FINAL

Hunters Point Shipyard Parcel F Validation Study Report

San Francisco Bay, California

Prepared for
Base Realignment and Closure
Program Management Office West
1230 Columbia St., Suite 1100
San Diego, CA 92101

CONTRACT NO. N68711-01-F-6102

Prepared by

BATTELLE
397 Washington Street
Duxbury, MA 02332

BLASLAND, BOUCK & LEE, INC.
1135 Eugenia Place, Suite C
Carpinteria, CA 93013

NEPTUNE & COMPANY
1505 15th Street, Suite B
Los Alamos, NM 87544

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EXECUTIVE SUMMARY

This report was prepared for the Southwest Division Naval Facilities Engineering Command to document the results of the Validation Study and human health evaluation of offshore sediments (Parcel F) at Hunters Point Shipyard (HPS) in San Francisco, CA. The primary purpose of the HPS Parcel F Validation Study and human health evaluation is to more clearly identify offshore areas that require evaluation in a Feasibility Study (FS) of remedial alternatives. Data gaps regarding sediment dynamics and physical characteristics also are addressed to support the evaluation of remedial alternatives for Parcel F sediments.

Data for three lines of evidence (i.e., sediment chemistry, toxicity and bioaccumulation) were collected at 59 HPS sampling stations in five areas (Areas I, III, VIII, IX, and X) and evaluated in a weight of evidence framework. Ancillary data, including field-collected tissue data and toxicity identification evaluation study results, were used to support the weight of evidence evaluation. Subsurface sediment samples were analyzed to broadly characterize the vertical extent of contamination. A human health evaluation was performed to assess potential health risks from the consumption of shellfish at HPS and to determine whether chemical concentrations in sport fish caught at HPS with fish are higher than those in fish caught elsewhere in San Francisco Bay. Site-specific data were used to develop preliminary remediation goals (PRGs) and identify areas for consideration in the Parcel F FS. FS-related data also were collected as part of the Validation Study to support the evaluation of remedial alternatives. This information included a sediment dynamics study, analysis of ^{210}Pb and ^{137}Cs radioisotopes in sediment cores, and physical and chemical sediment characterization.

The results for the three lines of evidence were evaluated using decision criteria specified in the Validation Study Work Plan (Battelle et al., 2001a). The weight of evidence approach was not intended to be prescriptive; rather, it was used as a tool to assist in data interpretation. The weight of evidence results were not used directly to identify areas for evaluation in the Parcel F FS because the integrated results for many stations indicated that additional evaluation was needed to determine whether or not the station should be included in the FS footprint. Therefore, all study results were evaluated to identify pathways and contaminants driving ecological and human health risk in each of the five areas included in the Validation Study.

Surface sediment chemistry results indicate that chemical concentrations generally are not elevated above ambient levels and Effects Range-Median values (ER-Ms) in Areas I (India Basin) and VIII (Eastern Wetland). The highest chemical concentrations are found in Areas III (Point Avisadero) and X (South Basin). The horizontal and vertical distributions of chemicals in Area III sediments are patchy and discontinuous. The chemicals detected in Area III sediments (i.e., copper, lead, mercury, polychlorinated biphenyls [PCBs], and tributyltin [TBT]) were most likely derived from historical ship painting and maintenance activities that were carried out in the adjacent dry docks. In Area X, the highest concentrations of PCBs, TBT, and metals (primarily copper, mercury, and lead) are found along the eastern shoreline of South Basin. Chemical concentrations decrease with increasing distance from this shoreline. The most likely sources of the contaminants in Area X are the Site IR-01/21 landfill area, Parcel E fill material, and/or a historical drum storage area used by the Triple A Machine Shop.

Sediment samples from Areas I, III, VIII, IX, and X were not acutely toxic to amphipods based on a 10-day bulk sediment bioassay. Sediment samples generally were not acutely toxic to echinoderms, as indicated by normal development of purple urchin (*S. purpuratus*) larvae exposed to intact sediment-water interface cores. However, normal larval development was below the ambient threshold for San Francisco Bay at 13 of the 59 HPS sampling stations. Larval toxicity at these stations did not appear to be related to elevated sediment chemical concentrations. Ammonia might have contributed to observed toxicity at some stations in Areas III and VIII. Other potential confounding factors that could have

contributed to toxicity were poor water quality, field replicate variability, and the presence of native flora and fauna in the undisturbed cores.

A laboratory bioaccumulation test was conducted to evaluate the uptake of sediment contaminants into the tissue of the clam *M. nasuta*. Screening and refined dose assessments were performed using depurated *M. nasuta* tissue data to evaluate potential risk to benthic-invertebrate eating birds (i.e., surf scoter) exposed to HPS sediments. Screening results indicated that most stations in Areas I and VIII pose little to no risk to surf scoters. A higher proportion of stations in Areas III, IX, and X showed a potential risk. The refined dose assessments identified copper, mercury, lead and PCBs as upper trophic level risk drivers when higher site use factors (i.e., ≥0.5) were considered. Hazard quotient (HQ_{low}) values for all chemicals except lead were below 1.0 when site use factors of ≤0.1 were used. HQ_{low} values for lead were high for all scenarios, including consideration of ambient exposure only. Based on these findings, PCBs, mercury and copper were identified as the primary risk drivers. Lead was identified as a potential contributor to risk, although it cannot be definitively identified as a primary risk driver because of the uncertainty associated with evaluating risk associated with exposure to lead. Potential risk from exposure to lead is qualitatively addressed because the highest lead concentrations are found in Area X sediment and generally co-occur with high PCB concentrations. Dose assessments were also performed using a small amount of field-collected bivalve and polychaete tissue data. These results supported the use of depurated laboratory *M. nasuta* tissue data in the food chain model to represent ingestion of bivalves by upper trophic level receptors, but did not support the use of the laboratory *M. nasuta* data to represent ingestion of polychaetes.

Potential human health risks from shellfish consumption and direct contact with sediment during shellfish collection were evaluated using *M. nasuta* tissue data from the laboratory bioaccumulation test. Risks associated with direct contact were more than 100 times lower than risks associated with shellfish ingestion. On an area-wide basis, cumulative risks to humans from Parcel F sediments are comparable to risks from ambient conditions in San Francisco Bay with the exception of exposure to PCBs. Risks associated with PCBs are elevated above reference levels on the south side of HPS, in Areas IX and X. The statistical comparison of chemical concentrations in sport fish tissue samples from HPS and San Francisco Bay reference sites indicated that PCBs in jacksmelt from HPS were elevated above ambient levels.

Based on these results, Area III (Point Avisadero) and Areas IX-X (South Basin) pose the greatest potential risk to ecological receptors. Mercury and copper were identified as the primary risk drivers in Area III, and PCBs were identified as the primary risk driver in Areas IX-X. Uncertainties associated with risks to receptors that forage primarily on polychaetes should be addressed as part of the risk management process in the FS. Human health risks from consuming shellfish in Areas IX-X exceed reference levels due to PCBs. Sediments in Areas I (India Basin) and VIII (Eastern Wetland) pose a low potential ecological or human health risk. Shoreline material in some areas may act as potential future sources of contamination to offshore areas. Therefore, Areas I, III, VIII, IX and X will be evaluated in the Parcel F FS. Remedial action objectives (RAOs) will be developed during the FS scoping process to address ecological and human health risk concerns as well as source control issues. In addition, radiological surveys will be performed in areas as recommended by the Historical Radiological Assessment (DON, 2004).

PRGs for sediment based on risk to benthic invertebrate-feeding birds (i.e., the surf scoter) from PCBs, mercury and copper were developed using the collocated sediment and laboratory-exposed *M. nasuta* tissue data. These data provide a strong, direct link between sediment-associated contaminants and tissue. Ranges of PRGs based on SUFs of 1 to 0.01 are 135 mg/kg to 13,500 mg/kg dry weight for copper, 0.94 mg/kg to 94 mg/kg dry weight for mercury, and 0.62 mg/kg to 62 mg/kg dry weight for PCBs. The PCB

PRGs were compared with PRGs developed for a piscivorous bird (i.e., the double-crested cormorant) and determined to be sufficiently protective for this receptor.

Information on sediment dynamics also was collected in the Validation Study to support the Parcel F FS. The FS-related data indicate that South Basin is an area of sediment accumulation with an average sedimentation rate of about 1 cm/yr. Infrequent winter storms cause wave-induced resuspension of sediments in South Basin, and extreme event storms may erode the sediment bed. Site-specific data on the erosional properties of the sediment bed were collected in 2003 to predict the effects of these erosional events with greater certainty. The FS-related data collected in the Validation Study will be integrated with additional data collected for the FS data gaps investigation (Battelle et al., 2005) in the Parcel F FS Report.

Additional contaminant distribution data in Areas III (Point Avisadero) and IX-X (South Basin) as part of the FS Data Gaps investigation in 2003 are provided in the *Parcel F FS Data Gaps Technical Memorandum* (Battelle et al., 2005). During the FS scoping process, these data will be considered in conjunction with the PRGs developed in this report and other information to delineate areas for evaluation in the FS.

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ACRONYMS AND ABBREVIATIONS

ADD	average daily dose
ADL	Arthur D. Little
AF	adherence factor
ASTM	American Society for Testing and Materials
AT	averaging time
ATT	Aqua Terra Technologies
AVS	acid volatile sulfide(s)
BAF	bioaccumulation factor
BDL	Battelle Duxbury Laboratory
bgs	below ground surface
BPTCP	(San Francisco) Bay Protection and Toxic Hot Spot Cleanup Program
BRAC	(Defense) Base Realignment and Closure Act (of 1990)
BSAF	biota-sediment accumulation factor
BSL	Battelle Sequim Laboratory
BTAG	Biological Technical Assistance Group
BW	body weight
CCR	California Code of Regulations
CDFG	California Department of Fish and Game
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (of 1980)
COPC	chemical of potential concern
COPEC	chemical of potential ecological concern
CSF	cancer slope factor
CSM	conceptual site model
CSO	combined sewer overflow
CTE	Central Tendency Exposure
DAF	dermal absorption factor
DBT	dibutyltin
DCCO	double-crested cormorant
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DQO	data quality objective
DTSC	(California) Department of Toxic Substances Control
EC50	median effective concentration
ED	exposure duration
EDD	electronic data deliverable
EF	exposure frequency
EFANE	Engineering Field Activity Northeast
EPC	exposure point concentration
ERA	ecological risk assessment
ER-L	effects range-low
ER-M	effects range-median
ERM-Q	effects range-median quotient
ERV	ecotoxicity reference value

ESAP	Environmental Sampling and Analysis Plan
EW	Eastern Wetland
FDA	(United States) Food and Drug Administration
FF	forage fish
FI	fraction ingested
FS	Feasibility Study
HBI	hard-bodied invertebrate
HDPE	high-density polyethylene
HEAST	(U.S. EPA) Health Effects Assessment Summary Tables
HHE	Human Health Evaluation
HI	hazard index
HLA	Harding Lawson Associates
HPAH	high molecular weight PAHs
HPS	Hunters Point Shipyard
HQ	hazard quotient
IB	India Basin
IR	Installation Restoration / ingestion rate
IRIS	(U.S. EPA) Integrated Risk Information System
LADD	lifetime average daily dose
LC50	lethal concentration
LDC	Laboratory Data Consultants
LFR	Levine-Fricke-Recon, Inc.
LOAEL	lowest observed adverse effects level
LPAH	low molecular weight PAHs
MBT	monobutyltin
MSD	minimum significant difference
NA	not available / not applicable
NAD	North American Datum
ND	not detected
NOAA	National Oceanic and Atmospheric Administration
NOEC	no observed effects concentration
NOAEL	no observed adverse effects level
NPL	National Priorities List
NS&T	National Oceanic and Atmospheric Administration Status and Trends
OEHHA	Office of Environmental Health Hazard Assessment
OR	Oil Reclamation
PA	Point Avisadero
PAH	polycyclic aromatic hydrocarbon
PCA	principal components analysis
PCB	polychlorinated biphenyl
PERL	Pacific Ecorisk Laboratory
PRC	PRC Environmental Management, Inc.
PRG	preliminary remediation goal

QAPP	Quality Assurance Project Plan
QC	quality control
RAO	remedial action objective
RfD	reference dose
RME	Reasonable Maximum Exposure
RMP	Regional Monitoring Program
ROC	receptor of concern
ROD	Record of Decision
RWQCB	(San Francisco Bay) Regional Water Quality Control Board
SA	(skin) surface area
SAIC	Science Applications International Corporation
SARA	Superfund Amendments and Reauthorization Act (of 1986)
SB	South Basin
SBI	soft-bodied invertebrate
SEM	simultaneously extractable metal(s)
SFEI	San Francisco Estuary Institute
SOP	Standard Operating Procedure
SPP	suspended particulate phase
SUF	site use factor
SVOC	semivolatile organic compound
SWDIV	Southwest Division Naval Facilities Engineering Command
SWI	sediment-water interface
SWIC	sediment-water interface core
SWRCB	State Water Resources Control Board
TBT	tributylin
TCDD	tetrachlorodibenzo-*p*-dioxin
TCLP	Toxicity Characteristic Leaching Procedure
TEF	toxic equivalency factor
TEQ	toxic equivalence quotient
TIE	Toxicity Identification Evaluation
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TPH-DRO	total petroleum hydrocarbons-diesel range organics
TRV	toxicity reference value
TTBT	tetrabutyltin
TtEMI	Tetra Tech EM, Inc.
UCL	upper confidence limit
USACE	United States Army Corps of Engineers
U.S. EPA	United States Environmental Protection Agency
U.S. FWS	United States Fish and Wildlife Service
UTL	upper tolerance limit
VS	Validation Study
WOE	weight of evidence
XRF	x-ray fluorescence

1.0 INTRODUCTION

This report was prepared for the Southwest Division Naval Facilities Engineering Command (SWDIV) to document the results of the Validation Study (VS) of offshore sediments (Parcel F) at Hunters Point Shipyard (HPS) in San Francisco, CA. The primary purpose of the HPS Parcel F Validation Study is to more clearly identify offshore areas that require evaluation in a Feasibility Study (FS) of remedial alternatives. Data gaps regarding sediment dynamics and physical characteristics also are addressed to support the evaluation of remedial alternatives for Parcel F sediments.

The Validation Study approach and sampling design are described in detail in the *Hunters Point Shipyard Parcel F Validation Study Work Plan* (VS Work Plan; Battelle et al., 2001a). The human health evaluation approach is described in the *Hunters Point Shipyard Parcel F Human Health Evaluation Work Plan* (HHE Work Plan; Battelle et al., 2001b). The scope and approach for the Validation Study were discussed in a series of meetings and conference calls between the Navy and technical representatives of United States Environmental Protection Agency (U.S. EPA) Region 9, the San Francisco Bay Regional Water Quality Control Board (RWQCB), the California Department of Toxic Substances Control (DTSC), the California Department of Fish and Game (CDFG), the National Oceanic and Atmospheric Administration (NOAA), and the United States Fish and Wildlife Service (U.S. FWS). The approach developed for the human health evaluation was based on discussions with the Navy and technical representatives of U.S. EPA Region 9 and DTSC.

The Parcel F FS data gaps investigation was conducted in 2003 to support development of the Parcel F FS. Results of this investigation are provided in a technical memorandum (Battelle et al., 2005).

1.1 Site Background

The following sections provide a brief overview of the site and summary of previous investigations at Parcel F.

1.1.1 Site Description

HPS is a former Navy installation located on a peninsula in the southeast corner of San Francisco, CA (Figure 1-1). The peninsula is bounded on the north, east, and south by San Francisco Bay and on the west by the Bayview Hunters Point district. HPS comprises about 955 acres, with approximately 457 acres of offshore sediment.

HPS has an irregular shoreline that trends generally in the N-S direction, with an E-W embayment (i.e., South Basin) on the south side of the peninsula. The water depth along the northern shore of HPS (i.e., India Basin) is generally less than 10 ft, increasing to greater than 50 ft in the shipping channel to the east of HPS. The water depths in the southern portion of the study area within South Basin range from 6 ft to less than 2 ft.

No streams or rivers enter the offshore area near HPS with the exception of Yosemite Creek at the head of South Basin (Figure 1-1). Yosemite Creek is very shallow, with a maximum depth of about 3 ft at high tide.

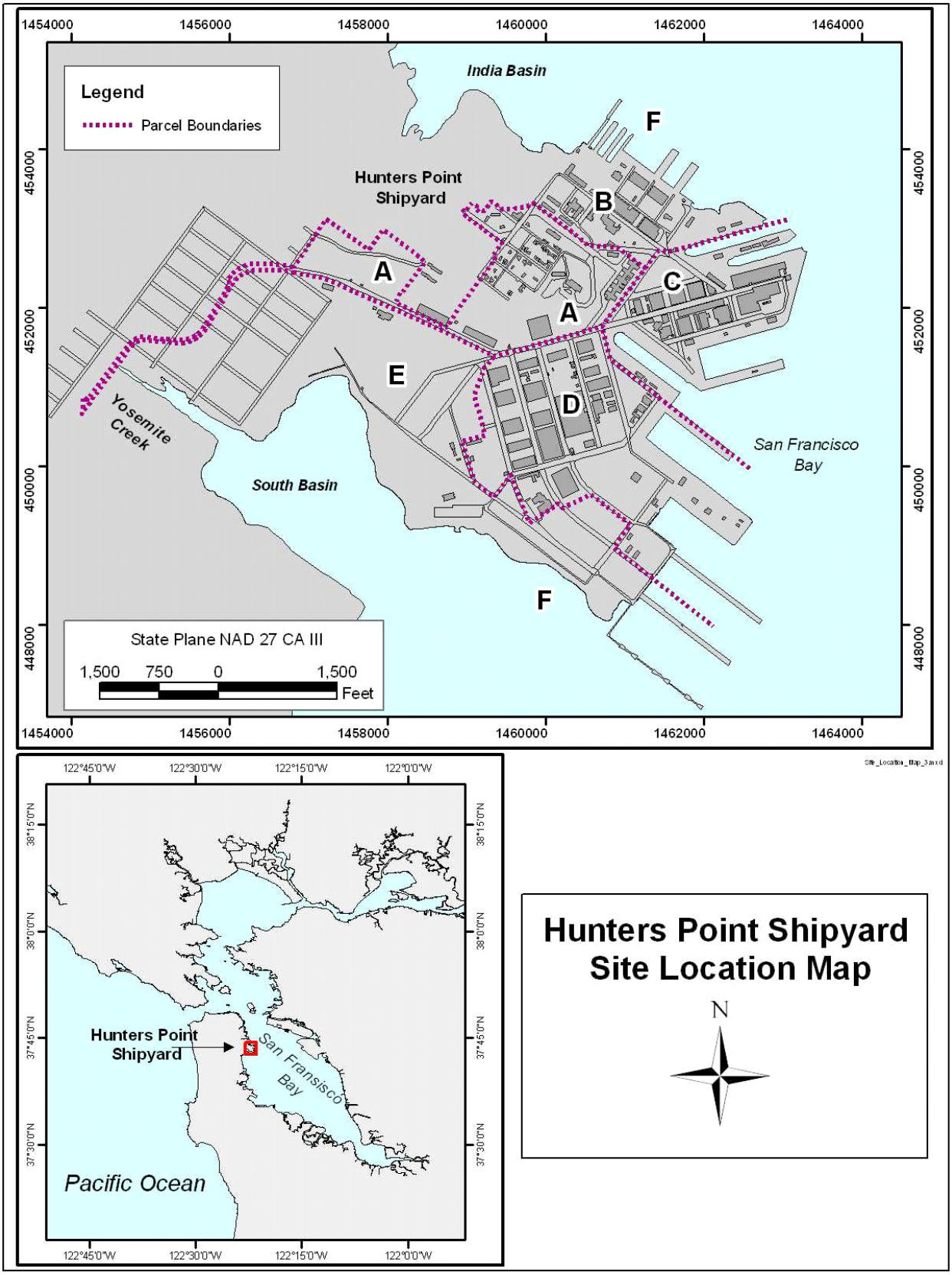


Figure 1-1. Hunters Point Shipyard Site Location Map

1.1.2 Site History

From 1945 to 1974, the Navy maintained and repaired ships at HPS. The facility was deactivated in 1974 and remained relatively unused until 1976, when it was leased to Triple A Machine Shop, a private ship repair company. In 1986, the Navy resumed occupancy of HPS. The facility was closed in 1991 under the Defense Base Realignment and Closure Act of 1990 (BRAC) and is in the process of conversion to nonmilitary use.

Historical site activities at HPS resulted in the release of chemicals to the environment, including offshore sediments. Potential sources of contamination to sediments are discussed further in Section 1.2. Environmental restoration activities at the site are being conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA).

1.1.3 Previous Studies

Previous studies at Parcel F include the Environmental Sampling and Analysis Plan (ESAP) program, qualitative and quantitative ecological risk assessments (ERAs), and a draft FS. The ESAP program was conducted in 1991 to evaluate the presence of contaminants in offshore areas and included measurements of sediment and water chemistry and toxicity (Aqua Terra Technologies [ATT], 1991). The ESAP data indicated that future quantitative data collection efforts should focus on offshore sediments as the main cause of toxicity to site receptors.

A Basewide Phase 1A ERA was conducted from 1991 to 1994 and included a qualitative assessment of offshore areas (PRC Environmental Management Inc. [PRC], 1994). This investigation, which corresponded to the problem formulation step of the U.S. EPA's ERA framework, consisted of a qualitative analysis of existing site data, biotic surveys, and fate and transport analyses. The Phase 1B ERA (PRC, 1996) was conducted from 1994 to 1996 and addressed the data gaps identified in the Phase 1A report. The Phase 1B investigation focused on characterizing offshore contamination associated with outfalls. Additionally, some data from the intertidal zone were collected during investigation of specific Installation Restoration (IR) sites in the upland part of HPS (Tetra Tech EM, Inc. [TtEMI], 1997). Data were used to describe the nature and extent of contamination in offshore sediment and to characterize risk.

A draft FS report was submitted to regulatory agencies for review in April 1998 (TtEMI and Levine-Fricke-Recon, Inc. [LFR], 1998). The report presented high-volume and low-volume remediation footprints for Parcel F based on two different decision flow processes, with the high-volume footprint based on a more conservative set of criteria. The primary criteria used to define the low-volume footprint were effects range-median (ER-M) values (Long and Morgan, 1991; Long et al., 1995) and bioaccumulation criteria for polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT). The low-volume footprint at Parcel F consists of five areas, as shown in Figure 1-2.

The *HPS Parcel F Data Summary Memorandum* was prepared in late 1999 to provide a common understanding of the site and a starting point for technical discussions with regulatory agencies and co-trustees in order to establish a path forward for Parcel F (Battelle et al., 1999). The *Data Summary Memorandum* provided a summary and evaluation of existing sediment chemistry and bioassay data, identified the uncertainties associated with each component of the existing data, and presented proposed dose assessment refinements. In addition, the results of a bioassay pre-test study were presented that evaluated the potential influence of confounding factors such as ammonia, salinity, and organism acclimation time on previous bioassay results. The *Data Summary Memorandum* was followed by development of the VS Work Plan (Battelle et al., 2001a) and the HHE Work Plan (Battelle et al., 2001b).

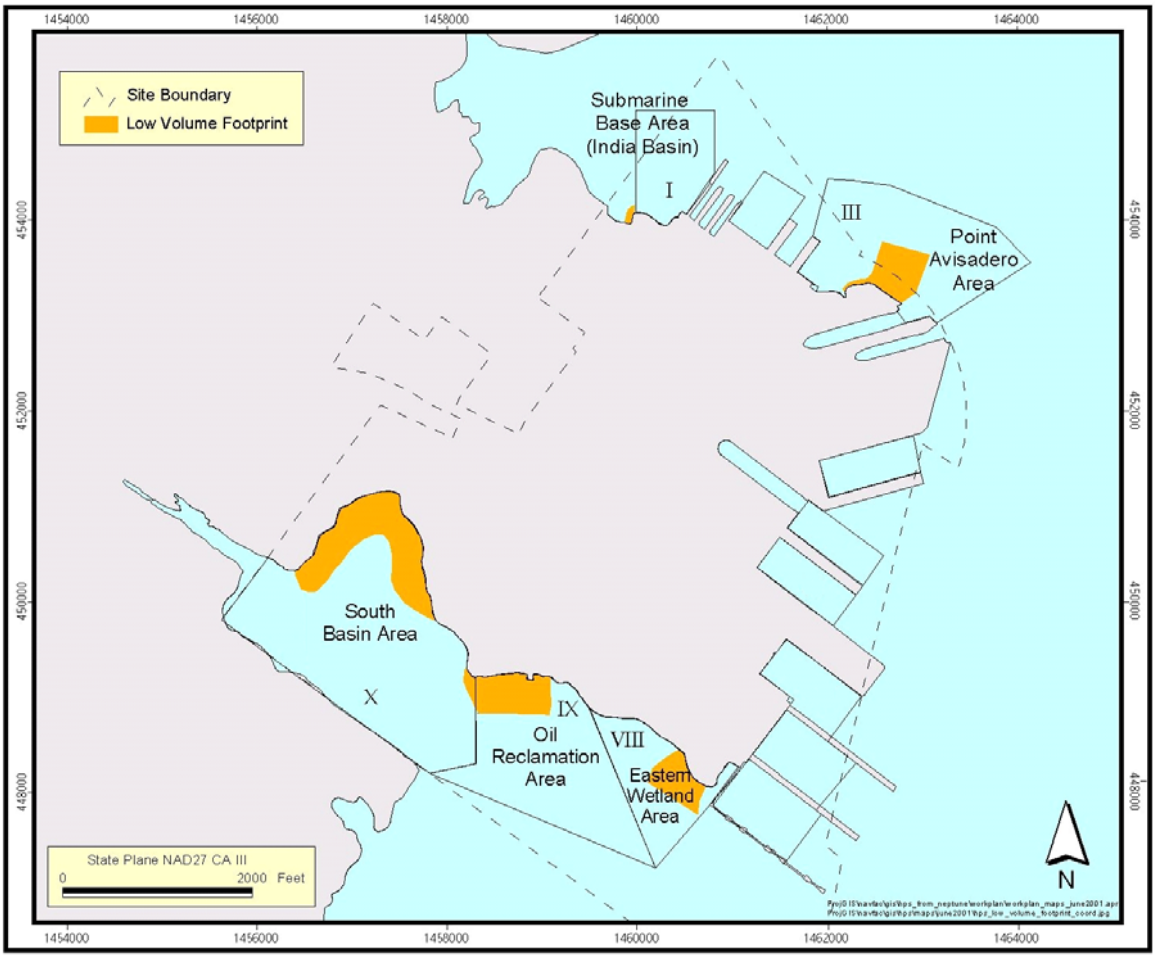


Figure 1-2. Hunters Point Shipyard Low-Volume Footprint

The Validation Study focuses on the five areas of the low-volume footprint at Parcel F (Figure 1-2). These five areas represent the areas of highest ecological hazard based on previous data. In order to more accurately define the boundaries of the low-volume footprint areas and contaminant distribution within each area, a sediment screening study was conducted in April 2000 to support the Validation Study sample design (Battelle et al., 2001a). Surface sediment samples were collected in a grid pattern from 95 locations in the five areas that define the low-volume footprint. The screening sample coverage was extended beyond the boundaries of the low-volume footprint in selected areas in accordance with agreements reached in technical discussions between the Navy and regulatory agencies, although not all of the extended areas proposed for screening by the agencies were sampled. The samples were screened for lead (Pb), copper (Cu), and zinc (Zn) using x-ray fluorescence (XRF), and for PCBs using an immunoassay technique. The screening results were used to ensure that the Validation Study sample stations spanned the entire range of contaminant concentrations and therefore were able to represent the full range of potential exposures. The results of this screening survey are reported in the VS Work Plan (Battelle et al., 2001a).

1.2 Source Characterization

This section presents a summary of the potential onshore sources of contamination that may have affected the five low-volume footprint areas included in the Validation Study: Area I (India Basin), Area III

(Point Avisadero), Area VIII (Eastern Wetland), Area IX (Oil Reclamation), and Area X (South Basin). Additional information on potential sources of contamination is included in the *Parcel F FS Data Gaps Technical Memorandum* (Battelle et al., 2005).

1.2.1 Area I (India Basin)

Potential onshore sources of contamination to offshore sediments in Area I (India Basin) are as follows:

- IR Site IR-07 shoreline contamination; and
- Stormwater outfalls.

Site IR-07 is the upland area adjacent to Area I (Figure 1-3). It is part of HPS Parcel B, which is in the process of undergoing remedial actions under CERCLA. Site IR-07 soils contained elevated concentrations of metals, polycyclic aromatic hydrocarbons (PAHs), fuels, pesticides, semivolatile organic compounds (SVOCs), and PCBs. These soils potentially could have been transported offshore via erosion and surface runoff. Excavation of these soils adjacent to riprap along the shoreline was halted in December 2000 due to construction and safety constraints. Additional sampling was conducted to complete the delineation of contamination in the shoreline and adjacent upland area (TtEMI, 2003a). These data will be used to support the development of a remedy for the Parcel B shoreline in the vicinity of Area I. A revetment blanket is a remedial alternative for shoreline areas that will be considered as part of the Parcel B Record of Decision (ROD) amendment process.

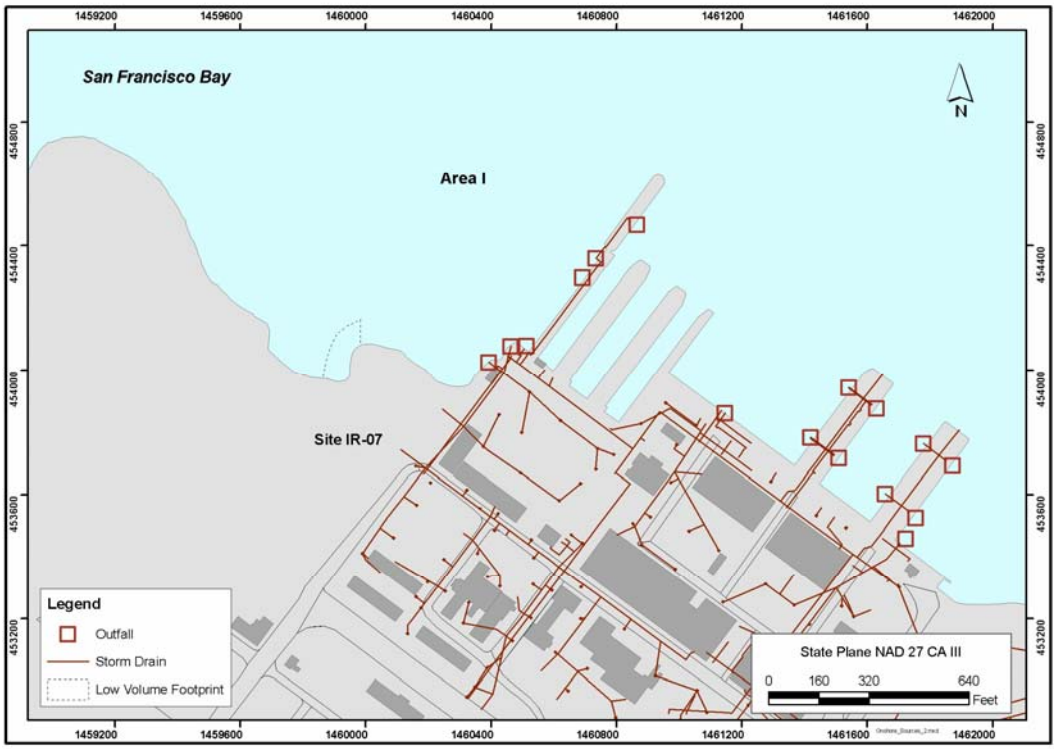


Figure 1-3. Potential Onshore Sources in Area I

Three stormwater outfalls are located at the southeastern corner of the Area I study area (Figure 1-3). Contaminated solids may have been transported into the offshore area via these outfalls in the past. The HPS stormwater drains were cleaned in 1997 and the outlets were sealed.

1.2.2 Area III (Point Avisadero)

Potential sources of contamination into Area III (Point Avisadero) are as follows:

- Stormwater outfalls;
- Drainage tunnel from Dry Docks 2 and 3; and
- Surface runoff and groundwater discharge from Site IR-26.

Multiple stormwater outfalls drain into Area III (Figure 1-4). These storm drains may have historically conveyed contaminated solids into the offshore area; they were cleaned of residual sediment in 1997.

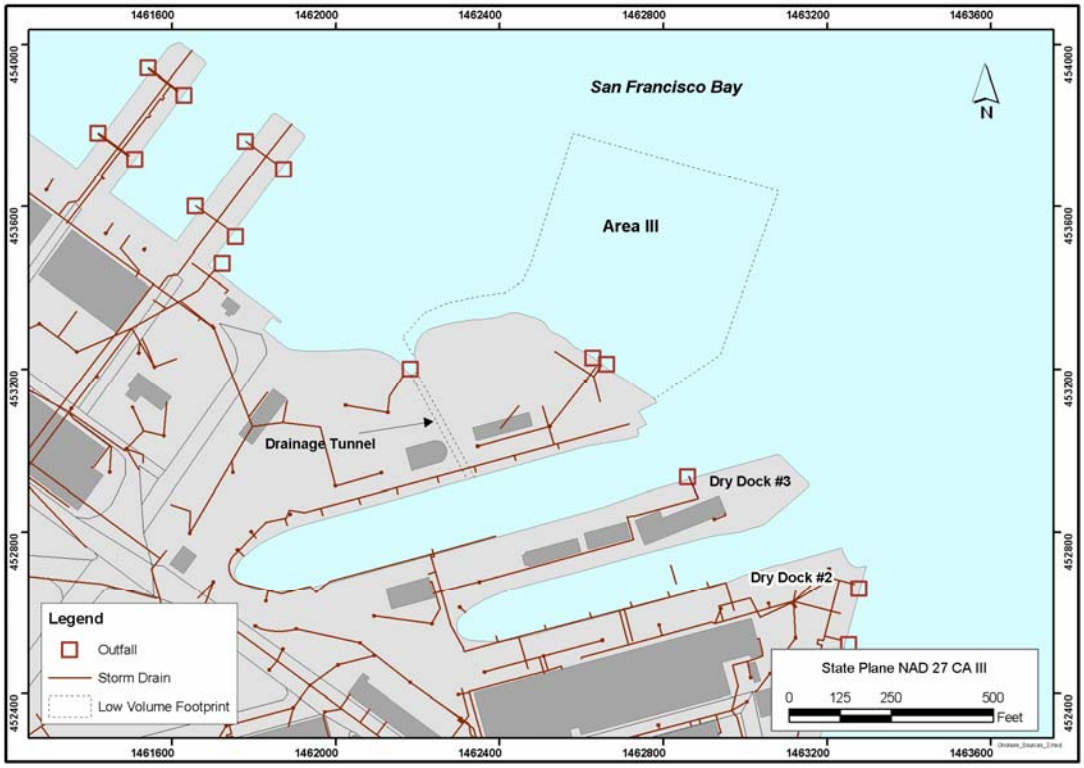


Figure 1-4. Potential Onshore Sources in Area III

A drainage tunnel that was used to rapidly drain water extends from Dry Docks 2 and 3 to an outfall on the north side of Point Avisadero (Figure 1-4) (Moffet and Nichols Engineers, 1981). This tunnel is 6-8 ft in diameter and also may have been a conduit for waste material from the dry docks, including paint chips, sandblast grit, oils, and other chemicals associated with ship maintenance and repair. This tunnel has not been used for some time and currently is blocked completely by a steel door approximately 25 feet in from the Area III shoreline.

Site IR-26 in HPS Parcel B contains soils contaminated with metals (chromium, copper, lead, and mercury) and PAHs. Contaminants from Site IR-26 may have been transported to the offshore area via stormwater outfalls, surface runoff, or groundwater discharge. Contaminated soils in Site IR-26 have been excavated, although some elevated levels of metals still remain at 10 ft below ground surface (bgs). A shoreline study was conducted in 2002-2003 to investigate the possible presence of contamination along the shoreline of Parcel B adjacent to Point Avisadero (TtEMI, 2003a). These data indicated that nine metals (antimony, arsenic, barium, cadmium, copper, lead, manganese, thallium, and zinc) were present at concentrations above HPS ambient levels. PAHs, several pesticides, PCBs, and total petroleum hydrocarbons (TPH) also were detected.

1.2.3 Area VIII (Eastern Wetland)

Potential sources of contamination into Area VIII (Eastern Wetland) are as follows:

- Stormwater outfall;
- Metal and other debris along the shoreline.

A stormwater outfall that drains HPS Parcel E is located on the west side of Area VIII (Figure 1-5). The storm drains were cleaned in 1997.

The Area VIII shoreline is composed of metal and other debris, and an annealed slag-like material. Leaching and runoff of this material is a potential source of metals to the offshore area. Removal of the

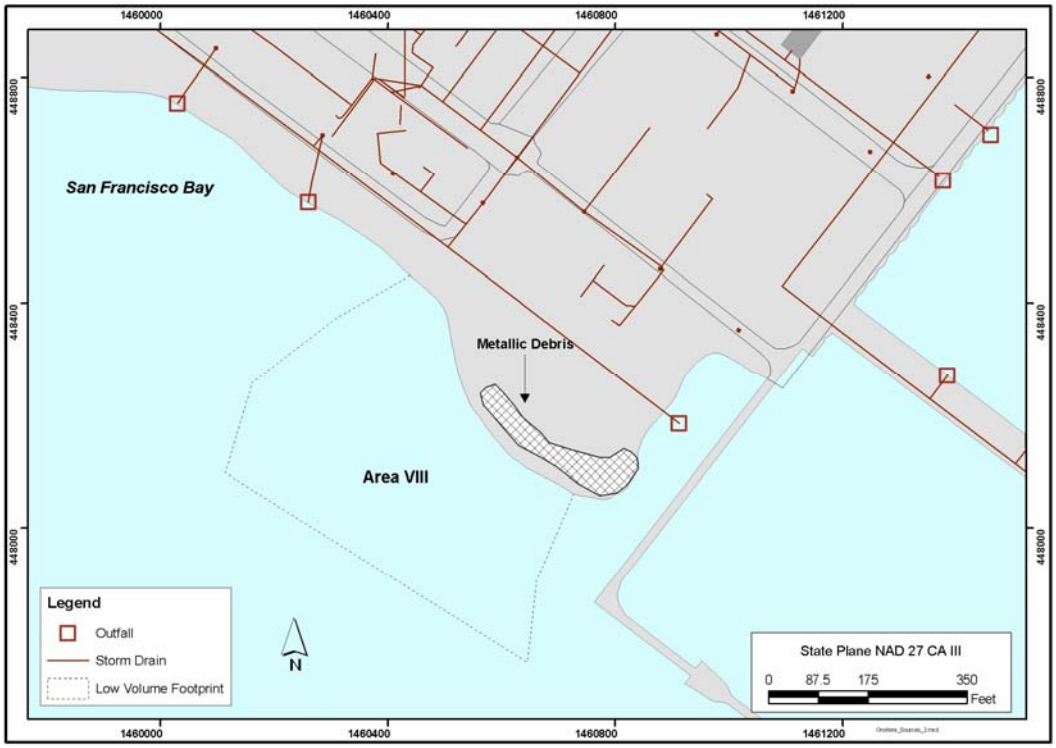


Figure 1-5. Potential Onshore Sources in Area VIII

metallic debris and slag from the shoreline adjacent to Area VIII is planned as part of the Parcel E remedial activities.

1.2.4 Area IX (Oil Reclamation)

A former small arms firing range is located adjacent to Area IX (Oil Reclamation) (Figure 1-6). Sampling and analysis of the Parcel E shoreline area and former firing range was conducted in 2002 to further characterize this area and results indicate that it is not a source of PCBs to Area IX (TtEMI, 2003b). The historical oil reclamation ponds (Site IR-03) are located approximately 1,000 ft east-southeast of Area IX. The ponds have been closed, sheet piling has been placed adjacent to the shoreline, and the shoreline has been stabilized in this area as part of onshore remediation activities.

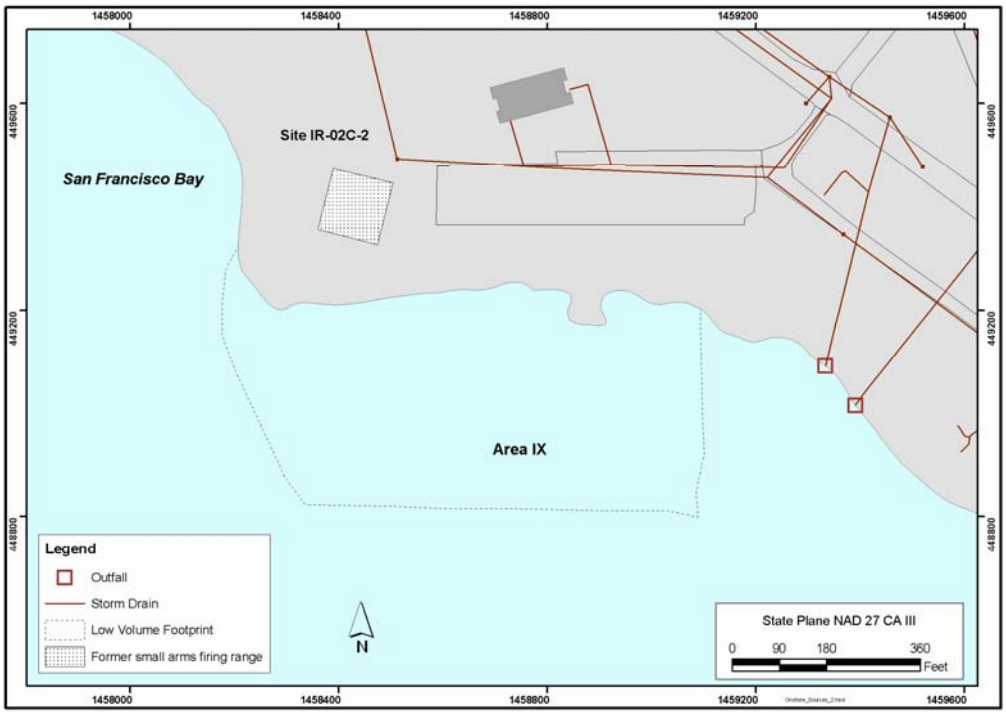


Figure 1-6. Potential Onshore Sources in Area IX

1.2.5 Area X (South Basin)

Potential sources of contamination into Area X (South Basin) are as follows:

- Industrial landfill area at Site IR-01/21;
- Former Triple A drum storage area;
- Metal debris and sand blast material along the shoreline;
- Offsite sources affecting sediments in Yosemite Creek.

