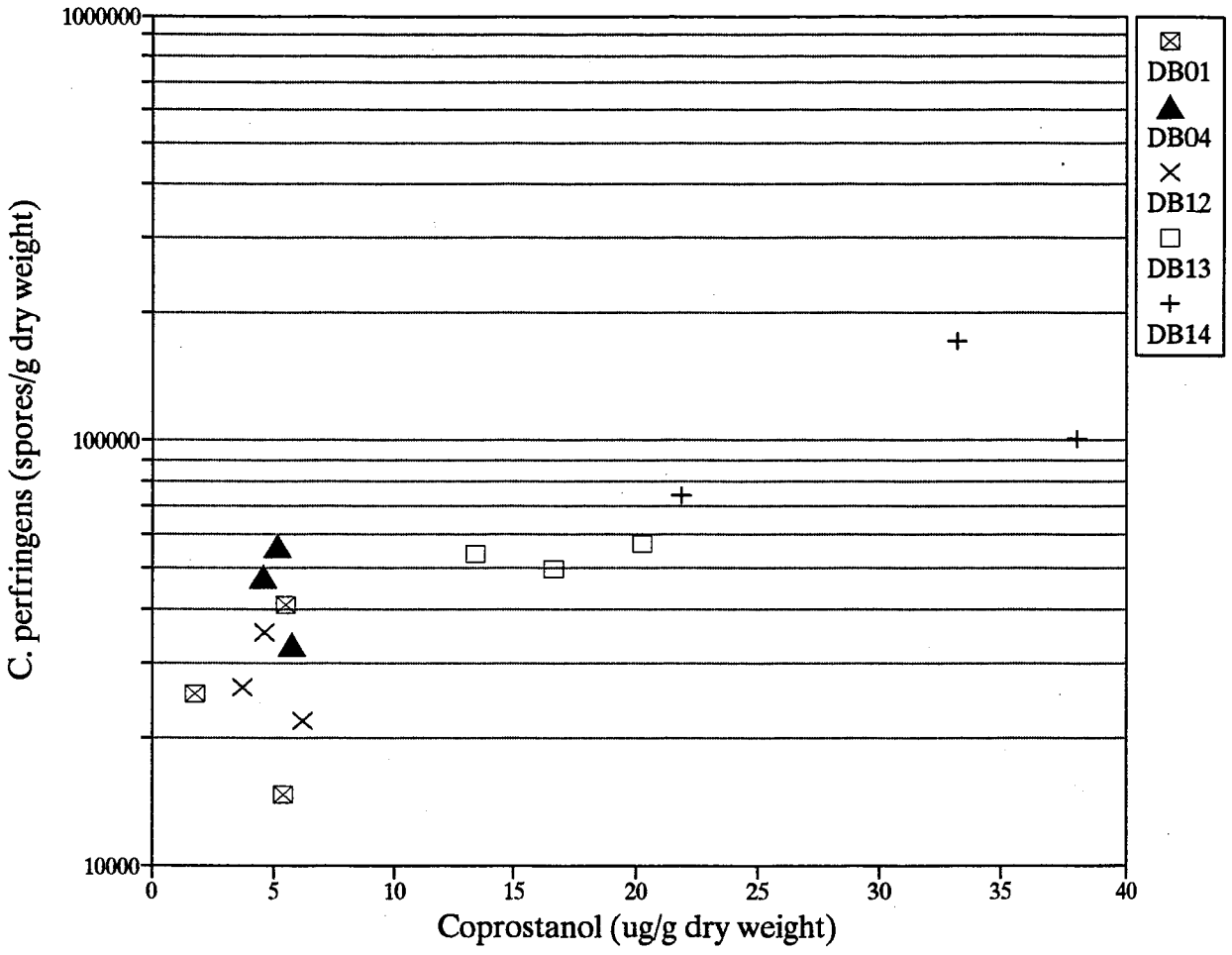

Figure 4-12. Sediment *Clostridium perfringens* Density versus Coprostanol Concentration

small difference for microbiological pollution and not enough to identify a CSO as the main source of the pollution.

Enterococcus

The densities of *Enterococcus* in the Old Harbor area ranged from approximately 1.7 (site DB09) to 15 cfu/g dry weight (site DB01). The density distribution for the area [Figures 4-11(a) and (b)] might suggest that DB01 has slightly elevated *Enterococcus* levels relative to the other Old Harbor sites. However, the statistical analysis indicates that no sites in the Old Harbor area had *Enterococcus* levels significantly higher than the reference site [Table 3-6(a)]. Additionally, the multiple comparison statistics data indicate that no site in the Old Harbor area had *Enterococcus* levels that were significantly higher than any of the other sites in the area [Table 3-7(a)].

The densities of *Enterococcus* in the Fox Point/Commercial Point area ranged from approximately 5.4 (site DB12) to 190 cfu/g dry weight (site DB14). The *Enterococcus* levels in this area were, in general, higher than in the Old Harbor area. All four sites (DB10, DB11, DB13, and DB14) had log-transformed *Enterococcus* levels significantly higher than the reference site [Table 3-6(b)]. The graphical presentation of the density distribution for the area [Figures 4-11(a) and (b)] might suggest that DB14 has elevated *Enterococcus* density relative to the other Fox Point/Commercial Point sites. However, the multiple comparison statistics data [Table 3-7(b)] indicate that none of these four sites had significantly higher *Enterococcus* levels than did the other sites in the Fox Point/Commercial Point area; the four sites were not significantly different from each other in densities of *Enterococcus*.

The data indicate that there are no significantly elevated levels of *Enterococcus* at any of the sites in the Old Harbor area. In the Fox Point/Commercial Point area, all sites are significantly elevated relative to the reference site. At first glance, the *Enterococcus* density distribution in the Fox Point/Commercial Point area appears to be similar to the distribution observed for *C. perfringens*, with site DB14 being elevated relative to the rest of the sites and a possible source of this pollutant. However, the statistical analysis indicated that there is no significant difference in *Enterococcus* densities among the four test sites at the tested level of confidence ($\alpha=0.05$), which may be due to poor precision in the site replicate analyses. The Commercial Point CSO (near DB14) may in fact be a source of *Enterococcus* pollution in the area, but the data are not sufficient to confidently identify a specific CSO as a significant source.

Fecal coliform

The densities of fecal coliform in the Old Harbor area ranged from approximately 3.2 (site DB01) to 31 cfu/g dry weight (site DB05). At first glance, the fecal coliform density distribution in the Old Harbor area would appear relatively uniform, with DB05 being slightly elevated. This lack of intersite variability is supported by the statistical analysis results, which indicate that no sites in the Old Harbor area had nontransformed or log-transformed fecal coliform densities significantly higher than those at the reference site [Table 3-6(a)]. Additionally, the multiple comparison statistics data indicate that no site in the Old Harbor area had fecal coliform levels that were significantly higher than any of the other sites in the area [Table 3-7(a)].

The densities of fecal coliform in the Fox Point/Commercial Point area ranged from approximately 8.5 (site DB12) to 57 cfu/g dry weight (site DB11). The fecal coliform levels in this area were, in general, higher than in the Old Harbor area. Sites DB11 and DB14 had nontransformed and log-transformed fecal coliform densities significantly higher than those at the reference site [Table 3-6(b)]. However, the multiple comparison statistics data [Table 3-7(b)] indicate that none of these four sites had significantly higher fecal coliform levels than the other sites in the Fox Point/Commercial Point area; the four sites were not significantly different from each other in densities of fecal coliform.

Fecal coliform densities had the least intersite variability of the three microbiological parameters, possibly due to shorter survival in the environment. The data indicate that there are no significantly elevated levels of fecal coliform at any of the sites in the Old Harbor area. In the Fox Point/Commercial Point area sites, DB11 and DB14 were significantly elevated relative to the reference site, but none of the four test sites had significantly higher levels than the other. The fecal coliform density distribution for the Fox Point/Commercial Point area does not look the same as the density distribution for the other two microbiological parameters. This could be because of short survival of fecal coliform and no recent discharges of this pollutant, or because the major source(s) of fecal coliform in Dorchester Bay really are different from the other two microbiological parameters. The higher density of fecal coliform at DB11 suggests there may be a significant upstream (Neponset River) source of this pollutant, or that fecal coliform survive better in the area of DB11 than in the area of the other sites. Unfortunately, the data are insufficient to answer questions about possible sources of fecal coliform to the Fox Point/Commercial Point area, or to identify a specific CSO as a significant source.

