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A Summary of Chemical and Biological Testing of Proposed Disposal of Sediment From Richmond Harbor Relative to the Deep Off-Shelf Reference Area, the Bay Farm Borrow Area, and the Alcatraz Environs Reference Area

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December 1993

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Pacific Northwest Laboratory
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A SUMMARY OF CHEMICAL AND BIOLOGICAL TESTING OF PROPOSED DISPOSAL OF SEDIMENT FROM RICHMOND HARBOR RELATIVE TO THE DEEP OFF-SHELF REFERENCE AREA, THE BAY FARM BORROW AREA, AND THE ALCATRAZ ENVIRONS REFERENCE AREA

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SUMMARY

The Water Resources Development Act of 1986 (Public Law 99-662) authorized the U.S. Army Corps of Engineers, San Francisco District, to dredge Richmond Harbor from its current navigational depth of -35 ft to -38 ft mean lower low water to accommodate large, deep-draft vessels. The proposed dredging areas are the four major reaches of Richmond Harbor: the Entrance Channel, Potrero Reach, Inner Harbor Channel, and Santa Fe Channel. Battelle/Marine Sciences Laboratory completed an ecological evaluation of Richmond Harbor sediments following the document entitled *Evaluation of Dredged Material Proposed for Ocean Disposal - Testing Manual* (EPA/USACE 1991), hereinafter referred to as the *1991 Implementation Manual.* The ecological evaluations included:

- describing the physical characteristics and measuring sediment samples for conventional parameters, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated pesticides, metals, and butyltins
- measuring the water column effects of dredged material disposal in suspended-particulate-phase (SPP) toxicity tests with the mysid *Holmesimysis sculpta*, the juvenile sanddab *Citharichthys stigmaeus*, and the larvae of the mussel *Mytilus edulis*
- measuring the deposited sediment toxicity of sediment composites to marine organisms in solid-phase toxicity tests with the polychaete *Nephtys caecoides*, bentnose clam *Macoma nasuta*, and amphipod *Rhepoxynius abronius*
- measuring the potential for bioaccumulation of chemical contaminants (PAHs, pesticides, PCBs, metals, and butyltins) from dredged material to *M. nasuta* and *N. caecoides.*

Chemical analyses were performed on 30 sediment samples; 28 of those samples were then combined to form 7 composites. The seven composites plus sediment from two additional stations located in the Potrero Turning Circle received both chemical and biological evaluations. The objective of this report is to compare the sediment chemistry, acute toxicity, and bioaccumulation results of the Richmond Harbor sediments to each of the reference areas; i.e., the Deep Off-Shelf Reference Area (R-OS), the Bay Farm Borrow Area (R-BF), and the Alcatraz Environs Reference Area (R-AM). The first seven sections of this report compare the Richmond Harbor sediments to R-OS. The two appendixes compare the Richmond Harbor sediments to R-BF (Appendix A) and R-AM (Appendix B). This report will enable the USACE to determine whether disposal at a reference area is appropriate for all or part of the dredged material from Richmond Harbor.

The Deep Off-Shelf Reference Area is located approximately 50 nautical miles southwest of the Golden Gate Bridge. The sediment collected at this site was found to be fine grained (84% silt and clay) with typical levels of total organic carbon and total volatile sulfides. These values

were among some of the highest found and were in the top 20% of the test treatments. The oil and grease and total petroleum hydrocarbon concentrations in R-OS sediments were low relative to the concentrations found in the Richmond Harbor test treatments.

The SPP toxicity tests showed that two of the seven SPP composites (COMP I and TC-5 Upper Comp) were statistically significantly acutely toxic when compared to R-OS. The SPP from COMP I was acutely toxic to *M. edulis* but an LC50 could not be calculated because there was not a 50% decrease in survival. The SPP from TC-5 Upper Comp was acutely toxic to *C. stigmaeus* and had a calculated LC50 of 75.4% SPP.

Solid-phase acute toxicity tests showed that three of the seven Richmond Harbor composites (COMP III, TC-5 Upper Comp, and COMP IV) were acutely toxic to *N. caecoides* relative to R-OS. The remaining test treatments showed no acute toxicity relative to the reference sediment R-OS.

Statistically significant bioaccumulation of one or more contaminants (PAHs, pesticides, PCBs, metals, and/or butyltins) occurred in the tissues exposed to the seven composites relative to those exposed to the reference sediment R-OS. However, bioaccumulation of similar classes of compounds and similar degrees of bioaccumulation did not often occur in both species. The number of compounds and the degree (magnitude) to which compounds were elevated in each species exposed to each treatment are presented in this report.

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1.0 INTRODUCTION

Richmond Harbor, a major West Coast port for shipping and petroleum refining, lies on the eastern shoreline of central San Francisco Bay near San Francisco, California (Figure 1.1). The current authorized navigational depth of Richmond Harbor is -35 ft mean lower low water (MLLW). Because this depth will no longer accommodate large, deep-draft vessels, a federal program is under way to widen channels and deepen the harbor to -38 ft MLLW. The proposed dredging areas are the four major reaches of Richmond Harbor: Entrance Channel, Potrero Reach, Inner Harbor Channel, and Santa Fe Channel (Figure 1.2). Between the Potrero Reach and Inner Harbor Channel, a turning area is being considered that will allow ships to negotiate the turn into and out of the Inner Harbor Channel area. This deepening and widening program will remove an estimated 1.5 million yd^3 of dredged material.

The Water Resources Development Act of 1986 (Public Law 99-662) authorized the U.S. Army Corps of Engineers (USACE), San Francisco District, to be responsible for dredging and/or disposal of Richmond Harbor sediment. Aquatic disposal (both in San Francisco Bay and at ocean sites) is a preferred disposal option for suitable Richmond Harbor sediment. To gain authorization for aquatic disposal, the deepening program must evaluate sediment in accordance with Section 103 of the Marine Protection, Research, and Sanctuaries Act of 1972 (Public Law 92-532) for disposal in the ocean and Section 404 of the Clean Water Act of 1972 (Public Law 95-217) for disposal in San Francisco Bay. These laws stipulate that the proposed disposal of dredged material into open water will not result in potential adverse environmental effects. To comply with Sections 103 and 404, the potentially harmful effects of the dredged material must be evaluated through chemical characterization, toxicity testing, and bioaccumulation testing prior to any dredging or disposal of material.

The USACE requested that Battelle/Marine Sciences Laboratory (MSL)[a] collect sediment and conduct chemical and biological evaluations under the guidelines established in Section 103. In June 1991, the MSL collected sediment cores (to a depth of -38 ft MLLW plus 2 ft overdepth) from 30 stations in Richmond Harbor. Sediments from 28 stations were sampled with the 12-in.-diameter core and combined into 7 composites (COMPs). These seven COMPs were subjected to physical/chemical evaluation and toxicological and bioaccumulation testing. Individual core samples from each of the 30 stations, collected with the 4-in.-diameter core, were geologically described and chemically analyzed. These 30 stations included the 28 samples taken with the 12-in.-diameter core plus sediment from 2 additional stations located in the Potrero Turning Circle. In addition to the dredged material samples, sediment from five reference stations and three control

(a) The Battelle/Marine Sciences Laboratory is part of the Pacific Northwest Laboratory, which is operated for the U.S. Department of Energy by Battelle Memorial Institute.

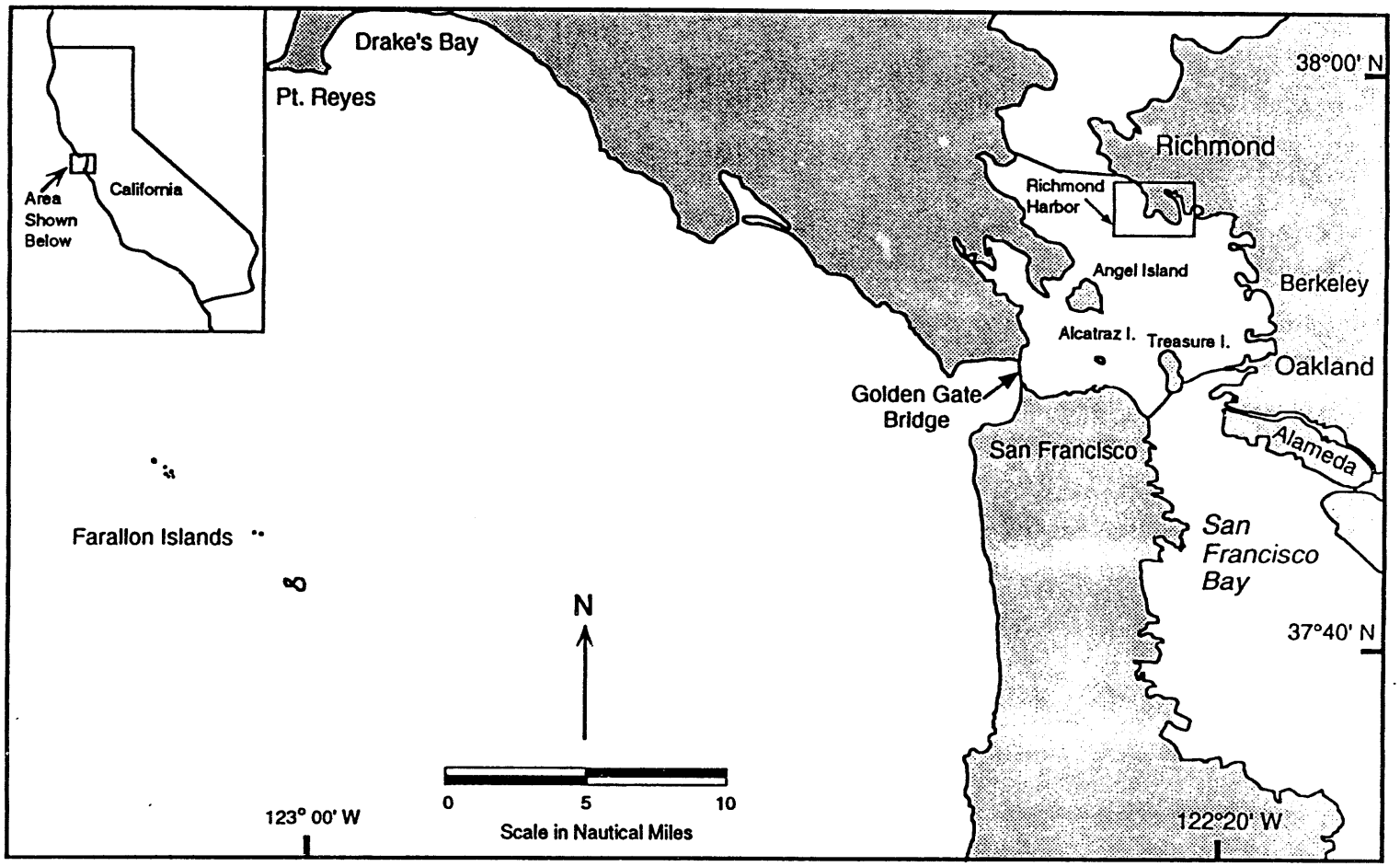


FIGURE 1.1. Overall View of San Francisco Bay and Richmond Harbor Study Area

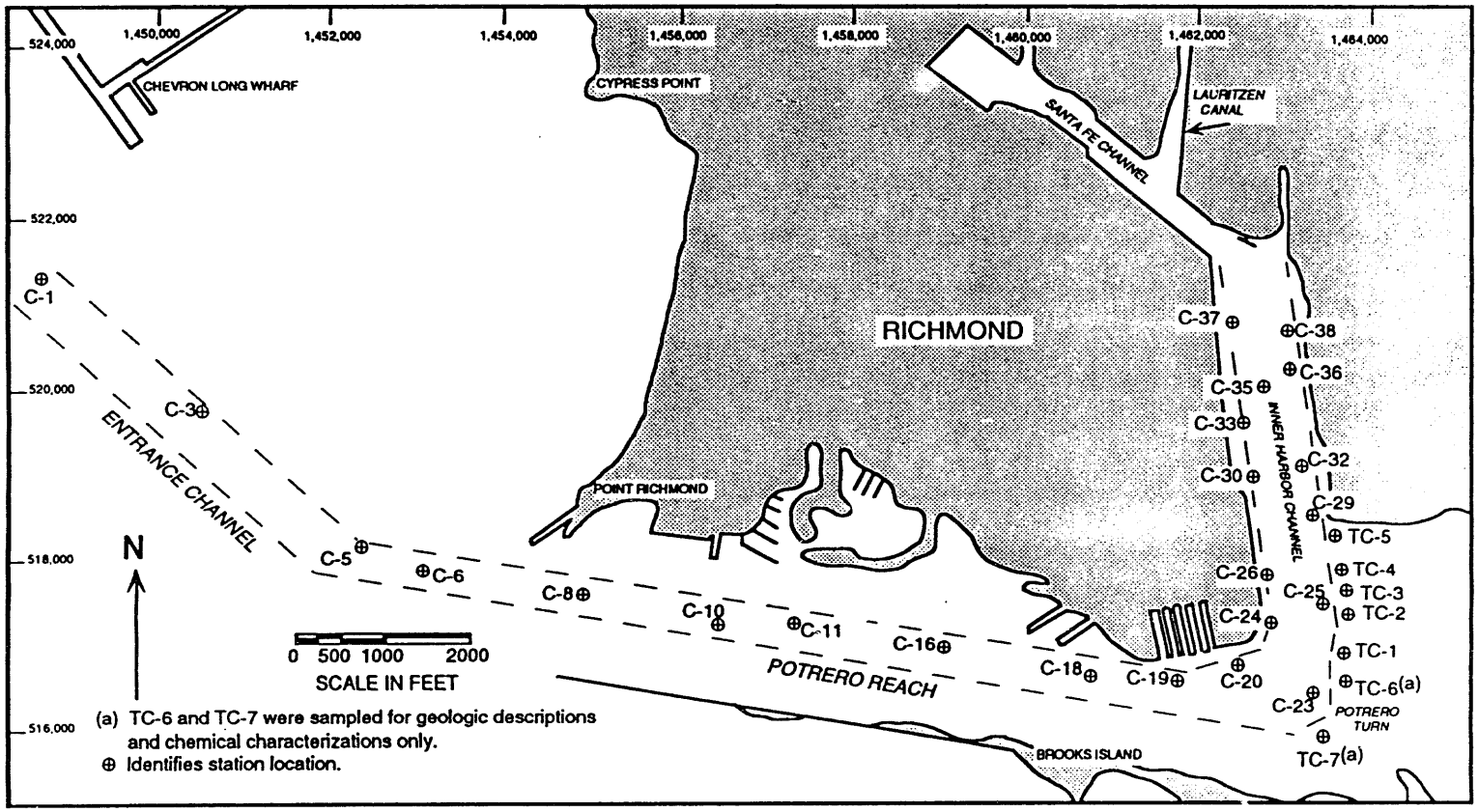


FIGURE 1.2. Location of Richmond Harbor Study Area

stations were collected with a pipe dredge or a Van Veen grab sampler and tested concurrently with the Richmond Harbor sediments. The reference stations allowed the biological responses and contaminant levels of a proposed dredged sediment sample to be compared to those at a potential disposal area that is "...substantially free of contaminants and which...reflects conditions that would exist in the vicinity of the disposal site had no dredged-material disposal ever occurred..." as stated in the *Evaluation of Dredged Material Proposed for Ocean Disposal* (EPA/USACE 1991), published jointly by the U.S. Environmental Protection Agency (EPA) and the USACE, hereinafter referred to as the *1991 Implementation Manual*. The control sediment allowed validation of test results through demonstration of adequate health and normal response of the test organisms to their native environment.

After field collection, sediments were shipped to the MSL to begin chemical analysis and toxicological testing. All testing done by the MSL followed the protocols in the *1991 Implementation Manual*. Chemical parameters included measurements of EPA priority pollutant metals, polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), chlorinated pesticides, butyltins, and conventional parameters (grain size, total organic carbon [TOC], total volatile solids [TVSs], oil and grease, and total petroleum hydrocarbons [TPHs]). The seven COMPs were evaluated in solid-phase, bioaccumulation, and suspended-particulate-phase (SPP) tests. Three species of marine organisms (the juvenile sanddab *Citharichthys stigmaeus*, the mysid *Holmesimysis sculpta*, and the larvae of the mussel *Mytilus edulis*) were used in SPP tests to evaluate water column effects of dredged material disposal. Three species of marine organisms (the polychaete *Nephtys caecoides*, the bentnose clam *Macoma nasuta*, and the amphipod *Rhepoxynius abronius*) were exposed to solid-phase testing. The 28-day exposure of *M. nasuta* and *N. caecoides* to the solid phase of the dredged material was used to measure the bioaccumulation potential of sediment-bound contaminants. The tissues of these organisms were also analyzed for the EPA priority pollutants and butyltins.

A designated disposal site was not identified at the time the testing and analysis were performed for the original Richmond Harbor Project. The toxicity and bioaccumulation results from the test treatments were statistically compared to all five reference sites by using Dunn's test (Dunn 1961). Physical, geological, and chemical characteristics of the test treatments were also compared to the five reference sediments. The results of these comparisons are presented in Pinza et al. (1992). In March 1993, the USACE requested the MSL to compare the Richmond Harbor sediment treatment data to three separate reference areas representing potential disposal areas. The toxicity and bioaccumulation results from the test sediments were statistically compared to each of the reference areas (i.e., those representing the potential disposal sites of the proposed dredged material from Richmond Harbor). The three potential disposal sites (Figures 1.3 through 1.5) that were identified by the USACE and the EPA are the Deep Off-Shelf Reference Area (R-OS), the Bay Farm Borrow Area (R-BF), and the Alcatraz Environs Reference

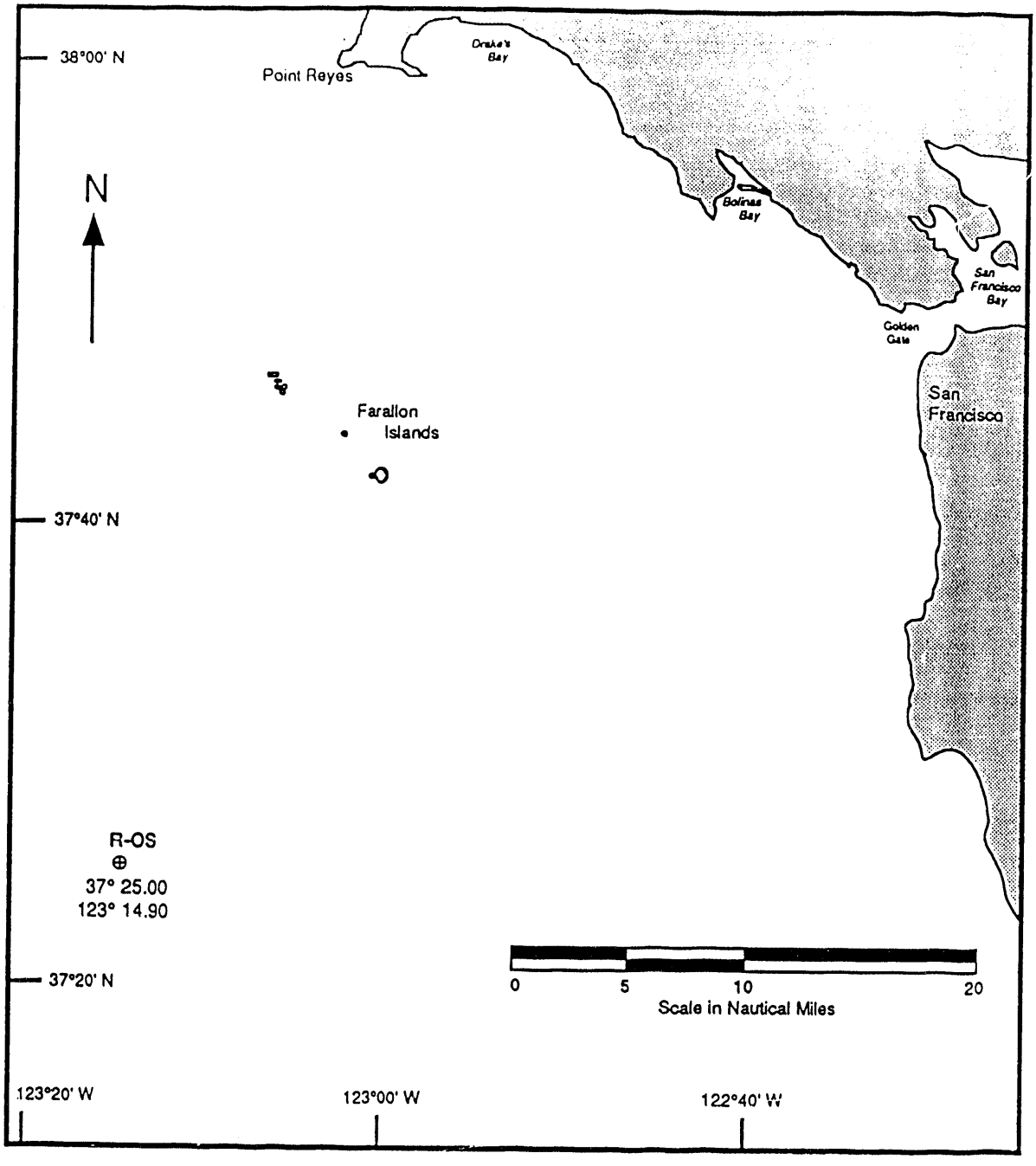


FIGURE 1.3. Location of Deep Off-Shelf Reference Area

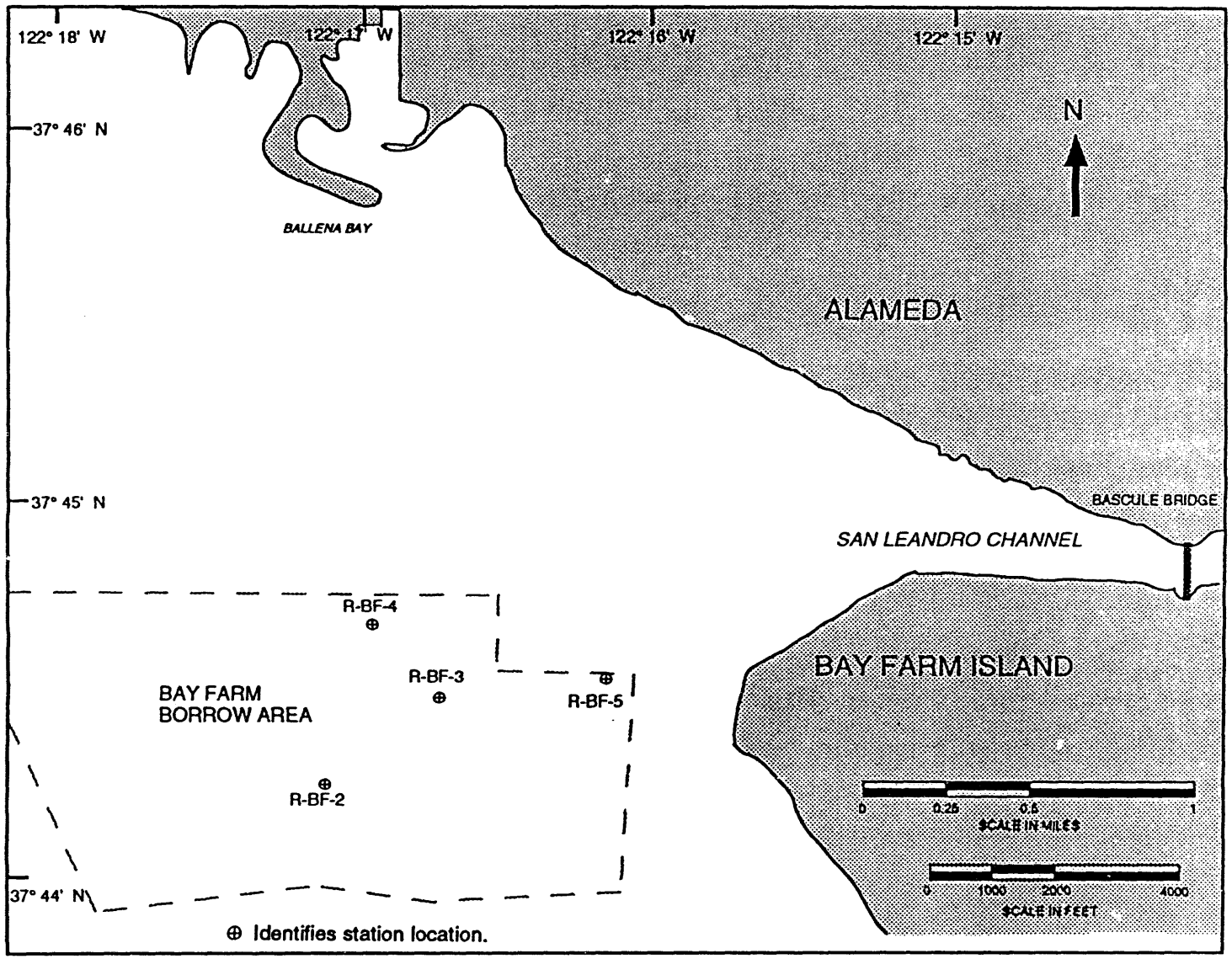


FIGURE 1.4. Location of Bay Farm Borrow Area

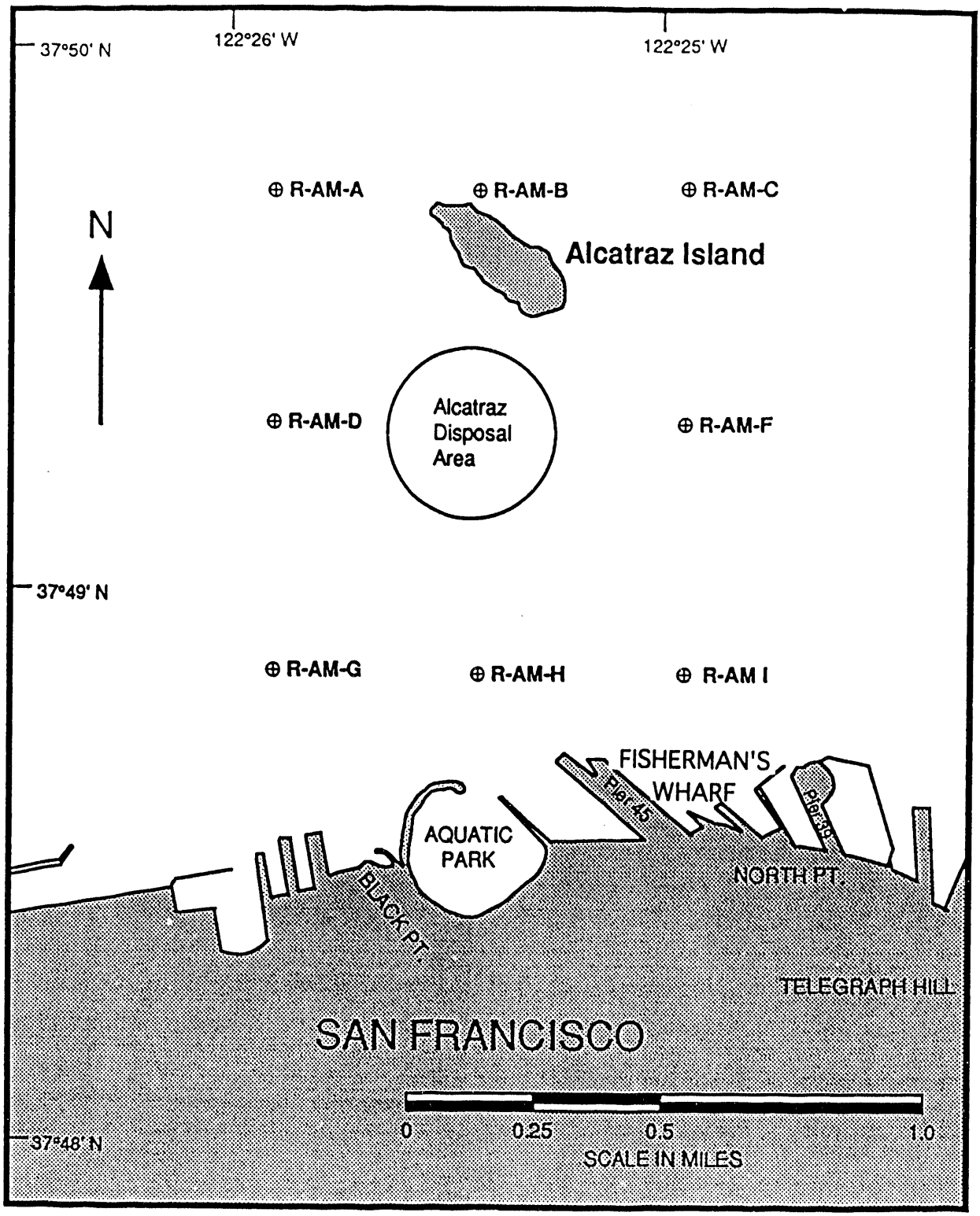


FIGURE 1.5. Location of Alcatraz Environs Reference Area

Area (R-AM). These three potential disposal sites received the same testing and analysis as the test treatments: sediment chemistry characterization, biological toxicity, and bioaccumulation testing.

In December 1992, the EPA released a *Draft Environmental Impact Statement (EIS) for San Francisco Bay Deep Water Dredged Material Disposal Site Designation* (EPA 1992) that described several offshore study areas and named three alternative ocean disposal sites. All three of the alternative sites are located off the continental slope (west of the continental shelf), approximately 50 nautical miles from the Golden Gate Bridge. Therefore, the focus of this report is the comparison of the Richmond Harbor test treatments with the Deep Off-Shelf Reference Area, because this area represents the best of the potential disposal sites. The Richmond Harbor test treatment data were also compared to the Bay Farm Borrow Area (R-BF) and the Alcatraz Environs Reference Area (R-AM). These comparisons are presented in Appendixes A and B, respectively.

This report provides information required to address potential ecological effects from the proposed disposal of Richmond Harbor sediment at two in-bay disposal sites or at the ocean disposal site. The report is divided into seven sections, including this introduction. Section 2.0 describes the materials and methods used for sample collection, processing, biological testing, physical and chemical analyses of sediments and tissues, types of data analysis specific for this report, and quality assurance requirements. Section 3.0 presents the results of geologic descriptions of the Richmond Harbor sediments. Section 4.0 contains the sediment chemistry results relative to reference sediment R-OS. Section 5.0 discusses the results of the toxicity testing relative to reference sediment R-OS. Section 6.0 includes the results of the bioaccumulation analysis of *M. nasuta* and *N. caecoides* tissues exposed to Richmond Harbor sediments relative to tissues exposed to reference sediment R-OS. Section 7.0 presents a discussion of the results and conclusions. Section 8.0 lists the literature cited in support of this report. Appendixes A and B evaluate the potential effects of the disposal of Richmond Harbor sediments at the Bay Farm Borrow Area or the Alcatraz Island Environs Reference Area, respectively.

2.0 MATERIALS AND METHODS

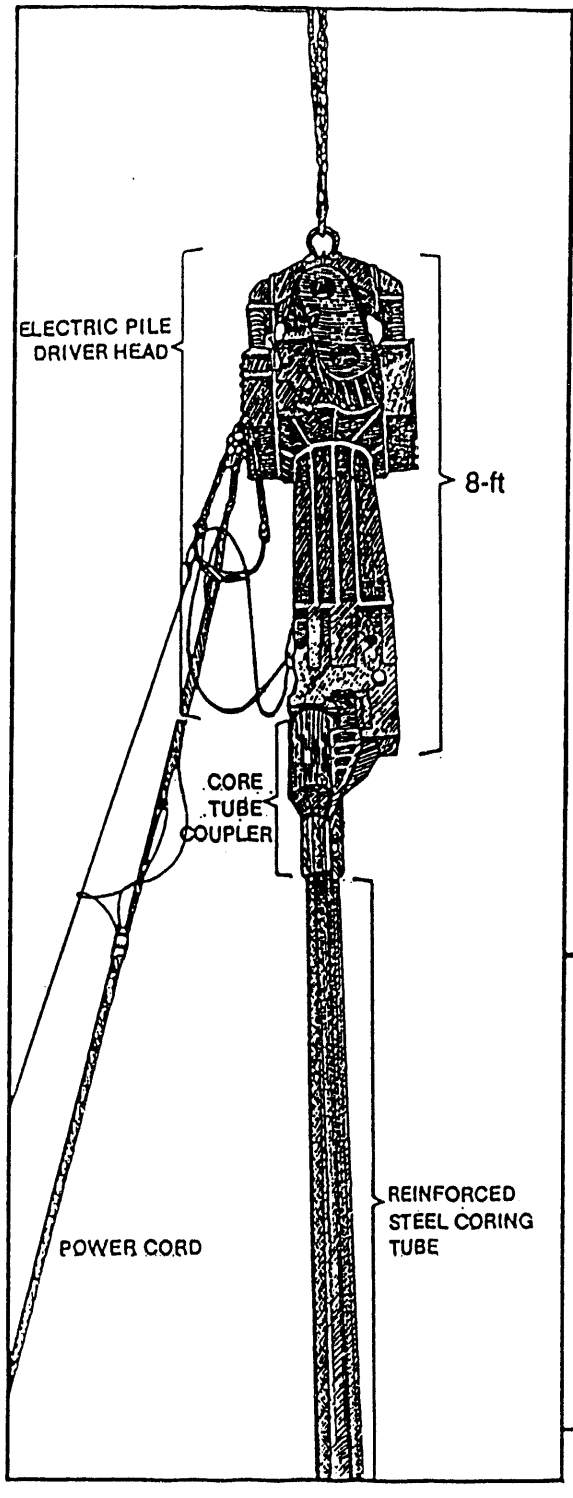
This section briefly describes the procedures used for sediment sampling, geologic descriptions, sample preparation and testing, and analysis and interpretation of data from the Richmond Harbor Project. The methods for data analysis used to compare the Richmond Harbor test treatment data to each of the reference areas (R-OS, R-BF, and R-AM) are described in detail. Specific field and laboratory procedures for the Richmond Harbor Project are presented in *Ecological Evaluation of Proposed Dredged Material from Richmond Harbor* (Pinza et al. 1992).

2.1 FIELD SAMPLING PROCEDURES

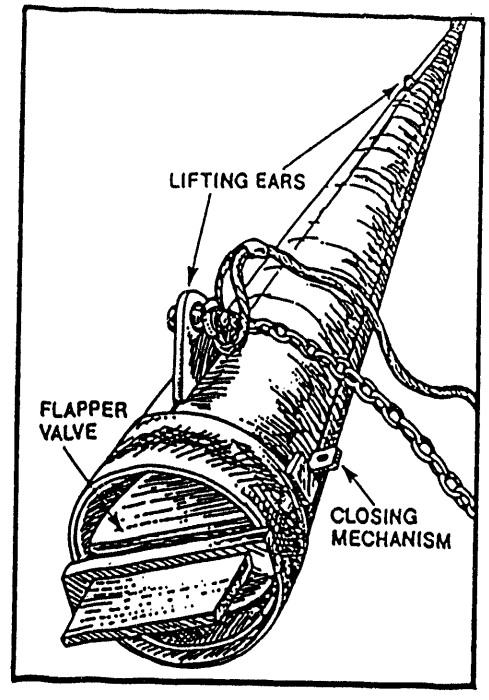
Sediment core samples were collected in June 1991 from 28 stations (12-in. core) and 30 stations (4-in. core) in Richmond Harbor using vibratory-hammer core samplers designed by MSL and Manson Construction, Richmond, California (Figure 2.1). The sediment samples were collected to -40 ft MLLW (38 ft plus 2 ft overdepth). Specific locations of sediment sampling stations were shown in Figure 1.2. The 12-in. core sampler was used to collect the large volume of sediment needed for biological testing while minimizing contamination caused by excessive sample handling. The 4-in. core sampler was used to collect sediment needed for geologic descriptions and chemical characterizations at each station. In addition to the test sediment samples, reference and control sediment samples were collected to provide a comparison for sediment chemistry and biological testing. The reference area sediment samples were collected using a pipe dredge sampler. Three control samples were collected using either an MSL-designed sand dredge, modified Van Veen grab sampler, or shovel and bucket.

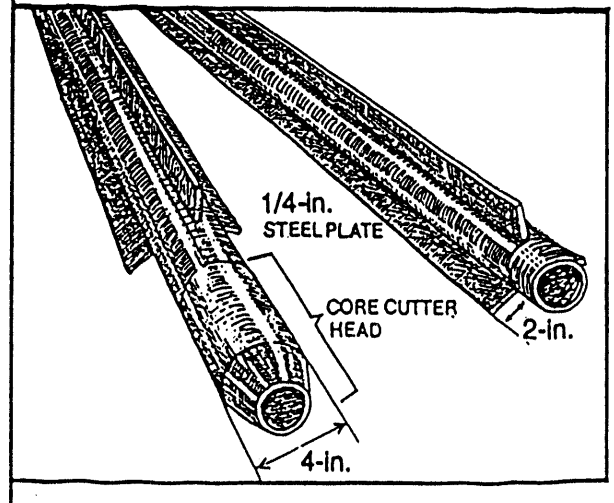
Navigation support for locating stations in Richmond Harbor was provided by Towill, Inc., Concord, California, and included a survey vessel and operator. The surveyors used a laser/range azimuth positioning system (EDM-Geodimeter AGA-120, Wild T-2, one-second theodolite). Towill also provided MLLW-corrected water depths at each station by measuring the actual depth with a recording fathometer, measuring the distance to the water surface elevation from a known elevation above sea level, and calculating the difference between the water surface elevation and 0-ft MLLW to provide for tidal heights at the time of sampling.

All stations were sampled to -40 ft MLLW using the 12- and 4-in. vibratory-hammer core samplers. The 12-in. core samples were taken at 28 stations and combined to form seven COMPs (COMPs I through VI) (Figure 2.2). The 4-in. core samples were collected from 30 stations and used for geologic description and sediment chemistry. The seven COMPs were also chemically analyzed and used for biological testing. The 4-in. cores were collected and stored in noncontaminating Lexan polycarbonate tubes that maintained the stratigraphic integrity



Vibratory-hammer Core





Core Cutter Head Assembly

FIGURE 2.1. Components of the 4- and 12-in. Vibratory-Hammer Coring Devices

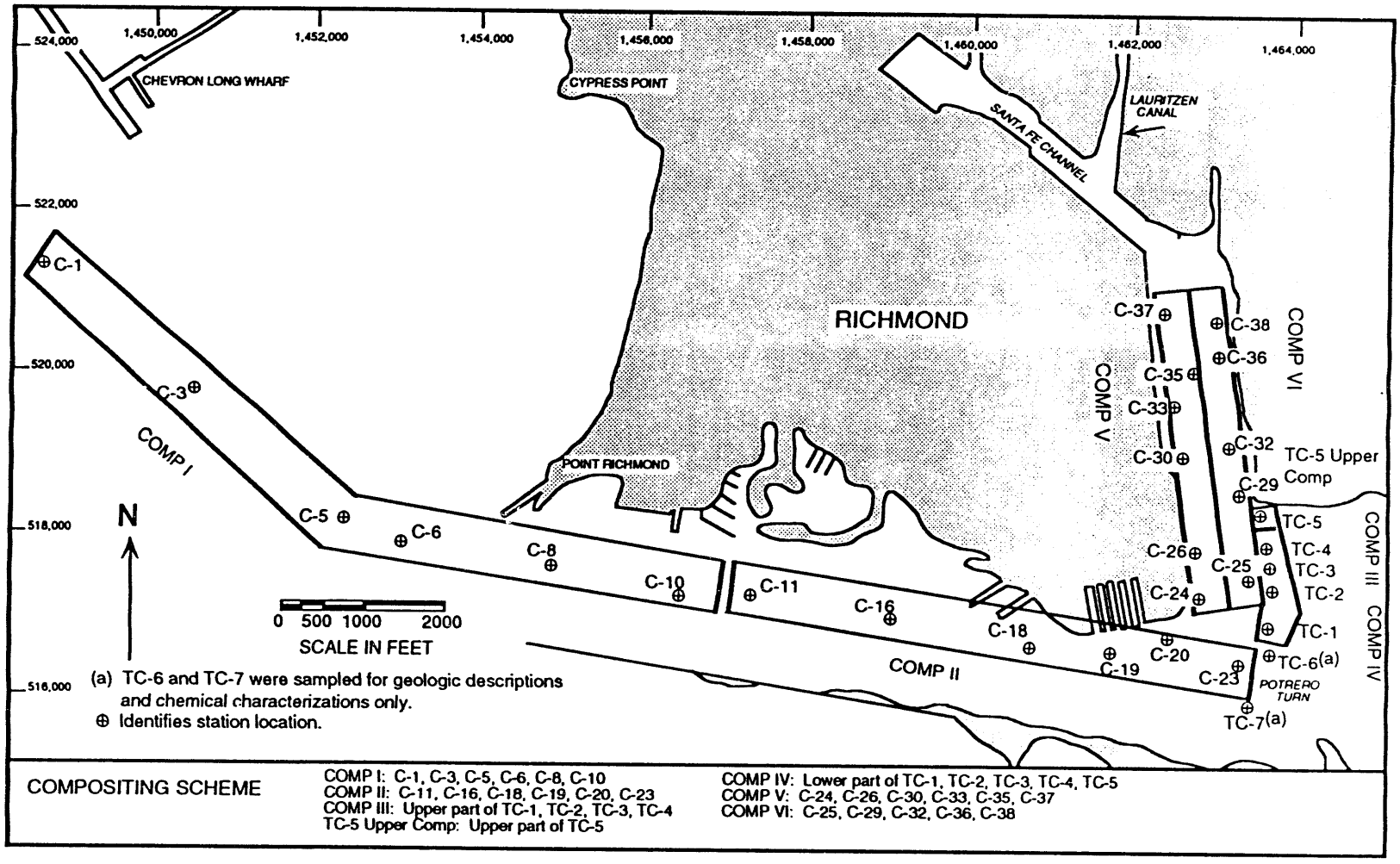


FIGURE 2.2. Compositing Scheme for Richmond Harbor Sediment Samples

of these sediments. This allowed a geologist to characterize the types of sediment at each station.

Both the 12- and 4-in. core samplers were deployed from the Manson Construction derrick barge Vasa. The coring apparatus was attached to an electric vibratory hammer and suspended by a crane on the derrick barge. When the coring apparatus was positioned directly above the sampling station, the core was lowered through the water to the sediment surface. For harder packed sediment, the vibratory hammer was engaged and driven through the sediment to project depth, as indicated by the water surface level relative to calibrations (ft) on the outside of the core barrel. For soft sediment, the weight of the coring apparatus caused penetration through the sediment without vibration. The coring apparatus was then extracted from the sediment, detached from the vibratory hammer, and lowered onto the barge deck.

As each 12-in. core was placed horizontally on deck, the hinged door of the core barrel was opened, and the sediment was measured from the mudline downward to ensure that appropriate depth was reached. If the required core length was achieved, the sediment was marked at -40 ft MLLW. If the required core length was not achieved, the sediment in the core barrel was removed and the core sampler rinsed with seawater to prepare for a second coring attempt.

Once the core segments were measured, the appropriate amount of sediment for chemical and biological analyses was transferred from the core barrel to an epoxy-coated container using a stainless-steel spade. Each sample container was labeled with the project name, station or composite designation, contributing station(s), total vertical segment of contributing core in feet, and the sampling date(s). The containers were sealed and kept cool (~4°C) in a freezer on board the sampling vessel until loaded into a refrigerated van at the end of the sampling day.