The landfill area at Site IR-01/21 (Figure 1-7) was used from 1958 to 1974 for the disposal of materials such as construction and industrial debris and waste, domestic refuse, sandblast waste, paint sludge, solvents, waste oils, transformers and electrical equipment and other potentially contaminating materials.

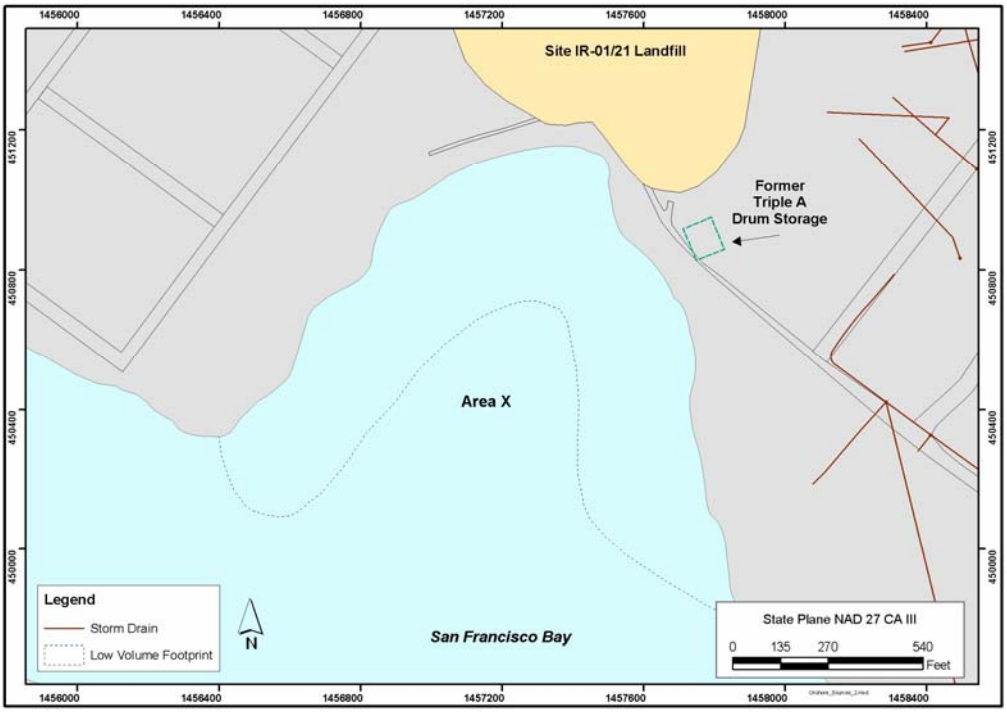


Figure 1-7. Potential Onshore Sources in Area X

There are no records that document disposal practices. In addition, historical aerial photographs indicate that the shoreline area was progressively filled from approximately 1946 through 1969. The shoreline on the northeast side of South Basin was filled from approximately 1965 to 1969. Contaminants from the landfill area may have been carried into the offshore area via erosion and transport of contaminated soils or fill material and groundwater discharge.

In 1994, a sheet pile wall was installed and riprap was placed along the shoreline side to control the additional movement of contaminants. After a landfill fire in 2000, a cap was placed over most of the landfill (TtEMI, 2001). This cap is expected to control infiltration of surface water. Further monitoring and investigation activities were initiated in 2002, including determining the lateral extent of the landfill, monitoring landfill gas, evaluating liquefaction potential, and wetlands delineation and assessment (TtEMI, 2002).

A former drum storage area previously operated by Triple A Machine Shop is located on the eastern shoreline of South Basin (Figure 1-7). No records exist about the types and quantities of materials stored in this area. If chemicals formerly stored in this area were released to the environment, then they could have been transported to the offshore area via surface drainage.

Debris along the shoreline of South Basin (e.g., metallic waste, kiln bricks, sandblast grit) may be another source of contaminants to the offshore area. Sampling and analysis of the HPS Parcel E shoreline area was conducted in 2002 to further investigate this potential source (TtEMI, 2003b). The Parcel E data gaps investigation found that the highest PCB concentrations along the Parcel E shoreline are located on the east side of Area X, south of the landfill and close to former drum storage area. The Navy is planning to remove the PCB hotspot adjacent to the sheet pile wall.

Yosemite Creek enters South Basin at the southwest corner of HPS. Yosemite Creek is listed as a Site of Concern by the RWQCB under the Bay Protection and Toxic Hot Spot Cleanup Program (BPTCP) (RWQCB, 1997). Contaminants identified in sediment samples collected from the Yosemite Creek area for this program were PCBs, PAHs, pesticides, and metals. Potential sources of contamination into Yosemite Creek upstream of HPS include the Bay Area Drum Superfund Site and outfalls associated with the City and County of San Francisco's combined sewer overflow (CSO) system. Given the weak tidal circulation in South Basin, significant upstream transport of contaminated sediments from the Parcel E shoreline adjacent to the landfill into Yosemite Creek is unlikely. The Public Utilities Commission, City and County of San Francisco issued a report in 1999 documenting contamination in Yosemite Creek (Arthur D. Little [ADL], 1999). Additional source characterization information for South Basin is being collected as part of the Parcel F FS Data Gaps investigation.

1.3 Objectives

The primary objective of this investigation is to identify the areas of offshore sediment requiring evaluation in an FS of remedial alternatives. Both ecological and human health risks were considered as described below. The results of these evaluations were integrated to identify the areas that will be evaluated in the Parcel F Feasibility Study.

1.3.1 Validation Study Objectives

The Validation Study focused on the five areas of the low-volume footprint (Figure 1-2). Specific objectives of the Validation Study were as follows:

1. Use three lines of evidence (sediment chemistry, toxicity, and bioaccumulation studies) and ancillary data to better identify areas of surface sediments that pose an unacceptable risk to the environment (i.e., that cause toxicity at levels exceeding San Francisco Bay reference conditions, or risk to upper trophic level receptors that exceeds San Francisco Bay reference conditions and toxicity reference values).

2. Collect data for the three lines of evidence at locations that span the range of chemical concentrations and, if possible, establish exposure-response relationships and develop preliminary remediation goals (PRGs).

3. Collect data regarding sediment characteristics and sediment dynamics to support the evaluation of remedial alternatives for Parcel F sediments.

The Validation Study focuses on soft subtidal sediments below the break in slope that forms the shoreline or below the toe of debris along the shoreline, as appropriate. Shoreline and intertidal areas that are covered with riprap or disposal debris such as concrete, bricks, or metal rebar have been characterized as part of Parcel B and Parcel E activities (TtEMI, 2003a and 2003b) and will be managed as part of the adjacent upland parcels. The debris-lined shoreline areas will be evaluated and managed as potential sources of contamination to offshore sediments.

1.3.2 Human Health Evaluation Objectives

The primary objective of the human health evaluation was to identify more clearly offshore sediments that pose an unacceptable human health risk. As with the Validation Study, the human health evaluation focuses on the five areas of the low-volume footprint (Figure 1-2). In addition, the difference in the risk associated with consuming fish from the HPS area relative to consuming fish from other locations within

San Francisco Bay was evaluated for the purposes of risk communication. The specific objectives of the human health evaluation were as follows:

1. Assess the potential risk associated with consumption of shellfish and contact with sediment during shellfishing within the low-volume footprint.

2. Collect and analyze fish tissue from the vicinity of HPS and at other Regional Monitoring Program (RMP) (San Francisco Estuary Institute [SFEI], 1999) sample sites throughout San Francisco Bay for statistical comparison in support of risk communication.

The results of the human health evaluation are integrated with the results of the Validation Study in this report to identify areas for evaluation in the Parcel F FS.

1.4 Report Organization

The main text of this report focuses on the identification of areas for evaluation in the Parcel F FS (i.e., the identification of unacceptable ecological and human health risks associated with exposure to offshore sediment). Results of the FS-related data collection (i.e., the sediment dynamics study and sediment characterization) are provided in appendices, as are other supporting data. The Validation Study Report is organized as follows:

Section 1.0: Introduction.

Section 2.0: Approach and Methods. This section presents the approach and methods used for the ecological and human health evaluations.

Section 3.0: Sample Collection and Analysis. This section presents the results of the field and laboratory data collection efforts.

Sections 4.0-6.0: Three Lines of Evidence. These sections present the results for the three lines of evidence for the ecological portion of the Validation Study: sediment chemistry, toxicity, and bioaccumulation.

Section 7.0: Ancillary Data. This section presents results for data collected to support evaluation of the three lines of evidence.

Section 8.0: Weight of Evidence Evaluation. This section presents the results of the weight of evidence (WOE) evaluation using the decision criteria specified in the VS Work Plan (Battelle et al., 2001a).

Section 9.0: Human Health Evaluation. This section presents the results of the human health risk assessment to support validation of the low-volume footprint and the comparison of fish tissue data from HPS and other sites in San Francisco Bay.

Section 10.0: Identification of the Parcel F FS Study Area. This section integrates the results of the ecological and human health evaluations and identifies areas for consideration in the FS. Site-specific PRGs are developed for the contaminants and exposure pathways that are driving risk at the site.

Section 11.0: Uncertainty. This section summarizes and evaluates the uncertainty associated with the Validation Study.

Section 12.0: Summary and Conclusions. The section summarizes the primary findings of the Validation Study.

Section 13.0: References.

Field and laboratory results are presented in Appendices A through D:

Appendix A: Field Data
Appendix B: Sediment Chemistry Data
Appendix C: Tissue Chemistry Data
Appendix D: Bioassay Data.

Supporting information for data analysis is provided in Appendices E through K:

Appendix E: Data Quality Assessment
Appendix F: Sediment Chemistry Data Analysis
Appendix G: Validation Study Position Papers
Appendix H: Dose Assessment
Appendix I: Toxicity Identification Evaluation
Appendix J: Human Health Risk Assessment
Appendix K: Human Health Risk Communication.

The results of the FS-related data collection are provided in Appendices L through N:

Appendix L: Sediment Dynamics Study
Appendix M: Radioisotope Data
Appendix N: Physical and Chemical Sediment Characterization.

Responses to regulatory agency comments on documents preceding the Validation Study Report are provided in Appendix O, and a report regarding a Toxicity Identification Evaluation (TIE) demonstration project conducted by Engineering Field Activity Northeast (EFANE) using sediments from HPS is provided in Appendix P. The responses to comments on the Draft and Draft Final Validation Study Report are provided in Appendix Q.

2.0 APPROACH AND METHODS

The approach and methods used for conducting the HPS Parcel F ecological and human health evaluations are presented below.

2.1 Validation Study

As shown in Figure 2-1, the identification of areas for evaluation in the Parcel F FS based on ecological risk focused on three lines of evidence (i.e., sediment chemistry, toxicity, and bioaccumulation) as well as ancillary data. Details for collecting the three lines of evidence and ancillary data were developed during technical discussions between the Navy and regulatory agencies throughout development of the VS Work Plan (Battelle et al., 2001a). Data quality objectives (DQOs) were developed in accordance with the U.S. EPA's seven-step DQO process (U.S. EPA, 2000). The results for individual lines of evidence and ancillary data were evaluated to identify the pathways and contaminants that were driving risk at the site. In cases where a relationship between sediment chemistry and adverse biological effects was observed, results were used to develop PRGs.

Some subsurface sediment chemistry data were collected in the Validation Study to evaluate the vertical extent of contamination. Additional sediment core data were collected as part of the Parcel F FS Data Gaps investigation in 2003 to better define the horizontal and vertical extent of contamination in Area III (Point Avisadero) and Areas IX-X (South Basin). The FS data gaps investigation analytical results are provided as an addendum to this report.

2.1.1 Validation Study Sampling Design

A statistically-based sampling design for the Validation Study was developed based on the results of the April 2000 sediment screening survey and historical sediment chemistry data as described in the VS Work Plan (Battelle et al., 2001a). These data were used to determine the number and location of samples that would provide adequate representation of Parcel F Areas I, III, VIII, IX, and X. Details of the approach used to stratify the site and develop statistically-based sample sizes are presented in Appendix C of the VS Work Plan (Battelle et al., 2001a). Table 2-1 summarizes the number of surface sediment sample locations in each of the five study areas. Data for the three lines of evidence were collected at all of the 59 HPS stations where surface sediment samples were collected. In addition, sediment cores were collected at 20 of the 59 HPS sampling stations to characterize sediment chemistry and physical characteristics at depth (two additional cores were collected from Yosemite Creek for radioisotope profiling only to estimate sediment accumulation rates). Field sample collection is discussed further in Section 3.0 of this report.

Data for the three lines of evidence also were collected from five San Francisco Bay reference site stations. Reference sites were selected based on the following criteria: (1) similar physical characteristics (i.e., grain size, total organic carbon [TOC] content) to HPS sediments, (2) representative of regional ambient conditions (i.e., not influenced by point sources of contamination), (3) history of use in support of past environmental evaluations for Navy programs or other programs in San Francisco Bay (i.e., established history of use), and (4) proximity to HPS. Three fine-grained reference stations and two coarse-grained reference stations were selected based on these criteria. The fine-grained reference stations were the BPTCP Reference 20006 (Paradise Cove); the RMP mid-bay reference station at Alameda Buoy; and Bay Farm, which is used to support United States Army Corps of Engineers (USACE) dredged material evaluations. Because coarse-grained sediment is found in some nearshore areas of HPS, two coarse-grained reference sites also were sampled: Red Rock, which is an RMP reference station; and the Alcatraz Environs reference site, which is used to support USACE dredged material evaluations. The five reference site station locations are shown in Figure 2-2.

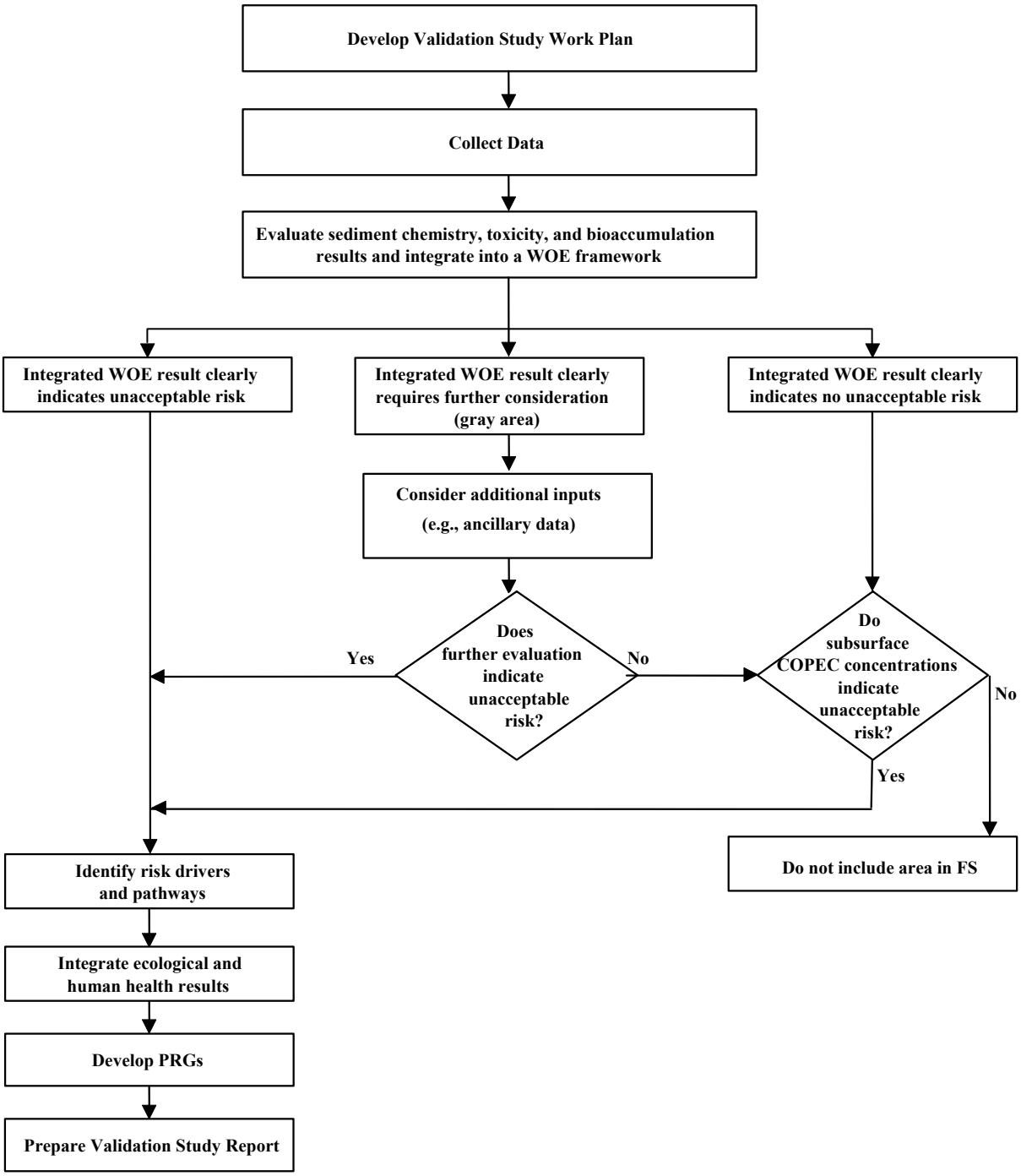


Figure 2-1. Validation Study Approach

Table 2-1. Summary of Validation Study Sample Stations by Area

Area[(a)]	Number of Surface Surface Sediment Samples	Number of Sediment Cores
I	6	2
III	16	6
VIII	8	2
IX	6	2
X	23	8
TOTAL	**59**	**20**

(a) Two additional cores were collected at Yosemite Creek for radioisotope analysis only to estimate sediment accumulation rates.

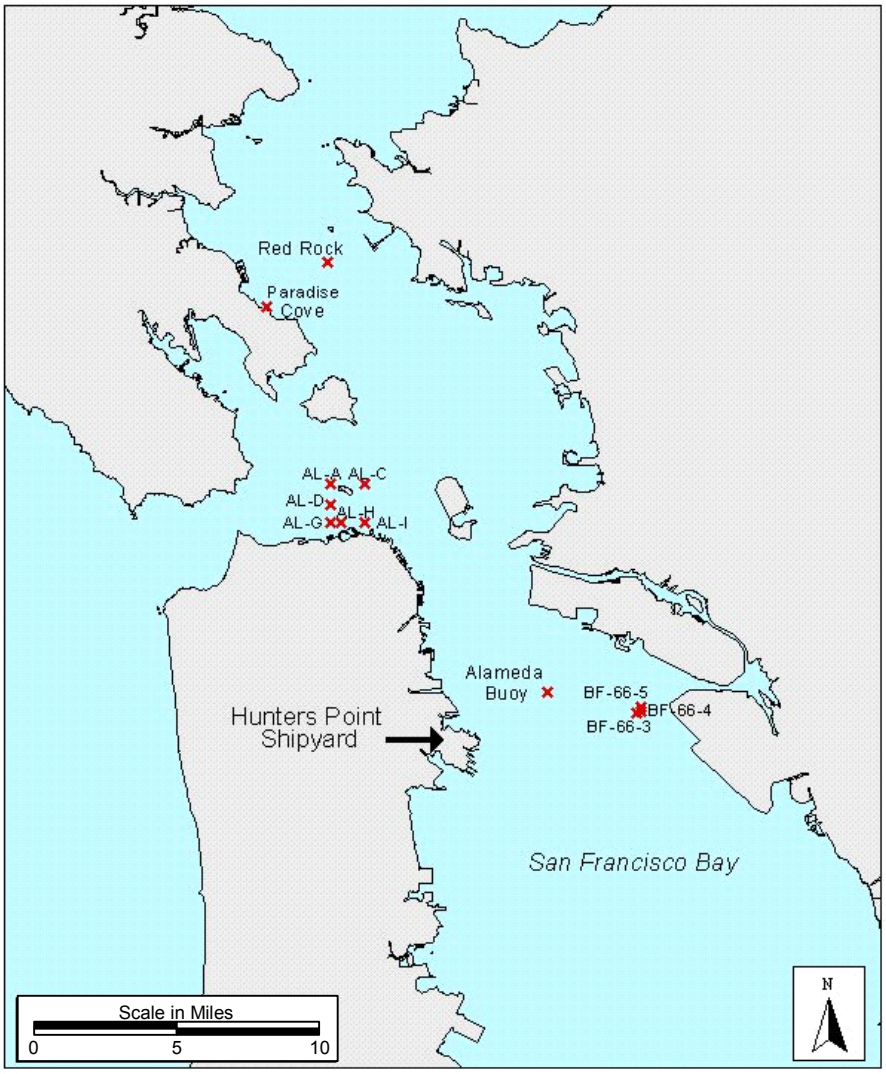


Figure 2-2. San Francisco Bay Reference Site Sampling Locations (AL=Alcatraz Environs, BF=Bay Farm)

2.1.2 Sediment Chemistry Line of Evidence

The sediment chemistry line of evidence was based on the results of chemical analysis of surface sediment samples collected from 59 HPS sampling stations and five reference site stations. Subsurface sediment samples were also collected from a subset of HPS stations. DQOs for the sediment chemistry line of evidence are presented in Table 2-2. Sediment chemistry analyses were performed using the methods developed by NOAA for use in the NOAA Status and Trends (NS&T) program because the methods are especially sensitive and appropriate for measurement of trace metal and organic contaminants in marine and estuarine sediment (NOAA, 1998).

Table 2-2. Data Quality Objectives for Sediment Chemistry

STEP 1: State the Problem The location and extent of sediments in Areas I, III, VIII, IX, and X that pose an unacceptable risk are not clearly defined.
STEP 2: Identify the Decision
1. Are COPEC concentrations in surface sediment elevated above ER-Ms? 2. Are COPEC concentrations in surface sediment elevated above ambient concentrations? 3. What is the vertical extent contamination? 4. What are the locations of surface and subsurface sediments with unacceptable COPEC concentrations? 5. Can surface sediment data be used to establish exposure-response relationships and develop PRGs?
STEP 3: Identify Inputs to the Decision
1. COPEC concentrations, grain size distribution, and TOC in surface and subsurface sediment samples 2. 1993-1997 sediment chemistry data for RMP and BPTCP ambient stations and ambient threshold values for San Francisco Bay (RWQCB, 1998). 3. ER-M values (Long and Morgan, 1991; Long et al., 1995). 4. Station location and depth to sediment. 5. Collocated biological data.
STEP 4: Define the Study Boundaries
Questions 1, 2, 4, and 5 were based on the upper 5 cm of sediment from stations in Areas I, III, VIII, IX, and X. Samples were not collected in shoreline or intertidal areas covered with riprap or disposal debris. Surface sediment from each sample station was represented by a localized composite sample to allow collection of sufficient sediment volume to support all required evaluations. Questions 3 and 4 are based on subsurface core samples taken from selected surface sample locations. Cores were collected to the depth of refusal or to a maximum of 10 ft. Subsurface composite samples were collected in 2-ft increments (e.g. 0-2 ft composite, 2-4 ft composite, etc.).
STEP 5: Develop a Decision Rule
COPEC concentrations in HPS samples were compared with ER-Ms where available and ambient threshold values for San Francisco Bay. For the WOE evaluation, ERM-Qs for surface sediment samples were calculated on a station-by-station basis. The ambient ERM-Q of 0.3 was calculated using 1993-1997 RMP and BPTCP ambient station data for the HPS COPECs with ER-Ms. Decision criteria are discussed in Section 2.1.6. Surface sediment chemistry and collocated biological data were used to develop PRGs.
STEP 6: Evaluate Decision Errors
Inadequate coverage of any portion of the study area could result in missing an area with elevated COPEC concentrations at the surface or at depth (false negative). This potential error was addressed in the sampling design. Uncertainty is associated with measurement error and comparison of sediment chemistry data with ER-M values and with the use of surface sediment chemistry and biological data to develop PRGs.
STEP 7: Optimize the Design for Obtaining Data The sampling design is presented in the VS Work Plan (Battelle et al., 2001a).

COPEC = chemical of potential ecological concern; PRG = preliminary remediation goal; TOC = total organic carbon; RMP = Regional Monitoring Program; BPTCP = Bay Protection and Toxic Hot Spot Cleanup Program; ER-M = Effects Range – Median; WOE = weight of evidence; ERM-Q = ER-M quotient.

Sediment samples were analyzed for all chemicals of potential ecological concern (COPECs) identified in the VS Work Plan (Battelle et al., 2001a) (Table 2-3). PCB analysis included identification and quantification of 22 individual PCB congeners, including the 18 congeners typically measured in the NS&T program and four additional coplanar congeners. Aroclors also were quantified to allow comparison with existing PCB data. Grain size distribution and TOC content were measured in each sample to support evaluation of contaminant bioavailability. Analyses were performed by the Battelle Duxbury Laboratory (BDL) (PCBs, pesticides, PAHs, and butyltins); the Battelle Sequim Laboratory (BSL) (metals); and Severn Trent Laboratories (TPH, grain size distribution, and TOC). Sediment chemistry results are presented in Section 4.0.

Table 2-3. COPEC List for the Validation Study

Analyte Group	Chemical(s)
Metals	Aluminum, antimony, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury (inorganic), molybdenum, nickel, selenium, silver, vanadium, and zinc
Low-molecular-weight PAHs	Acenaphthene, acenaphthylene, anthracene, fluorene, 2-methylnaphthalene, naphthalene, and phenanthrene
High-molecular-weight PAHs	Benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(g,h,i)perylene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-cd)pyrene, and pyrene
Chlorinated pesticides	Chlordanes, DDT, DDD, DDE, dieldrin, heptachlor, endrin, endosulfan II
PCBs	PCB008, PCB018, PCB028, PCB044, PCB052, PCB066, PCB077, PCB101, PCB105, PCB110, PCB118, PCB126, PCB128, PCB129, PCB138, PCB153, PCB170, PCB180, PCB187, PCB195, PCB206, PCB209; Aroclor 1016, Aroclor 1221, Aroclor 1232, Aroclor 1242, Aroclor 1248, Aroclor 1254, Aroclor 1260
Butyltins	Tributyltin
	Dibutyltin
TPH	TPH (extractables)

DDD = dichlorodiphenyldichloroethane; DDE = dichlorodiphenyldichloroethylene.

Sediment chemistry data were evaluated by comparing results with ER-Ms if available and ambient threshold values for sediment in San Francisco Bay (RWQCB, 1998). In addition, an ER-M quotient (ERM-Q) was calculated for each sample to support the WOE evaluation. The methodology for calculating ERM-Qs is provided in Appendix F. The ERM-Q for each HPS sample was compared with an ambient ERM-Q of 0.3. The ambient ERM-Q was calculated using 1993-1997 RMP and BPTCP ambient station data for the HPS COPECs with ER-Ms. The ambient ERM-Q represents the upper 95% confidence interval on the 95th percentile of the ERM-Qs calculated using the ambient station data. The number of COPECs exceeding ER-Ms and the magnitude of the exceedances also were determined for each sample. The decision criteria for sediment chemistry data in the WOE framework are discussed in Section 2.1.6. Surface sediment chemistry results and collocated biological data were used as appropriate to develop PRGs (Section 10.0).

2.1.3 Toxicity Line of Evidence

The toxicity line of evidence was based on two bioassay exposures: a 10-day bulk sediment bioassay using the amphipod *Eohaustorius estuarius*, and a 72-hour acute/sublethal sediment-water interface (SWI) test using larvae of the purple urchin *Strongylocentrotus purpuratus*.

Both tests were conducted using sediment from the 59 HPS sampling stations and five reference site stations. Each test is discussed further in following subsections.

2.1.3.1 Bulk Sediment Bioassay using E. estuarius

DQOs for the bulk sediment bioassay are presented in Table 2-4. Acute toxicity was determined through the use of a 10-day bioassay using the amphipod *E. estuarius* following the guidance presented by the American Society for Testing and Materials (ASTM) (1992) and U.S. EPA and USACE (1991) in the BSL Standard Operating Procedures (SOPs) described in the VS Work Plan (Battelle et al., 2001a). Amphipod testing was conducted at BSL. The amphipod exposure evaluated the upper 5 cm of surface sediment collected from multiple grab samples that were homogenized prior to exposure. Five replicates were tested for each station.

E. estuarius samples were collected from Yaquina Bay, OR, by Northwest Aquatic Sciences of Newport, OR. Test organisms were shipped to BSL, where they were acclimated slowly to test conditions and held for at least 48 hours between acclimation and test initiation.

Table 2-4. Data Quality Objectives for Bulk Sediment Bioassay

STEP 1: State the Problem The location and extent of sediments in Areas I, III, VIII, IX, and X that pose an unacceptable risk are not clearly defined.
STEP 2: Identify the Decision 1. Are surface sediment samples from HPS acutely toxic to benthic invertebrates? 2. What are the locations of HPS stations exhibiting acute toxicity? 3. Are confounding factors contributing to any observed toxicity? 4. Is observed toxicity due to COPECs?
STEP 3: Identify Inputs to the Decision 1. Amphipod survival after 10-day exposure to HPS sediment. 2. Amphipod survival after 10-day exposure to control sediment (≥90% survival in control is required to validate test). 3. Acceptable dose-response of *E. estuarius* to reference toxicants (i.e., cadmium, ammonia) in concurrent 4-day water-only test. 4. Reference envelope tolerance limit for *E. estuarius* survival in San Francisco Bay sediments (State Water Resources Control Board [SWRCB], 1998a). 5. Station location. 6. Grain size distribution of test sediment. 7. Interstitial water ammonia and salinity prior to test initiation. 8. Appropriate test organism acclimation. 9. Overlying water quality conditions during testing period: salinity, dissolved oxygen, pH, and temperature measured at the beginning and end of test in all containers. In addition, one of five replicates measured daily on days 2-9. 10. Measurement of interstitial water ammonia concentrations during the test, COPEC concentrations, grain size distribution, and TOC in HPS sediment samples.
STEP 4: Define the Study Boundaries Questions 1 and 2 were based on the results of exposure of the amphipod *E. estuarius* to the upper 5 cm of sediment from 59 HPS stations in Areas I, III, VIII, IX, and X. Samples were not collected in shoreline or intertidal areas covered with riprap or disposal debris. Surface sediment from each sample station was represented by a localized composite sample to allow collection of sufficient sediment volume to support all required evaluations.
STEP 5: Develop a Decision Rule Amphipod survival in HPS sediment samples was compared with the reference envelope tolerance limit for *E. estuarius* ($\alpha = 0.05$, P = 10) (SWRCB, 1998a). Decision criteria are discussed in Section 2.1.6. If interstitial water chemistry, grain size distribution, ammonia sensitivity, and acclimation rates were within acceptable limits, then any observed toxicity was not attributed to confounding factors.
STEP 6: Evaluate Decision Errors Data from the amphipod bioassays could over- or underestimate amphipod toxicity. In general, if toxicological risk is over-estimated (false positive), a possible consequence is unnecessary remedial work that itself could be biologically detrimental. If toxicological risk is underestimated (false negative), a possible consequence is to fail to conclude that remedial action is required and biological systems could continue to be detrimentally impacted.
STEP 7: Optimize the Design for Obtaining Data The sampling design is presented in the VS Work Plan (Battelle et al., 2001a).

COPEC = chemical of potential ecological concern; TOC = total organic carbon; HPS = Hunters Point Shipyard

Preliminary bulk sediment ammonia concentrations were measured to ensure that total ammonia levels were below the no observed effects concentration (NOEC) of 60 mg/L (0.8 mg/L unionized) for *E. estuarius*, as required by U.S. EPA (1994a). Interstitial water total ammonia concentrations also were measured at the beginning and end of each test in surrogate containers to monitor for changing conditions during testing.

The biological endpoint for this test is acute toxicity. Results are reported as the percentage of animals surviving the exposure on both a replicate and mean per station basis. Mean survival information for HPS stations was compared to the reference envelope tolerance limit for *E. estuarius* (SWRCB, 1998a) following the WOE criteria presented in Section 2.1.6. Reference site results also were compared to the reference envelope tolerance limit to determine whether observed toxicity was similar to historical limits. Bioassay test results are presented in Section 5.1.

2.1.3.2 Sediment-Water Interface Test Using S. purpuratus

DQOs for the SWI test are presented in Table 2-5. SWI testing was conducted on intact core samples (i.e., sediment-water interface cores [SWICs]) collected from the HPS sampling stations and San

Table 2-5. Data Quality Objectives for the Sediment-Water Interface Test

STEP 1: State the Problem The location and extent of sediments in Areas I, III, VIII, IX, and X that pose an unacceptable risk are not clearly defined.
STEP 2: Identify the Decision 1. Are surface sediment samples from HPS toxic to echinoderms as indicated by abnormal larval development? 2. What are the locations of HPS stations exhibiting toxicity to echinoderms? 3. Are confounding factors contributing to any observed toxicity? 4. Is observed toxicity due to COPECs?
STEP 3: Identify Inputs to the Decision 1. Percent normally developed larvae in HPS sediment cores. 2. Acceptable survival in seawater control (≥70% normal development). 3. Acceptable dose-response of larvae to reference toxicants (cadmium, ammonia) in concurrent 4-day water only test. 4. Ambient threshold value for normal larval development in San Francisco Bay (SWRCB, 1998b). 5. Station location and depth to sediment. 6. Water quality parameters recorded at beginning and end of test: dissolved oxygen, pH, salinity, and ammonia in overlying water; ammonia and sulfide in interstitial water. 7. COPEC concentrations, grain size distribution, and TOC in HPS sediment composited for sediment chemistry analysis.
STEP 4: Define the Study Boundaries Questions 1 and 2 were based on the sediment-water interface at stations in Areas I, III, VIII, IX, and X. Samples were not collected in shoreline or intertidal areas covered with riprap or disposal debris. The SWI from each sample station was represented by five intact cores.
STEP 5: Develop a Decision Rule The percentage of normally developed larvae in SWI cores from HPS stations was determined using the counting procedure described by Anderson et al. (1999). Test results were compared with the ambient threshold value for normal larval development used for the BPTCP (SWRCB, 1998b). Decision criteria are presented in Section 2.1.6. If ammonia concentrations in test water were within acceptable limits, then any observed toxicity was not attributed to potential confounding factors.
STEP 6: Evaluate Decision Errors Data from the SWI test could over- or underestimate toxicity to echinoderms. In general, if toxicological risk is overestimated (false positive), a possible consequence is unnecessary remedial work that itself could be biologically detrimental. If toxicological risk is underestimated (false negative), a possible consequence is to fail to conclude that remedial action is required and biological systems could continue to be detrimentally impacted. This test monitors for potential confounding factors such as ammonia, but does not mitigate these conditions.
STEP 7: Optimize the Design for Obtaining Data The sampling design is presented in the VS Work Plan (Battelle et al., 2001a).

HPS = Hunters Point Shipyard; COPEC = chemical of potential ecological concern; TOC = total organic carbon; SWI = sediment water interface; BPTCP = Bay Protection and Toxic Hot Spot Cleanup Program.

Francisco Bay reference site stations. Intact sediment cores could not be collected at Red Rock and Alcatraz Environs reference sites because of the hard bottom and coarse-grained nature of the sediment; therefore, homogenized sediment from individual grab samples was tested instead. SWI tests included six replicates (five test cores and one core that was used for water-quality measurements only). SWI testing was conducted by Pacific Ecorisk Laboratory (PERL) in Martinez, CA.

SWI testing methodology followed the guidance presented in Anderson et al. (1999). Performance criteria included ≥70% survival in seawater controls, and the use of standard reference toxicant tests to ensure that test organisms were sufficiently sensitive. Ammonia concentrations in overlying water were measured at the beginning and end of the test on composited water samples representing all five replicates.

The biological endpoint evaluated in this test was percentage of normally developed *S. purpuratus* larvae. Results for normal larval development were compared with the ambient threshold value for San Francisco Bay (SWRCB, 1998b). WOE decision criteria for the SWI test are provided in Section 2.1.6. SWI test results are presented in Section 5.2.

2.1.4 Bioaccumulation Line of Evidence

The potential bioavailability of sediment contaminants and consequent risk to upper trophic level receptors were evaluated through a laboratory bioaccumulation test and dose assessment, respectively. Uncertainty associated with this line of evidence was qualitatively evaluated using ancillary data, specifically, field-collected invertebrate and fish tissue (see Section 2.1.5.2) and nondepurated *M. nasuta* tissue from a laboratory bioaccumulation test (see Section 2.1.5.3). DQOs for the bioaccumulation line of evidence are provided in Table 2-6.

2.1.4.1 Laboratory Bioaccumulation Test

Bioavailability of sediment contaminants was evaluated with a 28-day flowthrough laboratory bioaccumulation exposure using the bent-nose clam, *Macoma nasuta*. Test procedures were consistent with guidance presented in U.S. EPA and USACE (1991). Bioaccumulation testing was conducted at BSL.

A total of 65 sediments were tested representing the 59 HPS sampling stations, five San Francisco Bay reference site stations, and one *M. nasuta* control. Performance criteria associated with this test included >80% control survival, and appropriate test organism sensitivity as assessed through a 4-day copper reference toxicant exposure. Five replicates of each reference site sediment and three replicates of each HPS station sample were tested. *M. nasuta* were depurated for 24 hours following test termination in clean seawater prior to preparation for chemical analyses. Chemical analyses were performed on one replicate tissue sample from each HPS station, and five replicate tissue samples from each reference site station. A total of five nondepurated replicates also were tested (one from each of five different HPS stations, as described in Section 2.1.5.3).

Reference site data were used to develop reference threshold values for COPEC concentrations in *M. nasuta* tissue. If tissue concentrations in samples from HPS stations exceeded the reference threshold values, then a dose assessment was conducted to evaluate potential risk to upper trophic level receptors (see Section 2.1.4.2).

2.1.4.2 Dose Assessment

If COPEC concentrations in *M. nasuta* tissue from an HPS sampling station exceeded reference threshold values, then a dose assessment in the form of a food-chain model was used to evaluate the potential risk to

Table 2-6. Data Quality Objectives for Bioaccumulation and Dose Assessment

STEP 1: State the Problem The location and extent of sediments in Areas I, III, VIII, IX, and X that pose an unacceptable risk are not clearly defined.
STEP 2: Identify the Decision 1. Are COPEC concentrations in *M. nasuta* tissue elevated above reference concentrations? 2. At locations where COPEC concentrations in *M. nasuta* tissue exceed reference, is potential risk to upper trophic level receptors unacceptable (as determined through a food chain model)? 3. What are the locations of HPS stations exhibiting unacceptable levels of bioaccumulation?
STEP 3: Identify Inputs to the Decision 1. Acceptable survival of *M. nasuta* in control sediment. 2. Sufficient *M. nasuta* tissue mass for acceptable detection of COPECs. 3. COPEC concentrations in depurated *M. nasuta* tissues in animals exposed for 28 days to HPS and reference site sediments. 4. Background COPEC concentrations in unexposed animals. 5. Percent lipid and percent moisture of tissue samples. 6. COPEC concentrations, grain size distribution, and TOC in HPS sampling station and reference site sediment samples. 7. Overlying water quality conditions during testing period: salinity, dissolved oxygen, pH, and temperature. 8. Food-chain model parameters.
STEP 4: Define the Study Boundaries Questions 1, 2, and 3 were based on the results of exposure of *M. nasuta* to the upper 5 cm of sediment from 59 HPS sampling stations in Areas I, III, VIII, IX, and X. Samples were not collected in shoreline or intertidal areas covered with riprap or disposal debris. Surface sediment from each sample station was represented by a localized composite sample to allow collection of sufficient sediment volume to support all required evaluations. Bioaccumulation tests were run for 28 days to allow data comparability with previous studies and other data sets. Five replicates of each reference site sediment and three replicates of each HPS station sediment sample were tested. A single depurated tissue sample from each HPS station was analyzed for all COPECs; five depurated replicate tissue samples from each reference site station also were analyzed. Question 1 also required data from reference sites. Reference sites had similar grain size and TOC characteristics as HPS sediments and were not affected by known point sources of contamination. Reference sites were sampled in the same way as HPS stations, with surface sediment represented by the upper 5 cm.
STEP 5: Develop a Decision Rule Reference site data were used to establish reference threshold values for each COPEC in *M. nasuta* tissue. *M. nasuta* tissue concentrations in single replicate samples from HPS were compared to reference threshold values. PCBs, Hg, and DDT compounds were considered priority COPECs because of their tendency to bioaccumulate. HQs were calculated for COPECs that exceeded reference values to evaluate the potential risk to upper trophic level receptors. Decision criteria are discussed in Section 2.1.6.
STEP 6: Evaluate Decision Errors In general, if bioaccumulation and risk from consumption of contaminated prey is overestimated (false positive), a potential consequence is unnecessary remedial work that itself could be biologically detrimental. If bioaccumulation and food-chain risks are underestimated (false negative), a possible consequence is to fail to conclude that remedial action is required and biological systems could continue to be detrimentally impacted. Field-collected invertebrates and nondepurated *M. nasuta* tissues were analyzed to help reduce uncertainty in estimates of food-chain risk.
STEP 7: Optimize the Design for Obtaining Data The sampling design is presented in the VS Work Plan (Battelle et al., 2001a).

COPEC = chemical of potential ecological concern; HPPS = Hunters Point Shipyard; HQ = hazard quotient; TOC = total organic carbon.

upper trophic level receptors. For the WOE evaluation, the food-chain model based on the *M. nasuta* data evaluated potential risks to avian predators that may forage on benthic invertebrates at HPS. Benthic invertebrate-eating birds were selected for evaluation because they have a significant potential for exposure to site COPECs through incidental ingestion of sediments based on their feeding behavior and through trophic transfer from their prey, which are usually resident to an area and in close association with sediment. WOE decision criteria based on the results of the dose assessment are provided in Section 2.1.6. Details of the food-chain model input parameters and results for the bioaccumulation line of evidence are presented in Section 6.0.