The relative densities of the three microbiological parameters did not follow a consistent pattern. For instance, site DB05 had one of the highest densities of fecal coliform but the lowest of *Enterococcus*. Site DB01 had the highest *Enterococcus* density in the Old Harbor area, but the lowest fecal coliform density of all sites. This lack of relationship between parameters may in part be due to large intrasite variability, or to differences in abilities to survive for periods in the varying local environments. *C. perfringens* is determined by analyzing for spores that can survive longer and in more diverse environmental conditions and may, therefore, not be expected to parallel the levels of *Enterococcus* (intermediate relative survival) and fecal coliform (short relative survival), although there appeared to be a relationship among the parameters for the more contaminated sites. DB14 had the highest levels of *C. perfringens, Enterococcus,* and coprostanol suggesting that BOS-90 (Commercial Point CSO) may be a source of sewage to the area.

4.4.2 Comparison with Historical Data

Little relevant historical sediment microbiological data were available for comparison with the data generated in this study. Shiaris *et al.* (1987) determined bacterial levels in sediment near the Fox Point CSO, and densities of 15,000 and 1,000,000 cfu/g dry weight were measured in sediment collected near the CSO point of discharge (near site DB13) for fecal coliform and *Enterococcus,* respectively. Shiaris *et al.* (1987) determined that there was a marked decrease in bacterial levels with distance away from the outfall, and at 100 to 300 m from the CSO point of discharge the densities were between 100 and 200 cfu/g for both fecal coliform and *Enterococcus*. The levels determined by Shiaris *et al.* were significantly higher than the levels determined in this study, but Shiaris' study was conducted before the Fox Point CSO had been improved (including routine chlorination of the effluent) and this study was performed after the Fox Point CSO improvements.

4.5 TOTAL VERSUS PARTIAL DIGESTION OF SEDIMENTS FOR METALS ANALYSIS

The three DB01 site-replicate samples were processed by both the total- and the partial-digestion procedure to determine analytical differences between these processing procedures for sediment metals analysis. This will facilitate comparison of analytical results between methods for samples that are similar to these.

The sediment metals concentration ratios for the total- versus partial-digestion procedures are presented in Figure 4-13. These are the same data that were given in Table 3-3(d). As expected, the nonanthropogenic metals (aluminum, iron, and manganese) are recovered to a higher degree using the total-digestion procedure. Approximately eight times higher aluminum, two and a half times higher manganese, and one and a half times higher iron levels were determined by the total-digestion method than by the partial-digestion method.

The amount of chromium and nickel were, similarly to iron, also approximately one and a half times higher in samples processed by the total-digestion procedure than by the partial-digestion procedure. This can be expected because, although these metals may be of anthropogenic origin, they are generally relatively tightly bound by the sediment matrix components, including organic carbon (DB01 was the site with the highest TOC). The recoveries/analytical results were approximately the same for cadmium, copper, lead, and zinc analysis in the samples processed by the two digestion procedures. The deviations from a total-/partial-digestion concentration ratio of approximately 1.0 for cadmium, copper, lead, and zinc can be attributed mostly to background corrections, significant figures in the data, and expected precision.

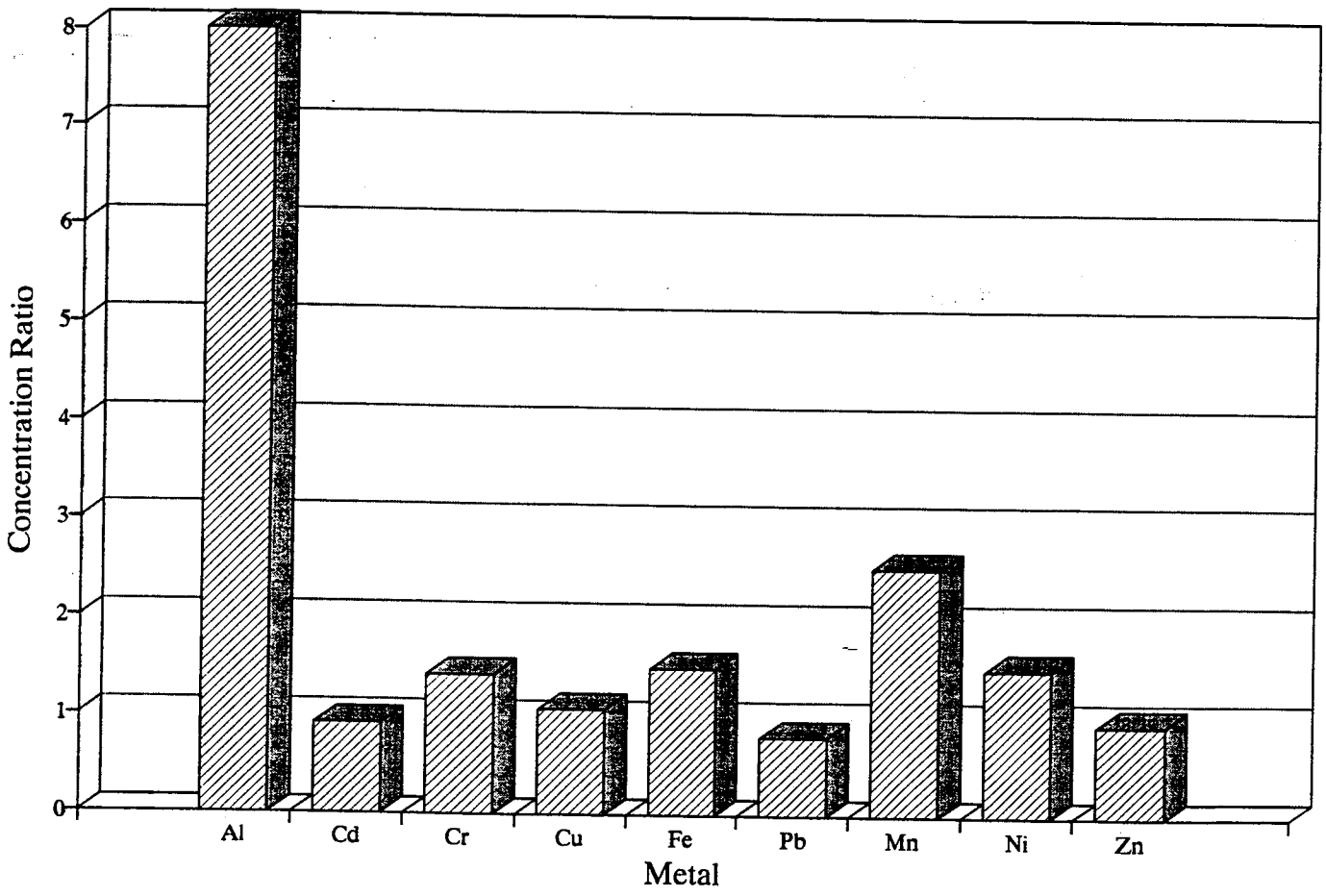

Figure 4-13. Sediment Metals Concentrations — Concentration Ratios for Total versus Partial Digestion (Site DB01)

5.0 SUMMARY

The primary goal of this study was to assess the affects of specific CSOs on the levels of pollutants in the sediments around the CSOs. Two areas of Dorchester Bay were studied: the Old Harbor area, which may receive direct discharge from seven CSOs (BOS-81 through BOS-87), and the area near the Fox Point (BOS-89) and Commercial Point (BOS-90) CSOs, which may receive direct discharge from these two CSOs, BOS-88, and indirect discharge from CSOs upstream of the Neponset River. Although the possible sources of pollutants are numerous, pollutant elevation relative to reference sites in the same general area can be used to help to determine if specific CSOs are contributing significant amounts of pollutants to the local environment. However, pollutant discharge data for potential sources and Harbor contaminant transport data are necessary to perform a thorough assessment of the impact of specific CSOs on the local sedimentary environment.

Bacterial contamination is generally considered the primary pollution problem associated with CSOs, and microbiological parameters are most often monitored for assessing pollution from wastewater treatment plants and CSOs, although elevated toxics levels and low dissolved oxygen are recognized as additional potential problems. In this study, bacteriological and toxic chemical (selected organics and metals) pollutants in sediments were studied in relation to specific CSOs. CSOs are never the sole source of any of these pollutants, and it is impossible to accurately determine the exact proportion of a pollutant originating from a specific CSO, although relative magnitudes of a pollutant originating at a source may be determined if sufficient information is available. Other potential sources of these pollutants include

- Stormwater not associated with CSOs
- Illegal connections to what should be otherwise uncontaminated storm drains
- Street runoff and runoff/discharge from nearby industrial and commercial activities
- Stream flow upstream of CSOs
- Sediment release of toxics
- Transport and deposition of pollutants originating elsewhere in the Harbor

When reviewing the statistical analysis data along with the site-mean concentration data, it may be surprising how few sites and parameters show statistically significant differences in contaminant concentration. The low number of sites with significant differences is the result of (1) lack of "real" differences in parameter values, (2) large intrasite variability in the determined site value for many

sites and parameters, and (3) relatively high "background" levels, in particular for the Fox Point/Commercial Point area.