Sediment was also collected to -40 ft MLLW using the 4-in. core sampler. One core was collected per site. The core barrel was lined with a 3.125-in. (inner diameter) clear, steam-cleaned, Lexan core liner. When each core was brought on board, the liner was pulled from the barrel and the sediment was measured from the mudline downward to determine if appropriate depth (-40 ft MLLW) was reached. If the core achieved project depth, it was carefully carried to the cutting stand where it was capped, sealed, labeled, and if necessary, cut into shorter sections to fit in the freezer. If the required core length was not achieved, the sediment in the core barrel was emptied and the core sampler rinsed with seawater to prepare for a second coring attempt. Each core label included an arrow pointing to the top of the core, the station designation, core section indicator (e.g., Section 1 of 2, Section 2 of 2), length interval from the mudline (e.g., 0 to 3 ft), and sampling date. When each 4-in. core was labeled and sealed, it was kept at ~4°C in a freezer on board the sampling vessel.

Originally, COMPs III and IV were to be made from the appropriate sections of cores taken from the Potrero Reach Turning Circle and stations TC-1 through TC-5. COMP III was to comprise the upper sections of the 12-in. cores from stations TC-1 through TC-5 and COMP IV was to comprise the lower sections of those same 12-in. cores; the division between the two was based on grain-size characteristics. However, when the core sample from Station TC-5 was examined in the field, the upper section appeared different from the other turning circle stations. Consequently, this section was kept separate and given the designation TC-5 Upper Comp. Because of this, COMP III actually comprises the upper sections of the 12-in. cores from stations TC-1 through TC-4.

Detailed sampling records were maintained for each station. These included the station name, date, type of core (12 or 4 in.), replicate number, uncorrected water depth, tide height, corrected water depth, required core length, sampling time, total core collected, and comments. At the end of each sampling day, cores were off-loaded from the barge and stored in a refrigerated van at the staging area. An inventory form was maintained daily as the core samples were placed onto the refrigerated van for shipment to MSL. When sampling was completed, the inventory form was confirmed and recorded on the MSL chain-of-custody forms. The custody forms (three carbon copies) were signed by the field leader, who kept one copy and sealed the others with the core samples.

Sediment samples from the five reference areas were collected with a pipe dredge deployed from the FV Cobra, a charter boat owned and operated by Bob Smith Sportfishing, Richmond, California. Sampling locations were determined by LORAN C (Long-Range Aids to Navigation, C Edition), variable fix and range radar systems, and visible ranges. Reference sampling records were maintained in a log book and consisted of station position, date, time, replicate, water depth, sediment type, and comments. All reference samples were kept in labeled coolers on board the sampling vessel until they were off-loaded to the refrigerated van.

The control sediment sampling stations were located in Sequim Bay, Washington; West Beach, Whidbey Island, Washington; and Tomales Bay, California. The control sediment from Sequim Bay, Washington, was collected with a modified Van Veen grab sampler (0.1 m^2) deployed from an MSL research vessel. West Beach sediment and *R. abronius* were collected with a small, MSL-designed anchor-dredge sampler. Tomales Bay control sediment was collected with a shovel by Brezina and Associates, Dillon Beach, California, concurrently with the test organism *N. caecoides*. The test organisms *M. nasuta*, *C. stigmaeus*, *H. sculpta*, and *M. edulis* were obtained by commercial supplies and sent to MSL for toxicity testing.

2.2 GEOLOGIC DESCRIPTION OF CORES

A geologic characterization of each Richmond Harbor sampling station was conducted by an MSL geologist on the 4-in. Lexan-lined core. The Lexan core tube maintains the stratigraphic integrity of the sediment. All core sections from one station were removed from storage, and the Lexan tube was cut longitudinally to split the core open to expose the sediment stratigraphy. The geologist measured and described the entire core from mudline to bottom, recording data on a core data log. The geologic characterization protocol was consistent with American Society for Testing and Materials (ASTM) Procedure D2488-84 (ASTM 1984). Sediment characteristics that were logged include dilatancy of silt/clay, toughness of silt/clay, plasticity of silt/clay, sediment type (engineering classification), color, consistency, cementation, sedimentary structure, reaction with hydrochloric acid, maximum particle size, and odor. In addition, any other diagnostic features, such as the presence of root traces, mollusk shells, and/or related detritus, were noted.

2.3 SEDIMENT SAMPLE PREPARATION

All sediment samples were shipped via refrigerated van or overnight courier service to the MSL in Sequim, Washington, where they were stored at 4° ± 2°C until processing. Sediment from reference and control areas was screened through a 0.5-mm sieve prior to mixing. The dredged material composited for testing was not sieved. All sediment used for chemical analysis and biological testing was thoroughly mixed using either stainless-steel utensils or epoxy-coated mixers until the sediment texture and color were consistent within the sample or composite. Once a sediment sample was thoroughly homogenized, it was referred to as a sediment treatment, indicating that all the necessary sample processing was completed and the sediment could be chemically analyzed and used in testing. Sample aliquots for chemical analyses were placed in clean, labeled containers appropriate for the parameters to be measured. Sample processing occurred within 14 days of the sample collection, as stated in the *1991 Implementation Manual.*

Table 2.1 summarizes the sample preparation and testing scheme for each Richmond Harbor sediment treatment and the reference and control sediments. This summary includes sample compositing strategy and the types of testing conducted with each sample.

2.4 DATA ANALYSIS AND INTERPRETATION

Several statistical analyses were conducted to determine the magnitude and significance of toxicity and bioaccumulation in test treatments relative to reference sediments. Each statistical test is based on a completely random design that allows unbiased comparison between treatments. In the Richmond Harbor report (Pinza et al. 1992), the toxicity and bioaccumulation results from the test treatments were statistically compared to all five reference areas by using Dunn's test because an appropriate disposal site was not identified. In March 1993, the USACE

TABLE 2.1. Summary of Sediment Compositing Strategy, Sample Preparation, and Testing

Sediment Treatment	Mudline (-ft MLLW)	Description	Sediment Chemistry	Solid-Phase Testing	Suspended-Particulate-Phase Testing
COMP I	NA[a]	Mudline to -40 ft MLLW from 12-in. core sections of C-1, C-3, C-5, C-6, C-8, C-10	YES	YES	YES
C-1	36.4	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-3	36.0	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-5	36.4	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-6	36.3	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-8	36.4	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-10	36.0	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
COMP II	NA	Mudline to -40 ft MLLW from 12-in. core sections of C-11, C-16, C-18, C-19, C-20, C-23	YES	YES	YES
C-11	37.3	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-16	36.2	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-18	36.1	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-19	35.9	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-20	36.2	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-23	32.8	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
COMP III	NA	Taken from upper 12-in. core sections of TC-1, TC-2, TC-3, TC-4	YES	YES	YES
TC-1 Upper	11.3	Mudline to -21.3 ft MLLW from 4-in. core	YES	NO	NO
TC-2 Upper	11.5	Mudline to -15.3 ft MLLW from 4-in. core	YES	NO	NO
TC-3 Upper	8.5	Mudline to -24.3 ft MLLW from 4-in. core	YES	NO	NO
TC-4 Upper	6.2	Mudline to -17.0 ft MLLW from 4-in. core	YES	NO	NO
TC-5 Upper Comp	NA	Upper Comp taken from mudline to -36.5 ft MLLW of a 12-in. core	YES	YES	YES
TC-5 Upper	21.9	Mudline to -34.0 ft MLLW from 4-in. core	YES	NO	NO
TC-5 Special Sample	NA	Sample taken from -30.2 ft to -32.7 ft MLLW of a 4-in. core	YES	NO	NO
COMP IV	NA	Taken from lower 12-in. core sections of TC-1, TC-2, TC-3, TC-4, TC-5	YES	YES	YES
TC-1 Lower	11.3	-21.3 ft to -36.5 ft MLLW from 4-in. core	YES	NO	NO
TC-2 Lower	11.5	-15.3 ft to -32.1 ft MLLW from 4-in. core	YES	NO	NO
TC-3 Lower	8.5	-24.3 ft to -34.3 ft MLLW from 4-in. core	YES	NO	NO
TC-4 Lower	6.2	-17.0 ft to -38.8 ft MLLW from 4-in. core	YES	NO	NO
TC-5 Lower	21.9	-36.5 ft to -39.6 ft MLLW from 4-in. core	YES	NO	NO
COMP V	NA	Mudline to -40 ft MLLW from 12-in. cores from C-24, C-26, C-30, C-33, C-35, C-37	YES	YES	YES
C-24	36.0	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-26	36.1	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-30	35.3	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-33	35.0	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-35	36.2	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-37	36.1	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO

TABLE 2.1. contd

Sediment Treatment	Mudline (-ft MLLW)	Description	Sediment Chemistry	Solid-Phase Testing	Suspended-Particulate-Phase Testing
COMP VI	NA	Mudline to -40 ft MLLW from 12-in. cores from C-25, C-29, C-32, C-36, C-38	YES	YES	YES
C-25	35.0	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-29	35.0	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-32	35.3	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-36	36.1	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
C-38	36.1	Mudline to -40 ft MLLW from 4-in. core	YES	NO	NO
TC-6 (1)	6.0	Mudline to -9.0 ft MLLW from 4-in. core	YES	NO	NO
TC-6 (2)	9.0	Mudline to -32.0 ft MLLW from 4-in. core	YES	NO	NO
TC-6 (3)	32.0	Mudline to -33.5 ft MLLW from 4-in. core	YES	NO	NO
TC-6 (4)	33.5	Mudline to -40.0 ft MLLW from 4-in. core	YES	NO	NO
TC-7 (1)	11.0	Mudline to -21.0 ft MLLW from 4-in. core	YES	NO	NO
TC-7 (2)	21.0	Mudline to -33.0 ft MLLW from 4-in. core	YES	NO	NO
TC-7 (3)	33.0	Mudline to -34.7 ft MLLW from 4-in. core	YES	NO	NO
TC-7 (4)	34.7	Mudline to -40.0 ft MLLW from 4-in. core	YES	NO	NO
R-AM	NA	Alcatraz Environs Reference Area	YES	YES	NO
R-BF	NA	Bay Farm Borrow Area	YES	YES	NO
R-OS	NA	Deep Off-Shelf Reference Area	YES	YES	NO
C-SB	NA	Sequim Bay control	YES	YES	NO
C-WB	NA	*R. abronius* native control (West Beach)	YES	YES	NO
C-NE	NA	*N. caecoides* native control (Tomales Bay)	YES	YES	NO

(a) NA Not applicable.

requested the MSL to compare the Richmond Harbor sediment treatment data to three separate reference areas (R-OS, R-BF, and R-AM) for the toxicity and bioaccumulation data using Dunnett's test (Dunnett 1964) at $\alpha = 0.05$. The *1991 Implementation Manual* recommends Dunnett's test for comparing test treatments to a single reference sediment. In the statistical comparison to one particular reference area, the data for the other reference areas were omitted from the data set. Such testing of nonindependent data increases the experiment-wise error rate. However, the errors are the identification of differences as statistically significant when they are not, and this approach is environmentally more conservative because more treatments are identified as significantly different from the reference sediment. The data were analyzed as requested, but it must be noted that it is possible to avoid statistical errors by comparing the data to all reference sediments at one time, maintaining the experiment-wise error rate, in a statistical test such as Tukey's Honestly Significant Difference test (Kramer 1956) or Dunn's test.

Solid-phase toxicity of all sediment treatments was compared by analysis of variance (ANOVA) tests on the arcsine square root of the proportion of organisms surviving the test. The arcsine square-root transformation stabilizes the within-class variances to meet the assumptions of the ANOVA. All treatments were compared to a particular reference area using Dunnett's test at $\alpha = 0.05$. Toxicity of a test treatment was considered statistically significantly different if it was statistically different from the reference sediment and if the survival in the treatment was ≥10% lower than the reference sediment for the test organism (20% lower than reference for *R. abronius*).

The results of SPP toxicity tests are used to determine compliance with water quality criteria during open-water disposal of dredged material. The data are compared to control seawater that represents the water column above a potential disposal site in the absence of dredged material disposal. Because SPP tests are a measure of water column effects, comparison to reference sediment is not appropriate. Two statistical tests are presented in the *1991 Implementation Manual* for the interpretation of SPP tests. The first test is a one-sided t-test between survival in control replicates and survival in the 100% SPP replicates. This test is performed only when survival in the 100% SPP is less than control (0% SPP) survival and when control survival is greater than 90% (70% *M. edulis* test), indicating test validity. Prior to conducting the t-test, angular transformation (arcsine of the square root) of the proportion surviving in test replicates is performed to reduce possible heterogeneity of variance between control and 100% SPP mean survivals. The second test required by the *1991 Implementation Manual* is an LC50 calculation, the concentration of SPP that is lethal to 50% of the individuals tested. The LC50 values for these tests were calculated using the Trimmed Spearman-Karber method (Hamilton et al. 1977). The Spearman-Karber estimator is appropriate only if there is increasing mortality with increasing concentration and if 50% or greater mortality is observed in test solutions when normalized to control survival. If 50% mortality does not occur in the 100% SPP dilutions for any treatments, then LC50 values are reported as >100% SPP. The same method was used to calculate EC50 values (the concentration where 50% of the test individuals show a certain effect) for the bivalve SPP test and LC50 values for all reference toxicant tests.

The test species *M. nasuta* and *N. caecoides* were exposed to the Richmond Harbor test treatments and the reference sediments and then the tissues were chemically analyzed for potential contaminants of concern. Before statistical analysis of *M. nasuta* and *N. caecoides* tissue concentrations, a visual inspection of the tissue chemistry data was performed. If visual inspection showed that a compound was undetected in all of the replicate samples in a test treatment or that the mean tissue concentration in the reference sediments was greater than that in the test treatments, no further analysis was performed. If the detected concentration of a compound exceeded that of any reference sediments, statistical analysis was performed. In all cases, detection limits were used in numerical calculations when a compound was undetected.

If contaminants of concern were detected, the test treatments were compared to each of the reference sediments using ANOVA and Dunnett's test for comparison of all means. Analytical detection limit values were used for replicates where the compound was not detected. If all replicates of a test treatment were flagged with U (analyte was not present above the level of associated value) or J (analyte detected below the method detection limits [MDL] but above the instrument detection limit [IDL] qualifications by the analytical laboratory), the treatment was not analyzed. Dunnett's test identifies treatment mean concentrations that are statistically significantly greater than the reference sediment mean concentrations. In addition to statistically significant bioaccumulation, the magnitude of the difference between mean contaminant concentrations found in the test treatment tissues and the mean concentrations found in the tissues exposed to each of the reference areas was reported. As discussed earlier, the likelihood of statistical error is increased by comparing the Richmond Harbor sediment treatment data to each of the reference areas separately using Dunnett's test.

3.0 GEOLOGY

This section provides a description of the geology of the Richmond Harbor sediment based on the characterization of 30 sediment cores collected June 17 through 20, 1991. The core samples were geologically described according to ASTM Procedure D2488-84: *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)* (ASTM 1984). The following sediment characteristics were logged: dry strength of silt/clay, dilatancy of silt/clay, toughness of silt/clay, plasticity of silt/clay, sediment type (i.e., engineering classification), color, consistency (i.e., firmness), cementation, sedimentary structure, reaction with hydrochloric acid, maximum particle size, and odor. In addition, other diagnostic features, such as the presence of root traces, mollusk shells, and/or related detritus, were noted. For detailed description of the materials and methods used for describing the sediment cores see Appendixes A and B in *Ecological Evaluation of Proposed Dredged Material from Richmond Harbor* (Pinza et al. 1992).

Two geologic units were identified in the Richmond Harbor Project area: older bay mud (OBM) and younger bay mud (YBM) (USACE 1975). The firm to hard OBM sediments include both estuarine and terrestrial deposits; the soft, dark YBM sediments are marine deposits. The OBM and YBM are distinguished from each other on the basis of consistency and color. The OBM sediments are firm to hard in consistency and are various shades of red, brown, yellow, or gray; whereas the YBM sediments are generally very soft in consistency and dark gray to black in color. The OBM and YBM are described in detail below.

In the Richmond Harbor Project area, the OBM is composed primarily of estuarine deposits of clay to silty or sandy clay with occasional lenses and thin beds of sand. The OBM sediments are firm to hard in consistency, brown or gray in color, and have no odor. Traces of organic matter were observed in 10 cores. Figures 3.1 displays the estimated YBM/OBM boundary in the Richmond Harbor sediment treatments C-1 through C-38 and TC-1 through TC-7. The range of mudline depths and the YBM/OBM boundary for each sediment treatment are listed in Table 3.1. Four to 6 ft of silty sand were encountered at -32 ft MLLW in cores from turning basin stations TC-1 through TC-4. The sand unit was green to brown in color, contained rounded and angular pebbles, and exhibited stratification and graded bedding. Nodules of calcium carbonate were observed in samples from stations C-29, C-32, C-35, C-36, C-38, and TC-3, which are all located within the Inner Harbor Channel. Nodules of iron oxide were observed in samples from stations C-18, C-19, C-25, C-37, TC-1, TC-2, and TC-4, which are located in the Potrero Reach (and the proposed turning basin). These iron oxide areas appear to have experienced postdepositional subaerial alteration.

Shells and shell fragments were commonly observed in YBM sediments, and a concentrated layer of oyster shells was identified at stations TC-3 and TC-4 at approximately

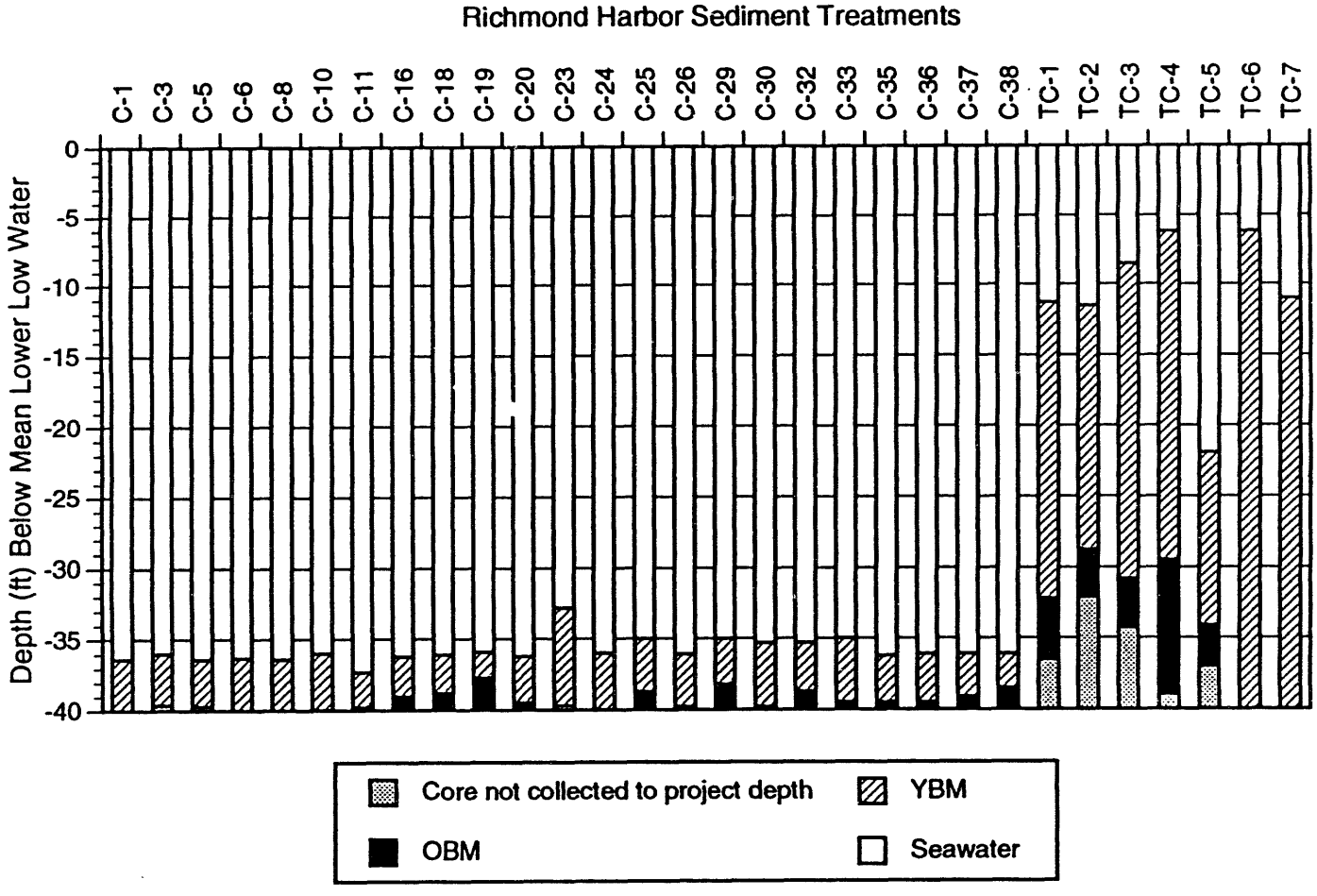


FIGURE 3.1. Estimated YBM/OBM Boundary for Richmond Harbor Sediment Treatments C-1 Through C-38 and TC-1 Through TC-7

TABLE 3.1. Summary of Geologic Descriptions

Sediment Treatment	Mudline (-ft MLLW)	Sediment Thickness (ft) YBM[a]	OBM[b]	Physical Description (to -40 ft MLLW)
C-1	36.4	4.2	0.0	Clayey sand with shell fragments
C-3	36.0	3.6	0.0	Silty clay
C-5	36.4	3.3	0.0	Silty clay with sand
C-6	36.3	4.7	0.0	Clayey sand with gravelly sand
C-8	36.4	5.5	0.0	Silts and fine sands; clay
C-10	36.0	4.6	0.0	Silts and fine sands; clay; silty sands
C-11	37.3	2.5	0.0	Clayey sand
C-16	36.2	2.8	1.9	YBM clay; OBM clayey sand
C-18	36.1	2.7	1.6	YBM clayey sand; OBM clay with silts
C-19	35.9	1.8	3.2	YBM clayey sand; OBM sandy clays
C-20	36.2	3.3	1.0	YBM clayey sand; OBM sandy silt
C-23	32.8	6.9	0.0	High-plasticity clay
C-24	36.0	4.3	0.0	Clayey sand
C-25	35.0	3.7	1.6	YBM clay; OBM clay with iron oxides
C-26	36.1	3.7	0.8	YBM clay; OBM clayey sand
C-29	35.0	3.2	7.3	YBM clay; OBM high-plasticity clay
C-30	35.3	4.5	0.2	YBM clay; OBM clayey sand
C-32	35.3	3.4	2.1	YBM clay; OBM high-plasticity clay
C-33	35.0	4.5	5.9	YBM clay; OBM high-plasticity clay
C-35	36.2	3.3	1.7	YBM clay; OBM high-plasticity clay
C-36	36.1	3.4	1.4	YBM clay; OBM high-plasticity clay
C-37	36.1	3.0	1.9	YBM clay; OBM clay with silty sands
C-38	36.1	2.4	2.5	YBM clay; OBM high-plasticity clay
TC-1	11.3	20.9	4.3	YBM clay; OBM clayey sands
TC-2	11.5	17.3	3.3	YBM clay; OBM high-plasticity clay
TC-3	8.5	22.3	3.5	YBM clay; OBM clay with gravelly sands
TC-4	6.2	23.3	9.5	YBM clay; OBM gravelly sands
TC-5	21.9	12.2	2.9	YBM clay; OBM clay
TC-6	6.2	38.8	0.0	High-plasticity clays
TC-7	11.0	29.5	0.0	High-plasticity clays

(a) YBM Younger bay mud.
(b) OBM Older bay mud.

-20 ft MLLW. A layer of silty to gravelly sand was identified at stations C-6 and C-10 at approximately -40 ft MLLW. The sand layer contains shells and was laminated or cross-laminated at station TC-6, consistent with deposition in a deltaic environment. The thickness and extent of the sand layer are unknown.

The USACE (1975) subdivided the YBM into a semi-consolidated bay mud member overlain by a soft bay mud member. The firmness of the YBM unit increases slightly with depth, probably as a result of compaction beneath the weight of overlying sediment. The primary unit identified at the Richmond Harbor area is the soft bay mud member; however, the semi-consolidated bay mud member was tentatively identified at stations TC-2 and TC-3.

4.0 SEDIMENT CHEMISTRY

Forty-two individual sediment samples and seven COMPs were analyzed for physical and chemical parameters. The parameters measured included grain size, TOC, TVS, oil and grease, TPH, PAHs, pesticides, PCBs, metals, and butyltins. Sediment chemistry results are reported in dry weight and complete chemistry results and quality control information are presented in Appendix C of *Ecological Evaluation of Proposed Dredged Material from Richmond Harbor* (Pinza et al. 1992).

4.1 CONVENTIONAL SEDIMENT MEASUREMENTS

Conventional sediment measurements include grain size, TOC, TVS, oil and grease, and TPH. Grain size, TOC, and TVS are expressed as a percent of the sample dry weight. Oil and grease and TPH concentrations are expressed as mg/kg dry weight. A summary of sediment conventional measurements is shown in Table 4.1. The number of test treatments (no replicate samples) with concentrations exceeding those found in reference sediment R-OS are noted and consist of 42 individual sediment samples and 7 COMPs for a total of 49 test treatments.

Richmond Harbor grain size results are presented in Table 4.1 and Figure 4.1. The majority of stations contained fine-grained sediments, with ≥50% belonging to the silt and clay fractions. The grain size distribution of sediment in COMPs I, II, III, V, and VI represented a mixture of OBM and YBM in their respective stations. COMP IV primarily represented the deeper OBM unit and contained equal amounts of sand, silt, and clay. Station TC-2, which was composited with other TC stations to make COMP IV, was predominantly silt and clay (the sand layer began at -36 ft MLLW). The specific length and placement of the sand layer are depicted in the core logs in Appendix B of Pinza et al. (1992). Reference sediment R-OS was primarily fine grained, with 16% sand and 84% silt and clay.

Individual stations TC-6 and TC-7 represented core lengths of 39 and 35 ft, respectively. Each core was divided into four sections based on grain size characteristics. Sections (1), (2), and (4) at both stations were categorized as silt and/or clay, while section (3) consisted of a layer of sand and mollusk shells.

The concentrations of TOC (Table 4.1 and Figure 4.2) in the test treatments ranged from 0.15% dry weight in TC-6(3) to 1.18% dry weight in C-8. Reference sediment R-OS had the highest concentration of TOC at 1.44% dry weight. The test treatments with the higher TOC values were also predominantly fine grained.

The concentrations of TVS (Table 4.1 and Figure 4.3) in the test treatments ranged from 1.53% dry weight in TC-6(3) to 6.55% dry weight in C-8. Ten test treatments had higher concentrations of TVS than the reference sediment R-OS (5.74% dry weight). The same pattern

TABLE 4.1. Conventional Sediment Measurement Results (grain size, total organic carbon, and total volatile solids in percent dry weight; oil and grease and total petroleum hydrocarbons in mg/kg dry weight)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
COMP I	0	9	45	46	0.99	6.10	63.22	41.39
C-1	0	23	42	35	0.80	4.75	91.26	68.41
C-3	0	12	44	44	0.93	5.52	89.17	65.03
C-5	0	5	51	44	1.01	5.68	144.92	92.66
C-6	0	4	46	50	1.09	6.12	108.89	88.21
C-8	0	1	41	58	1.18	6.55	132.45	104.76
C-10	0	4	45	51	1.08	5.90	151.75	115.92
COMP II	0	8	44	48	0.73	5.49	118.30	91.00
C-11	0	1	41	58	1.14	6.46	99.86	76.06
C-16	0	25	34	41	0.59	3.98	93.04	74.71
C-18	3	13	39	45	0.81	4.73	124.58	95.91
C-19	0	20	49	31	0.28	3.38	42.91	27.30
C-20	7	28	29	36	0.67	4.66	103.58	78.82
C-23	0	3	45	52	0.74	4.54	68.91	46.08
COMP III	2	11	54	33	0.68	3.65	44.06	26.74
TC-1 Upper	0	3	57	40	0.79	3.96	90.29	34.60
TC-2 Upper	0	8	49	43	0.90	5.19	132.78	79.16
TC-3 Upper	0	6	65	29	0.59	3.03	37.83	19.54
TC-4 Upper	5	12	57	26	0.54	2.87	73.52	16.77
TC-5 Upper Comp	0	10	43	47	0.91	5.00	311.19	281.16
TC-5 Upper Rep 1	0	8	45	47	0.93	5.14	297.24	256.11
TC-5 Upper Rep 2	0	8	44	48	0.94	5.09	230.74	189.60
TC-5 Upper Rep 3	0	8	43	49	0.96	5.09	418.34	350.10
TC-5 Special Sample	0	5	45	50	1.07	5.65	18.83	10.99

TABLE 4.1. (contd)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
COMP IV	3	26	43	28	0.39	3.32	19.06	10.50
TC-1 Lower	7	21	39	33	0.43	3.00	9.80	5.67
TC-1 Lower Dup	NM[a]	NM	NM	NM	0.42	NM	NM	NM
TC-2 Lower	3	9	47	41	0.60	3.45	24.30	13.27
TC-3 Lower	12	48	22	18	0.26	2.07	13.03	8.58
TC-3 Lower Dup	NM	NM	NM	NM	0.28	NM	NM	NM
TC-4 Lower	3	30	40	27	0.25	2.22	14.14	8.10
TC-5 Lower	3	30	39	28	0.41	2.50	24.65	7.79
COMP V	1	2	34	63	1.08	6.38	186.23	141.25
C-24	0	2	39	59	0.79	4.96	76.55	54.99
C-26	1	6	37	56	1.01	5.93	138.15	107.13
C-30	0	3	38	59	1.06	6.26	218.95	174.70
C-30 Dup	NM	NM	NM	NM	1.06	NM	NM	NM
C-33	0	3	37	60	0.92	6.06	100.39	83.05
C-35	0	5	41	54	0.84	5.52	151.47	119.79
C-37	0	16	41	43	0.60	4.77	263.31	150.44
COMP VI	0	3	36	61	1.03	6.52	252.06	185.70
C-25	0	16	41	43	0.49	4.06	76.89	63.25
C-29	0	6	51	43	0.57	4.61	91.93	72.97
C-29 Dup	NM	NM	NM	NM	0.59	NM	NM	NM
C-32	0	2	54	44	0.60	4.74	167.80	140.78
C-32 Dup	NM	NM	NM	NM	0.60	NM	NM	NM
C-36	0	5	40	55	0.89	5.62	223.76	180.06
C-38	1	6	45	48	0.59	4.65	118.09	101.70
TC-6 (1)	2	11	50	37	0.79	4.48	37.60	25.13
TC-6 (2)	0	3	61	36	0.71	3.56	27.74	14.43
TC-6 (3)	1	77	11	11	0.15	1.53	5.64	2.63
TC-6 (4)	0	10	45	45	0.56	3.50	15.57	9.01

TABLE 4.1. (contd)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
TC-7 (1)	0	3	60	37	0.81	3.63	27.50	24.48
TC-7 (2)	0	2	59	39	0.72	3.62	62.33	20.42
TC-7 (3)	0	67	18	15	0.23	1.68	6.50	5.68
TC-7 (4)	0	14	45	41	0.54	3.33	16.87	15.21
R-OS	0	16	62	22	1.44[b]	5.74	39.26	17.09

(a) NM Not measured.
(b) Mean of replicate values.

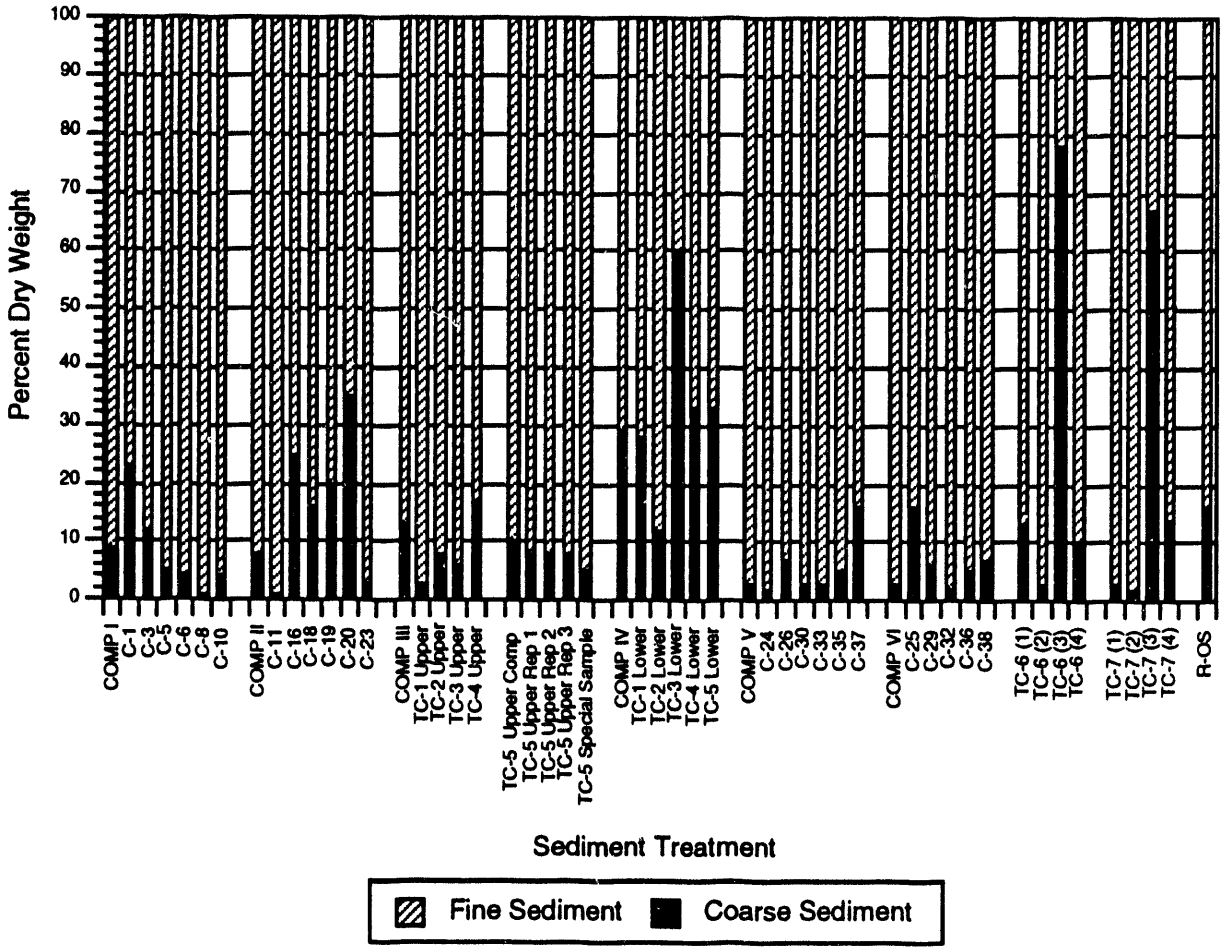


FIGURE 4.1. Grain Size Distribution in Sediment Treatments

observed between fine-grained sediments and TOC was applicable to fine-grained sediments and TVS. Sediment treatments with higher TVS values come from fine-grained sediment stations.

Oil and grease and TPH concentrations are shown in Table 4.1 and Figures 4.4 and 4.5. Oil and grease concentrations in the test treatments ranged from 5.6 mg/kg dry weight at TC-6(3) to 418.34 mg/kg dry weight at TC-5 Upper Rep 3. Thirty-six of the 49 test treatments had higher concentrations of oil and grease than reference sediment R-OS (39.3 mg/kg dry weight). The concentrations of TPH in the test treatments ranged from 2.6 mg/kg at TC-6(3) to 350.1 mg/kg at TC-5 Upper Rep. 3. Thirty-eight of the 49 test treatments had higher concentrations of TPH than reference sediment R-OS (17.1 mg/kg dry weight). Test treatment TC-6(3) had the lowest oil and grease and TPH levels, possibly attributed to its coarse grain size (sand) in contrast to the other sediment treatments.

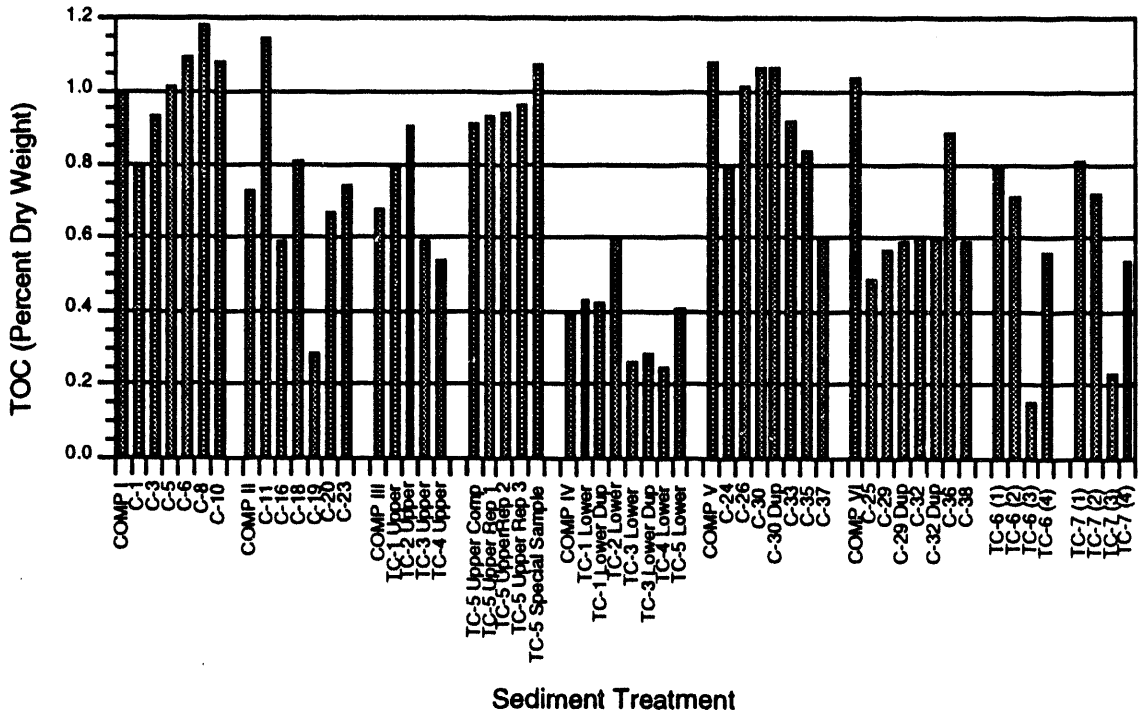


FIGURE 4.2. Concentrations of Total Organic Carbon in Sediment Treatments (reference sediment R-OS had a concentration of 1.44% dry weight)

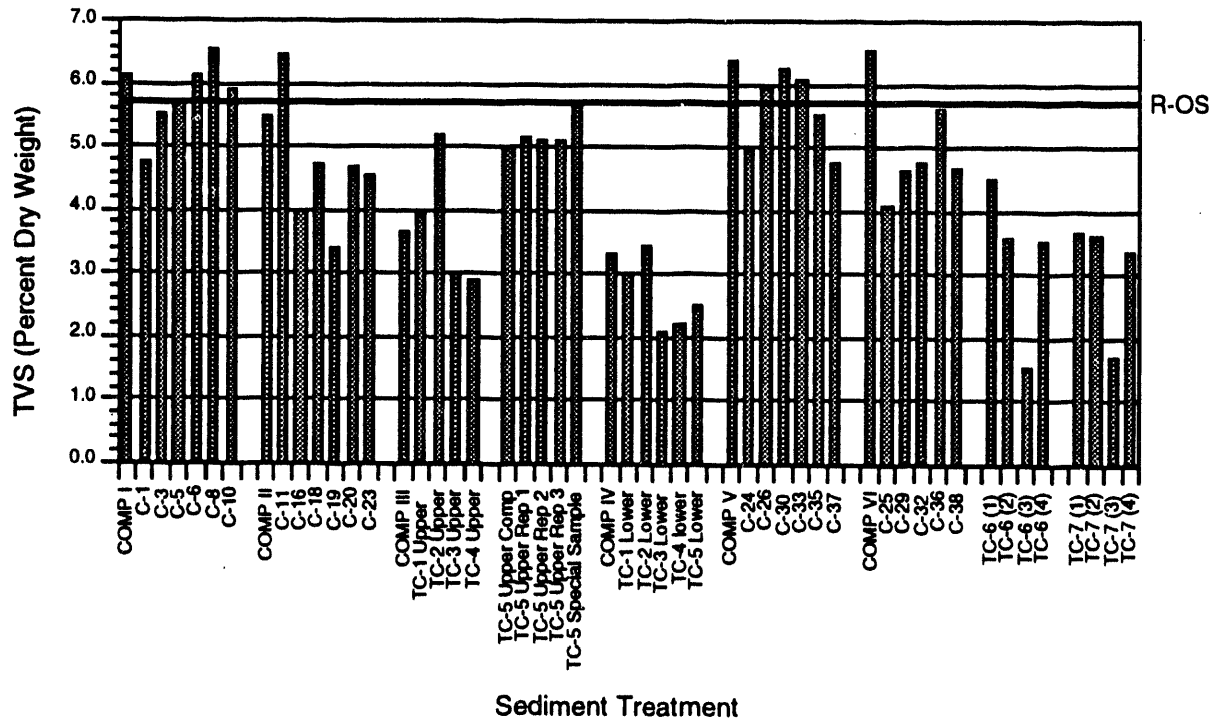


FIGURE 4.3. Concentrations of Total Volatile Solids in Sediment Treatments

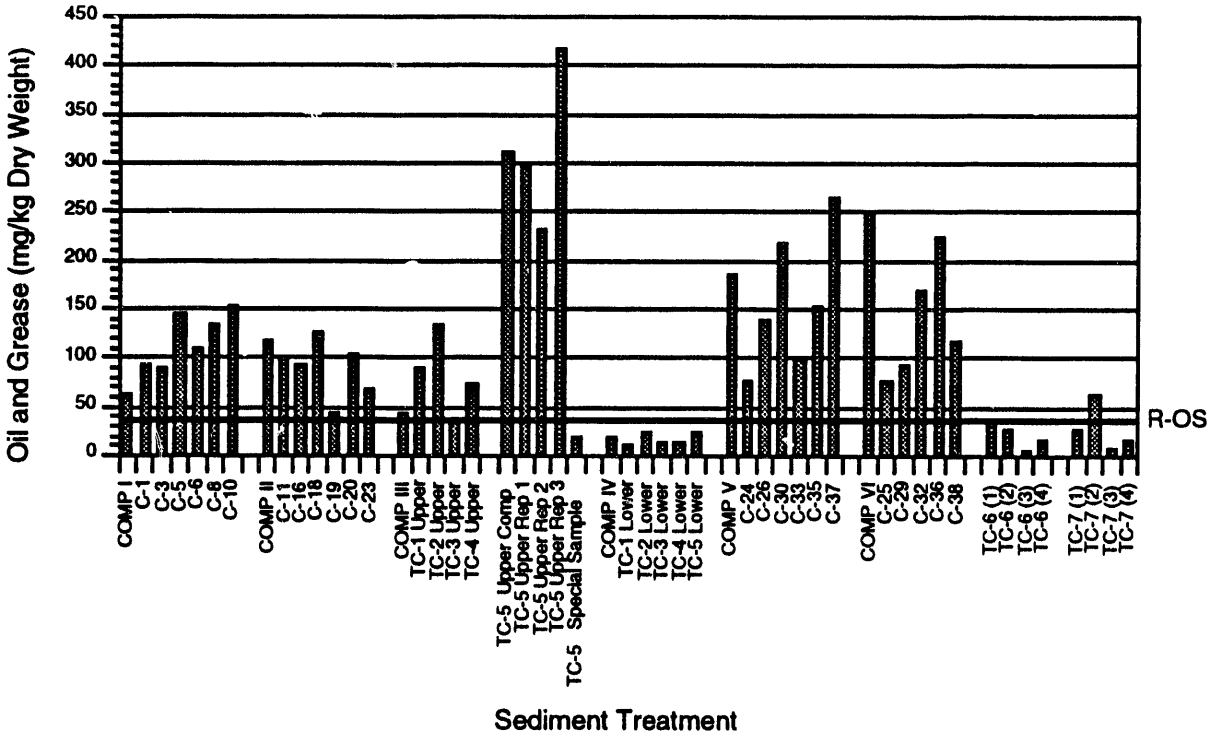


FIGURE 4.4. Concentrations of Oil and Grease in Sediment Treatments

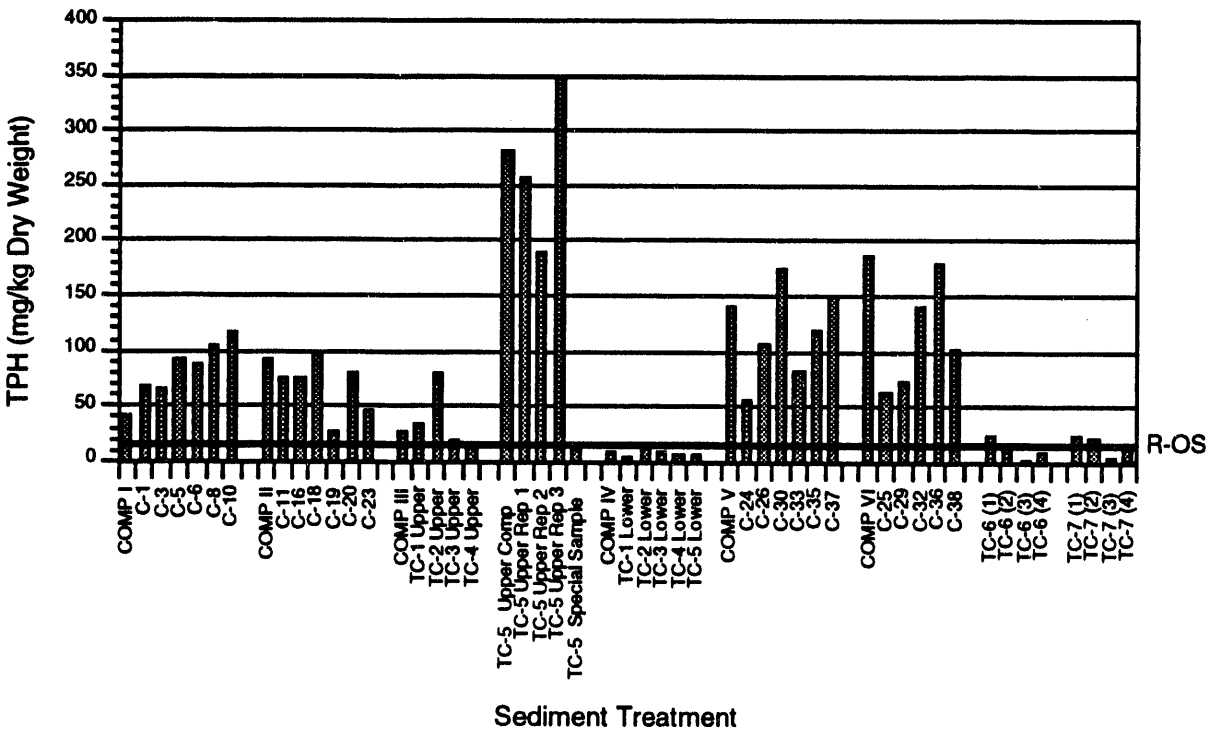


FIGURE 4.5. Concentrations of Total Petroleum Hydrocarbons in Sediment Treatments

Sediment treatments with the highest concentrations of oil and grease also had the highest concentrations of TPH.