2.1.5 Ancillary Data

To address specific areas of uncertainty associated with the WOE evaluation, ancillary data were collected. These data were not included in the quantitative WOE evaluation, but were used to verify the assumptions of the WOE model and to support identification of the pathways and contaminants driving risk at the site. Results of the ancillary data collection are presented in Section 7.0.

2.1.5.1 Toxicity Identification Evaluation

TIE tests were conducted as part of the Validation Study on sediment samples from a subset of HPS stations to further evaluate potential causes of toxicity. TIE analyses were conducted on samples from areas where confounding factors were believed to have influenced previous toxicity test results (Battelle et al., 1999). The tests were performed by BSL, and focused on the influence of ammonia on toxicity to larvae of the purple urchin, *S. purpuratus,* using suspended particulate phase (SPP) test media. Results were used to evaluate the likely cause of observed toxicity. The design and results of TIE testing are presented in Section 7.1.

The TIE tests also were coordinated with an independent TIE study conducted by Science Applications International Corporation (SAIC) for EFANE as part of a larger TIE demonstration project. The SAIC study measured toxicity from a porewater exposure and used TIE procedures to determine the relative contribution to observed toxicity of various chemical groups, including ammonia, sulfides, metals, and organics compounds. Although the SAIC study was not designed to specifically address Validation Study objectives, the two TIEs were complementary and included samples from the same stations. Results from the SAIC study are summarized in Section 7.1, and a full report is provided in Appendix P.

2.1.5.2 Field-Collected Tissues

Benthic invertebrates and forage fish were collected from HPS study Areas I, III, VIII, IX, and X and analyzed for all COPECs identified in the VS Work Plan (Battelle et al., 2001a). These data could not be used directly in the WOE evaluation because field tissue samples were not collected at every sampling station (i.e., available tissue mass was insufficient), and the WOE evaluation was conducted on a station-by-station basis. The field-collected tissue data were used primarily to support interpretation of the bioaccumulation line of evidence. DQOs for field-collected tissues are presented in Table 2-7. Results are presented in Section 7.2.

Invertebrate Tissue. Field-collected benthic invertebrate tissue from each of the five study areas was obtained and analyzed to help evaluate the validity of the laboratory measure of bioaccumulation as compared with potential bioaccumulation in the field. Tissue samples were sorted into hard-body (mollusks) and soft-body taxa (polychaetes) for separate analyses. Sample data were compared with laboratory *M. nasuta* tissue data, and were used in dose assessment calculations.

Fish Tissue. To evaluate potential risk to piscivorous birds from consumption of contaminated prey, ecologically relevant forage fish species were collected in the five Parcel F study areas. Forage fish species included the Pacific staghorn sculpin (*Leptocottus armatus*), the yellowfin goby (*Acanthogobius flavimanus*), and the chameleon goby (*Tridentiger trigonocephalus*). These species are known prey items for piscivorous birds and marine mammals (Wang, 1986; Torok, 1994; Madenjian et al., 1999), are closely associated with sediments, and have locally abundant populations of all life stages in nearshore and bridge (San Mateo and Dumbarton) areas of southern San Francisco Bay (Aplin, 1967; Wang, 1986). Fish samples were analyzed for their whole-body tissue burden.

Table 2-7. Data Quality Objectives for Ancillary Data

STEP 1: State the Problem The location and extent of sediments in Areas I, III, VIII, IX, and X that pose an unacceptable risk are not clearly defined.
STEP 2: Identify the Decision
1. Do COPEC concentrations in field-collected invertebrate tissue support the results of laboratory bioaccumulation measurements in depurated and nondepurated *M. nasuta* tissues? 2. What is the contribution of sediment remaining in the digestive tract to the overall contaminant load in *M. nasuta* exposed to sediment from HPS? 3. Do COPEC concentrations in forage fish species pose an unacceptable risk to upper trophic level receptors?
STEP 3: Identify Inputs to the Decision
1. COPEC concentrations in field-collected invertebrate and forage fish tissue. 2. COPEC concentrations in nondepurated *M. nasuta* tissues from a subset of HPS stations. 3. COPEC concentrations in depurated *M. nasuta* tissues from the same subset of HPS stations.
STEP 4: Define the Study Boundaries
Invertebrate and fish tissue were collected at Areas I, III, VIII, IX, and X. Samples were not collected in shoreline or intertidal areas covered with riprap or disposal debris. Forage fish species were limited to those that are known prey items for piscivorous birds and marine mammals, are closely associated with sediments, and have locally abundant populations of all life stages in the nearshore areas of south San Francisco Bay. In cases where insufficient field-collected tissue mass was available for all analyses, then analyses were prioritized as follows: PCBs/pesticides/PAHs, metals, and butyltins. Nondepurated *M. nasuta* tissue samples were collected from a subset of HPS stations that were expected to span the range of COPEC concentrations.
STEP 5: Develop a Decision Rule
COPEC concentrations in field-collected invertebrate tissue were compared with COPEC concentrations in depurated and nondepurated tissues from the laboratory bioaccumulation test to provide a qualitative assessment of the suitability of *M. nasuta* data for estimation of risk to upper trophic level receptors. COPEC concentrations in nondepurated *M. nasuta* tissue were compared with corresponding depurated tissues to evaluate the contribution of sediment remaining in the digestive tract of the clam. COPEC concentrations in field-collected forage fish tissue were used to evaluate whether consumption of fish poses a potential risk to piscivorous birds. If HQs calculated using a food chain model exceed threshold values, then potential risk to piscivorous birds was inferred.
STEP 6: Evaluate Decision Errors
In general, if bioaccumulation and risk from consumption of contaminated prey is overestimated (false positive), a potential consequence is unnecessary remedial work that itself could be biologically detrimental. If bioaccumulation and food-chain risks are underestimated (false negative), a possible consequence is to fail to conclude that remedial action is required and biological systems could continue to be detrimentally impacted. Field-collected invertebrates and fish and nondepurated *M. nasuta* tissues were analyzed to help reduce uncertainty in estimates of food-chain risk.
STEP 7: Optimize the Design for Obtaining Data The sampling design is presented in the VS Work Plan (Battelle et al., 2001a).

COPEC = chemical of potential ecological concern; HPS = Hunters Point Shipyard.

2.1.5.3 Nondepurated M. nasuta *Tissue*

As discussed in Section 2.1.4.1, one nondepurated *M. nasuta* replicate from each of the five study areas was analyzed. Tissue data for the nondepurated clams were used to qualitatively evaluate the degree to which laboratory measurements simulate exposure in the field, and to evaluate the contribution of sediment remaining in the digestive tract to the overall contaminant load in a clam. The five nondepurated replicates were taken from stations that were expected to span the range of sediment COPEC concentrations. Results are presented in Section 7.2.

2.1.6 Weight of Evidence Framework

The data collected for the three lines of evidence were evaluated using a WOE approach. It should be noted that the WOE approach is not intended to be prescriptive; rather, it is used as a tool to assist in data interpretation. It was not the sole basis for identifying areas for evaluation in the FS. Figure 2-1 illustrates how the WOE fits into the data evaluation process for the Validation Study. The details of the WOE framework were developed in consultation with the Navy and agency technical group and other technical experts in an iterative process and are documented in the VS Work Plan (Battelle et al., 2001); however, consensus was not reached on how the WOE would be used to identify areas for evaluation in the FS.

The WOE approach comprises five steps as follows:

1. **Determine the weight of the endpoint.**

   The four endpoints (sediment chemistry, toxicity to amphipods, toxicity to echinoderm larvae, and bioaccumulation) were given equal weight.

2. **Determine the nature (i.e., whether the finding is positive or negative) and magnitude of the result.**

   The nature and magnitude criteria for each endpoint were developed in consultation with the Navy and agency technical group and other technical experts. The finding and magnitude criteria for the Validation Study are presented in Table 2-8.

3. **Integrate the weight, finding, and magnitude for a given endpoint result.**

   The weight, finding, and magnitude for each endpoint result were integrated to determine (a) whether or not the result for that endpoint validates inclusion in the FS footprint, and (b) the level of certainty associated with that conclusion.

4. **Integrate all endpoint results for a given sample location**.

   All endpoint results for a given station were integrated to determine if the location (a) should remain in the FS footprint, (b) should be excluded from the FS footprint, or (c) requires the consideration of additional inputs to make a determination (i.e., the WOE results are equivocal, resulting in a "gray" area).

5. **Map WOE results from Step 4.**

   Thiessen polygons were constructed using standard geometric techniques to identify the area surrounding each station that was assumed to be represented by the findings of that station. Thiessen polygons were created by constructing straight lines from each station to every nearby selected station that can be reached without crossing any other straight line, and then constructing the perpendicular bisector of each radius. Each Thiessen polygon represents the single station located within the polygon, and all points within a given Thiessen polygon are closer to that station than to any adjacent station (RWQCB, 2001). The WOE results for all stations were then mapped onto these polygons to provide a visual representation of the evaluation.

Table 2-8. WOE Scoring Matrix for HPS Validation Study

Score	Attribute	Sediment Chemistry	Amphipod Bioassay	Echinoderm Larvae SWI Bioassay	*M. nasuta* Bioaccumulation
+2	High Positive	• ERM-Q >1.25 **or** • 7 or more COPECs >ER-Ms **or** • Any one COPEC >10X its ER-M	≤50% survival relative to control response	≤50% normal development relative to control response	One or more priority[(b)] COPECs or two or more nonpriority COPECs exceed reference[(c)] and • HQ_{low} >10 **or** • HQ_{high} >1.
+1	Low Positive	• ERM-Q >0.5 but ≤1.25 **or** • 4-6 COPECs >ER-Ms **or** • Any one COPEC >5X its ER-M	>50% but ≤69.5% survival relative to control response	>50% but ≤60% normal development relative to control response	One or more priority[(b)] COPECs or two or more nonpriority COPECs exceed reference and • HQ_{low} ≤10 • HQ_{high} ≤1.
–1	Low Negative	• ERM-Q ≤0.5 but >UTL of ambient ERM-Q (0.3)[(a)] **or** • 1-3 COPECs >ER-Ms	>69.5% but ≤80% survival relative to control response	>60% but ≤80% normal development relative to control response	No priority[(b)] COPECs or no more than one nonpriority COPEC exceeds reference and HQ_{low} ≤1.
–2	High Negative	• ERM-Q ≤UTL of ambient ERM-Q (0.3)[(a)] **or** • All individual COPECs <ER-Ms	>80% survival relative to control response	>80% normal development relative to control response	No COPEC concentrations in HPS tissues exceed reference.

(a) Ambient ERM-Qs calculated from 1993-1997 RMP and BPTCP reference site data, using HPS COPEC list for which there are ER-Ms. The upper tolerance limit (UTL) of 0.3 represents the upper 95% confidence interval on the 95th percentile of the ERM-Qs calculated for the reference site data (upper 95, 95 UTL).

(b) Priority COPECs are PCBs, Hg, and DDx.

(c) Tissue concentrations in one replicate tissue sample were compared with reference threshold values derived from the reference site distribution. Comparisons to reference were based on individual COPECs except for PCBs, low molecular weight PAHs, high molecular weight PAHs, and DDx, which were summed.

COPEC = chemical of potential ecological concern; HQ = hazard quotient; ERM-Q = ER-M quotient.

"Gray" areas required further evaluation before a decision could be made about inclusion in the FS study boundary. Further evaluations that were conducted on "gray" areas included but were not limited to the following:

- Detailed examination of results for individual lines of evidence
- Results for ancillary data collected to support the WOE (e.g., field-collected invertebrate and fish tissue)
- Human health evaluation results, and
- Status of source control and potential for future contamination by onshore sources.

Results of the WOE evaluation are presented in Section 8.0.

2.2 Human Health Evaluation

The Parcel F human health evaluation focused on the potential human health impact from exposure to offshore sediment in HPS study Areas I, III, VIII, IX, and X. Based on available information regarding the likely future land uses at HPS, it was determined that potential exposures to humans could occur as the result of consumption of aquatic species such as fish and shellfish, and direct contact with sediment during shellfish collection. As discussed in Appendix B of the HHE Work Plan (Battelle et al., 2001b), due to the relative mobility of most recreationally preferred fish species, it is difficult to attribute measured tissue concentrations in fish to a specific sediment source. Therefore, this evaluation focused on the measured chemical concentrations in shellfish tissue (i.e., *M. nasuta*) generated from the laboratory bioaccumulation test (see Section 2.1.4.1) to more clearly define the distribution of site sediments that pose an unacceptable risk to human health. A risk assessment based on consumption of shellfish and direct contact with sediment during shellfish collection was conducted and the results were integrated with the ecological data from the Validation Study, as shown in Figure 2-3, to identify areas for consideration in the FS.

Although concentrations of chemicals measured in recreationally preferred fish tissue cannot be directly linked with specific source sediments, an evaluation of the relative potential risks associated with consuming these species also was undertaken for risk communication purposes. Currently available data from the RMP (RWQCB et al., 1995; SFEI, 1999) indicate that concentrations of six chemicals or groups of chemicals (i.e., PCBs, dioxins, mercury, dieldrin, DDT, and chlordane) in fish collected from throughout the San Francisco Bay are high enough to pose a potential risk to recreational anglers (Office of Environmental Health Hazard Assessment [OEHHA], 1994). Although this is a regional issue, concerns have been raised regarding the relative risks of consuming fish caught from the vicinity of HPS compared to fish caught from other locations within San Francisco Bay.

Preliminary evaluations based on historical data indicate that levels of chemicals in fish from the vicinity of HPS are similar to those collected elsewhere in the Bay; however, additional data were required for a statistically defensible comparison (see Appendix B of the HHE Work Plan [Battelle et al., 2001b]). To address this issue in the current investigation, fish tissues were collected from the vicinity of HPS and from selected areas in San Francisco Bay and then analyzed to support risk communication. The study design and objectives of this fish collection effort were not designed to identify areas for evaluation in the FS.

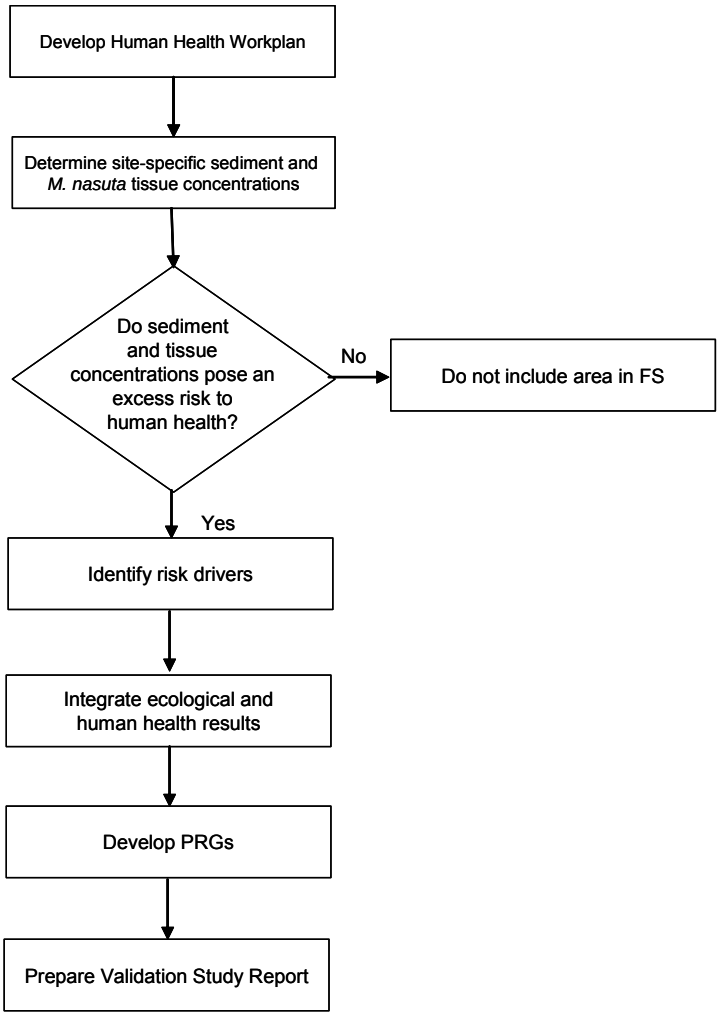


Figure 2-3. Integration of Ecological and Human Health Evaluations

2.2.1 Human Health Risk Assessment

DQOs for the human health risk assessment are presented in Table 2-9. Based on available information, one exposure scenario, the consumption of shellfish exposed to site-specific sediments, was identified and considered. All bioaccumulative chemicals identified by U.S. EPA Region 9 were evaluated as chemicals of potential concern (COPCs) (Table 2-10). In addition, dioxin was included as a COPC for six sampling stations identified in Areas VIII, IX, and X that were located as close as possible to a potential onshore source. Dioxins also were evaluated in *M. nasuta* tissues exposed to sediments from each of the five reference stations.

M. nasuta tissue data were used to calculate the potential carcinogenic risks and noncarcinogenic hazard quotients to humans as described in Section 9.0. Stations where the cumulative risk level exceeded 1×10^{-6} or where the cumulative hazard quotient (HQ) was greater than one were considered for evaluation in the FS. Comparison to risks associated with reference sites also was considered when identifying areas for the FS. Results of the human health risk assessment are provided in Section 9.0.

Table 2-9. Data Quality Objectives for Human Health Risk Assessment

STEP 1: State the Problem The location and extent of sediments in Areas I, III, VIII, IX, and X that pose an unacceptable health risk are not clearly defined.
STEP 2: Identify the Decision Do COPCs in *Macoma nasuta* tissues exposed to sediments from HPS in a 28-day laboratory bioaccumulation test result in an excess human health risk for individuals consuming shellfish?
STEP 3: Identify Inputs to the Decision 1. Results of analyses of 28-day *M. nasuta* bioaccumulation test for 59 stations in Areas I, III, VIII, IX, and X and five reference stations. 2. Calculated potential carcinogenic risks and noncarcinogenic hazard quotients for shellfish tissue ingestion based on HPS reference site *M. nasuta* tissue concentrations.
STEP 4: Define the Study Boundaries Analytical chemistry data from *M. nasuta* exposed to the upper 5 cm of sediment from 59 stations in Areas I, III, VIII, IX, and X. Samples were not collected in shoreline or intertidal areas covered with riprap or disposal debris. Surface sediment from each sample station was represented by a localized composite sample to allow collection of sufficient sediment volume to support all required evaluations.
STEP 5: Develop a Decision Rule If the concentration of any COPC in *M. nasuta* tissue samples was associated with a carcinogenic risk that exceeds 1×10^{-6} or a noncarcinogenic hazard quotient that exceeded 1, the calculated risk and hazard quotient exceeds those associated with reference stations and the uncertainty in the exposure parameters was acceptable, then the station was considered for inclusion in the FS. Comparison to reference conditions was also considered.
STEP 6: Evaluate Decision Errors In general, if bioaccumulation and risk from consumption of contaminated shellfish is overestimated (false positive), a potential consequence is unnecessary remedial work that itself could be biologically detrimental. If risks are underestimated (false negative), a possible consequence is to fail to conclude that remedial action is required and human health could continue to be detrimentally impacted. To control these possible errors, exposure point concentrations were developed using both the mean and the lower of the 95th upper confidence limit on the mean tissue concentrations or the maximum observed concentration to support food-chain modeling.
STEP 7: Optimize the Design for Obtaining Data The *M. nasuta* bioaccumulation study design developed for the ecological portion of the Validation Study is adequate to support the evaluation of human health risk. The sampling design is described in the VS Work Plan (Battelle, 2001a).

COPC = chemical of potential concern; HPS = Hunters Point Shipyard; FS = Feasibility Study.

Table 2-10. COPCs for Human Health Evaluation

Trace Metals	Organics	
Ag	Naphthalene	4,4′-DDD
As	Acenaphthylene	4,4′-DDE
Cd	Acenaphthene	2,4′-DDE
Cr	Fluorene	4,4′-DDT
Cu	Phenanthrene	2,4′-DDT
Hg	Fluoranthene	*alpha*-Chlordane
Ni	Pyrene	Dieldrin
Pb	Anthracene	2,4′-DDD
Sb	2-Methylnaphthalene	Endrin
Se	Benzo(a)anthracene	Endosulfan II
Zn	Chrysene	*gamma*-Chlordane
	Benzo(b)fluoranthene	Heptachlor
	Benzo(k)fluoranthene	Total PCBs[(a)]
	Benzo(a)pyrene	Tributyltin
	Indeno(1,2,3-c,d)pyrene	Dibutyltin
	Dibenz(a,h)anthracene	2,3,7,8-TCDD[(b)]
	Benzo(g,h,i)perylene	

(a) Total PCB is based on the 2 times the sum of 22 PCB congeners.
(b) The 17 dibenzo-*p*-dioxins and polychlorinated dibenzofurans defined in U.S. EPA Method 8290 were measured and reported in *M. nasuta* tissue. The concentration of each isomer was multiplied by the assigned toxicity equivalence factor (TEF) and the resulting values was summed to estimate a total 2,3,7,8-TCDD equivalence.

2.2.2 Risk Communication

Data quality objectives for the risk communication study are provided in Table 2-11. The objective of the risk communication portion of the human health evaluation was to determine whether risks associated with consuming fish from the vicinity of HPS are significantly higher than those associated with consuming fish from other (i.e., ambient) locations throughout San Francisco Bay. For the purpose of this study, it was assumed that all exposure parameters relevant to the calculation of risk associated with fish consumption (e.g., ingestion rate, exposure duration, etc.) were the same for anglers at both HPS and ambient locations with the exception of the concentration of chemicals in fish tissue. Therefore, the focus of the study was to determine if the concentration of chemicals in fish tissue near HPS was the same or different from the "ambient" conditions in the rest of the bay. Any similarity or difference noted in the chemical concentrations would indicate a parallel similarity or difference in risk associated with consumption of fish.

Table 2-11. Data Quality Objectives for Risk Communication Study

STEP 1: State the Problem The relative health risk associated with consuming fish caught near HPS compared with the consumption of fish caught elsewhere in San Francisco Bay is not known.
STEP 2: Identify the Decision Are concentrations of chemicals in fish from the vicinity of HPS statistically significantly different from those in fish from other (ambient) locations in San Francisco Bay?
STEP 3: Identify Inputs to the Decision 1. Results of analysis of fish tissues collected at HPS and at ambient locations following RMP protocols. This includes compositing equal portions of whole body (jacksmelt and surfperch) to produce composite samples of at least 100 g. 2. Results of statistical comparisons of HPS and ambient tissue data.
STEP 4: Define the Study Boundaries Fish were collected at three offshore areas around HPS, and at the following San Francisco Bay locations: San Francisco Waterfront, San Mateo Bridge, and Bay Farm.
STEP 5: Develop a Decision Rule If the mean concentration of chemicals in fish tissues from HPS was statistically greater ($\alpha = 0.5$) than the mean concentration of chemicals in fish collected from ambient locations, then the need for risk communication to inform potential receptors was identified.
STEP 6: Evaluate Decision Errors Probability of failing to determine that fish tissues in HPS were greater than ambient, when in "truth" they are elevated by 90%, will be limited to 5%; and the probability of incorrectly determining they are the same will be limited to 5%. Failure to properly determine that HPS fish are more contaminated would result in a failure to communicate increased risk associated with consuming fish from this site. Improperly determining HPS fish tissue COPC concentrations are elevated over ambient fish COPC concentrations would result in falsely alarming the public and the associated costs for risk communication. Both error types are of concern.
STEP 7: Optimize the Design for Obtaining Data Six composite samples of two separate species were collected at HPS and from three ambient locations (i.e., two composites from each ambient location). The development of this sample size estimate was based on the procedures discussed in the HHE Work Plan (Battelle et al., 2001b).

COPC = chemical of potential ecological concern; RMP = Regional Monitoring Program; HPS = Hunters Point Shipyard.

The methods used to collect and prepare the fish tissue samples were based on those used in the RMP (RWQCB et al., 1995; SFEI, 1999) to ensure comparability of the data. This evaluation focused on whole body (including skin) minus head, tail, and guts from perch and jacksmelt (attempts to collect a third target species, white croaker, were unsuccessful). To evaluate whether concentrations of COPCs in fish collected at HPS were different from concentrations in fish collected from ambient locations in San

Francisco Bay, a statistically based sampling design was developed. The null and alternative hypotheses were as follows:

Null Hypothesis (**H_O**): The mean COPC residue in filets from HPS (μ_{HP}) is less than or equal to the mean ambient residue (μ_A).

Alternative Hypothesis (**H_A**): The mean COPC residue in filets from HPS is significantly greater ($\alpha = 0.5$) than the mean ambient residue.

Failure to reject **H_O** would lead to the conclusion that sport fish caught from HPS pose the same or lower risk to human health than those caught from ambient locations. Alternatively, rejecting **H_O** would lead to the conclusion that fish caught from HPS may pose a greater risk to human health than do those caught from ambient locations. Results of the risk communication study are presented in Section 9.0.

2.3 Feasibility Study Support

In addition to data required to identify areas for evaluation in the FS, additional data gaps had been identified regarding sediment characteristics and sediment dynamics. These data are needed to support the evaluation of remedial alternatives for Parcel F sediments. The objectives of FS-related sampling were as follows:

1. Characterize sediment dynamics in the areas most likely to require management to predict the likelihood of surface and subsurface sediment mobilization under various wind, wave, and current conditions. These data were used to predict the transport and fate of sediment bound contaminants.

2. Determine sediment accumulation rates and characterize the degree of mixing within the sediment column through the analysis of radioisotopes to support the evaluation of sediment dynamics.

3. Provide information regarding physical and chemical characteristics of sediment that can be used to evaluate various treatment and disposal options.

The sediment dynamics study included field measurements of currents, waves, and suspended sediment concentrations, to characterize typical hydrodynamic conditions; and sediment transport modeling, to predict the likelihood of sediment resuspension and transport away from the site under various conditions. DQOs for the sediment dynamics study are provided in Table 2-12. The sediment dynamics study is presented in Appendix L of this report.

Profiles of the radioisotopes ^{210}Pb and ^{137}Cs were measured in five cores from HPS and two cores in Yosemite Creek. Radioisotope data were used in combination with geologic core descriptions and information on benthic infauna to estimate sediment accumulation rates and characterize the degree of vertical mixing of surface and subsurface sediments. DQOs for radioisotope profiling are provided in Table 2-13. Radioisotope results are presented in Appendix M.

Measurement of physical and chemical sediment characteristics was coordinated with sediment chemistry data collection and included parameters such as grain size distribution, TOC, and hazardous waste characterization. Sediment from selected areas underwent treatability testing for dewatering and stabilization. DQOs for FS-related sediment characterization are provided in Table 2-14. Results of the FS-related data characterization are presented in Appendix N.

Table 2-12. Data Quality Objectives for Sediment Dynamics Study

STEP 1: State the Problem The fate and transport of sediment-bound contaminants in areas most likely to require management have not been adequately characterized.
STEP 2: Identify the Decision
1. What are the magnitude and direction of sediment flux at selected locations around HPS? 2. What are sediment transport patterns around HPS? 3. What is the likelihood of sediment mobilization in selected offshore areas under various wind, wave, current, and runoff conditions?
STEP 3: Identify Inputs to the Decision
1. Time-series measurements of waves, currents, suspended sediment concentrations, salinity, and temperature. 2. Grain size distribution data. 3. Existing data for extreme wind, wave, and current conditions in south San Francisco Bay. 4. Predictive sediment transport modeling using site-specific field measurements.
STEP 4: Define the Study Boundaries
Questions 1 and 3 addressed South Basin and Area III (northwest of Point Avisadero). Question 2 addressed the subtidal region surrounding HPS. Questions 1 and 2 were based on data collected over a period of one month (one tidal cycle) during the winter and summer seasons. Question 3 was based on historical data for extreme weather conditions.
STEP 5: Develop a Decision Rule
Time-series measurements of sediment transport parameters were used to evaluate the relative importance of various hydrodynamic forces at HPS and to estimate the magnitudes and directions of suspended sediment flux over the deployment period at selected locations. This information was used to characterize the fate and transport of sediment-bound contaminants. Predictive sediment transport models and field data were used to characterize sediment transport patterns around HPS and predict sediment mobilization under various wind, wave, and runoff conditions.
STEP 6: Evaluate Decision Errors Sediment dynamics involve complex processes that vary spatially and temporally. Consequently, numerous sources of uncertainty exist in field measurements and models. A combination of field measurements and calculations will provide multiple lines of evidence to characterize sediment dynamics and reduce the relative importance of any individual result. Incorrect estimates of sediment flux could result in incorrect predictions of contaminant fate and transport or incorrect identification of areas of sediment erosion and deposition. These erroneous conclusions could influence the selection of appropriate sediment management strategies. Incorrect predictions of the likelihood of subsurface sediment remobilization under extreme conditions could result in a recommendation to leave contaminated subsurface sediments in place, when the potential for remobilization is actually greater than predicted.
STEP 7: Optimize the Design for Obtaining Data (See Appendix L)

HPS = Hunters Point Shipyard.

Table 2-13. Data Quality Objectives for Radioisotope Profiling

STEP 1: State the Problem Sediment accumulation rates at HPS are not well characterized and the degree of mixing in the sediment profile is not known. This information is needed to characterize the fate and transport of sediment-bound contaminants.
STEP 2: Identify the Decision
4. What are the depositional environment and sedimentation history in each area of the low-volume footprint? 5. What are sediment accumulation rates in depositional areas of the low-volume footprint? 6. What are the degree and depth of vertical mixing in each area of the low-volume footprint?
STEP 3: Identify Inputs to the Decision
5. Location and depth to sediment. 6. Detailed geologic description of sediment cores. 7. ^{210}Pb and ^{137}Cs radioisotope profiles. 8. Benthic fauna composition and abundance data.
STEP 4: Define the Study Boundaries
Questions 1, 2, and 3 addressed the five HPS study areas (i.e., Areas I, III, VIII, IX, and X) and Yosemite Creek. Questions 2 and 3 addressed sediment cores collected to a depth of 100 cm. Radioisotopes were measured in samples collected from 2-cm intervals every 10 cm to a depth of 100 cm.
STEP 5: Develop a Decision Rule
Geologic descriptions of cores were used to describe depositional environments. Radioisotope data were used to estimate sediment accumulation rates to support an assessment of the degree and rate of natural capping through sediment accretion. Radioisotope profiles and benthic fauna data were used to evaluate the degree and depth of vertical mixing of surface and subsurface sediments. These data are needed to support identification of a depth at which contaminants might be considered to be effectively buried.
STEP 6: Evaluate Decision Errors An overestimate of the sediment accumulation rate could result in an underestimate of the time required to achieve natural recovery of an area. An underestimate of the thickness of the mixed zone could result in an underestimate of the depth at which sediments might be considered to be effectively buried. A potential consequence of these errors would be to recommend leaving contaminated subsurface sediments in place, when the potential for remobilization is actually greater than predicted.
STEP 7: Optimize the Design for Obtaining Data (See Appendix M)

HPS = Hunters Point Shipyard.

Table 2-14. Data Quality Objectives for Feasibility Study-Related Sediment Characterization

STEP 1: State the Problem Physical and chemical sediment data are needed to identify the most feasible options for remediating sediment.
STEP 2: Identify the Decision 1. What are the physical and chemical characteristics of sediment that will influence the feasibility of treatment, disposal, or reuse options? 2. What dewatering and stabilization methods would be most effective for HPS sediments?
STEP 3: Identify Inputs to the Decision 1. COPEC concentrations (measured using NS&T methods), grain size distribution, and TOC in HPS sediment samples. 2. TCLP and concentrations. 3. Moisture content of dewatered sediment samples. 4. Compaction characteristics, bearing ratio, and strength of stabilized sediment samples.
STEP 4: Define the Study Boundaries Questions 1 and 2 were based on sediment composites from areas that represent sediment most likely to require remediation (i.e., sediments with the highest COPEC concentrations).
STEP 5: Develop a Decision Rule COPEC concentration data were compared with beneficial reuse guidelines (RWQCB, 2000). If COPEC concentrations exceeded guidelines, then the corresponding reuse option will be an inappropriate remediation option for that sediment in the FS. COPEC concentration data and TCLP data were compared with hazardous waste thresholds (22 CCR Division 4.5, Chapter 11). If concentrations exceeded threshold values, then the sediment would be considered hazardous when evaluating remedial options in the FS. Treatability test results for various dewatering and stabilization methods were compared with each other to identify the most effective method for analyzing HPS sediments.
STEP 6: Evaluate Decision Errors Composites that are tested for FS-related characterization and may not adequately represent sediments that will require remediation. If test results are not sufficiently representative, then data could lead to incorrect conclusions and decisions regarding the most appropriate remedial technologies or alternatives.
STEP 7: Optimize the Design for Obtaining Data (See Appendix N)

HPS = Hunters Point Shipyard; COPEC = contaminant of potential ecological concern; TOC = total organic carbon; NS&T = NOAA Status and Trends; TCLP = Toxicity Characteristic Leaching Procedure; FS = Feasibility Study; CCR = California Code of Regulations.

3.0 SAMPLE COLLECTION AND ANALYSIS

This section presents the results of the Validation Study field and laboratory data collection effort, including the human health evaluation. Field and laboratory work for the ecological and human health evaluations were conducted concurrently.

3.1 Sample Collection

The major elements of the Validation Study and human health evaluation field programs were as follows:

- Collection of surface sediment samples and SWICs at 59 HPS sampling stations and five San Francisco Bay reference site stations to provide material for the sediment chemistry, toxicity, and bioaccumulation lines of evidence. Surface sediment samples also were collected at three additional stations at HPS for sediment chemistry analysis only.

- Collection of sediment cores from 20 HPS sampling stations to support the characterization of subsurface chemical concentrations and evaluation of remedial alternatives. Two additional sediment cores were collected from Yosemite Creek for radioisotope profiling only to estimate sediment accumulation rates.

- Collection of benthic invertebrate and forage fish samples to support the evaluation of the bioaccumulation line of evidence.

- Collection of fish from three areas at HPS and three San Francisco Bay sites to support the human health risk communication effort.

Sediment dynamics data to support the evaluation of remedial alternatives for Parcel F sediments were collected in winter 2001 and in summer 2001. The sediment dynamics field efforts are discussed in Appendix L. Radioisotope profiles of ^{210}Pb and ^{137}Cs were measured in five HPS sediment cores and the two Yosemite Creek sediment cores; results are discussed in Appendix M. FS-related sediment characterization also was conducted on samples from study Areas III and X; results are discussed in Appendix N.

Sampling requirements and procedures are described in detail in the VS Work Plan (Battelle et al., 2001a) and HHE Work Plan (Battelle et al., 2001b). Sample collection results are discussed in detail in the *HPS Parcel F Validation Study and Human Health Evaluation Field Summary Report* (Battelle, 2001) and summarized below. Surface sediment, vibracore, invertebrate and fish sample collection data are provided in Appendix A.

3.1.1 Sediment Sampling

Sediment sampling included collection of SWICs, bulk surface sediment from grabs, and vibracores. Surface sediment samples and SWICs were collected from May 1 through May 22, 2001, at 59 HPS sampling stations and five San Francisco Bay reference site stations; HPS sampling locations are shown on Figures 3-1 through 3-5, and reference site locations are shown in Figure 2-2. Three additional stations in Area III were sampled for sediment chemistry only. Sediment cores were collected at 20 HPS sampling stations and two Yosemite Creek locations from May 15 through May 18, 2001; sample locations are shown on Figures 3-1 through 3-6. Radioisotope core locations are shown in Figure 3-7. Surface sediment, SWIC, and sediment core sample data are provided in Appendix A.