Organics

Significantly elevated levels of PAH were measured in the sediment at site DB01 in the Old Harbor area. The PAH concentrations were significantly lower at all other Old Harbor sites, including site DB02 which was the site closest to DB01, suggesting point-source pollution. DB01 was sampled near the point of discharge from BOS-87 and the data suggest that this CSO may have contributed to the elevated PAH in the sediment at DB01. However, it is also possible that a significant proportion of these elevated PAH levels are unrelated to the CSO and the result of pollutant transport from other parts of the Harbor. There is insufficient pollutant transport and hydrodynamic information for the Old Harbor area to completely interpret the data with respect to possible sources, and irrefutably identify BOS-87 as a significant source of PAH.

The PAH levels in the sediment at DB14, near the Commercial Point CSO (BOS-90), were statistically significantly elevated in comparison to the levels at other sites in the Fox Point/Commercial Point area, suggesting that BOS-90 might be a source of PAH pollution. However, other studies have suggested that this part of Dorchester Bay is an area of significant deposition of pollutants transported from other parts of the Harbor (Gallagher *et al.*, 1990; Wallace *et al.*, 1988; Eganhouse and Sherblom, 1990; Wallace, 1990; MDC, 1979; MDEQE, 1986), which may in part explain the elevated levels of contaminants in the sediment. CSO BOS-90 may indeed be a major contributor of PAH to the sediment at DB14, but the levels are not dramatically higher than those at sites in the same general area that are not expected to be impacted by CSOs, suggesting that there may be other significant sources of PAH to this area, either local (e.g., nearby yacht club and/or Commercial Point runoff), or distant.

The data indicated that none of the CSOs near site DB01 (BOS-87), site DB04 (BOS-83), site DB13 (BOS-89), or site DB14 (BOS-90) contributes significant amounts of LAB to the sediment at these sites. The LAB levels in the sediment were similar, and not significantly different from those at the reference site, suggesting that the source of most of the LABs in the sediment is more remote. The data indicate that statistically the coprostanol levels are significantly elevated at sites DB13 and DB14. The coprostanol concentrations were highest at site DB14 and decreased with distance from this site. CSO BOS-90 may be a contributor of coprostanol to the sediment near site DB14 and the surrounding

area, but the levels are not dramatically higher than at sites not expected to be impacted by CSOs. This suggests that there may also be other major sources of coprostanol. Eganhouse and Sherblom (1990) determined that the distribution of organic sewage tracer compounds (LABs and coprostanol) in the Savin Hill Cove area were different from the discharge of the nearby Fox Point CSO (BOS-89), and suggested that these tracer organic compounds originate in releases from the Nut Island wastewater treatment plant. The data generated in this study are consistent with the Eganhouse and Sherblom observations. However, the CSO LAB and coprostanol data in this study are insufficient to thoroughly evaluate the Dorchester Bay CSOs contribution to total LAB and coprostanol in the sediment. The LAB/coprostanol ratios measured in the sediment near the Fox Point and Commercial Point CSOs were slightly lower than those measured by Eganhouse and Sherblom (1990) around Fox Point. This may be the result of reduced LAB concentrations in the Nut Island sludge (if indeed this is the primary source). An LAB/coprostanol ratio of 0.08 was determined for Nut Island sludge in this study, as compared to a ratio of 0.2 by Eganhouse and Sherblom in their earlier study. This lower ratio can be attributed primarily to a lower LAB concentration in the sludge.

Metals

Significantly elevated levels of cadmium, zinc, and lead were measured in the sediment at site DB01 in the Old Harbor area and, to a lesser degree, the concentrations of copper were also elevated at this site as compared to the background for the Old Harbor area (site DB03). The same metals were also slightly elevated at site DB04. The metals concentrations were significantly lower at site DB02, which was nearest to DB01, suggesting point-source pollution. The data suggest that CSO BOS-87 may have contributed to the elevated levels of cadmium, zinc, lead, and copper in the sediment at DB01, and BOS-83 may have contributed, to a lesser degree, to concentrations of the same metals at DB04. However, as with PAH, pollutant transport may be a significant factor contributing to these elevated concentrations, and without an understanding of the transport and deposition of contaminants in the Old Harbor area the data cannot be fully interpreted.

The same metals that were found to be elevated at site DB01 in the Old Harbor area (cadmium, zinc, lead, and copper) were also elevated at site DB14 in the Fox Point/Commercial Point area. However, the metals concentrations appear to be higher in most of the Fox Point/Commercial Point area than the rest of the Harbor. Wallace *et al.* (1988c) also found sites in this area to have the highest particulate cadmium, zinc, lead, and copper concentrations in water samples collected throughout Boston Harbor. Wallace *et al.* (1990) found that cadmium, zinc, lead, and copper concentrations in

Savin Hill Cove sediment, adjacent to the Fox Point CSO, were among the highest in Boston Harbor. He concluded that the Fox Point CSO contributed little to the elevated metals concentrations that he measured around this CSO, and attributed the elevated levels to transport from elsewhere in the Harbor. Although the DB14 concentrations of these metals are significantly elevated statistically, as compared to the reference site, the magnitude of the concentration difference is not large enough to confidently identify the Commercial Point CSO as a source of these pollutants. Pollutant transport from other parts of the Harbor may be a major factor.

Microbiology

The *Clostridium perfringens* densities were slightly elevated at sites DB01 and DB04 in the Old Harbor area, but not sufficiently elevated to confidently identify a CSO as the source of this pollutant. In the Fox Point/Commercial Point area, DB14 was the only site with significantly elevated levels of *Clostridium perfringens* and *Enterococcus*. The data suggest that BOS-90 (Commercial Point CSO) may have contributed to the sediment densities of *Clostridium perfringens* and *Enterococcus* at DB14. The fecal coliform levels were not elevated at this site, suggesting that there had not been recent input of sewage pollution at DB14 at the time of sampling.

6.0 CONCLUSION

Of the CSOs investigated, BOS-87 is the CSO that can be linked to sediment pollution with the greatest degree of confidence, based on the data generated in this study. The significantly elevated levels of PAH and metals (cadmium, zinc, lead, and copper) at DB01 suggest that BOS-87 may have contributed to the sediment concentrations of these contaminants. These results are consistent with the fact that BOS-87 discharges stormwater primarily, including street runoff, from a relatively large drainage area and little combined sewage (MWRA communication). Site DB04 was the only other site studied in the Old Harbor area that may have pollution originating from CSO (BOS-83), as determined by slightly elevated levels of the same metals that were elevated at DB01. It is important to bear in mind that the organics and metals measured in the sediments may have been deposited in the sediment over several years, and may not accurately represent current CSO discharge. Furthermore, without reliable Harbor pollutant transport data and hydrodynamic information for the area, one cannot conclusively implicate these CSOs as the primary source of these pollutants.

Elevated levels of organics (PAH and coprostanol), metals (cadmium, zinc, lead, and copper), and bacteria (*Clostridium perfringens* and *Enterococcus*) were measured at DB14, and may be contributed to by the Commercial Point CSO, but the data do not convincingly support this because the levels at DB14 were not dramatically elevated over the concentrations for the rest of the area. However, the levels of the sewage-indicating parameters (coprostanol, *Clostridium perfringens,* and *Enterococcus*) implicate BOS-90 as a possible source of sewage more than as a source of toxic chemicals. It should be noted that the samples collected for this study were obtained before the new Commercial Point CSO facility (which screens and chlorinates the CSO effluent) went on line during the fall of 1990, and the pollutant levels measured in this study may therefore not be representative of current levels.

The Fox Point/Commercial Point area had, on average, higher contaminant levels than the Old Harbor area. Gallagher *et al.* (1990), who performed work in the Fox Point area, and summarized the work of Eganhouse and Sherblom (1990) and of Wallace *et al.* (1990), concluded that the data available were insufficient to attribute the increased levels of organics, metals, and fecal coliform in this area to the Fox Point CSO. Elevated contaminant levels were attributed to transport and deposition of pollutants from other parts of the Harbor, and the data in this study suggest that this may indeed be the case for much of the pollution, particularly toxic chemicals, measured in the Fox Point/Commercial Point area.

The data suggest that BOS-87 and BOS-90 may be significant sources of pollutants to nearby sediments. However, the sites with elevated levels of different pollutants, DB01, DB04, DB10, DB13, and DB14, were also the sites with high TOC and the highest percent mud. This is consistent with common knowledge of the behavior of organic and metal contaminants and with findings by Wallace *et al.* (1990), who found a correlation between elevated organic carbon and elevation of metals concentrations, including the metals that were elevated in this study, in Dorchester Bay samples. The data are insufficient to determine, with a high degree of confidence, if (1) these TOC and percent mud levels are independent of the source of the pollutants, and the sediments concentrate these pollutants from the overlying waters, or (2) the TOC and mud are discharged along with the pollutants from local CSOs, or (3) the TOC, particulates, and pollutants are transported from elsewhere in the Harbor and deposited at these locations. These questions might be answered with more CSO-specific discharge data and with reliable hydrodynamic data including an understanding of the transport, deposition, and erosion of the areas.