4.2 POLYNUCLEAR AROMATIC HYDROCARBONS

Sixteen PAH compounds were analyzed in Richmond Harbor sediment treatments. The PAH results are reported in two groups based on molecular weight. The low-molecular-weight compounds (LPAH) are naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene. The high-molecular-weight compounds (HPAH) are chrysene, fluoranthene, pyrene, benzo(a)anthracene, benzo(b)- and benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene.

The results of LPAH and HPAH analyses are shown in Figure 4.6 and Table 4.2. Concentrations of LPAHs ranged from 11 to 810 µg/kg dry weight, while concentrations of HPAHs ranged from 0.0 to 2417 µg/kg dry weight. HPAHs comprised a greater fraction of total PAHs in 42 out of the 49 sediment treatments. The nine sediment treatments where LPAHs were higher included the COMP IV treatment, TC-3 Lower, TC-6, and TC-7. Most of the treatments with higher LPAH concentrations contained relatively small quantities of total PAHs in coarse-grained sediments in deeper core segments. Reference sediment R-OS had an LPAH concentration of 77 µg/kg dry weight and an HPAH concentration of 115 µg/kg dry weight. All but 13 test treatments had greater concentrations of total PAHs than in reference sediment R-OS.

4.3 CHLORINATED PESTICIDES AND POLYCHLORINATED BIPHENYLS

Three pesticides were detected in the test treatments from Richmond Harbor as shown in Figures 4.7, 4.8, and 4.9. Three pesticides were found at the highest concentrations in test treatment C-38 (4,4'-DDD), C-36 (4,4'-DDE), and COMP VI (4,4'-DDT). Test treatments C-38 and C-36 are two of the stations comprising COMP VI. Reference sediment R-OS had concentrations of these three pesticides that were either undetected or detected below the method detection limit. Aroclor 1254 was the only detected PCB in the Richmond Harbor test treatments (Figure 4.10). Twenty-four of the 49 test treatments had higher concentrations of Aroclor 1254 than reference sediment R-OS. The two test treatments with the highest levels of pesticides and PCBs had predominantly fine-grained sediments with relatively high TOC, oil and grease, and TPHs.

4.4 METALS

Ten metals were measured in Richmond Harbor test treatments and were reported in Table 4.2. Figures 4.11 through 4.20 provide a comparison of metals concentrations in the Richmond Harbor test treatments to reference sediment R-OS. Table 4.2 shows the test treatments with higher concentrations of metals than in reference sediment R-OS.

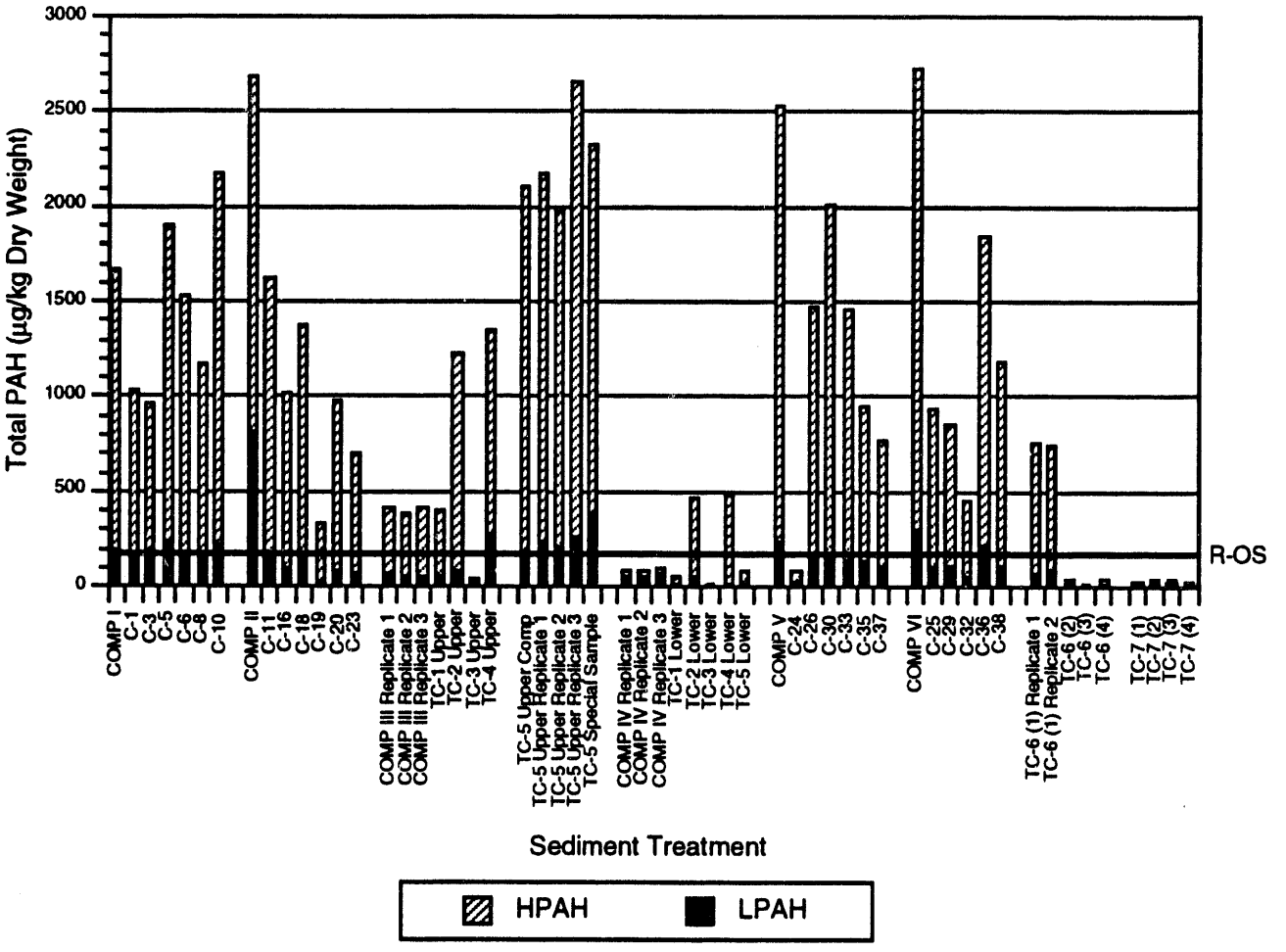


FIGURE 4.6. Concentrations of Total Polynuclear Aromatic Hydrocarbons in Sediment Treatments

Concentrations of silver (Ag) in the test treatments ranged from 0.078 mg/kg dry weight in TC-6(3) to 1.299 mg/kg dry weight in TC-5 Special Sample. Six test treatments had concentrations of Ag that were above those found in reference sediment R-OS (0.501 mg/kg dry weight). All but one of these elevated levels are associated with the upper sections and special sample from station TC-5.

Concentrations of arsenic (As) in the sediment treatments ranged from 5.91 mg/kg dry weight at TC-7(3) to 24.80 mg/kg dry weight at TC-5 Special Sample. All the Richmond Harbor test treatments had concentrations of As that exceeded those found in reference sediment R-OS (4.01 mg/kg dry weight). The highest concentrations of As in sediment during this study were found in the upper sections and special sample from station TC-5.

TABLE 4.2. Organics and Metals Sediment Measurement Results (organics in µg/kg dry weight; metals in mg/kg dry weight; shading indicates detected values greater than reference sediment R-OS)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
COMP I	193	1475	0.362	13.10	0.351	181	55.9	0.323	114.8	30.5	0.80 U[a]	133.1	3.1	3.3
C-1	165	868	0.280	11.80	0.333	211	51.1	0.221	112.1	23.1	0.79 U	119.9	0.8 J[b]	0.8 J
C-3	177	793	0.338	13.30	0.342	238	59.0	0.288	120.8	27.6	0.93	132.6	1.4 J	1.2 J
C-5	235	1662	0.383	14.90	0.278	195	59.8	0.333	113.3	29.7	0.84 U	137.3	2.6	2.1 J
C-6	170	1358	0.400	14.20	0.323	188	63.6	0.357	115.4	31.9	1.14	143.6	1.5 J	1.3 J
C-8	153	1024	0.458	16.60	0.361	207	70.4	0.375	127.7	34.2	0.82 U	154.9	1.3 J	1.7 J
C-10	217	1962	0.492	12.50	0.368	205	61.7	0.399	112.0	38.9	0.82 U	150.0	2.5 U	2.4 U
COMP II	810	1874	0.314	14.00	0.380	197	57.4	0.358	105.5	24.9	0.82 U	124.5	1.0 J	1.6 J
C-11	170	1454	0.448	14.50	0.306	202	71.3	0.439	120.6	36.0	0.93	159.4	1.5 J	2.4 U
C-16	104	916	0.293	13.20	0.257	315	50.8	0.293	99.4	25.9	0.77 U	114.3	23.5	7.8
C-18	160	1223	0.389	12.90	0.396	240	59.4	0.356	115.6	33.9	0.81 U	139.3	0.9 J	2.4 U
C-19	36	302	0.195	10.20	0.308	156	42.0	0.140	91.3	20.1	0.80 U	90.0	0.8 J	1.2 J
C-20	87	897	0.337	11.90	0.311	196	55.1	0.357	94.1	31.5	0.80 U	129.1	4.1	2.8
C-23	70	636	0.251	11.60	0.268	196	57.2	0.230	115.4	21.6	0.78 U	119.7	0.7 J	0.5 J
COMP III	63[c]	338[c]	0.160	10.84	0.342	203	38.5	0.175	87.1	16.6	0.79 U	92.3	1.6 J	1.3 J
TC-1 Upper	57	346	0.172	11.90	0.338	194	46.3	0.144	109.1	14.6	0.79 U	109.4	0.5 J	2.4 U
TC-2 Upper	87	1142	0.369	14.60	0.238	205	55.4	0.408	105.3	29.4	0.81 U	137.4	2.5 U	2.6 U
TC-3 Upper	15	27	0.111	12.60	0.290	241	37.6	0.058	95.8	10.4	0.81 U	88.4	2.5 U	0.4 J
TC-4 Upper	272	1078	0.114	12.14	0.309	253	31.4	0.066	92.7	11.1	0.78 U	83.1	0.3 J	2.4 U
TC-5 Upper Comp	187	1924	0.769	18.20	0.799	230	81.2	1.048	110.4	60.0	1.44	220.0	2.3	1.9 J
TC-5 Upper Rep 1	232	1949	0.856	19.50	1.209	207	81.1	1.081	108.9	56.2	0.83 U	220.0	2.5 U	9.3
TC-5 Upper Rep 2	207	1784	0.880	21.00	0.835	194	82.7	1.110	105.0	53.8	0.82 U	214.0	2.5 U	3.7
TC-5 Upper Rep 3	259	2397	0.840	19.40	0.871	218	80.4	1.047	110.7	57.2	0.85	214.0	2.5 U	11.4
TC-5 Special Sample	388	1940	1.299	24.80	1.294	206	96.4	1.431	111.2	62.1	0.84 U	260.0	2.5 U[d]	2.4 U[d]

TABLE 4.2. (contd)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
COMP IV	58[c]	32[c]	0.110	10.27	0.362	184	36.5	0.101	84.6	11.1	0.77 U	76.1	0.4 J	1.6 J
TC-1 Lower	16	38	0.103	9.58	0.211	320	40.1	0.119	93.1	11.5	0.98	84.4	2.5 U	0.3 J
TC-2 Lower	50	425	0.121	10.25	0.276	253	40.2	0.103	91.8	11.3	0.79 U	87.1	2.5 U	2.4 U
TC-3 Lower	13	2	0.159	9.22	0.347	229	33.2	0.077	83.5	10.0	0.75 U	65.9	2.5 U	2.4 U
TC-4 Lower	22	462	0.107	10.86	0.237	269	32.3	0.116	89.5	10.8	0.81 U	66.0	2.5 U	0.3 J
TC-5 Lower	19	62	0.075	7.85	0.217	248	26.5	0.105	57.2	13.1	0.78 U	55.2	2.5 U	2.4 U
COMP V	239	2296	0.448	14.50	0.556	196	74.4	0.562	123.5	46.4	0.83 U	179.3	3.4	3.6
C-24	28	55	0.279	13.80	0.291	223	64.3	0.295	117.1	24.1	0.83	130.8	1.3 J	0.9 J
C-26	151	1326	0.500	14.60	0.379	205	72.4	0.486	117.0	47.6	0.82	172.0	2.5 U	2.4 U
C-30	169	1842	0.527	14.20	0.428	184	79.0	0.529	121.1	52.1	0.82 U	178.0	2.4 J	3.6
C-33	145	1313	0.483	15.40	0.655	217	71.5	0.437	130.9	44.1	0.84 U	173.5	2.5 J	3.5
C-35	139	815	0.440	12.70	0.544	204	69.7	0.453	116.4	44.8	0.82 U	160.6	3.2	3.2
C-37	95	681	0.343	9.14	0.431	261	55.2	0.321	102.3	31.6	1.04	131.9	3.9	2.4 U
COMP VI	305	2417	0.471	12.50	0.428	211	72.8	0.535	123.4	48.3	0.84 U	172.9	4.7	2.4 U
C-25	97	837	0.304	9.82	0.290	209	53.2	0.271	101.0	30.2	0.78 U	120.7	2.5 U	2.4 U
C-29	112	750	0.307	10.70	0.457	181	49.0	0.243	102.6	27.8	0.84 U	126.5	2.5 U	2.4 U
C-32	51	408	0.340	12.10	0.456	189	59.6	0.303	112.6	32.9	1.32	137.2	1.6 J	2.4
C-36	226	1616	0.450	13.40	0.609	210	64.5	0.423	111.6	44.8	0.81 U	158.7	2.5 U	2.4 U
C-38	112	1072	0.339	7.72	1.232	189	56.5	0.292	103.9	33.9	2.01	137.4	1.6 J	2.7
TC-6 (1)[e]	76[c]	675[c]	0.182	12.90	0.350	207	38.1	0.276	102.2	22.5	0.82 U	103.1	0.6 J	1.2 J
TC-6 (2)	24	19	0.117	12.04	0.328	209	37.6	0.054	103.7	9.4	0.80 U	95.0	2.5 U	2.4 U
TC-6 (3)	11	2	0.078	6.13	0.105	226	16.2	0.088	46.1	8.3	0.73 U	35.2	2.5 U	2.4 U
TC-6 (4)	22	20	0.128	10.26	0.222	211	44.7	0.060	102.8	11.9	0.78 U	86.8	2.5 U	2.4 U

TABLE 4.2. (contd)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
TC-7 (1)[e]	13	11	0.107	9.83	0.303	197	39.6	0.052	100.5	12.0	0.83 U	94.5	2.5 U	2.4 U
TC-7 (2)	26	15	0.121	12.40	0.309	242	46.5	0.063	112.8	10.8	1.12	99.6	2.5 U	2.4 U
TC-7 (3)	37	0	0.082	5.91	0.125	286	21.5	0.078	53.2	9.4	0.76 U	41.8	0.5 J	0.3 J
TC-7 (4)	21	6	0.118	10.95	0.237	204	45.5	0.062	101.5	9.0	0.80 U	87.3	2.5 U	2.4 U
R-OS	77	115	0.501	4.01	0.616	172	30.7	0.146	82.8	9.2	2.57	91.0	2.5 U	0.5 J

(a) U Analyte not present above level of associated value.
(b) J Analyte detected below method detection limit but above instrument detection limit.
(c) Mean of replicate measurements.
(d) Sample had interference in chromatogram; internal standard was altered to give approximate numbers for this sample.
(e) Stations TC-6 and TC-7 were split into four separate core sections that were composited, subsampled for chemistry, and used for geologic descriptions.