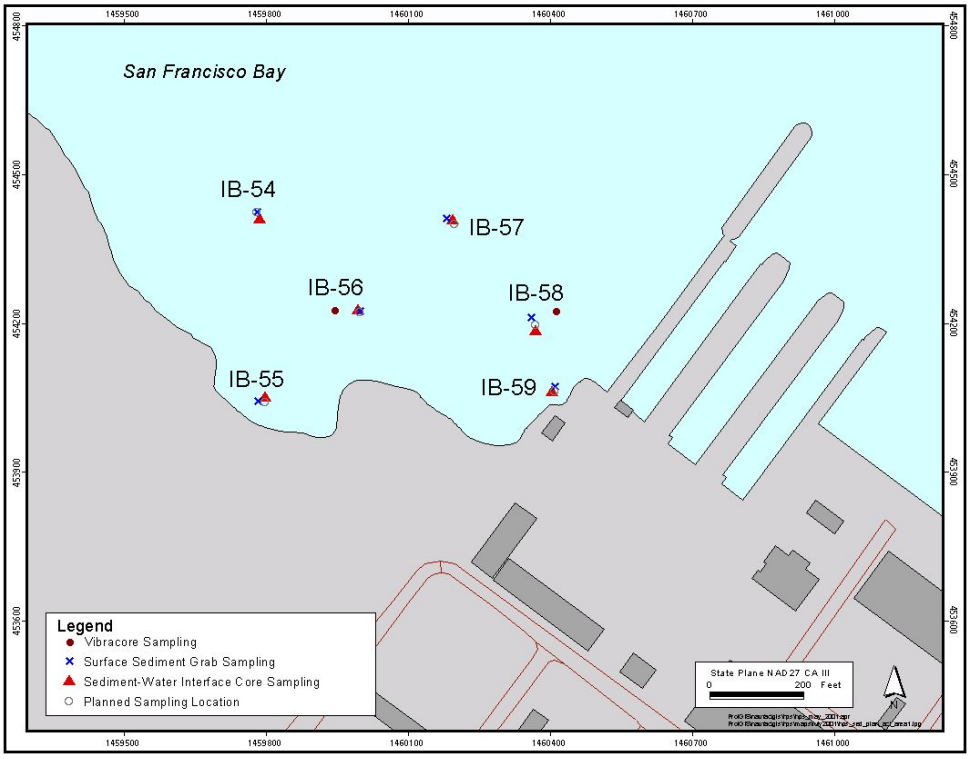


Figure 3-1. Sediment Sampling Locations in Area I, India Basin

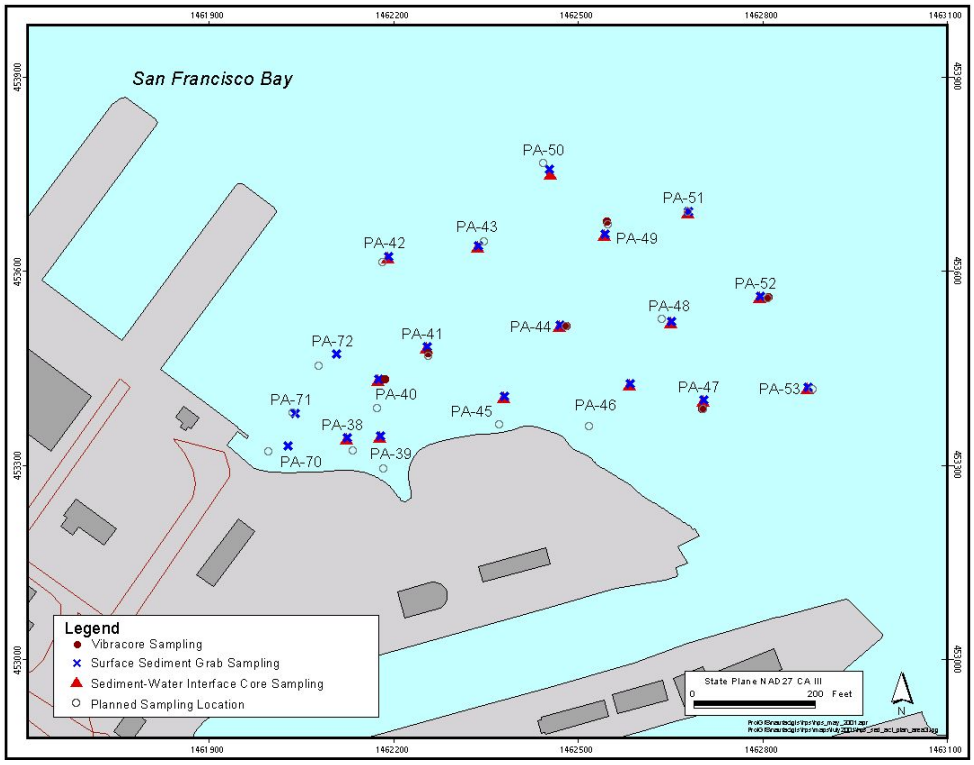


Figure 3-2. Sediment Sampling Locations in Area III, Point Avisadero

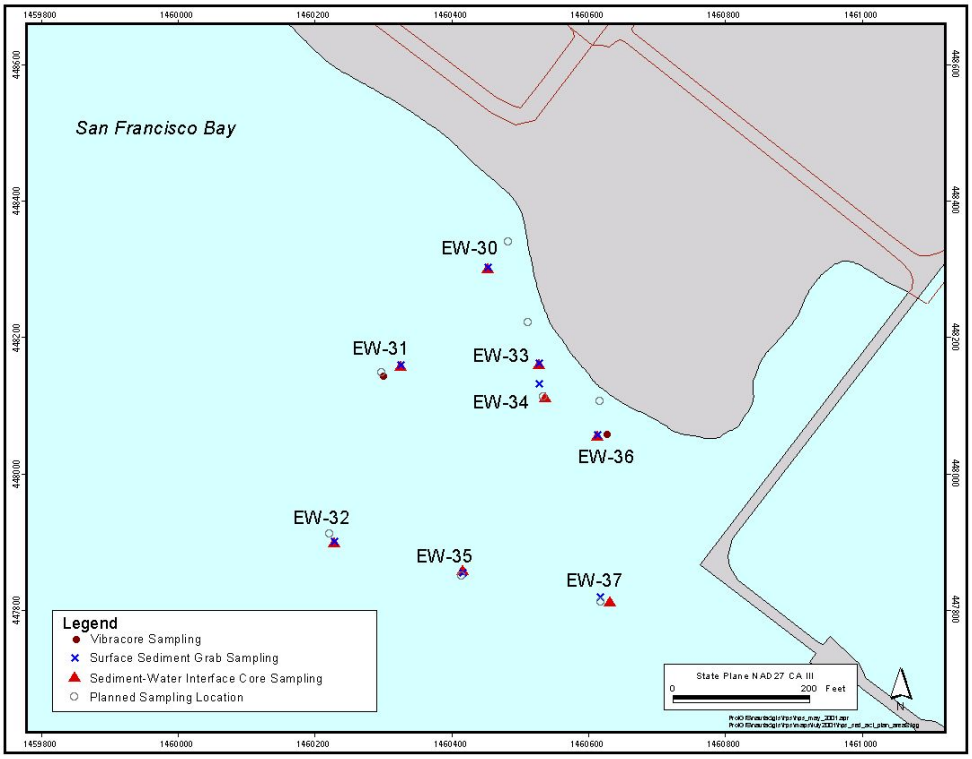


Figure 3-3. Sediment Sampling Locations in Area VIII, Eastern Wetland

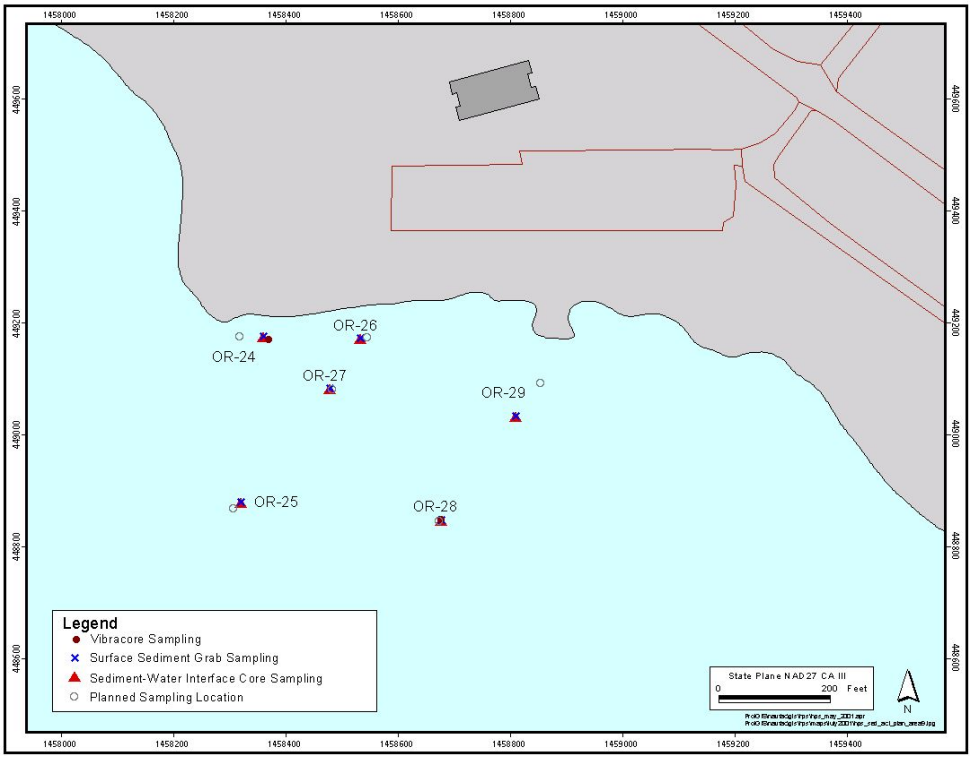


Figure 3-4. Sediment Sampling Locations in Area IX, Oil Reclamation

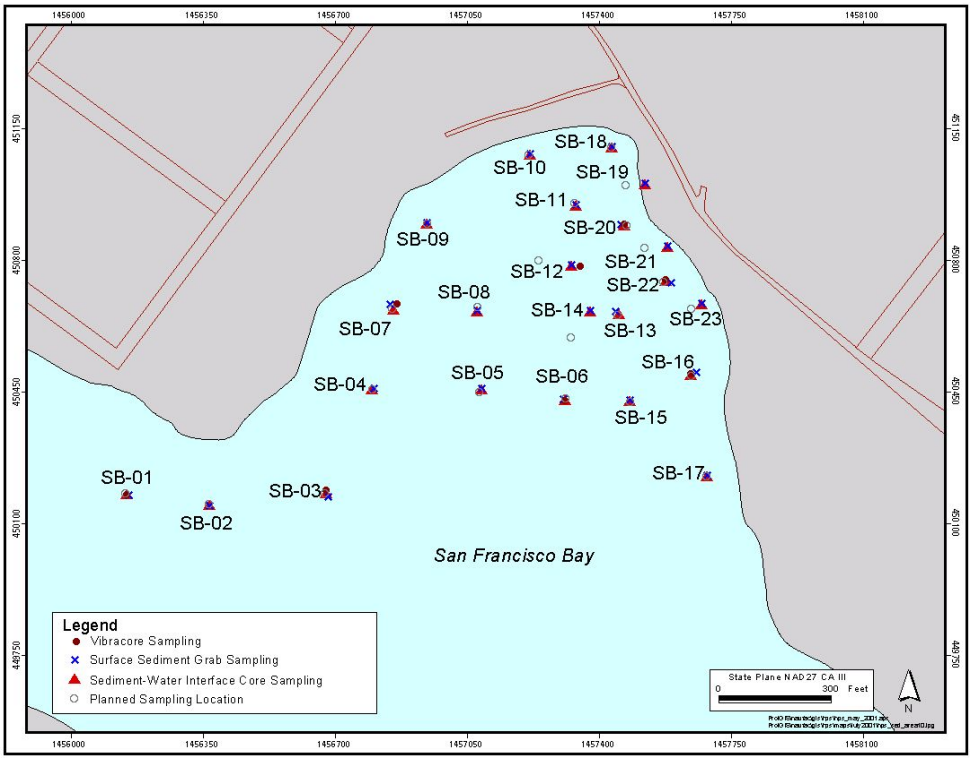


Figure 3-5. Sediment Sampling Locations in Area X, South Basin

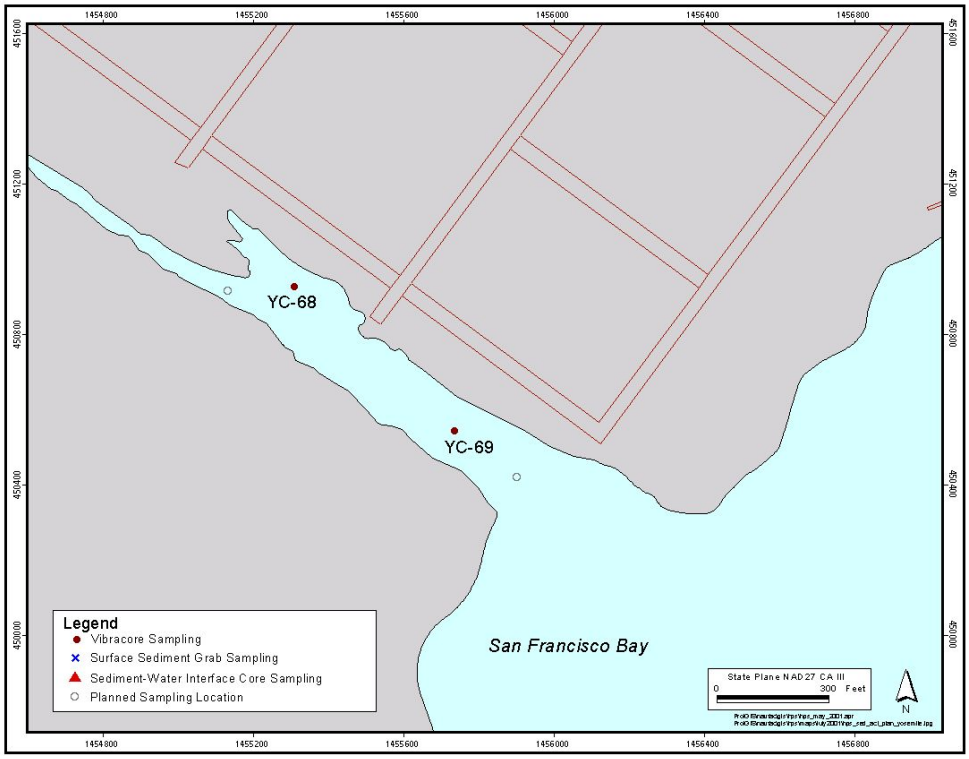


Figure 3-6. Vibracore Sampling Locations in Yosemite Creek

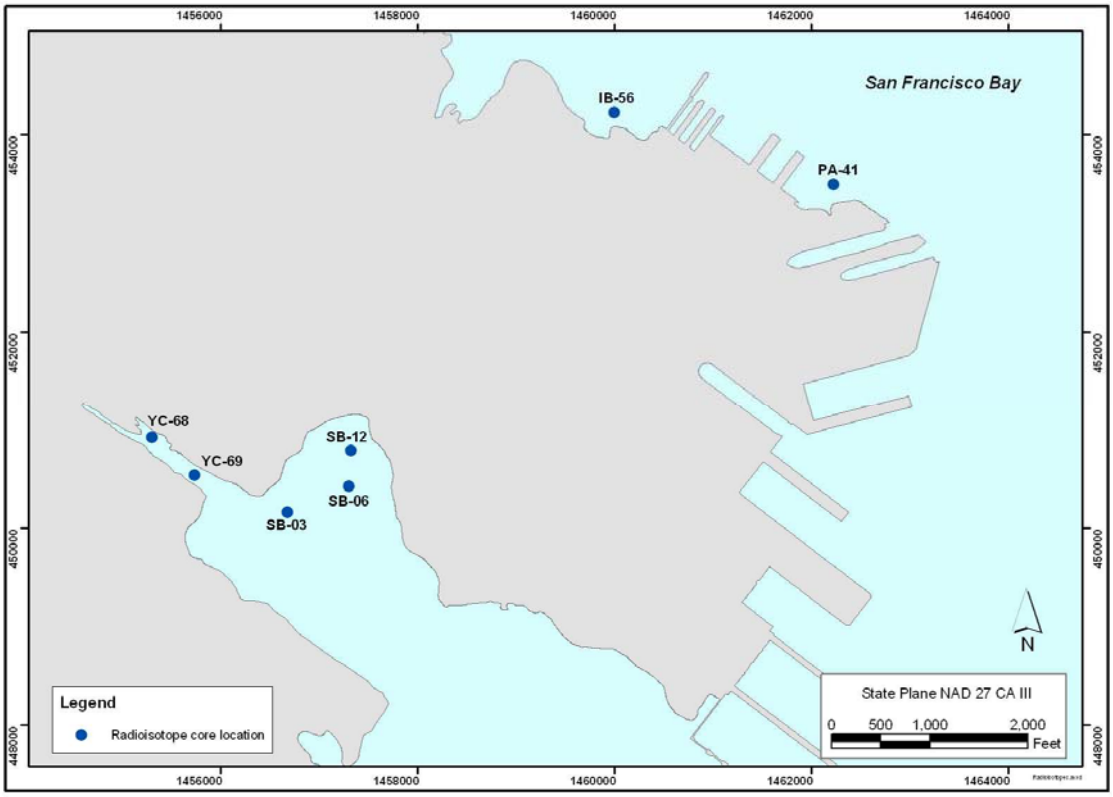


Figure 3-7. Radioisotope Core Sampling Locations

3.1.1.1 Sediment Sample Locations

The actual positions of the HPS sampling, reference site, and sediment core stations generally were close to the target locations specified in the VS Work Plan, with the following exceptions. Several nearshore stations in Area X (South Basin) were repositioned prior to sampling because the originally planned locations were considered to be too far offshore. Specifically, nearshore Stations SB-19, SB-21, and SB-23 were shifted shoreward to ensure that soft sediments in the areas with the highest chemical concentrations were sampled (Figure 3-5). To avoid a large gap in spatial coverage, station SB-12 was moved to the east. Three additional stations at HPS, PA-70, PA-71, and PA-72, located northwest of the outfall in Area III (Point Avisadero) were not included in the VS Work Plan, but were sampled at the request of SWDIV for sediment chemistry only.

In Areas III, VIII, and IX, the following stations were located near riprap banks or debris fields and were moved offshore to the nearest soft sediment: PA-38, PA-39, PA-45, PA-46, EW-30, EW-33, EW-36, OR-24, and OR-29. Because Stations PA-38 and PA-39 were repositioned farther offshore, Station PA-40 also was relocated to maintain its position relative to Stations PA-38 and PA-39. In Area X, Station SB-14 was sampled northeast of the planned location because the boat ran aground in shallow water.

3.1.1.2 Surface Sediment Sampling

Surface (upper 5 cm) sediment samples for sediment chemistry, toxicity, and bioaccumulation testing were collected from May 2 through May 22, 2001 at all 59 planned HPS sampling stations, five reference site stations, and three additional stations at HPS. Three vessels were used for sediment sampling: the

R/V Sea Dog, R/V Retriever and Brezina and Associates' 17-ft Boston Whaler (CF 6341 FM). Most stations were sampled using either a single (0.1-m^2) or double (0.2-m^2) Van Veen grab sampler. Subsurface (5-10 cm) sediment for the EFANE TIE study also was taken from the Van Veen grabs at Stations PA-40, PA-41, and SB-20. Surface sediment was collected from the sandy Red Rock and Alcatraz Environs reference sites using a drag sampler. Surface sediment from Stations SB-18, SB-19, SB-21, and SB-23 was collected from the beach at low tide using a clean stainless steel spoon.

Each Van Veen grab was opened and examined for acceptability prior to removal of the sediment sample. Grabs were rejected if the sampler overpenetrated, if the sediment surface was disturbed, or if debris interfered with grab operation. If the grab was acceptable, precleaned stainless steel utensils were used to scoop sediment into labeled epoxy-coated pails. A clean set of utensils was used for each sample. Multiple grabs were required at all stations to obtain sufficient volume for all analyses. Vessels were repositioned slightly (within 5 m of position) as needed to prevent sampling in the exact same location. In all bulk sediment samples, large or obvious organisms and biological structures such as worms, worm tubes, crabs, gobies, anemones, and mussels were removed from the sediment samples. Presence of organisms was noted along with other sediment characteristics in the field logs (see Table A-3, Appendix A).

Composite samples for treatability testing in support of the FS were collected from selected stations in Areas III and X. Treatability testing required 12 gal of wet sediment. In Area III, surface sediment collected at and between stations PA-38 and PA-39 was composited for treatability testing. In Area X, approximately 1.8 gal of surface sediment from each of stations SB-17, SB-18, SB-19, SB-20, SB-21, SB-22, and SB-23 were composited for treatability testing.

Two types of field quality control (QC) samples were collected. Field duplicate samples of surface sediment for sediment chemistry only were collected at one station in each of the five study areas. Field duplicates were collected at the same time in the same manner as the original field sample, but were placed in a different pail with a unique sample identifier. Field duplicates of sediment were handled and shipped in the same manner as all other samples. One equipment blank (water) sample was collected in each of the five study areas, consisting of laboratory deionized water passed over a clean set of stainless steel utensils (no more than 1 L water per utensil) into appropriately labeled sample containers.

3.1.1.3 Sediment-Water Interface Cores

SWICs for the SWI test on *S. purpuratus* larvae were collected prior to, or concurrently with, surface sediment sampling to ensure collection of an undisturbed SWI. Two methods were used to collect most SWICs: push coring, and collection by hand from the Van Veen grab sample. SWICs were stored upright in a cooler with ice before and during transport to PERL. All SWIC samples were transported by PERL to their laboratory either the day of or the day following sample collection.

Undisturbed SWICs were collected successfully from May 1 through 21, 2001, at all 59 HPS sampling stations and at three of the five San Francisco Bay reference site stations (Paradise Cove, Alameda Buoy, and Bay Farm). At the Red Rock and Alcatraz Environs (the coarse-grained) reference sites, undisturbed SWICs could not be collected because of the sandy bottom and high currents. A drag sampler was used to collect surface sediment; homogenized sediment from multiple drags was placed in the SWIC tubes and gently covered with seawater.

3.1.1.4 Sediment Core Samples

Sediment cores were collected successfully from May 15 through May 18, 2001, at all 22 planned stations at HPS and Yosemite Creek. Two 4-inch-diameter mini-vibracore units, owned and operated by TEG Oceanographic Services, were used. Core recovery was between 7.5 ft and 9.8 ft at all HPS sampling

stations except EW-36 (5.8 ft) and PA-40 (refusal at 4.1 ft). Cores were 4.4 ft and 3.9 ft in length at Yosemite Creek Stations YC-68 and YC-69, respectively (these cores were collected for radioisotope analysis only).

3.1.2 Field-Collected Tissues

Field-collected tissues were collected to provide ancillary data to support evaluation of the bioaccumulation line of evidence. Detailed sample collection information is provided in Appendix A.

3.1.2.1 Invertebrate Sampling

Sediment-associated benthic invertebrate samples were collected successfully from May 9 through May 16, 2001 and from June 25 through June 26, 2001. Invertebrate sampling locations are shown in Figures 3-8 through 3-12. Soft-bodied invertebrate samples were collected by sieving Van Veen grab samples through a 5-mm mesh screen and then thoroughly rinsing any invertebrates retained on a 1-mm mesh screen, or by hand-picking from sediment in the intertidal zone at low tide. Polychaete worms were the most abundant soft-bodied organisms. Worm tubes were carefully removed and rinsed away prior to collecting worm tissue.

Clams were not as abundant or widespread as the worms. Most clams were collected in shallow water or from the beach at low tide, under and around rocks and tires. Clams were found in all areas except Area III (Point Avisadero). Invertebrate samples were shipped to BDL, where they were processed and distributed to the analytical laboratories.

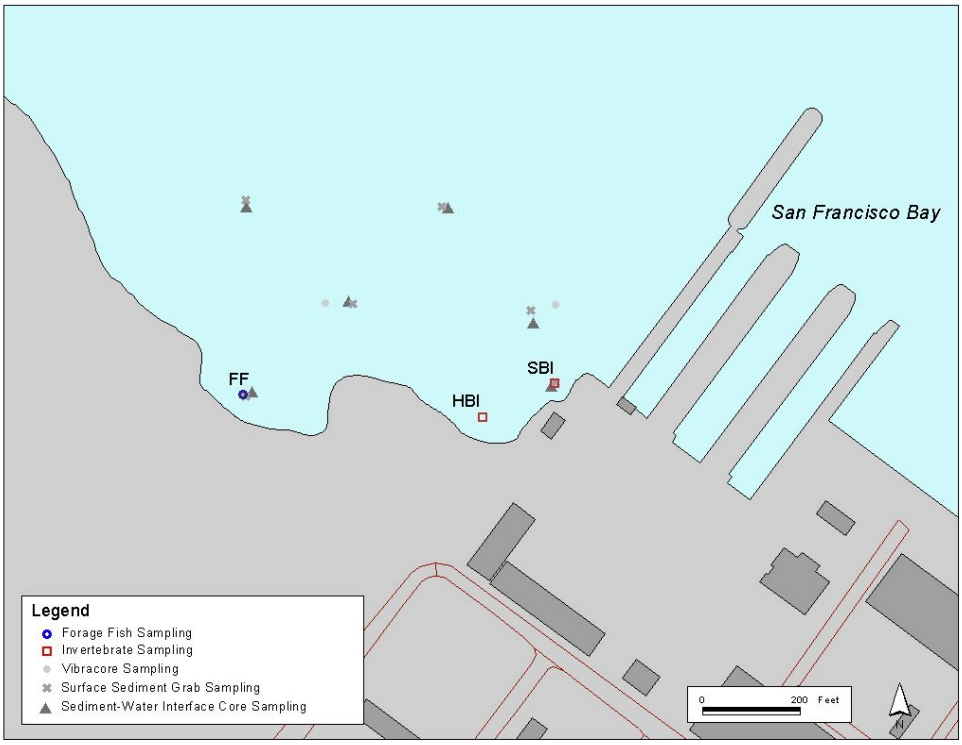


Figure 3-8. Invertebrate and Forage Fish Sampling Locations in Area I, India Basin

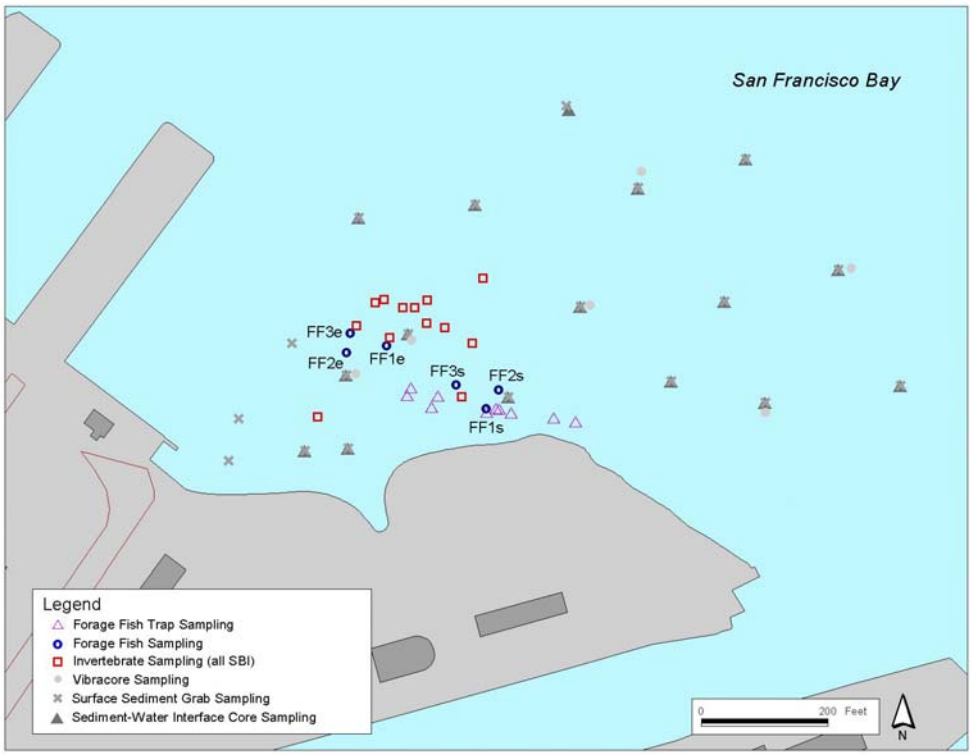


Figure 3-9. Invertebrate and Forage Fish Sampling Locations in Area III, Point Avisadero

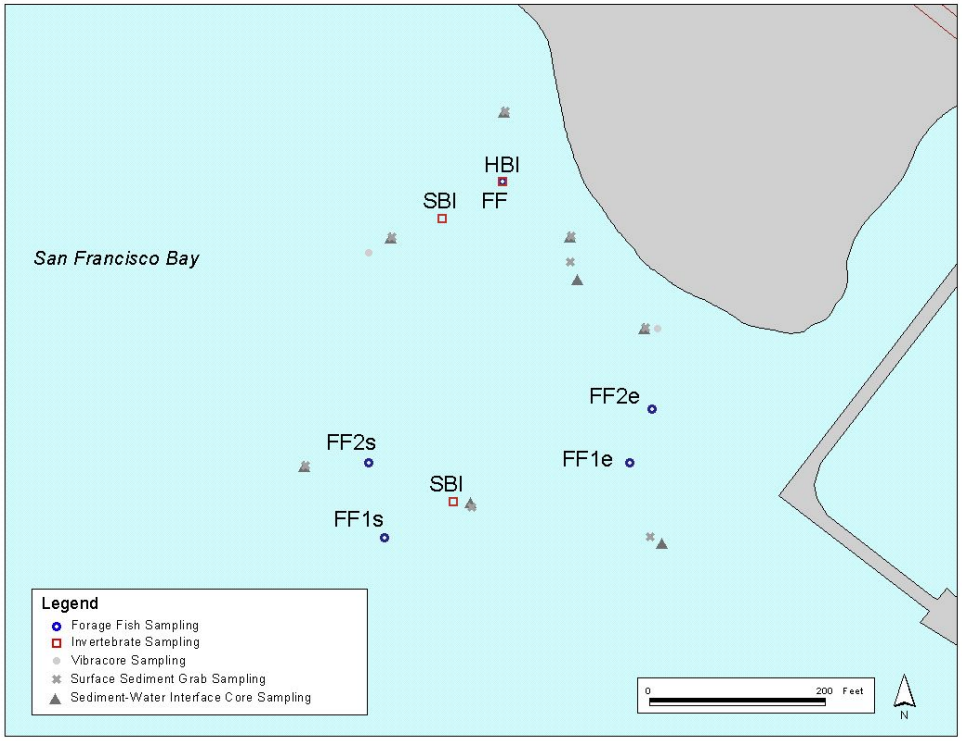


Figure 3-10. Invertebrate and Forage Fish Sampling Locations in Area VIII, Eastern Wetland

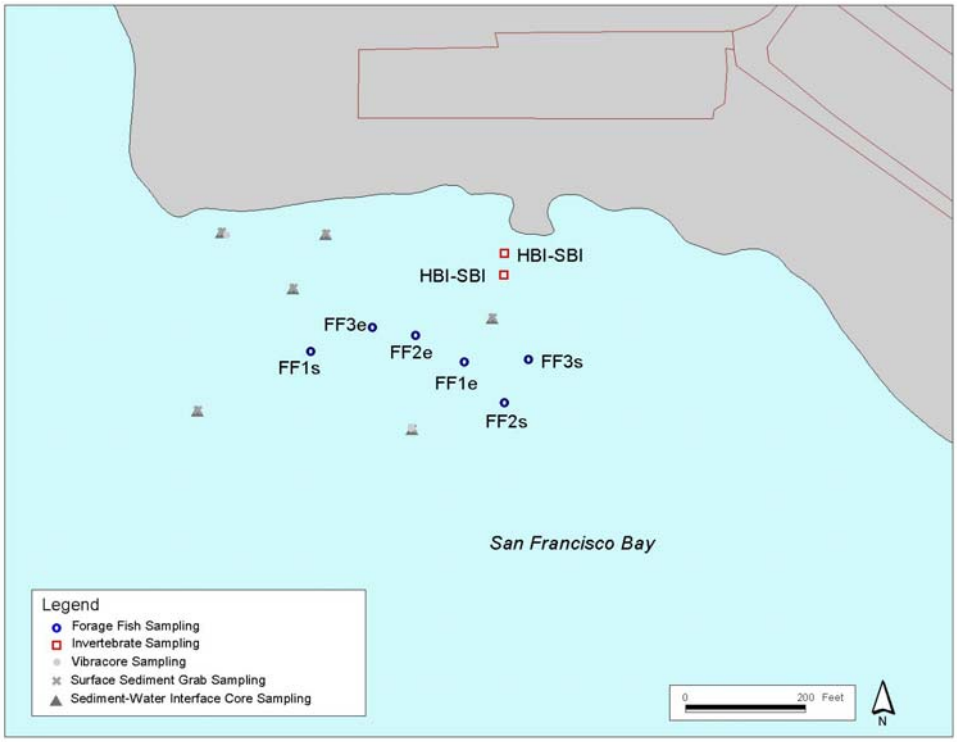


Figure 3-11. Invertebrate and Forage Fish Sampling Locations in Area IX, Oil Reclamation

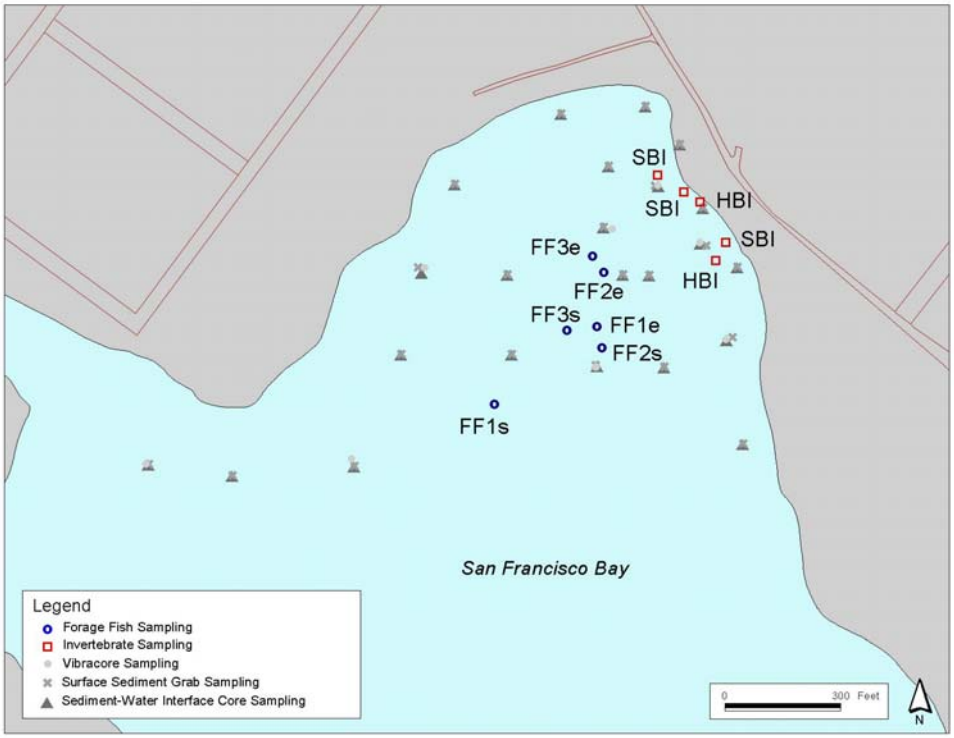


Figure 3-12. Invertebrate and Forage Fish Sampling Locations in Area X, South Basin

3.1.2.2 Forage Fish Sampling

Small, sediment-associated forage fish samples (gobies and sculpins) were collected from May 11 through June 28, 2001 using a variety of methods. Sampling locations are shown in Figures 3-8 through 3-12. An 8-ft, 0.25-inch mesh cod end otter trawl and a 10-ft, 0.125-inch delta mesh beach seine proved to be the most effective methods for collecting forage fish in all areas. Minnow traps proved to be ineffective for collecting the target fish in Area I where 10 traps deployed overnight yielded just one bay pipefish (*Syngnathus leptorhynchus*) and none of the target species. Traps were more effective in Area III where traps deployed over two nights yielded a number of forage fish. The Area III sample was augmented by the catch from three trawls.

The target forage fish, staghorn sculpins (*Leptocottus armatus*) and the various goby species, were caught in sufficient numbers to complete forage fish composites in all areas except Area VIII. In Area VIII, other fish species in the target size range provided sufficient mass to make up the composite. Forage fish samples were shipped to BDL, where composite samples were prepared, split, and distributed to the analytical laboratories for chemical analysis.

3.1.3 Human Health Evaluation Fish Sampling

Fish species commonly associated with human consumption were collected from three areas at HPS and four San Francisco Bay sites. Fish were collected at HPS from May 12 through May 19, 2001; sampling locations are shown in Figure 3-13. San Francisco Bay reference site sampling was conducted at San Francisco Pier 7, Berkeley Pier, and San Mateo Bridge from May 21 through May 23, 2001. A fourth location, Bay Farm, was added on June 13, 2001 because one of the target species was not obtained from Berkeley Pier. Sampling locations are shown in Figure 3-14. Sampling information and catch records are provided in Appendix A.

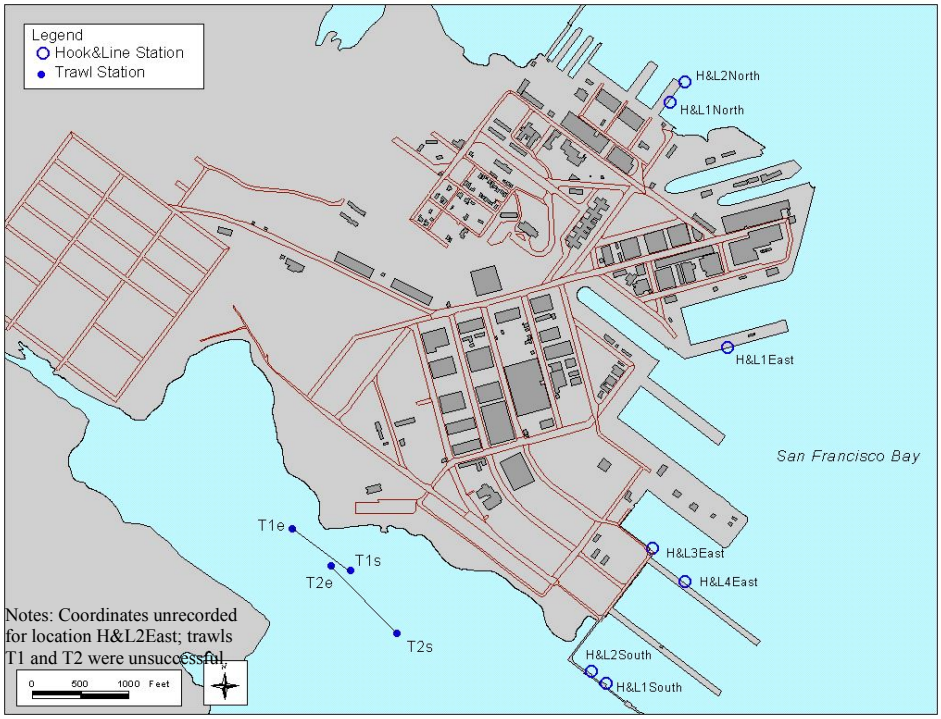


Figure 3-13. Human Health Evaluation Fish Sampling Locations Near HPS

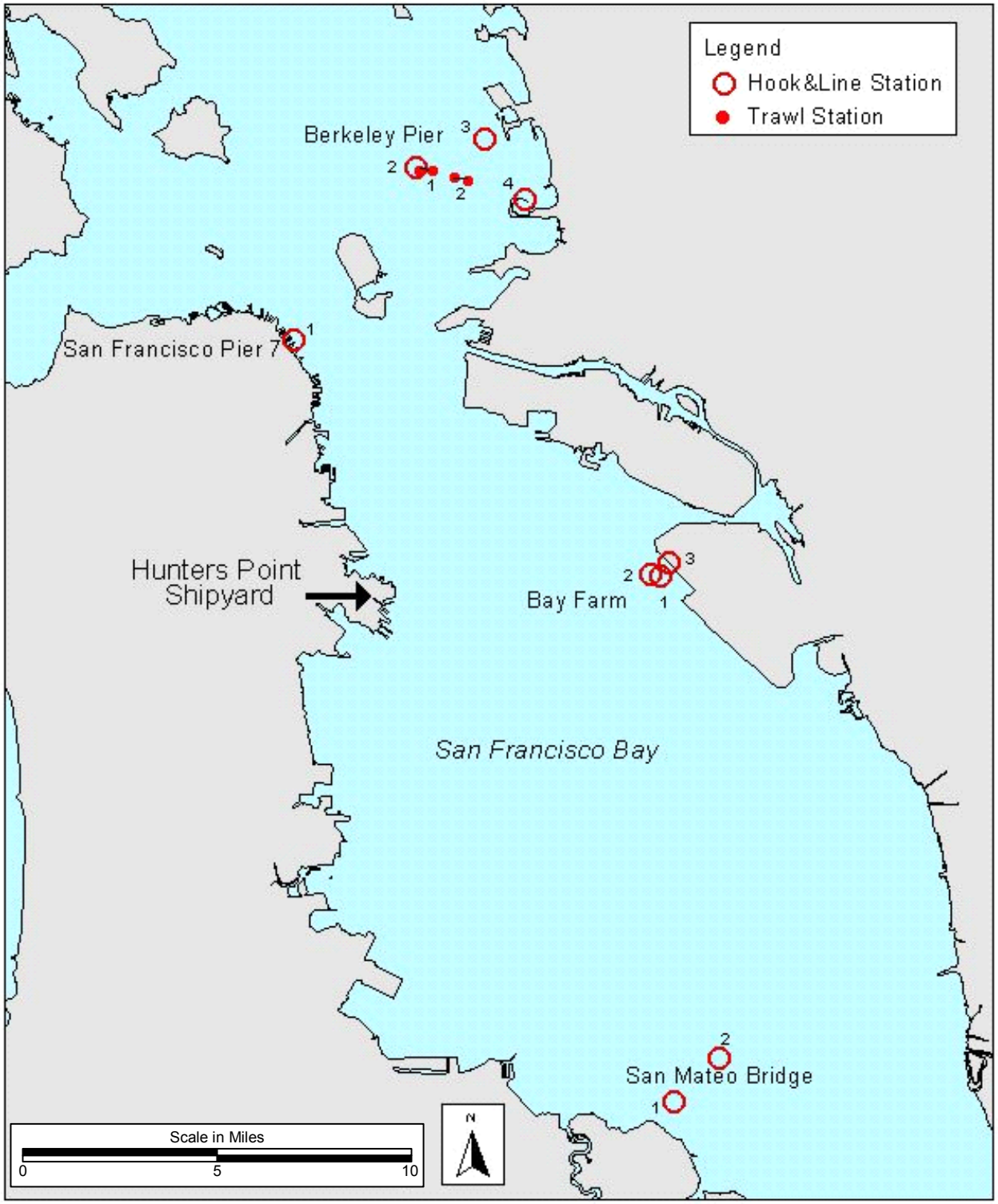


Figure 3-14. Human Health Evaluation Fish Sampling Location at San Francisco Bay Reference Sites

Baited hook and line was the most effective method of collection, and mirrored the most common techniques practiced by recreational fishers in these areas. Trawls also were conducted over appropriate substrates (soft bottom) using a 16-ft otter trawl (0.5-inch mesh cod end). Trawling was performed in the HPS south region and at the Berkeley Pier site; however, this collection technique yielded no target species. In the field, fish samples were rinsed with seawater, sorted by species and size class, placed in labeled Teflon™ bags, and frozen in dry ice in a cooler. Whole body fish samples were shipped directly from the field to BDL for processing.

Catch rates were highest in areas with structure and high tidal flows. One of the primary target species for the human health evaluation, white croaker (*Genyonemus lineatus*), was not collected at any sampling location. Jacksmelt (*Atherinopsis californiensis*) was the only target fish species collected at all sampling locations; jacksmelt generally dominated catches in terms of both biomass and abundance. Jacksmelt catches were distributed fairly evenly between HPS and San Francisco Bay sites. The third target species, shiner surfperch (*Cymatogaster aggregata*), was the second most abundant species, although only four individuals were collected from all of the San Francisco Bay sites combined. A variety of other surfperch species were caught and retained for inclusion in the human health evaluation: black surfperch (*Embiotoca jacksoni*), walleye surfperch (*Hyperprosopon argenteum*), white surfperch (*Phanerodon furcatus*), and silver surfperch (*Hyperprosopon ellipticum*). Topsmelt (*Atherinops affinis*) was another nontarget fish species retained during field sampling; topsmelt samples were archived.

3.2 Sample Preparation

Sediment and tissue samples were homogenized and in some cases composited following sample collection and prior to analysis. Sample preparation procedures for surface sediment samples and sediment core samples are described in Sections 3.2.1 and 3.2.2, respectively. Sample preparation procedures for field-collected invertebrates, forage fish, and human health evaluation fish are described in Section 3.2.3.

3.2.1 Surface Sediment Samples

All surface sediment samples collected for analysis are listed in Table 3-1. Surface sediment samples were shipped to BSL by refrigerated truck. Upon receipt, they were stored in a padlocked walk-in cooler designated solely for the project and monitored daily. Samples were processed in the order of field collection to ensure that holding times were met. Each sediment sample with a volume of ≥5 gal was transferred to a 5-cubic-ft, high-density polyethylene (HDPE) drum of a cement-style mixer and mixed for 10 minutes. If the sample volume was <5 gal (e.g., field duplicates), it was homogenized directly in the 5-gal epoxy-coated sample collection bucket using a stainless steel paint-mixing paddle and hand drill.

After each sample was homogenized, sample aliquots were collected using clean, solvent (methylene chloride)-rinsed stainless steel spoons and spatulas for the various physical, chemical, and biological analyses. Subsamples for toxicological analysis were returned to the collection buckets and stored in the walk-in cooler. Archive samples were frozen. Analytical samples were placed in labeled coolers corresponding to the designated analytical laboratories, together with chain of custody documentation, and shipped. If samples were not shipped immediately (e.g., if processed on a Sunday), they were stored at 4±2°C and shipped as soon as possible.