Although the data generated in this study do not conclusively prove or disprove that the Dorchester Bay CSOs are significant sources of pollution to Dorchester Bay sediment, valuable and useful data have been generated. The data suggest that some CSOs are elevating sediment pollutant concentrations in the immediate vicinity of the CSO discharge, but pollutant transport and hydrodynamic data for the Harbor are needed to more fully interpret the data. The data are insufficient to determine if the CSOs significantly contribute sediment pollution to Dorchester Bay as a whole. This may be because the CSO pollution contributions are low relative to "remote" sources of pollution (e.g., Deer Island and Nut Island discharges). If indeed these remote sources are the major sources of pollution to Dorchester Bay sediments today, sediment contaminant concentrations may be expected to slowly (over a number of years) decrease after the treatment plant sludges and effluents no longer are discharged into the Harbor. With the large reduction in these remote sources, CSOs will become a more significant source of pollution to the Dorchester Bay and Harbor sediments.

The results of this study are a good initial assessment of the relative importance of CSOs to sediment contamination in Dorchester Bay. However, sediment contaminant concentration measurements are an indirect measurement of CSO originating pollution, and without good estimates of contaminant loads and reliable pollution transport data, the sediment concentrations cannot be conclusively linked

with CSOs. To better assess the importance of CSOs as sources of pollution, the following two types of information are needed.

- CSO pollution loads.
- Transport of contaminated sediments within the Harbor.

CSO effluent characterization data on discharge volumes and pollutant concentrations (to calculate mean annual loads) would be required to directly determine the amounts of pollution the CSOs contribute to Boston Harbor. It would be a significant undertaking to generate complete CSO characterization and pollutant transport data. CSO discharge is highly variable in both concentrations and flow, which makes it difficult to obtain representative CSO effluent samples, and the transport of contaminated sediments from more remote sources to Dorchester Bay involves complex processes that are difficult to model.

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Appendix A

ORGANICS DATA FOR SEDIMENT, EFFLUENT, AND SLUDGE FIELD SAMPLES

APPENDIX A (1 OF 3)

Sample dry wt (g)	1.000	21.394	20.897	20.642	10.434	11.709	10.309	21.905	22.980	22.336	23.593	22.269	23.041	21.940	21.955	22.174
Site ID		DB03	DB03	DB03	DB10	DB10	DB10	DB05	DB05	DB05	DB06	DB06	DB06	DB02	DB02	DB02
Analyte	JD08PB*	MWRA063	MWRA064	MWRA065	MWRA072	MWRA073	MWRA074	MWRA090	MWRA091	MWRA092	MWRA093	MWRA094	MWRA095	MWRA099	MWRA100	MWRA10
naphthalene	ND	30.88	36.56	47.03	114.86	209.73	116.83	6.83	6.37	6.90	6.54	6.86	6.21	12.17	7.36	13.00
2-methylnaphthalene	ND	29.01	31.34	63.99	80.96	261.54	114.63	9.38	7.18	7.89	6.10	8.32	6.09	14.14	11.88	16.63
1-methylnaphthalene	ND	13.77	13.98	29.67	46.58	138.20	59.53	3.78	3.31	3.81	3.39	4.43	2.98	7.77	5.84	9.88
biphenyl	ND	8.69	11.14	19.09	22.54	87.19	40.87	4.47	2.63	3.57	2.88	3.40	2.56	5.42	6.32	6.44
2,6-dimethylnaphthalene	ND	18.87	19.28	51.41	42.95	185.34	79.32	6.22	5.23	ND	4.18	5.50	3.87	10.39	8.82	13.09
acenaphthylene	ND	24.95	22.40	71.92	77.14	448.96	180.55	8.04	5.93	10.12	5.88	8.66	5.34	12.53	15.16	17.11
acenaphthene	ND	10.37	20.87	16.19	140.02	220.08	106.45	3.67	2.97	3.48	4.09	4.41	2.37	9.65	8.32	10.43
2,3,5-trimethylnaphthalene	ND	5.53	6.32	11.96	18.73	44.03	21.84	1.25	1.37	ND	ND	ND	ND	2.57	2.21	2.48
fluorene	ND	15.20	23.77	23.22	141.61	231.90	122.42	3.48	3.69	4.36	4.53	4.60	3.41	12.90	10.28	14.39
phenanthrene	ND	116.76	183.16	185.66	1305.26	2004.27	1215.61	35.43	29.21	38.89	37.83	45.34	29.29	118.16	103.28	134.37
anthracene	ND	33.23	65.13	50.69	265.34	508.19	261.13	9.40	7.89	11.15	9.29	10.82	7.76	23.28	24.48	25.80
1-methylphenanthrene	ND	20.38	24.45	37.67	121.79	220.77	133.59	5.07	4.40	5.95	5.06	6.06	3.41	12.31	11.61	13.16
fluoranthene	14.98	223.66	313.17	310.19	2191.02	2858.56	2111.27	73.05	64.94	85.40	71.99	101.88	63.69	211.67	197.82	257.53
pyrene	ND	255.72	337.63	337.11	1885.43	2375.00	1860.62	66.33	61.39	78.98	64.85	92.74	56.73	185.53	173.72	217.58
benz[a]anthracene	ND	123.02	182.04	157.57	1019.33	963.67	896.53	36.18	34.15	42.20	34.96	51.28	31.36	99.25	94.82	118.25
chrysene	ND	142.35	190.45	184.68	1126.34	1028.06	1010.65	41.01	40.11	49.83	39.76	59.09	37.71	113.85	107.69	135.85
benzo[b]fluoranthene	ND	178.65	202.52	269.75	1304.79	3252.00	1379.98	50.00	54.63	55.79	48.20	58.01	42.71	133.62	111.28	139.93
benzo[k]fluoranthene	ND	149.39	178.77	232.61	987.94	2204.04	1166.11	40.44	44.34	43.14	38.01	43.71	36.62	96.30	86.58	118.80
benzo(e)pyrene	ND	128.34	153.54	188.11	844.73	2000.41	940.38	31.89	42.47	37.27	32.25	37.95	29.42	84.60	71.78	94.59
benzo(a)pyrene	ND	169.03	220.52	231.57	1145.38	2699.01	1198.15	38.84	45.10	45.95	39.82	45.02	35.45	107.36	89.12	118.76
perylene	ND	39.38	52.56	54.26	260.53	578.20	252.46	10.27	10.31	12.11	10.06	11.51	9.40	24.49	21.10	27.43
indeno[1,2,3-c,d]pyrene	ND	103.90	132.29	128.57	714.95	1387.30	755.59	29.21	28.45	32.05	27.71	30.61	25.19	70.01	61.84	79.25
dibenz[a,h]anthracene	ND	20.03	24.82	25.40	124.61	249.16	123.36	4.97	7.39	4.98	4.98	5.06	4.31	11.95	10.03	13.97
benzo[g,h,i]perylene	ND	88.65	109.52	92.90	561.47	1004.36	557.67	15.48	26.82	26.70	22.39	25.19	21.27	58.13	44.22	64.75
Group 1 PAH	ND	133.64	155.71	264.95	567.47	1291.52	648.16	36.01	31.54	28.91	29.79	35.77	25.97	72.25	58.00	82.62
Group 2 PAH	14.98	1582.73	2045.29	2158.45	11905.97	20021.57	12000.31	427.40	449.77	502.30	424.91	550.54	384.46	1172.27	1048.89	1359.25
Total PAH	14.98	1949.76	2556.26	2821.20	14544.27	25159.98	14705.54	534.71	540.26	610.52	524.74	670.46	467.16	1438.06	1285.55	1663.46
Surrogate Recoveries (%)																
d8-naphthalene	26	44	38	32	47	30	30	38	43	34	47	34	46	40	34	28
d10-acenaphthene	55	59	45	68	56	66	60	69	73	71	73	69	76	76	73	67
d12-perylene	70	59	47	49	55	23	48	74	65	81	77	93	80	78	84	76
d14-dibenz[a,h]anthracene	99	95	74	78	82	30	67	114	111	129	122	158	124	120	123	121

* Procedural Blank reported in ng.
Sample concentrations reported in ng/g dry weight
ND: Not detected

APPENDIX A (2 OF 3)