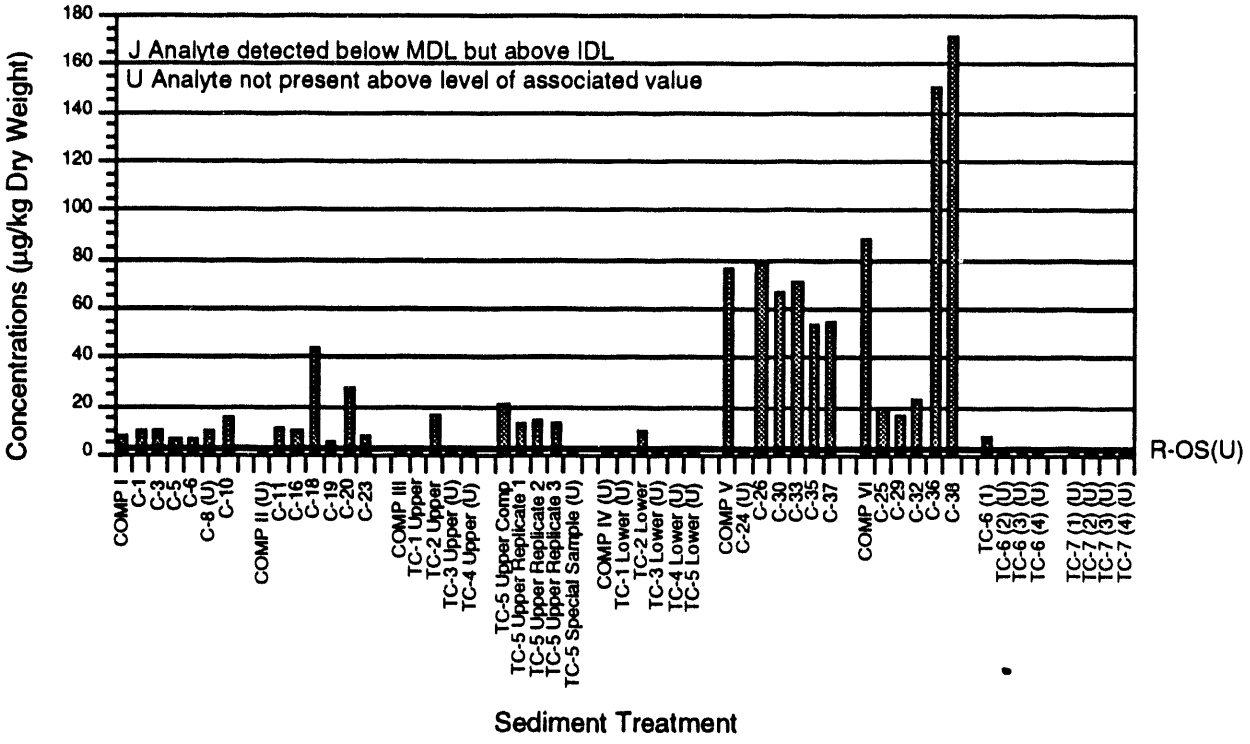


FIGURE 4.7. Concentrations of 4,4'-DDD in Sediment Treatments

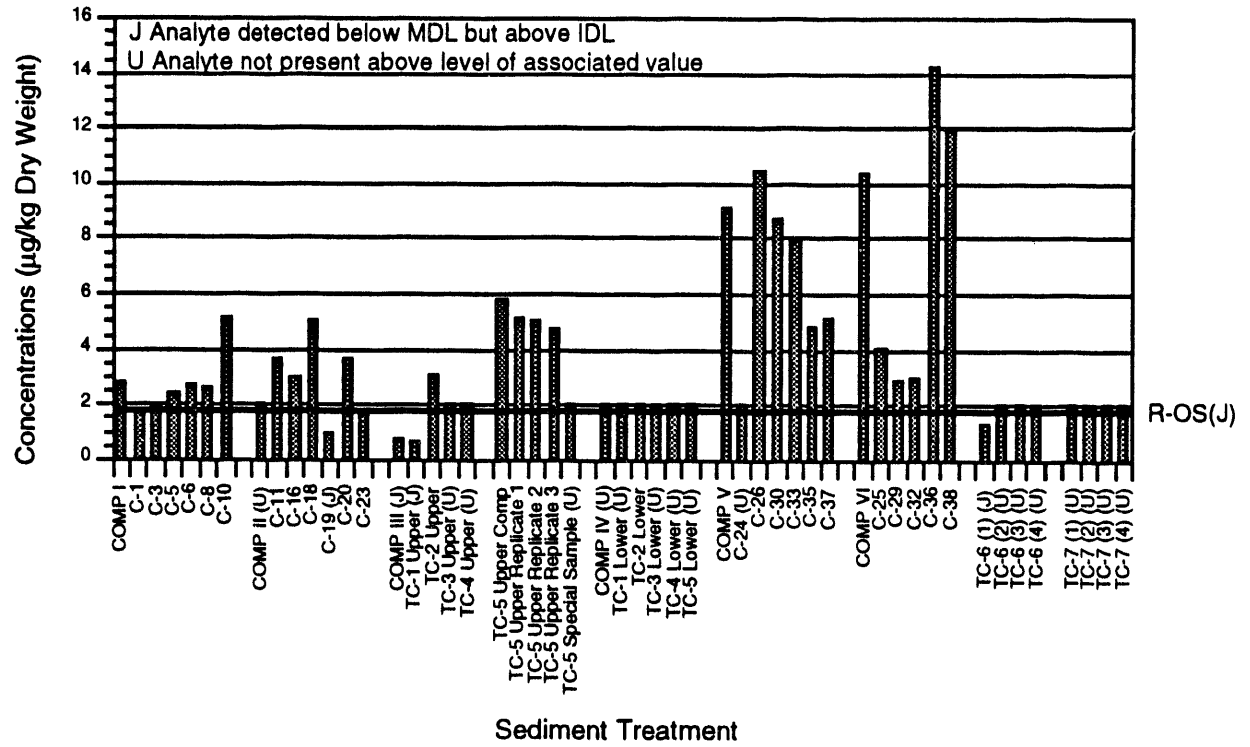


FIGURE 4.8. Concentrations of 4,4'-DDE in Sediment Treatments

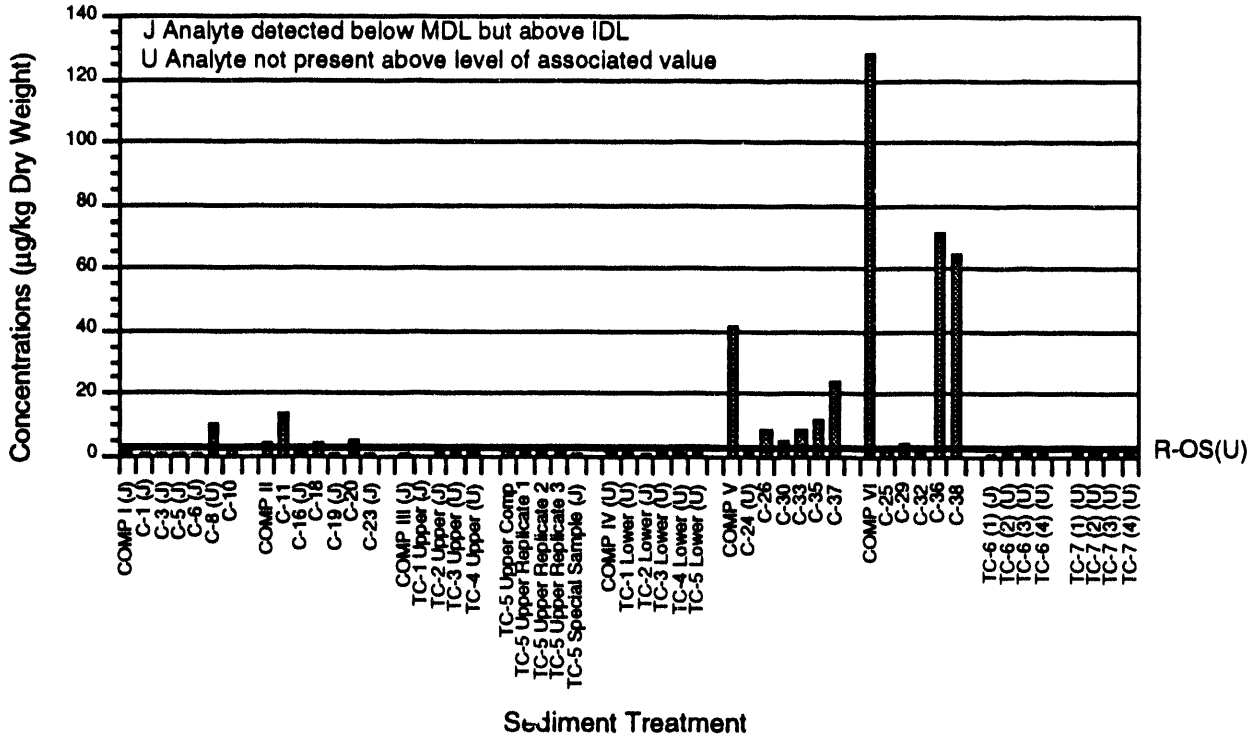


FIGURE 4.9. Concentrations of 4,4'-DDT in Sediment Treatments

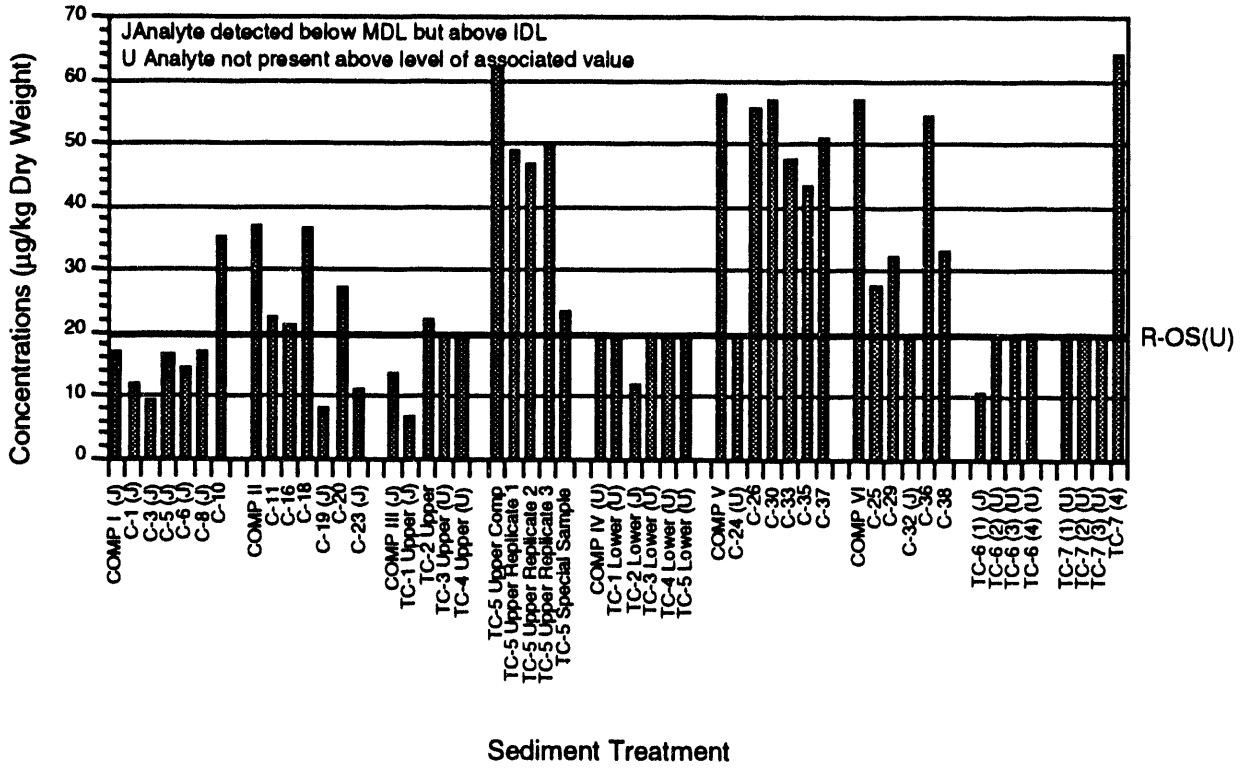


FIGURE 4.10. Concentrations of Aroclor 1254 in Sediment Treatments

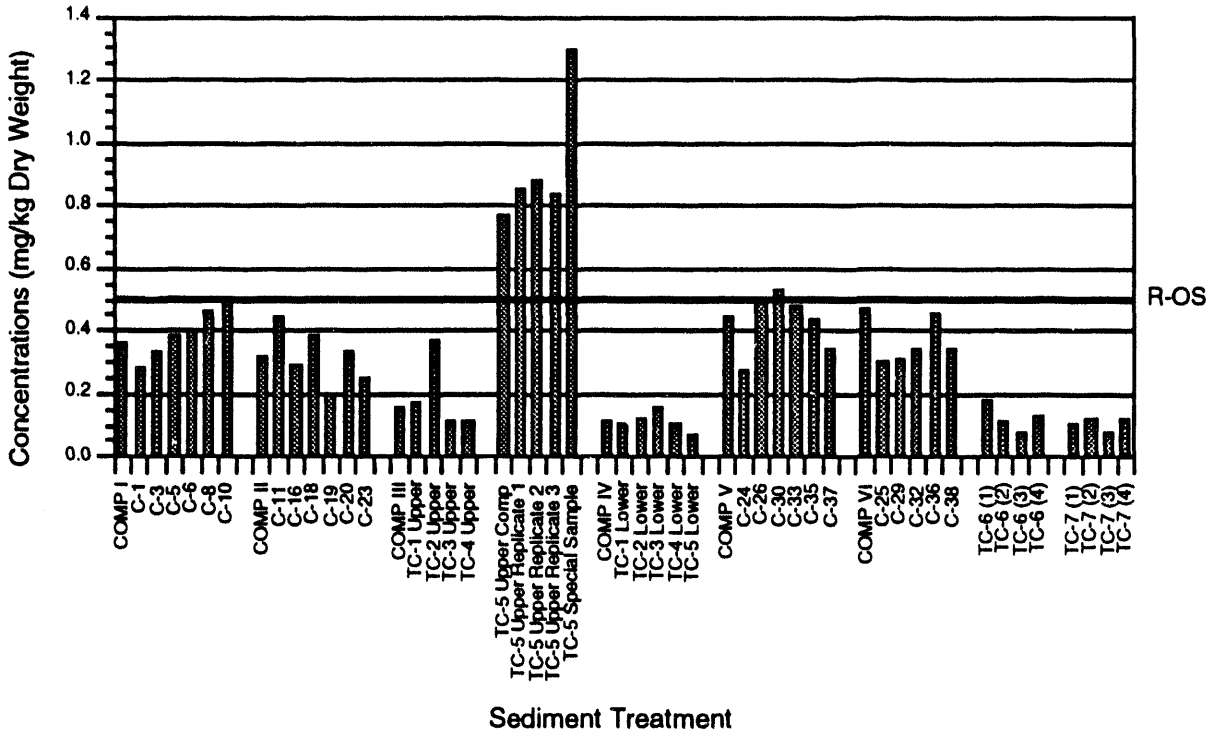


FIGURE 4.11. Concentrations of Silver in Sediment Treatments

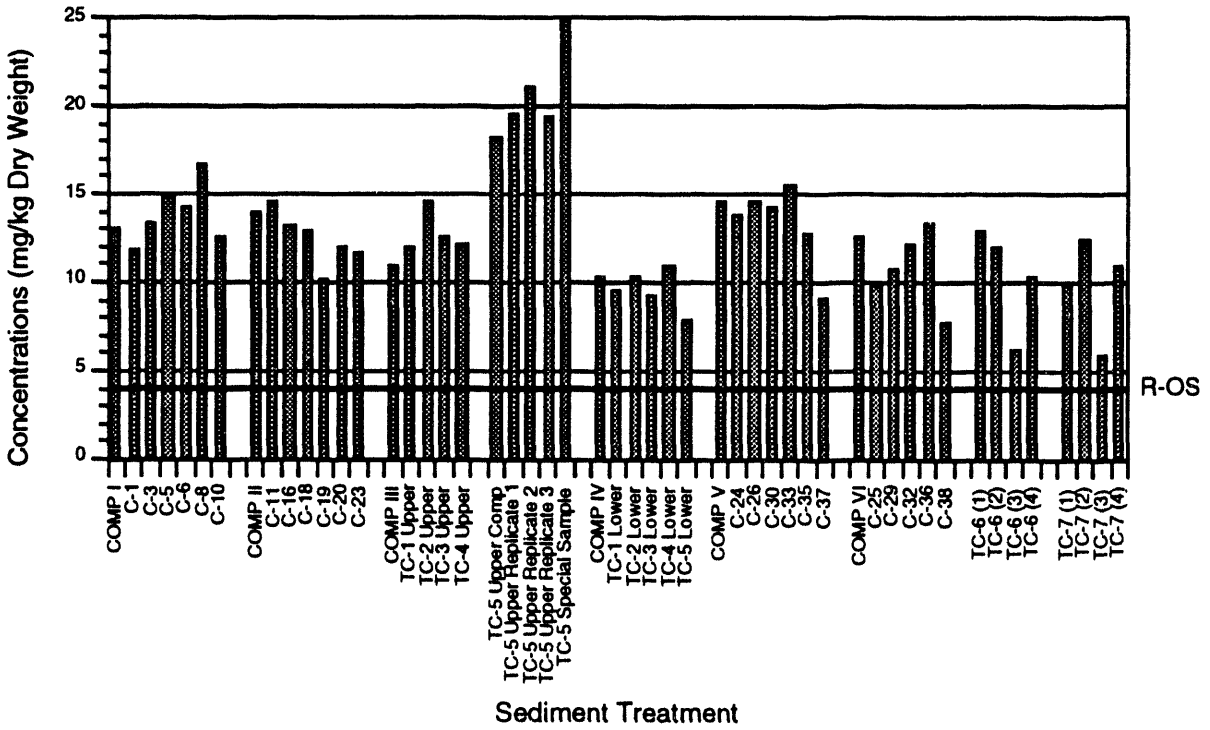


FIGURE 4.12. Concentrations of Arsenic in Sediment Treatments

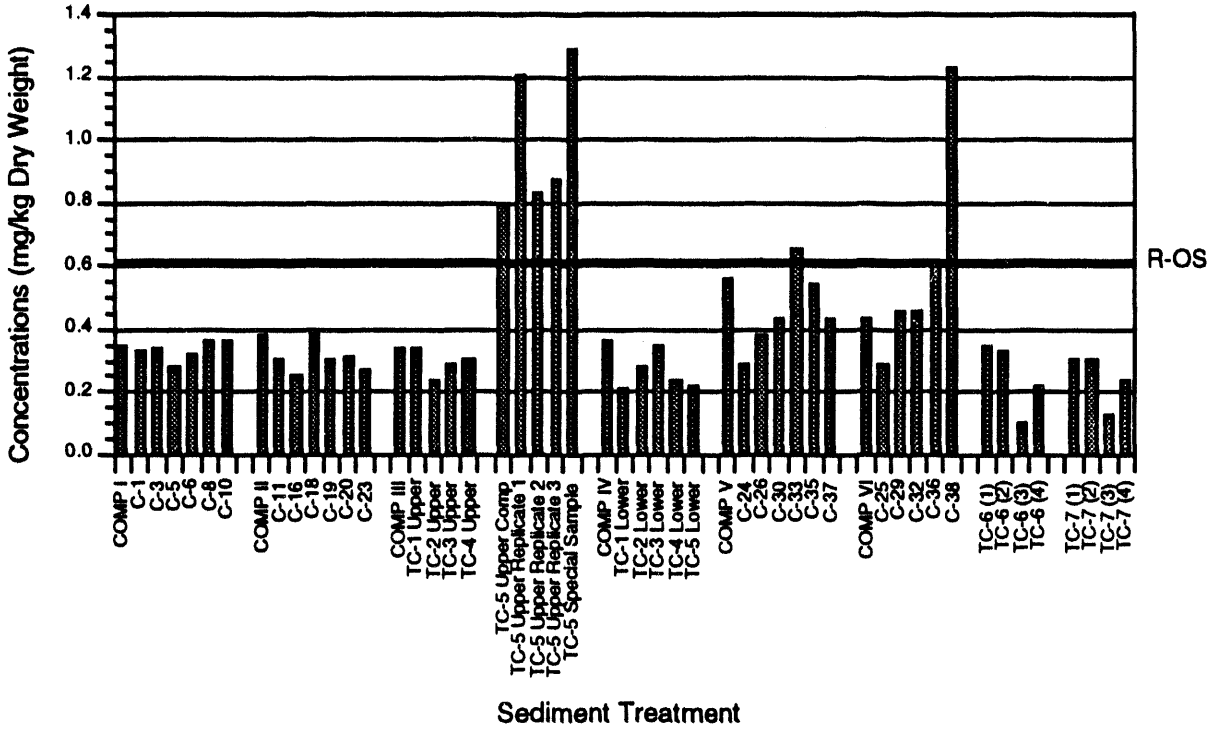


FIGURE 4.13. Concentrations of Cadmium in Sediment Treatments

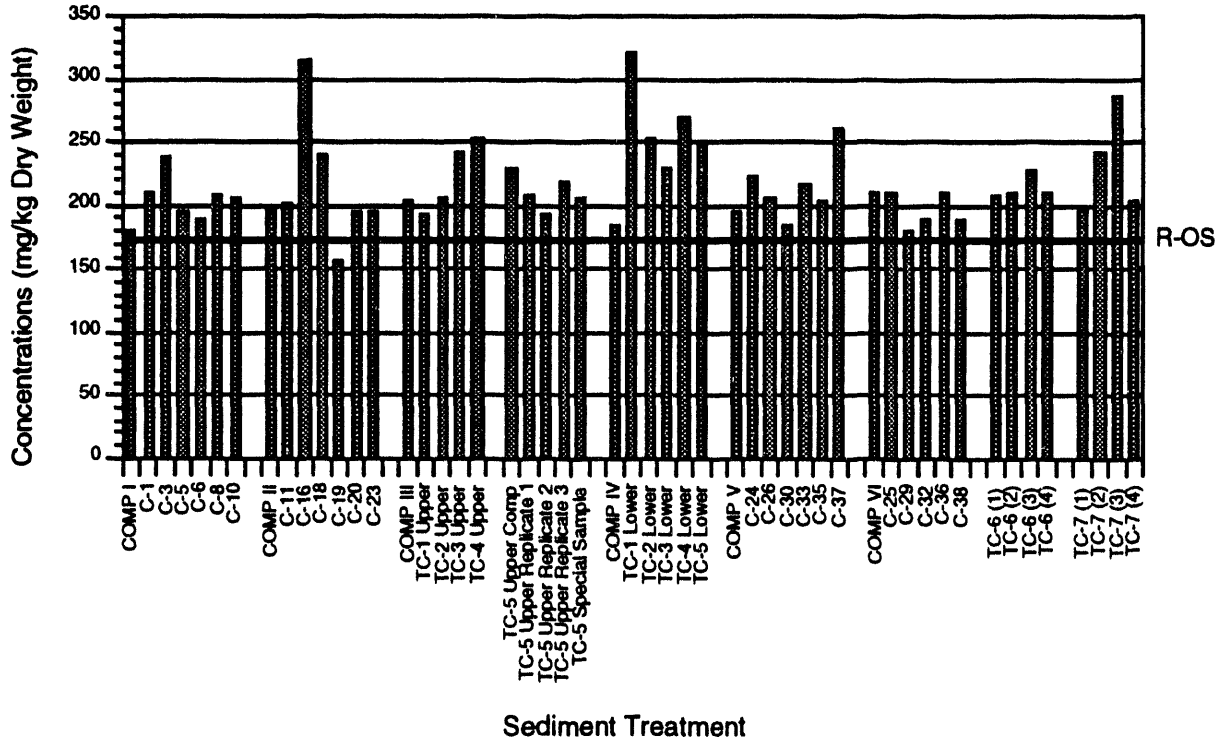


FIGURE 4.14. Concentrations of Chromium in Sediment Treatments

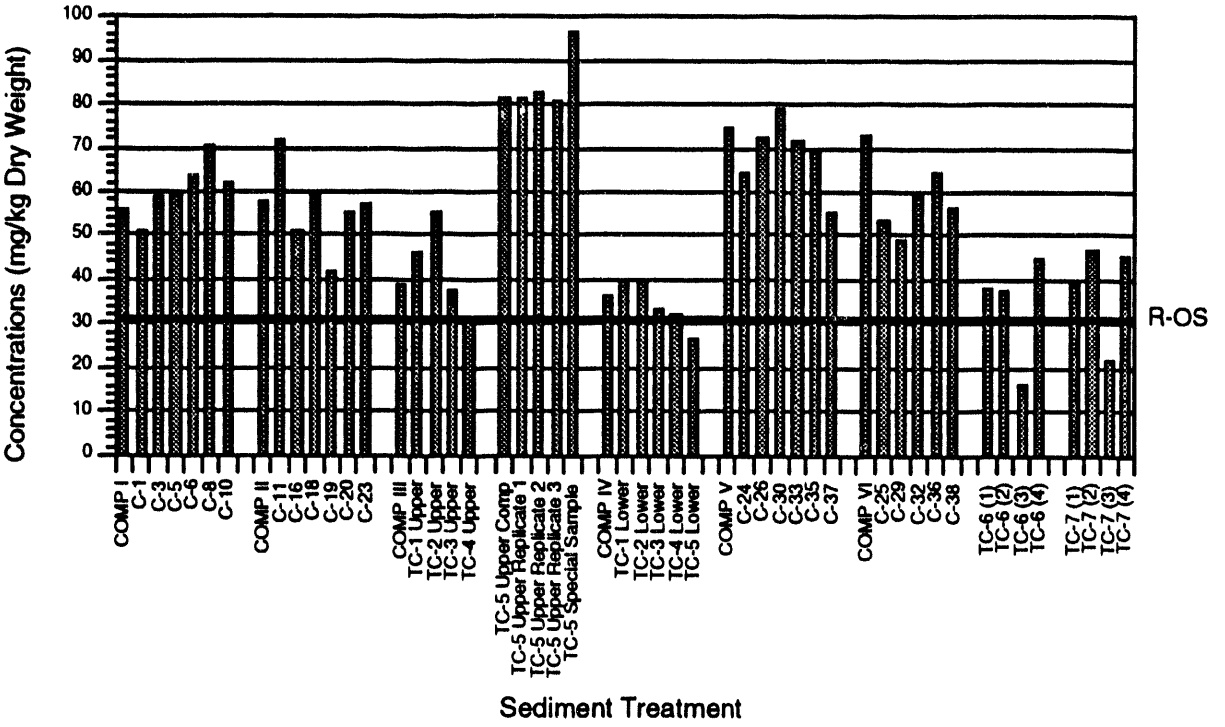


FIGURE 4.15. Concentrations of Copper in Sediment Treatments

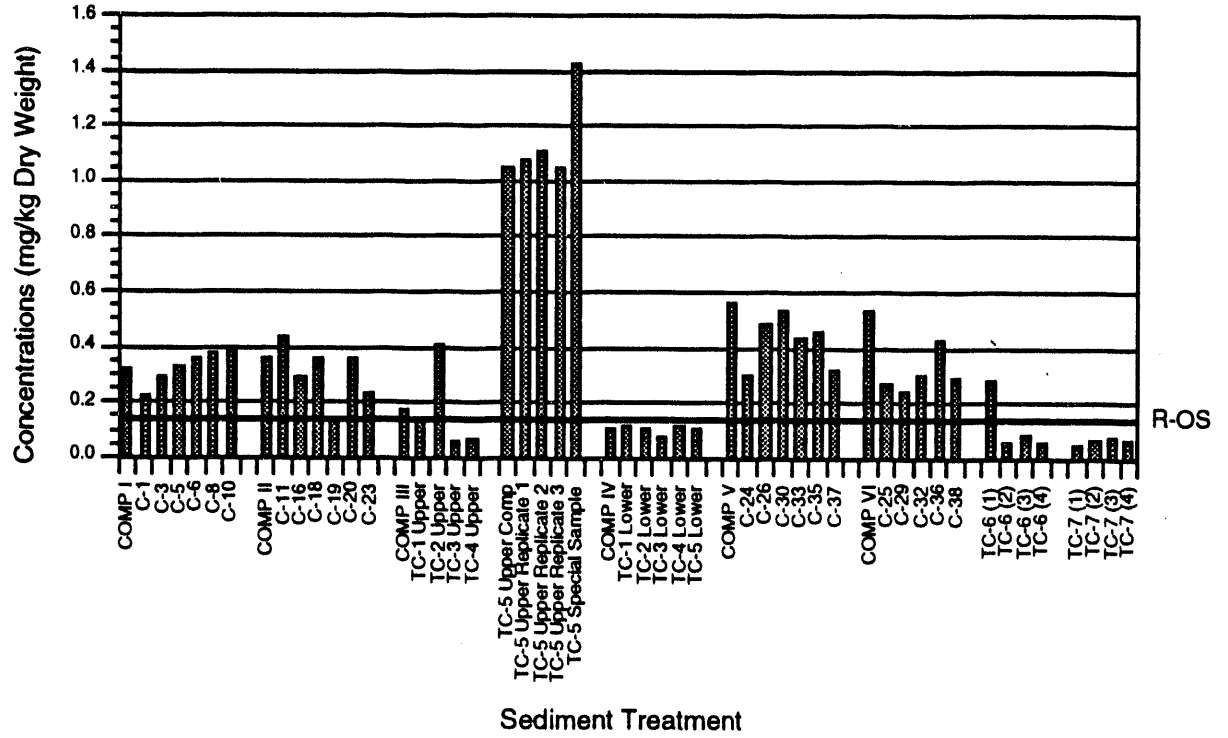


FIGURE 4.16. Concentrations of Mercury in Sediment Treatments

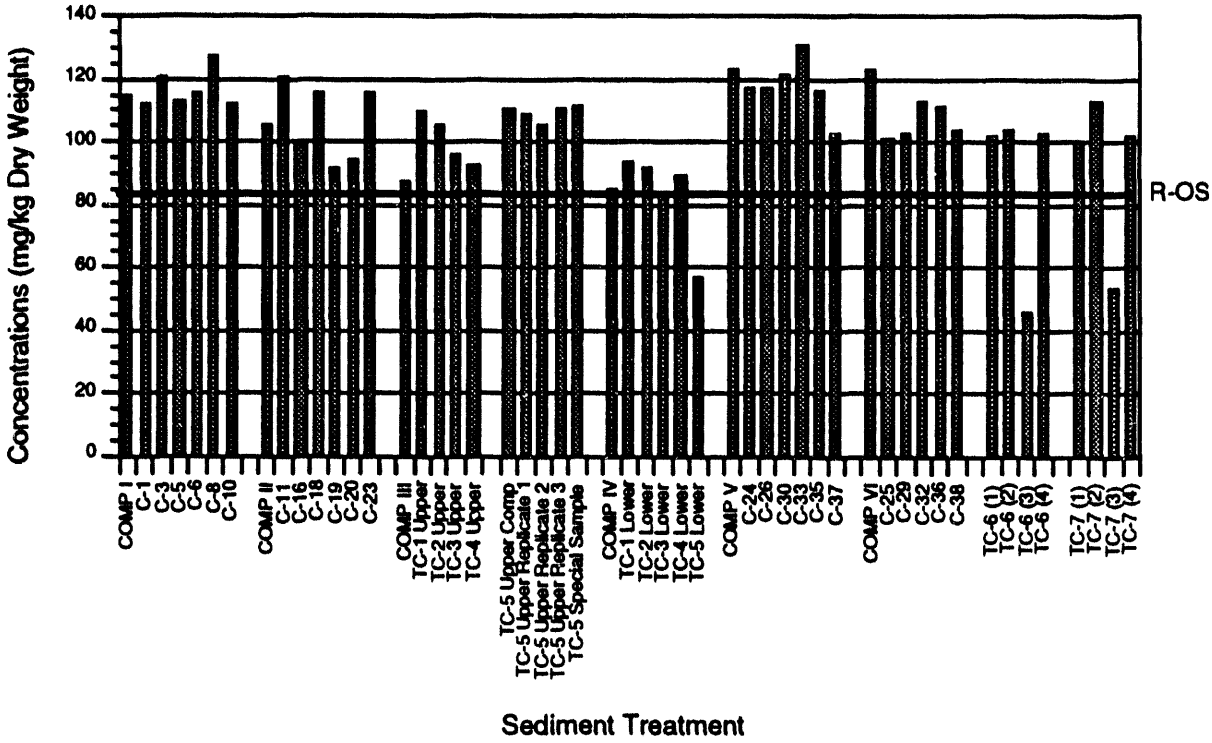


FIGURE 4.17. Concentrations of Nickel in Sediment Treatments

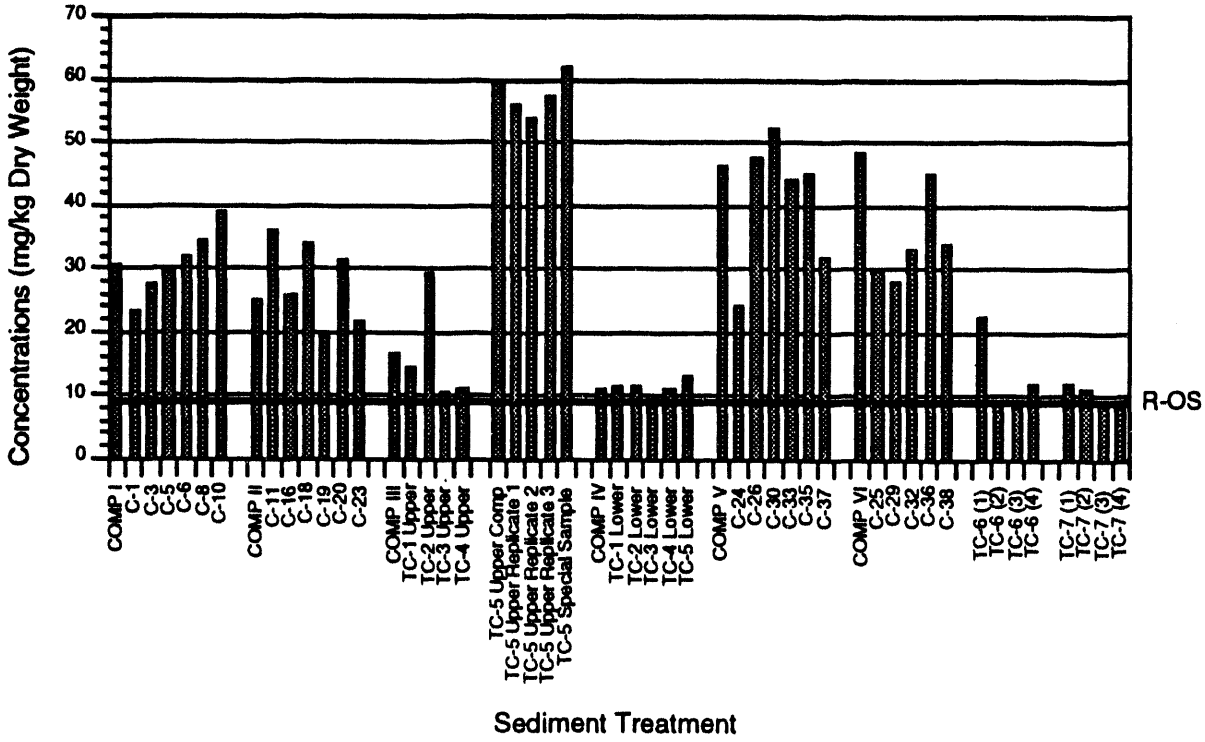


FIGURE 4.18. Concentrations of Lead in Sediment Treatments

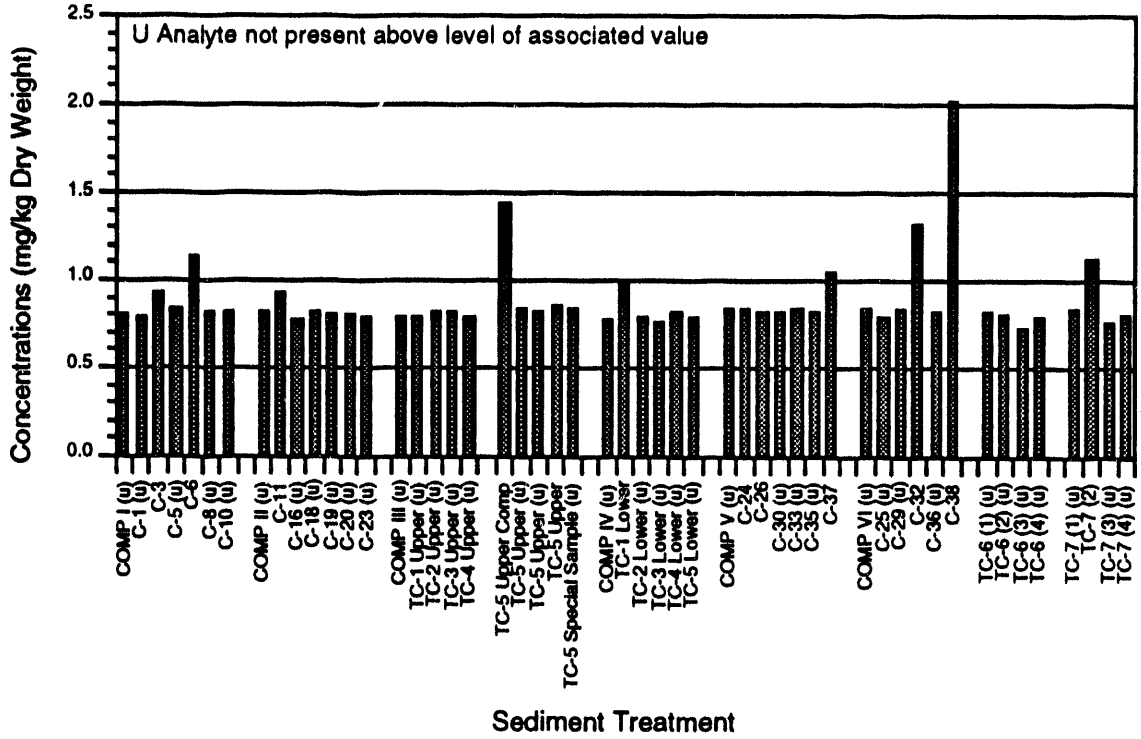


FIGURE 4.19. Concentrations of Selenium in Sediment Treatments (reference sediment R-OS had a concentration of 2.57 mg/kg dry weight)

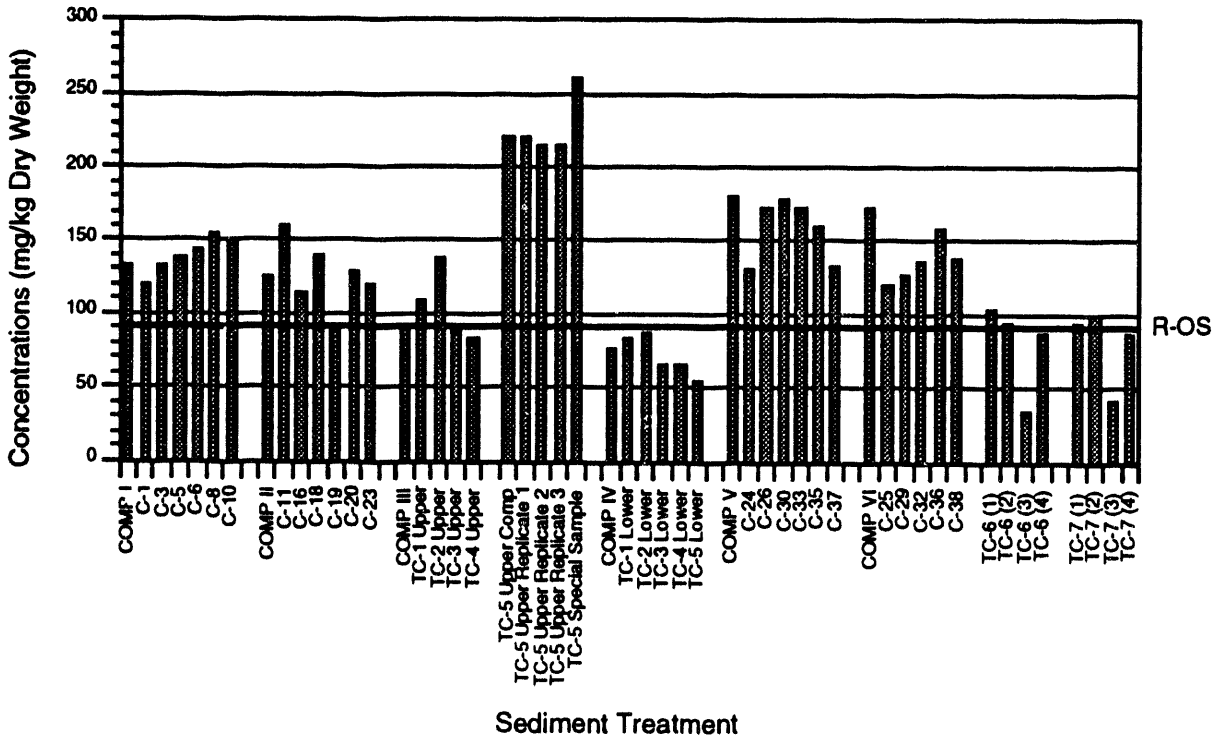


FIGURE 4.20. Concentrations of Zinc in Sediment Treatments

Cadmium (Cd) concentrations ranged from 0.105 mg/kg dry weight in TC-6(3) to 1.294 mg/kg dry weight in TC-5 Special Sample. Five test treatments had Cd concentrations that were above those found in reference sediment R-OS (0.616 mg/kg dry weight). All but two of these elevated levels are associated with the upper sections and special sample from station TC-5.

Concentrations of chromium (Cr) in the test treatments ranged from 156 mg/kg dry weight at C-19 to 320 mg/kg dry weight at TC-1 Lower. All the Richmond Harbor test treatments, except station C-19, had Cr concentrations that exceeded those found in reference sediment R-OS (172 mg/kg dry weight).

Concentrations of copper (Cu) in the test treatments ranged from 16.2 mg/kg dry weight at treatment TC-6(3) to 96.4 mg/kg dry weight at TC-5 Special Sample. All the Richmond Harbor test treatments, except stations TC-5 Lower, TC-6(3), and TC-7(3), had Cu concentrations that exceeded those found in reference sediment R-OS (30.7 mg/kg dry weight).

Mercury (Hg) concentrations in test treatments ranged from 0.052 mg/kg dry weight at TC-7(1) to 1.431 mg/kg dry weight at TC-5 Special Sample. Thirty-two test treatments had Hg concentrations that exceeded those found in reference sediment R-OS (0.146 mg/kg dry weight). The highest Hg concentrations in sediment observed during this study were found in the upper sections and special sample from station TC-5.

Nickel (Ni) concentrations in the test treatments ranged from 46.1 mg/kg dry weight at TC-6(3) to 130.9 mg/kg dry weight at C-33. All the Richmond Harbor test treatments, except TC-5 Lower, TC-6(3), and TC-7(3), had Ni concentrations that exceeded those found in reference sediment R-OS (82.8 mg/kg dry weight).

Concentrations of lead (Pb) in the test treatments ranged from 8.3 mg/kg dry weight at TC-6(3) to 62.1 mg/kg dry weight at TC-5 Special Sample. All the Richmond Harbor test treatments, except TC-6(3) and TC-7(4), had Pb concentrations that exceeded those found in reference sediment R-OS (9.2 mg/kg dry weight).

Selenium (Se) was detected in 12 test treatments, with concentrations ranging from 0.82 mg/kg dry weight at C-26 to 1.44 mg/kg dry weight at TC-5 Upper Comp. Reference sediment R-OS had an Se concentration of 2.57 mg/kg dry weight, which was higher than any of the test treatments.

Concentrations of zinc (Zn) in the test treatments ranged from 35.2 mg/kg dry weight in TC-6(3) to 260 mg/kg dry weight in TC-5 Special Sample. Thirty-six test treatments had Zn concentrations that exceeded those found in reference sediment R-OS (91.0 mg/kg dry weight).

4.5 BUTYLTINS

Monobutyltin (MBT) was detected at 4 µg/kg dry weight in TC-5 Upper Rep 3 and at 19 µg/kg dry weight in TC-5 Special Sample. Monobutyltin was undetected in reference sediment R-OS. Dibutyltin (DBT) concentrations (Figure 4.21) ranged from 0.3 µg/kg dry weight at TC-1 lower, TC-4 lower, and TC-7(3) to 11.4 µg/kg dry weight at TC-5 Upper Rep 3. The concentration of dibutyltin in reference sediment R-OS was 0.5 µg/kg dry weight. Twenty-two test treatments had detected concentrations of dibutyltin that exceeded those found in reference sediment R-OS. Tributyltin (TBT) concentrations (Figure 4.22) ranged from 0.3 µg/kg dry weight at TC-4 Upper to 23.5 µg/kg dry weight at C-16. Tributyltin was undetected in reference sediment R-OS. Eight test treatments had detected concentrations of tributyltin that were above those found in reference sediment R-OS.

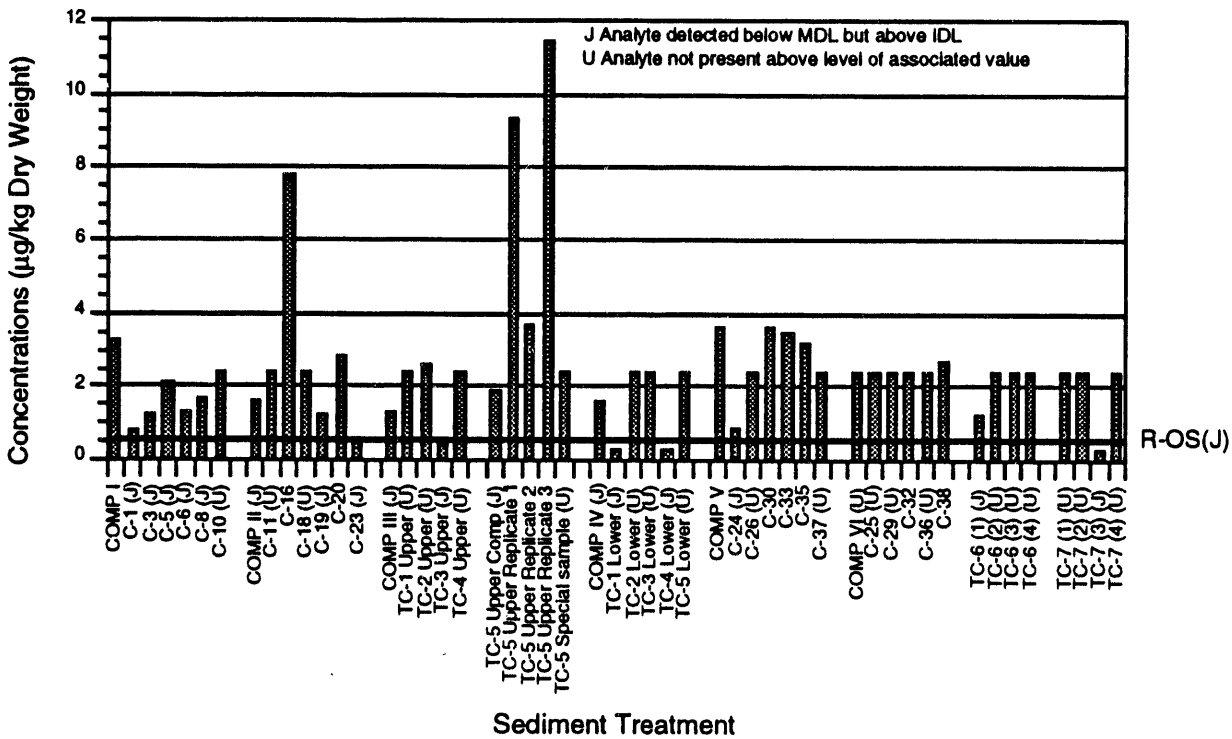


FIGURE 4.21. Concentrations of Dibutyltin in Sediment Treatments

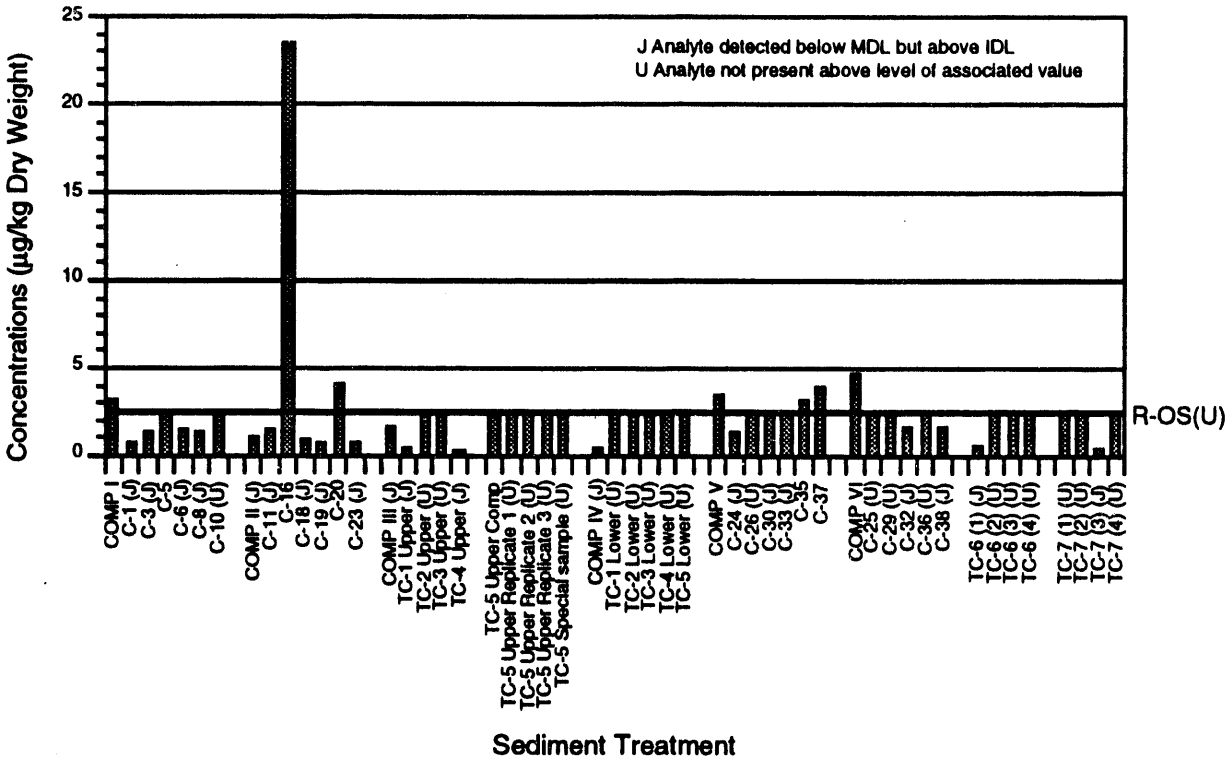


FIGURE 4.22. Concentrations of Tributyltin in Sediment Treatments

5.0 TOXICOLOGY

Sediment from seven Richmond Harbor treatments were tested for solid-phase and SPP toxicity to evaluate benthic (deposited sediment) and water column effects of dredged material disposal in an aquatic environment. Three species of marine organisms were exposed to the test treatments in 10-day acute toxicity solid-phase tests. Survival in the test treatments was statistically compared to survival in reference treatment R-OS using ANOVA Dunnett's test ($\alpha = 0.05$). Statistically significant acute toxicity in a test treatment was defined by two criteria, as stated in the *1991 Implementation Manual*: 1) mean survival was statistically significantly lower than the reference in Dunnett's test and 2) mean survival was at least 10% lower than the reference (20% lower than reference for amphipods).

Three species of marine organisms were exposed to 0%, 10%, 50%, and 100% concentrations of SPP prepared from sediment composites. Water column effects were evaluated by comparing survival in the 0% and 100% SPP concentrations using a t-test and calculating the LC50 or EC50, where appropriate. The LC50 or EC50 is the concentration of SPP that would be lethal to or produce an effect in 50% of the test population.

A summary of the toxicology results is presented in the following sections. The complete toxicology data are located in *Ecological Evaluation of Proposed Dredged Material from Richmond Harbor* (Pinza et al. 1992).

5.1 SOLID-PHASE TOXICITY

Three species of marine organisms were exposed in 10-day acute toxicity tests: *M. nasuta*, *N. caecoides*, and *R. abronius*. *M. nasuta* and *N. caecoides* were tested under flow-through conditions, while *R. abronius* was tested under static conditions. All tests were validated by at least 90% survival in the "native" control treatment. The results of the tests are presented in Table 5.1.

Table 5.1 shows that survival for *M. nasuta* and *R. abronius* was not statistically significantly decreased in any test treatment relative to reference R-OS. The survival for *N. caecoides* showed statistically significant mortality in the treatments COMP III, TC-5 Upper Comp, and COMP IV. The location of stations with elevated solid-phase acute toxicity results are presented in Figure 5.1.

5.2 SUSPENDED-PARTICULATE-PHASE TOXICITY

The test species for the SPP toxicity test were *H. sculpta*, *C. stigmaeus*, and *M. edulis*. Table 5.2 shows percent survival in the control (0% SPP) compared to the 100% SPP, and calculable LC50 concentrations if survival was below 50% relative to the 0% control (Figure 5.2). The *C. stigmaeus* SPP test shows that one composite (TC-5 Upper Comp) had a significant

TABLE 5.1. Ten-Day Solid-Phase Toxicity Test Results (bold type indicates mean survival significantly lower than reference based on Dunnett's test; shaded box indicates greater than 10% difference between treatment mean and reference mean survival for *M. nasuta* and *N. caecoides*, 20% difference for *R. abronius*)

Treatment	Mean Percent Survival in 10-Day Solid-Phase Test		
	M. nasuta	*N. caecoides*	*R. abronius*
CONTROL[a]	100.0	97.0	100.0
R-OS	99.0	95.0	66.0
COMP I	100.0	91.0	77.0
COMP II	96.0	89.0	80.0
COMP III	99.0	79.0	58.0
TC-5 Upper Comp	100.0	79.0	82.0
COMP IV	97.6	73.0	76.0
COMPV	100.0	93.0	87.0
COMP VI	99.0	91.0	83.0

(a) Control treatment used to validate only test organism survival and not used in statistical analysis.

difference in survival between the 0% and 100% SPP tests and an LC50 value of 75.4% SPP was calculated. The *M. edulis* SPP test shows that test treatment COMP I produced a significant difference in survival in the 100% SPP (72.6%) but this statistical difference did not produce a calculable LC50 value. The *H. sculpta* SPP test shows that survival between the control and 100% SPP dilutions was not statistically significantly different for any of the test treatments.

TABLE 5.2. Suspended-Particulate-Phase Toxicity Test Results (bold indicates mean survival in 100% SPP significantly lower than control in 2-sample t-test, $\alpha = 0.05$)

Treatment	Mysid *H. sculpta*			Bivalve Larvae *M. edulis*			Sanddab *C. stigmaeus*		
	Mean Survival (%)		LC50 as	Mean Survival (%)		LC50 as	Mean Survival (%)		LC50 as
	0% SPP	100% SPP	% SPP	0% SPP	100% SPP	% SPP	0% SPP	100% SPP	% SPP
COMP I	100	98	>100[a]	96.9	**72.6**	>100	95	98	>100
COMP II	100	95	>100	84.4	95.7	>100	95	93	>100
COMP III	100	98	>100	92.0	83.5	>100	93	100	>100
TC-5 Upper Comp	98	95	>100	93.8[b]	76.0	>100	100	**23**	75.4
COMP IV	93	98	>100	87.2	85.2	>100	98	90	>100
COMP V	93	85	>100	89.1	84.6	>100	98	93	>100
COMP VI	95	90	>100	92.6	78.7	>100	95	98	>100

(a) Test organism survival was > 50% in all concentrations.
(b) Used mean control survival of COMP I, COMP III, and COMP VI to estimate control survival for TC-5 Upper Comp.

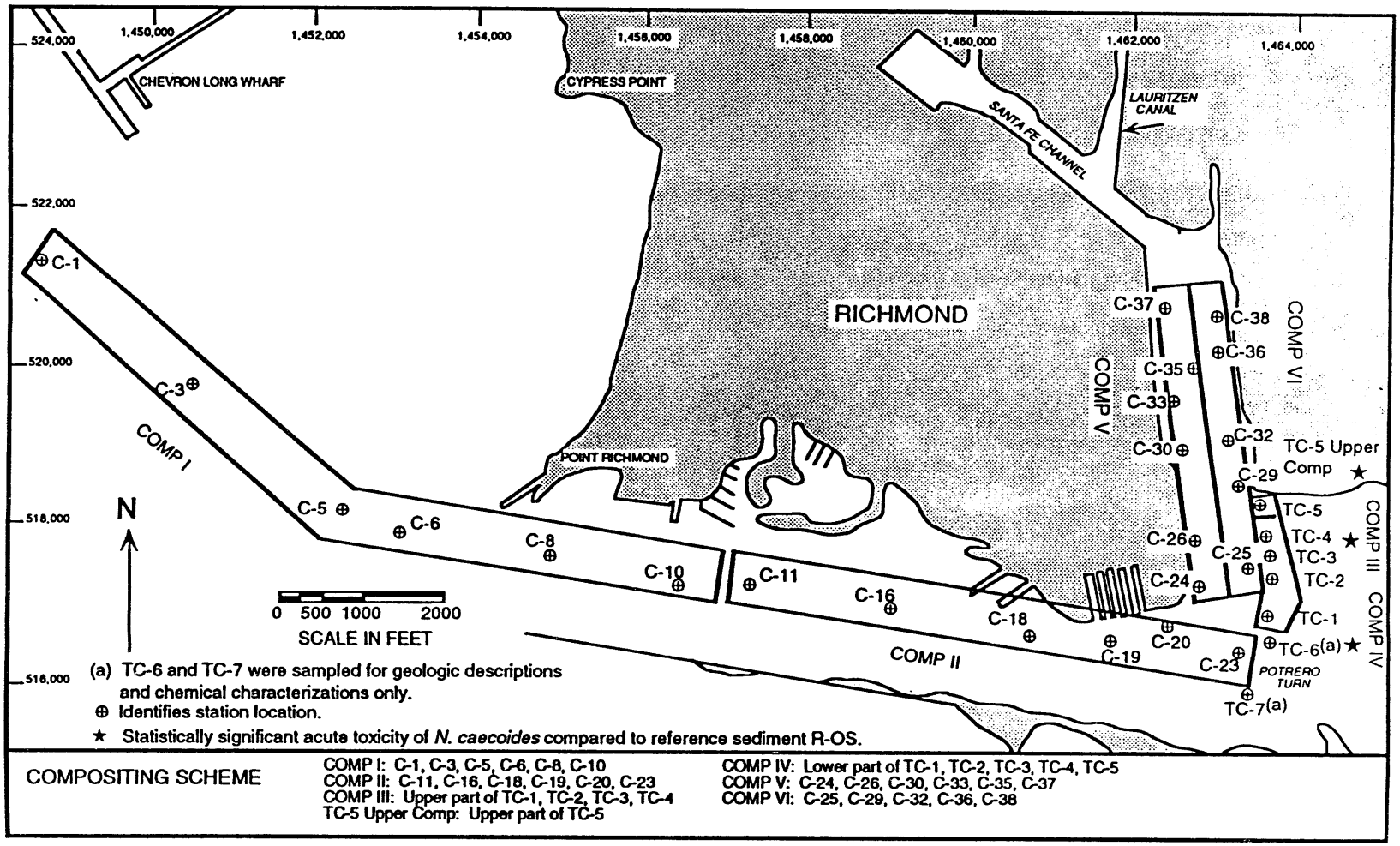


FIGURE 5.1. Sediment Treatments with Acute Toxicity Compared to Reference Sediment R-OS

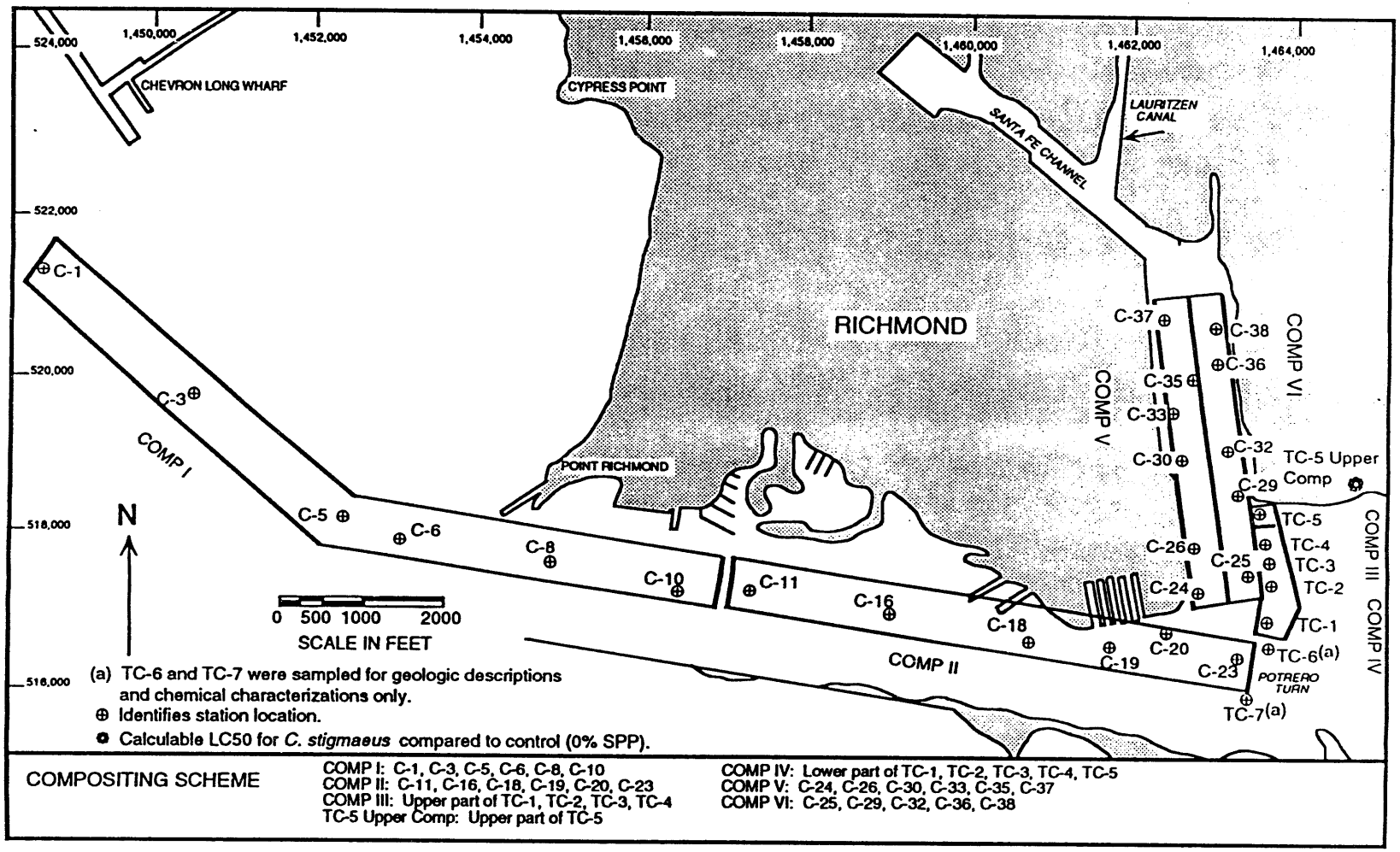


FIGURE 5.2. Richmond Harbor Composites that Produced a Calculable LC50 Value in Suspended-Particulate-Phase Test(s) When Compared to the Control

6.0 BIOACCUMULATION

The evaluation of tissue bioaccumulation results relative to the Deep Off-Shelf Reference Area for the Richmond Harbor Project are presented in Sections 6.1 and 6.2. The complete tissue chemistry, quality control results, and quality control summaries are located in *Ecological Evaluation of Proposed Dredged Material from Richmond Harbor* (Pinza et al. 1992).

M. nasuta and *N. caecoides* were exposed to solid-phase sediment treatments from Richmond Harbor over a 28-day testing period. The 28-day test was designed to evaluate the bioaccumulation potential of chemical contaminants from each sediment treatment. The tissues of *M. nasuta* and *N. caecoides* were analyzed for approximately 50 contaminants of concern, including PAHs, pesticides, PCBs as aroclors, metals, and butyltins (tri- and di-).

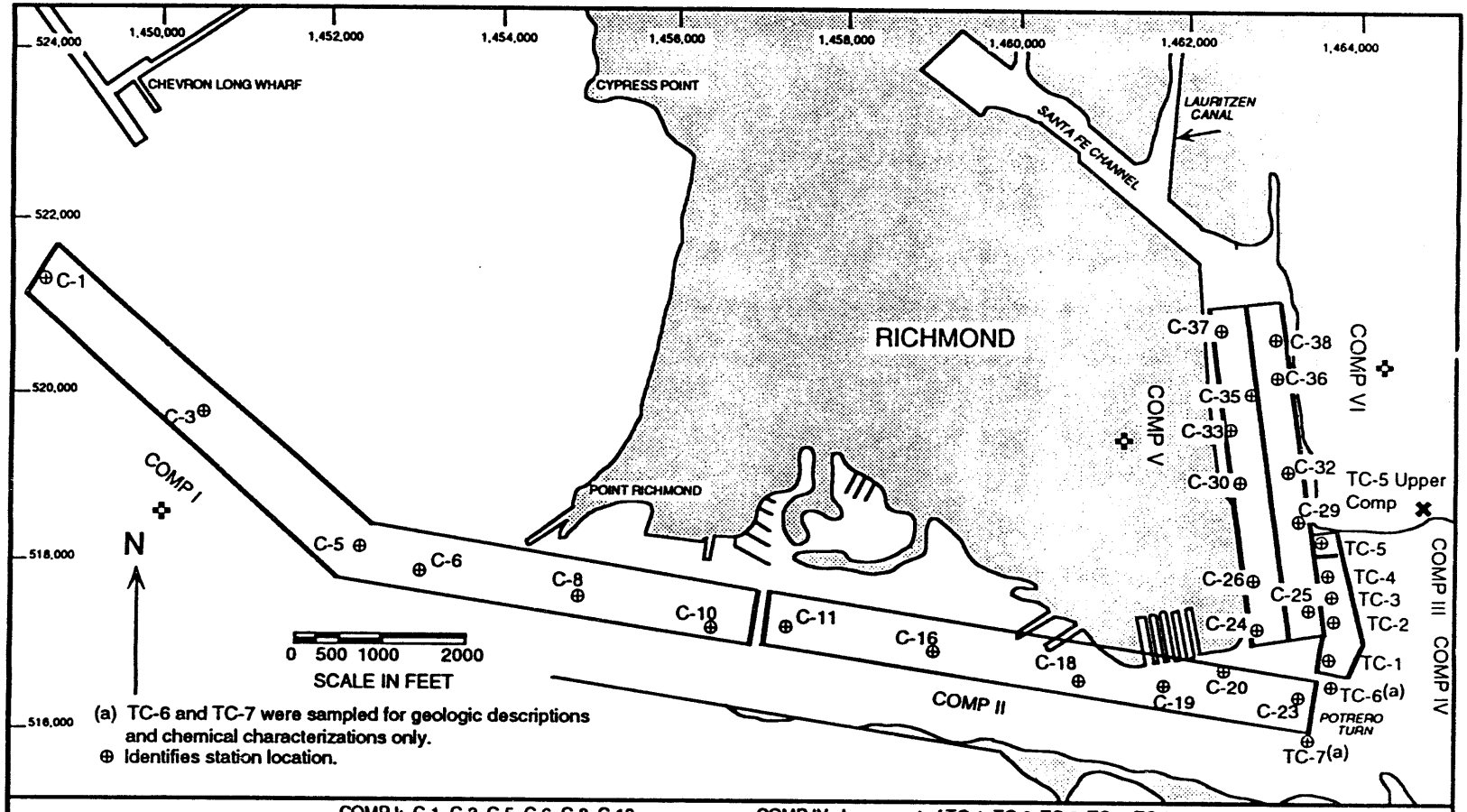
The tissue concentrations of *M. nasuta* and *N. caecoides* exposed to the test treatments were statistically compared to the tissue concentrations of the organisms exposed to reference sediment R-OS using Dunnett's test at $\alpha = 0.05$. Statistical analysis was performed if a detected compound was present in at least one replicate of a given test treatment. When a compound was not detected in any replicate sample, the detection limit value was used in the statistical analyses. If visual inspection showed that the mean tissue concentration in the reference sediment was greater than that in the test treatments, no further analysis was performed. Bioaccumulation was defined as statistically significant if the mean test treatment concentration was determined to be statistically significantly greater than the mean reference (R-OS) concentration using Dunnett's test.