Table 3-1. Surface Sediment Sample Summary

Area	Station		Sample ID	Organics[a]	Metals	TPH-DRO	TOC	Grain Size	Bioassays	BSL TIE	SAIC TIE	Archive
India Basin												
Area I	IB- 54		AAB-158	Y	Y	Y	Y	Y	Y	–	–	Y
Area I	IB- 55		AAB-160	Y	Y	Y	Y	Y	Y	–	–	Y
Area I	IB- 56		AAB-159	Y	Y	Y	Y	Y	Y	–	–	Y
Area I	IB- 57		AAB-129	Y	Y	Y	Y	Y	Y	–	–	Y
Area I	IB- 58		AAB-130	Y	Y	Y	Y	Y	Y	–	–	Y
Area I	IB- 59		AAB-161	Y	Y	Y	Y	Y	Y	–	–	Y
Area I	IB- 59	field duplicate	AAB-163	Y	Y	Y	Y	Y	–	–	–	Y
Point Avisadero												
Area III	PA- 38		AAB-133	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area III	PA- 39		AAB-128	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area III	PA- 39	field duplicate	AAB-155	Y	Y	Y	Y	Y	–	–	–	Y
Area III	PA- 40		AAB-132	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area III	PA- 40	5-10 cm TIE	AAB-131	Y	Y	Y	Y	Y	–	–	Y	Y
Area III	PA- 41		AAB-092	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area III	PA- 41	5-10 cm TIE	AAB-093	Y	Y	Y	Y	Y	–	–	Y	Y
Area III	PA- 42		AAB-086	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 43		AAB-087	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 44		AAB-091	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 45		AAB-126	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 46		AAB-127	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 47		AAB-089	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 48		AAB-088	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 49		AAB-083	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 50		AAB-094	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 51		AAB-085	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 52		AAB-084	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 53		AAB-090	Y	Y	Y	Y	Y	Y	–	–	Y
Area III	PA- 70		AAB-137	Y	Y	Y	Y	Y	–	–	–	Y
Area III	PA- 71		AAB-136	Y	Y	Y	Y	Y	–	–	–	Y
Area III	PA- 72		AAB-135	Y	Y	Y	Y	Y	–	–	–	Y
Eastern Wetland												
Area VIII	EW- 30		AAB-107	Y	Y	Y	Y	Y	Y	–	–	Y
Area VIII	EW- 31		AAB-104	Y	Y	Y	Y	Y	Y	–	–	Y
Area VIII	EW- 32		AAB-095	Y	Y	Y	Y	Y	Y	–	–	Y
Area VIII	EW- 33		AAB-124	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area VIII	EW- 33	field duplicate	AAB-106	Y	Y	Y	Y	Y	–	–	–	Y
Area VIII	EW- 34		AAB-108	Y	Y	Y	Y	Y	Y	–	–	Y
Area VIII	EW- 35		AAB-097	Y	Y	Y	Y	Y	Y	–	–	Y
Area VIII	EW- 36		AAB-105	Y	Y	Y	Y	Y	Y	–	–	Y
Area VIII	EW- 37		AAB-142	Y	Y	Y	Y	Y	Y	–	–	Y

Table 3-1. Surface Sediment Sample Summary (continued)

Area	Station		Sample ID	Organics[a]	Metals	TPH-DRO	TOC	Grain Size	Bioassays	BSL TIE	SAIC TIE	Archive
Oil Reclamation												
Area IX	OR- 24		AAB-125	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area IX	OR- 25		AAB-103	Y	Y	Y	Y	Y	Y	–	–	Y
Area IX	OR- 26		AAB-116	Y	Y	Y	Y	Y	Y	–	–	Y
Area IX	OR- 27		AAB-117	Y	Y	Y	Y	Y	Y	–	–	Y
Area IX	OR- 28		AAB-096	Y	Y	Y	Y	Y	Y	–	–	Y
Area IX	OR- 29		AAB-118	Y	Y	Y	Y	Y	Y	–	–	Y
Area IX	OR- 29	field duplicate	AAB-123	Y	Y	Y	Y	Y	–	–	–	Y
South Basin												
Area X	SB- 01		AAB-148	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 02		AAB-143	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 03		AAB-122	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 04		AAB-121	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 05		AAB-141	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 06		AAB-120	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 07		AAB-119	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 08		AAB-115	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 09		AAB-145	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 10		AAB-144	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 11		AAB-139	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 12		AAB-154	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 12	field duplicate	AAB-140	Y	Y	Y	Y	Y	–	–	–	Y
Area X	SB- 13		AAB-113	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 14		AAB-138	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 15		AAB-114	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 16		AAB-112	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 17		AAB-146	Y	Y	Y	Y	Y	Y	–	–	Y
Area X	SB- 18		AAB-100	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area X	SB- 19		AAB-101	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area X	SB- 20		AAB-109	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area X	SB- 20	5-10 cm TIE	AAB-110	Y	Y	Y	Y	Y	–	–	Y	Y
Area X	SB- 21		AAB-102	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area X	SB- 22		AAB-111	Y	Y	Y	Y	Y	Y	Y	Y	Y
Area X	SB- 23		AAB-099	Y	Y	Y	Y	Y	Y	Y	Y	Y
Reference Sites												
Paradise Cove	PC- 63		AAB-162	Y	Y	Y	Y	Y	Y	Y	Y	Y
Alcatraz Environs	AL- 64		AAB-098	Y	Y	Y	Y	Y	Y	–	–	Y
Red Rock	RR- 65		AAB-165	Y	Y	Y	Y	Y	Y	–	–	Y
Bay Farm	BF- 66		AAB-156	Y	Y	Y	Y	Y	Y	–	–	Y
Alameda Buoy	AB- 67		AAB-157	Y	Y	Y	Y	Y	Y	–	–	Y

(a) Organics include PAHs, PCBs, pesticides, and butyltins.

3.2.2 Sediment Cores

Sediment core samples were shipped via refrigerated truck to BSL and stored in a dedicated walk-in cooler. Sediment core samples were processed in the order of field collection to ensure that holding times were met. Each core was scored longitudinally with a circular saw without penetrating the core tubing, and a clean linoleum knife was used to cut through the scored tubing. The core halves were pried apart using a clean, solvent-rinsed stainless steel spatula. The lithology of each core sample was described by a geologist following ASTM Method D 2488-84 (ASTM, 1984). The description included sediment type, color, consistency, cementation, structure, hydrochloric acid reaction, odor, and any unusual characteristics (e.g., oily sediment, shell fragments, wood chips). Core logs are provided in Appendix A.

After the core was described, it was marked in 0-2 ft, 2-4 ft, 4-6 ft, and >6 ft sections, and sediment for physical and chemical analysis was removed from the center of each section with a clean, solvent-rinsed spatula or spoon, except as noted below for radioisotope subsamples. Sediment in direct contact with the core liner or core cap was not collected. Sediment was homogenized by hand using a clean, solvent-rinsed stainless steel spoon in a clean, labeled, stainless steel bowl until a homogeneous color and texture was observed. Sample aliquots were collected from each homogenized 2-ft section as shown in Table 3-2.

Seven cores (five from HPS and two from Yosemite Creek) were sampled for radioisotope analysis. The radioisotope samples were collected from 2-cm intervals at locations 10 cm apart (i.e., 0-2 cm, 10-12 cm, 20-22 cm) up to 92 cm. The sediment was removed from both halves of the core using a clean wooden tongue depressor for each 2-cm interval.

As with the surface sediment samples, archive samples were frozen and other analytical samples were placed in labeled coolers corresponding to the designated analytical laboratories, together with chain of custody documentation and distributed to the analytical laboratories. If samples were not shipped immediately (e.g., if processed on a Sunday), they were stored at 4±2°C and shipped as soon as possible.

3.2.3 Tissue Composites

Field-collected tissue samples were processed at BDL prior to chemical analysis as described below.

3.2.3.1 Invertebrates

Field-collected invertebrate samples were separated into soft-bodied invertebrate (worm) or hard-bodied invertebrate (clam) samples in the field. One composite sample of each invertebrate type was prepared for each of the five study areas. No clams were found in Area III. Clam tissues were removed from the shells using titanium knives. Worms and clam tissue samples were weighed, homogenized with titanium probes and split into aliquots for chemical analyses as shown in Table 3-3. If samples were not shipped immediately, they were stored at -20°C and shipped as soon as possible.

3.2.3.2 Forage Fish

Forage fish tissue composites were prepared from frozen whole-body fish samples. One forage fish composite was prepared for each of the five study areas. Forage fish tissue composites were weighed, homogenized with titanium probes, split into aliquots for chemical analysis as shown in Table 3-3, and distributed to the analytical laboratories. If samples were not shipped immediately, they were stored at –20°C and shipped as soon as possible.

Table 3-2. Core Sample Summary

Area	Station and Depth		Sample ID	Organics[a]	Metals	TPH-DRO	TOC	Grain Size	Archive	Radioisotopes[b]	TCLP[c]
India Basin											
Area I	IB- 56	0-2′	AAB-205	Y	Y	Y	Y	Y	Y	–	–
Area I	IB- 56	2-4′	AAB-206	Y	Y	Y	Y	Y	Y	–	–
Area I	IB- 56	4-6′	AAB-207	Y	Y	Y	Y	Y	Y	–	–
Area I	IB- 56	>6′	AAB-269	–	–	–	–	–	Y	–	–
Area I	IB- 59	0-2′	AAB-247	Y	Y	Y	Y	Y	Y	–	–
Area I	IB- 59	2-4′	AAB-248	Y	Y	Y	Y	Y	Y	–	–
Area I	IB- 59	4-6′	AAB-249	Y	Y	Y	Y	Y	Y	–	–
Area I	IB- 59	>6′	AAB-283	–	–	–	–	–	Y	–	–
Area I	IB- 56	0-2 cm	AAB-318	–	–	–	–	–	–	Y	–
Area I	IB- 56	10-12 cm	AAB-319	–	–	–	–	–	–	Y	–
Area I	IB- 56	20-22 cm	AAB-320	–	–	–	–	–	–	Y	–
Area I	IB- 56	30-32 cm	AAB-321	–	–	–	–	–	–	Y	–
Area I	IB- 56	40-42 cm	AAB-322	–	–	–	–	–	–	Y	–
Area I	IB- 56	50-52 cm	AAB-323	–	–	–	–	–	–	Y	–
Area I	IB- 56	60-62 cm	AAB-324	–	–	–	–	–	–	Y	–
Area I	IB- 56	70-72 cm	AAB-325	–	–	–	–	–	–	Y	–
Area I	IB- 56	80-82 cm	AAB-326	–	–	–	–	–	–	Y	–
Area I	IB- 56	90-92 cm	AAB-327	–	–	–	–	–	–	Y	–
Point Avisadero											
Area III	PA- 40	0-2′	AAB-244	Y	Y	Y	Y	Y	Y	–	Y
Area III	PA- 40	2-4′	AAB-245	Y	Y	Y	Y	Y	Y	–	Y
Area III	PA- 41	0-2′	AAB-196	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 41	2-4′	AAB-197	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 41	4-6′	AAB-198	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 41	>6′	AAB-266	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 44	0-2′	AAB-226	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 44	2-4′	AAB-227	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 44	4-6′	AAB-228	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 44	>6′	AAB-276	–	–	–	–	–	Y	–	–
Area III	PA- 47	0-2′	AAB-223	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 47	2-4′	AAB-224	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 47	4-6′	AAB-225	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 47	>6′	AAB-275	–	–	–	–	–	Y	–	–
Area III	PA- 49	0-2′	AAB-232	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 49	2-4′	AAB-233	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 49	4-6′	AAB-234	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 49	>6′	AAB-278	–	–	–	–	–	Y	–	–
Area III	PA- 52	0-2′	AAB-229	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 52	2-4′	AAB-230	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 52	4-6′	AAB-231	Y	Y	Y	Y	Y	Y	–	–
Area III	PA- 52	>6′	AAB-277	–	–	–	–	–	Y	–	–

Table 3-2. Core Sample Summary (page 2 of 4)

Area	Station and Depth		Sample ID	Organics[a]	Metals	TPH-DRO	TOC	Grain Size	Archive	Radioisotopes[b]	TCLP[c]
Point Avisadero (continued)											
Area III	PA- 41	0-2 cm	AAB-288	–	–	–	–	–	–	Y	–
Area III	PA- 41	20-22 cm	AAB-289	–	–	–	–	–	–	Y	–
Area III	PA- 41	10-12 cm	AAB-290	–	–	–	–	–	–	Y	–
Area III	PA- 41	30-32 cm	AAB-291	–	–	–	–	–	–	Y	–
Area III	PA- 41	42-44 cm	AAB-292	–	–	–	–	–	–	Y	–
Area III	PA- 41	50-52 cm	AAB-293	–	–	–	–	–	–	Y	–
Area III	PA- 41	60-62 cm	AAB-294	–	–	–	–	–	–	Y	–
Area III	PA- 41	70-72 cm	AAB-295	–	–	–	–	–	–	Y	–
Area III	PA- 41	80-82 cm	AAB-296	–	–	–	–	–	–	Y	–
Area III	PA- 41	90-92 cm	AAB-297	–	–	–	–	–	–	Y	–
Eastern Wetland											
Area VIII	EW- 31	0-2′	AAB-238	Y	Y	Y	Y	Y	Y	–	–
Area VIII	EW- 31	2-4′	AAB-239	Y	Y	Y	Y	Y	Y	–	–
Area VIII	EW- 31	4-6′	AAB-240	Y	Y	Y	Y	Y	Y	–	–
Area VIII	EW- 31	>6′	AAB-280	–	–	–	–	–	Y	–	–
Area VIII	EW- 36	0-2′	AAB-262	Y	Y	Y	Y	Y	Y	–	–
Area VIII	EW- 36	2-4′	AAB-263	Y	Y	Y	Y	Y	Y	–	–
Area VIII	EW- 36	4-6′	AAB-264	Y	Y	Y	Y	Y	Y	–	–
Oil Reclamation											
Area IX	OR- 24	0-2′	AAB-241	Y	Y	Y	Y	Y	Y	–	–
Area IX	OR- 24	2-4′	AAB-242	Y	Y	Y	Y	Y	Y	–	–
Area IX	OR- 24	4-6′	AAB-243	Y	Y	Y	Y	Y	Y	–	–
Area IX	OR- 24	>6′	AAB-281	–	–	–	–	–	Y	–	–
Area IX	OR- 28	0-2′	AAB-220	Y	Y	Y	Y	Y	Y	–	–
Area IX	OR- 28	2-4′	AAB-221	Y	Y	Y	Y	Y	Y	–	–
Area IX	OR- 28	4-6′	AAB-222	Y	Y	Y	Y	Y	Y	–	–
Area IX	OR- 28	>6′	AAB-274	Y	Y	Y	Y	Y	Y	–	–
South Basin											
Area X	SB- 01	0-2′	AAB-259	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 01	2-4′	AAB-260	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 01	4-6′	AAB-261	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 01	>6′	AAB-287	–	–	–	–	–	Y	–	–
Area X	SB- 03	0-2′	AAB-208	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 03	2-4′	AAB-209	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 03	4-6′	AAB-210	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 03	>6′	AAB-270	–	–	–	–	–	Y	–	–
Area X	SB- 06	0-2′	AAB-202	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 06	2-4′	AAB-203	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 06	4-6′	AAB-204	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 06	>6′	AAB-268	–	–	–	–	–	Y	–	–
Area X	SB- 07	0-2′	AAB-235	Y	Y	Y	Y	Y	Y	–	–

Table 3-2. Core Sample Summary (page 3 of 4)

Area	Station and Depth		Sample ID	Organics[a]	Metals	TPH-DRO	TOC	Grain Size	Archive	Radioisotopes[b]	TCLP[c]
South Basin (continued)											
Area X	SB- 07	2-4′	AAB-236	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 07	4-6′	AAB-237	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 07	>6′	AAB-279	–	–	–	–	–	Y	–	–
Area X	SB- 12	0-2′	AAB-199	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 12	2-4′	AAB-200	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 12	4-6′	AAB-201	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 12	>6′	AAB-267	–	–	–	–	–	Y	–	–
Area X	SB- 16	0-2′	AAB-256	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 16	2-4′	AAB-257	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 16	4-6′	AAB-258	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 16	>6′	AAB-286	–	–	–	–	–	Y	–	–
Area X	SB- 20	0-2′	AAB-250	Y	Y	Y	Y	Y	Y	–	Y
Area X	SB- 20	2-4′	AAB-251	Y	Y	Y	Y	Y	Y	–	Y
Area X	SB- 20	4-6′	AAB-252	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 20	>6′	AAB-284	–	–	–	–	–	Y	–	–
Area X	SB- 22	0-2′	AAB-253	Y	Y	Y	Y	Y	Y	–	Y
Area X	SB- 22	2-4′	AAB-254	Y	Y	Y	Y	Y	Y	–	Y
Area X	SB- 22	4-6′	AAB-255	Y	Y	Y	Y	Y	Y	–	–
Area X	SB- 22	>6′	AAB-285	–	–	–	–	–	Y	–	–
Area X	SB- 03	0-2 cm	AAB-328	–	–	–	–	–	–	Y	–
Area X	SB- 03	10-12 cm	AAB-329	–	–	–	–	–	–	Y	–
Area X	SB- 03	20-22 cm	AAB-330	–	–	–	–	–	–	Y	–
Area X	SB- 03	30-32 cm	AAB-331	–	–	–	–	–	–	Y	–
Area X	SB- 03	40-42 cm	AAB-332	–	–	–	–	–	–	Y	–
Area X	SB- 03	50-52 cm	AAB-333	–	–	–	–	–	–	Y	–
Area X	SB- 03	60-62 cm	AAB-334	–	–	–	–	–	–	Y	–
Area X	SB- 03	70-72 cm	AAB-335	–	–	–	–	–	–	Y	–
Area X	SB- 03	80-82 cm	AAB-336	–	–	–	–	–	–	Y	–
Area X	SB- 03	90-92 cm	AAB-337	–	–	–	–	–	–	Y	–
Area X	SB- 12	70-72 cm	AAB-305	–	–	–	–	–	–	Y	–
Area X	SB- 12	80-82 cm	AAB-306	–	–	–	–	–	–	Y	–
Area X	SB- 12	0-2 cm	AAB-298	–	–	–	–	–	–	Y	–
Area X	SB- 12	10-12 cm	AAB-299	–	–	–	–	–	–	Y	–
Area X	SB- 12	20-22 cm	AAB-300	–	–	–	–	–	–	Y	–
Area X	SB- 12	30-32 cm	AAB-301	–	–	–	–	–	–	Y	–
Area X	SB- 12	40-42 cm	AAB-302	–	–	–	–	–	–	Y	–
Area X	SB- 12	50-52 cm	AAB-303	–	–	–	–	–	–	Y	–
Area X	SB- 12	60-62 cm	AAB-304	–	–	–	–	–	–	Y	–
Area X	SB- 12	90-92 cm	AAB-307	–	–	–	–	–	–	Y	–
Area X	SB- 06	0-2 cm	AAB-308	–	–	–	–	–	–	Y	–
Area X	SB- 06	10-12 cm	AAB-309	–	–	–	–	–	–	Y	–

Table 3-2. Core Sample Summary (page 4 of 4)

Area	Station and Depth		Sample ID	Organics[a]	Metals	TPH-DRO	TOC	Grain Size	Archive	Radioisotopes[b]	TCLP[c]
South Basin (continued)											
Area X	SB- 06	20-22 cm	AAB-310	–	–	–	–	–	–	Y	–
Area X	SB- 06	30-32 cm	AAB-311	–	–	–	–	–	–	Y	–
Area X	SB- 06	40-42 cm	AAB-312	–	–	–	–	–	–	Y	–
Area X	SB- 06	50-52 cm	AAB-313	–	–	–	–	–	–	Y	–
Area X	SB- 06	60-62 cm	AAB-314	–	–	–	–	–	–	Y	–
Area X	SB- 06	70-72 cm	AAB-315	–	–	–	–	–	–	Y	–
Area X	SB- 06	80-82 cm	AAB-316	–	–	–	–	–	–	Y	–
Area X	SB- 06	90-92 cm	AAB-317	–	–	–	–	–	–	Y	–
Yosemite Creek											
Yosemite Creek	YC- 68	0-2 cm	AAB-338	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	10-12 cm	AAB-339	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	20-22 cm	AAB-340	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	30-32 cm	AAB-341	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	40-42 cm	AAB-342	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	50-52 cm	AAB-343	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	60-62 cm	AAB-344	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	70-72 cm	AAB-345	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	80-82 cm	AAB-346	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 68	90-92 cm	AAB-347	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	0-2 cm	AAB-348	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	10-12 cm	AAB-349	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	20-22 cm	AAB-350	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	30-32 cm	AAB-351	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	40-42 cm	AAB-352	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	50-52 cm	AAB-353	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	60-62 cm	AAB-354	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	70-72 cm	AAB-355	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	80-82 cm	AAB-356	–	–	–	–	–	–	Y	–
Yosemite Creek	YC- 69	90-92 cm	AAB-357	–	–	–	–	–	–	Y	–

(a) Organics include PAHs, PCBs, pesticides, and butyltins.
(b) ^{210}Pb and ^{137}Cs
(c) TCLP = Toxicity Characteristic Leaching Procedure.

Table 3-3. Field-Collected Tissue Sample Summary

Area	Sample Type	Sample ID	PAHs	PCBs	Pesticides	Butyltins	Metals
India Basin							
Area I	bivalve (clam)	AAB-369	Y	Y	Y	Y	Y
Area I	polychaete	AAB-398	Y	Y	Y	Y	Y
Area I	Area I forage fish	AAB-400	Y	Y	Y	Y	Y
Point Avisadero							
Area III	polychaete	AAB-460	Y	Y	Y	Y	Y
Area III	Area III forage fish	AAB-401	Y	Y	Y	Y	Y
Eastern Wetland							
Area VIII	polychaete	AAB-372	Y	Y	Y	Y	Y
Area VIII	bivalve (clam)	AAB-377	Y	Y	Y	Y	Y
Area VIII	Area VIII forage fish	AAB-402	Y	Y	Y	Y	Y
Oil Reclamation							
Area IX	bivalve (clam)	AAB-404	Y	Y	Y	Y	Y
Area IX	polychaete	AAB-456	Y	Y	Y	Y	Y
Area IX	Area IX forage fish	AAB-403	Y	Y	Y	Y	Y
South Basin							
Area X	polychaete	AAB-453	Y	Y	Y	Y	Y
Area X	bivalve (clam)	AAB-399	Y	Y	Y	Y	Y
Area X	Area X forage fish	AAB-465	Y	Y	Y	Y	Y

3.2.3.3 Human Health Evaluation Fish

Fish tissue composites for the human health evaluation were prepared from frozen whole-body fish samples. Two composites each of jacksmelt and surfperch were prepared from each HPS sampling region (north, east, and south) and three San Francisco Bay areas (San Francisco Pier 7, San Mateo Bridge, and Bay Farm). Fish were distributed as evenly as possible between the two composites per area. At some locations, shiner surfperch were not caught in sufficient numbers to provide adequate tissue mass, and several surfperch species (shiner, silver, black, and/or walleye) were combined to obtain sufficient tissue for all analyses.

Procedures for fish tissue sample processing generally followed the protocols developed by Moss Landing Marine Laboratories (2001) for the RMP (SFEI, 1999). Each fish was placed on a Teflon™ sheet and weighed and measured. Each fish then was rinsed with Milli-Q water and scales were removed to the extent possible. The head, fins, and tails were cut off and the guts removed and discarded. All cutting was done with either titanium or ceramic tools. Each fish was rinsed again, and the remaining fish tissue (muscle and skin) was cut into approximately 1-inch cubes. The composite then was prepared by combining approximately equal portions (by weight) from each individual fish. The 1-inch cubes were combined directly into a precleaned glass jar with a Teflon™-lined lid, and homogenized using a titanium probe until the sample was a uniform consistency. Sample aliquots were collected for chemical analysis as shown in Table 3-4. Samples were stored at -20°C until they were shipped or hand-carried to the analytical laboratories. Any 1-inch cubes of fish tissue remaining after the composites were created were wrapped in Teflon™ and frozen.

Table 3-4. Human Health Fish Tissue Sample Summary

Area[a]	Species	Composite	Sample Description	PAHs	PCBs	Pesticides	Butyltins	Metals
Bay Farm	Jacksmelt	1	BF_REF_JACKSMELT_COMP_1	Y	Y	Y	Y	Y
Bay Farm	Jacksmelt	2	BF_REF_JACKSMELT_COMP_2	Y	Y	Y	Y	Y
Bay Farm	Perch spp.	1	BF_REF_PERCH_COMP_1	Y	Y	Y	Y	Y
Bay Farm	Perch spp.	2	BF_REF_PERCH_COMP_2	Y	Y	Y	Y	Y
San Francisco Pier 7	Jacksmelt	1	SFP7_REF_JACKSMELT_COMP_1	Y	Y	Y	Y	Y
San Francisco Pier 7	Jacksmelt	2	SFP7_REF_JACKSMELT_COMP_2	Y	Y	Y	Y	Y
San Francisco Pier 7	Perch spp.	1	SFP7_REF_PERCH_COMP_1	Y	Y	Y	Y	Y
San Francisco Pier 7	Perch spp.	2	SFP7_REF_PERCH_COMP_2	Y	Y	Y	Y	Y
San Mateo Bridge	Jacksmelt	1	SMB_REF_JACKSMELT_COMP_1	Y	Y	Y	Y	Y
San Mateo Bridge	Jacksmelt	2	SMB_REF_JACKSMELT_COMP_2	Y	Y	Y	Y	Y
San Mateo Bridge	Perch spp.	1	SMB_REF_PERCH_COMP_1	Y	Y	Y	Y	Y
San Mateo Bridge	Perch spp.	2	SMB_REF_PERCH_COMP_2	Y	Y	Y	Y	Y
Hunters Point East	Jacksmelt	1	HPSE_JACKSMELT_COMP_1	Y	Y	Y	Y	Y
Hunters Point East	Jacksmelt	2	HPSE_JACKSMELT_COMP_2	Y	Y	Y	Y	Y
Hunters Point East	Perch spp.	1	HPSE_PERCH_COMP_1	Y	Y	Y	Y	Y
Hunters Point East	Perch spp.	2	HPSE_PERCH_COMP_2	Y	Y	Y	Y	Y
Hunters Point North	Jacksmelt	1	HPSN_JACKSMELT_COMP_1	Y	Y	Y	Y	Y
Hunters Point North	Jacksmelt	2	HPSN_JACKSMELT_COMP_2	Y	Y	Y	Y	Y
Hunters Point North	Perch spp.	1	HPSN_PERCH_COMP_1	Y	Y	Y	Y	Y
Hunters Point North	Perch spp.	2	HPSN_PERCH_COMP_2	Y	Y	Y	Y	Y
Hunters Point South	Jacksmelt	1	HPSS_JACKSMELT_COMP_1	Y	Y	Y	Y	Y
Hunters Point South	Jacksmelt	2	HPSS_JACKSMELT_COMP_2	Y	Y	Y	Y	Y
Hunters Point South	Perch spp.	1	HPSS_PERCH_COMP_1	Y	Y	Y	Y	Y
Hunters Point South	Perch spp.	2	HPSS_PERCH_COMP_2	Y	Y	Y	Y	Y

(a) Fish also were collected from Berkeley Pier; however, samples were not analyzed because all species of interest were not collected.

3.3 Sample Analysis

As soon as sample preparation was completed, samples were shipped or hand-carried to the laboratories for chemical analysis. The laboratories that performed each type of analysis were as follows:

- Metals and radioisotopes: BSL, Sequim, WA
- PCBs, pesticides, PAHs, butyltins: BDL, Duxbury, MA
- TPH and TCLP: Severn Trent Laboratories, Los Angeles, CA
- Grain size: Severn Trent Laboratories, Burlington, VT
- TOC and dioxins: Severn Trent Laboratories, Sacramento, CA
- Treatability studies: STS Consultants, Vernon Hills, IL

Results were provided to Battelle in hard copy and electronic format. All data were loaded into a centralized database prior to data validation. The output of the database was audited for completeness, accuracy, and consistency. All sample results and QC data are provided in Appendices B and C.

3.4 Data Validation

All COPEC data were submitted to Laboratory Data Consultants (LDC) (Carlsbad, CA) for independent, third-party data validation. The chemistry data for this study were generated using low-level (i.e., NS&T) analytical methods that are appropriate for the assessment of ecological and human health risk. There are no formal guidelines for the validation of these methods, nor for the toxicological testing methods. Consequently, validation emulated functional guideline criteria, evaluating the data versus the requirements of the Quality Assurance Project Plan (QAPP) (Battelle et al., 2001a) and laboratory SOPs referenced in the QAPP. Total petroleum hydrocarbon-diesel range organics (TPH-DRO) data were generated according to U.S. EPA SW-846 Method 8015B and were validated according to standard Contract Laboratory Program practices.

The data were validated in accordance with SWDIV Environmental Work Instruction #1 (Chemical Data Validation) for a Naval facility that is listed on the National Priorities List (NPL): 20% of the samples received Level IV validation and 80% of the samples received Level-III data validation. Level III data validation assumed that reported data values were correct as reported. Data quality was assessed by verifying that the criteria defined in the QAPP for each compound class were achieved.

Level IV data validation was based on the assessment of raw data packages, which include all data required for a full review and assessment of compound selection, integration, interference assessment, and requantification (e.g., spectra and chromatograms). Level IV data validation included requantification of reported QC and field sample values using the raw data files. In addition, instrument performance, calibration methods, and calibration standards were reviewed to ensure that the detection limits and data values were accurate and appropriate. The results of the validation were presented in formal validation reports. Validation (final) qualifiers were entered by the validators into an electronic data deliverable (EDD). Therefore, all data are reported with both laboratory (pre-validation) and final (post-validation) qualifiers that indicate data fitness for use. Toxicity test data were also validated to ensure compliance with laboratory SOPs, although data qualifiers were not assigned. Data quality and an assessment of the fitness of the data for use in the Validation Study are described in detail in Appendix E.

4.0 SEDIMENT CHEMISTRY

This section presents results of the sediment chemistry line of evidence. Chemistry results for surface and subsurface sediment samples are presented, and the nature and extent of contamination and possible sources are discussed. The WOE evaluation of sediment chemistry data is presented in Section 8.0. Complete sediment chemistry results are provided in Appendix B and information supporting the sediment chemistry data analysis is provided in Appendix F.

After the data validation process was completed and the sediment chemistry data were finalized, results were prepared for data analysis by calculating summed totals for PCBs, low molecular weight PAHs (LPAHs), high molecular weight PAHs (HPAHs), and DDx compounds. ERM-Qs for each sample were also calculated. Data preparation is described in detail in Appendix F, including identification of compounds included in the calculated totals. Sample results were compared with ER-Ms and ambient data for San Francisco Bay to identify areas where chemical concentrations were elevated relative to these benchmarks.

4.1 Surface Sediment

Surface sediments were defined as the upper 5 cm of sediment. Surface sediment samples from 59 HPS sampling stations and five reference sites were analyzed for conventional parameters (grain size and TOC), metals, PCBs, pesticides, PAHs, TPH, and butyltins as shown in Table 3-1. Three additional surface sediment samples from Stations PA-70, PA-71, and PA-72 were collected and analyzed for sediment chemistry only.

4.1.1 Conventional Parameters

Grain size and TOC data for surface sediment samples are presented below.

4.1.1.1 Grain Size

Grain size data are summarized as percent fines (silt plus clay fractions) in Table 4-1; complete results are provided in Table B-1 (Appendix B). Samples with greater than 40% fines were considered fine-grained, and samples with less than 40% fines were considered coarse-grained. Two of the San Francisco Bay reference sites are coarse grained: Red Rock (20.3% fines) and Alcatraz Environs (2.8% fines). The other three reference sites were fine-grained, ranging from 77.1% fines (Alameda Buoy) to 99.7% fines (Bay Farm).

Grain size in the HPS surface sediment samples ranged from 8.6% fines at Station SB-19 (along the shoreline of South Basin) to 99.6% fines at Station SB-03 (near the mouth of Yosemite Creek). Nine of the 59 HPS stations were coarse-grained, four in Area X (South Basin) and five in Area VIII (Eastern Wetland). All five coarse-grained stations in Area VIII were located close to shore.

4.1.1.2 Total Organic Carbon

TOC data are summarized in Table 4-1; complete results are provided in Table B-2 (Appendix B). TOC in reference site samples ranged from 650 mg/kg at Alcatraz Environs to 14,700 mg/kg at Bay Farm. TOC in the HPS surface sediment samples ranged from 2,030 mg/kg in the coarse-grained sample from Station EW-30 to 24,600 mg/kg in the sample from Station OR-29 (the TOC concentrations in both of these samples and several other samples from Areas VIII, IX, and X are estimated due to greater than 5% calcium carbonate in the samples). In general, higher TOC concentrations were associated with finer-grained samples, as expected.

Table 4-1. Conventional Parameters in Surface Sediment Samples

Area	Station ID	Percent Fines	TOC (mg/kg dry wt)
Reference Sites			
Alameda Buoy	AB-67	77.1	8,880
Alcatraz Environs	AL-64	2.8	650
Bay Farm	BF-66	99.7	14,700
Paradise Cove	PC-63	98.3	9,950 J
Red Rocks	RR-65	20.3	3,720
Area I (India Basin)			
Area I	IB-54	98.2	11,600
Area I	IB-55	81.9	12,900
Area I	IB-56	98.2	9,640
Area I	IB-57	99.0	10,500
Area I	IB-58	98.9	10,700
Area I	IB-59 Field duplicate	82.9	14,500 J
Area I	IB-59	85.1	14,100
Area III (Point Avisadero)			
Area III	PA-38	97.0	11,000 J
Area III	PA-39 Field duplicate	98.3	10,300
Area III	PA-39	96.5	8,770
Area III	PA-40	96.4	11,300 J
Area III	PA-41	80.0	11,200 J
Area III	PA-42	70.2	9,430
Area III	PA-43	71.5	9,180
Area III	PA-44	54.3	8,430 J
Area III	PA-45	63.7	7,770
Area III	PA-46	59.0	10,400
Area III	PA-47	62.5	11,100
Area III	PA-48	67.7	9,010
Area III	PA-49	66.8	8,160
Area III	PA-50	78.5	11,900 J
Area III	PA-51	65.1	9,500
Area III	PA-52	69.3	8,810
Area III	PA-53	79.2	11,400 J
Area III	PA-70	98.2	11,100 J
Area III	PA-71	98.9	10,700 J
Area III	PA-72	98.8	12,500 J
Area VIII (Eastern Wetland)			
Area VIII	EW-30	9.9	2,030 J
Area VIII	EW-31	13.0	3,320
Area VIII	EW-32	97.3	12,800
Area VIII	EW-33 Field duplicate	12.0	6,190 J
Area VIII	EW-33	14.4	8,940 J
Area VIII	EW-34	13.5	8,450 J
Area VIII	EW-35	97.7	12,100
Area VIII	EW-36	17.6	6,340 J
Area VIII	EW-37	70.1	10,400

Table 4-1. Conventional Parameters in Surface Sediment Samples (continued)

Area	Station ID	Percent Fines	TOC (mg/kg dry wt)
Area IX (Oil Reclamation)			
Area IX	OR-24	53.9	17,500 J
Area IX	OR-25	98.7	11,900
Area IX	OR-26	91.3	14,300 J
Area IX	OR-27	88.6	13,000 J
Area IX	OR-28	97.8	13,200
Area IX	OR-29 Field duplicate	49.7	13,800 J
Area IX	OR-29	54.6	24,600 J
Area X (South Basin)			
Area X	SB-01	64.3	13,500 J
Area X	SB-02	88.5	15,300 J
Area X	SB-03	99.6	18,700 J
Area X	SB-04	99.6	15,600 J
Area X	SB-05	98.6	15,200
Area X	SB-06	99.4	16,400 J
Area X	SB-07	93.7	13,800 J
Area X	SB-08	98.7	15,900 J
Area X	SB-09	40.7	7,860
Area X	SB-10	68.9	11,100
Area X	SB-11	95.1	17,000
Area X	SB-12 Field duplicate	89.9	15,600
Area X	SB-12	97.2	16,800
Area X	SB-13	97.1	15,800 J
Area X	SB-14	97.4	15,200
Area X	SB-15	98.9	15,700 J
Area X	SB-16	47.4	13,600 J
Area X	SB-17	83.3	12,600
Area X	SB-18	15.8	4,340
Area X	SB-19	8.6	3,260
Area X	SB-20	92.7	16,300 J
Area X	SB-21	28.2	6,890
Area X	SB-22	87.4	17,000 J
Area X	SB-23	19.2	6,960

J = Estimated value.

4.1.2 Metals

Eighteen (18) metals were analyzed in the HPS and reference site samples. Tabulated results are provided in Table B-3 (Appendix B). Statistical summaries of metals concentrations in surface sediment samples are provided in Tables 4-2 through 4-7. Box plots showing the distribution of each metal in the five HPS study areas along with reference site data and San Francisco Bay ambient station data from the RMP and BPTCP are provided in Figures F-1 through F-10 (Appendix F). The numbers of samples in each area that exceeded the ER-M for each metal are summarized in Table 4-8. Mercury, copper, chromium, lead and nickel exceeded their respective ER-Ms in at least one sample.

Table 4-2. Statistical Summary of Surface Sediment Sample Data for Area I (India Basin)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	6	6	11.65	12.83	0	-	-	-	-	-	-
Aroclor-1221	6	6	11.65	12.83	0	-	-	-	-	-	-
Aroclor-1232	6	6	11.65	12.83	0	-	-	-	-	-	-
Aroclor-1242	6	6	11.65	12.83	0	-	-	-	-	-	-
Aroclor-1248	6	6	11.65	12.83	0	-	-	-	-	-	-
Aroclor-1254	6	6	11.65	12.83	0	-	-	-	-	-	-
Aroclor-1260	6	6	11.65	12.83	0	-	-	-	-	-	-
PCB101	6	0	-	-	6	0.42	1.103	0.715	2.75	0.9047	IB-55
PCB105	6	0	-	-	6	0.17	0.3817	0.23	0.79	0.2848	IB-55
PCB110	6	0	-	-	6	0.62	1.467	0.825	3.38	1.142	IB-55
PCB118	6	0	-	-	6	0.4	0.8583	0.58	1.92	0.5885	IB-55
PCB126	6	6	0.15	0.17	0	-	-	-	-	-	-
PCB128	6	4	0.2	0.22	2	0.34	0.455	0.455	0.57	0.1626	IB-55
PCB129	6	6	0.09	0.09	0	-	-	-	-	-	-
PCB138	6	0	-	-	6	0.86	2.595	1.165	6.12	2.413	IB-55
PCB153	6	0	-	-	6	1.08	3.932	1.465	9.81	4.045	IB-55
PCB170	6	0	-	-	6	0.12	1.157	0.385	3.15	1.353	IB-59
PCB18	6	3	0.08	0.09	3	0.08	0.13	0.14	0.17	0.04583	IB-55
PCB180	6	0	-	-	6	0.95	2.728	1.17	6.37	2.583	IB-59
PCB187	6	0	-	-	6	0.47	1.752	0.615	4.17	1.839	IB-59
PCB195	6	0	-	-	6	0.1	0.3183	0.145	0.71	0.2963	IB-59
PCB206	6	1	0.09	0.09	5	0.13	0.474	0.29	0.97	0.3653	IB-59
PCB209	6	1	0.1	0.1	5	0.24	1.192	0.62	3.05	1.192	IB-55
PCB28	6	0	-	-	6	0.12	0.1933	0.19	0.3	0.07118	IB-59
PCB44	6	0	-	-	6	0.1	0.2467	0.165	0.6	0.1897	IB-55
PCB52	6	0	-	-	6	0.24	0.485	0.345	1.08	0.3206	IB-55
PCB66	6	3	0.12	0.14	3	0.17	0.2033	0.19	0.25	0.04163	IB-55
PCB77	6	6	0.17	0.19	0	-	-	-	-	-	-
PCB8	6	6	0.17	0.19	0	-	-	-	-	-	-
2,4'-DDD	6	6	0.11	0.12	0	-	-	-	-	-	-
2,4'-DDE	6	6	0.14	0.15	0	-	-	-	-	-	-
2,4'-DDT	6	6	0.13	0.14	0	-	-	-	-	-	-
4,4'-DDD	6	0	-	-	6	0.66	1.187	1.1	1.92	0.4441	IB-55
4,4'-DDE	6	0	-	-	6	0.89	1.273	1.24	1.84	0.329	IB-59
4,4'-DDT	6	1	0.1	0.1	5	0.28	0.556	0.49	0.83	0.2286	IB-56
Diesel Range Organics	6	0	-	-	6	22	45	44.5	81	21.69	IB-55

Table 4-2. Statistical Summary of Surface Sediment Sample Data for Area I (India Basin) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	6	0	-	-	6	63500	69220	70750	72500	3506	IB-54
Antimony	6	0	-	-	6	0.7	0.909	0.859	1.24	0.2112	IB-59
Arsenic	6	0	-	-	6	9.69	10.5	10.45	11.4	0.5824	IB-59
Barium	6	0	-	-	6	438	469.3	460.5	533	32.79	IB-55
Cadmium	6	0	-	-	6	0.2	0.2252	0.223	0.264	0.02451	IB-55
Chromium	6	0	-	-	6	156	205.8	163	319	70.77	IB-55
Cobalt	6	0	-	-	6	15.3	16.8	15.85	21.4	2.32	IB-59
Copper	6	0	-	-	6	40	58.85	44.5	117	30	IB-59
Iron	6	0	-	-	6	39800	41830	41850	43700	1357	IB-59
Lead	6	0	-	-	6	21.6	41.12	24.25	126	41.65	IB-55
Manganese	6	0	-	-	6	411	428	422.5	450	14.53	IB-59
Mercury	6	0	-	-	6	0.241	0.3115	0.315	0.407	0.061	IB-55
Molybdenum	6	0	-	-	6	0.763	1.028	0.8915	1.63	0.3231	IB-56
Nickel	6	0	-	-	6	83.6	126.4	91.7	232	61.68	IB-59
Selenium	6	0	-	-	6	0.273	0.3368	0.3195	0.43	0.06102	IB-59
Silver	6	0	-	-	6	0.253	0.2793	0.277	0.321	0.02545	IB-59
Vanadium	6	0	-	-	6	121	136.2	139	141	7.679	IB-59
Zinc	6	0	-	-	6	111	122.3	121	136	9.309	IB-59
Benzo(a)anthracene	6	0	-	-	6	97.76	134.3	110.9	236.4	53.4	IB-59
Benzo(a)pyrene	6	0	-	-	6	170.2	203.9	181.1	299.1	49.92	IB-59
Benzo(b)fluoranthene	6	0	-	-	6	114.2	151.5	123.8	264.6	57.71	IB-59
Benzo(g,h,i)perylene	6	0	-	-	6	149.9	169.9	157.2	220.9	27.86	IB-59
Benzo(k)fluoranthene	6	0	-	-	6	104.5	143.9	122.8	255.4	56.8	IB-59
Chrysene	6	0	-	-	6	125.8	186.9	145.5	375.2	96.19	IB-59
Dibenzo(a,h)anthracene	6	0	-	-	6	16.74	24.14	18.71	42.79	10.43	IB-59
Fluoranthene	6	0	-	-	6	217.5	272.2	243.7	418.9	75.67	IB-59
Indeno(1,2,3-cd)pyrene	6	0	-	-	6	136.4	160.3	144.9	223.8	33.44	IB-59
Pyrene	6	0	-	-	6	288.6	331.7	311.3	436.7	55.71	IB-59
2-Methylnaphthalene	6	0	-	-	6	6.17	8.003	6.69	12.98	2.666	IB-59
Acenaphthene	6	0	-	-	6	4.92	7.682	7.08	11.82	2.473	IB-59
Acenaphthylene	6	0	-	-	6	7.36	10.32	9.985	13.18	2.291	IB-59
Anthracene	6	0	-	-	6	34.47	77.88	52.86	228.2	74.06	IB-59
Fluorene	6	0	-	-	6	8.45	14.55	11.97	32.71	9.117	IB-59
Naphthalene	6	0	-	-	6	12.24	14.22	12.86	19.27	2.753	IB-59
Phenanthrene	6	0	-	-	6	78.77	111.1	104.3	167.2	31.85	IB-59