Sample dry weight (g)		26.379	15.942	26.095	21.498	21.055	20.769	10.860	17.102	18.084	18.592	17.790	17.774	23.229	24.263	25.7
Site ID		DB12	DB12	DB12	DB14	DB14	DB14	DB13	DB13	DB13	DB04	DB04	DB04	DB01	DB01	DB
Analyte	JD17PB*	MWRA066	MWRA067	MWRA068	MWRA069	MWRA070	MWRA071	MWRA078	MWRA079	MWRA080	MWRA087	MWRA088	MWRA089	MWRA096	MWRA097	MWRA0
naphthalene	27.81	65.26	90.30	73.09	221.61	223.10	272.87	174.84	117.39	148.19	141.53	108.01	115.23	429.44	1255.66	412.
2-methylnaphthalene	ND	55.15	78.73	58.84	162.22	167.72	206.61	109.91	67.96	101.30	80.68	58.42	66.49	251.57	870.95	261.
1-methylnaphthalene	ND	24.35	38.93	24.92	109.85	113.05	126.84	49.04	32.03	46.13	45.30	31.89	33.74	200.57	719.20	220.
biphenyl	ND	15.08	24.43	19.58	58.53	86.86	99.48	91.41	57.52	66.60	53.47	42.65	48.25	97.42	288.29	84.
2,6-dimethylnaphthalene	ND	38.71	57.31	44.39	209.30	272.47	255.08	115.57	192.88	181.21	160.13	45.71	163.18	195.57	589.54	165.
acenaphthylene	ND	61.70	110.12	64.27	178.79	201.76	216.40	142.27	108.63	135.38	107.96	89.44	97.42	208.22	730.28	200.
acenaphthene	ND	28.06	41.68	28.21	368.95	354.06	412.73	75.92	53.74	69.72	111.95	62.14	57.50	841.22	2061.16	887.
2,3,5-trimethylnaphthalene	ND	4.59	21.71	11.84	179.18	210.62	185.54	25.65	16.03	24.91	19.52	12.05	15.37	143.84	266.18	97.
fluorene	ND	32.45	70.06	34.38	419.64	411.36	488.17	96.69	62.29	82.81	125.67	72.86	75.37	966.17	2471.50	942.
phenanthrene	ND	276.66	559.62	263.12	3929.40	3900.28	4193.19	837.36	581.77	710.39	1122.59	668.95	672.75	7716.48	11595.85	7046.
anthracene	ND	89.04	255.51	96.10	940.25	919.85	1080.91	281.13	179.66	236.36	319.67	196.56	215.26	2004.96	4694.97	2027.
1-methylphenanthrene	ND	45.05	86.38	45.57	486.77	477.37	410.57	95.90	81.05	49.15	127.35	76.27	77.15	721.37	1405.08	841.
fluoranthene	ND	376.71	741.44	351.16	5556.66	5419.57	4559.49	1275.68	929.25	803.74	1261.09	901.28	956.09	8272.42	7873.26	8182.
pyrene	ND	392.59	785.11	358.27	4694.81	4479.05	4614.49	1174.71	917.83	884.48	1219.34	844.41	877.96	7396.14	9534.76	7234.
benz[a]anthracene	ND	159.99	331.67	135.61	2034.03	1770.79	1796.27	415.41	353.31	279.98	441.20	326.04	353.68	4015.18	6299.18	3940.
chrysene	ND	157.25	311.55	124.68	2270.23	1969.42	2028.17	463.43	406.35	304.25	431.95	342.95	369.13	4047.16	5846.35	3737.
benzo[b]fluoranthene	ND	297.44	537.13	349.24	2496.55	2631.83	2985.52	974.47	681.14	897.02	822.83	543.53	564.93	4463.13	6042.62	3062.
benzo[k]fluoranthene	ND	242.30	418.13	284.72	2144.08	2048.69	2361.07	834.28	626.42	795.29	690.09	482.85	516.16	2934.52	4291.35	2145.
benzo(e)pyrene	ND	231.39	370.20	259.87	1902.79	1991.71	2177.84	705.56	522.74	675.34	602.30	416.41	425.30	2831.00	4029.13	2150.
benzo(a)pyrene	ND	376.74	627.11	415.42	2581.96	2623.79	2926.00	883.42	669.88	864.54	837.08	560.80	586.36	4271.60	6279.69	3160.
perylene	ND	87.83	150.56	96.12	693.32	677.38	780.30	239.45	176.96	227.44	205.03	147.58	145.64	975.07	1613.56	719.
indeno[1,2,3-c,d]pyrene	ND	203.61	327.15	244.77	1933.98	2025.29	1961.54	647.87	483.62	581.25	558.94	377.01	379.35	2786.65	4247.54	1967.
dibenz[a,h]anthracene	ND	33.43	54.72	39.97	290.61	291.71	277.18	101.53	71.88	87.53	83.74	59.25	62.24	428.93	673.70	299.
benzo[g,h,i]perylene	ND	177.34	280.91	204.49	1782.90	1966.64	1849.91	578.88	461.24	528.18	489.41	348.75	349.42	2493.35	3641.12	1727.
phenyl decane	ND	50.93	77.40	64.08	247.91	324.25	338.05	147.98	100.50	159.10	64.51	65.16	48.63	108.94	94.50	138.
phenyl undecane	ND	200.47	287.80	316.68	670.83	843.45	902.42	576.89	416.53	631.69	276.89	221.41	203.25	410.55	478.28	276.
phenyl dodecane	ND	306.36	478.37	360.31	833.86	1044.74	1109.23	904.42	547.66	850.86	429.08	386.57	288.02	400.47	440.22	265.
phenyl tridecane	ND	200.38	393.46	234.62	424.69	703.42	667.84	578.65	467.70	550.21	324.84	256.35	242.09	295.70	270.78	163.
phenyl tetradecane	ND	164.96	361.02	204.77	382.83	591.62	555.86	558.44	349.83	459.60	276.16	223.55	206.70	280.08	254.62	186.
coprostanol (ug/g)	ND	3.71	4.62	6.24	21.96	38.00	33.13	20.28	13.41	16.63	5.77	5.17	4.55	5.49	5.42	1.
Group 1 PAH	27.81	265.57	443.43	293.03	1788.57	1875.68	1945.67	667.60	569.63	633.69	700.17	405.20	546.53	2908.52	7578.10	2942.
Group 2 PAH	ND	2648.78	4785.11	2768.20	27688.61	27218.47	27537.47	8055.25	6123.65	6701.61	7437.97	5203.27	5440.61	43940.08	58758.69	37607.
Total PAH	27.81	3472.72	6370.45	3628.63	35646.42	35234.34	36266.16	10390.38	7851.55	8781.18	10058.81	6815.78	7223.96	58691.97	87320.89	51517.
Total LAB	ND	923.09	1598.04	1180.46	2560.12	3507.48	3573.40	2766.38	1882.22	2651.46	1371.49	1153.03	988.69	1495.74	1538.39	1030.
Surrogate recoveries (%)																
d8-naphthalene	94	83	72	98	DO	DO	DO	91	52	87	93	78	79	DO	DO	
d10-acenaphthene	94	95	89	109	DO	DO	DO	100	59	100	105	89	88	DO	DO	
d12-perylene	81	47	49	39	DO	DO	DO	40	29	30	44	43	45	DO	DO	
d14-dibenz[a,h]anthracene	78	85	83	66	DO	DO	DO	50	38	45	53	52	55	DO	DO	
1-phenyl nonane	79	88	84	98	DO	DO	DO	98	57	102	101	87	87	DO	DO	
androstanol	59	82	80	81	76	107	92	75	51	78	82	82	90	88	74	

* Procedural Blank reported in ng.
Sample concentrations reported in ng/g dry weight
ND: Not detected
DO: Diluted out

APPENDIX A. (3 OF 3)

Sample volume (L)	0.500	0.365	0.365	0.100	0.375	0.100	0.450
Site ID	NA	FP	CP	DI-S	DI-WW	NI-S	NI-WW
Analyte	JD19PB*	MWRA071-W	MWRA072-W	MWRA073-W	MWRA074-W	MWRA075-W	MWRA076-W
phenyl decane	ND	ND	ND	122.71	1.47	105.02	1.50
phenyl undecane	ND	ND	ND	319.17	4.56	400.44	6.21
phenyl dodecane	ND	ND	ND	299.45	5.01	638.13	7.83
phenyl tridecane	ND	ND	ND	125.05	3.08	329.56	4.50
phenyl tetradecane	ND	ND	ND	113.16	1.73	232.13	2.63
Total LAB	ND	ND	ND	979.54	15.83	1705.28	22.67
coprostanol	ND	6.31	1.75	43418.42	125.82	22699.37	192.12
Surrogate Recovery (%)							
1-phenyl nonane	84	70	73	148	71	105	76
androstanol	33	70	63	58	63	73	63

* Procedural Blank reported in µg.
Sample concentrations reported in µg/L
ND: Not detected