Statistically significant bioaccumulation is not as readily translated into ecological importance as the combination of statistically significant acute toxicity and the difference in mortality between test and reference treatments. In this report, the results of bioaccumulation analyses show 1) the number of contaminants in *M. nasuta* and *N. caecoides* tissues that were statistically significantly elevated above reference sediment R-OS, 2) the concentrations of those contaminants that were statistically significantly elevated, and 3) the magnitude of that elevation (i.e., a contaminant concentration in test treatment tissues may be ≥2 but <5 times higher, ≥5 but <10 times higher, or ≥10 times that in tissues exposed to reference sediment R-OS). All of these factors should be considered when interpreting bioaccumulation data.

6.1 *M. nasuta* BIOACCUMULATION

6.1.1 Polynuclear Aromatic Hydrocarbon Bioaccumulation in *M. nasuta*

M. nasuta were exposed to the seven Richmond Harbor composites for 28 days to determine if the contaminants of concern were elevated in the tissues exposed to the sediment treatments (Figure 6.1). The ANOVA data for all comparisons conducted for the *M. nasuta* tissues



COMPOSITING SCHEME

COMP I: C-1, C-3, C-5, C-6, C-8, C-10
COMP II: C-11, C-16, C-18, C-19, C-20, C-23
COMP III: Upper part of TC-1, TC-2, TC-3, TC-4
TC-5 Upper Comp: Upper part of TC-5
COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5
COMP V: C-24, C-26, C-30, C-33, C-35, C-37
COMP VI: C-25, C-29, C-32, C-36, C-38

✤ Statistically significant mean LPAH concentrations in *M. nasuta* tissues compared to reference sediment R-OS.

✖ Mean LPAH concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥2 but <5 times the mean concentrations in the tissues exposed to reference sediment R-OS.

◆ Mean LPAH concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥5 but <10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

✠ Mean LPAH concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

FIGURE 6.1 Sediment Treatments with Low-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in *M. nasuta* Tissues Statistically Significantly Greater than Those Exposed to Reference Sediment R-OS

are presented in Table 6.1. The LPAH results (µg/kg dry weight) are summarized in Table 6.2. Phenanthrene was statistically significantly different in the tissues exposed to COMP I, COMP V and COMP VI at magnitudes of <2 times those found in the tissues exposed to reference sediment R-OS. The test treatment TC-5 Upper Comp, located in the turning circle, was comprised of 84% YBM and was statistically significantly different for phenanthrene and anthracene in the *M. nasuta* tissues at a magnitude of ≥2 but <5 times the concentrations found in the tissues exposed to reference sediment R-OS.

The statistical analyses of HPAH results (µg/kg dry weight) are presented in Table 6.3. The tissues exposed to COMP V, COMP VI, and TC-5 Upper Comp were statistically significantly different for at least three HPAH compounds at a magnitude of ≥10 times the reference sediment R-OS. The Inner Harbor Channel stations, represented by COMP V and COMP VI, were statistically significantly different for benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)pyrene in *M. nasuta* tissues exposed to these test treatments at levels ranging from 9 to 13 times that found in the tissues exposed to reference sediment R-OS (Figure 6.2). Tissues exposed to TC-5 Upper Comp showed statistically significant differences for 7 of the 10 HPAH compounds analyzed at a magnification ranging from 12 to 30 times above the tissues exposed to reference sediment R-OS. Pyrene had the highest tissue elevations in 5 of the 7 treatments at magnifications of ≥5 times the tissue concentrations found in reference sediment R-OS.

6.1.2 Pesticide and Polychlorinated Biphenyl Bioaccumulation in *M. nasuta*

The results of the pesticide and PCB (µg/kg dry weight) analyses using Dunnett's test are presented in Table 6.4. Only two of the pesticide compounds analyzed were statistically significantly elevated in tissues exposed to Richmond Harbor sediments compared to the tissues exposed to reference sediment R-OS. Levels of 4,4'-DDD were statistically significantly different in all the test composites, with the exception of COMP IV, at magnifications ranging from 4.5 to 158 times those found in tissues exposed to reference sediment R-OS. The greatest statistically significant elevations of this pesticide occurred in the tissues exposed to the composites from the Inner Harbor Channel sediments (COMP V and COMP VI) (Figure 6.3). Tissues exposed to COMP V, COMP VI, and TC-5 Upper Comp were also statistically significantly different for the pesticide 4,4'-DDE at a magnitude of ≥2 but <5 times the tissues exposed to reference sediment R-OS.

As shown in Table 6.4, Aroclor 1254 was statistically significantly different for all the test treatments compared to reference sediment R-OS. These statistically significant differences were at magnitudes ranging from 1.7 to 8.9 times the concentrations measured in the tissues exposed to reference sediment R-OS.

TABLE 6.1. ANOVA Results for Chemical Parameters in Tissues of *M. nasuta* Compared to Reference Sediment R-OS

Parameter	Sum of Squares Treatment	Sum of Squares Residual	Degrees of Freedom Treatment	Degrees of Freedom Residual	F-ratio	p-value
Polynuclear Aromatic Hydrocarbons						
Naphthalene	2.131	3.800	7	32	2.564	0.0324
Acenaphthylene	0.306	24.354	3	16	0.067	0.9766
Acenaphthene	0.536	9.179	7	32	0.267	0.9624
Fluorene	0.795	1.482	7	32	2.453	0.0392
Phenanthrene	3.970	1.370	7	32	13.245	0.0001
Anthracene	5.155	10.375	7	32	2.272	0.0537
Fluoranthene	31.628	1.969	7	32	73.435	0.0001
Pyrene	77.177	1.992	7	32	177.155	0.0001
Benzo(a)anthracene	33.512	10.479	7	32	14.619	0.0001
Chrysene	37.182	4.085	7	32	41.613	0.0001
Benzo(b)fluoranthene	42.920	3.135	7	32	62.588	0.0001
Benzo(k)fluoranthene	42.771	5.575	7	32	35.070	0.0001
Benzo(a)pyrene	38.403	4.053	6	28	44.216	0.0001
Indeno(1,2,3-c,d)pyrene	8.056	6.142	5	24	6.295	0.0007
Benzo(g,h,i)perylene	7.372	4.410	5	24	8.024	0.0001
Dibenzo(a,h)anthracene	0.256	4.787	3	16	0.285	0.8356
Chlorinated Pesticides						
Alpha-BHC	10.501	24.664	7	32	1.946	0.0944
Delta-BHC	0.498	5.405	3	16	0.491	0.6934
Gamma-BHC	1.515	3.174	7	32	2.182	0.0627
4,4'-DDD	131.366	4.034	7	32	148.861	0.0001
4,4'-DDE	41.294	3.074	7	32	61.411	0.0001
4,4'-DDT	2.859	22.521	3	16	0.677	0.5787
Dieldrin	23.694	17.794	6	28	6.214	0.0003
Endosulfan II	1.405	18.223	3	16	0.411	0.7472
Polychlorinated Biphenyl						
Aroclor 1254	21.012	0.885	7	32	108.577	0.0001
Metals						
Silver	4.591	13.930	7	32	1.507	0.2004
Arsenic	0.212	0.724	7	32	1.339	0.2649
Cadmium	1.492	4.358	7	32	1.565	0.1817
Chromium	0.679	3.992	7	32	0.778	0.6106
Copper	0.465	1.369	7	32	1.552	0.1858
Mercury	2.180	3.463	7	32	2.878	0.0190
Nickel	0.476	2.358	7	32	0.923	0.5019
Lead	1.749	1.527	7	32	5.235	0.0005
Selenium	0.426	1.335	7	32	1.459	0.2171
Zinc	0.558	0.920	7	32	2.771	0.0227
Butyltins						
Tributyltin	0.774	1.944	7	32	1.820	0.1176
Dibutyltin	3.918	16.992	6	28	1.076	0.4003

TABLE 6.2. Mean Low-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	(Concentrations in µg/kg Dry Weight)					
	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
R-OS	12.43	8.26 UJ[a]	3.86	5.04 UJ	10.89	2.61 UJ
COMP I	---[b]	---	---	---	15.08	---
COMP II	---	---	---	---	---	---
COMP III	---	---	---	---	---	---
TC-5 Upper Comp	20.96	---	---	---	**27.88**	**6.11**
COMP IV	---	---	---	---	---	---
COMP V	---	---	---	---	16.48	---
COMP VI	21.09	---	---	---	16.02	---

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.

(b) --- Mean value not statistically significantly different from reference sediment R-OS.

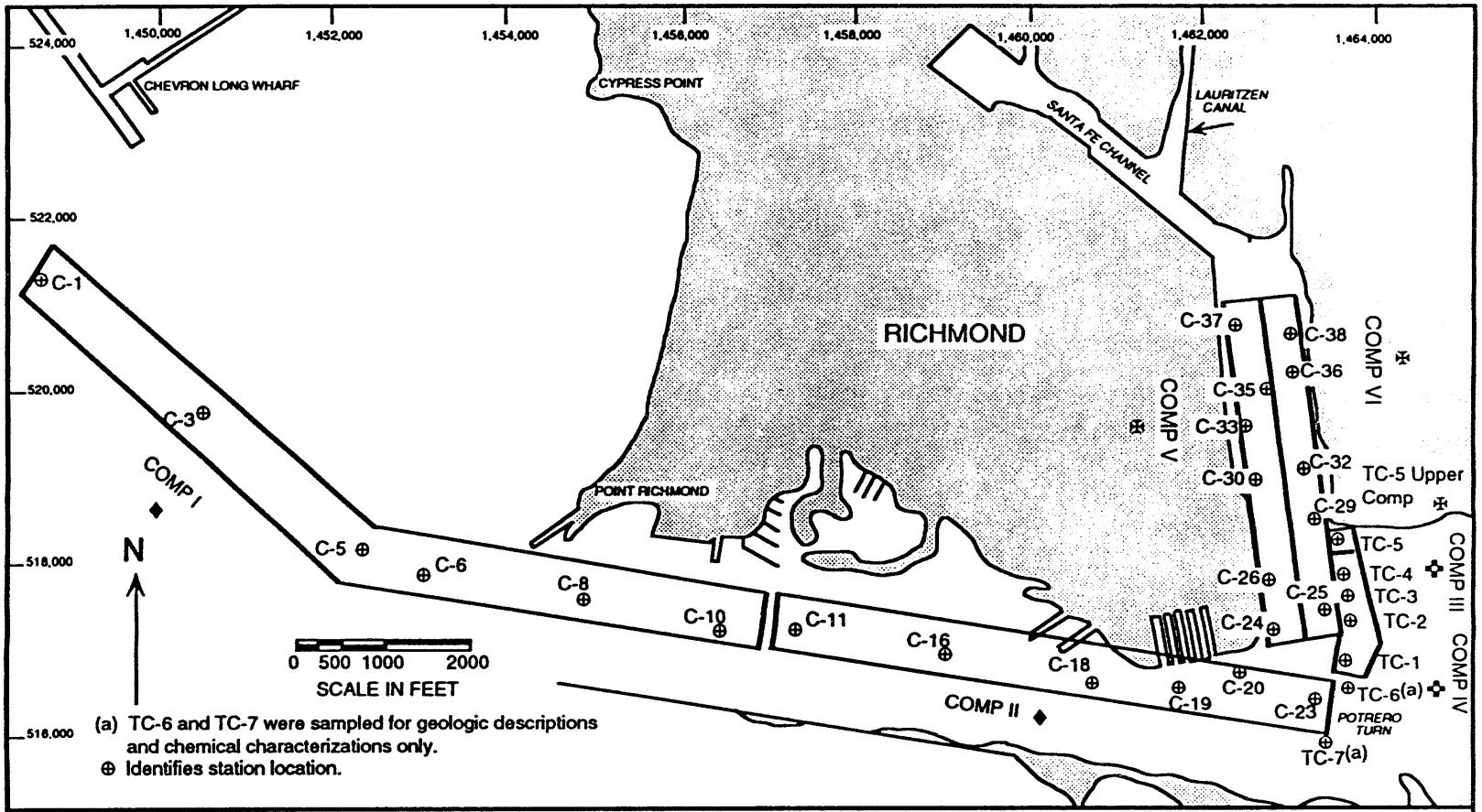
TABLE 6.3. Mean High-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

(Concentrations in µg/kg Dry Weight)

Sediment Treatment	Fluor-anthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b) fluor-anthene	Benzo(k) fluor-anthene	Benzo(a) pyrene	Indeno (1,2,3-c,d) pyrene	Benzo (g,h,i) perylene
R-OS	12.31	8.67	3.86 UJ[a]	5.19	4.41 UJ	3.66 UJ	3.72 UJ	5.29 UJ	7.26 UJ
COMP I	**36.02**	**61.42**	**10.84**	**15.97**	**24.51**	**16.15**	**15.68**	9.20	10.98
COMP II	**25.42**	**48.99**	—[b]	**11.70**	**21.01**	**14.28**	**14.57**	9.00	11.24 UJ
COMP III	—	—	—	—	7.52 UJ	—	—	—	—
TC-5 Upper Comp	**154.17**	**267.23**	**44.94**	**69.35**	**80.93**	**61.72**	**62.08**	**22.49**	**27.07**
COMP IV	—	—	—	—	8.00 UJ	6.87 UJ	—	—	—
COMP V	**41.63**	**146.49**	**18.76**	**26.50**	**57.06**	**37.37**	**35.83**	**14.35**	**18.17**
COMP VI	**34.97**	**149.63**	**17.54**	**24.73**	**55.03**	**38.39**	**34.79**	**13.35**	**16.81**

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.

(b) — Mean value not statistically significantly different from reference sediment R-OS.



COMPOSITING SCHEME

COMP I: C-1, C-3, C-5, C-6, C-8, C-10
COMP II: C-11, C-16, C-18, C-19, C-20, C-23
COMP III: Upper part of TC-1, TC-2, TC-3, TC-4
TC-5 Upper Comp: Upper part of TC-5
COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5
COMP V: C-24, C-26, C-30, C-33, C-35, C-37
COMP VI: C-25, C-29, C-32, C-36, C-38

✤ Statistically significant mean HPAH concentrations in *M. nasuta* tissues compared to reference sediment R-OS.

✖ Mean HPAH concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥2 but <5 times the mean concentrations in the tissues exposed to reference sediment R-OS.

◆ Mean HPAH concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥5 but <10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

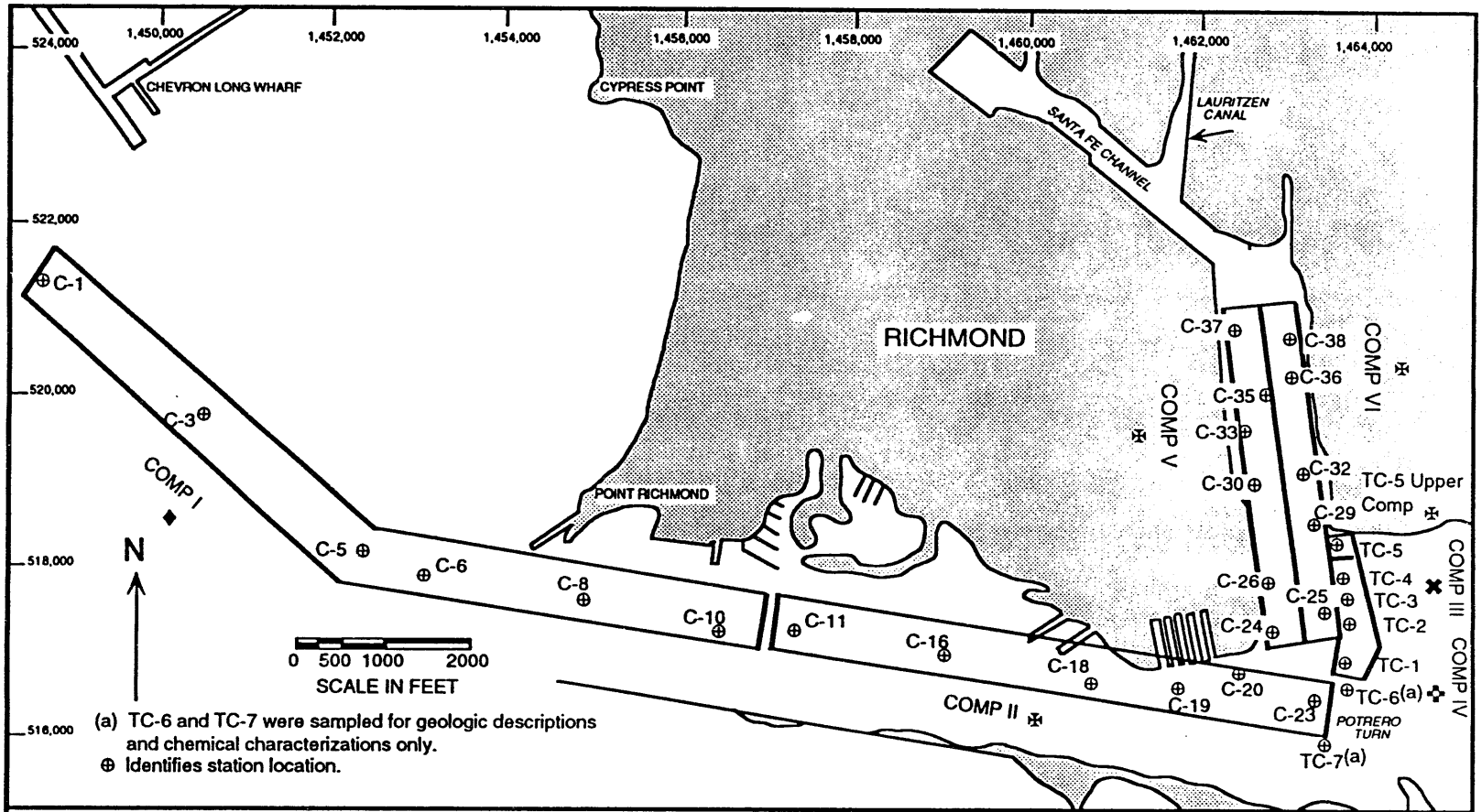
✠ Mean HPAH concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

FIGURE 6.2. Sediment Treatments with High-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in *M. nasuta* Tissues Statistically Significantly Greater than Those Exposed to Reference Sediment R-OS

TABLE 6.4. Mean Pesticide and Polychlorinated Biphenyl Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	(Concentrations in µg/kg Dry Weight)								
Sediment Treatment	Alpha BHC	Delta BHC	Gamma BHC	4,4' DDD	4,4' DDE	4,4' DDT	Dieldrin	Endo-sulfan II	Aroclor 1254
R-OS	1.107	0.514 UJE[a]	4.094 E[b]	0.505	3.991	1.330 U[c]	4.128 UJ[d]	1.575 UJ	22.827
COMP I	---[e]	—	—	4.104	—	—	—	—	**78.013**
COMP II	—	—	—	**8.423**	—	—	—	—	**92.039**
COMP III	—	—	—	**2.285**	—	—	—	—	**58.732**
TC-5 Upper Comp	—	—	—	**11.178**	**9.719**	—	—	—	**173.525**
COMP IV	—	—	—	—	—	—	—	—	37.798
COMP V	—	—	—	**66.266**	**18.332**	—	—	—	**158.738**
COMP VI	—	—	—	**79.833**	**18.541**	—	—	—	**202.853**

(a) UJE Mean of undetected values, values detected below method detection limit, or estimated values.
(b) E Value is an estimate; analyte not detected on confirmation column.
(c) U Undetected in all replicates; value is mean of dry weight detection limits.
(d) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.
(e) — Mean value not statistically significantly different from reference sediment R-OS.



COMPOSITING SCHEME

COMP I: C-1, C-3, C-5, C-6, C-8, C-10
COMP II: C-11, C-16, C-18, C-19, C-20, C-23
COMP III: Upper part of TC-1, TC-2, TC-3, TC-4
TC-5 Upper Comp: Upper part of TC-5
COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5
COMP V: C-24, C-26, C-30, C-33, C-35, C-37
COMP VI: C-25, C-29, C-32, C-36, C-38

✣ Statistically significant mean PCB and/or pesticide concentrations in *M. nasuta* tissues compared to reference sediment R-OS.

✖ Mean PCB and/or pesticide concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥2 but <5 times the mean concentrations in the tissues exposed to reference sediment R-OS.

◆ Mean PCB and/or pesticide concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥5 but <10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

✠ Mean PCB and/or pesticide concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

FIGURE 6.3. Sediment Treatments with Polychlorinated Biphenyl and Pesticide Concentrations in *M. nasuta* Tissues Statistically Significantly Greater than Those Exposed to Reference Sediment R-OS

6.1.3 Metals Bioaccumulation in *M. nasuta*

Metals results are reported as mg/kg dry weight in Table 6.5. Four (As, Cu, Pb, and Zn) of the 10 metals analyzed had statistically significant differences in the tissues exposed to the test treatments relative to reference sediment R-OS. These statistically significant differences were all at magnifications of <2 times those found in the tissues exposed to reference sediment R-OS. Lead was statistically significantly different for tissues exposed to four of the seven test treatments (COMP II, COMP V, COMP VI, and TC-5 Upper Comp) relative to reference sediment R-OS (Figure 6.4).

6.1.4 Butyltin Bioaccumulation in *M. nasuta*

The organotins, tributyltin and dibutyltin, were not statistically significantly elevated in the tissues exposed to the Richmond Harbor test treatments relative to the tissues exposed to reference sediment R-OS. Statistical evaluations were performed and the results are presented in Table 6.6.

6.2 *N. caecoides* BIOACCUMULATION

6.2.1 Polynuclear Aromatic Hydrocarbon Bioaccumulation in *N. caecoides*

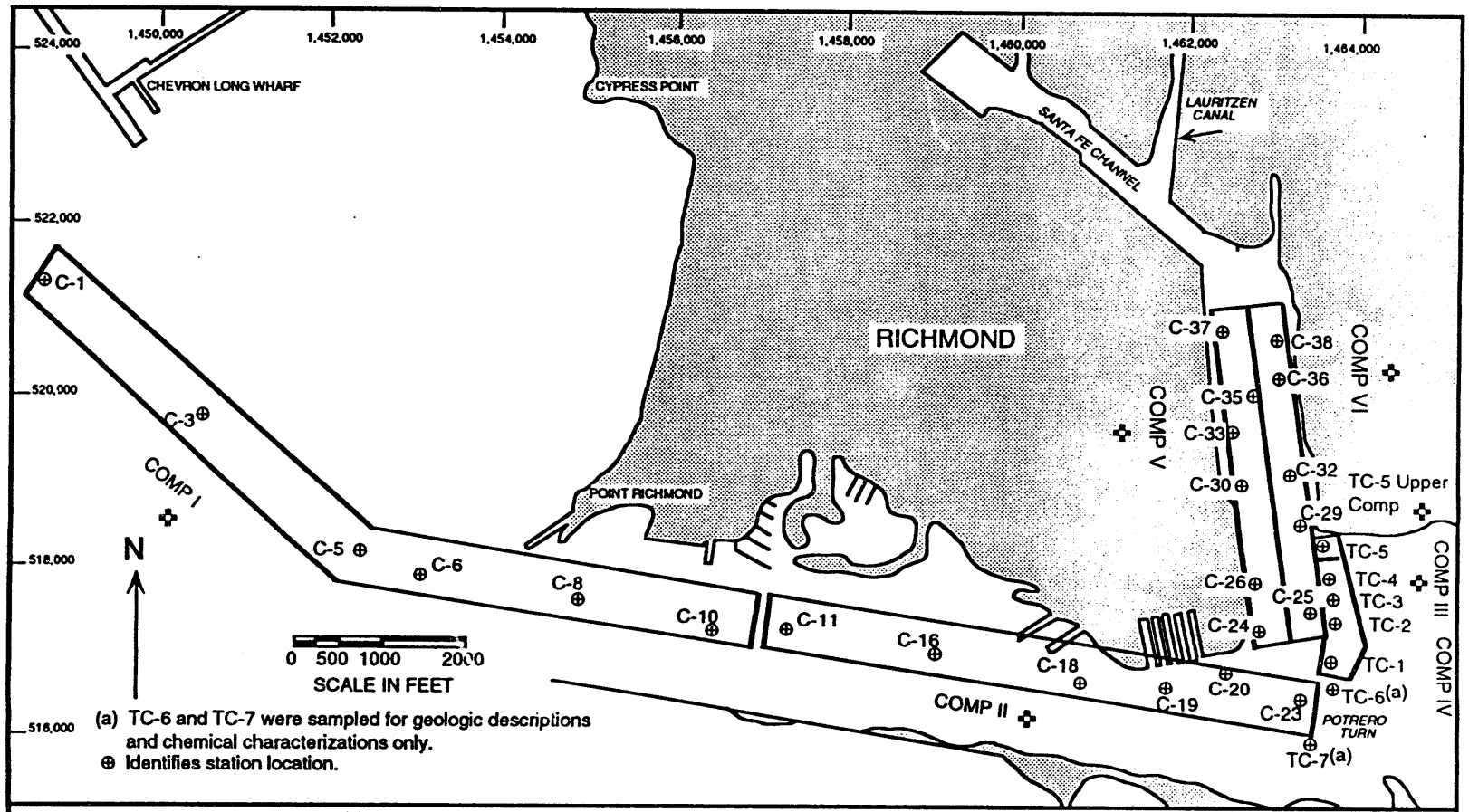
The ANOVA data for all comparisons conducted for the *N. caecoides* tissues are presented in Table 6.7. Table 6.8 summarizes the mean *N. caecoides* tissue values for the detectable LPAH compounds in µg/kg dry weight. Two LPAH compounds, fluorene and phenanthrene, produced statistically significantly elevated levels in the tissues exposed to test treatments COMP I and TC-5 Upper Comp relative to the tissues exposed to reference sediment R-OS, at magnitudes ranging from <2 to ≥2 but <5 times the reference sediment R-OS. Tissues exposed to COMP I were statistically significantly elevated for phenanthrene at a magnitude of <2 times reference sediment R-OS. Tissues exposed to TC-5 Upper Comp were also statistically significantly elevated for phenanthrene at a magnitude of ≥2 but <5 times when compared to the tissues exposed to reference sediment R-OS (Figure 6.5).

Results of the statistical analyses of HPAH compounds (µg/kg dry weight) in *N. caecoides* tissues are reported in Table 6.9. Three of the 10 HPAH compounds analyzed (fluoranthene, pyrene, and chrysene) had statistically significantly elevated tissue levels in at least 5 of the test treatments when compared to reference sediment R-OS. *N. caecoides* tissues exposed to COMP I and COMP II were statistically significantly different for pyrene and at a magnitude of ≥2 but <5 times those found in the tissues exposed to reference sediment R-OS. Tissues exposed to COMP III were statistically significantly elevated for pyrene when compared to tissues exposed to reference sediment R-OS. The *N. caecoides* tissues exposed to sediment from TC-5 Upper Comp were statistically significantly different for the three HPAH compounds at

TABLE 6.5. Mean Metals Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	(Concentrations in mg/kg Dry Weight)									
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
R-OS	0.502	27.0	0.222	2.71	14.70	0.066	5.62	1.22	1.65	96.9
COMP I	---(a)	---	---	---	20.26	---	---	---	---	---
COMP II	---	---	---	---	---	---	---	1.81	---	---
COMP III	---	33.5	---	---	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	---	---	---	---	2.13	---	127.4
COMP IV	---	---	---	---	---	---	---	---	---	---
COMP V	---	---	---	---	---	---	---	2.14	---	135.1
COMP VI	---	---	---	---	21.72	---	---	2.32	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-OS.



COMPOSITING SCHEME

COMP I: C-1, C-3, C-5, C-6, C-8, C-10
COMP II: C-11, C-16, C-18, C-19, C-20, C-23
COMP III: Upper part of TC-1, TC-2, TC-3, TC-4
TC-5 Upper Comp: Upper part of TC-5
COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5
COMP V: C-24, C-26, C-30, C-33, C-35, C-37
COMP VI: C-25, C-29, C-32, C-36, C-38

✤ Statistically significant mean metals concentrations in *M. nasuta* tissues compared to reference sediment R-OS.

✖ Mean metals concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥2 but <5 times the mean concentrations in the tissues exposed to reference sediment R-OS.

◆ Mean metals concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥5 but <10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

✠ Mean metals concentrations in *M. nasuta* tissues that were statistically significantly different at a magnification of ≥10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

FIGURE 6.4. Sediment Treatments with Metals Concentrations in *M. nasuta* Tissues Statistically Significantly Greater than Those Exposed to Reference Sediment R-OS

TABLE 6.6. Mean Butyltin Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	(Concentrations in µg/kg Dry Weight) Tributyltin	Dibutyltin
R-OS	48.2	9.4
COMP I	---(a)	---
COMP II	---	---
COMP III	---	---
TC-5 Upper Comp	---	---
COMP IV	---	---
COMP V	---	---
COMP VI	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-OS.

magnitudes ranging from 12 to 36 times above those found in the tissues exposed to reference sediment R-OS (Figure 6.6). The Inner Harbor Channel test treatments (COMP V and COMP VI) were statistically significantly different for pyrene at a magnitude of ≥10 times those found in reference sediment R-OS. The concentration of fluoranthene and chrysene in the tissues exposed to these test treatments was at a magnitude of ≥2 but <5 times those found in reference sediment R-OS.

6.2.2 Pesticide and Polychlorinated Biphenyl Bioaccumulation in *N. caecoides*

Two chlorinated pesticides and one PCB (µg/kg dry weight) were statistically significantly elevated in the *N. caecoides* tissues exposed to the test treatments relative to reference sediment R-OS (Table 6.10). Five test treatments (COMP I, COMP II, COMP V, COMP VI, and TC-5 Upper Comp) all had levels of 4,4'-DDD that were statistically significantly different and at magnitudes ranging from 3 to 61 times the concentrations found in the tissues exposed to reference sediment R-OS. Levels of the pesticide 4,4'-DDE in the *N. caecoides* tissues were also statistically significant for these same five test treatments in the tissues exposed to reference sediment R-OS (Figure 6.7).

N. caecoides tissues exposed to four test treatments (COMP II, COMP V, COMP VI, and TC-5 Upper Comp) were statistically significant for Aroclor 1254 at a magnitude of <2 times that found in the tissues exposed to reference sediment R-OS.

6.2.3 Metals Bioaccumulation in *N. caecoides*

Table 6.11 presents the mean *N. caecoides* tissue values (mg/kg dry weight) for the metals analysis using Dunnett's test. Two metals (As and Pb) showed statistically significant

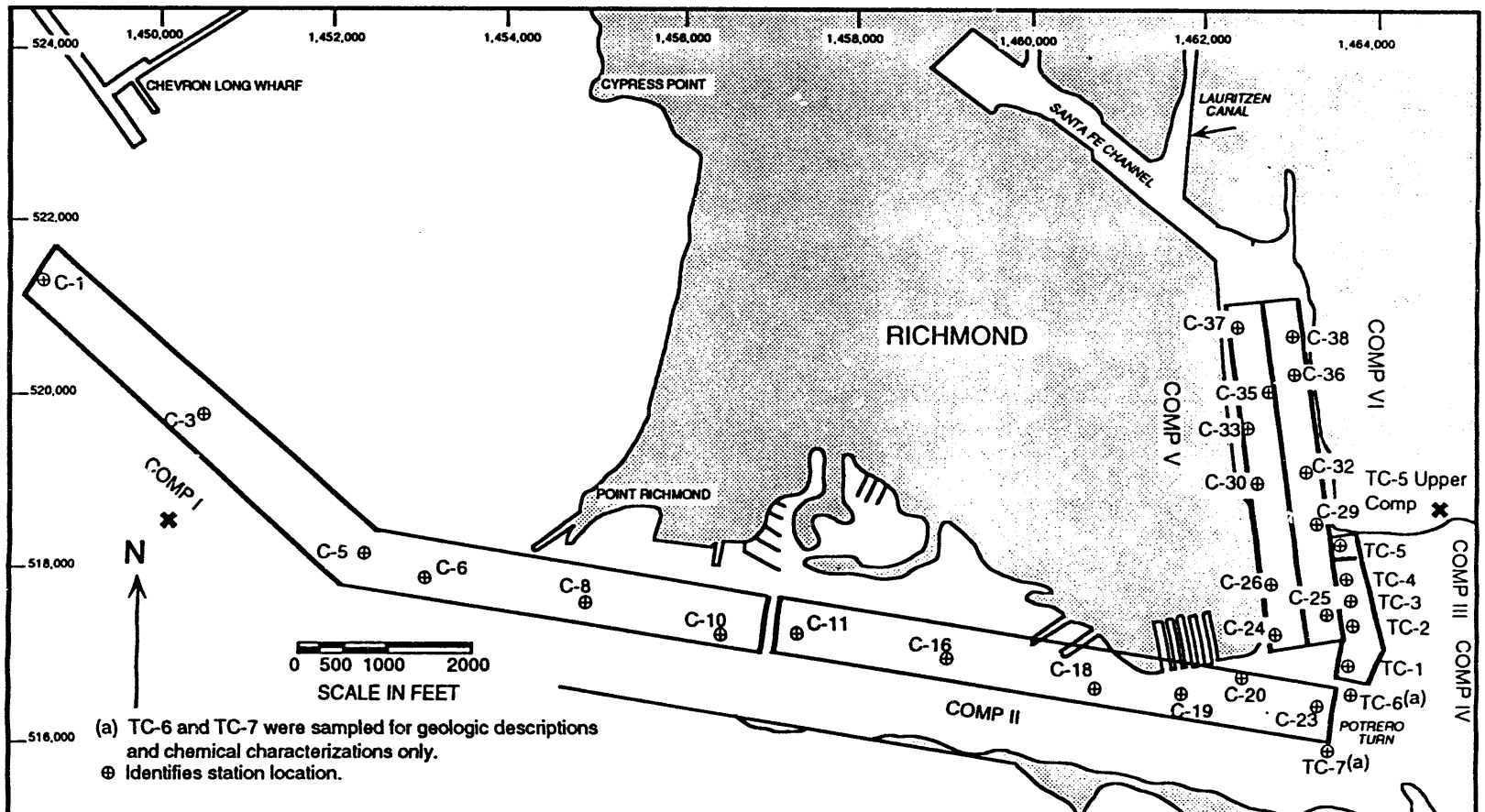
TABLE 6.7. ANOVA Results for Chemical Parameters in Tissues of *N. caecoides* Compared to Reference Sediment R-OS

Parameter	Sum of Squares Treatment	Sum of Squares Residual	Degrees of Freedom Treatment	Degrees of Freedom Residual	F-ratio	p-value
Polynuclear Aromatic Hydrocarbons						
Naphthalene	2.758	11.413	7	32	1.105	0.3839
Acenaphthylene	0.565	18.802	2	12	0.180	0.8372
Acenaphthene	5.083	31.215	7	32	0.744	0.6365
Fluorene	5.910	8.291	7	32	3.258	0.0100
Phenanthrene	5.943	1.302	7	32	20.862	0.0001
Anthracene	14.052	28.257	7	32	2.273	0.0535
Fluoranthene	31.484	1.196	7	32	120.337	0.0001
Pyrene	61.901	1.254	7	32	225.578	0.0001
Benzo(a)anthracene	31.829	75.854	7	32	1.918	0.0991
Chrysene	34.101	2.961	7	32	52.650	0.0001
Benzo(b)fluoranthene	22.382	69.351	7	32	1.475	0.2113
Benzo(k)fluoranthene	27.451	70.581	7	32	1.778	0.1263
Benzo(a)pyrene	9.442	45.816	5	24	0.989	0.4449
Indeno(1,2,3-c,d)pyrene	1.397	14.655	2	12	0.572	0.5792
Dibenzo(a,h)anthracene	1.561	13.452	2	12	0.696	0.5174
Benzo(g,h,i)perylene	3.395	58.249	6	28	0.272	0.9454
Chlorinated Pesticides						
Alpha-BHC	4.024	43.005	6	28	0.437	0.8480
Delta-BHC	1.320	6.025	3	16	1.169	0.3525
Lindane	2.290	12.394	6	28	0.862	0.5343
4,4'-DDD	82.683	11.475	6	28	33.626	0.0001
4,4'-DDE	31.215	3.131	7	32	45.575	0.0001
Dieldrin	27.053	26.980	6	28	4.679	0.0021
Endosulfan I	2.549	11.981	3	16	1.135	0.3648
Endosulfan II	4.171	36.704	5	24	0.545	0.7401
Endosulfan sulfate	1.360	14.813	4	20	0.459	0.7648
Endrin	0.774	2.681	2	12	1.732	0.2184
Endrin aldehyde	0.160	3.738	2	12	0.256	0.7781
Polychlorinated Biphenyl						
Aroclor 1254	19.215	3.646	7	32	24.092	0.0001
Metals						
Silver	2.121	6.847	7	32	1.416	0.2332
Arsenic	0.583	0.675	7	32	3.946	0.0033
Cadmium	0.158	1.163	7	32	0.619	0.7358
Chromium	1.188	3.866	7	32	1.404	0.2378
Copper	0.296	0.526	7	32	2.574	0.0319
Mercury	0.245	0.841	7	32	1.329	0.2690
Nickel	0.707	1.333	7	32	2.423	0.0413
Lead	2.990	0.784	7	32	17.428	0.0001
Selenium	0.699	2.851	7	32	1.122	0.3741
Zinc	0.045	0.216	7	32	0.947	0.4855
Butyltins						
Tributyltin	1.866	16.891	7	32	0.505	0.8238
Dibutyltin	1.107	6.488	4	20	0.853	0.5083

TABLE 6.8. Mean Low-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	(Concentrations in µg/kg Dry Weight)					
	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
R-OS	23.43	41.65 U[a]	17.95 UJ[b]	5.86 J[c]	15.84	9.53 UJ
COMP I	---[d]	---	---	**17.82 UJ**	22.32	---
COMP II	---	---	---	---	---	---
COMP III	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	**26.23 UJ**	**56.60**	---
COMP IV	---	---	---	---	---	---
COMP V	---	---	---	---	---	---
COMP VI	---	---	---	---	---	---

(a) U Undetected in all replicates; value is mean of dry weight detection limits.
(b) UJ Undetected or detected below method detection limit in all replicates; value is mean of detected values and detection limits.
(c) J Analyte detected below method detection limit, but above instrument detection limit.
(d) --- Mean value not statistically significantly different from reference sediment R-OS.



COMPOSITING SCHEME		
	COMP I: C-1, C-3, C-5, C-6, C-8, C-10 COMP II: C-11, C-16, C-18, C-19, C-20, C-23 COMP III: Upper part of TC-1, TC-2, TC-3, TC-4 TC-5 Upper Comp: Upper part of TC-5	COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5 COMP V: C-24, C-26, C-30, C-33, C-35, C-37 COMP VI: C-25, C-29, C-32, C-36, C-38

✣ Statistically significant mean LPAH concentrations in *N. caecoides* tissues compared to reference sediment R-OS.

✖ Mean LPAH concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥2 but <5 times the mean concentrations in the tissues exposed to reference sediment R-OS.

◆ Mean LPAH concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥5 but <10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

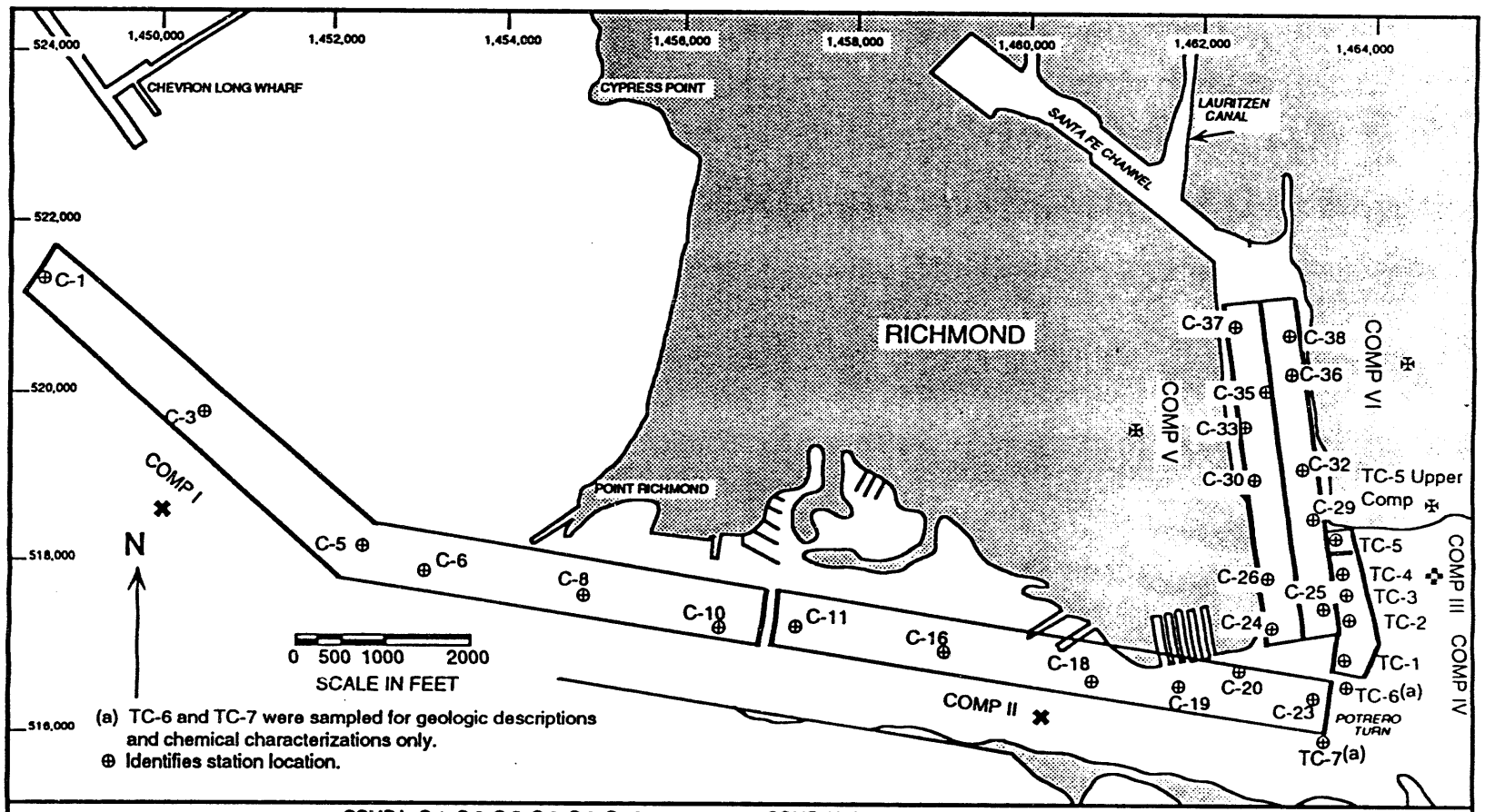
✠ Mean LPAH concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

FIGURE 6.5. Sediment Treatments with Low-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in *N. caecoides* Tissues Statistically Significantly Greater than Those Exposed to Reference Sediment R-OS

TABLE 6.9. Mean High-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	(Concentrations in µg/kg Dry Weight)								
Sediment Treatment	Fluor-anthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b) fluor-anthene	Benzo(k) fluor anthene	Benzo(a) pyrene	Indeno (1,2,3-c,d) pyrene	Benzo (g,h,i) perylene
R-OS	11.15 J[a]	13.73 J	26.51 UJ[b]	7.48 UJ	27.13 UJ	22.63 UJ	27.39 U[c]	32.85 U	39.07 UJ
COMP I	21.21	**58.74**	—[d]	13.29	—	—	—	—	—
COMP II	21.37	**67.48**	—	14.62	—	—	—	—	—
COMP III	—	19.65	—	—	—	—	—	—	—
TC-5 Upper Comp	**210.17**	**491.66**	—	**87.64**	—	—	—	—	—
COMP IV	—	—	—	—	—	—	—	—	—
COMP V	**28.44**	**188.07**	—	**25.62**	—	—	—	—	—
COMP VI	**28.51**	**191.61**	—	**25.47**	—	—	—	—	—

(a) J Analyte detected below method detection limit, but above instrument detection limit.
(b) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.
(c) U Undetected in all replicates; value is mean of dry weight detection limits.
(d) — Mean value not statistically significantly different from reference sediment R-OS.