Table 4-2. Statistical Summary of Surface Sediment Sample Data for Area I (India Basin) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	6	0	-	-	6	0.07	0.1817	0.09	0.5	0.1716	IB-55
Dieldrin	6	6	0.1	0.11	0	-	-	-	-	-	-
Endosulfan II	6	6	0.1	0.11	0	-	-	-	-	-	-
Endrin	6	6	0.09	0.1	0	-	-	-	-	-	-
Gamma-chlordane	6	5	0.08	0.09	1	0.14	0.14	0.14	0.14	-	IB-59
Heptachlor	6	6	0.09	0.09	0	-	-	-	-	-	-
Dibutyltin	6	5	2.029	2.227	1	10.86	10.86	10.86	10.86	-	IB-59
Monobutyltin	6	6	1.073	1.178	0	-	-	-	-	-	-
Tetrabutyltin	6	6	2.543	2.791	0	-	-	-	-	-	-
Tributyltin	6	5	1.446	1.587	1	17.73	17.73	17.73	17.73	0	IB-59
Total organic carbon	6	0	-	-	6	9640	11570	11150	14100	1661	IB-59

Table 4-3. Statistical Summary of Surface Sediment Sample Data for Area III (Point Avisadero)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	19	19	9.67	13.2	0	-	-	-	-	-	-
Aroclor-1221	19	19	9.67	13.2	0	-	-	-	-	-	-
Aroclor-1232	19	19	9.67	13.2	0	-	-	-	-	-	-
Aroclor-1242	19	19	9.67	13.2	0	-	-	-	-	-	-
Aroclor-1248	19	19	9.67	13.2	0	-	-	-	-	-	-
Aroclor-1254	19	18	9.67	13.2	1	79.12	79.12	79.12	79.12	0	PA-53
Aroclor-1260	19	11	10.11	13.2	8	47.22	482.2	734.8	2544	816.9	PA-45
PCB101	19	0	-	-	19	0.45	3.38	9.857	70.14	16.68	PA-45
PCB105	19	4	0.08	0.09	15	0.14	0.25	0.5787	2.06	0.6401	PA-53
PCB110	19	0	-	-	19	0.55	1.65	5.083	33.21	7.791	PA-45
PCB118	19	0	-	-	19	0.33	1.15	3.074	17.79	4.273	PA-45
PCB126	19	19	0.12	0.17	0	-	-	-	-	-	-
PCB128	19	8	0.17	0.22	11	0.31	1.54	3.25	15.09	4.417	PA-45
PCB129	19	18	0.07	0.1	1	4.2	4.2	4.2	4.2	0	PA-45
PCB138	19	0	-	-	19	0.35	3.06	27.14	226.6	55.04	PA-45
PCB153	19	0	-	-	19	0.96	6.1	39.85	310.7	77.14	PA-45
PCB170	19	0	-	-	19	0.09	1.39	16.58	133.3	32.62	PA-45
PCB18	19	4	0.07	0.07	15	0.05	0.21	0.3927	1.4	0.4231	PA-39
PCB180	19	1	0.1	0.1	18	0.84	2.675	33.41	257.4	64.34	PA-45
PCB187	19	0	-	-	19	0.44	1.52	15.89	122.5	30.37	PA-45
PCB195	19	3	0.08	0.08	16	0.08	0.57	3.329	22.22	5.824	PA-45
PCB206	19	5	0.08	0.09	14	0.12	0.725	1.896	8.66	2.632	PA-45
PCB209	19	11	0.08	0.11	8	0.15	0.545	0.63	1.44	0.4153	PA-42
PCB28	19	1	0.1	0.1	18	0.11	0.245	0.4694	1.77	0.4419	PA-39
PCB44	19	3	0.09	0.12	16	0.14	0.51	0.7781	2.2	0.6454	PA-53
PCB52	19	2	0.1	0.1	17	0.25	3.47	3.461	10.59	3.317	PA-46
PCB66	19	15	0.1	0.14	4	0.24	0.325	0.535	1.25	0.4788	PA-39
PCB77	19	19	0.14	0.2	0	-	-	-	-	-	-
PCB8	19	11	0.15	0.19	8	0.27	0.625	0.6113	1.07	0.2901	PA-41
2,4'-DDD	19	18	0.09	0.13	1	0.84	0.84	0.84	0.84	0	PA-49
2,4'-DDE	19	19	0.12	0.16	0	-	-	-	-	-	-
2,4'-DDT	19	19	0.11	0.15	0	-	-	-	-	-	-
4,4'-DDD	19	0	-	-	19	0.57	1.11	1.133	1.74	0.3538	PA-41
4,4'-DDE	19	0	-	-	19	0.48	1.11	1.065	1.54	0.3374	PA-50
4,4'-DDT	19	8	0.08	0.11	11	0.14	0.32	0.3927	0.84	0.2261	PA-44
Diesel Range Organics	19	1	13	13	18	28	47	54.11	130	25.2	PA-47

Table 4-3. Statistical Summary of Surface Sediment Sample Data for Area III (Point Avisadero) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	19	0	-	-	19	59100	66500	66910	72000	3887	PA-40
Antimony	19	0	-	-	19	0.554	0.779	1.775	16.8	3.662	PA-44
Arsenic	19	0	-	-	19	8.74	11.3	11.71	18.2	1.893	PA-47
Barium	19	0	-	-	19	404	469	463	568	36.93	PA-41
Cadmium	19	0	-	-	19	0.185	0.238	0.2756	0.76	0.1262	PA-47
Chromium	19	0	-	-	19	162	189	226.4	391	73.98	PA-46
Cobalt	19	0	-	-	19	14	17.1	17.4	21.6	1.646	PA-45
Copper	19	0	-	-	19	32.7	57.7	171.6	1050	252.9	PA-47
Iron	19	0	-	-	19	38700	40700	41170	46500	1858	PA-46
Lead	19	0	-	-	19	18.1	25.9	43.83	275	59.66	PA-47
Manganese	19	0	-	-	19	423	501	498.7	615	46.08	PA-48
Mercury	19	0	-	-	19	0.145	0.425	0.9037	7.47	1.628	PA-47
Molybdenum	19	0	-	-	19	0.611	0.897	0.95	1.47	0.1986	PA-42
Nickel	19	0	-	-	19	84	89.6	109.1	250	49.21	PA-46
Selenium	19	0	-	-	19	0.222	0.337	0.3703	0.855	0.1388	PA-70
Silver	19	0	-	-	19	0.177	0.274	0.2742	0.434	0.05359	PA-47
Vanadium	19	0	-	-	19	108	130	133.2	157	11.54	PA-50
Zinc	19	0	-	-	19	90.8	109	125.3	322	54.46	PA-47
Benzo(a)anthracene	19	0	-	-	19	81.25	253.3	300.1	600.9	159.6	PA-41
Benzo(a)pyrene	19	0	-	-	19	124.4	370.1	402.8	754.2	200.3	PA-53
Benzo(b)fluoranthene	19	0	-	-	19	85.76	225.6	273	549.9	134.4	PA-41
Benzo(g,h,i)perylene	19	0	-	-	19	107.3	280.6	301.2	551.6	141.8	PA-53
Benzo(k)fluoranthene	19	0	-	-	19	83.35	231.4	274.6	546.2	134.7	PA-41
Chrysene	19	0	-	-	19	103.8	286.7	350.9	715.3	182.6	PA-41
Dibenzo(a,h)anthracene	19	0	-	-	19	12.24	41.4	47.06	94.77	25.42	PA-41
Fluoranthene	19	0	-	-	19	186.2	617	627	1214	310.3	PA-41
Indeno(1,2,3-cd)pyrene	19	0	-	-	19	99.82	268.2	295.6	536.3	141.5	PA-53
Pyrene	19	0	-	-	19	224.8	734.4	739.4	1468	379.3	PA-53
2-Methylnaphthalene	19	0	-	-	19	4.13	8.21	10.16	20.36	4.833	PA-41
Acenaphthene	19	0	-	-	19	4.44	21.18	29.5	181.8	39.03	PA-41
Acenaphthylene	19	0	-	-	19	6.98	14.05	22.28	58.06	15.33	PA-53
Anthracene	19	0	-	-	19	36.25	100.6	132.4	489.3	105.4	PA-42
Fluorene	19	0	-	-	19	8.2	22.38	30.89	92.42	22.35	PA-41
Naphthalene	19	0	-	-	19	7.72	18.54	21.06	45.73	10.09	PA-52
Phenanthrene	19	0	-	-	19	72.75	305.3	325.2	763.1	215.2	PA-52

Table 4-3. Statistical Summary of Surface Sediment Sample Data for Area III (Point Avisadero) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	19	6	0.06	0.07	13	0.03	0.12	0.1492	0.37	0.08665	PA-44
Dieldrin	19	19	0.08	0.11	0	-	-	-	-	-	-
Endosulfan II	19	19	0.09	0.12	0	-	-	-	-	-	-
Endrin	19	19	0.08	0.1	0	-	-	-	-	-	-
Gamma-chlordane	19	19	0.07	0.09	0	-	-	-	-	-	-
Heptachlor	19	19	0.07	0.1	0	-	-	-	-	-	-
Dibutyltin	19	8	1.772	2.217	11	12.98	29.89	28.63	57.38	12.14	PA-41
Monobutyltin	19	19	0.8598	1.173	0	-	-	-	-	-	-
Tetrabutyltin	19	19	2.037	2.779	0	-	-	-	-	-	-
Tributyltin	19	7	1.262	1.58	12	14.7	95.21	91.06	207.6	52.3	PA-41
Total organic carbon	19	0	-	-	19	7770	10400	10090	12500	1392	PA-72

Table 4-4. Statistical Summary of Surface Sediment Sample Data for Area VIII (Eastern Wetland)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	8	8	7.07	13.82	0	-	-	-	-	-	-
Aroclor-1221	8	8	7.07	13.82	0	-	-	-	-	-	-
Aroclor-1232	8	8	7.07	13.82	0	-	-	-	-	-	-
Aroclor-1242	8	8	7.07	13.82	0	-	-	-	-	-	-
Aroclor-1248	8	8	7.07	13.82	0	-	-	-	-	-	-
Aroclor-1254	8	8	7.07	13.82	0	-	-	-	-	-	-
Aroclor-1260	8	8	7.07	13.82	0	-	-	-	-	-	-
PCB101	8	0	-	-	8	0.31	0.665	0.7238	1.2	0.3119	EW-32
PCB105	8	0	-	-	8	0.08	0.14	0.1662	0.29	0.08158	EW-32
PCB110	8	0	-	-	8	0.25	0.65	0.6375	0.95	0.2626	EW-32
PCB118	8	0	-	-	8	0.14	0.46	0.4562	0.78	0.2179	EW-32
PCB126	8	8	0.09	0.18	0	-	-	-	-	-	-
PCB128	8	5	0.12	0.23	3	0.13	0.16	0.17	0.22	0.04583	EW-33
PCB129	8	8	0.05	0.1	0	-	-	-	-	-	-
PCB138	8	0	-	-	8	0.97	1.78	1.741	2.69	0.561	EW-36
PCB153	8	0	-	-	8	1.36	2.505	2.458	3.6	0.7051	EW-36
PCB170	8	0	-	-	8	0.56	0.985	0.9675	1.46	0.3372	EW-35
PCB18	8	5	0.05	0.05	3	0.05	0.06	0.05667	0.06	0.005774	EW-35
PCB180	8	0	-	-	8	0.92	1.81	1.801	2.57	0.5804	EW-36
PCB187	8	0	-	-	8	0.62	1.08	1.112	1.64	0.3094	EW-36
PCB195	8	0	-	-	8	0.13	0.195	0.205	0.32	0.06211	EW-36
PCB206	8	0	-	-	8	0.13	0.18	0.2088	0.49	0.1168	EW-36
PCB209	8	0	-	-	8	0.07	0.15	0.2762	1.31	0.4196	EW-36
PCB28	8	5	0.07	0.08	3	0.14	0.15	0.15	0.16	0.01	EW-32
PCB44	8	5	0.06	0.07	3	0.21	0.26	0.2533	0.29	0.04041	EW-32
PCB52	8	1	0.07	0.07	7	0.08	0.13	0.2214	0.43	0.1437	EW-32
PCB66	8	8	0.08	0.15	0	-	-	-	-	-	-
PCB77	8	8	0.11	0.21	0	-	-	-	-	-	-
PCB8	8	6	0.1	0.2	2	0.16	0.165	0.165	0.17	0.007071	EW-35
2,4'-DDD	8	8	0.07	0.13	0	-	-	-	-	-	-
2,4'-DDE	8	8	0.08	0.16	0	-	-	-	-	-	-
2,4'-DDT	8	8	0.08	0.15	0	-	-	-	-	-	-
4,4'-DDD	8	2	0.06	0.07	6	0.21	0.58	0.6033	1.03	0.37	EW-32
4,4'-DDE	8	0	-	-	8	0.2	0.41	0.5887	1.19	0.4236	EW-32
4,4'-DDT	8	5	0.06	0.06	3	0.12	0.32	0.3233	0.53	0.205	EW-37
Diesel Range Organics	8	6	8.6	17	2	11	13.5	13.5	16	3.536	EW-31

Table 4-4. Statistical Summary of Surface Sediment Sample Data for Area VIII (Eastern Wetland) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	8	0	-	-	8	42000	48900	55050	74900	13430	EW-32
Antimony	8	0	-	-	8	0.642	0.844	1.214	3.64	1.01	EW-33
Arsenic	8	0	-	-	8	5.18	7.655	8.12	11.1	2.342	EW-32
Barium	8	0	-	-	8	332	378	391.5	458	49.08	EW-32
Cadmium	8	0	-	-	8	0.184	0.252	0.2338	0.271	0.03752	EW-32
Chromium	8	0	-	-	8	158	221	235.6	400	81.51	EW-30
Cobalt	8	0	-	-	8	12.7	14.95	15.51	18.8	2.811	EW-31
Copper	8	0	-	-	8	12	27.2	31.06	52.8	14.96	EW-32
Iron	8	0	-	-	8	22100	29850	33350	46500	8964	EW-32
Lead	8	0	-	-	8	15.7	20.05	21.36	29.8	4.962	EW-32
Manganese	8	0	-	-	8	428	478.5	494.6	579	59.47	EW-33
Mercury	8	0	-	-	8	0.0808	0.1204	0.1605	0.286	0.08619	EW-32
Molybdenum	8	0	-	-	8	0.381	0.667	0.7381	1.17	0.3118	EW-32
Nickel	8	0	-	-	8	59.6	64.15	74.06	97.5	16.31	EW-32
Selenium	8	5	0.126	0.126	3	0.305	0.407	0.3943	0.471	0.08372	EW-35
Silver	8	1	0.066	0.066	7	0.0732	0.235	0.2086	0.397	0.1342	EW-32
Vanadium	8	0	-	-	8	81.4	107.6	114.7	162	35.3	EW-32
Zinc	8	0	-	-	8	47	87.25	90.54	127	26.91	EW-32
Benzo(a)anthracene	8	0	-	-	8	10.89	57.47	61.18	127.5	47.87	EW-37
Benzo(a)pyrene	8	0	-	-	8	21.6	86.21	96.41	197.4	69.86	EW-37
Benzo(b)fluoranthene	8	0	-	-	8	13.63	48.52	59.01	117.7	43.84	EW-37
Benzo(g,h,i)perylene	8	0	-	-	8	21.05	59.64	83.55	165.6	60.92	EW-37
Benzo(k)fluoranthene	8	0	-	-	8	15.62	56.38	63.04	129	44.89	EW-37
Chrysene	8	0	-	-	8	16.39	70.94	74.71	156	56.87	EW-37
Dibenzo(a,h)anthracene	8	0	-	-	8	1.486	7.82	8.094	15.58	6.082	EW-37
Fluoranthene	8	0	-	-	8	37.09	132.4	135.4	276.4	94.37	EW-37
Indeno(1,2,3-cd)pyrene	8	0	-	-	8	17.23	55.64	74.5	149.9	55.9	EW-37
Pyrene	8	0	-	-	8	46.44	178	178.6	359.3	124.6	EW-37
2-Methylnaphthalene	8	0	-	-	8	1.591	3.304	3.591	6.39	1.942	EW-32
Acenaphthene	8	0	-	-	8	0.68	1.388	2.769	6.24	2.411	EW-32
Acenaphthylene	8	0	-	-	8	1.092	4.015	4.565	8.54	2.996	EW-30
Anthracene	8	0	-	-	8	2.91	15.18	20.47	43.16	17.03	EW-37
Fluorene	8	0	-	-	8	1.289	3.945	4.324	8.61	3.035	EW-32
Naphthalene	8	2	3.512	4.103	6	4.63	11.24	10.1	15.95	4.569	EW-34
Phenanthrene	8	0	-	-	8	11.84	48.03	57.67	132.9	46.12	EW-30

Table 4-4. Statistical Summary of Surface Sediment Sample Data for Area VIII (Eastern Wetland) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	8	5	0.05	0.05	3	0.11	0.15	0.1367	0.15	0.02309	EW-35
Dieldrin	8	8	0.06	0.12	0	-	-	-	-	-	-
Endosulfan II	8	8	0.06	0.12	0	-	-	-	-	-	-
Endrin	8	8	0.06	0.11	0	-	-	-	-	-	-
Gamma-chlordane	8	7	0.05	0.1	1	0.02	0.02	0.02	0.02	0	EW-31
Heptachlor	8	8	0.05	0.1	0	-	-	-	-	-	-
Dibutyltin	8	5	1.2	1.31	3	3.801	4.818	4.659	5.359	0.7911	EW-35
Monobutyltin	8	8	0.6346	1.294	0	-	-	-	-	-	-
Tetrabutyltin	8	8	1.503	3.065	0	-	-	-	-	-	-
Tributyltin	8	5	0.8546	0.9332	3	4.519	6.271	5.869	6.816	1.2	EW-32
Total organic carbon	8	0	-	-	8	2030	8695	8048	12800	3909	EW-32

Table 4-5. Statistical Summary of Surface Sediment Sample Data for Area IX (Oil Reclamation)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	6	6	9.06	13.14	0	-	-	-	-	-	-
Aroclor-1221	6	6	9.06	13.14	0	-	-	-	-	-	-
Aroclor-1232	6	6	9.06	13.14	0	-	-	-	-	-	-
Aroclor-1242	6	6	9.06	13.14	0	-	-	-	-	-	-
Aroclor-1248	6	6	9.06	13.14	0	-	-	-	-	-	-
Aroclor-1254	6	6	9.06	13.14	0	-	-	-	-	-	-
Aroclor-1260	6	0	-	-	6	82.08	211.4	195	402.8	129.8	OR-24
PCB101	6	0	-	-	6	3.03	6.615	5.55	12.93	3.993	OR-24
PCB105	6	0	-	-	6	0.52	0.8467	0.87	1.11	0.2678	OR-26
PCB110	6	0	-	-	6	2.05	4.108	3.845	6.75	1.989	OR-24
PCB118	6	0	-	-	6	1.63	3.213	3.125	4.78	1.438	OR-26
PCB126	6	6	0.12	0.17	0	-	-	-	-	-	-
PCB128	6	0	-	-	6	0.64	1.46	1.36	2.61	0.8494	OR-24
PCB129	6	6	0.07	0.1	0	-	-	-	-	-	-
PCB138	6	0	-	-	6	6.95	18.68	17.2	34.87	11.46	OR-24
PCB153	6	0	-	-	6	9.84	30.3	28.35	59.15	19.93	OR-24
PCB170	6	0	-	-	6	4.27	9.868	9.555	17.55	5.486	OR-24
PCB18	6	1	0.09	0.09	5	0.08	0.106	0.09	0.16	0.03209	OR-27
PCB180	6	0	-	-	6	7.48	20.98	19.59	42.6	13.81	OR-24
PCB187	6	0	-	-	6	4.14	11.87	11.14	23.1	7.53	OR-24
PCB195	6	0	-	-	6	0.78	1.657	1.695	2.7	0.8169	OR-24
PCB206	6	0	-	-	6	0.4	0.825	0.86	1.12	0.2641	OR-26
PCB209	6	0	-	-	6	0.18	0.3867	0.41	0.57	0.1425	OR-27
PCB28	6	0	-	-	6	0.11	0.2283	0.245	0.29	0.06463	OR-24
PCB44	6	0	-	-	6	0.3	0.5717	0.565	0.88	0.2579	OR-27
PCB52	6	0	-	-	6	0.7	1.218	1.09	1.97	0.5481	OR-24
PCB66	6	6	0.1	0.14	0	-	-	-	-	-	-
PCB77	6	6	0.13	0.2	0	-	-	-	-	-	-
PCB8	6	5	0.13	0.19	1	0.21	0.21	0.21	0.21	0	OR-28
2,4'-DDD	6	6	0.09	0.12	0	-	-	-	-	-	-
2,4'-DDE	6	6	0.11	0.16	0	-	-	-	-	-	-
2,4'-DDT	6	6	0.1	0.15	0	-	-	-	-	-	-
4,4'-DDD	6	0	-	-	6	0.91	1.885	1.76	3.08	0.9426	OR-24
4,4'-DDE	6	0	-	-	6	0.33	0.9817	1.045	1.5	0.3999	OR-26
4,4'-DDT	6	1	0.11	0.11	5	0.12	0.462	0.57	0.78	0.2993	OR-24
Diesel Range Organics	6	4	12	15	2	36	42.5	42.5	49	9.192	OR-25

Table 4-5. Statistical Summary of Surface Sediment Sample Data for Area IX (Oil Reclamation) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	6	0	-	-	6	52000	64820	67350	73000	8397	OR-25
Antimony	6	0	-	-	6	0.587	2.016	2.3	3.17	0.9059	OR-27
Arsenic	6	0	-	-	6	8.9	11.32	11.05	13.6	1.653	OR-26
Barium	6	0	-	-	6	293	392.3	388.5	458	59.86	OR-28
Cadmium	6	0	-	-	6	0.223	0.3338	0.35	0.399	0.06494	OR-26
Chromium	6	0	-	-	6	167	320	334	464	132.7	OR-27
Cobalt	6	0	-	-	6	17.5	19.33	18.9	22.6	1.8	OR-25
Copper	6	0	-	-	6	55.1	69.4	61.15	97.5	18.14	OR-24
Iron	6	0	-	-	6	41200	44920	44900	48700	2885	OR-26
Lead	6	0	-	-	6	11.9	40.53	43.45	60.1	16.96	OR-24
Manganese	6	0	-	-	6	386	494.5	495	624	92.66	OR-24
Mercury	6	0	-	-	6	0.303	0.4318	0.4155	0.602	0.1049	OR-26
Molybdenum	6	0	-	-	6	0.83	1.35	1.4	1.71	0.3426	OR-27
Nickel	6	0	-	-	6	94.9	115.3	108	160	24.15	OR-24
Selenium	6	0	-	-	6	0.233	0.3207	0.3445	0.406	0.06945	OR-28
Silver	6	0	-	-	6	0.12	0.3253	0.3765	0.435	0.1246	OR-28
Vanadium	6	0	-	-	6	134	151.7	151.5	171	14.05	OR-25
Zinc	6	0	-	-	6	114	142.5	139	179	23.75	OR-24
Benzo(a)anthracene	6	0	-	-	6	51.3	90.98	87.76	151.5	35.53	OR-24
Benzo(a)pyrene	6	0	-	-	6	109.2	157.6	157.6	203.6	46.27	OR-25
Benzo(b)fluoranthene	6	0	-	-	6	68.26	106.5	105.3	149.3	33.33	OR-24
Benzo(g,h,i)perylene	6	0	-	-	6	113.1	149.8	145.8	193.2	37.33	OR-25
Benzo(k)fluoranthene	6	0	-	-	6	72.97	112.3	107.7	169.1	34.55	OR-24
Chrysene	6	0	-	-	6	70.65	139.1	127.3	262	67.4	OR-24
Dibenzo(a,h)anthracene	6	0	-	-	6	8.82	16.13	15.36	24.81	5.948	OR-24
Fluoranthene	6	0	-	-	6	132	188.6	176.9	291.2	61.42	OR-24
Indeno(1,2,3-cd)pyrene	6	0	-	-	6	89.9	130.3	122.8	181	40.38	OR-25
Pyrene	6	0	-	-	6	170.6	240.6	234.8	328	71.14	OR-24
2-Methylnaphthalene	6	0	-	-	6	5.23	7.323	7.245	9.85	1.616	OR-24
Acenaphthene	6	0	-	-	6	2.13	4.058	3.515	7.62	2.07	OR-24
Acenaphthylene	6	0	-	-	6	4.71	7.278	6.595	10.17	2.176	OR-24
Anthracene	6	0	-	-	6	11.38	28.14	25.92	60.85	17.28	OR-24
Fluorene	6	0	-	-	6	3.27	6.653	6.745	11.34	2.768	OR-24
Naphthalene	6	0	-	-	6	10.37	13.35	14.11	15.85	2.276	OR-25
Phenanthrene	6	0	-	-	6	40.37	75.4	69.14	135.2	33.05	OR-24

Table 4-5. Statistical Summary of Surface Sediment Sample Data for Area IX (Oil Reclamation) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	6	0	-	-	6	0.14	0.27	0.265	0.41	0.1114	OR-24
Dieldrin	6	5	0.08	0.11	1	0.44	0.44	0.44	0.44	0	OR-24
Endosulfan II	6	6	0.08	0.12	0	-	-	-	-	-	-
Endrin	6	6	0.07	0.1	0	-	-	-	-	-	-
Gamma-chlordane	6	1	0.09	0.09	5	0.08	0.27	0.34	0.42	0.1673	OR-27
Heptachlor	6	6	0.07	0.1	0	-	-	-	-	-	-
Dibutyltin	6	0	-	-	6	2.686	10.32	8.112	20.75	6.987	OR-24
Monobutyltin	6	5	0.8002	1.262	1	2.688	2.688	2.688	2.688	0	OR-24
Tetrabutyltin	6	6	1.895	2.99	0	-	-	-	-	-	-
Tributyltin	6	0	-	-	6	3.298	21.55	12.13	65.91	23.3	OR-24
Total organic carbon	6	0	-	-	6	11900	15750	13750	24600	4741	OR-29

Table 4-6. Statistical Summary of Surface Sediment Sample Data for Area X (South Basin)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	22	22	7.12	152.8	0	-	-	-	-	-	-
Aroclor-1221	22	22	7.12	152.8	0	-	-	-	-	-	-
Aroclor-1232	22	22	7.12	152.8	0	-	-	-	-	-	-
Aroclor-1242	22	22	7.12	152.8	0	-	-	-	-	-	-
Aroclor-1248	22	22	7.12	152.8	0	-	-	-	-	-	-
Aroclor-1254	22	22	7.12	152.8	0	-	-	-	-	-	-
Aroclor-1260	23	0	-	-	23	102.2	1101	541	5394	1349	SB-21
PCB101	23	0	-	-	23	3.83	33.6	24.16	124.9	28.49	SB-21
PCB105	23	2	0.06	1.2	21	0.9	4.452	4.07	14.12	2.898	SB-21
PCB110	23	0	-	-	23	2.98	21.93	16.98	65.87	14.6	SB-21
PCB118	23	0	-	-	23	2.72	16.15	13.68	33.85	8.418	SB-21
PCB126	22	22	0.09	2	0	-	-	-	-	-	-
PCB128	23	0	-	-	23	1.03	7.986	5.96	28.65	6.661	SB-21
PCB129	22	21	0.05	0.1	1	4.17	4.17	4.17	4.17	0	SB-23
PCB138	23	0	-	-	23	9.46	96.89	59.34	441.8	105.6	SB-21
PCB153	23	0	-	-	23	13.17	143.8	78.98	637.9	161.3	SB-21
PCB170	23	0	-	-	23	5	55.23	27.65	291.6	70.91	SB-21
PCB18	23	1	0.1	0.1	22	0.09	0.3482	0.32	0.96	0.1886	SB-02
PCB180	23	0	-	-	23	8.91	110.1	51.21	569.3	140.5	SB-21
PCB187	23	0	-	-	23	5.11	60.57	29.09	288	75.04	SB-21
PCB195	23	0	-	-	23	0.85	10.86	4.11	59.62	15.03	SB-21
PCB206	23	0	-	-	23	0.47	5.237	1.91	23.42	6.653	SB-23
PCB209	23	0	-	-	23	0.17	1.598	0.73	7.01	1.667	SB-10
PCB28	23	1	0.14	0.14	22	0.15	0.7736	0.735	1.74	0.402	SB-02
PCB44	23	0	-	-	23	0.47	2.574	1.88	8.3	1.902	SB-02
PCB52	23	0	-	-	23	0.93	5.206	5.11	11.21	2.642	SB-02
PCB66	23	11	0.08	1.6	12	1.04	2.038	1.91	3.35	0.7487	SB-11
PCB77	22	22	0.11	2.2	0	-	-	-	-	-	-
PCB8	23	3	0.12	0.21	20	0.12	0.6075	0.545	1.29	0.3204	SB-01
2,4'-DDD	22	22	0.07	1.4	0	-	-	-	-	-	-
2,4'-DDE	22	22	0.08	1.8	0	-	-	-	-	-	-
2,4'-DDT	22	22	0.08	1.8	0	-	-	-	-	-	-
4,4'-DDD	23	0	-	-	23	0.97	8.161	4.19	43.61	10.95	SB-21
4,4'-DDE	22	1	1.2	1.2	21	1.06	6.1	5.25	18.4	4.104	SB-02
4,4'-DDT	23	3	0.06	0.07	20	0.26	1.132	0.915	3.6	0.842	SB-21
Diesel Range Organics	23	8	14	18	15	17	59.93	49	150	36.99	SB-21

Table 4-6. Statistical Summary of Surface Sediment Sample Data for Area X (South Basin) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	23	0	-	-	23	39100	64430	69600	74100	10430	SB-08
Antimony	23	0	-	-	23	0.485	3.164	2.2	10.6	2.516	SB-16
Arsenic	23	0	-	-	23	5.86	10.69	11.3	14.3	1.964	SB-10
Barium	23	0	-	-	23	400	512	472	893	120.2	SB-19
Cadmium	23	0	-	-	23	0.219	0.4546	0.413	0.845	0.169	SB-01
Chromium	23	0	-	-	23	167	228	207	451	63.55	SB-16
Cobalt	23	0	-	-	23	10.5	16.93	17.6	21.9	2.973	SB-21
Copper	23	0	-	-	23	66.1	121.4	89.1	319	73.92	SB-21
Iron	23	0	-	-	23	15700	40150	43600	47800	8956	SB-15
Lead	23	0	-	-	23	11	85.21	86.3	142	35.6	SB-22
Manganese	23	0	-	-	23	271	431.6	439	580	60.82	SB-16
Mercury	23	0	-	-	23	0.232	0.7069	0.617	1.47	0.3201	SB-21
Molybdenum	23	0	-	-	23	0.704	1.136	1.12	1.83	0.2558	SB-09
Nickel	23	0	-	-	23	72.5	113.3	107	199	28.65	SB-16
Selenium	23	1	0.126	0.126	22	0.151	0.334	0.3515	0.457	0.0873	SB-20
Silver	23	0	-	-	23	0.139	0.4829	0.521	0.709	0.1578	SB-11
Vanadium	23	0	-	-	23	50.9	132.1	141	172	28.11	SB-21
Zinc	23	0	-	-	23	164	202.3	195	297	30.26	SB-21
Benzo(a)anthracene	23	0	-	-	23	25.84	180.8	132.4	628.9	132.9	SB-21
Benzo(a)pyrene	23	0	-	-	23	53.23	269	244.2	631.9	124.8	SB-21
Benzo(b)fluoranthene	23	0	-	-	23	34.72	200.7	174	484.5	99.53	SB-21
Benzo(g,h,i)perylene	23	0	-	-	23	55.35	239.2	240.6	384.4	82.64	SB-21
Benzo(k)fluoranthene	23	0	-	-	23	40.84	206.9	182.8	499.6	103.8	SB-21
Chrysene	23	0	-	-	23	39.44	245	189.9	743.9	166.1	SB-21
Dibenzo(a,h)anthracene	23	0	-	-	23	4.03	36.16	29.93	104.2	22.06	SB-21
Fluoranthene	23	0	-	-	23	59.71	325	294.2	952.6	191.9	SB-21
Indeno(1,2,3-cd)pyrene	23	0	-	-	23	43.92	217.1	208.4	412.8	84.34	SB-21
Pyrene	23	0	-	-	23	79.82	389.7	365.9	1065	205.2	SB-21
2-Methylnaphthalene	23	0	-	-	23	3.7	18.15	16.32	49.04	9.28	SB-02
Acenaphthene	23	0	-	-	23	1.08	7.586	6.893	21.31	4.218	SB-21
Acenaphthylene	23	0	-	-	23	2.26	11.9	10.65	43.71	8.798	SB-23
Anthracene	23	0	-	-	23	6.99	51.75	34.8	234.3	54.26	SB-21
Fluorene	23	0	-	-	23	2.02	14.69	10.07	81.46	17.13	SB-21
Naphthalene	23	1	7.7	7.7	22	8.27	30.66	27.24	58.7	12.96	SB-10
Phenanthrene	23	0	-	-	23	22.01	149.5	103.8	668	141.8	SB-21

Table 4-6. Statistical Summary of Surface Sediment Sample Data for Area X (South Basin) (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	23	0	-	-	23	0.2	1.433	0.94	5.47	1.452	SB-14
Dieldrin	22	7	0.07	1.4	15	0.75	2.467	1.7	10.41	2.443	SB-02
Endosulfan II	22	22	0.06	1.4	0	-	-	-	-	-	-
Endrin	22	22	0.06	1.2	0	-	-	-	-	-	-
Gamma-chlordane	23	0	-	-	23	0.17	2.266	1.25	10.53	2.524	SB-02
Heptachlor	22	21	0.05	1.2	1	2.13	2.13	2.13	2.13	0	SB-14
Dibutyltin	23	0	-	-	23	2.724	16.33	13.63	51.17	11.35	SB-23
Monobutyltin	22	19	0.653	1.305	3	1.172	2.184	2.083	3.295	1.065	SB-19
Tetrabutyltin	23	23	1.547	3.09	0	-	-	-	-	-	-
Tributyltin	23	0	-	-	23	3.081	23.84	16.07	129.3	27.13	SB-23
Total organic carbon	23	0	-	-	23	3260	13250	15200	18700	4371	SB-03

Table 4-7. Statistical Summary of Surface Sediment Sample Data for Reference Sites

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	5	5	6.96	14.42	0	-	-	-	-	-	-
Aroclor-1221	5	5	6.96	14.42	0	-	-	-	-	-	-
Aroclor-1232	5	5	6.96	14.42	0	-	-	-	-	-	-
Aroclor-1242	5	5	6.96	14.42	0	-	-	-	-	-	-
Aroclor-1248	5	5	6.96	14.42	0	-	-	-	-	-	-
Aroclor-1254	5	5	6.96	14.42	0	-	-	-	-	-	-
Aroclor-1260	5	5	6.96	14.42	0	-	-	-	-	-	-
PCB101	5	1	0.06	0.06	4	0.16	0.63	0.345	1.67	0.7002	AB-67
PCB105	5	2	0.06	0.06	3	0.11	0.2233	0.15	0.41	0.1629	AB-67
PCB110	5	1	0.07	0.07	4	0.13	0.745	0.55	1.75	0.7175	AB-67
PCB118	5	1	0.07	0.07	4	0.08	0.5775	0.44	1.35	0.5496	AB-67
PCB126	5	5	0.09	0.19	0	-	-	-	-	-	-
PCB128	5	5	0.12	0.24	0	-	-	-	-	-	-
PCB129	5	5	0.05	0.11	0	-	-	-	-	-	-
PCB138	5	1	0.06	0.06	4	0.21	1.302	0.865	3.27	1.37	AB-67
PCB153	5	1	0.09	0.09	4	0.25	1.498	0.84	4.06	1.743	AB-67
PCB170	5	2	0.06	0.07	3	0.14	0.5067	0.22	1.16	0.5672	AB-67
PCB18	5	4	0.05	0.1	1	0.21	0.21	0.21	0.21	0	AB-67
PCB180	5	2	0.06	0.07	3	0.42	1.423	1.54	2.31	0.9504	AB-67
PCB187	5	2	0.06	0.07	3	0.17	0.6967	0.38	1.54	0.7379	AB-67
PCB195	5	4	0.06	0.11	1	0.23	0.23	0.23	0.23	0	AB-67
PCB206	5	4	0.05	0.11	1	0.84	0.84	0.84	0.84	0	AB-67
PCB209	5	4	0.06	0.12	1	0.81	0.81	0.81	0.81	0	AB-67
PCB28	5	3	0.07	0.12	2	0.2	0.305	0.305	0.41	0.1485	AB-67
PCB44	5	3	0.06	0.11	2	0.15	0.29	0.29	0.43	0.198	AB-67
PCB52	5	2	0.07	0.11	3	0.19	0.36	0.25	0.64	0.2443	AB-67
PCB66	5	4	0.07	0.15	1	0.14	0.14	0.14	0.14	0	AB-67
PCB77	5	5	0.1	0.21	0	-	-	-	-	-	-
PCB8	5	5	0.1	0.21	0	-	-	-	-	-	-
2,4'-DDD	5	5	0.07	0.14	0	-	-	-	-	-	-
2,4'-DDE	5	5	0.08	0.17	0	-	-	-	-	-	-
2,4'-DDT	5	5	0.08	0.16	0	-	-	-	-	-	-
4,4'-DDD	5	1	0.06	0.06	4	0.41	1.505	1.25	3.11	1.182	PC-63
4,4'-DDE	5	1	0.06	0.06	4	0.31	0.6825	0.745	0.93	0.2647	AB-67
4,4'-DDT	5	4	0.06	0.12	1	1.65	1.65	1.65	1.65	-	PC-63
Diesel Range Organics	5	3	8.5	15	2	32	41.5	41.5	51	13.44	BF-66

Table 4-7. Statistical Summary of Surface Sediment Sample Data for Reference Sites (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	5	0	-	-	5	44300	64340	69700	75900	12710	BF-66
Antimony	5	0	-	-	5	0.361	0.663	0.773	0.929	0.2649	AB-67
Arsenic	5	0	-	-	5	6.69	10.15	10.8	12.1	2.137	BF-66
Barium	5	0	-	-	5	405	444.6	428	501	40.43	AL-64
Cadmium	5	0	-	-	5	0.156	0.3632	0.192	0.841	0.292	AL-64
Chromium	5	0	-	-	5	103	154	161	176	29.19	AB-67
Cobalt	5	0	-	-	5	10.3	17.26	17.8	22.6	4.431	RR-65
Copper	5	0	-	-	5	16.5	33.28	40.1	47.9	14.39	BF-66
Iron	5	0	-	-	5	20600	38860	41200	49500	10800	BF-66
Lead	5	0	-	-	5	12.3	21.46	21.6	29.7	7.465	AB-67
Manganese	5	0	-	-	5	390	520.6	554	634	99.35	RR-65
Mercury	5	0	-	-	5	0.0252	0.2146	0.289	0.384	0.1568	AB-67
Molybdenum	5	0	-	-	5	0.293	0.6416	0.782	0.851	0.2499	AB-67
Nickel	5	0	-	-	5	39.8	78.36	85.8	101	23.06	BF-66
Selenium	5	1	0.126	0.126	4	0.124	0.3315	0.352	0.498	0.1621	BF-66
Silver	5	1	0.066	0.066	4	0.123	0.3113	0.292	0.538	0.1757	AB-67
Vanadium	5	0	-	-	5	62.7	130.1	142	159	38.47	BF-66
Zinc	5	0	-	-	5	42.5	94.76	105	130	34.16	BF-66
Benzo(a)anthracene	5	0	-	-	5	12.47	54.82	46.02	125.4	42.02	AB-67
Benzo(a)pyrene	5	0	-	-	5	23.31	106.8	97.2	239.9	83.11	AB-67
Benzo(b)fluoranthene	5	0	-	-	5	16.7	67.83	62.3	146.9	51.2	AB-67
Benzo(g,h,i)perylene	5	0	-	-	5	20.93	100.7	87.7	221.1	81.09	AB-67
Benzo(k)fluoranthene	5	0	-	-	5	14.52	65.99	60.81	145.1	49.4	AB-67
Chrysene	5	0	-	-	5	15.38	69.28	64.67	139.7	44.62	AB-67
Dibenzo(a,h)anthracene	5	0	-	-	5	2.06	10.26	8.09	24.52	8.893	AB-67
Fluoranthene	5	0	-	-	5	34.24	135	117.5	306.4	102.3	AB-67
Indeno(1,2,3-cd)pyrene	5	0	-	-	5	21	90.45	80.41	200	72.13	AB-67
Pyrene	5	0	-	-	5	44.9	174.7	152.1	383.3	125.6	AB-67
2-Methylnaphthalene	5	0	-	-	5	1.17	3.85	3.88	7.15	2.701	AB-67
Acenaphthene	5	0	-	-	5	1.04	4.04	2.51	12.37	4.716	AB-67
Acenaphthylene	5	0	-	-	5	1.02	5.488	4.97	12.03	4.013	AB-67
Anthracene	5	0	-	-	5	2.73	16.98	12.49	42.47	15.05	AB-67
Fluorene	5	0	-	-	5	1.06	4.764	4.11	10.93	3.774	AB-67
Naphthalene	5	1	3.17	3.17	4	3.68	10.14	10.19	16.5	5.448	AB-67
Phenanthrene	5	0	-	-	5	14.22	57.37	47.15	142.4	49.67	AB-67

Table 4-7. Statistical Summary of Surface Sediment Sample Data for Reference Sites (continued)

Analyte	No. Samples	Non-detects			Detects						
		N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	5	4	0.05	0.08	1	0.12	0.12	0.12	0.12	0	BF-66
Dieldrin	5	5	0.06	0.12	0	-	-	-	-	-	-
Endosulfan II	5	5	0.06	0.13	0	-	-	--	-	-	-
Endrin	5	5	0.05	0.11	0	-	-	-	-	-	-
Gamma-chlordane	5	5	0.05	0.1	0	-	-	-	-	-	-
Heptachlor	5	5	0.05	0.11	0	-	-	-	-	-	-
Dibutyltin	5	4	1.342	2.595	1	1.315	1.315	1.315	1.315	0	AL-64
Monobutyltin	5	5	0.6246	1.373	0	-	-	-	-	-	-
Tetrabutyltin	5	5	1.48	3.252	0	-	-	-	-	-	-
Tributyltin	5	4	0.9561	1.849	1	4.038	4.038	4.038	4.038	0	AL-64
Total organic carbon	5	0	-	-	5	650	7580	8880	14700	5498	BF-66

Table 4-8. Summary of Metals that Exceed ER-Ms in Surface Sediment Samples

Chemical	ER-M[a] (mg/kg)	Number of Samples Exceeding ER-M/Total Number of Samples					
		I	III	VIII	IX	X	Total
Silver (Ag)	3.7	0/6	0/19	0/8	0/6	0/23	0/62
Aluminum (Al)	NA	–	–	–	–	–	–
Arsenic (As)	70	0/6	0/19	0/8	0/6	0/23	0/62
Barium (Ba)	NA	–	–	–	–	–	–
Cadmium (Cd)	9.6	0/6	0/19	0/8	0/6	0/23	0/62
Cobalt (Co)	NA	–	–	–	–	–	–
Chromium (Cr)	370	0/6	1/19	1/8	3/6	1/23	6/62
Copper (Cu)	270	0/6	4/19	0/8	0/6	3/23	7/62
Iron (Fe)	NA	–	–	–	–	–	–
Mercury (Hg)	0.71	0/6	5/19	0/8	0/6	9/23	14/62
Manganese (Mn)	NA	–	–	–	–	–	–
Molybdenum (Mo)	NA	–	–	–	–	–	–
Nickel (Ni)	51.6	6/6	19/19	8/8	6/6	23/23	62/62
Lead (Pb)	218	0/6	1/19	0/8	0/6	0/23	1/62
Antimony (Sb)	25	0/6	0/19	0/8	0/6	0/23	0/62
Selenium (Se)	1.4	0/6	0/19	0/8	0/6	0/23	0/62
Vanadium (Vn)	NA	–	–	–	–	–	–
Zinc (Zn)	410	0/6	0/19	0/8	0/6	0/23	0/62

(a) Source: Long et al., 1995.
NA = not available.