Appendix B

METALS DATA FOR SEDIMENT FIELD SAMPLES

APPENDIX B. METALS DATA FOR SEDIMENT FIELD SAMPLES

Site ID	Sample ID	Al	Cd*	Cr*	Cu	Fe	Pb	Mn	Ni*	Zn
DB01	MWRA098	62800	8.866	118.6	216.9	25800	454.1	414	40.7	1378.4
DB01	MWRA097	69100	8.195	120.5	232.2	29700	492.4	432	41.6	1561.4
DB01	MWRA096	63700	7.768	109.8	196.1	29200	459.7	445	137.9	1476.1
DB02	MWRA101	43700	0.387	26.6	16.3	9450	39.9	236	9.3	45.6
DB02	MWRA100	55400	0.318	28.3	18.9	11600	37.5	297	12.8	44.7
DB02	MWRA099	47200	0.281	19.5	11.9	8580	30.0	181	8.4	36.6
DB03	MWRA063**	54900	0.472	59.5	36.2	19600	46.3	281	15.2	91.1
DB03	MWRA064	46000	0.551	64.5	37.3	17400	48.6	295	15.9	79.6
DB03	MWRA065	58500	0.769	124.6	72.1	25600	84.1	439	26.8	122.2
DB04	MWRA089	69000	1.416	187.7	146.9	34900	140.9	527	44.3	205.3
DB04	MWRA088	74000	1.594	199.5	158.7	37300	150.7	577	52.7	297.5
DB04	MWRA087	80100	1.500	200.1	163.4	38700	157.3	605	46.6	322.7
DB05	MWRA092	47600	0.196	28.8	13.7	11000	31.6	278	8.7	32.3
DB05	MWRA091	43500	0.153	25.2	14.4	12200	29.8	289	12.3	27.1
DB05	MWRA090	43800	0.210	36.9	19.2	13900	39.0	355	12.9	38.8
DB06	MWRA093	54900	0.214	41.7	26.6	17200	42.1	512	17.1	43.4
DB06	MWRA094	50300	0.388	34.2	13.2	12300	36.7	329	12.8	68.1
DB06	MWRA095	48200	0.161	26.6	15.8	12100	31.4	318	11.6	28.6
DB10	MWRA072	70400	2.270	215.6	222.0	48000	458.7	541	53.7	507.3
DB10	MWRA073	68800	2.313	223.7	214.9	47500	426.0	569	51.0	469.0
DB10	MWRA074	75100	2.295	213.7	208.7	43200	397.4	562	50.0	441.5
DB12	MWRA066	65200	1.099	161.1	99.7	29800	105.4	531	33.1	151.5
DB12	MWRA067	68400	1.150	164.7	106.4	30700	111.3	534	33.7	158.8
DB12	MWRA068	59700	0.924	178.7	103.4	31700	113.2	543	35.3	156.1
DB13	MWRA078	77100	1.946	212.3	179.2	40400	189.6	577	46.7	333.3
DB13	MWRA079	75500	2.048	212.1	179.1	40200	192.5	605	44.5	346.6
DB13	MWRA080	69600	2.031	211.8	187.0	39800	192.7	592	41.8	346.9
DB14	MWRA069	71500	2.281	152.7	175.6	39500	547.6	517	45.0	433.9
DB14	MWRA070	66900	2.696	161.9	179.9	35400	522.4	513	42.7	425.6
DB14	MWRA071	70700	2.418	166.3	193.6	36200	497.9	529	45.2	440.6

* Samples were blank corrected for this analyte
** Sample concentrations are the mean of duplicate analyses
Sample concentrations reported in µg/g

Appendix C

MICROBIOLOGY DATA FOR SEDIMENT FIELD SAMPLES

APPENDIX C

SITE	SAMPLE ID	C. perfringens Spores/g, dry weight (thousands)	Enterococcus cfu/g, dry weight	Fecal coliform cfu/g, dry weight
DB01	MWRA096	41.1	26.0	5.7
DB01	MWRA097	14.7	14.0	<1
DB01	MWRA098	25.3	6.1	3.7
DB02	MWRA099	3.22	7.2	22.5
DB02	MWRA100	2.16	6.1	<1
DB02	MWRA101	4.7	2.0	2.0
DB03	MWRA063	10.5	10.0	10.7
DB03	MWRA064	9.29	4.4	7.2
DB03	MWRA065	19.1	0.3	6.0
DB04	MWRA087	33	6.7	9.0
DB04	MWRA088	56.2	0.4	10.0
DB04	MWRA089	47.4	7.0	8.9
DB05	MWRA090	4.49	3.8	54.1
DB05	MWRA091	3.58	0.7	4.7
DB05	MWRA092	3.16	0.9	34.9
DB06	MWRA093	1.68	7.4	25.3
DB06	MWRA094	1.52	9.6	3.2
DB06	MWRA095	2.77	1.7	20.7
DB07	MWRA084	2.28	9.1	3.7
DB07	MWRA085	5.55	12.5	3.3
DB07	MWRA086	2.68	6.8	37.0
DB08	MWRA081	9.03	1.1	3.5
DB08	MWRA082	18.4	1.8	16.4
DB08	MWRA083	15.8	6.9	6.5
DB09	MWRA102	1.77	2.3	5.6
DB09	MWRA103	2.51	2.0	4.6
DB09	MWRA104	2.33	0.8	10.0
DB10	MWRA072	31.1	23.3	5.8
DB10	MWRA073	31	30.0	66.7
DB10	MWRA074	41.6	28.1	27.4
DB11	MWRA075	25	40.6	90.9
DB11	MWRA076	30.1	23.4	48.4
DB11	MWRA077	21.1	31.4	31.4
DB12	MWRA066	26.3	8.7	3.3
DB12	MWRA067	35.3	3.7	17.1
DB12	MWRA068	21.8	3.8	5.0
DB13	MWRA078	57	90.4	19.6
DB13	MWRA079	53.6	25.2	35.0
DB13	MWRA080	49.6	22.9	12.5
DB14	MWRA069	74.2	454.5	30.3
DB14	MWRA070	101	82.1	48.7
DB14	MWRA071	171	33.3	26.4

Appendix D

MOISTURE CONTENT, TOC, AND GRAIN-SIZE DATA FOR SEDIMENT FIELD SAMPLES

APPENDIX D

SITE ID	SAMPLE ID	% Water	TOC weight %, dry weight	Grain-size distribution % Gravel	% Sand	% Silt	% Clay
DB01	MWRA096	65	6.28	10.3	57.6	23.1	9
DB01	MWRA097	52	7.9 **	17	57.7	21.2	4
DB01	MWRA098	49	4.59	13.5	53.5	27.4	5.7
DB02	MWRA099	31	0.60	2.4	91.6	4	2.1
DB02	MWRA100	25	0.29	1.9	90.5	5.8	1.9
DB02	MWRA101	26	0.44	2.3	89.3	6.1	2.2
DB03	MWRA063	30	0.78	14.5	71.4	8.7	5.4
DB03	MWRA064	35	0.90	15	63.1	14.5	7.4
DB03	MWRA065	42	1.24	17.1	63.5	13.5	5.9
DB04	MWRA087	70	3.11 **	0	27.2	58.8	14
DB04	MWRA088	74	3.15	0	48.5	39	12.5
DB04	MWRA089	73	3.20	0.9	32.1	55.4	11.6
DB05	MWRA090	26	0.40	0.1	92.3	5.5	2.1
DB05	MWRA091	26	0.31	0	93.1	4.4	2.5
DB05	MWRA092	24	0.21	0	92.8	5.4	1.8
DB06	MWRA093	23	0.22	0.2	93.5	4.5	1.8
DB06	MWRA094 *	23	0.26	1.2	92.7	4.5	1.7
DB06	MWRA095	25	0.31	0	94.3	3.8	1.9
DB07	MWRA084 *	18	1.10	18.0	78.7	2.1	1.3
DB07	MWRA085	40	0.70	23.6	63.7	9.4	3.3
DB07	MWRA086	27	0.23	27.4	68.2	2.6	1.8
DB08	MWRA081	34	0.98	27.8	58.4	10	3.7
DB08	MWRA082	53	0.97	1.5	77.7	15.1	5.8
DB08	MWRA083	46	1.18	3.7	81.9	10.3	4
DB09	MWRA102	25	0.13	8.6	88.3	1.8	1.4
DB09	MWRA103	24	0.20	4.2	92.8	2.1	0.9
DB09	MWRA104	25	0.19 **	20.1	76.7	2.9	0.4
DB10	MWRA072	70	4.91	8	25.6	50.9	15.5
DB10	MWRA073	70	4.63	18.9	19.7	46.1	15.3
DB10	MWRA074	69	4.08	15.5	24.2	47.8	12.5
DB11	MWRA075	67	3.30	0.3	26.8	58.9	13.9
DB11	MWRA076	69	2.96	2.5	27.3	55.5	14.7
DB11	MWRA077	65	3.15 **	1.1	18	61.5	19.5
DB12	MWRA066	54	1.76	0	55.3	32.7	12
DB12	MWRA067	62	2.2 **	1.7	53.8	34.1	10.4
DB12	MWRA068	60	1.68	1.6	55.2	31.7	11.5
DB13	MWRA078	77	3.62	0	19.2	58.3	22.5
DB13	MWRA079	75	4.10	0	18.7	58.8	22.5
DB13	MWRA080	74	3.75	0	29	50.4	20.6
DB14	MWRA069	67	4.32	0	34	55.3	10.7
DB14	MWRA070	61	4.08 **	0	35.4	53.8	10.8
DB14	MWRA071	64	4.52	0	38.3	51	10.7