COMPOSITING SCHEME		
	COMP I: C-1, C-3, C-5, C-6, C-8, C-10 COMP II: C-11, C-16, C-18, C-19, C-20, C-23 COMP III: Upper part of TC-1, TC-2, TC-3, TC-4 TC-5 Upper Comp: Upper part of TC-5	COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5 COMP V: C-24, C-26, C-30, C-33, C-35, C-37 COMP VI: C-25, C-29, C-32, C-36, C-38

✤ Statistically significant mean HPAH concentrations in *N. caecoides* tissues compared to reference sediment R-OS.

✖ Mean HPAH concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥2 but <5 times the mean concentrations in the tissues exposed to reference sediment R-OS.

♦ Mean HPAH concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥5 but <10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

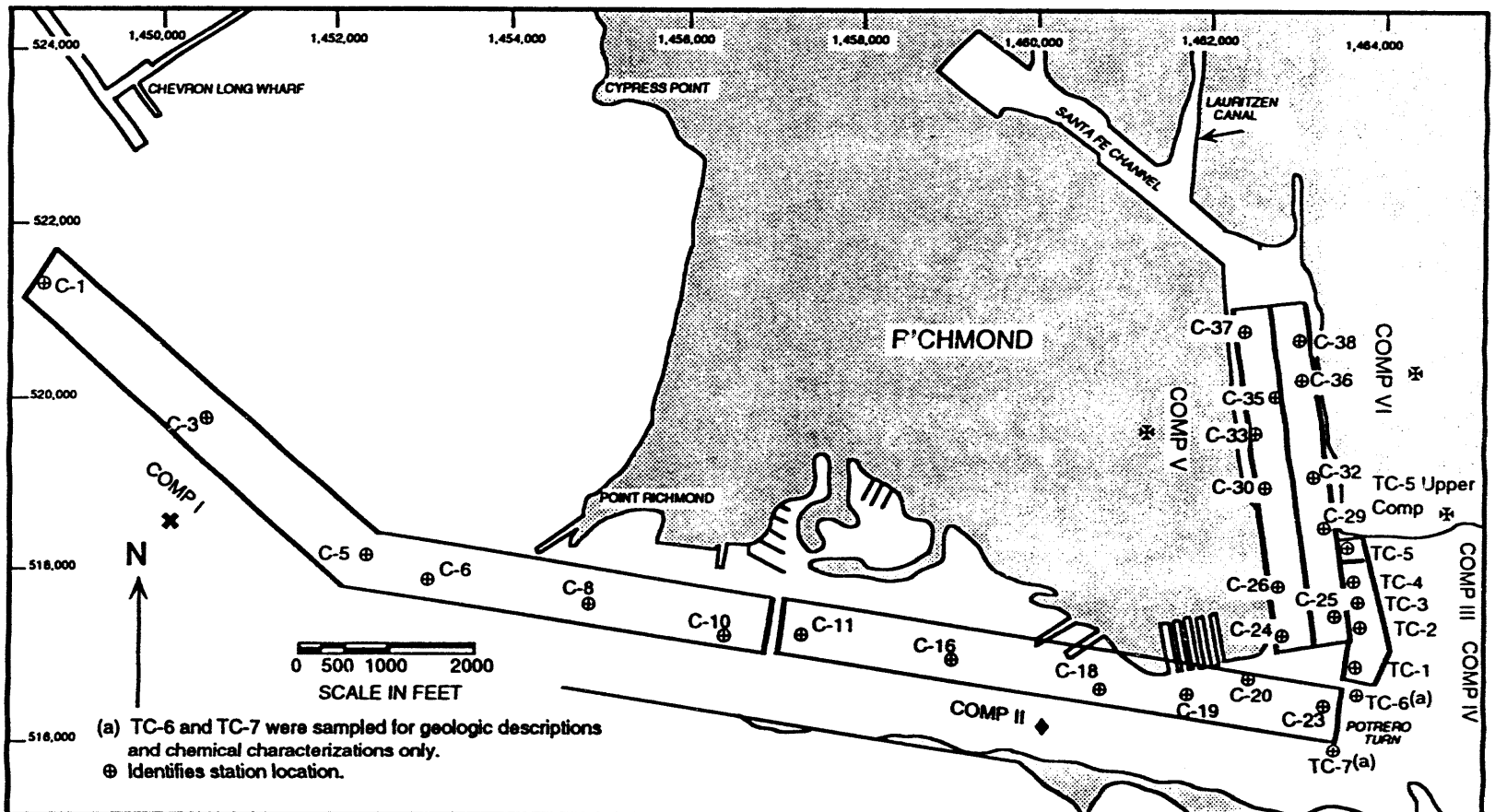
✠ Mean HPAH concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

FIGURE 6.6. Sediment Treatments with High-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in *N. caecoides* Tissues Statistically Significantly Greater than Those Exposed to Reference Sediment R-OS

TABLE 6.10. Mean Pesticide and Polychlorinated Biphenyl Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	(Concentrations in µg/kg Dry Weight)									
Sediment Treatment	Alpha BHC	Delta BHC	Gamma BHC	4,4' DDD	4,4' DDE	Dieldrin	Endo-sulfan I	Endo-sulfan II	Endosulfan sulfate	Aroclor 1254
R-OS	2.22 UJ[a]	2.57 U[b]	2.34 UJE[c]	1.73 U	7.94	26.84 U	7.38 U	7.38 U	7.38 U	73.75 U
COMP I	—[d]	—	—	**5.97**	12.70	—	—	—	—	—
COMP II	—	—	—	**12.97**	14.58	—	—	—	—	172.22
COMP III	—	—	—	—	—	—	—	—	—	—
TC-5 Upper Comp	—	—	—	**18.80**	**23.27**	—	—	—	—	410.42
COMP IV	—	—	—	—	—	—	—	—	—	—
COMP V	—	—	—	**76.11**	**40.41**	—	—	—	—	317.81
COMP VI	—	—	—	**105.48**	**37.33**	—	—	—	—	362.74

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.
(b) U Undetected in all replicates; value is mean of dry weight detection limits.
(c) UJE Mean of undetected values, values detected below method detection limit, or estimated values.
(d) — Mean value not statistically significantly different from reference sediment R-OS.



(a) TC-6 and TC-7 were sampled for geologic descriptions and chemical characterizations only.
⊕ Identifies station location.

COMPOSITING SCHEME

COMP I: C-1, C-3, C-5, C-6, C-8, C-10
COMP II: C-11, C-16, C-18, C-19, C-20, C-23
COMP III: Upper part of TC-1, TC-2, TC-3, TC-4
TC-5 Upper Comp: Upper part of TC-5
COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5
COMP V: C-24, C-26, C-30, C-33, C-35, C-37
COMP VI: C-25, C-29, C-32, C-36, C-38

✣ Statistically significant mean PCB and/or pesticide concentrations in *N. caecoides* tissues compared to reference sediment R-OS.

✖ Mean PCB and/or pesticide concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥2 but <5 times the mean concentrations in the tissues exposed to reference sediment R-OS.

♦ Mean PCB and/or pesticide concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥5 but <10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

✠ Mean PCB and/or pesticide concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

FIGURE 6.7. Sediment Treatments with Polychlorinated Biphenyl and Pesticide Concentrations in *N. caecoides* Tissues Statistically Significantly Greater than Those Exposed to Reference Sediment R-OS

TABLE 6.11. Mean Metals Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnifcation; shaded box indicates ≥ 10-fold magnification)

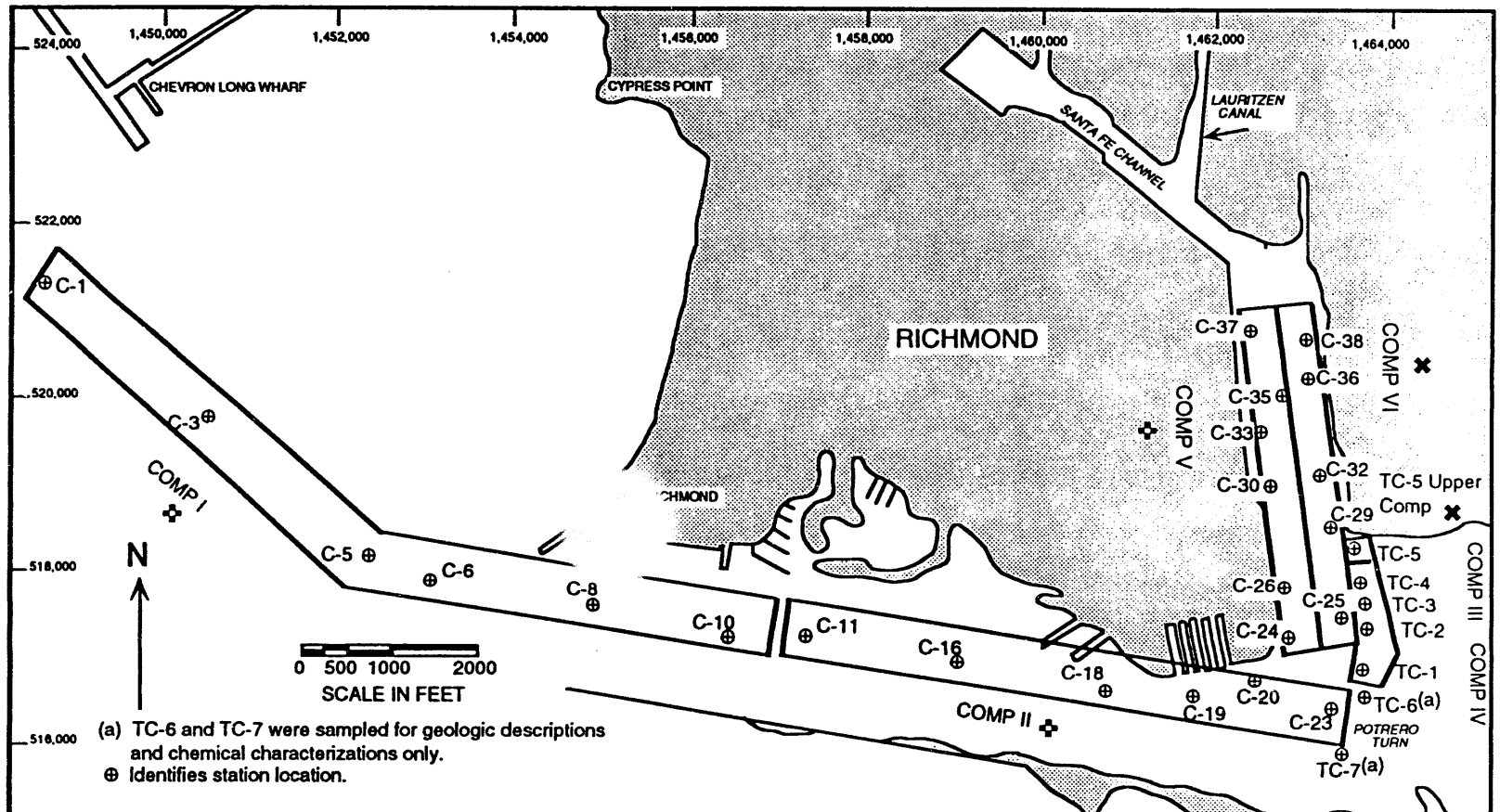
Sediment Treatment	(Concentrations in mg/kg Dry Weight)									
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
R-OS	0.041	24.1	1.16	0.86	11.86	0.074	5.33	0.62	1.87	182.1
COMP I	---(a)	34.7	---	---	---	---	---	1.05	---	---
COMP II	---	31.1	---	---	---	---	---	0.96	---	---
COMP III	---	---	---	---	---	---	---	---	---	---
TC-5 Upper Comp	---	35.8	---	---	---	---	---	**1.26**	---	---
COMP IV	---	---	---	---	---	---	---	---	---	---
COMP V	---	31.1	---	---	---	---	---	1.12	---	---
COMP VI	---	32.8	---	---	---	---	---	**1.24**	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-OS.

elevations in *N. caecoides* tissues for five Richmond Harbor test treatments relative to tissues exposed to reference sediment R-OS (Figure 6.8). Concentrations of Pb in the tissues exposed to TC-5 Upper Comp and COMP VI were statistically significantly different at a magnitude of ≥2 but <5 times those found in the tissues exposed to reference sediment R-OS.

6.2.4 Butyltin Bioaccumulation in *N. caecoides*

Results of the statistical analyses for butyltin levels (mg/kg dry weight) in the tissues of *N. caecoides* are summarized in Table 6.12. No statistical significance was observed in the mean concentrations of tributyltin and dibutyltin in *N. caecoides* tissues exposed to Richmond Harbor test treatments relative to the tissues exposed to reference sediment R-OS.



COMPOSITING SCHEME

COMP I: C-1, C-3, C-5, C-6, C-8, C-10
COMP II: C-11, C-16, C-18, C-19, C-20, C-23
COMP III: Upper part of TC-1, TC-2, TC-3, TC-4
TC-5 Upper Comp: Upper part of TC-5
COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5
COMP V: C-24, C-26, C-30, C-33, C-35, C-37
COMP VI: C-25, C-29, C-32, C-36, C-38

✤ Statistically significant mean metals concentrations in *N. caecoides* tissues compared to reference sediment R-OS.

✖ Mean metals concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥2 but <5 times the mean concentrations in the tissues exposed to reference sediment R-OS.

♦ Mean metals concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥5 but <10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

✠ Mean metals concentrations in *N. caecoides* tissues that were statistically significantly different at a magnification of ≥10 times the mean concentrations in the tissues exposed to reference sediment R-OS.

FIGURE 6.8. Sediment Treatments with Metals Concentrations in *N. caecoides* Tissues Statistically Significantly Greater than Those Exposed to Reference Sediment R-OS

TABLE 6.12. Mean Butyltin Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-OS (plain type indicates statistical significance above R-OS; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-OS mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	(Concentrations in µg/kg Dry Weight) Tributyltin	Dibutyltin
R-OS	105.77	78.53 U[a]
COMP I	---[b]	---
COMP II	---	---
COMP III	---	---
TC-5 Upper Comp	---	---
COMP IV	---	---
COMP V	---	---
COMP VI	---	---

(a) U Undetected in all replicates; value is mean of dry weight detection limits.
(b) --- Mean value not statistically significantly different from reference sediment R-OS.

7.0 DISCUSSION AND CONCLUSIONS

The requirements for Tier III testing in the *1991 Implementation Manual* are considered to be the most sensitive, environmentally protective suite of tests conducted on dredged material. Tier III testing was conducted on dredged material from Richmond Harbor by comparing sediment chemistry, water column toxicity, deposited sediment (solid-phase) toxicity, and deposited sediment bioaccumulation to that found in reference sediment R-OS.

In this section, comparisons of dredged material from Richmond Harbor to the Deep Off-Shelf Reference Area are provided to evaluate the acceptability of this sediment for ocean disposal. For each station, sediment contaminant levels, contribution to acute toxicity, either as water column effect or deposited sediment effect, and potential for bioaccumulation are presented in Figure 7.1. This matrix is a summary of sediment chemistry, acute toxicity, and bioaccumulation potential for the test treatments relative to reference sediment R-OS. Bioaccumulation potential is categorized by the number of contaminants that were elevated in *M. nasuta* and *N. caecoides* tissues exposed to the test treatments and the magnitude of tissue elevations (i.e., 2-, 5-, 10-times) relative to the tissues exposed to reference sediment R-OS. The portrayal of the information in Figure 7.2 is helpful for showing where contaminants were accumulated by *M. nasuta* and/or *N. caecoides* to varying degrees and where experimental toxicity was observed.

7.1 COMPARISON OF RICHMOND HARBOR AND DEEP OFF-SHELF SEDIMENT CHARACTERISTICS

In general, fine-grained sediments (silt and clay) were positively correlated with higher organic carbon and volatile solids. The Deep Off-Shelf Reference Area sediment is quite fine grained (84% silt and clay) and has typical levels of TOC and volatiles that are associated with fine-grained sediment. The grain-size, TOC, and TVS sediment values for the Deep Off-Shelf Reference Area sediments were within the top 20% of the test treatments. The oil and grease and TPH concentrations in the Deep Off-Shelf Reference Area sediments were low relative to the concentrations found in the Richmond Harbor test treatments.

7.2 POTENTIAL WATER COLUMN EFFECTS FOLLOWING DISPOSAL OF PROPOSED DREDGED MATERIAL FROM RICHMOND HARBOR AT THE DEEP OFF-SHELF REFERENCE AREA

Determination of compliance for water column effects involves deciding whether the concentration of dissolved plus suspended contaminants, after allowance for initial mixing, is greater than 0.01 of the acutely toxic concentration beyond the boundaries of the disposal site within the first 4 hours after disposal. The acutely toxic concentration in this case is taken to be

Sediment Treatments	YBM	Sediment Chemistry					Toxicity		Significant Bioaccumulation						Bioaccumulation ≥ 2 but < 5 times						Bioaccumulation ≥ 5 but < 10 times						Bioaccumulation ≥ 10 times					
	Average % of test material that is YBM	Sediment LPAH > R-OS	Sediment HPAH > R-OS	Sediment pesticide and PCB > R-OS	Sediment metals > R-OS	Sediment butyltins > R-OS	Species associated with SPP toxicity	Species with solid-phase acute toxicity	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds
COMP I	100	√	√	2	7	2			1/2	9/3	1/2	1/	1/2		/1	5/1	/1	1/				2/	1/									
COMP II	72	√	√	2	7	1				8/3	1/2	1/1	1/2			5/1		1/				1/	/1						1/			
COMP III	100		√	1	7	1		N		1/1	1/	1/	1/				1/	1/														
TC-5 Upper Comp	84	√	√	4	9	1	C	N	3/2	9/3	2/2	1/1	2/2		2/2	2/	1/1		/1					1/				7/3	1/1			
COMP IV	55				5	1		N		2/		1/																				
COMP V	69	√	√	4	7	2			1/	9/3	2/2	1/1	2/2			4/2	1/					2/	/1	1/				3/1	1/1			
COMP VI	52	√	√	4	7	1			2/	9/3	2/2	1/1	2/2			5/2	1/1		/1			1/		1/				3/1	1/1			

YBM younger bay mud member.

√ Total low-molecular-weight polynuclear aromatic hydrocarbons (LPAH) or high-molecular-weight polynuclear aromatic hydrocarbons (HPAH) with detected values above reference sediment R-OS.

SPP Suspended-particulate-phase toxicity.

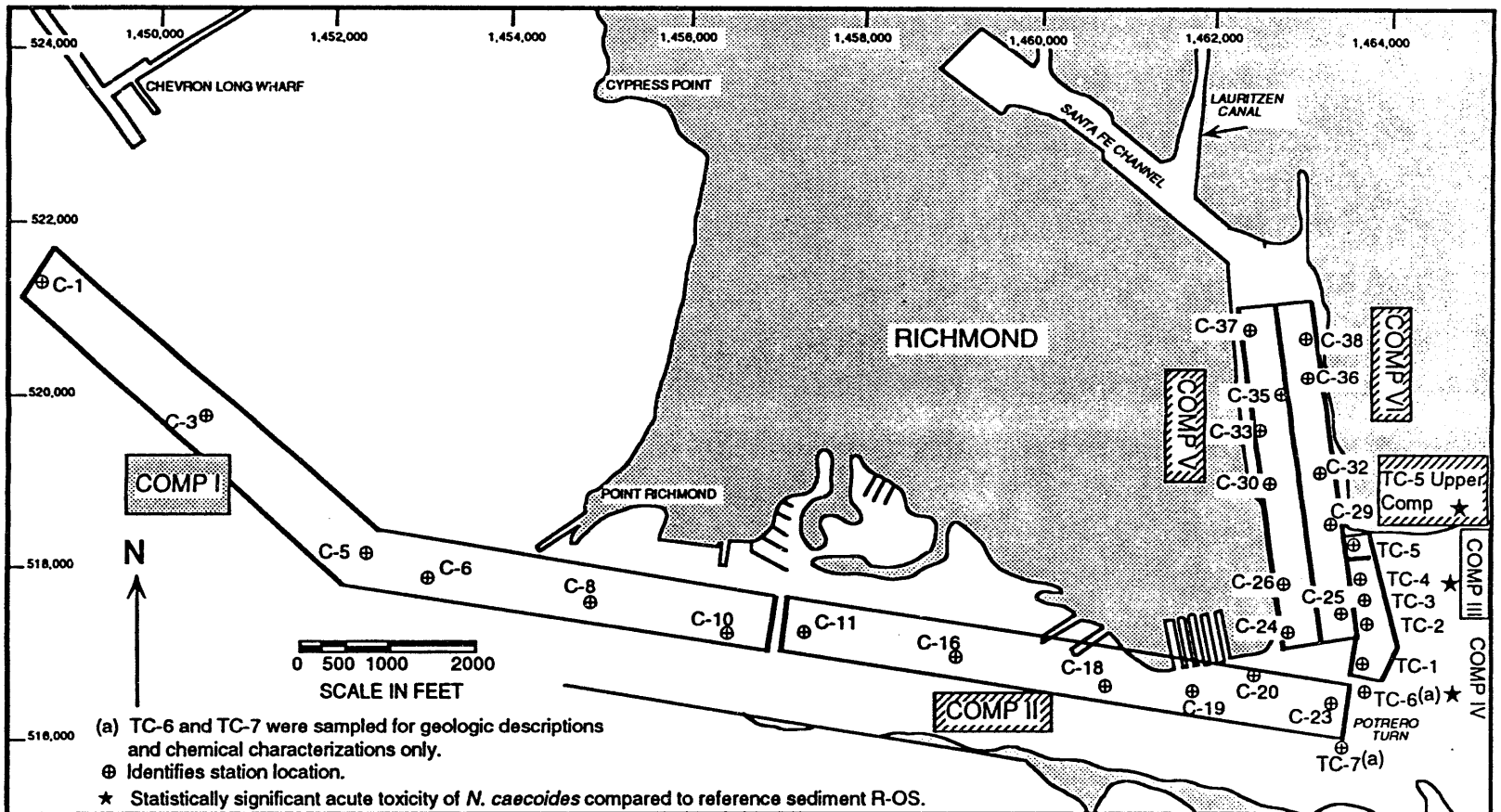
C Calculable LC50 values in *C. stigmaeus*.

N Acute toxicity in *N. caecoides* 10-day test.

Number of compounds bioaccumulating in *M. nasuta* tissues.
Number of compounds bioaccumulating in *N. caecoides* tissues.

PCB Polychlorinated biphenyl.

FIGURE 7.1. Matrix of Sediment Characteristics, Significant Acute Toxicity, and Significant Bioaccumulation for Sediment Treatments Representing Dredged Material from Richmond Harbor Relative to Reference Sediment R-OS



COMPOSITING SCHEME

COMP I: C-1, C-3, C-5, C-6, C-8, C-10
COMP II: C-11, C-16, C-18, C-19, C-20, C-23
COMP III: Upper part of TC-1, TC-2, TC-3, TC-4
TC-5 Upper Comp: Upper part of TC-5
COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5
COMP V: C-24, C-26, C-30, C-33, C-35, C-37
COMP VI: C-25, C-29, C-32, C-36, C-38

☐ Indicates bioaccumulation ≥2 times reference sediment R-OS.
▒ Indicates bioaccumulation ≥5 times reference sediment R-OS.
▨ Indicates bioaccumulation ≥10 times reference sediment R-OS.

FIGURE 7.2. Sediment Treatments with Acute Toxicity and/or Bioaccumulation of at Least One Contaminant in the Tissues of at Least One Species (*M. nasuta* or *N. caecoides*) at ≥2, ≥5, and ≥10 Times the Level Found in Tissues Exposed to the Reference Sediment R-OS

the median lethal concentration (LC50); therefore, statistically significant acute toxicity in SPP tests requires at least 50% mortality in an SPP treatment. Computer modeling would be required to predict whether concentrations greater than 0.01 of the acutely toxic SPP concentrations are likely to occur beyond the boundaries of the disposal site within the first 4 hours after disposal.

Seven Richmond Harbor test treatments were exposed in SPP toxicity tests to assess water column effects of dredged material disposal. Two of the seven SPP composites (COMP I and TC-5 Upper Comp) showed statistically significant acute toxicity. The SPP from COMP I was acutely toxic to *M. edulis* but an LC50 value could not be calculated because there was not a 50% decrease in survival. The SPP from TC-5 Upper Comp was acutely toxic to *C. stigmaeus* and an LC50 of 75.4% SPP was calculated.

Richmond Harbor Channel composites COMP II, COMP III, COMP IV, COMP V, and COMP VI showed no statistically significant acute toxicity in SPP tests.

7.3 POTENTIAL DEPOSITED SEDIMENT TOXICITY EFFECTS AND BIOACCUMULATION FOLLOWING DISPOSAL OF PROPOSED DREDGED MATERIAL FROM RICHMOND HARBOR AT THE DEEP OFF-SHELF REFERENCE AREA

Three of the seven Richmond Harbor composite test treatments (COMP III, TC-5 Upper Comp, and COMP IV) were acutely toxic to *N. caecoides* (Table 7.1). These test treatments included COMP III, TC-5 Upper Comp, and COMP IV. All three of these test treatments are located in the area of the proposed turning circle between Potrero Reach and Santa Fe Channel. The remaining test treatments, COMP I, COMP II, COMP V, and COMP VI, did not show acute toxicity relative to reference sediment R-OS.

COMP III (consisting of the upper portions of the turning circle area cores) consisted of 100% YBM that also had higher concentrations of the HPAH benzo(b)fluoranthene, the pesticide 4,4'-DDD, PCB Aroclor 1254, and arsenic in the *M. nasuta* tissues exposed to this test treatment than the *M. nasuta* tissues after exposure to reference sediment R-OS. *N. caecoides* tissues exposed to COMP III showed statistically significant differences for one HPAH compound (pyrene) relative to reference sediment R-OS. In two cases, there were elevated levels of tissue contamination at magnitudes of ≥2 but <5 times the concentrations found in reference sediment R-OS

The Inner Harbor Channel test treatment TC-5 Upper Comp consisted of 84% YBM and produced statistically significant differences for LPAHs, HPAHs, pesticides, one PCB, and metals in both the *M. nasuta* and *N. caecoides* tissues exposed to this sediment relative to reference sediment R-OS. Seven of the HPAH compounds and one pesticide in the *M. nasuta* tissues and three HPAH compounds and one pesticide in the *N. caecoides* tissues exposed to TC-5 Upper Comp had magnification of ≥10 times those found in reference sediment R-OS.

TABLE 7.1. Summary of Acute Toxicity in Richmond Harbor Sediments Relative to Reference Sediment R-OS

Treatment	Affected Species	Test Treatment Mean Percent Survival	R-OS Mean Percent Survival
COMP III	*N. caecoides*	79.0	95.0
TC-5 Upper Comp	*N. caecoides*	79.0	95.0
COMP IV	*N. caecoides*	73.0	95.0

Inner Harbor Channel COMP IV (consisting of the lower portions of the turning circle area cores) consisted of 55% YBM and had statistically significantly elevated levels of two HPAH compounds (benzo[b]fluoranthene and benzo[k]fluoranthene) in the *M. nasuta* tissues relative to R-OS. The mean tissue concentrations of the two elevated compounds were either undetected or detected below the MDL but were statistically significantly elevated relative to reference sediment R-OS. One PCB (Aroclor 1254) was statistically significantly different in the *M. nasuta* tissues exposed to COMP IV at an increase of <2 times the concentrations found in reference sediment R-OS.

Test treatments COMP I and COMP II are located in the entrance channel and Potrero Reach area. These two test treatments had no statistically significant acute toxicity but there were several organic compounds and metals that were statistically significantly elevated in both the *M. nasuta* and *N. caecoides* tissues exposed to these test treatments relative to reference sediment R-OS. The magnitude of statistically significant bioaccumulation in the tissues exposed to COMP I were <10 times those found in reference sediment R-OS. The *M. nasuta* tissues exposed to COMP II had statistically significant elevations of the pesticide 4,4'-DDD at a magnitude of 17 times above those found in reference sediment R-OS.

Test treatments COMP V and COMP VI are located in the Inner Harbor Channel. These two test treatments had no statistically significant acute toxicity to either of these two composite treatments. Both *M. nasuta* and *N. caecoides* tissues exposed to these two test treatments had the greatest number of statistically significantly elevated compound concentrations at magnifications ranging as high as ≥10 times those found in reference sediment R-OS. The HPAHs (pyrene, benzo[b]-fluoranthene, and benzo[k]fluoranthene) were elevated in the *M. nasuta* tissues exposed to test treatments COMP V and COMP VI at magnitudes of ≥10 times those found in reference sediment R-OS. The mean tissue concentrations of the pesticide 4,4'-DDD in the *M. nasuta* and *N. caecoides* tissues ranged from 44 to 158 times those found in the tissues exposed to reference sediment R-OS.

Another method for evaluating contaminant bioaccumulation in tissues is by comparing the contaminant concentrations in tissues exposed to test treatments to the action levels for poisonous or deleterious substances in fish and shellfish for human consumption published by

the U. S. Food and Drug Administration (FDA) and is presented in the *1991 Implementation Manual.* The maximum concentration found in the tissues of *M. nasuta* and *N. caecoides* exposed to Richmond Harbor sediment treatments and reference sediment R-OS is compared to the FDA action level in Table 7.2. This table shows that the concentrations of pesticides and PCBs found in *M. nasuta* and *N. caecoides* tissues during the Richmond Harbor Project (Pinza et al. 1992) were less than the FDA action levels.

Figure 7.2 showed the location of all of the Richmond Harbor test treatments, the respective composites, and whether the composite was associated with statistically significant toxicity and/or bioaccumulation. Each composite test treatment shows the maximum level of elevated bioaccumulation for at least one contaminant in the tissues of at least one species exposed to test treatments relative to reference sediment R-OS. The matrix in Figure 7.1 showed, for each test treatment, the number of contaminants in *M. nasuta* and *N. caecoides* that were elevated above a range of magnitude (2-, 5-, 10-times) and where similar classes of contaminants were accumulated by both species.

The occurrence of statistically significant bioaccumulation in one or more species and the magnitude of that bioaccumulation are significant factors in the interpretation of bioaccumulation data. Another important factor to consider is the number of individual compounds in each class of compounds that were bioaccumulated by each species. This information can then be used to evaluate the implications of toxicologically important compounds or combinations of compounds. The summary information presented in Figures 7.1 and 7.2 will assist USACE and other resource

TABLE 7.2. Comparison of Contaminant Concentrations in Tissues Exposed to Proposed Dredged Material from Richmond Harbor to U.S. Food and Drug Administration Action Levels for Poisonous and Deleterious Substances in Fish and Shellfish for Human Food

Substance	FDA Action Level (mg/kg wet weight)	Maximum Concentration[a] (mg/kg wet weight) in Tissues Exposed to Richmond Harbor or Deep Off-Shelf Sediments	
		M. nasuta	*N. caecoides*
Pesticides			
Chlordane	0.3	0.01	0.057
DDT+DDE	5.0	0.005	0.01
Dieldrin+Aldrin	0.3	0.002	0.02
Endrin	0.3	0.002	0.02
Heptachlor + Heptachlor Epoxide	0.3	0.0007	0.01
Toxaphene	5.0	0.01	0.05
Industrial Chemicals			
PCBs	2.0	0.03	0.2

(a) Maximum concentration is for a single replicate; therefore, any mean value would be lower.

agencies in evaluating disposal of dredged material from Richmond Harbor at the Deep Off-Shelf Reference Area.

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APPENDIX A

POTENTIAL EFFECTS OF DISPOSAL OF RICHMOND HARBOR SEDIMENTS AT THE BAY FARM BORROW AREA

APPENDIX A

POTENTIAL EFFECTS OF DISPOSAL OF RICHMOND HARBOR SEDIMENTS AT THE BAY FARM BORROW AREA

This appendix presents the results of statistical comparisons and a Tier III evaluation of Richmond Harbor test treatments relative to the Bay Farm Borrow Area (R-BF) (Figure A.1). All methods and results for sampling, physical descriptions, sediment chemistry, biological testing, and tissue chemistry for the Richmond Harbor test treatments and the Bay Farm Borrow Area are contained in the report entitled *Ecological Evaluation of Proposed Dredged Material from Richmond Harbor* (Pinza et al. 1992). This appendix examines the results of the physical/chemical analysis, acute toxicity, and tissue chemistry of the Richmond Harbor test treatments relative to R-BF. As stated in Section 2.4 of the report, the use of Dunnett's test (Dunnett 1964) for statistical comparisons of nonindependent data sets increases the chance of error in all comparisons, but that these errors identify more significant differences instead of fewer.

A.1 SEDIMENT CHARACTERISTICS

Reference sediment R-BF consists almost entirely of silt and clay. Eighteen of the 49 test treatments had coarser grain size than R-BF (Table A.1). The highest concentrations of organic carbon and volatile solids were found in the test treatments containing fine-grained sediments. Nineteen of the 49 test treatments had concentrations of oil and grease that exceeded those found in reference sediment R-BF. Seventeen of the 49 test treatments had concentrations of TPH that exceeded those found in reference sediment R-BF. Nine of the 49 test treatments had concentrations of total LPAHs and total HPAHs that exceeded reference sediment R-BF (Table A.2). Detectable concentrations of pesticides were found in 28 of the 49 test treatments at levels exceeding the concentrations found in reference sediment R-BF. Detectable concentrations of PCBs were found in 19 of the 49 test treatments at levels exceeding the concentrations found in reference sediment R-BF. All of the 49 test treatments, except station TC-6(3), had concentrations of at least 2 of the 10 metals that were above reference sediment R-BF. Tributyltin (TBT) and dibutyltin (DBT) were detected at concentrations below the method detection limit but above the instrument detection limit in reference sediment R-BF. Sixteen of the 49 test treatments had concentrations of either TBT or DBT or both that exceeded reference sediment R-BF.

A.2 WATER COLUMN EFFECTS

The evaluation of water column effects does not change with comparisons to different reference sediments because reference sediment R-BF is not tested for water column toxicity.

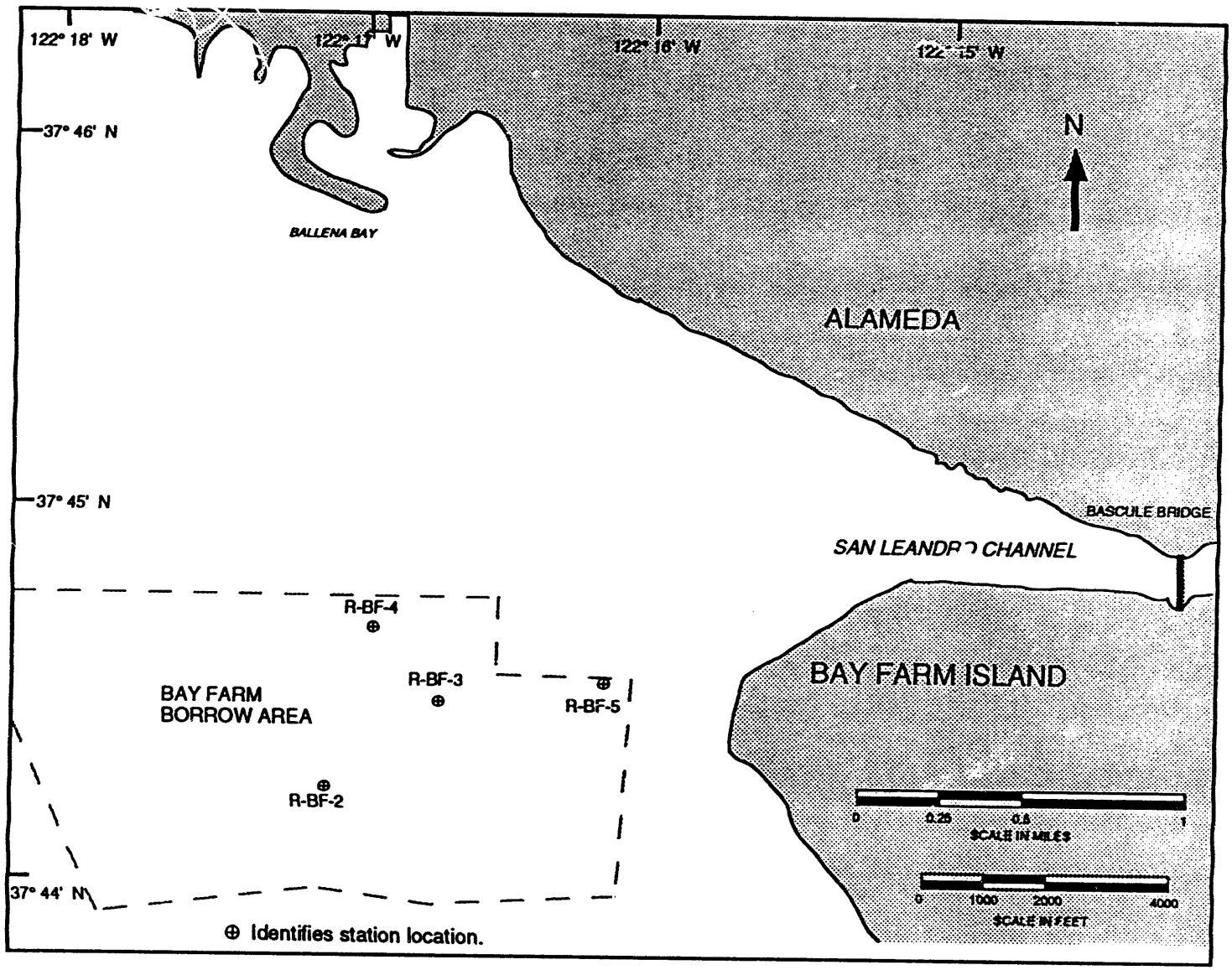


FIGURE A.1. Location of Bay Farm Borrow Area

TABLE A.1. Conventional Sediment Measurement Results (grain size, total organic carbon, and total volatile solids in percent dry weight; oil and grease and total petroleum hydrocarbons in mg/kg dry weight)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
COMP I	0	9	45	46	0.99	6.10	63.22	41.39
C-1	0	23	42	35	0.80	4.75	91.26	68.41
C-3	0	12	44	44	0.93	5.52	89.17	65.03
C-5	0	5	51	44	1.01	5.68	144.92	92.66
C-6	0	4	46	50	1.09	6.12	108.89	88.21
C-8	0	1	41	58	1.18	6.55	132.45	104.76
C-10	0	4	45	51	1.08	5.90	151.75	115.92
COMP II	0	8	44	48	0.73	5.49	118.30	91.00
C-11	0	1	41	58	1.14	6.46	99.86	76.06
C-16	0	25	34	41	0.59	3.98	93.04	74.71
C-18	3	13	39	45	0.81	4.73	124.58	95.91
C-19	0	20	49	31	0.28	3.38	42.91	27.30
C-20	7	28	29	36	0.67	4.66	103.58	78.82
C-23	0	3	45	52	0.74	4.54	68.91	46.08
COMP III	2	11	54	33	0.68	3.65	44.06	26.74
TC-1 Upper	0	3	57	40	0.79	3.96	90.29	34.60
TC-2 Upper	0	8	49	43	0.90	5.19	132.78	79.16
TC-3 Upper	0	6	65	29	0.59	3.03	37.83	19.54
TC-4 Upper	5	12	57	26	0.54	2.87	73.52	16.77
TC-5 Upper Comp	0	10	43	47	0.91	5.00	311.19	281.16
TC-5 Upper Rep 1	0	8	45	47	0.93	5.14	297.24	256.11
TC-5 Upper Rep 2	0	8	44	48	0.94	5.09	230.74	189.60
TC-5 Upper Rep 3	0	8	43	49	0.96	5.09	418.34	350.10
TC-5 Special Sample	0	5	45	50	1.07	5.65	18.83	10.99

TABLE A.1. (contd)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
COMP IV	3	26	43	28	0.39	3.32	19.06	10.50
TC-1 Lower	7	21	39	33	0.43	3.00	9.80	5.67
TC-1 Lower Dup	NM[a]	NM	NM	NM	0.42	NM	NM	NM
TC-2 Lower	3	9	47	41	0.60	3.45	24.30	13.27
TC-3 Lower	12	48	22	18	0.26	2.07	13.03	8.58
TC-3 Lower Dup	NM	NM	NM	NM	0.28	NM	NM	NM
TC-4 Lower	3	30	40	27	0.25	2.22	14.14	8.10
TC-5 Lower	3	30	39	28	0.41	2.50	24.65	7.79
COMP V	1	2	34	63	1.08	6.38	186.23	141.25
C-24	0	2	39	59	0.79	4.96	76.55	54.99
C-26	1	6	37	56	1.01	5.93	138.15	107.13
C-30	0	3	38	59	1.06	6.26	218.95	174.70
C-30 Dup	NM	NM	NM	NM	1.06	NM	NM	NM
C-33	0	3	37	60	0.92	6.06	100.39	83.05
C-35	0	5	41	54	0.84	5.52	151.47	119.79
C-37	0	16	41	43	0.60	4.77	263.31	150.44
COMP VI	0	3	36	61	1.03	6.52	252.06	185.70
C-25	0	16	41	43	0.49	4.06	76.89	63.25
C-29	0	6	51	43	0.57	4.61	91.93	72.97
C-29 Dup	NM	NM	NM	NM	0.59	NM	NM	NM
C-32	0	2	54	44	0.60	4.74	167.80	140.78
C-32 Dup	NM	NM	NM	NM	0.60	NM	NM	NM
C-36	0	5	40	55	0.89	5.62	223.76	180.06
C-38	1	6	45	48	0.59	4.65	118.09	101.70
TC-6 (1)	2	11	50	37	0.79	4.48	37.60	25.13
TC-6 (2)	0	3	61	36	0.71	3.56	27.74	14.43
TC-6 (3)	1	77	11	11	0.15	1.53	5.64	2.63
TC-6 (4)	0	10	45	45	0.56	3.50	15.57	9.01

TABLE A.1. (contd)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
TC-7 (1)	0	3	60	37	0.81	3.63	27.50	24.48
TC-7 (2)	0	2	59	39	0.72	3.62	62.33	20.42
TC-7 (3)	0	67	18	15	0.23	1.68	6.50	5.68
TC-7 (4)	0	14	45	41	0.54	3.33	16.87	15.21
R-BF	0	12	34	54	1.00	6.08	103.19	83.64

(a) NM Not measured.