A box plot of mercury concentrations in surface sediment samples is presented in Figure 4-1, and a mercury distribution map is provided in Figure 4-2 (the size of the circles on the map is proportional to concentration, and concentrations exceeding the ER-M are shown in red). Mercury is elevated relative to ambient levels at Areas III, IX, and X, and exceeds the ER-M in Areas III and X. The highest concentration (7.47 mg/kg) was detected in a sample from Area III (PA-47). The highest concentrations are found along the eastern shoreline of Area X (South Basin) and near the eastern shore of Area III.

Copper data are shown in Figures 4-3 (box plot) and 4-4 (distribution map). Copper was detected at levels above the ER-M at Areas III and X. The maximum concentration of 1,050 mg/kg was detected in the same sample (PA-47) with the highest mercury concentration. The highest copper concentrations are found along the eastern shoreline of Area X and at several locations in Area III.

Lead results are shown in Figures 4-5 (box plot) and 4-6 (distribution map). Lead exceeds the ER-M at only one station in Area III (PA-47). Lead concentrations appear to be elevated relative to ambient levels in Areas IX and X, and at a few stations in Areas I and III.

Chromium and nickel results are shown in Figures 4-7 (box plot) and 4-8 (box plot), respectively. Chromium appears to be slightly elevated relative to the reference sites and ambient levels in several areas, and exceeds the ER-M at six stations: three in Area IX and one each in Areas X, III, and VIII (Figure 4-7). Nickel was measured at concentrations above the ER-M at all HPS stations; however, nickel concentrations also exceed the ER-M at all five reference sites and in the vast majority of ambient sites. Nickel concentrations exceed ambient levels in several samples from all areas except Area VIII (Figure 4-8).

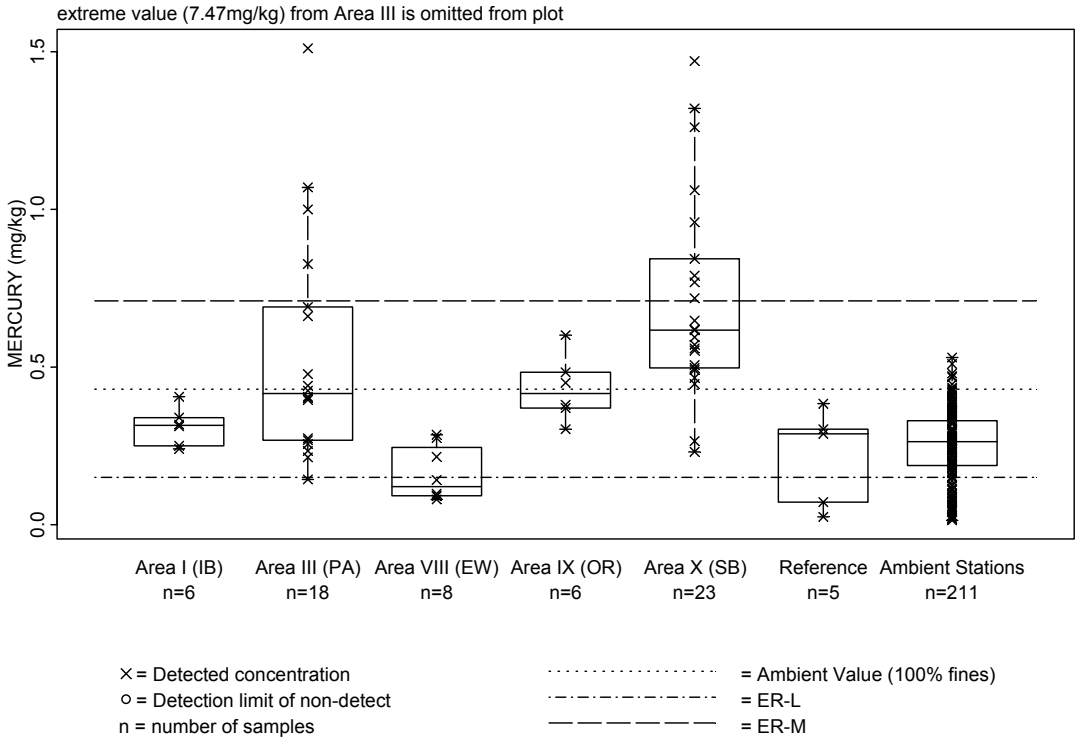


Figure 4-1. Box Plot of Mercury in Surface Sediment Samples

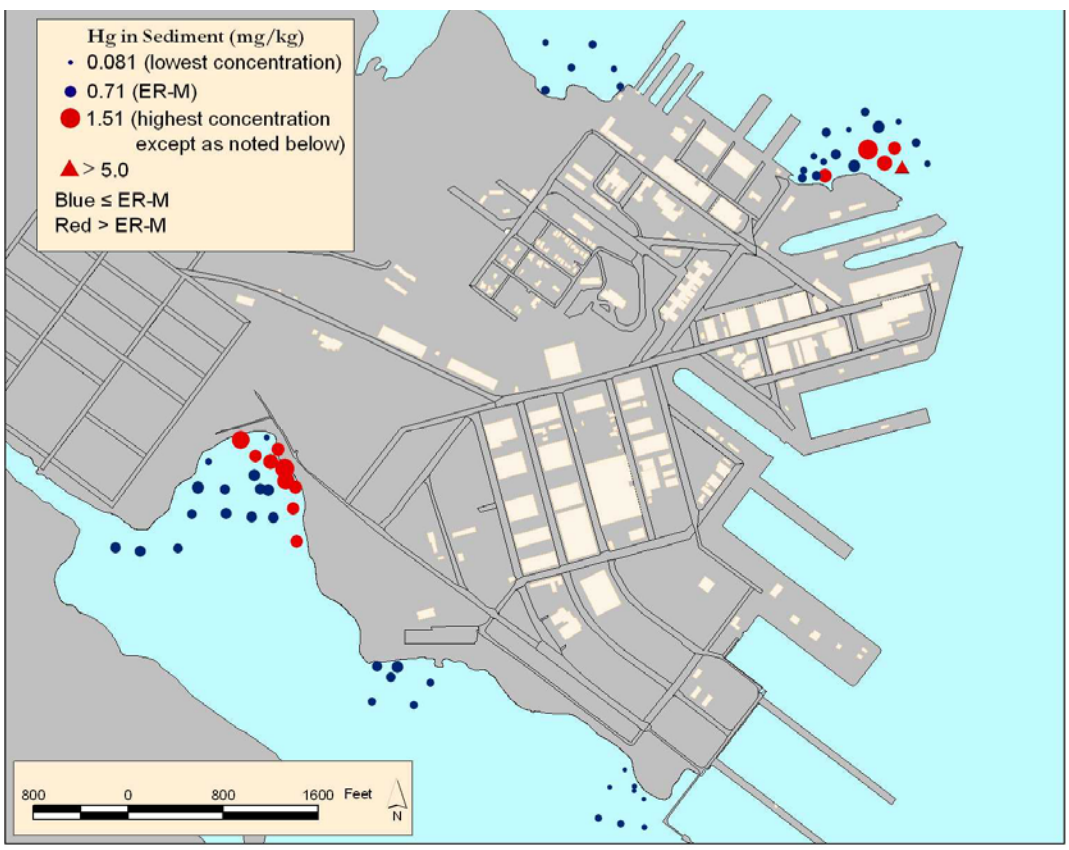


Figure 4-2. Distribution of Mercury in Surface Sediment Samples

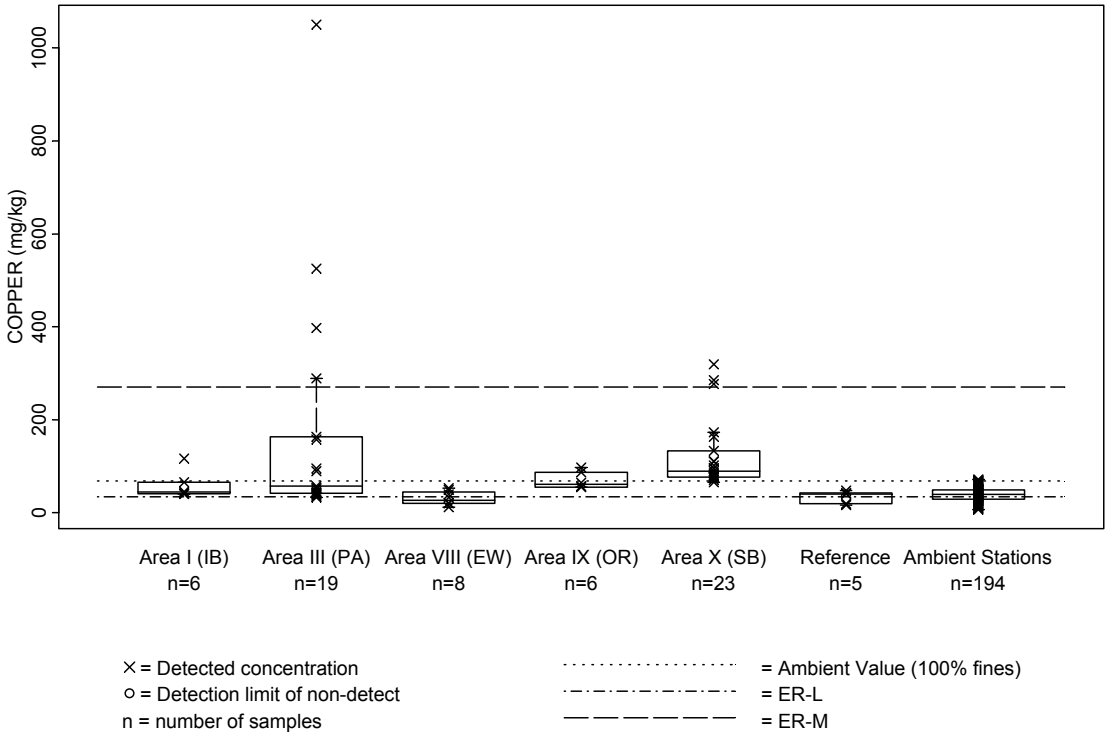


Figure 4-3. Box Plot of Copper in Surface Sediment Samples

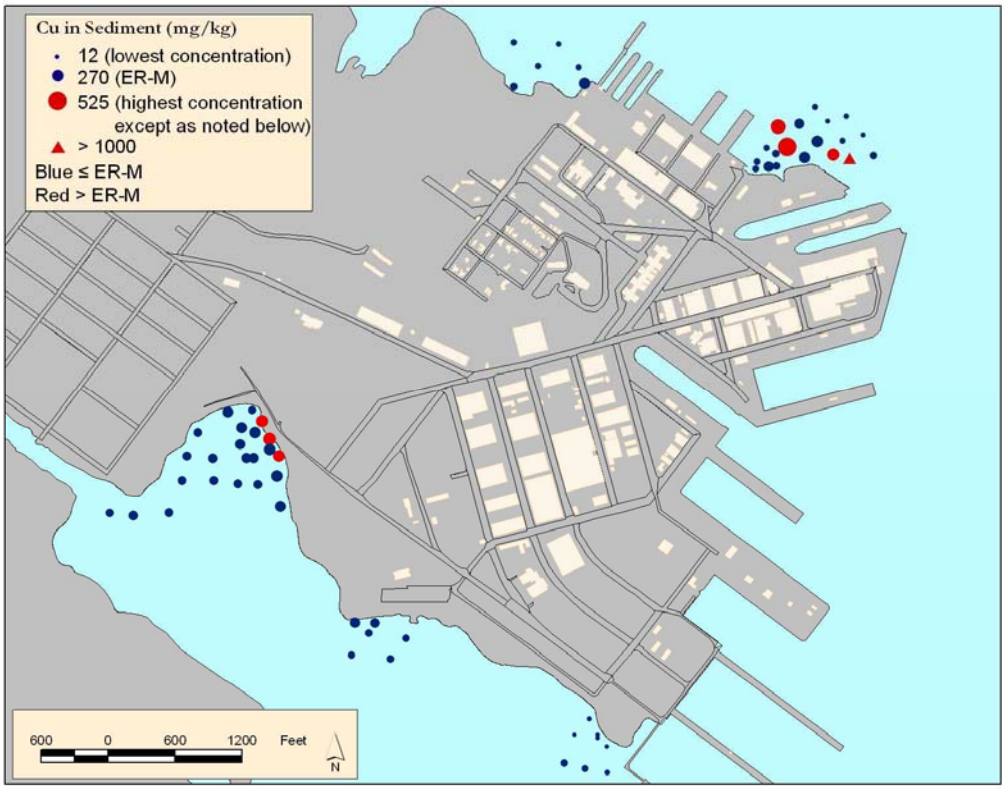


Figure 4-4. Distribution of Copper in Surface Sediment Samples

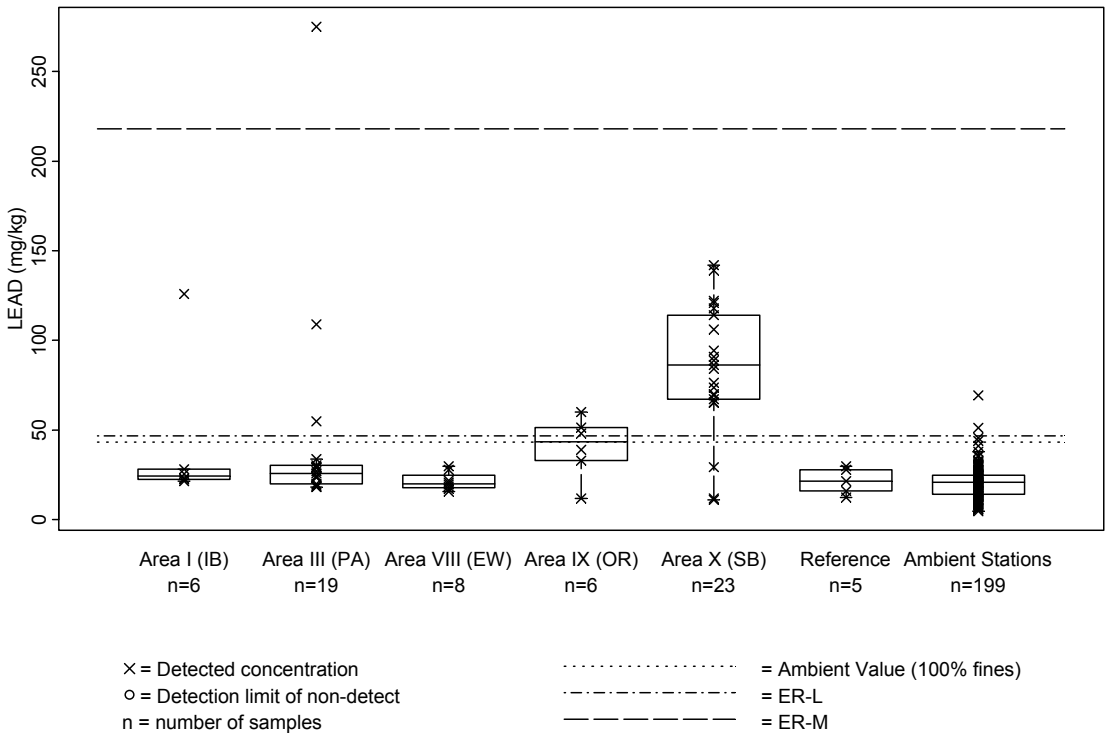


Figure 4-5. Box Plot of Lead in Surface Sediment Samples

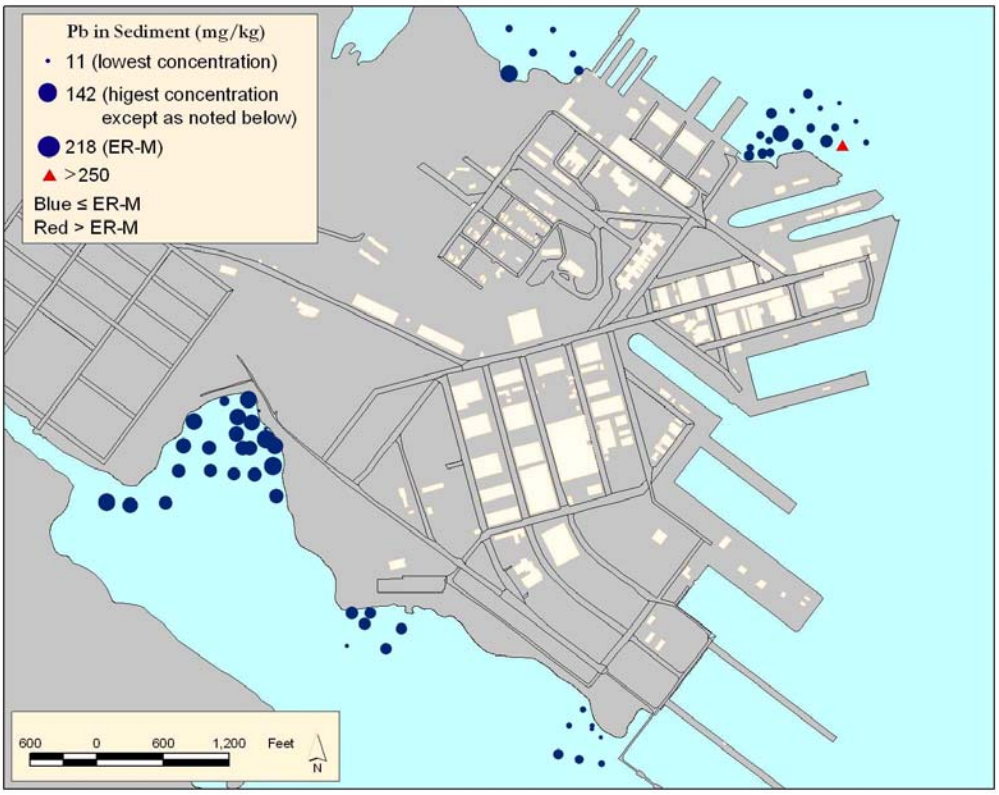


Figure 4-6. Distribution of Lead in Surface Sediment Samples

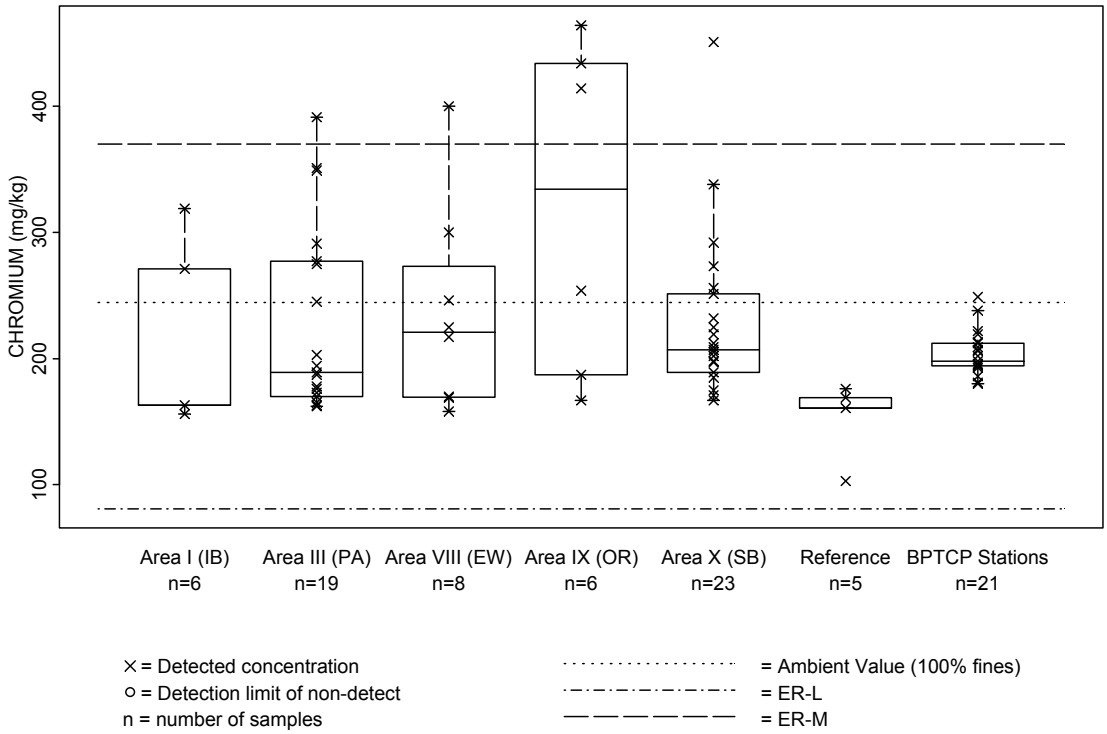


Figure 4-7. Box Plot of Chromium in Surface Sediment Samples

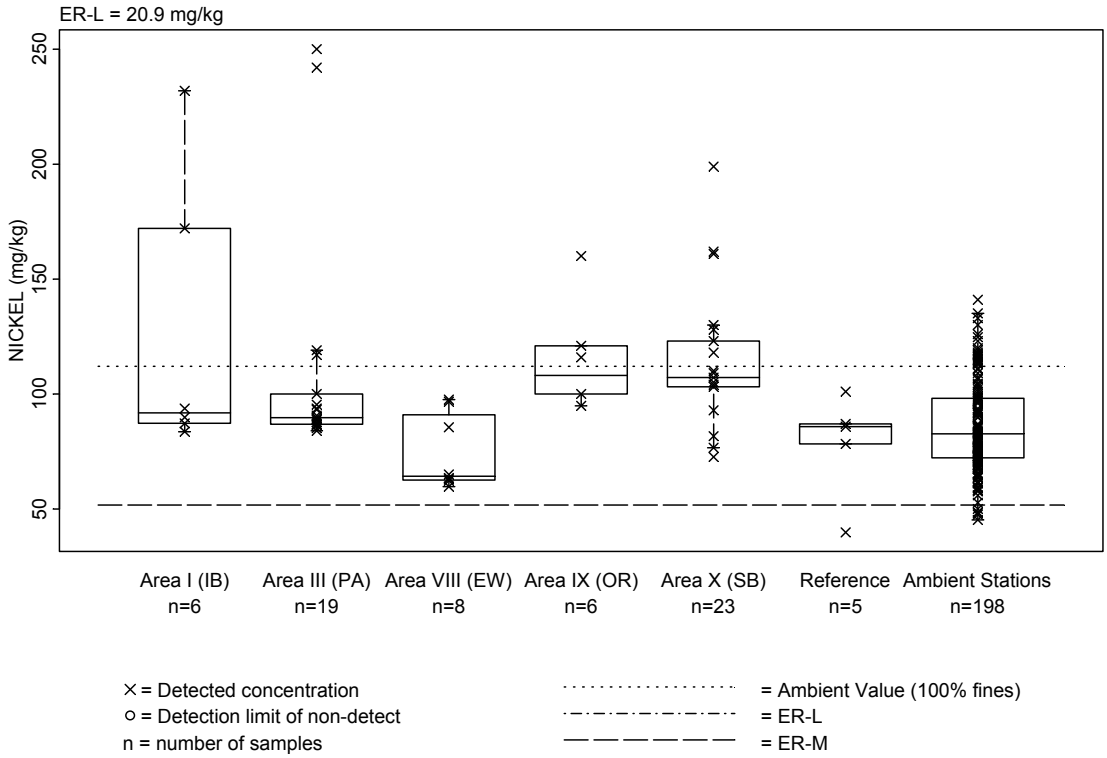


Figure 4-8. Box Plot of Nickel in Surface Sediment Samples

Concentrations of seven metals (aluminum, arsenic, cobalt, iron, manganese, selenium, and vanadium) in HPS samples are similar to those found in reference site or ambient stations. Antimony is elevated relative to reference and ambient levels in Area X and at one station in Area III (PA-44); however, all concentrations were well below the ER-M. Barium concentrations were higher than reference site concentrations at three Area X stations (SB-19, SB-21, and SB-23). No ambient data or ER-M data are available for barium.

Cadmium concentrations in Area X, and to a lesser extent in Areas IX and III, were elevated relative to the ambient concentrations; however, all values were more than an order of magnitude below the ER-M. One reference site sample (Alcatraz Environs) also had an elevated level of cadmium. Molybdenum was slightly higher in some stations than at the reference sites. No ambient data or ER-M data are available for molybdenum. Silver concentrations appear to be slightly elevated in Area X, although all HPS concentrations were below the ER-M. Zinc concentrations were elevated relative to the reference sites and ambient stations along the eastern shore of Area X and to a lesser extent at Areas III and IX. All zinc concentrations were below the ER-M.

4.1.3 Organic Chemicals

PCBs, pesticides, PAHs, and butyltins were analyzed in all HPS and reference site samples. Statistical summaries of organic chemical concentrations in surface sediment samples are provided in Tables 4-2 through 4-7. Table 4-9 lists the organic chemicals, the corresponding ER-Ms (where available), and the number of samples in each of the five study areas that exceeded ER-Ms. Total PCBs exceeded the ER-M in 30 of 62 HPS samples. The pesticide 4,4′-DDD exceeded the ER-M in three samples, and total DDx and dieldrin exceeded the ER-M in one sample each. An ER-M has not been developed for tributyltin; therefore, sample concentrations were compared with a sediment screening value developed for Puget Sound sediments (Roy F. Weston, 1996; see page F-2). The screening value of 25.1 µg/kg was exceeded in 18 of 62 HPS samples. Results for organic chemicals in surface sediments are discussed further in the following subsections.

4.1.3.1 PCBs

Complete laboratory results for 22 individual PCB congeners and seven Aroclors are provided in Tables B-4 and B-5, respectively (Appendix B). Calculated values for total PCBs are presented in Table B-42 and are summarized in Table 4-10. Total PCBs were calculated as two times the sum of 22 congeners, treating nondetected values as zeros. Total PCBs are commonly reported as two times the sum of the 18 congeners measured in the NS&T program; however, for this study, very little difference was found between two times the sums of 18 or 22 congeners. Aroclor data were collected to allow comparison to other data sets as required. PCBs were reported as Aroclor 1260 in all but one HPS sample where PCBs were detected. Aroclor 1254 was detected in the sample from Station PA-53 in Area III.

The distribution of PCBs in surface sediments is shown in Figures 4-9 (box plot) and 4-10 (distribution map). PCBs are elevated above the ER-M in Areas III and X, and to a lesser extent in Area IX. The highest concentrations in Area X are found along the eastern shore, where seven stations have PCB levels above 1 mg/kg (SB-11, SB-16, and SB-19 through SB-23). The highest observed concentration was 5,186 µg/kg at Station SB-21. PCB concentrations decrease with increasing distance from the eastern shore of South Basin, although concentrations increase in samples collected near the western edge of Area X near the mouth of Yosemite Creek.

Table 4-9. Summary of Organic Chemicals Exceeding ER-M in Surface Sediment Samples

Chemical	ER-M[a] µg/kg	Number of Samples Exceeding ER-M/Total Number of Samples					
		I	III	VIII	IX	X	Total
PCBs							
Aroclor 1016	NA	–	–	–	–	–	–
Aroclor 1221	NA	–	–	–	–	–	–
Aroclor 1232	NA	–	–	–	–	–	–
Aroclor 1242	NA	–	–	–	–	–	–
Aroclor 1259	NA	–	–	–	–	–	–
Aroclor 1260	NA	–	–	–	–	–	–
22 PCB congeners	NA	–	–	–	–	–	–
Total PCBs[b]	180	0/6	6/19	0/8	3/6	21/23	30/62
Pesticides							
4-4′ DDT	7	0/6	0/19	0/8	0/6	0/23	0/62
4-4′ DDE	27	0/6	0/19	0/8	0/6	0/23	0/62
4-4′ DDD	20	0/6	0/19	0/8	0/6	3/23	3/62
2-4′ DDT	NA	–	–	–	–	–	–
2-4′ DDE	NA	–	–	–	–	–	–
2-4′ DDD	NA	–	–	–	–	–	–
Total DDx[c]	46.1	0/6	0/19	0/8	0/6	1/23	1/62
Dieldrin	8	0/6	0/19	0/8	0/6	1/23	1/62
Endrin	45	0/6	0/19	0/8	0/6	0/23	0/62
alpha-Chlordane	6	0/6	0/19	0/8	0/6	0/23	0/62
gamma-Chlordane	NA	–	–	–	–	–	–
Endosulfan	NA	–	–	–	–	–	–
Heptachlor	NA	–	–	–	–	–	–
LPAHs							
2-Methylnaphthalene	670	0/6	0/19	0/8	0/6	0/23	0/62
Acenaphthene	500	0/6	0/19	0/8	0/6	0/23	0/62
Acenaphthylene	640	0/6	0/19	0/8	0/6	0/23	0/62
Anthracene	1,100	0/6	0/19	0/8	0/6	0/23	0/62
Fluorene	540	0/6	0/19	0/8	0/6	0/23	0/62
Naphthalene	2,100	0/6	0/19	0/8	0/6	0/23	0/62
Phenanthrene	1,500	0/6	0/19	0/8	0/6	0/23	0/62
Total LPAH[d]	3,160	0/6	0/19	0/8	0/6	0/23	0/62
HPAHs							
Benzo(a)anthracene	1,600	0/6	0/19	0/8	0/6	0/23	0/62
Benzo(a)pyrene	1,600	0/6	0/19	0/8	0/6	0/23	0/62
Benzo(b)fluoranthene	NA	–	–	–	–	–	–
Benzo(g,h,i)perylene	NA	–	–	–	–	–	–
Benzo(k)fluoranthene	NA	–	–	–	–	–	–
Chrysene	2,800	0/6	0/19	0/8	0/6	0/23	0/62
Dibenzo(a,h)anthracene	260	0/6	0/19	0/8	0/6	0/23	0/62
Fluoranthene	5,100	0/6	0/19	0/8	0/6	0/23	0/62
Indeno(1,2,3-cd)pyrene	NA	–	–	–	–	–	–
Pyrene	2,600	0/6	0/19	0/8	0/6	0/23	0/62
Total HPAH[e]	9,600	0/6	0/19	0/8	0/6	0/23	0/62
Butyltins							
Tributyltin	25.1[f]	0/6	11/19	0/8	2/6	5/23	18/62
Dibutyltin	NA	–	–	–	–	–	–

(a) Long et al., 1995.
(b) Total PCB = 2 X sum of 22 congeners.
(c) Total DDx = sum of six isomers.
(d) Total LPAH = sum of 7 LPAHs.
(e) Total HPAH = sum of 6 HPAHs.
(f) Screening value based on 2% organic carbon (Roy F. Weston, 1996).
NA = not available.

Table 4-10. Total Concentrations of Organic Chemicals in Surface Sediment Samples

Area	Station	Concentration in µg/kg dry weight			
		Total PCB[(a)]	Total DDx[(b)]	Total HPAH[(c)]	Total LPAH[(d)]
Reference Sites					
Alameda Buoy	AB-67	43	3	1,932	244
Alcatraz Environs	AL-64	0	0	522	58
Bay Farm	BF-66	14	2	942	89
Paradise Cove	PC-63	6	6	777	91
Red Rock	RR-65	2	1	206	21
Area I (India Basin)					
Area I	IB-54	17	3	1,456	155
Area I	IB-55	89	4	1,895	240
Area I	IB-56	17	3	1,494	173
Area I	IB-57	12	2	1,461	203
Area I	IB-58	15	2	1,592	206
Area I	IB-59	77	4	2,774	485
Area I	IB-59 field duplicate	64	5	7,522	1,921
Area III (Point Avisadero)					
Area III	PA-38	587	3	2,650	313
Area III	PA-39	374	3	2,209	271
Area III	PA-39 field duplicate	258	3	4,466	443
Area III	PA-40	30	3	1,581	217
Area III	PA-41	704	4	6,754	1,225
Area III	PA-42	1,130	3	4,853	900
Area III	PA-43	22	1	1,712	257
Area III	PA-44	68	3	3,518	560
Area III	PA-45	2,463	3	3,982	542
Area III	PA-46	357	2	2,635	348
Area III	PA-47	112	3	5,082	757
Area III	PA-48	16	2	3,233	616
Area III	PA-49	11	1	4,009	594
Area III	PA-50	13	3	3,364	490
Area III	PA-51	14	1	5,366	805
Area III	PA-52	15	1	6,173	1,187
Area III	PA-53	91	4	6,505	1,140
Area III	PA-70	77	2	2138	271
Area III	PA-71	24	2	1748	224
Area III	PA-72	12	2	1,109	141
Area VIII (Eastern Wetland)					
Area VIII	EW-30	14	1	1,040	197
Area VIII	EW-31	12	0	544	47
Area VIII	EW-32	29	3	1,444	177
Area VIII	EW-33	21	1	205	29
Area VIII	EW-33 field duplicate	32	0	123	15

Table 4-10. Total Concentrations of Organic Chemicals in Surface Sediment Samples (continued)

Area	Station	Concentration in µg/kg dry weight			
		Total PCB[(a)]	Total 4,4′-DDx[(b)]	Total HPAH[(c)]	Total LPAH[(d)]
Area VIII	EW-34	20	0	225	39
Area VIII	EW-35	29	2	1,232	127
Area VIII	EW-36	33	1	290	29
Area VIII	EW-37	24	2	1,695	163
Area IX (Oil Reclamation)					
Area IX	OR-24	425	4	1,895	250
Area IX	OR-25	101	2	1,586	158
Area IX	OR-26	321	5	1,068	131
Area IX	OR-27	279	4	1,006	101
Area IX	OR-28	87	2	1,549	136
Area IX	OR-29	142	2	887	77
Area IX	OR-29 field duplicate	127	5	785	82
Area X (South Basin)					
Area X	SB-01	557	17	2,136	241
Area X	SB-02	938	35	2,782	398
Area X	SB-03	180	5	1,288	139
Area X	SB-04	314	7	1,722	169
Area X	SB-05	280	6	1,467	136
Area X	SB-06	113	3	437	39
Area X	SB-07	425	10	2,053	267
Area X	SB-08	370	8	1,569	162
Area X	SB-09	352	8	1,243	145
Area X	SB-10	723	18	2,403	388
Area X	SB-11	1,113	17	2,290	248
Area X	SB-12	681	13	1,968	185
Area X	SB-12 field duplicate	639	13	2,029	219
Area X	SB-13	739	39	2,023	203
Area X	SB-14	568	14	1,856	204
Area X	SB-15	410	6	1,812	207
Area X	SB-16	1,786	5	3,872	276
Area X	SB-17	892	30	2,995	272
Area X	SB-18	830	11	3,063	323
Area X	SB-19	3,075	4	775	82
Area X	SB-20	1,565	16	2,693	281
Area X	SB-21	5,186	53	5,907	1,104
Area X	SB-22	1,817	10	2,697	234
Area X	SB-23	3,708	6	4,068	805

(a) Two times sum of 22 congeners.
(b) Sum of 4,4′-DDD, 4,4′-DDE and 4,4′-DDT.
(c) Sum of 10 individual HPAHs.
(d) Sum of 7 individual LPAHs.

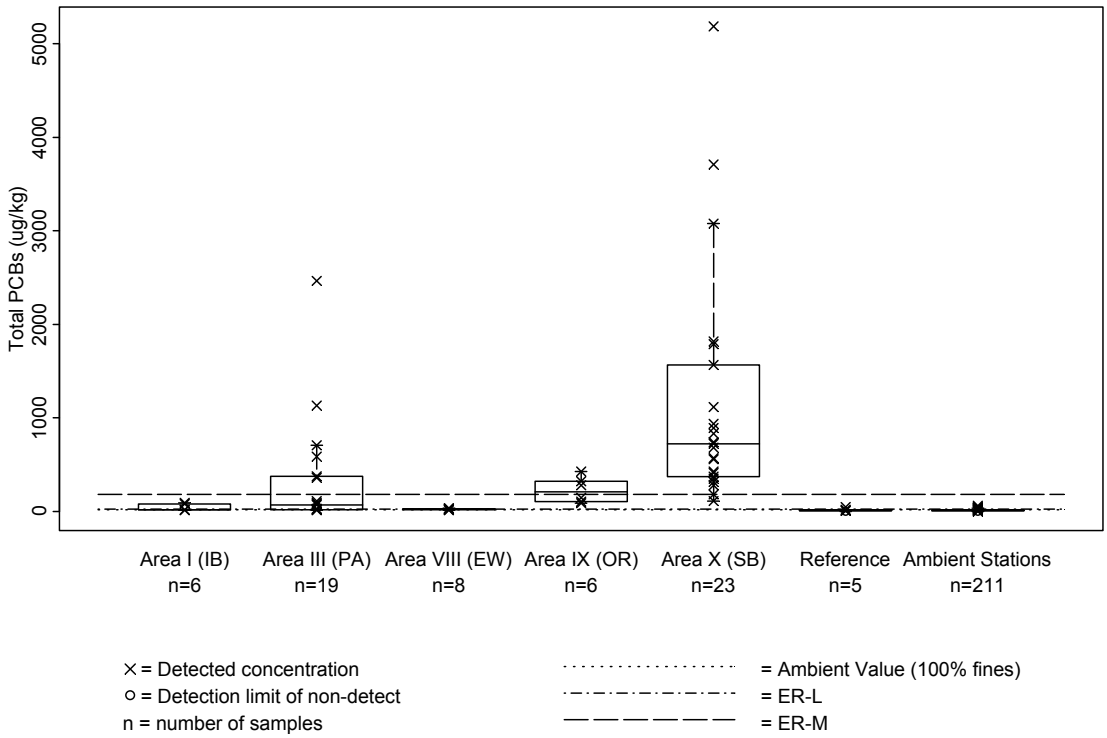


Figure 4-9. Box Plot of Total PCBs in Surface Sediment Samples

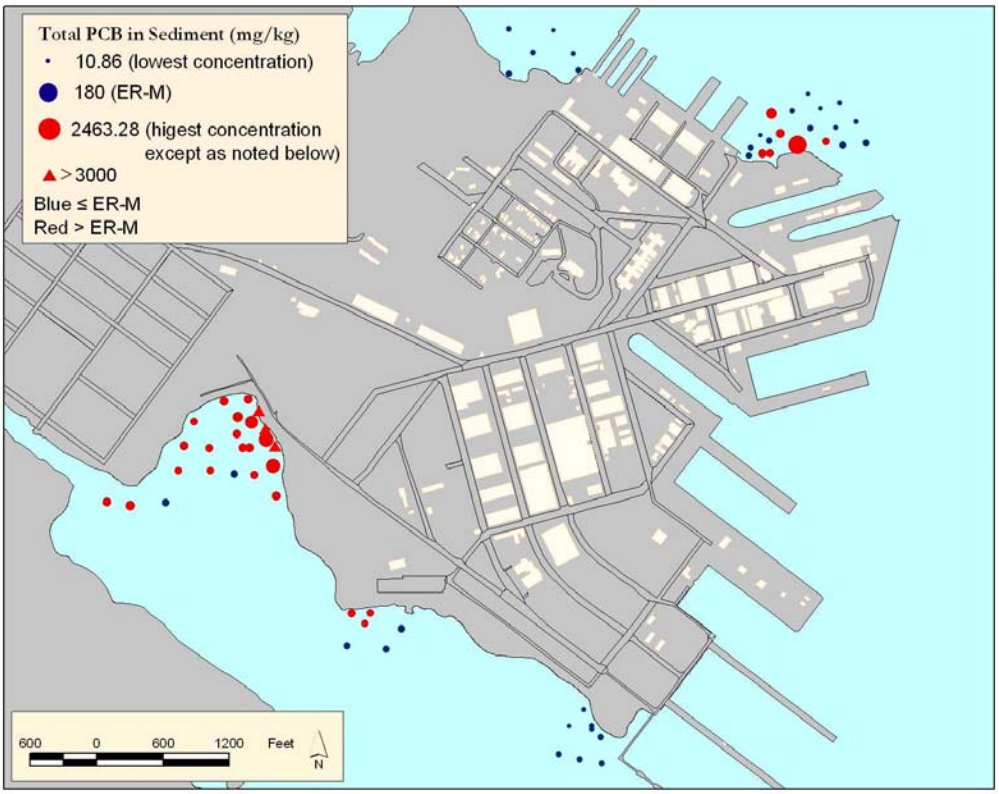


Figure 4-10. Distribution of Total PCBs in Surface Sediment Samples

PCBs exceeded the ER-M in three samples from Area IX. Concentrations in these samples ranged from 279 µg/kg to 425 µg/kg. Four stations in Area III had PCBs concentrations greater than 500 µg/kg; however, the spatial pattern is more heterogeneous than that observed in Area X. The highest concentration in Area III was 2,463 µg/kg at Station PA-45.