* Reported values are the mean of duplicate analysis
** Reported values are the mean of replicate analysis

Appendix E

ORGANICS QUALITY CONTROL DATA

APPENDIX E (1 OF 4)

Site ID	Sample ID	Surrogate Compound Percent Recoveries					
		d8-naph	d10-acen	d12-pery	d14-dibenz	1-phenyl nonane	androstanol
DB03	MWRA063	44	59	59	95	NA	NA
DB03	MWRA064	38	45	47	74	NA	NA
DB03	MWRA065	32	68	49	78	NA	NA
DB12	MWRA066	83	95	47	85	88	82
DB12	MWRA067	72	89	49	83	84	80
DB12	MWRA068	98	109	39	66	98	81
DB14	MWRA069	DO	DO	DO	DO	DO	76
DB14	MWRA070	DO	DO	DO	DO	DO	107
DB14	MWRA071	DO	DO	DO	DO	DO	92
DB10	MWRA072	47	56	55	82	NA	NA
DB10	MWRA073	30	66	23	30	NA	NA
DB10	MWRA074	30	60	48	67	NA	NA
DB13	MWRA078	91	100	40	50	98	75
DB13	MWRA079	52	59	29	38	57	51
DB13	MWRA080	87	100	30	45	102	78
DB04	MWRA087	93	105	44	53	101	82
DB04	MWRA088	78	89	43	52	87	82
DB04	MWRA089	79	88	45	55	87	90
DB05	MWRA090	38	69	74	114	NA	NA
DB05	MWRA091	43	73	65	111	NA	NA
DB05	MWRA092	34	71	81	129	NA	NA
DB06	MWRA093	47	73	77	122	NA	NA
DB06	MWRA094	34	69	93	158	NA	NA
DB06	MWRA095	46	76	80	124	NA	NA
DB01	MWRA096	DO	DO	DO	DO	DO	88
DB01	MWRA097	DO	DO	DO	DO	DO	74
DB01	MWRA098	DO	DO	DO	DO	DO	88
DB02	MWRA099	40	76	78	120	NA	NA
DB02	MWRA100	34	73	84	123	NA	NA
DB02	MWRA101	28	67	76	121	NA	NA
FP	MWRA071-W	NA	NA	NA	NA	70	70
CP	MWRA072-W	NA	NA	NA	NA	73	63
DI-S	MWRA073-W	NA	NA	NA	NA	148	58
DI-WW	MWRA074-W	NA	NA	NA	NA	71	63
NI-S	MWRA075-W	NA	NA	NA	NA	105	73
NI-WW	MWRA076-W	NA	NA	NA	NA	76	63

DO - Surrogate diluted out
NA: Not applicable - Sample was not analyzed for this parameter

APPENDIX E (2 OF 4)

SEDIMENT BATCH 1 MS/MSD DATA)

Analyte	JD08PB (ng)	JD06MS (ng)	JD07MSD (ng)	%RPD	Background sample MWRA065 (ng)	JD06MS (% Recoveries)	JD07MSD (% Recoveries)	Average
naphthalene	ND	3982.47	4079.72	2	970.73	91	94	92
2-methylnaphthalene	ND	5462.10	7894.69	36	1320.92	127	202	165
1-methylnaphthalene	ND	5069.74	7447.84	38	612.50	132	203	167
biphenyl	ND	5114.50	7465.24	37	394.05	143	214	178
2,6-dimethylnaphthalene	ND	5662.59	8735.08	43	1061.25	139	232	185
acenaphthylene	ND	5847.04	9271.92	45	1484.66	137	245	191
acenaphthene	ND	3773.31	3918.35	4	334.11	100	104	102
2,3,5-trimethylnaphthalene	ND	3072.59	3245.88	5	246.82	96	101	99
fluorene	ND	3805.10	4290.63	12	479.25	102	116	109
phenanthrene	ND	6073.20	7789.48	25	3832.32	68	120	94
anthracene	ND	3350.44	3825.22	13	1046.31	92	111	101
1-methylphenanthrene	ND	3789.88	4288.33	12	777.59	92	107	100
fluoranthene	14.98	8611.46	9490.85	10	6402.88	67	94	80
pyrene	ND	8806.04	9814.85	11	6958.53	56	86	71
benz[a]anthracene	ND	6170.02	6741.88	9	3252.62	103	123	113
chrysene	ND	6578.01	6932.44	5	3812.10	84	94	89
benzo[b]fluoranthene	ND	8267.96	8278.15	0	5568.27	82	82	82
benzo[k]fluoranthene	ND	6640.65	6918.41	4	4801.59	56	64	60
benzo(e)pyrene	ND	6247.39	6364.94	2	3882.88	71	75	73
benzo(a)pyrene	ND	7272.40	7128.11	2	4780.04	84	79	81
perylene	ND	3334.49	3316.93	1	1119.96	89	88	89
indeno[1,2,3-c,d]pyrene	ND	4892.90	4751.79	3	2653.87	76	72	74
dibenz[a,h]anthracene	ND	2837.09	3360.64	17	524.28	93	114	103
benzo[g,h,i]perylene	ND	4007.26	3206.09	22	1917.68	71	44	58
				15 = average				107 = average
Surrogate Recoveries	(%)	(ng)	(ng)			(%)	(%)	
d8-naphthalene	26	605.00	397.57			50	33	
d10-acenaphthene	55	904.87	907.98			75	76	
d12-perylene	70	913.09	893.91			76	74	
d14-dibenz[a,h]anthracene	99	1531.87	1421.78			128	118	

APPENDIX E (3 OF 4)

					Background sample			
Analyte	JD17PB (ng)	JD15MS (ng)	JD16MSD (ng)	%RPD	MWRA067 (ng)	JD15MS (% Recoveries)	JD16MSD	Average
naphthalene	27.81	4646.27	4732.63	2	1439.61	97	99	98
2-methylnaphthalene	ND	4666.79	4848.28	4	1255.18	105	111	108
1-methylnaphthalene	ND	4058.92	4148.92	2	620.66	102	105	103
biphenyl	ND	3959.97	3863.01	2	389.45	108	105	106
2,6-dimethylnaphthalene	ND	4472.50	4873.32	9	913.70	108	120	114
acenaphthylene	ND	4996.35	5505.52	10	1755.48	102	118	110
acenaphthene	ND	3819.50	3786.12	1	664.53	92	91	91
2,3,5-trimethylnaphthalene	ND	3333.86	3280.84	2	346.06	101	99	100
fluorene	ND	4249.22	4165.77	2	1116.93	96	93	94
phenanthrene	ND	9508.48	10415.28	9	8921.47	18	45	31
anthracene	ND	4708.34	4912.04	4	4073.28	25	33	29
1-methylphenanthrene	ND	4493.71	4374.66	3	1377.03	95	92	93
fluoranthene	ND	11608.54	12290.13	6	11820.00	-6	14	4
pyrene	ND	12677.84	13136.85	4	12516.16	5	19	12
benz[a]anthracene	ND	5860.41	5742.24	2	5287.42	20	16	18
chrysene	ND	5729.15	5595.38	2	4966.78	23	19	21
benzo[b]fluoranthene	ND	10467.99	10855.61	4	8562.94	58	70	64
benzo[k]fluoranthene	ND	8530.93	9739.24	13	6665.81	57	93	75
benzo(e)pyrene	ND	8352.14	9017.58	8	5901.67	74	94	84
benzo(a)pyrene	ND	11592.40	12802.73	10	9997.36	54	94	74
perylene	ND	4650.95	4712.79	1	2400.22	90	93	92
indeno[1,2,3-c,d]pyrene	ND	7617.32	8008.92	5	5215.41	82	95	89
dibenz[a,h]anthracene	ND	3221.06	3071.53	5	872.27	94	88	91
benzo[g,h,i]perylene	ND	6634.74	6923.68	4	4478.29	74	83	79
1-phenyl decane	ND	2196.99	2295.26	4		97	102	99
1-phenyl undecane	ND	1887.87	1895.27	0		94	95	95
1-phenyl dodecane	ND	1896.58	1861.04	2		93	91	92
1-phenyl tridecane	ND	2013.15	1978.30	2		91	89	90
1-phenyl tetradecane	ND	2579.24	2412.23	7		94	88	91
coprostanol (µg/g)	ND	6.91	7.32	6		91	101	96
				---				---
				4 =average				78 =average
Surrogate Recoveries	(%)	(ng)	(ng)			(%)	(%)	
d8-naphthalene	94	1577.92	1594.74			79	80	
d10-acenaphthene	94	1808.43	1942.71			90	97	
d12-perylene	81	1068.21	1038.61			53	52	
d14-dibenz[a,h]anthracene	78	1979.14	1944.55			99	97	
phenyl nonane	79	1823.74	1958.75			84	90	
androstanol	59					78	82	