TABLE A.2. Organics and Metals Sediment Measurement Results (organics in µg/kg dry weight; metals in mg/kg dry weight; shading indicates detected values greater than reference sediment R-BF)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
COMP I	193	1475	0.362	13.10	0.351	181	55.9	0.323	114.8	30.5	0.80 U[a]	133.1	3.1	3.3
C-1	165	868	0.280	11.80	0.333	211	51.1	0.221	112.1	23.1	0.79 U	119.9	0.8 J[b]	0.8 J
C-3	177	793	0.338	13.30	0.342	238	59.0	0.288	120.8	27.6	0.93	132.6	1.4 J	1.2 J
C-5	235	1662	0.383	14.90	0.278	195	59.8	0.333	113.3	29.7	0.84 U	137.3	2.6	2.1 J
C-6	170	1358	0.400	14.20	0.323	188	63.6	0.357	115.4	31.9	1.14	143.6	1.5 J	1.3 J
C-8	153	1024	0.458	16.60	0.361	207	70.4	0.375	127.7	34.2	0.82 U	154.9	1.3 J	1.7 J
C-10	217	1962	0.492	12.50	0.368	205	61.7	0.399	112.0	38.9	0.82 U	150.0	2.5 U	2.4 U
COMP II	810	1874	0.314	14.00	0.380	197	57.4	0.358	105.5	24.9	0.82 U	124.5	1.0 J	1.6 J
C-11	170	1454	0.448	14.50	0.306	202	71.3	0.439	120.6	36.0	0.93	159.4	1.5 J	2.4 U
C-16	104	916	0.293	13.20	0.257	315	50.8	0.293	99.4	25.9	0.77 U	114.3	23.5	7.8
C-18	160	1223	0.389	12.90	0.396	240	59.4	0.356	115.6	33.9	0.81 U	139.3	0.9 J	2.4 U
C-19	36	302	0.195	10.20	0.308	156	42.0	0.140	91.3	20.1	0.80 U	90.0	0.8 J	1.2 J
C-20	87	897	0.337	11.90	0.311	196	55.1	0.357	94.1	31.5	0.80 U	129.1	4.1	2.8
C-23	70	636	0.251	11.60	0.268	196	57.2	0.230	115.4	21.6	0.78 U	119.7	0.7 J	0.5 J
COMP III	63[c]	338[c]	0.160	10.84	0.342	203	38.5	0.175	87.1	16.6	0.79 U	92.3	1.6 J	1.3 J
TC-1 Upper	57	346	0.172	11.90	0.338	194	46.3	0.144	109.1	14.6	0.79 U	109.4	0.5 J	2.4 U
TC-2 Upper	87	1142	0.369	14.60	0.238	205	55.4	0.408	105.3	29.4	0.81 U	137.4	2.5 U	2.6 U
TC-3 Upper	15	27	0.111	12.60	0.290	241	37.6	0.058	95.8	10.4	0.81 U	88.4	2.5 U	0.4 J
TC-4 Upper	272	1078	0.114	12.14	0.309	253	31.4	0.066	92.7	11.1	0.78 U	83.1	0.3 J	2.4 U
TC-5 Upper Comp	187	1924	0.769	18.20	0.799	230	81.2	1.048	110.4	60.0	1.44	220.0	2.3	1.9 J
TC-5 Upper Rep 1	232	1949	0.856	19.50	1.209	207	81.1	1.081	108.9	56.2	0.83 U	220.0	2.5 U	9.3
TC-5 Upper Rep 2	207	1784	0.880	21.00	0.835	194	82.7	1.110	105.0	53.8	0.82 U	214.0	2.5 U	3.7
TC-5 Upper Rep 3	259	2397	0.840	19.40	0.871	218	80.4	1.047	110.7	57.2	0.85	214.0	2.5 U	11.4
TC-5 Special Sample	388	1940	1.299	24.80	1.294	206	96.4	1.431	111.2	62.1	0.84 U	260.0	2.5 U[d]	2.4 U[d]

TABLE A.2. (contd)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
COMP IV	58[c]	32[c]	0.110	10.27	0.362	184	36.5	0.101	84.6	11.1	0.77 U	76.1	0.4 J	1.6 J
TC-1 Lower	16	38	0.103	9.58	0.211	320	40.1	0.119	93.1	11.5	0.98	84.4	2.5 U	0.3 J
TC-2 Lower	50	425	0.121	10.25	0.276	253	40.2	0.103	91.8	11.3	0.79 U	87.1	2.5 U	2.4 U
TC-3 Lower	13	2	0.159	9.22	0.347	229	33.2	0.077	83.5	10.0	0.75 U	65.9	2.5 U	2.4 U
TC-4 Lower	22	462	0.107	10.86	0.237	269	32.3	0.116	89.5	10.8	0.81 U	66.0	2.5 U	0.3 J
TC-5 Lower	19	62	0.075	7.85	0.217	248	26.5	0.105	57.2	13.1	0.78 U	55.2	2.5 U	2.4 U
COMP V	239	2296	0.448	14.50	0.556	196	74.4	0.562	123.5	46.4	0.83 U	179.3	3.4	3.6
C-24	28	55	0.279	13.80	0.291	223	64.3	0.295	117.1	24.1	0.83	130.8	1.3 J	0.9 J
C-26	151	1326	0.500	14.60	0.379	205	72.4	0.486	117.0	47.6	0.82	172.0	2.5 U	2.4 U
C-30	169	1842	0.527	14.20	0.428	184	79.0	0.529	121.1	52.1	0.82 U	178.0	2.4 J	3.6
C-33	145	1313	0.483	15.40	0.655	217	71.5	0.437	130.9	44.1	0.84 U	173.5	2.5 J	3.5
C-35	139	815	0.440	12.70	0.544	204	69.7	0.453	116.4	44.8	0.82 U	160.6	3.2	3.2
C-37	95	681	0.343	9.14	0.431	261	55.2	0.321	102.3	31.6	1.04	131.9	3.9	2.4 U
COMP VI	305	2417	0.471	12.50	0.428	211	72.8	0.535	123.4	48.3	0.84 U	172.9	4.7	2.4 U
C-25	97	837	0.304	9.82	0.290	209	53.2	0.271	101.0	30.2	0.78 U	120.7	2.5 U	2.4 U
C-29	112	750	0.307	10.70	0.457	181	49.0	0.243	102.6	27.8	0.84 U	126.5	2.5 U	2.4 U
C-32	51	408	0.340	12.10	0.456	189	59.6	0.303	112.6	32.9	1.32	137.2	1.6 J	2.4
C-36	226	1616	0.450	13.40	0.609	210	64.5	0.423	111.6	44.8	0.81 U	158.7	2.5 U	2.4 U
C-38	112	1072	0.339	7.72	1.232	189	56.5	0.292	103.9	33.9	2.01	137.4	1.6 J	2.7
TC-6 (1)[e]	76[c]	675[c]	0.182	12.90	0.350	207	38.1	0.276	102.2	22.5	0.82 U	103.1	0.6 J	1.2 J
TC-6 (2)	24	19	0.117	12.04	0.328	209	37.6	0.054	103.7	9.4	0.80 U	95.0	2.5 U	2.4 U
TC-6 (3)	11	2	0.078	6.13	0.105	226	16.2	0.088	46.1	8.3	0.73 U	35.2	2.5 U	2.4 U
TC-6 (4)	22	20	0.128	10.26	0.222	211	44.7	0.060	102.8	11.9	0.78 U	86.8	2.5 U	2.4 U

TABLE A.2. (contd)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
TC-7 (1)[e]	13	11	0.107	9.83	0.303	197	39.6	0.052	100.5	12.0	0.83 U	94.5	2.5 U	2.4 U
TC-7 (2)	26	15	0.121	12.40	0.309	242	46.5	0.063	112.8	10.8	1.12	99.6	2.5 U	2.4 U
TC-7 (3)	37	0	0.082	5.91	0.125	286	21.5	0.078	53.2	9.4	0.76 U	41.8	0.5 J	0.3 J
TC-7 (4)	21	6	0.118	10.95	0.237	204	45.5	0.062	101.5	9.0	0.80 U	87.3	2.5 U	2.4 U
R-BF[c]	203	1934	0.469	9.03	0.208	228	56.1	0.427	116.4	36.4	0.82 U	139.1	1.9 J	1.5 J

(a) U Analyte not present above level of associated value.
(b) J Analyte detected below method detection limit but above instrument detection limit.
(c) Mean of replicate measurements.
(d) Sample had interference in chromatogram; internal standard was altered to give approximate numbers for this sample.
(e) Stations TC-6 and TC-7 were split into four separate core sections that were composited, subsampled for chemistry, and used for geologic descriptions.

There was no acute toxicity to the mysid *H. sculpta*, but the 100% SPP of TC-5 Upper Comp was acutely toxic to the juvenile sanddab *C. stigmaeus* with an LC50 calculated at 75.4% SPP (Table A.3). In the bivalve larvae test, 100% SPP of COMP I was acutely toxic to the mussel *M. edulis*; however, no LC50 could be calculated because mortality did not exceed 50% of the population relative to the control.

A.3 DEPOSITED SEDIMENT TOXICITY

The solid-phase of Richmond Harbor sediments was not acutely toxic to the bentnose clam *M. nasuta* in 10-day exposures. In addition, survival was never reduced more than 5% from reference sediment R-BF. Compared to reference sediment R-BF (Table A.4), there was a statistically significant reduction in survival for the polychaete *N. caecoides* in exposure to the sediment in COMP IV. The amphipod *R. abronius* showed statistically significant reduction in survival in exposure to the sediment in COMP III.

A.4 DEPOSITED SEDIMENT BIOACCUMULATION

The concentrations of contaminants in *M. nasuta* and *N. caecoides* exposed to the Richmond Harbor sediment treatments were compared to the FDA action limits (EPA/USACE 1991) for contaminants in fish and shellfish. None of the FDA action limits were exceeded for any of the contaminants. The tissue concentrations in *M. nasuta* and *N. caecoides* exposed to the Richmond Harbor test treatments were statistically compared to the tissue concentrations that were exposed to reference sediment R-BF by using Dunnett's test.

The *M. nasuta* tissues exposed to the Richmond Harbor test treatments were statistically significantly different for one LPAH (phenanthrene), nine HPAHs [fluoranthene, pyrene,

TABLE A.3. Suspended-Particulate-Phase Toxicity Test Results (bold indicates mean survival in 100% SPP significantly lower than control in 2-sample t-test, $\alpha = 0.05$)

	Mysid *H. sculpta*			Bivalve Larvae *M. edulis*			Sanddab *C. stigmaeus*		
	Mean Survival (%)		LC50 as	Mean Survival (%)		LC50 as	Mean Survival (%)		LC50 as
Treatment	0% SPP	100% SPP	% SPP	0% SPP	100% SPP	% SPP	0% SPP	100% SPP	% SPP
COMP I	100	98	>100[a]	96.9	**72.6**	>100	95	98	>100
COMP II	100	95	>100	84.4	95.7	>100	95	93	>100
COMP III	100	98	>100	92.0	83.5	>100	93	100	>100
TC-5 Upper Comp	98	95	>100	93.8[b]	76.0	>100	100	**23**	75.4
COMP IV	93	98	>100	87.2	85.2	>100	98	90	>100
COMP V	93	85	>100	89.1	84.6	>100	98	93	>100
COMP VI	95	90	>100	92.6	78.7	>100	95	98	>100

(a) Test organism survival was > 50% in all concentrations.
(b) Used mean control survival of COMP I, COMP III, and COMP VI to estimate control survival for TC-5 Upper Comp.

TABLE A.4. Ten-Day Solid-Phase Toxicity Test Results (bold indicates mean survival significantly lower than reference based on Dunnett's test; shaded box indicates greater than 10% difference between treatment mean and reference mean survival for *M. nasuta* and *N. caecoides*, 20% difference for *R. abronius*)

Treatment	Mean Percent Survival in 10-Day Solid-Phase Test		
	M. nasuta	*N. caecoides*	*R. abronius*
CONTROL[a]	100.0	97.0	100.0
R-BF	98.0	92.0	88.0
COMP I	100.0	91.0	77.0
COMP II	96.0	89.0	80.0
COMP III	99.0	79.0	**58.0**
TC-5 Upper Comp	100.0	79.0	82.0
COMP IV	97.0	**73.0**	76.0
COMP V	100.0	93.0	87.0
COMP VI	99.0	91.0	83.0

(a) Control treatment used to validate only test organism survival and not used in statistical analysis.

benzo(a)-anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno-(1,2,3-c,d) pyrene, and benzo(g,h,i)perylene], three pesticides (4,4'-DDD, 4,4'-DDE, and dieldrin), one PCB (Aroclor 1254), and one metal (silver) as shown in Tables A.5 through A.10. The ANOVA data for all comparisons conducted for the *M. nasuta* tissues are presented in Table A.7. Phenanthrene was statistically significantly different in the *M. nasuta* tissues exposed to TC-5 Upper Comp at a magnitude of <2 times the concentrations found in the tissues exposed to reference sediment R-BF. All nine HPAH compounds were statistically significantly different in the *M. nasuta* tissues exposed to TC-5 Upper Comp at magnitudes ranging from <2 times to ≥5 but <10 times the concentrations found in the tissues exposed to reference sediment R-BF. *M. nasuta* tissues exposed to COMP V and COMP VI were statistically significantly different for pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)-pyrene at magnitudes ranging from <2 times to ≥2 but <5 times the concentrations found in the tissues exposed to reference sediment R-BF. The pesticide 4,4'-DDD was statistically significantly different in the *M. nasuta* tissues exposed to COMP II at a magnitude of ≥2 but <5 times the concentration found in the tissues exposed to reference sediment R-BF. *M. nasuta* tissues exposed to test treatments TC-5 Upper Comp, COMP V, and COMP VI were statistically significantly different for the pesticides 4,4'-DDD, 4,4'-DDE, and dieldrin and the PCB (Aroclor 1254) at magnitudes ranging from <2 times to ≥10 times the concentrations found in reference sediment R-BF. Silver was statistically significantly different in *M. nasuta* tissues exposed to COMP VI at a magnitude of ≥2 but <5 times the concentrations found in reference sediment R-BF.

TABLE A.5. Mean Low-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight					
	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
R-BF	15.69	7.13 UJ[a]	4.59 UJ	5.16	14.02	3.39
COMP I	---[b]	---	---	---	---	---
COMP II	---	---	---	---	---	---
COMP III	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	---	27.88	---
COMP IV	---	---	---	---	---	---
COMP V	---	---	---	---	---	---
COMP VI	---	---	---	---	---	---

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.
(b) --- Mean value not statistically significantly different from reference sediment R-BF.

TABLE A.6. Mean High-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	Concentrations in µg/kg Dry Weight								
Sediment Treatment	Fluor-anthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b) fluor-anthene	Benzo(k) fluor-anthene	Benzo(a) pyrene	Indeno (1,2,3-c,d) pyrene	Benzo (g,h,i) perylene
R-BF	45.69	48.62	12.73	22.25	32.63	17.58	21.31	10.74	17.30
COMP I	---(a)	—	—	—	—	—	—	—	—
COMP II	—	—	—	—	—	—	—	—	—
COMP III	—	—	—	—	—	—	—	—	—
TC-5 Upper Comp	**154.17**	**267.23**	**44.94**	**69.35**	**80.93**	**61.72**	**62.08**	**22.49**	27.07
COMP IV	—	—	—	—	—	—	—	—	—
COMP V	—	**146.49**	—	—	57.06	**37.37**	35.83	—	—
COMP VI	—	**149.63**	—	—	55.03	**38.39**	34.79	—	—

(a) --- Mean value not statistically significantly different from reference sediment R-BF.

TABLE A.7. ANOVA Results for Chemical Parameters in Tissues of *M. nasuta* Compared to Reference Sediment R-BF

Parameter	Sum of Squares Treatment	Sum of Squares Residual	Degrees of Freedom Treatment	Degrees of Freedom Residual	F-ratio	p-value
Polynuclear Aromatic Hydrocarbons						
Naphthalene	1.825	2.854	7	32	2.923	0.0175
Acenaphthylene	1.727	27.238	3	16	0.338	0.7980
Acenaphthene	0.452	9.618	7	32	0.215	0.9793
Fluorene	0.789	1.582	7	32	2.280	0.0530
Phenanthrene	3.606	1.311	7	32	12.575	0.0001
Anthracene	3.848	8.723	7	32	2.016	0.0836
Fluoranthene	28.945	1.888	7	32	70.092	0.0001
Pyrene	62.752	1.946	7	32	147.386	0.0001
Benzo(a)anthracene	28.102	8.642	7	32	14.866	0.0001
Chrysene	33.064	3.942	7	32	38.343	0.0001
Benzo(b)fluoranthene	28.638	2.469	7	32	53.018	0.0001
Benzo(k)fluoranthene	29.251	3.879	7	32	34.472	0.0001
Benzo(a)pyrene	22.584	1.942	6	28	54.261	0.0001
Indeno(1,2,3-c,d)pyrene	2.514	2.503	5	24	4.820	0.0034
Dibenzo(a,h)anthracene	0.627	8.275	3	16	0.404	0.7519
Benzo(g,h,i)perylene	4.017	2.090	6	28	8.970	0.0001
Chlorinated Pesticides						
Alpha-BHC	11.612	20.840	7	32	2.547	0.0333
Delta-BHC	0.201	4.660	3	16	0.230	0.8743
Gamma-BHC	1.415	3.004	7	32	2.153	0.0660
4,4'-DDD	103.642	4.065	7	32	116.568	0.0001
4,4'-DDE	41.449	3.588	7	32	52.815	0.0001
4,4'-DDT	3.043	22.611	3	16	0.718	0.5557
Dieldrin	30.124	13.095	6	28	10.736	0.0001
Endosulfan II	1.471	10.151	3	16	0.773	0.5261
Polychlorinated Biphenyl						
Aroclor 1254	11.672	0.959	7	32	55.646	0.0001
Metals						
Silver	6.589	13.776	7	32	2.187	0.0622
Arsenic	0.150	0.708	7	32	0.967	0.4715
Cadmium	1.746	4.382	7	32	1.821	0.1172
Chromium	0.597	3.983	7	32	0.685	0.6835
Copper	0.192	1.368	7	32	0.640	0.7195
Mercury	2.352	3.339	7	32	3.220	0.0107
Nickel	0.420	2.353	7	32	0.817	0.5803
Lead	1.074	1.483	7	32	3.311	0.0092
Selenium	0.409	1.443	7	32	1.295	0.2844
Zinc	0.444	1.016	7	32	1.998	0.0864
Butyltins						
Tributyltin	0.948	1.808	7	32	2.397	0.0432
Dibutyltin	3.798	16.724	6	28	1.060	0.4095

TABLE A.8. Mean Pesticide and Polychlorinated Biphenyl Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	Concentrations in µg/kg Dry Weight								
Sediment Treatment	Alpha BHC	Delta BHC	Gamma BHC	4,4' DDD	4,4' DDE	4,4' DDT	Dieldrin	Endo-sulfan II	Aroclor 1254
R-BF	1.339	0.667 U[a]	3.629 E[b]	2.542	3.934	1.403 U	0.764 J[c]	1.650 UJ[d]	99.709
COMP I	—[e]	—	—	—	—	—	—	—	—
COMP II	—	—	—	**8.423**	—	—	—	—	—
COMP III	—	—	—	—	—	—	—	—	—
TC-5 Upper Comp	—	—	—	**11.178**	**9.719**	—	**2.081 JE[f]**	—	173.525
COMP IV	—	—	—	—	—	—	—	—	—
COMP V	—	—	—	**66.266**	**18.332**	—	**6.245**	—	158.738
COMP VI	—	—	—	**79.833**	**18.541**	—	**7.294**	—	**202.853**

(a) U Undetected in all replicates; value is mean of dry weight detection limits.
(b) E Value is an estimate; analyte not detected on confirmation column.
(c) J Analyte detected below method detection limit but above instrument detection limit.
(d) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.
(e) — Mean value not statistically significantly different from reference sediment R-BF.
(f) JE Mean of values either detected below the method detection limit or estimated as a result of second column confirmation.

TABLE A.9. Mean Metals Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in mg/kg Dry Weight									
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
R-BF	0.243	28.3	0.259	1.95	17.54	0.101	5.17	2.03	1.60	126.4
COMP I	---(a)	---	---	---	---	---	---	---	---	---
COMP II	---	---	---	---	---	---	---	---	---	---
COMP III	---	---	---	---	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	---	---	---	---	---	---	---
COMP IV	---	---	---	---	---	---	---	---	---	---
COMP V	---	---	---	---	---	---	---	---	---	---
COMP VI	**0.622**	---	---	---	---	---	---	---	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-BF.

TABLE A.10. Mean Butyltin Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight	
	Tributyltin	Dibutyltin
R-BF	67.4	7.0
COMP I	---(a)	---
COMP II	---	---
COMP III	---	---
TC-5 Upper Comp	---	---
COMP IV	---	---
COMP V	---	---
COMP VI	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-BF.

The *N. caecoides* tissues exposed to the Richmond Harbor test treatments were statistically significantly different for two LPAHs (fluorene and phenanthrene), three HPAHs (fluoranthene, pyrene, and chrysene), three pesticides (4,4'-DDD, 4,4'-DDE, and dieldrin), one PCB (Aroclor 1254), and one metal (copper) as shown in Tables A.11 through A.16. The ANOVA data for all comparisons conducted for the *N. caecoides* tissues are presented in Table A.13. *N. caecoides* tissues exposed to TC-5 Upper Comp were statistically significantly different for fluorene and phenanthrene at a magnitude of ≥2 but <5 times the concentrations found in the *N. caecoides* tissues exposed to reference sediment R-BF. Tissues exposed to the test treatments TC-5 Upper Comp, COMP V, and COMP VI were statistically significantly different for pyrene and chrysene at magnitudes ranging from <2 times to ≥5 but <10 times the concentrations found in reference sediment R-BF. Fluoranthene was statistically significantly different for *N. caecoides* tissues exposed to TC-5 Upper Comp at a magnitude of ≥5 but <10 times the concentrations found in reference sediment R-BF. *N. caecoides* tissues exposed to COMP I were statistically significantly different for dieldrin, and tissues exposed to COMP II were statistically significantly different for 4,4'-DDD at magnitudes of ≥2 but <5 times the concentrations found in reference sediment R-BF. Tissues exposed to test treatments TC-5 Upper Comp, COMP V, and COMP VI were statistically significantly different for 4,4'-DDD, 4,4'-DDE, and the PCB (Aroclor 1254) at magnitudes of ≥2 but <5 times to ≥10 times the concentrations found in reference sediment R-BF. Copper was statistically significantly different for *N. caecoides* tissues exposed to COMP I, COMP II, and COMP VI at magnitudes of <2 times the concentrations found in the tissues exposed to reference sediment R-BF.

TABLE A.11. Mean Low-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight					
	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
R-BF	31.55	43.67 U[a]	23.60 U	7.89 J[b]	25.06	7.50 UJ[c]
COMP I	---[d]	---	---	---	---	---
COMP II	---	---	---	---	---	---
COMP III	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	**26.23 UJ**	**56.60**	---
COMP IV	---	---	---	---	---	---
COMP V	---	---	---	---	---	---
COMP VI	---	---	---	---	---	---

(a) U Undetected in all replicates; value is mean of dry weight detection limits.
(b) J Analyte detected below method detection limit but above instrument detection limit.
(c) UJ Undetected or detected below method detection limit in all replicates; value is mean of detected values and detection limits.
(d) --- Mean value not statistically significantly different from reference sediment R-BF.

TABLE A.12. Mean High-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	Concentrations in µg/kg Dry Weight								
Sediment Treatment	Fluor-anthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b) fluor-anthene	Benzo(k) fluor anthene	Benzo(a) pyrene	Indeno (1,2,3-c,d) pyrene	Benzo (g,h,i) perylene
R-BF	29.11	55.70	18.91 UJ[a]	19.10	11.75 UJ	16.76 UJ	25.53 UJ	29.56 UJ	29.06 UJ
COMP I	---[b]	—	—	—	—	—	—	—	—
COMP II	—	—	—	—	—	—	—	—	—
COMP III	—	—	—	—	—	—	—	—	—
TC-5 Upper Comp	**210.17**	**491.66**	—	**87.64**	—	—	—	—	—
COMP IV	—	—	—	—	—	—	—	—	—
COMP V	—	**188.07**	—	25.62	—	—	—	—	—
COMP VI	—	**191.61**	—	25.47	—	—	—	—	—

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.

(b) — Mean value not statistically significantly different from reference sediment R-BF.

TABLE A.13. ANOVA Results for Chemical Parameters in Tissues of *N. caecoides* Compared to Reference Sediment R-BF

Parameter	Sum of Squares Treatment	Sum of Squares Residual	Degrees of Freedom Treatment	Degrees of Freedom Residual	F-ratio	p-value
Polynuclear Aromatic Hydrocarbons						
Naphthalene	2.950	12.434	7	32	1.084	0.3961
Acenaphthylene	0.878	18.095	2	12	0.291	0.7526
Acenaphthene	6.355	27.296	7	32	1.064	0.4083
Fluorene	5.147	8.441	7	32	2.787	0.0221
Phenanthrene	5.359	1.402	7	32	17.477	0.0001
Anthracene	13.604	23.392	7	32	2.659	0.0275
Fluoranthene	27.906	1.306	7	32	97.697	0.0001
Pyrene	48.776	1.139	7	32	195.710	0.0001
Benzo(a)anthracene	31.311	70.491	7	32	2.031	0.0816
Chrysene	29.568	1.129	7	32	119.707	0.0001
Benzo(b)fluoranthene	20.761	64.373	7	32	1.474	0.2116
Benzo(k)fluoranthene	27.063	62.062	7	32	1.993	0.0870
Benzo(a)pyrene	8.385	47.637	5	24	0.845	0.5315
Indeno(1,2,3-c,d)pyrene	0.703	16.445	2	12	0.256	0.7780
Dibenzo(a,h)anthracene	1.906	15.736	2	12	0.727	0.5035
Benzo(g,h,i)perylene	2.170	60.622	6	28	0.167	0.9835
Chlorinated Pesticides						
Alpha-BHC	4.729	33.212	6	28	0.664	0.6787
Delta-BHC	1.568	5.307	3	16	1.576	0.2343
Lindane	2.291	11.777	6	28	0.908	0.5035
4,4'-DDD	78.067	16.323	6	28	22.319	0.0001
4,4'-DDE	30.468	2.996	7	32	46.485	0.0001
Dieldrin	23.461	37.092	6	28	2.952	0.0232
Endosulfan I	2.844	11.265	3	16	1.347	0.2945
Endosulfan II	3.254	39.242	5	24	0.398	0.8453
Endosulfan sulfate	1.363	14.551	4	20	0.468	0.7584
Endrin	0.761	1.965	2	12	2.324	0.1403
Endrin aldehyde	0.341	3.023	2	12	0.678	0.5262
Polychlorinated Biphenyl						
Aroclor 1254	15.047	3.113	7	32	22.099	0.0001
Metals						
Silver	1.955	7.137	7	32	1.252	0.3046
Arsenic	0.283	0.616	7	32	2.097	0.0727
Cadmium	0.216	1.160	7	32	0.851	0.5542
Chromium	1.240	3.778	7	32	1.501	0.2024
Copper	0.368	0.519	7	32	3.235	0.0104
Mercury	0.366	0.823	7	32	2.032	0.0814
Nickel	0.801	1.217	7	32	3.008	0.0152
Lead	2.200	0.760	7	32	13.239	0.0001
Selenium	0.746	2.990	7	32	1.141	0.3631
Zinc	0.034	0.217	7	32	0.714	0.6606
Butyltins						
Tributyltin	2.168	16.609	7	32	0.597	0.7538
Dibutyltin	0.537	7.227	4	20	0.371	0.8263

TABLE A.14. Mean Pesticide and Polychlorinated Biphenyl Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	Concentrations in µg/kg Dry Weight									
Sediment Treatment	Alpha BHC	Delta BHC	Gamma BHC	4,4'-DDD	4,4'-DDE	Dieldrin	Endo-sulfan I	Endo-sulfan II	Endosulfan sulfate	Aroclor 1254
R-BF	2.70 U[a]	2.70 U	2.05 UJE[b]	2.78	9.40	9.18 UJE	7.73 U	6.53 UJE	7.09 UJE	151.91
COMP I	—[c]	—	—	—	—	**37.18 UJ**[d]	—	—	—	—
COMP II	—	—	—	**12.97**	—	—	—	—	—	—
COMP III	—	—	—	—	—	—	—	—	—	—
TC-5 Upper Comp	—	—	—	**18.80**	**23.27**	—	—	—	—	**410.42**
COMP IV	—	—	—	—	—	—	—	—	—	—
COMP V	—	—	—	**76.11**	**40.41**	—	—	—	—	**317.81**
COMP VI	—	—	—	**105.48**	**37.33**	—	—	—	—	**362.74**

(a) U Undetected in all replicates; value is mean of dry weight detection limits.
(b) UJE Mean of undetected values, values detected below method detection limit, or estimated values.
(c) — Mean value not statistically significantly different from reference sediment R-BF.
(d) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.

TABLE A.15. Mean Metals Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in mg/kg Dry Weight									
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
R-BF	0.031	29.6	0.95	0.91	10.80	0.084	4.41	1.07	1.46	186.0
COMP I	---(a)	---	---	---	14.16	---	---	---	---	---
COMP II	---	---	---	---	13.82	---	---	---	---	---
COMP III	---	---	---	---	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	---	---	---	---	---	---	---
COMP IV	---	---	---	---	---	---	---	---	---	---
COMP V	---	---	---	---	---	---	---	---	---	---
COMP VI	---	---	---	---	13.20	---	---	---	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-BF.

TABLE A.16. Mean Butyltin Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-BF (plain type indicates statistical significance above R-BF; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-BF mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight	
	Tributyltin	Dibutyltin
R-BF	146.92 UJ[a]	57.00
COMP I	---[b]	---
COMP II	---	---
COMP III	---	---
TC-5	---	---
COMP IV	---	---
COMP V	---	---
COMP VI	---	---

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.
(b) --- Mean value not statistically significantly different from reference sediment R-BF.

A.5 CONCLUSIONS

In this appendix, comparisons of Richmond Harbor dredged material to the Bay Farm Borrow Area are provided to evaluate the acceptability of this sediment for in-bay disposal. For each test treatment, sediment contaminant levels, contribution to acute toxicity, either as water column effect or deposited sediment effect, and potential for bioaccumulation are shown in Figures A.2 and A.3. The matrix is a summary of sediment chemistry, acute toxicity, and bioaccumulation potential for the test treatments relative to reference sediment R-BF. For the bioaccumulation potential, the matrix shows the number of contaminants in *M. nasuta* and *N. caecoides* that were elevated above a range of magnitudes (2-, 5-, 10-fold) and where similar classes of contaminants were accumulated by both species. This appendix is intended to assist the USACE, the EPA, and other resource agencies in evaluating the potential effects of in-bay disposal of dredged material from Richmond Harbor.

Sediment Treatments	YBM	Sediment Chemistry					Toxicity		Significant Bioaccumulation						Bioaccumulation ≥ 2 but < 5 times						Bioaccumulation ≥ 5 but < 10 times						Bioaccumulation ≥ 10 times					
	Average % of test material that is YBM	Sediment LPAH > R-BF	Sediment HPAH > R-BF	Sediment pesticide and PCB > R-BF	Sediment metals > R-BF	Sediment butyltins > R-BF	Species associated with SPP toxicity	Species with solid-phase acute toxicity	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds
COMP I	100			1	2	2					1		1			1	1															
COMP II	72	√		1	3	1					1/1		1			1	1															
COMP III	100				2			R																								
TC-5 Upper Comp	84			3	9	2	C		1/2	9/3	3/2	1/1			2	7/1	3/1	1				1/2	1									
COMP IV	55				2	1		N																								
COMP V	69	√	√	4	7	2				4/2	3/2	1/1				2/1	1/1	1					1						1/1			
COMP VI	52	√	√	4	8	1				4/2	3/2	1/1	1/1			2/1	1/1	1/1	1				1						1/1			

YBM younger bay mud member.

√ Total low-molecular-weight polynuclear aromatic hydrocarbons (LPAH) or high-molecular-weight polynuclear aromatic hydrocarbons (HPAH) with detected values above reference sediment R-BF.

SPP Suspended-particulate-phase toxicity.

C Calculable LC50 values in *C. stigmaeus.*

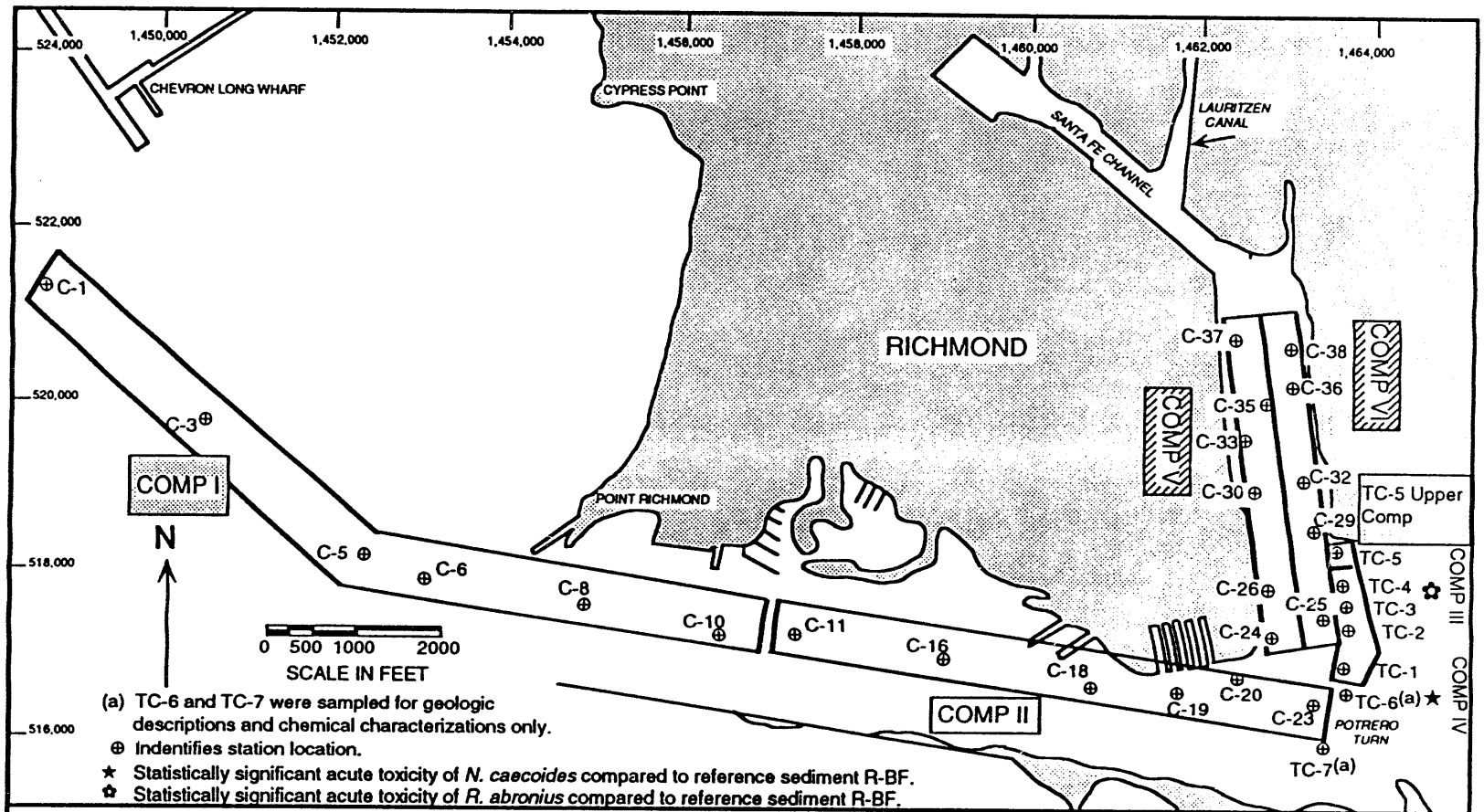
R Acute toxicity in *R. abronius* 10-day test.

N Acute toxicity in *N. caecoides* 10-day test.

Number of compounds bioaccumulating in *M. nasuta* tissues.
Number of compounds bioaccumulating in *N. caecoides* tissues.

PCB Polychlorinated biphenyl.

FIGURE A.2. Matrix of Sediment Characteristics, Significant Acute Toxicity, and Significant Bioaccumulation for Sediment Treatments Representing Dredged Material from Richmond Harbor Relative to Reference Sediment R-BF



COMPOSITING SCHEME

COMP I: C-1, C-3, C-5, C-6, C-8, C-10
COMP II: C-11, C-16, C-18, C-19, C-20, C-23
COMP III: Upper part of TC-1, TC-2, TC-3, TC-4
TC-5 Upper Comp: Upper part of TC-5
COMP IV: Lower part of TC-1, TC-2, TC-3, TC-4, TC-5
COMP V: C-24, C-26, C-30, C-33, C-35, C-37
COMP VI: C-25, C-29, C-32, C-36, C-38

Indicates bioaccumulation ≥2 times reference sediment R-BF.
Indicates bioaccumulation ≥5 times reference sediment R-BF.
Indicates bioaccumulation ≥10 times reference sediment R-BF.

FIGURE A.3. Sediment Treatments with Acute Toxicity and/or Bioaccumulation of at Least One Contaminant in the Tissues of at Least One Species (*M. nasuta* or *N. caecoides*) at ≥2, ≥5, and ≥10 Times the Level Found in Tissues Exposed to the Reference Sediment R-BF

A.6 REFERENCES

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APPENDIX B

POTENTIAL EFFECTS OF DISPOSAL OF RICHMOND HARBOR SEDIMENTS AT THE ALCATRAZ ENVIRONS REFERENCE AREA

APPENDIX B

POTENTIAL EFFECTS OF DISPOSAL OF RICHMOND HARBOR SEDIMENTS AT THE ALCATRAZ ENVIRONS REFERENCE AREA

This appendix presents the results of statistical comparisons and a Tier III evaluation of Richmond Harbor test treatments relative to the Alcatraz Environs Reference Area (R-AM) (Figure A.1). All methods and results for sampling, physical descriptions, sediment chemistry, biological testing, and tissue chemistry for the Richmond Harbor test treatments and the Alcatraz Environs Reference Area contained in the report entitled *Ecological Evaluation of Proposed Dredged Material from Richmond Harbor* (Pinza et al. 1992). This appendix examines the results of the physical/chemical sediment analysis, acute toxicity, and tissue chemistry of the Richmond Harbor test treatments relative to R-AM. As stated in Section 2.4 of the report, the use of Dunnett's test (Dunnett 1964) for statistical comparisons of nonindependent data sets increases the chance of error in all comparisons but that these errors should be toward identifying more significant differences instead of fewer.

B.1 SEDIMENT CHARACTERISTICS

Reference sediment R-AM consists almost entirely of sand. All of the test treatments had a finer grain size than R-AM (Table B.1). The highest concentrations of organic carbon and volatile solids were found in the test treatments containing fine-grained sediments. All but three test treatments (TC-1 Lower, TC-6[3], and TC-7[3]) had concentrations of oil and grease and TPH that exceeded those found in reference sediment R-AM. Sediments from 9 of the 49 test treatments had concentrations of PAHs that exceeded reference sediment R-AM (Table B.2). Detectable concentrations of pesticides were found in 33 of the 49 test treatments at levels exceeding the concentrations found in reference sediment R-AM. Detectable concentrations of PCBs were found in 25 of the 49 test treatments at levels exceeding the concentrations found in reference sediment R-AM. At least 7 of the 10 metals were found in all of the test treatments at concentrations above reference sediment R-AM. Tributyltin (TBT) and dibutytlin (DBT) were detected at concentrations below the method detection limit but above the instrument detection limit in the reference sediment R-AM. Sediments from 14 of the 49 test treatments had concentrations of either TBT or DBT or both that exceeded reference sediment R-AM.

B.2 WATER COLUMN EFFECTS

The evaluation of water column effects does not change with comparisons to different reference sediments because reference sediment R-AM is not tested for water column toxicity.