APPENDIX E (4 OF 4)

WATER BATCH 1 MS/MSD

LAB Analyte	JD19PB	JD20BS (ng)	JD21SD (ng)	%RPD	JD20BS (% Recovery)	JD21SD	Average
1-pheny decane	ND	2316.51	2348.69	1	103	104	103
1-pheny undecane	ND	2170.47	2164.29	0	109	108	108
1-pheny dodecane	ND	2181.25	2206.49	1	107	108	108
1-pheny tridecane	ND	2480.34	2518.30	2	112	113	113
1-pheny tetradecane	ND	2704.14	2786.50	3	99	102	100
coprostanol (µg/g)	ND	15.22	22.42	38	6	24	15
				8 = average			91 = average

Surrogate Recoveries	(%)	(ng)	(ng)	(%)	(%)
phenyl nonane	84	1614.87	1547.61	74	71
androstanol	33			17	46

Blank spikes contain no background level of LAB or coprostanol; no correction needed

Appendix F

METALS QUALITY CONTROL DATA

APPENDIX F. METALS QUALITY CONTROL DATA

Total Digestion

Procedural Blanks	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
	ug	ng	ng	ug	ug	ug	ug	ng	ug
GQ29-PB	<191	3.02	227	<0.50	<9.6	<0.101	<1.01	116	<0.50
GQ30-PB	<162	3.40	298	0.43	13.6	0.128	<0.85	94	<0.43
Blank Correction	none	3.21	263	none	none	none	none	105	none

Duplicates ug/g	Al	Cd*	Cr*	Cu	Fe	Pb	Mn	Ni*	Zn
MWRA063(-1)	54800	0.389	53.0	29.4	20200	42.0	267	13.7	68.7
MWRA063(-2)	54900	0.554	66.0	42.9	19000	50.6	294	16.7	113.4
Mean	54900	0.472	59.5	36.2	19600	46.3	281	15.2	91.1
%RPD	<1	35	22	37	6	19	10	20	49

Matrix Spike Data	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
	ug	ng	ng	ug	ug	ug	ug	ng	ug
MWRA063-MS	***	613	39555	33.3	***	137	219	14855	151
Expected		616	39685	33.9		136	194	13751	147
%R		100	100	98		100	113	108	103

SRM NBS 1646 ug/g Recovery	Al	% R	Cd*	% R	Cr*	% R	Cu	% R	Fe	%R
Expected	62500		0.36		76		18		33500	
GQ31-SRM	69900	112	0.897	249	70.3	92	21.9	122	32649	97
GQ32-SRM	84300	135	0.306	85	73.9	97	21.5	120	33475	100

	Pb	%R	Mn	%R	Ni*	%R	Zn	%R
Expected	28.2		375		32		138	
GQ31-SRM	30.9	110	390	104	35.5	111	121.9	88
GQ32-SRM	29.9	106	399	106	33.1	103	119.6	87

Partial Digestion

Procedural Blanks	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
	ug	ng	ng	ug	ug	ug	ug	ng	ug
GQ85-PB	<21	<2.88	91.1	<0.48	<4.8	<0.048	<1.92	<95.9	1.01
GQ86-PB	<21	<2.91	<82.3	<0.48	<4.8	<0.048	<1.94	<96.8	0.97
Blank Correction	None	None	None	None	None	None	None	None	0.99

Duplicates ug/g	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn*
MWRA096P(-1)	7950	8.34	85.1	198	18700	499	164	26.9	1420
MWRA096P(-2)	8320	8.83	81.5	188	19400	529	194	26.1	1570
Mean	8140	8.59	83.3	193	19100	514	179	26.5	1500
%RPD	5	6	4	5	4	6	17	3	10

Matrix Spike Data	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
		ng	ng	ug		ug	ug	ng	ug
MWRA096P-MS	***	9023	104087	198	***	695	304	34696	1564
Expected		9520	112500	228		665	313	37825	1700
% R		95	93	87		105	97	92	92

SRM NBS 1646 ug/g Recovery	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn *
GQ84-SRM	11500	0.371	32.9	14.4	24000	24	238	25.8	120
Expected	62500	0.36	76	18	33500	28.2	375	32	138
% R	18	103	43	80	72	85	63	81	87

Detection limits	Al	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Zn
	ug/mL	ng/mL	ng/mL	ng/mL	ug/mL	ng/mL	ug/mL	ng/mL	ug/mL
IDL	3.8	0.06	1.8	5	0.19	1.5	0.04	2.0	0.03
MDL ug/g^	190	0.003	0.09	0.25	9.5	0.075	2	0.1	1.5

^ 1 g sample; 50 mL analyte
* Blank Corrected
*** No Al or Fe matrix spike added; background levels prohibitively high

%R: Percent Recovery

Appendix G

TOC QUALITY CONTROL DATA

APPENDIX G. TOC QUALITY CONTROL DATA

		TOC (weight %, dry weight)			
	Standard	Determined			
Sample ID	Conc	Conc	Duplicate	Average	%RPD
Procedural Blank Data					
BLANK 1		0.009		0.008	
BLANK 2		0.009			
BLANK 3		0.005			
Standard Check Data					
0.0396 STD	0.0396	0.041			3.5
0.101 STD	0.101	0.101			0.0
0.397 STD	0.397	0.400			0.8
0.865 STD	0.865	0.835			3.5
0.397 STD	0.397	0.398			0.3
0.397 STD	0.397	0.405			2.0
0.865 STD	0.865	0.835			3.5
0.0396 STD	0.0396	0.042			5.9
0.397 STD	0.397	0.400			0.8
0.865 STD	0.865	0.867			0.2
0.397 STD	0.397	0.401			1.0
0.397 STD	0.397	0.400			0.8
0.865 STD	0.865	0.852			1.5
0.397 STD	0.397	0.400			0.8
0.865 STD	0.865	0.846			2.2
0.078 STD	0.078	0.081			3.8
0.078 STD	0.078	0.078			0.0
0.078 STD	0.078	0.081			3.8
1.262 STD	1.262	1.250			1.0
0.078 STD	0.078	0.081			3.8
0.101 STD	0.101	0.102			1.0
0.0396 STD	0.0396	0.041			3.5
0.078 STD	0.078	0.082			5.0
				Average:	2.1
Replicate Analysis Data					
MWRA 017-TOC		4.48	4.46	4.47	0.4
MWRA 020-TOC		3.44		3.38	3.6
MWRA 020-TOC DUP		3.32			
MWRA 022-TOC		2.87	3.04	2.96	5.8
MWRA 032-TOC		1.04	0.93	0.99	11.2
MWRA 034-TOC		4.80	4.94	4.87	2.9
MWRA 034-TOC DUP		2.88	2.81	2.85	2.5
MWRA 067-TOC		2.22	2.17	2.20	2.3
MWRA 070-TOC		4.02	4.14	4.08	2.9
MWRA 077-TOC		3.10	3.20	3.15	3.2
MWRA 087-TOC		3.12	3.09	3.11	1.0
MWRA 097-TOC		8.01	7.78	7.90	2.9
MWRA 104-TOC		0.19	0.18	0.19	5.4
				Average:	3.7

Average and %RPD data for MWRA020 are calculated from the two field replicates: MWRA020 and MWRA020-DUP.

Standard Conc: Concentration of standard material analyzed
%RPD: Relative percent difference.

Appendix H

GRAIN-SIZE QUALITY CONTROL DATA

APPENDIX H. GRAIN SIZE QUALITY CONTROL DATA

Sample ID		Grain-size distribution % Gravel	% Sand	% Silt	% Clay
MWRA084		27.8	69.2	1.9	1.1
MWRA084-DUP		8.2	88.1	2.3	1.4
	Mean:	18	78.7	2.1	1.3
	%RPD:	108.9	24.0	19.0	23.1
MWRA094		1.5	92.3	4.5	1.7
MWRA094-DUP		0.8	93.1	4.5	1.6
	Mean:	1.2	92.7	4.5	1.7
	%RPD:	58.3	0.9	0.0	5.9

%RPD: Relative percent difference.