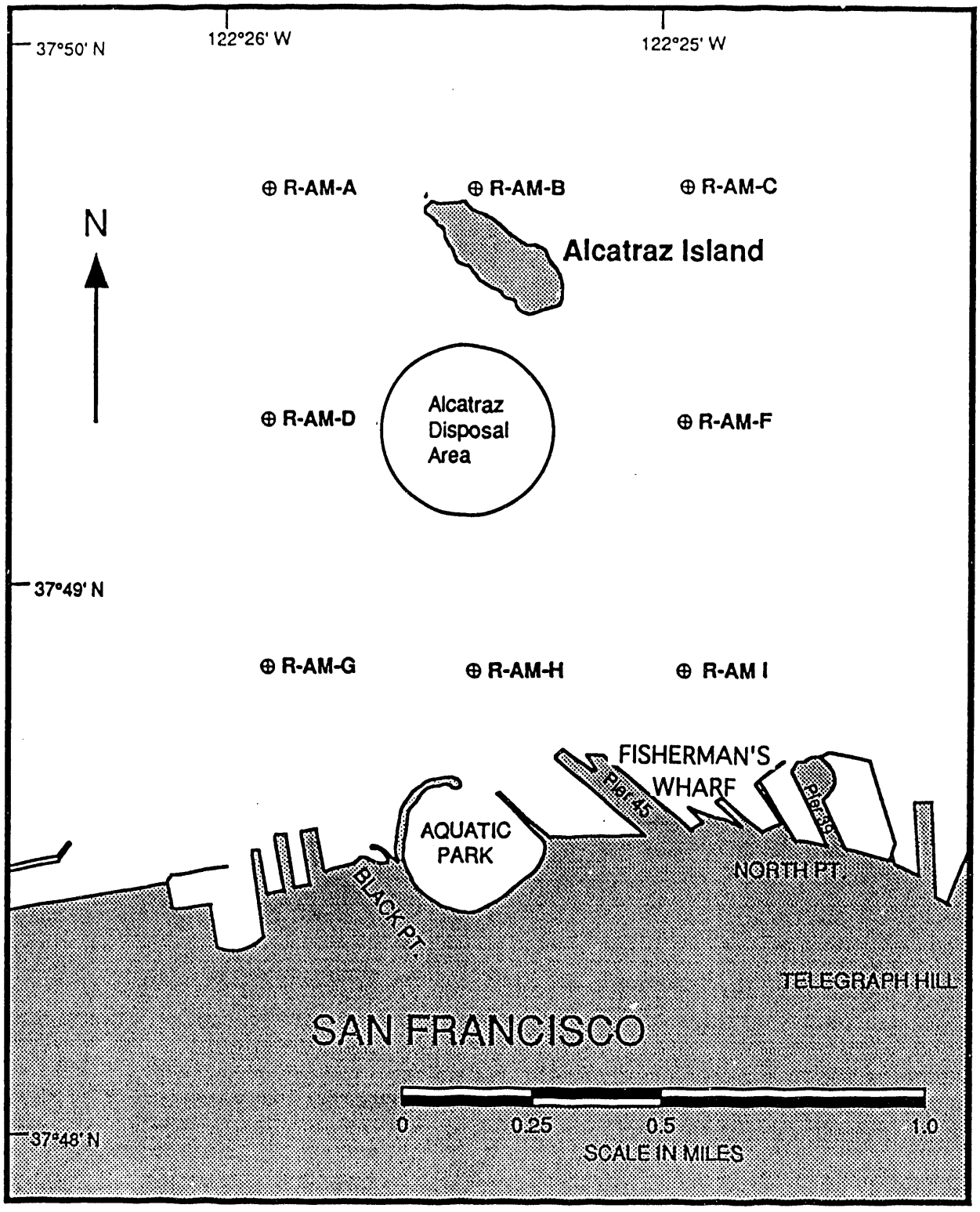

FIGURE B.1. Location of Alcatraz Environs Reference Area

TABLE B.1. Conventional Sediment Measurement Results (grain size, total organic carbon, and total volatile solids in percent dry weight; oil and grease and total petroleum hydrocarbons in mg/kg dry weight)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
COMP I	0	9	45	46	0.99	6.10	63.22	41.39
C-1	0	23	42	35	0.80	4.75	91.26	68.41
C-3	0	12	44	44	0.93	5.52	89.17	65.03
C-5	0	5	51	44	1.01	5.68	144.92	92.66
C-6	0	4	46	50	1.09	6.12	108.89	88.21
C-8	0	1	41	58	1.18	6.55	132.45	104.76
C-10	0	4	45	51	1.08	5.90	151.75	115.92
COMP II	0	8	44	48	0.73	5.49	118.30	91.00
C-11	0	1	41	58	1.14	6.46	99.86	76.06
C-16	0	25	34	41	0.59	3.98	93.04	74.71
C-18	3	13	39	45	0.81	4.73	124.58	95.91
C-19	0	20	49	31	0.28	3.38	42.91	27.30
C-20	7	28	29	36	0.67	4.66	103.58	78.82
C-23	0	3	45	52	0.74	4.54	68.91	46.08
COMP III	2	11	54	33	0.68	3.65	44.06	26.74
TC-1 Upper	0	3	57	40	0.79	3.96	90.29	34.60
TC-2 Upper	0	8	49	43	0.90	5.19	132.78	79.16
TC-3 Upper	0	6	65	29	0.59	3.03	37.83	19.54
TC-4 Upper	5	12	57	26	0.54	2.87	73.52	16.77
TC-5 Upper Comp	0	10	43	47	0.91	5.00	311.19	281.16
TC-5 Upper Rep 1	0	8	45	47	0.93	5.14	297.24	256.11
TC-5 Upper Rep 2	0	8	44	48	0.94	5.09	230.74	189.60
TC-5 Upper Rep 3	0	8	43	49	0.96	5.09	418.34	350.10
TC-5 Special Sample	0	5	45	50	1.07	5.65	18.83	10.99

TABLE B.1. (contd)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
COMP IV	3	26	43	28	0.39	3.32	19.06	10.50
TC-1 Lower	7	21	39	33	0.43	3.00	9.80	5.67
TC-1 Lower Dup	NM[a]	NM	NM	NM	0.42	NM	NM	NM
TC-2 Lower	3	9	47	41	0.60	3.45	24.30	13.27
TC-3 Lower	12	48	22	18	0.26	2.07	13.03	8.58
TC-3 Lower Dup	NM	NM	NM	NM	0.28	NM	NM	NM
TC-4 Lower	3	30	40	27	0.25	2.22	14.14	8.10
TC-5 Lower	3	30	39	28	0.41	2.50	24.65	7.79
COMP V	1	2	34	63	1.08	6.38	186.23	141.25
C-24	0	2	39	59	0.79	4.96	76.55	54.99
C-26	1	6	37	56	1.01	5.93	138.15	107.13
C-30	0	3	38	59	1.06	6.26	218.95	174.70
C-30 Dup	NM	NM	NM	NM	1.06	NM	NM	NM
C-33	0	3	37	60	0.92	6.06	100.39	83.05
C-35	0	5	41	54	0.84	5.52	151.47	119.79
C-37	0	16	41	43	0.60	4.77	263.31	150.44
COMP VI	0	3	36	61	1.03	6.52	252.06	185.70
C-25	0	16	41	43	0.49	4.06	76.89	63.25
C-29	0	6	51	43	0.57	4.61	91.93	72.97
C-29 Dup	NM	NM	NM	NM	0.59	NM	NM	NM
C-32	0	2	54	44	0.60	4.74	167.80	140.78
C-32 Dup	NM	NM	NM	NM	0.60	NM	NM	NM
C-36	0	5	40	55	0.89	5.62	223.76	180.06
C-38	1	6	45	48	0.59	4.65	118.09	101.70
TC-6 (1)	2	11	50	37	0.79	4.48	37.60	25.13
TC-6 (2)	0	3	61	36	0.71	3.56	27.74	14.43
TC-6 (3)	1	77	11	11	0.15	1.53	5.64	2.63
TC-6 (4)	0	10	45	45	0.56	3.50	15.57	9.01

TABLE B.1. (contd)

Sediment Treatment	Gravel (>2000 µm)	Sand (62.5-2000 µm)	Silt (3.9-62.5 µm)	Clay (<3.9 µm)	Total Organic Carbon	Total Volatile Solids	Oil and Grease	Total Petroleum Hydrocarbons
TC-7 (1)	0	3	60	37	0.81	3.63	27.50	24.48
TC-7 (2)	0	2	59	39	0.72	3.62	62.33	20.42
TC-7 (3)	0	67	18	15	0.23	1.68	6.50	5.68
TC-7 (4)	0	14	45	41	0.54	3.33	16.87	15.21
R-AM	0	95	2	3	0.06	0.99	11.63	6.44

(a) NM Not measured.

TABLE B.2. Organics and Metals Sediment Measurement Results (organics in µg/kg dry weight; metals in mg/kg dry weight; shading indicates detected values greater than Reference Sediment R-AM)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
COMP I	193	1475	0.362	13.10	0.351	181	55.9	0.323	114.8	30.5	0.80 U[a]	133.1	3.1	3.3
C-1	165	868	0.280	11.80	0.333	211	51.1	0.221	112.1	23.1	0.79 U	119.9	0.8 J[b]	0.8 J
C-3	177	793	0.338	13.30	0.342	238	59.0	0.288	120.8	27.6	0.93	132.6	1.4 J	1.2 J
C-5	235	1662	0.383	14.90	0.278	195	59.8	0.333	113.3	29.7	0.84 U	137.3	2.6	2.1 J
C-6	170	1358	0.400	14.20	0.323	188	63.6	0.357	115.4	31.9	1.14	143.6	1.5 J	1.3 J
C-8	153	1024	0.458	16.60	0.361	207	70.4	0.375	127.7	34.2	0.82 U	154.9	1.3 J	1.7 J
C-10	217	1962	0.492	12.50	0.368	205	61.7	0.399	112.0	38.9	0.82 U	150.0	2.5 U	2.4 U
COMP II	810	1874	0.314	14.00	0.380	197	57.4	0.358	105.5	24.9	0.82 U	124.5	1.0 J	1.6 J
C-11	170	1454	0.448	14.50	0.306	202	71.3	0.439	120.6	36.0	0.93	159.4	1.5 J	2.4 U
C-16	104	916	0.293	13.20	0.257	315	50.8	0.293	99.4	25.9	0.77 U	114.3	23.5	7.8
C-18	160	1223	0.389	12.90	0.396	240	59.4	0.356	115.6	33.9	0.81 U	139.3	0.9 J	2.4 U
C-19	36	302	0.195	10.20	0.308	156	42.0	0.140	91.3	20.1	0.80 U	90.0	0.8 J	1.2 J
C-20	87	897	0.337	11.90	0.311	196	55.1	0.357	94.1	31.5	0.80 U	129.1	4.1	2.8
C-23	70	636	0.251	11.60	0.268	196	57.2	0.230	115.4	21.6	0.78 U	119.7	0.7 J	0.5 J
COMP III	63[c]	338[c]	0.160	10.84	0.342	203	38.5	0.175	87.1	16.6	0.79 U	92.3	1.6 J	1.3 J
TC-1 Upper	57	346	0.172	11.90	0.338	194	46.3	0.144	109.1	14.6	0.79 U	109.4	0.5 J	2.4 U
TC-2 Upper	87	1142	0.369	14.60	0.238	205	55.4	0.408	105.3	29.4	0.81 U	137.4	2.5 U	2.6 U
TC-3 Upper	15	27	0.111	12.60	0.290	241	37.6	0.058	95.8	10.4	0.81 U	88.4	2.5 U	0.4 J
TC-4 Upper	272	1078	0.114	12.14	0.309	253	31.4	0.066	92.7	11.1	0.78 U	83.1	0.3 J	2.4 U
TC-5 Upper Comp	187	1924	0.769	18.20	0.799	230	81.2	1.048	110.4	60.0	1.44	220.0	2.3	1.9 J
TC-5 Upper Rep 1	232	1949	0.856	19.50	1.209	207	81.1	1.081	108.9	56.2	0.83 U	220.0	2.5 U	9.3
TC-5 Upper Rep 2	207	1784	0.880	21.00	0.835	194	82.7	1.110	105.0	53.8	0.82 U	214.0	2.5 U	3.7
TC-5 Upper Rep 3	259	2397	0.840	19.40	0.871	218	80.4	1.047	110.7	57.2	0.85	214.0	2.5 U	11.4
TC-5 Special Sample	388	1940	1.299	24.80	1.294	206	96.4	1.431	111.2	62.1	0.84 U	260.0	2.5 U[d]	2.4 U[d]

TABLE B.2. (contd)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
COMP IV	58[c]	32[c]	0.110	10.27	0.362	184	36.5	0.101	84.6	11.1	0.77 U	76.1	0.4 J	1.6 J
TC-1 Lower	16	38	0.103	9.58	0.211	320	40.1	0.119	93.1	11.5	0.98	84.4	2.5 U	0.3 J
TC-2 Lower	50	425	0.121	10.25	0.276	253	40.2	0.103	91.8	11.3	0.79 U	87.1	2.5 U	2.4 U
TC-3 Lower	13	2	0.159	9.22	0.347	229	33.2	0.077	83.5	10.0	0.75 U	65.9	2.5 U	2.4 U
TC-4 Lower	22	462	0.107	10.86	0.237	269	32.3	0.116	89.5	10.8	0.81 U	66.0	2.5 U	0.3 J
TC-5 Lower	19	62	0.075	7.85	0.217	248	26.5	0.105	57.2	13.1	0.78 U	55.2	2.5 U	2.4 U
COMP V	239	2296	0.448	14.50	0.556	196	74.4	0.562	123.5	46.4	0.83 U	179.3	3.4	3.6
C-24	28	55	0.279	13.80	0.291	223	64.3	0.295	117.1	24.1	0.83	130.8	1.3 J	0.9 J
C-26	151	1326	0.500	14.60	0.379	205	72.4	0.486	117.0	47.6	0.82	172.0	2.5 U	2.4 U
C-30	169	1842	0.527	14.20	0.428	184	79.0	0.529	121.1	52.1	0.82 U	178.0	2.4 J	3.6
C-33	145	1313	0.483	15.40	0.655	217	71.5	0.437	130.9	44.1	0.84 U	173.5	2.5 J	3.5
C-35	139	815	0.440	12.70	0.544	204	69.7	0.453	116.4	44.8	0.82 U	160.6	3.2	3.2
C-37	95	681	0.343	9.14	0.431	261	55.2	0.321	102.3	31.6	1.04	131.9	3.9	2.4 U
COMP VI	305	2417	0.471	12.50	0.428	211	72.8	0.535	123.4	48.3	0.84 U	172.9	4.7	2.4 U
C-25	97	837	0.304	9.82	0.290	209	53.2	0.271	101.0	30.2	0.78 U	120.7	2.5 U	2.4 U
C-29	112	750	0.307	10.70	0.457	181	49.0	0.243	102.6	27.8	0.84 U	126.5	2.5 U	2.4 U
C-32	51	408	0.340	12.10	0.456	189	59.6	0.303	112.6	32.9	1.32	137.2	1.6 J	2.4
C-36	226	1616	0.450	13.40	0.609	210	64.5	0.423	111.6	44.8	0.81 U	158.7	2.5 U	2.4 U
C-38	112	1072	0.339	7.72	1.232	189	56.5	0.292	103.9	33.9	2.01	137.4	1.6 J	2.7
TC-6 (1)[e]	76[c]	675[c]	0.182	12.90	0.350	207	38.1	0.276	102.2	22.5	0.82 U	103.1	0.6 J	1.2 J
TC-6 (2)	24	19	0.117	12.04	0.328	209	37.6	0.054	103.7	9.4	0.80 U	95.0	2.5 U	2.4 U
TC-6 (3)	11	2	0.078	6.13	0.105	226	16.2	0.088	46.1	8.3	0.73 U	35.2	2.5 U	2.4 U
TC-6 (4)	22	20	0.128	10.26	0.222	211	44.7	0.060	102.8	11.9	0.78 U	86.8	2.5 U	2.4 U

TABLE B.2. (contd)

Sediment Treatment	Low PAH	High PAH	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn	TBT	DBT
TC-7 (1)[e]	13	11	0.107	9.83	0.303	197	39.6	0.052	100.5	12.0	0.83 U	94.5	2.5 U	2.4 U
TC-7 (2)	26	15	0.121	12.40	0.309	242	46.5	0.063	112.8	10.8	1.12	99.6	2.5 U	2.4 U
TC-7 (3)	37	0	0.082	5.91	0.125	286	21.5	0.078	53.2	9.4	0.76 U	41.8	0.5 J	0.3 J
TC-7 (4)	21	6	0.118	10.95	0.237	204	45.5	0.062	101.5	9.0	0.80 U	87.3	2.5 U	2.4 U
R-AM	535	1839	0.033[c]	6.87[c]	0.055[c]	284[c]	10.7[c]	0.030[c]	45.2[c]	15.8[c]	0.72 U[c]	35.1[c]	2.5 U[c]	1.8 UJ[c]

(a) U Analyte not present above level of associated value.
(b) J Analyte detected below method detection limit but above instrument detection limit.
(c) Mean of replicate measurements.
(d) Sample had interference in chromatogram; internal standard was altered to give approximate numbers for this sample.
(e) Stations TC-6 and TC-7 were split into four separate core sections that were composited, subsampled for chemistry, and used for geologic descriptions.

There was no acute toxicity to the mysid *H. sculpta*, but the 100% SPP of TC-5 Upper Comp was acutely toxic to the juvenile sanddab *C. stigmaeus* with an LC50 calculated at 75.4% SPP (Table B.3). In the bivalve larvae test, 100% SPP of COMP I was acutely toxic to the mussel *M. edulis*; however, no LC50 could be calculated because mortality did not exceed 50% of the population relative to the control.

B.3 DEPOSITED SEDIMENT TOXICITY

The solid phase of Richmond Harbor sediments was not acutely toxic to the bentnose clam *M. nasuta* in 10-day exposures. In addition, survival was never reduced more than 5% from reference sediment R-AM. Compared to reference sediment R-AM (Table B.4), there was statistically significant reduction in survival for the polychaete *N. caecoides* in exposure to the sediment in COMP IV. The amphipod *R. abronius* showed statistically significant reduction in survival in exposure to the sediment in COMP III.

B.4 DEPOSITED SEDIMENT BIOACCUMULATION

The concentrations of contaminants in *M. nasuta* and *N. caecoides* exposed to the Richmond Harbor sediment treatments were compared to the FDA action limits (EPA/USACE 1991) for contaminants in fish and shellfish. None of the FDA action limits were exceeded for any of the contaminants. The tissue concentrations in *M. nasuta* and *N. caecoides* exposed to the Richmond Harbor test treatments were statistically compared to the tissue concentrations that were exposed to reference sediment R-AM by using Dunnett's test.

The *M. nasuta* tissues exposed to the Richmond Harbor test treatments were statistically significantly different for three pesticides (4,4'-DDD, 4,4'-DDE, and dieldrin), one PCB

TABLE B.3. Suspended-Particulate-Phase Toxicity Test Results (bold indicates mean survival in 100% SPP significantly lower than control in 2-sample t-test, $\alpha = 0.05$)

	Mysid *H. sculpta*			Bivalve Larvae *M. edulis*			Sanddab *C. stigmaeus*		
	Mean Survival (%)		LC50 as	Mean Survival (%)		LC50 as	Mean Survival (%)		LC50 as
Treatment	0% SPP	100% SPP	% SPP	0% SPP	100% SPP	% SPP	0% SPP	100% SPP	% SPP
COMP I	100	98	>100[a]	96.9	**72.6**	>100	95	98	>100
COMP II	100	95	>100	84.4	95.7	>100	95	93	>100
COMP III	100	98	>100	92.0	83.5	>100	93	100	>100
TC-5 Upper Comp	98	95	>100	93.8[b]	76.0	>100	100	**23**	75.4
COMP IV	93	98	>100	87.2	85.2	>100	98	90	>100
COMP V	93	85	>100	89.1	84.6	>100	98	93	>100
COMP VI	95	90	>100	92.6	78.7	>100	95	98	>100

(a) Test organism survival was > 50% in all concentrations.
(b) Used mean control survival of COMP I, COMP III, and COMP VI to estimate control survival for TC-5 Upper Comp.

TABLE B.4. Ten-Day Solid-Phase Toxicity Test Results (bold indicates mean survival significantly lower than reference based on Dunnett's test; shaded box indicates greater than 10% difference between treatment mean and reference mean survival for *M. nasuta* and *N. caecoides*, 20% difference for *R. abronius*)

Treatment	Mean Percent Survival in 10-Day Solid-Phase Test		
	M. nasuta	*N. caecoides*	*R. abronius*
CONTROL[a]	100.0	97.0	100.0
R-AM	98.0	93.0	90.0
COMP I	100.0	91.0	77.0
COMP II	96.0	89.0	80.0
COMP III	99.0	79.0	**58.0**
TC-5 Upper Comp	100.0	79.0	82.0
COMP IV	97.0	**73.0**	76.0
COMP V	100.0	93.0	87.0
COMP VI	99.0	91.0	83.0

(a) Control treatment used to validate only test organism survival and not used in statistical analysis.

(Aroclor 1254), and one metal (lead) as shown in Tables B.5 through B.10. The ANOVA data for all comparisons conducted for the *M. nasuta* tissues are presented in Table B.7. *M. nasuta* tissues exposed to COMP I and COMP II were statistically significantly different for 4,4'-DDD and 4,4'-DDE at magnitudes ranging from <2 times to ≥10 times the concentrations found in reference sediment R-AM. Tissues exposed to COMP III was statistically significantly different for 4,4'-DDD at a magnitude of ≥2 but <5 times the concentrations found in the tissues exposed to the reference R-AM. *M. nasuta* tissues exposed to TC-5 Upper Comp were statistically significantly different for 4,4'-DDD, 4,4'-DDE, and the PCB (Aroclor 1254) at magnitudes ranging from <2 times to ≥10 times the concentrations found in reference sediment R-AM. The three pesticides (4,4'-DDD, 4,4'-DDE, and dieldrin) and the PCB (Aroclor 1254) were statistically significantly different in the *M. nasuta* tissues exposed to COMP V and COMP VI at magnitudes ranging from <2 times to ≥10 times the concentrations found in reference sediment R-AM. Lead was statistically significantly different for *M. nasuta* tissues exposed to COMP VI at a magnitude of <2 times the concentration found in the tissues exposed to reference sediment R-AM.

The *N. caecoides* tissues exposed to the Richmond Harbor test treatments were statistically significantly different for three HPAHs (fluoranthene, pyrene, and chrysene), two pesticides (4,4'-DDD and 4,4'-DDE), one PCB (Aroclor 1254), and two metals (arsenic and lead) as shown in Tables B.11 through B.16. The ANOVA data for all comparisons conducted for the *N. caecoides* tissues are presented in Table B.13. *N. caecoides* tissues exposed to TC-5 Upper Comp were statistically significantly different for fluoranthene, pyrene, and chrysene at magnitudes ranging from <2 times to ≥2 but <5 times the concentrations found in the tissues

TABLE B.5. Mean Low-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight					
	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
R-AM	15.55	6.33 UJ[a]	3.85 UJ	7.26	46.04	18.15
COMP I	---[b]	---	---	---	---	---
COMP II	---	---	---	---	---	---
COMP III	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	---	---	---
COMP IV	---	---	---	---	---	---
COMP V	---	---	---	---	---	---
COMP VI	---	---	---	---	---	---

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of uetected values and dry weight detection limits.

(b) --- Mean value not statistically significantly different from reference sediment R-AM.

TABLE B.6. Mean High-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	Concentrations in µg/kg Dry Weight								
Sediment Treatment	Fluor-anthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b) fluor-anthene	Benzo(k) fluor-anthene	Benzo(a) pyrene	Indeno (1,2,3-c,d) pyrene	Benzo (g,h,i) perylene
R-AM	287.09	316.09	115.81	182.84	75.95	86.86	105.19	29.82	30.42
COMP I	---(a)	—	—	—	—	—	—	—	—
COMP II	—	—	—	—	—	—	—	—	—
COMP III	—	—	—	—	—	—	—	—	—
TC-5 Upper Comp	—	—	—	—	—	—	—	—	—
COMP IV	—	—	—	—	—	—	—	—	—
COMP V	—	—	—	—	—	—	—	—	—
COMP VI	—	—	—	—	—	—	—	—	—

(a) --- Mean value not statistically significantly different from reference sediment R-AM.

TABLE B.7. ANOVA Results for Chemical Parameters in Tissues of *M. nasuta* Compared to Reference Sediment R-AM

Parameter	Sum of Squares Treatment	Sum of Squares Residual	Degrees of Freedom Treatment	Degrees of Freedom Residual	F-ratio	p-value
Polynuclear Aromatic Hydrocarbons						
Naphthalene	1.838	4.012	7	32	2.094	0.0731
Acenaphthylene	0.861	20.512	3	16	0.224	0.8784
Acenaphthene	0.515	9.012	7	32	0.261	0.9644
Fluorene	1.092	1.938	7	32	2.575	0.0318
Phenanthrene	8.835	2.009	7	32	20.103	0.0001
Anthracene	13.456	9.272	7	32	6.634	0.0001
Fluoranthene	50.272	2.057	7	32	111.731	0.0001
Pyrene	76.247	2.244	7	32	155.334	0.0001
Benzo(a)anthracene	51.093	10.082	7	32	23.166	0.0001
Chrysene	57.899	5.079	7	32	52.112	0.0001
Benzo(b)fluoranthene	32.711	3.500	7	32	42.722	0.0001
Benzo(k)fluoranthene	39.305	4.604	7	32	39.027	0.0001
Benzo(a)pyrene	32.509	3.173	6	28	47.809	0.0001
Indeno(1,2,3-c,d)pyrene	4.593	3.862	5	24	5.709	0.0013
Dibenzo(a,h)anthracene	0.108	6.427	3	16	0.090	0.9647
Benzo(g,h,i)perylene	5.520	3.300	6	28	7.807	0.0001
Chlorinated Pesticides						
Alpha-BHC	14.144	20.987	7	32	3.081	0.0134
Delta-BHC	0.658	4.931	3	16	0.712	0.5590
Gamma-BHC	1.397	3.547	7	32	1.800	0.1216
4,4'-DDD	145.228	16.591	7	32	40.015	0.0001
4,4'-DDE	43.782	3.478	7	32	57.554	0.0001
4,4'-DDT	3.527	23.000	3	16	0.818	0.5027
Dieldrin	24.441	16.566	6	28	6.885	0.0001
Endosulfan II	7.233	47.189	3	16	0.817	0.5029
Polychlorinated Biphenyl						
Aroclor 1254	11.750	1.173	7	32	45.809	0.0001
Metals						
Silver	5.076	12.778	7	32	1.816	0.1183
Arsenic	0.150	0.808	7	32	0.847	0.5573
Cadmium	1.693	4.356	7	32	1.777	0.1266
Chromium	0.537	4.793	7	32	0.512	0.8187
Copper	0.187	1.343	7	32	0.637	0.7221
Mercury	2.078	3.311	7	32	2.870	0.0192
Nickel	0.452	2.339	7	32	0.884	0.5299
Lead	1.085	1.470	7	32	3.374	0.0083
Selenium	0.436	1.351	7	32	1.475	0.2115
Zinc	0.502	1.016	7	32	2.258	0.0550
Butyltins						
Tributyltin	1.251	1.584	7	32	3.610	0.0056
Dibutyltin	4.710	15.196	6	28	1.446	0.2327

TABLE B.8. Mean Pesticide and Polychlorinated Biphenyl Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

	Concentrations in µg/kg Dry Weight								
Sediment Treatment	Alpha BHC	Delta BHC	Gamma BHC	4,4' DDD	4,4'-DDE	4,4'-DDT	Dieldrin	Endo-sulfan II	Aroclor 1254
R-AM	2.041	0.939 U[a]	3.565 JE[b]	0.532 UJ[c]	2.413	1.612	2.931 UJ	1.701 UJ	88.554
COMP I	—[d]	—	—	**4.104**	4.704	—	—	—	—
COMP II	—	—	—	**8.423**	**5.060**	—	—	—	—
COMP III	—	—	—	**2.285**	—	—	—	—	—
TC-5 Upper Comp	—	—	—	**11.178**	**9.719**	—	—	—	173.525
COMP IV	—	—	—	—	—	—	—	—	—
COMP V	—	—	—	**66.266**	**18.332**	—	**6.245**	—	158.738
COMP VI	—	—	—	**79.833**	**18.541**	—	**7.294**	—	**202.853**

(a) U Analyte not present above the level of associated value.
(b) J Value is mean of either values are below the method detection limit or estimated as a result of second column confirmation.
(c) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.
(d) — Mean value not statistically significantly different from reference sediment R-AM.

TABLE B.9. Mean Metals Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in mg/kg Dry Weight									
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
R-AM	0.305	28.7	0.253	2.26	17.66	0.084	4.54	1.62	1.67	133.0
COMP I	---(a)	---	---	---	---	---	---	---	---	---
COMP II	---	---	---	---	---	---	---	---	---	---
COMP III	---	---	---	---	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	---	---	---	---	---	---	---
COMP IV	---	---	---	---	---	---	---	---	---	---
COMP V	---	---	---	---	---	---	---	---	---	---
COMP VI	---	---	---	---	---	---	---	2.32	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-AM.

TABLE B.10. Mean Butyltin Concentrations in the Tissues of *M. nasuta* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight) Tributyltin	Dibutyltin
R-AM	73.7	10.1
COMP I	---(a)	---
COMP II	---	---
COMP III	---	---
TC-5 Upper Comp	---	---
COMP IV	---	---
COMP V	---	---
COMP VI	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-AM.

exposed to reference sediment R-AM. *N. caecoides* tissues exposed to four of the seven test treatments were statistically significantly different for 4,4'-DDD, 4,4'-DDE, and Aroclor 1254 at magnitudes ranging from <2 times to ≥10 times the concentrations found in reference sediment R-AM. Tissues exposed to test treatment COMP I were statistically significantly different for 4,4'-DDD and 4,4'-DDE at magnitudes of ≥2 but <5 times the concentrations found in reference sediment R-AM. Arsenic and lead were statistically significantly different in *N. caecoides* tissues exposed to COMP I, COMP II, TC-5 Upper Comp, COMP V, and COMP VI at magnitudes of <2 times the concentrations found in reference sediment R-AM.

B.5 CONCLUSIONS

In this appendix, comparisons of Richmond Harbor dredged material to the Alcatraz Environs Reference Area are provided to evaluate the acceptability of this sediment for in-bay disposal. For each test treatment, sediment contaminant levels, contribution to acute toxicity, either as water column effect or deposited sediment effect, and potential for bioaccumulation are shown in Figures B.2 and B.3. The matrix is a summary of sediment chemistry, acute toxicity, and bioaccumulation potential for the test treatments relative to reference sediment R-AM. For the bioaccumulation potential, the matrix shows the number of contaminants in *M. nasuta* and *N. caecoides* that were elevated above a range of magnitudes (2-, 5-, 10-fold) and where similar classes of contaminants were accumulated by both species. This appendix is intended to assist the USACE, the EPA, and other resource agencies in evaluating the potential effects of in-bay disposal of dredged material from Richmond Harbor.

TABLE B.11. Mean Low-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight					
	Naphthalene	Acenaphthylene	Acenaphthene	Fluorene	Phenanthrene	Anthracene
R-AM	48.08	42.32 UJ[a]	19.66 UJ	15.11 UJ	58.10	11.07 J[b]
COMP I	---[c]	---	---	---	---	---
COMP II	---	---	---	---	---	---
COMP III	---	---	---	---	---	---
TC-5 Upper Comp	---	---	---	---	---	---
COMP IV	---	---	---	---	---	---
COMP V	---	---	---	---	---	---
COMP VI	---	---	---	---	---	---

(a) UJ Undetected or detected below method detection limit in all replicates; value is mean of detected values and detection limits.
(b) J Analyte detected below method detection limit but above instrument detection limit.
(c) --- Mean value not statistically significantly different from reference sediment R-AM.

TABLE B.12. Mean High-Molecular-Weight Polynuclear Aromatic Hydrocarbon Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight								
	Fluor-anthene	Pyrene	Benzo(a) anthracene	Chrysene	Benzo(b) fluor-anthene	Benzo(k) fluor-anthene	Benzo(a) pyrene	Indeno (1,2,3-c,d) pyrene	Benzo (g,h,i) perylene
R-AM	125.61	273.46	19.02 UJ[a]	51.78	22.02 UJ	18.36 UJ	27.80 UJ	36.82 U[b]	45.04 UJ
COMP I	---[c]	—	—	—	—	—	—	—	—
COMP II	—	—	—	—	—	—	—	—	—
COMP III	—	—	—	—	—	—	—	—	—
TC-5 Upper Comp	210.17	**491.66**	—	87.64	—	—	—	—	—
COMP IV	—	—	—	—	—	—	—	—	—
COMP V	—	—	—	—	—	—	—	—	—
COMP VI	—	—	—	—	—	—	—	—	—

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.
(b) U Undetected in all replictaes; value is mean of dry weight detection limits.
(c) — Mean value not statistically significantly different from reference sediment R-AM.

TABLE B.13. ANOVA Results for Chemical Parameters in Tissues of *N. caecoides* Compared to Reference Sediment R-AM

Parameter	Sum of Squares Treatment	Sum of Squares Residual	Degrees of Freedom Treatment	Degrees of Freedom Residual	F-ratio	p-value
Polynuclear Aromatic Hydrocarbons						
Naphthalene	3.728	13.656	7	32	1.248	0.3067
Acenaphthylene	0.495	27.294	2	12	0.109	0.8977
Acenaphthene	5.122	31.597	7	32	0.741	0.6392
Fluorene	5.340	10.076	7	32	2.423	0.0413
Phenanthrene	9.141	1.265	7	32	33.036	0.0001
Anthracene	14.274	21.577	7	32	3.024	0.0148
Fluoranthene	37.854	1.271	7	32	136.121	0.0001
Pyrene	54.880	1.161	7	32	216.103	0.0001
Benzo(a)anthracene	31.311	69.231	7	32	2.068	0.0765
Chrysene	35.339	0.972	7	32	166.252	0.0001
Benzo(b)fluoranthene	20.799	72.058	7	32	1.320	0.2733
Benzo(k)fluoranthene	26.323	67.576	7	32	1.781	0.1257
Benzo(a)pyrene	6.482	55.769	5	24	0.558	0.7310
Indeno(1,2,3-c,d)pyrene	1.466	15.464	2	12	0.569	0.5807
Dibenzo(a,h)anthracene	1.553	14.274	2	12	0.653	0.5381
Benzo(g,h,i)perylene	2.187	73.014	6	28	0.140	0.9896
Chlorinated Pesticides						
Alpha-BHC	3.882	36.020	6	28	0.503	0.8008
Delta-BHC	1.339	6.843	3	16	1.044	0.4001
Lindane	2.447	14.744	6	28	0.775	0.5966
4,4'-DDD	82.373	12.290	6	28	31.279	0.0001
4,4'-DDE	34.720	3.640	7	32	43.609	0.0001
Dieldrin	27.221	27.798	6	28	4.570	0.0024
Endosulfan I	2.574	12.797	3	16	1.073	0.3885
Endosulfan II	4.241	37.521	5	24	0.543	0.7422
Endosulfan sulfate	1.364	15.630	4	20	0.436	0.7808
Endrin	0.766	3.498	2	12	1.314	0.3047
Endrin aldehyde	0.173	4.555	2	12	0.228	0.7996
Polychlorinated Biphenyl						
Aroclor 1254	16.731	3.163	7	32	24.178	0.0001
Metals						
Silver	3.143	6.787	7	32	2.117	0.0702
Arsenic	0.647	0.640	7	32	4.621	0.0012
Cadmium	0.172	1.142	7	32	0.690	0.6795
Chromium	1.188	3.652	7	32	1.487	0.2074
Copper	0.297	0.709	7	32	1.916	0.0996
Mercury	0.268	0.896	7	32	1.367	0.2530
Nickel	0.734	1.213	7	32	2.767	0.0229
Lead	3.028	0.773	7	32	17.914	0.0001
Selenium	0.659	2.768	7	32	1.088	0.3937
Zinc	0.022	0.212	7	32	0.483	0.8394
Butyltins						
Tributyltin	1.853	17.791	7	32	0.476	0.8446
Dibutyltin	0.830	7.851	4	20	0.528	0.7163

TABLE B.14. Mean Pesticide and Polychorinated Biphenyl Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight									
	Alpha BHC	Delta BHC	Gamma BHC	4,4'-DDD	4,4'-DDE	Dieldrin	Endo-sulfan I	Endo-sulfan II	Endosulfan sulfate	Aroclor 1254
R-AM	2.72 UJE[a]	2.88 U[b]	2.45 UJE	1.94 U	5.08	30.07 U	8.27 U	8.27 U	8.27 U	96.74
COMP I	---[c]	—	—	**5.97**	**12.70**	—	—	—	—	—
COMP II	—	—	—	**12.97**	**14.58**	—	—	—	—	172.22
COMP III	—	—	—	—	—	—	—	—	—	—
TC-5 Upper Comp	—	—	—	**18.80**	**23.27**	—	—	—	—	**410.42**
COMP IV	—	—	—	—	—	—	—	—	—	—
COMP V	—	—	—	**76.11**	**40.41**	—	—	—	—	**317.81**
COMP VI	—	—	—	**105.48**	**37.33**	—	—	—	—	**362.74**

(a) UJE Mean of undetected values, values detected below method detection limit, or estimated values.
(b) U Undetected in all replicates; value is mean of dry weight detection limits.
(c) — Mean value not statistically significantly different from reference sediment R-AM.

TABLE B.15. Mean Metals Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in mg/kg Dry Weight									
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Zn
R-AM	0.056	23.5	1.18	0.84	12.07	0.078	5.56	0.62	1.57	196.7
COMP I	---(a)	34.7	---	---	---	---	---	1.05	---	---
COMP II	---	31.1	---	---	---	---	---	0.96	---	---
COMP III	---	---	---	---	---	---	---	---	---	---
TC-5 Upper Comp	---	35.8	---	---	---	---	---	1.26	---	---
COMP IV	---	---	---	---	---	---	---	---	---	---
COMP V	---	31.1	---	---	---	---	---	1.12	---	---
COMP VI	---	32.8	---	---	---	---	---	1.24	---	---

(a) --- Mean value not statistically significantly different from reference sediment R-AM.

TABLE B.16. Mean Butyltin Concentrations in the Tissues of *N. caecoides* that Were Statistically Significantly Different from Reference Sediment R-AM (plain type indicates statistical significance above R-AM; bold type indicates ≥ 2 but < 5-fold magnification of treatment mean compared to R-AM mean; shading indicates ≥ 5 but < 10-fold magnification; shaded box indicates ≥ 10-fold magnification)

Sediment Treatment	Concentrations in µg/kg Dry Weight	
	Tributyltin	Dibutyltin
R-AM	119.03	45.31 UJ[a]
COMP I	---[b]	---
COMP II	---	---
COMP III	---	---
TC-5	---	---
COMP IV	---	---
COMP V	---	---
COMP VI	---	---

(a) UJ Analyte either undetected or detected below method detection limit in all replicates; value is mean of detected values and dry weight detection limits.

(b) --- Mean value not statistically significantly different from reference sediment R-AM.

Sediment Treatments	YBM	Sediment Chemistry					Toxicity		Significant Bioaccumulation						Bioaccumulation ≥ 2 but < 5 times						Bioaccumulation ≥ 5 but < 10 times						Bioaccumulation ≥ 10 times					
	Average % of test material that is YBM	Sediment LPAH > R-AM	Sediment HPAH > R-AM	Sediment pesticide and PCB > R-AM	Sediment metals > R-AM	Sediment butyltins > R-AM	Species associated with SPP toxicity	Species with solid-phase acute toxicity	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds	# of LPAH compounds	# of HPAH compounds	# of pesticide compounds	# of PCB compounds	# of metals compounds	# of butyltin compounds
COMP I	100			3	8	2					2/2		/2				/2						1/									
COMP II	72	√	√	2	8						2/2	/1	/2				1/1						/1						1/			
COMP III	100			1	8			R			1/						1/															
TC-5 Upper Comp	84		√	4	9	1	C			/3	2/2	1/1	/2			/1	1/1	/1					/1						1/			
COMP IV	55				7			N																								
COMP V	69		√	4	8	2					3/2	1/1	/2				1/	/1					1/1						1/1			
COMP VI	52		√	4	8	1					3/2	1/1	1/2				1/	1/1					1/1						1/1			

YBM younger bay mud member.

√ Total low-molecular-weight polynuclear aromatic hydrocarbons (LPAH) or high-molecular-weight polynuclear aromatic hydrocarbons (HPAH) with detected values above reference sediment R-AM.

SPP Suspended-particulate-phase toxicity.

C Calculable LC50 values in *C. stigmaeus.*

R Acute toxicity in *R. abronius* 10-day test.

N Acute toxicity in *N. caecoides* 10-day test.

Number of compounds bioaccumulating in *M. nasuta* tissues.
Number of compounds bioaccumulating in *N. caecoides* tissues.

PCB Polychlorinated biphenyl.

FIGURE B.2. Matrix of Sediment Characteristics, Significant Acute Toxicity, and Significant Bioaccumulation for Sediment Treatments Representing Dredged Material from Richmond Harbor Relative to Reference Sediment R-AM

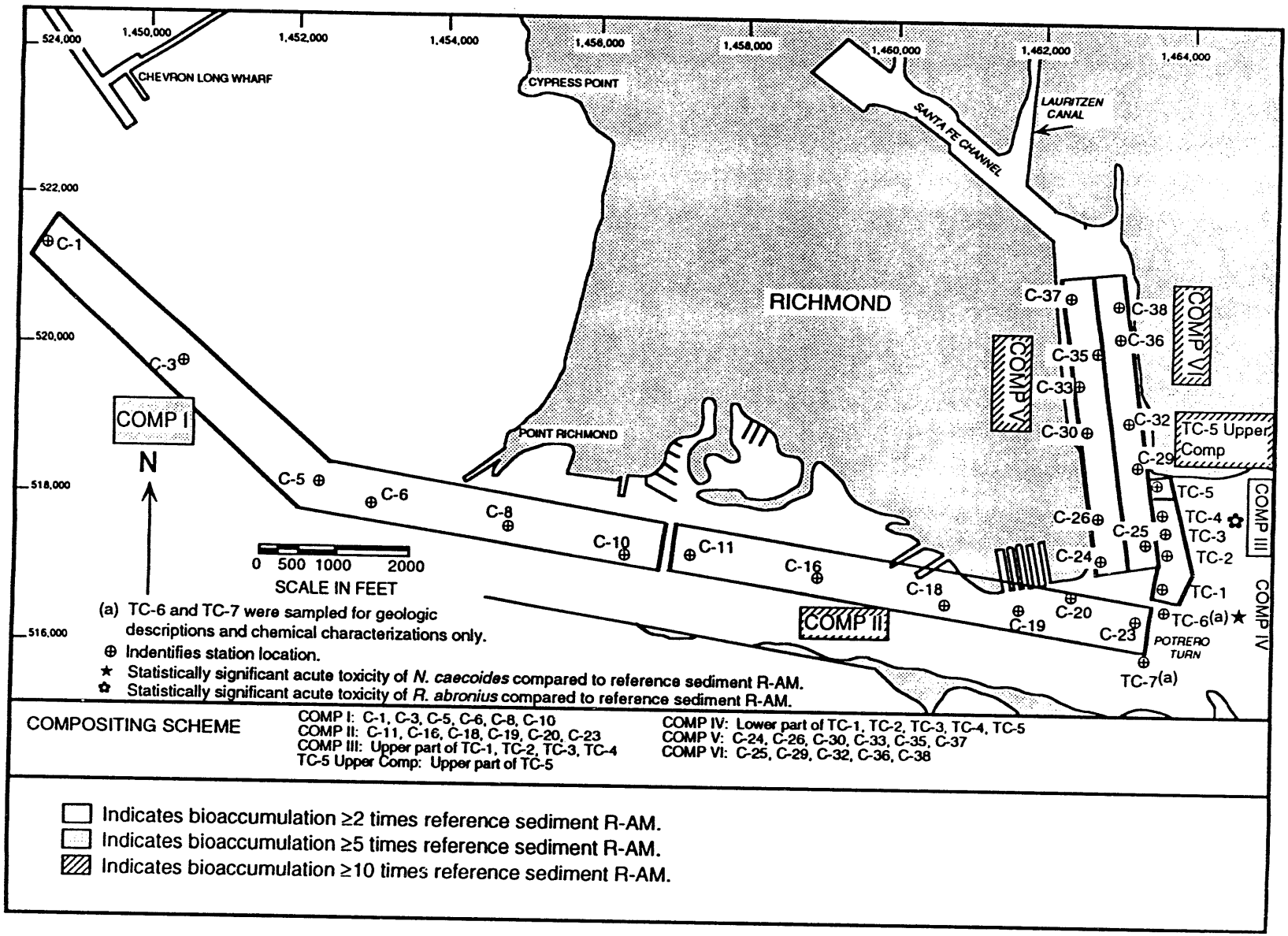

FIGURE B.3. Sediment Treatments with Acute Toxicity and/or Bioaccumulation of at Least One Contaminant in the Tissues of at Least One Species (*M. nasuta* or *N. caecoides*) at ≥2, ≥5, and ≥10 Times the Level Found in Tissues Exposed to the Reference Sediment R-AM

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