4.1.3.2 Pesticides

Pesticide results for surface sediment samples are provided in Table B-6 (Appendix B) and box plots are provided in Figures F-11 through F-15 (Appendix F). Detected pesticides include 4,4′-DDD; 4,4′-DDE; 4,4′-DDT; *gamma*-chlordane and *alpha*-chlordane; and dieldrin. All were found primarily in Area X. The pesticide 4,4′-DDD exceeded the ER-M in three samples from Area X, and total 4,4′-DDx exceeded the ER-M at one station (SB-21). Dieldrin exceeded the ER-M at one station near the mouth of Yosemite Creek (SB-02).

Calculated total DDx values are provided in Table B-42 and are summarized in Table 4-10. The distribution of total DDx in surface sediments is shown in Figures 4-11 (box plot) and 4-12 (distribution map). The box plot clearly shows that concentrations of total DDx are elevated in South Basin relative to other areas at HPS; however, the range of values is within the range observed in ambient stations across San Francisco Bay. Figure 4-12 shows the highest total DDx concentrations along the eastern shore of South Basin and near the mouth of Yosemite Creek.

4.1.3.3 PAHs and TPH

For the Validation Study, seven LPAHs and 10 HPAHs were analyzed (Table 4-9). Complete results are presented in Table B-7 (Appendix B). Calculated total LPAH and HPAH concentrations are presented in Table B-42 and are summarized in Table 4-10. Total HPAH concentrations are the sum of 10 individual HPAHs for the purpose of the sediment chemistry evaluation; however, the sum of six HPAHs (benzo[a]-anthracene, benzo[a]pyrene, chrysene, dibenz[a,h]anthracene, fluoranthene, and pyrene) was used in the calculation of the ERM-Q because the ER-M is based on those six HPAHs (Long et al., 1995).

Box plots for individual PAHs are shown in Figures F-16 through F-23; and box plots for total HPAHs and LPAHs are shown in Figures F-26 and F-27, respectively (Appendix F). Both HPAHs and LPAHs appear to be slightly elevated in Area III and to a lesser degree in Area X; however, none of the individual PAHs or total PAHs exceed ER-Ms at any station (Table 4-9). In Area III, the stations that consistently had the higher concentrations of PAHs were PA-52, PA-41, PA-53, and PA-51. The highest PAH concentrations in Area X were found at Stations SB-21, SB-22 and SB-23 along the eastern shoreline of South Basin.

TPH in the diesel range also were analyzed (see Table B-8, Appendix B). In general, there was little evidence of elevated concentrations of TPH. Concentrations ranged from 8.6 mg/kg at Station EW-30 in Area VIII to 150 mg/kg at Station SB-21 in Area X.

4.1.3.4 Butyltins

Tributyltin (TBT) and dibutyltin (DBT) results are provided in Table B-9 (Appendix B). Tetrabutyltin (TTBT) and monobutyltin (MBT) also were measured, although they are not Parcel F COPECs. Box plots of TBT and DBT are presented in Figure F-24 (Appendix F). TBT appeared to be elevated relative to reference and ambient stations in Area III and to a lesser extent in Areas X and IX. DBT generally showed the same spatial distribution as TBT.

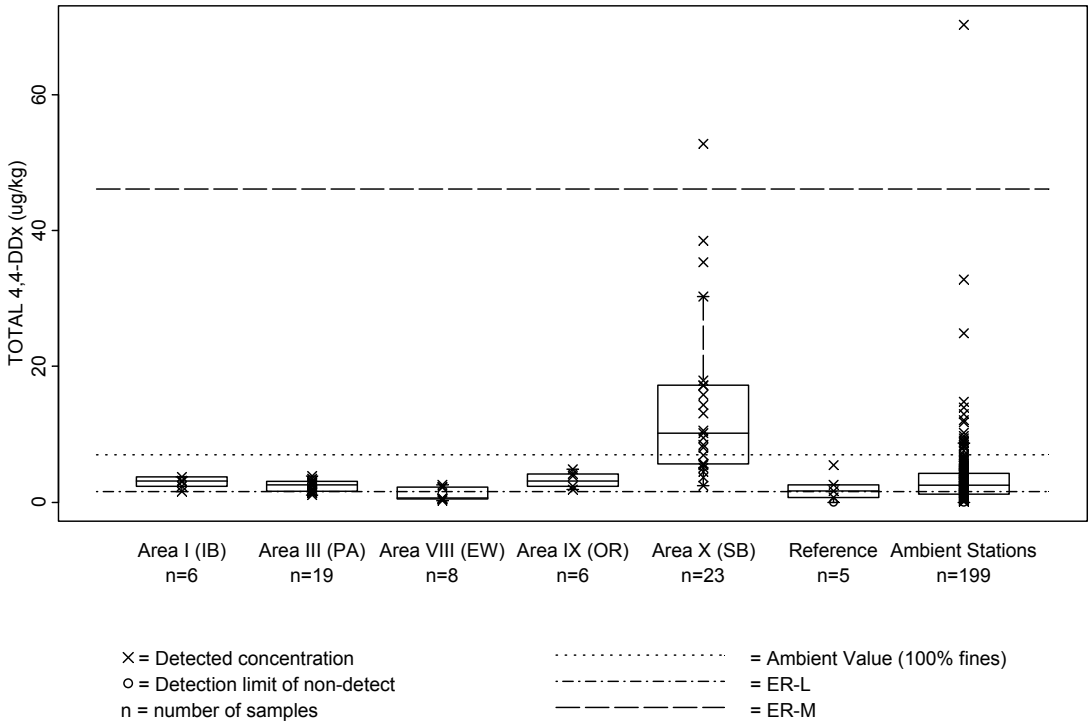


Figure 4-11. Box Plot of Total DDx in Surface Sediment Samples

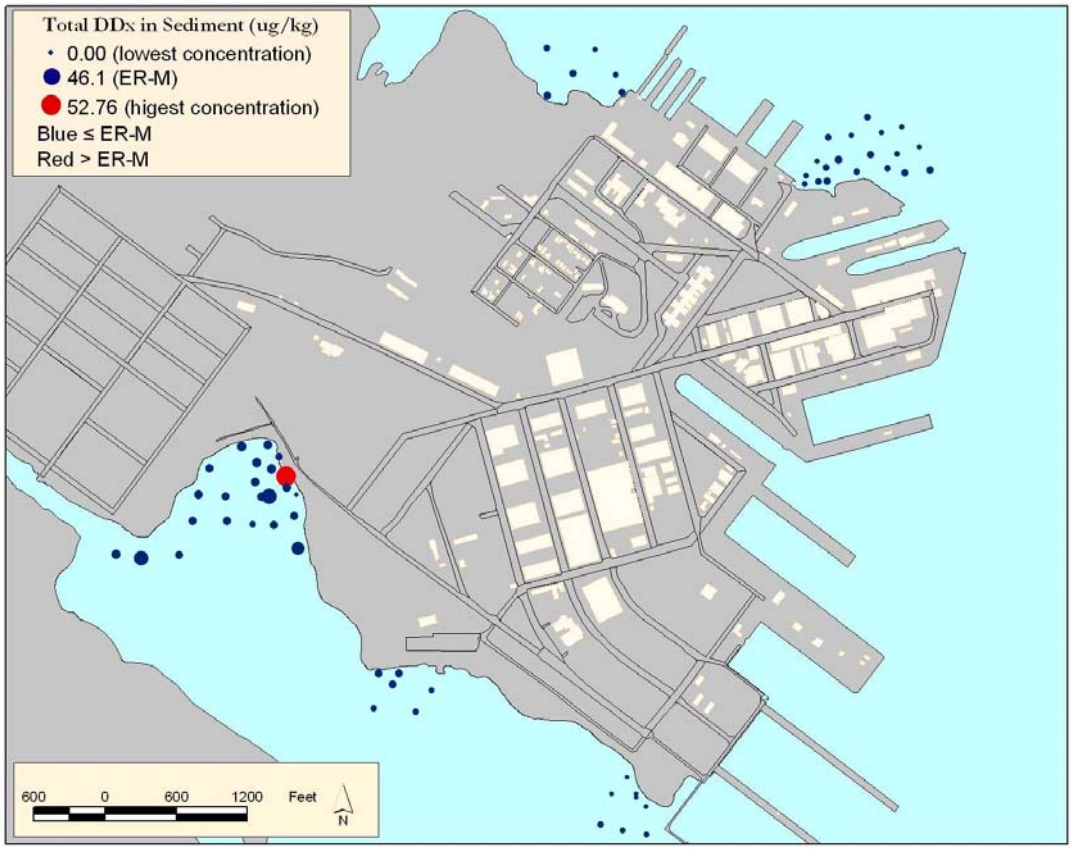


Figure 4-12. Distribution of Total DDx in Surface Sediment Samples

4.2 Subsurface Sediment

Sediment cores were collected at 20 HPS sampling stations and at two stations in Yosemite Creek (the Yosemite Creek cores were analyzed for radioisotopes only). Core lengths ranged from approximately 4 ft (PA-40 in Area III) to 9.5 ft at a number of Area X stations. Core sample chemistry data were used to characterize the vertical extent of contamination.

4.2.1 Conventional Parameters

Grain size and TOC content in sediment cores samples are described below.

4.2.1.1 Grain Size

Grain size data for sediment core samples are provided in Table B-10 (Appendix B). There was little variation in grain size with depth in fine-grained cores from Areas I, IX, and X, with the exception of SB-01 near the mouth of Yosemite Creek. SB-01 was slightly coarser in the 0-2 ft interval (69.5% fines) than in the 2-4 ft and 4-6 ft intervals (97.6% and 88.1% fines, respectively). The cores from Area VIII were consistently coarse-grained with depth, ranging from 12.9% to 28.6 % fines. The cores from Area III showed the greatest variability in grain size, with both lateral and vertical changes in grain size.

4.2.1.2 Total Organic Carbon

TOC results for subsurface samples are provided in Table B-11 (Appendix B). As with the surface sediment samples, TOC content was inversely related to grain size. TOC content ranged from 2,310 mg/kg in a coarse-grained sample from Station EW-32 (4-6 ft interval) to 24,200 mg/kg in a fine-grained sample from SB-20 (2-4 ft interval).

TOC content generally decreased with increasing depth in Area X. The 4-6 ft interval contained approximately one-half of the TOC as the 0-2 ft interval. TOC content was lower in Area IX than in Area X, with a maximum concentration of 10,900 mg/kg in the 0-2 ft sample from Station OR-28. Samples from Area VIII had the lowest levels of TOC, corresponding to the coarser-grained sediment.

TOC concentrations in samples from Area III were heterogeneous, with the highest observed TOC in the 0-2 ft interval at three stations, and in the 2-4 ft interval at the other three stations. In general, TOC was lower in Area III than in Area X. Despite the high percent fines at the two stations where cores were obtained in Area I, TOC concentrations ranged from 8,270 mg/kg to a high of 11,700 mg/kg.

4.2.2 Metals

Complete results for metals in sediment core samples are presented in Table B-12 (Appendix B). Statistical summaries of metals results for HPS and reference subsurface sediment samples are summarized in Tables 4-11 through 4-15. The following metals were found to exceed ER-Ms in core samples at more than one HPS station: mercury, copper, chromium, lead, nickel, and zinc. Table 4-16 summarizes the data for those metals in core samples where ER-Ms were exceeded. All concentrations were below ER-Ms in core samples from Areas VIII and IX. In Area I, mercury slightly exceeded the ER-M of 0.71 mg/kg in the 2-4 ft sample from Station IB-56. Otherwise, all metals concentrations were below ER-Ms.

In Area III, metals concentrations exceeded ER-Ms in core samples from Stations PA-40, PA-41, PA-44, and PA-47. Sandblast grit was observed in the upper 2 ft of sediment from PA-40 and PA-41 (see core logs in Appendix A). The depth that corresponded with the highest chemical concentrations varied with

Table 4-11. Statistical Summary of Sediment Core Sample Data for Area I (India Basin)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	2	6	6	10.08	12.73	0	-	-	-	-	-	-
Aroclor-1221	2	6	6	10.08	12.73	0	-	-	-	-	-	-
Aroclor-1232	2	6	6	10.08	12.73	0	-	-	-	-	-	-
Aroclor-1242	2	6	6	10.08	12.73	0	-	-	-	-	-	-
Aroclor-1248	2	6	6	10.08	12.73	0	-	-	-	-	-	-
Aroclor-1254	2	6	6	10.08	12.73	0	-	-	-	-	-	-
Aroclor-1260	2	6	4	10.75	12.73	2	93.29	100	100	106.8	9.539	IB-59 4-6
PCB101	2	6	1	0.1	0.1	5	0.91	3.468	4.93	5.4	2.265	IB-56 2-4
PCB105	2	6	1	0.09	0.09	5	0.34	0.72	0.9	1.03	0.3322	IB-56 2-4
PCB110	2	6	1	0.11	0.11	5	1.25	3.102	3.58	4.81	1.726	IB-59 4-6
PCB118	2	6	1	0.11	0.11	5	0.81	2.024	2.23	3.3	1.134	IB-59 4-6
PCB126	2	6	6	0.13	0.16	0	-	-	-	-	-	-
PCB128	2	6	4	0.18	0.22	2	0.45	0.625	0.625	0.8	0.2475	IB-59 4-6
PCB129	2	6	6	0.07	0.09	0	-	-	-	-	-	-
PCB138	2	6	1	0.09	0.09	5	1.76	5.444	6.74	8.85	3.317	IB-59 4-6
PCB153	2	6	1	0.14	0.14	5	2.38	8.214	10.5	13.46	5.139	IB-59 4-6
PCB170	2	6	1	0.09	0.09	5	0.35	2.094	2.3	4.02	1.655	IB-59 4-6
PCB18	2	6	3	0.08	0.09	3	0.41	0.4767	0.47	0.55	0.07024	IB-56 2-4
PCB180	2	6	0	-	-	6	0.18	4.232	3.73	8.33	3.623	IB-59 4-6
PCB187	2	6	1	0.09	0.09	5	0.83	3.276	4.04	5.48	2.214	IB-59 4-6
PCB195	2	6	1	0.09	0.09	5	0.14	0.648	0.86	1.04	0.4287	IB-59 4-6
PCB206	2	6	1	0.08	0.08	5	0.37	0.762	0.85	1.17	0.3541	IB-59 4-6
PCB209	2	6	1	0.09	0.09	5	0.45	1.098	1.04	2.37	0.7746	IB-56 2-4
PCB28	2	6	2	0.11	0.13	4	0.23	0.6375	0.725	0.87	0.2851	IB-59 4-6
PCB44	2	6	1	0.1	0.1	5	0.19	0.8	0.94	1.54	0.5573	IB-56 2-4
PCB52	2	6	1	0.1	0.1	5	0.41	1.456	1.66	2.68	0.9964	IB-56 2-4
PCB66	2	6	3	0.12	0.14	3	0.2	0.3767	0.33	0.6	0.204	IB-59 4-6
PCB77	2	6	6	0.15	0.19	0	-	-	-	-	-	-
PCB8	2	6	3	0.16	0.19	3	0.35	0.4733	0.41	0.66	0.1644	IB-56 2-4
2,4'-DDD	2	6	6	0.1	0.12	0	-	-	-	-	-	-
2,4'-DDE	2	6	6	0.12	0.15	0	-	-	-	-	-	-
2,4'-DDT	2	6	6	0.11	0.14	0	-	-	-	-	-	-
4,4'-DDD	2	6	1	0.1	0.1	5	0.96	1.656	1.64	2.32	0.5547	IB-56 0-2
4,4'-DDE	2	6	2	0.09	0.09	4	0.43	0.9025	0.72	1.74	0.5913	IB-59 2-4
4,4'-DDT	2	6	5	0.09	0.1	1	0.16	0.16	0.16	0.16	0	IB-56 0-2

Table 4-11. Statistical Summary of Sediment Core Sample Data for Area I (India Basin) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	2	6	0	-	-	6	72200	76800	77650	79200	2590	IB-59 2-4
Antimony	2	6	0	-	-	6	0.842	1.338	1.305	1.96	0.438	IB-56 2-4
Arsenic	2	6	0	-	-	6	12.7	13.68	13	16.5	1.488	IB-56 2-4
Barium	2	6	0	-	-	6	428	449.3	451.5	462	12.68	IB-56 0-2
Cadmium	2	6	0	-	-	6	0.165	0.3995	0.359	0.764	0.2182	IB-56 2-4
Chromium	2	6	0	-	-	6	151	174.2	174.5	191	16.04	IB-56 0-2
Cobalt	2	6	0	-	-	6	18.4	19.27	19.1	20.8	0.8892	IB-59 2-4
Copper	2	6	0	-	-	6	46	62.47	64.45	77.5	11.14	IB-59 4-6
Iron	2	6	0	-	-	6	42500	44900	45150	48200	2141	IB-59 2-4
Lead	2	6	0	-	-	6	34.4	60.93	53.8	106	30.25	IB-59 4-6
Manganese	2	6	0	-	-	6	389	453.8	431.5	576	66.76	IB-56 4-6
Mercury	2	6	0	-	-	6	0.324	0.447	0.3715	0.719	0.1563	IB-56 2-4
Molybdenum	2	6	0	-	-	6	1.31	1.48	1.44	1.76	0.1626	IB-56 2-4
Nickel	2	6	0	-	-	6	90.5	111.1	114	125	12.06	IB-59 4-6
Selenium	2	6	0	-	-	6	0.377	0.4613	0.42	0.628	0.09805	IB-59 4-6
Silver	2	6	0	-	-	6	0.165	0.5338	0.563	0.804	0.2169	IB-59 4-6
Vanadium	2	6	0	-	-	6	146	162.2	164	176	10.03	IB-59 2-4
Zinc	2	6	0	-	-	6	88.4	128.2	134	149	20.91	IB-59 4-6
Benzo(a)anthracene	2	6	0	-	-	6	87.33	212.4	164.7	452.9	143.9	IB-56 2-4
Benzo(a)pyrene	2	6	0	-	-	6	147.6	390.8	341.7	799.8	251.4	IB-56 2-4
Benzo(b)fluoranthene	2	6	0	-	-	6	91.41	257.2	247.3	478.8	145	IB-56 2-4
Benzo(g,h,i)perylene	2	6	0	-	-	6	94.62	319.1	287.5	649.5	208.1	IB-56 2-4
Benzo(k)fluoranthene	2	6	0	-	-	6	110.7	258.1	241.8	476.1	146.7	IB-56 2-4
Chrysene	2	6	0	-	-	6	110.5	248.8	199.2	501.7	159.4	IB-56 2-4
Dibenzo(a,h)anthracene	2	6	0	-	-	6	19.35	41.86	37.04	81.8	25.25	IB-56 2-4
Fluoranthene	2	6	0	-	-	6	170.7	398.7	311.6	805.2	266	IB-56 2-4
Indeno(1,2,3-cd)pyrene	2	6	0	-	-	6	98.89	314.3	278.6	643.6	206.9	IB-56 2-4
Pyrene	2	6	0	-	-	6	224.9	565.1	473.3	1121	362.8	IB-56 2-4
2-Methylnaphthalene	2	6	0	-	-	6	5.624	10.21	10.27	14.29	3.822	IB-56 0-2
Acenaphthene	2	6	0	-	-	6	3.017	9.825	9.535	17.04	5.627	IB-56 0-2
Acenaphthylene	2	6	0	-	-	6	6.834	18.88	14.98	42.22	14.2	IB-56 2-4
Anthracene	2	6	0	-	-	6	26.83	64.84	49.52	135.1	44.25	IB-56 2-4
Fluorene	2	6	0	-	-	6	7.181	13.83	11.84	24.54	7.564	IB-56 2-4
Naphthalene	2	6	0	-	-	6	13.47	27.19	25.61	47.97	14.02	IB-56 2-4
Phenanthrene	2	6	0	-	-	6	39.04	164.9	138.3	330.7	118.4	IB-56 2-4

Table 4-11. Statistical Summary of Sediment Core Sample Data for Area I (India Basin) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	2	6	4	0.07	0.08	2	0.31	0.395	0.395	0.48	0.1202	IB-59 4-6
Dieldrin	2	6	6	0.09	0.11	0	-	-	-	-	-	-
Endosulfan II	2	6	6	0.09	0.11	0	-	-	-	-	-	-
Endrin	2	6	6	0.08	0.1	0	-	-	-	-	-	-
Gamma-chlordane	2	6	4	0.07	0.09	2	0.38	0.39	0.39	0.4	0.01414	IB-59 4-6
Heptachlor	2	6	6	0.07	0.09	0	-	-	-	-	-	-
Dibutyltin	2	6	4	1.826	2.169	2	3.329	4.191	4.191	5.053	1.219	IB-56 0-2
Monobutyltin	2	6	6	0.949	1.155	0	-	-	-	-	-	-
Tetrabutyltin	2	6	6	2.248	2.735	0	-	-	-	-	-	-
Tributyltin	2	6	6	1.278	1.555	0	-	-	-	-	-	-
Total organic carbon	2	6	0	-	-	6	8270	10190	10260	11700	1270	IB-59 4-6

Table 4-12. Statistical Summary of Sediment Core Sample Data for Area III (Point Avisadero)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	6	17	17	7.28	11.75	0	-	-	-	-	-	-
Aroclor-1221	6	17	17	7.28	11.75	0	-	-	-	-	-	-
Aroclor-1232	6	17	17	7.28	11.75	0	-	-	-	-	-	-
Aroclor-1242	6	17	17	7.28	11.75	0	-	-	-	-	-	-
Aroclor-1248	6	17	17	7.28	11.75	0	-	-	-	-	-	-
Aroclor-1254	6	17	17	7.28	11.75	0	-	-	-	-	-	-
Aroclor-1260	6	17	14	7.28	11.75	3	34.05	184.8	182.2	338	152	PA-41 2-4
PCB101	6	17	6	0.09	0.11	11	0.23	3.985	1.76	12.38	4.429	PA-41 0-2
PCB105	6	17	8	0.07	0.09	9	0.11	0.8	0.58	2.14	0.6888	PA-41 0-2
PCB110	6	17	6	0.1	0.12	11	0.04	2.98	1.7	9.68	2.971	PA-41 0-2
PCB118	6	17	7	0.1	0.12	10	0.13	1.778	1.06	5.61	1.737	PA-41 0-2
PCB126	6	17	17	0.09	0.15	0	-	-	-	-	-	-
PCB128	6	17	15	0.15	0.2	2	0.52	0.59	0.59	0.66	0.09899	PA-40 2-4
PCB129	6	17	17	0.05	0.09	0	-	-	-	-	-	-
PCB138	6	17	6	0.08	0.1	11	0.35	4.51	1.44	18.27	6.033	PA-41 2-4
PCB153	6	17	6	0.12	0.15	11	0.55	5.735	3.04	24.05	6.792	PA-41 0-2
PCB170	6	17	6	0.08	0.1	11	0.18	2.416	0.77	11.87	3.627	PA-41 2-4
PCB18	6	17	11	0.06	0.08	6	0.1	1.107	0.84	2.52	1.006	PA-40 2-4
PCB180	6	17	6	0.09	0.11	11	0.38	3.551	2.1	12.49	3.803	PA-41 0-2
PCB187	6	17	6	0.08	0.1	11	0.23	2.468	1.62	8.93	2.664	PA-41 0-2
PCB195	6	17	9	0.07	0.09	8	0.14	1.472	0.62	7.5	2.462	PA-41 2-4
PCB206	6	17	10	0.07	0.09	7	0.23	1.823	0.62	9.68	3.474	PA-41 2-4
PCB209	6	17	9	0.08	0.1	8	0.2	0.7687	0.545	2.46	0.7405	PA-41 2-4
PCB28	6	17	11	0.09	0.12	6	0.18	1.442	0.895	3.21	1.314	PA-40 2-4
PCB44	6	17	9	0.08	0.11	8	0.14	1.757	1.175	4.74	1.868	PA-41 0-2
PCB52	6	17	10	0.08	0.11	7	0.42	10.7	2.86	47.8	16.89	PA-41 0-2
PCB66	6	17	15	0.09	0.12	2	0.92	2.175	2.175	3.43	1.775	PA-40 2-4
PCB77	6	17	17	0.11	0.18	0	-	-	-	-	-	-
PCB8	6	17	13	0.13	0.17	4	0.57	1	0.865	1.7	0.5149	PA-41 0-2
2,4'-DDD	6	17	17	0.07	0.11	0	-	-	-	-	-	-
2,4'-DDE	6	17	17	0.09	0.14	0	-	-	-	-	-	-
2,4'-DDT	6	17	17	0.08	0.13	0	-	-	-	-	-	-
4,4'-DDD	6	17	8	0.09	0.1	9	0.76	1.781	1.03	5.05	1.506	PA-41 0-2
4,4'-DDE	6	17	7	0.08	0.09	10	0.14	0.932	0.635	2.87	0.8902	PA-41 0-2
4,4'-DDT	6	17	15	0.06	0.1	2	0.22	0.595	0.595	0.97	0.5303	PA-41 0-2

Table 4-12. Statistical Summary of Sediment Core Sample Data for Area III (Point Avisadero) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	6	17	0	-	-	17	45500	69490	70800	82400	9275	PA-44 4-6
Antimony	6	17	0	-	-	17	0.444	3.536	1.64	18.8	4.722	PA-44 4-6
Arsenic	6	17	0	-	-	17	6.05	13.38	12.3	32	5.981	PA-47 0-2
Barium	6	17	0	-	-	17	410	512.1	457	941	148.7	PA-40 0-2
Cadmium	6	17	0	-	-	17	0.176	0.4385	0.421	0.768	0.1942	PA-41 2-4
Chromium	6	17	0	-	-	17	149	245	167	913	192.4	PA-40 2-4
Cobalt	6	17	0	-	-	17	8.51	17.57	17.3	23	3.604	PA-40 2-4
Copper	6	17	0	-	-	17	29	378.7	50.8	2150	667.6	PA-41 2-4
Iron	6	17	0	-	-	17	36300	44140	44500	50700	3963	PA-44 4-6
Lead	6	17	0	-	-	17	11.1	103.8	56.6	583	140.9	PA-40 2-4
Manganese	6	17	0	-	-	17	442	616.6	541	1090	184	PA-44 4-6
Mercury	6	17	0	-	-	17	0.0709	3.104	0.369	43.1	10.33	PA-47 0-2
Molybdenum	6	17	0	-	-	17	0.398	1.943	1.27	6.94	1.683	PA-40 0-2
Nickel	6	17	0	-	-	17	90.6	119.7	106	223	32.84	PA-40 2-4
Selenium	6	17	0	-	-	17	0.155	0.38	0.413	0.509	0.1087	PA-49 0-2
Silver	6	17	0	-	-	17	0.0708	0.3038	0.295	0.607	0.1675	PA-41 2-4
Vanadium	6	17	0	-	-	17	45.8	122.7	137	169	35.74	PA-44 2-4
Zinc	6	17	0	-	-	17	79.7	175.8	96.5	557	143.9	PA-41 0-2
Benzo(a)anthracene	6	17	3	0.52	1.02	14	0.48	353	284.2	1147	359.3	PA-52 4-6
Benzo(a)pyrene	6	17	3	0.41	1.24	14	0.47	498.1	376.5	1624	499.3	PA-52 4-6
Benzo(b)fluoranthene	6	17	1	1.42	1.42	16	1.54	274.1	169.6	884.7	282.2	PA-52 4-6
Benzo(g,h,i)perylene	6	17	2	1.28	1.5	15	1.11	364.5	235.4	1243	384.8	PA-52 4-6
Benzo(k)fluoranthene	6	17	3	0.45	1	14	0.31	318	253	954.8	296.5	PA-52 4-6
Chrysene	6	17	1	1.79	1.79	16	1.8	347.5	200.4	1194	377.9	PA-52 4-6
Dibenzo(a,h)anthracene	6	17	3	0.2	0.37	14	0.18	56.75	45.83	166.1	52.8	PA-52 4-6
Fluoranthene	6	17	0	-	-	17	1.71	617.3	309.9	2604	785.3	PA-52 4-6
Indeno(1,2,3-cd)pyrene	6	17	2	0.54	0.68	15	0.49	353.5	219.7	1213	373.5	PA-52 4-6
Pyrene	6	17	2	2.56	2.64	15	1.98	929.9	536.3	3292	1025	PA-52 4-6
2-Methylnaphthalene	6	17	0			17	1.64	13.03	5.851	33.2	12.1	PA-52 2-4
Acenaphthene	6	17	3	0.19	0.3	14	0.16	36.2	31.54	110.1	34.88	PA-41 2-4
Acenaphthylene	6	17	3	0.06	0.08	14	0.06	38.67	19.42	164.8	55.36	PA-52 4-6
Anthracene	6	17	2	0.63	0.74	15	0.53	144.7	71.4	591.8	195.8	PA-52 2-4
Fluorene	6	17	0	-	-	17	1.75	36.02	16.66	131.6	44.01	PA-52 2-4
Naphthalene	6	17	6	1.87	2.67	11	5.73	49.6	40.33	94.55	36	PA-52 4-6
Phenanthrene	6	17	0	-	-	17	3.77	381.7	162.6	1651	526.8	PA-52 4-6

Table 4-12. Statistical Summary of Sediment Core Sample Data for Area III (Point Avisadero) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	6	17	14	0.05	0.08	3	0.06	0.11	0.12	0.15	0.04583	PA-47 0-2
Dieldrin	6	17	17	0.06	0.1	0	-	-	-	-	-	-
Endosulfan II	6	17	17	0.06	0.1	0	-	-	-	-	-	-
Endrin	6	17	17	0.06	0.09	0	-	-	-	-	-	-
Gamma-chlordane	6	17	16	0.05	0.08	1	3.31	3.31	3.31	3.31	0	PA-41 0-2
Heptachlor	6	17	17	0.05	0.09	0	-	-	-	-	-	-
Dibutyltin	6	17	9	1.686	2.075	8	4.228	63.99	13.49	169.2	77.21	PA-41 0-2
Monobutyltin	6	17	15	0.8421	1.098	2	4.557	6.459	6.459	8.361	2.69	PA-40 2-4
Tetrabutyltin	6	17	14	1.995	2.601	3	8.726	12.34	10.98	17.33	4.459	PA-41 0-2
Tributyltin	6	17	8	1.23	1.479	9	5.17	351	67.12	1024	461.7	PA-41 0-2
Total organic carbon	6	17	0	-	-	17	6940	11190	11200	15400	2340	PA-47 2-4

Table 4-13. Statistical Summary of Sediment Core Sample Data for Area VIII (Eastern Wetland)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	2	6	6	6.71	7.5	0	-	-	-	-	-	-
Aroclor-1221	2	6	6	6.71	7.5	0	-	-	-	-	-	-
Aroclor-1232	2	6	6	6.71	7.5	0	-	-	-	-	-	-
Aroclor-1242	2	6	6	6.71	7.5	0	-	-	-	-	-	-
Aroclor-1248	2	6	6	6.71	7.5	0	-	-	-	-	-	-
Aroclor-1254	2	6	6	6.71	7.5	0	-	-	-	-	-	-
Aroclor-1260	2	6	6	6.71	7.5	0	-	-	-	-	-	-
PCB101	2	6	3	0.06	0.07	3	0.13	0.5	0.21	1.16	0.573	EW-31 0-2
PCB105	2	6	4	0.06	0.06	2	0.15	0.27	0.27	0.39	0.1697	EW-36 0-2
PCB110	2	6	4	0.07	0.07	2	0.53	0.755	0.755	0.98	0.3182	EW-31 0-2
PCB118	2	6	4	0.07	0.08	2	0.36	0.44	0.44	0.52	0.1131	EW-31 0-2
PCB126	2	6	6	0.09	0.1	0	-	-	-	-	-	-
PCB128	2	6	6	0.11	0.13	0	-	-	-	-	-	-
PCB129	2	6	6	0.05	0.05	0	-	-	-	-	-	-
PCB138	2	6	4	0.06	0.06	2	1.59	1.69	1.69	1.79	0.1414	EW-31 0-2
PCB153	2	6	4	0.09	0.1	2	2.84	3.14	3.14	3.44	0.4243	EW-31 0-2
PCB170	2	6	3	0.06	0.06	3	0.47	0.85	0.81	1.27	0.4015	EW-36 0-2
PCB18	2	6	6	0.05	0.05	0	-	-	-	-	-	-
PCB180	2	6	1	0.07	0.07	5	0.19	0.95	0.46	1.99	0.8879	EW-31 0-2
PCB187	2	6	2	0.06	0.06	4	0.04	0.76	0.615	1.77	0.8308	EW-31 0-2
PCB195	2	6	4	0.06	0.06	2	0.18	0.225	0.225	0.27	0.06364	EW-31 0-2
PCB206	2	6	4	0.05	0.06	2	0.11	0.195	0.195	0.28	0.1202	EW-36 0-2
PCB209	2	6	4	0.06	0.06	2	0.09	0.105	0.105	0.12	0.02121	EW-31 0-2
PCB28	2	6	5	0.07	0.08	1	0.17	0.17	0.17	0.17	0	EW-36 2-4
PCB44	2	6	6	0.06	0.07	0	-	-	-	-	-	-
PCB52	2	6	6	0.06	0.07	0	-	-	-	-	-	-
PCB66	2	6	6	0.07	0.08	0	-	-	-	-	-	-
PCB77	2	6	6	0.1	0.11	0	-	-	-	-	-	-
PCB8	2	6	6	0.1	0.11	0	-	-	-	-	-	-
2,4'-DDD	2	6	6	0.06	0.07	0	-	-	-	-	-	-
2,4'-DDE	2	6	6	0.08	0.09	0	-	-	-	-	-	-
2,4'-DDT	2	6	6	0.07	0.08	0	-	-	-	-	-	-
4,4'-DDD	2	6	6	0.06	0.07	0	-	-	-	-	-	-
4,4'-DDE	2	6	5	0.05	0.06	1	0.19	0.19	0.19	0.19	0	EW-31 0-2
4,4'-DDT	2	6	6	0.06	0.06	0	-	-	-	-	-	-

Table 4-13. Statistical Summary of Sediment Core Sample Data for Area VIII (Eastern Wetland) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	2	6	0	-	-	6	42300	46000	45350	50200	3313	EW-31 2-4
Antimony	2	6	0	-	-	6	0.3	1.842	0.384	9.26	3.634	EW-36 0-2
Arsenic	2	6	0	-	-	6	5.8	7.53	7.085	10.1	1.59	EW-36 2-4
Barium	2	6	0	-	-	6	319	368.3	373	407	34.87	EW-36 4-6
Cadmium	2	6	0	-	-	6	0.104	0.141	0.131	0.204	0.03743	EW-36 2-4
Chromium	2	6	0	-	-	6	145	189.3	187	236	35.51	EW-36 0-2
Cobalt	2	6	0	-	-	6	12.4	14.53	14.75	17.3	1.805	EW-36 2-4
Copper	2	6	0	-	-	6	9.82	15.92	12.35	31	8.342	EW-36 0-2
Iron	2	6	0	-	-	6	23100	24680	24450	27000	1566	EW-36 0-2
Lead	2	6	0	-	-	6	5.73	10.93	9.15	20.2	5.781	EW-36 0-2
Manganese	2	6	0	-	-	6	510	560	560	630	44.1	EW-36 0-2
Mercury	2	6	0	-	-	6	0.0547	0.1484	0.1365	0.292	0.079	EW-31 4-6
Molybdenum	2	6	0	-	-	6	0.423	0.5353	0.521	0.666	0.09961	EW-31 4-6
Nickel	2	6	0	-	-	6	68.7	75.05	74.75	82	6.27	EW-36 0-2
Selenium	2	6	4	0.126	0.126	2	0.134	0.1435	0.1435	0.153	0.01344	EW-31 2-4
Silver	2	6	4	0.066	0.066	2	0.0826	0.3248	0.3248	0.567	0.3425	EW-36 4-6
Vanadium	2	6	0	-	-	6	69.3	78.1	78.6	87.1	6.44	EW-36 4-6
Zinc	2	6	0	-	-	6	38.5	51.25	45.2	84.7	17.13	EW-36 0-2
Benzo(a)anthracene	2	6	0	-	-	6	36.95	860	332	3634	1375	EW-31 4-6
Benzo(a)pyrene	2	6	0	-	-	6	56.79	984.7	387.3	4201	1591	EW-31 4-6
Benzo(b)fluoranthene	2	6	0	-	-	6	31.9	462.1	195.9	1934	728.9	EW-31 4-6
Benzo(g,h,i)perylene	2	6	0	-	-	6	43.77	565.3	233.9	2433	921	EW-31 4-6
Benzo(k)fluoranthene	2	6	0	-	-	6	36.28	611.7	254.4	2581	974.8	EW-31 4-6
Chrysene	2	6	0	-	-	6	40.35	893.9	327.6	3741	1414	EW-31 4-6
Dibenzo(a,h)anthracene	2	6	0	-	-	6	5.041	97.57	39.08	398.6	149.9	EW-31 4-6
Fluoranthene	2	6	0	-	-	6	86.7	2063	595.1	9735	3772	EW-31 4-6
Indeno(1,2,3-cd)pyrene	2	6	0	-	-	6	43.36	563.3	232.8	2377	896.8	EW-31 4-6
Pyrene	2	6	0	-	-	6	110.3	2532	766.6	11750	4534	EW-31 4-6
2-Methylnaphthalene	2	6	0	-	-	6	2.229	22.42	12.68	71.55	25.91	EW-31 4-6
Acenaphthene	2	6	0	-	-	6	3.287	24.41	7.719	100.9	38.03	EW-31 4-6
Acenaphthylene	2	6	0	-	-	6	3.689	162.7	32.92	753.2	292.7	EW-31 4-6
Anthracene	2	6	0	-	-	6	19.34	890	126.9	4512	1781	EW-31 4-6
Fluorene	2	6	0	-	-	6	5.122	227.1	33.28	1082	424	EW-31 4-6
Naphthalene	2	6	0	-	-	6	4.14	44.34	30.44	141.2	50.65	EW-31 4-6
Phenanthrene	2	6	0			6	55.83	2306	385.1	11410	4481	EW-31 4-6

Table 4-13. Statistical Summary of Sediment Core Sample Data for Area VIII (Eastern Wetland) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	2	6	6	0.04	0.05	0	-	-	-	-	-	-
Dieldrin	2	6	6	0.06	0.06	0	-	-	-	-	-	-
Endosulfan II	2	6	6	0.06	0.07	0	-	-	-	-	-	-
Endrin	2	6	6	0.05	0.06	0	-	-	-	-	-	-
Gamma-chlordane	2	6	6	0.05	0.05	0	-	-	-	-	-	-
Heptachlor	2	6	6	0.05	0.05	0	-	-	-	-	-	-
Dibutyltin	2	6	6	1.157	1.27	0	-	-	-	-	-	-
Monobutyltin	2	6	6	0.6121	0.6716	0	-	-	-	-	-	-
Tetrabutyltin	2	6	6	1.45	1.591	0	-	-	-	-	-	-
Tributyltin	2	6	6	0.8243	0.9045	0	-	-	-	-	-	-
Total organic carbon	2	6	1	3660	3660	5	2310	5012	3970	9360	2720	EW-36 2-4

Table 4-14. Statistical Summary of Sediment Core Sample Data for Area IX (Oil Reclamation)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	2	6	6	9.06	11.53	0	-	-	-	-	-	-
Aroclor-1221	2	6	6	9.06	11.53	0	-	-	-	-	-	-
Aroclor-1232	2	6	6	9.06	11.53	0	-	-	-	-	-	-
Aroclor-1242	2	6	6	9.06	11.53	0	-	-	-	-	-	-
Aroclor-1248	2	6	6	9.06	11.53	0	-	-	-	-	-	-
Aroclor-1254	2	6	6	9.06	11.53	0	-	-	-	-	-	-
Aroclor-1260	2	6	5	9.06	11.53	1	96.46	96.46	96.46	96.46	0	OR-28 0-2
PCB101	2	6	2	0.08	0.1	4	0.19	1.58	1.025	4.08	1.713	OR-28 0-2
PCB105	2	6	4	0.07	0.09	2	0.11	0.41	0.41	0.71	0.4243	OR-28 0-2
PCB110	2	6	2	0.09	0.11	4	0.17	1.072	0.76	2.6	1.056	OR-28 0-2
PCB118	2	6	3	0.09	0.11	3	0.21	0.8933	0.41	2.06	1.015	OR-28 0-2
PCB126	2	6	6	0.12	0.15	0	-	-	-	-	-	-
PCB128	2	6	6	0.15	0.2	0	-	-	-	-	-	-
PCB129	2	6	6	0.07	0.08	0	-	-	-	-	-	-
PCB138	2	6	2	0.08	0.09	4	0.56	2.863	1.215	8.46	3.765	OR-28 0-2
PCB153	2	6	2	0.12	0.14	4	0.82	4.995	2.82	13.52	5.788	OR-28 0-2
PCB170	2	6	2	0.08	0.09	4	0.19	1.415	0.435	4.6	2.132	OR-28 0-2
PCB18	2	6	5	0.06	0.08	1	0.06	0.06	0.06	0.06	0	OR-28 0-2
PCB180	2	6	2	0.08	0.1	4	0.52	3.13	1.85	8.3	3.508	OR-28 0-2
PCB187	2	6	2	0.08	0.09	4	0.25	2.002	1.405	4.95	2.04	OR-28 0-2
PCB195	2	6	3	0.07	0.08	3	0.15	0.46	0.35	0.88	0.3772	OR-28 0-2
PCB206	2	6	3	0.07	0.08	3	0.07	0.2567	0.24	0.46	0.1955	OR-28 0-2
PCB209	2	6	3	0.08	0.09	3	0.1	0.3467	0.31	0.63	0.2669	OR-24 4-6
PCB28	2	6	5	0.09	0.12	1	0.25	0.25	0.25	0.25	0	OR-28 0-2
PCB44	2	6	5	0.08	0.1	1	0.51	0.51	0.51	0.51	0	OR-28 0-2
PCB52	2	6	5	0.09	0.11	1	0.91	0.91	0.91	0.91	0	OR-28 0-2
PCB66	2	6	6	0.1	0.12	0	-	-	-	-	-	-
PCB77	2	6	6	0.14	0.17	0	-	-	-	-	-	-
PCB8	2	6	5	0.13	0.17	1	0.26	0.26	0.26	0.26	0	OR-28 0-2
2,4'-DDD	2	6	6	0.09	0.11	0	-	-	-	-	-	-
2,4'-DDE	2	6	6	0.11	0.14	0	-	-	-	-	-	-
2,4'-DDT	2	6	6	0.1	0.13	0	-	-	-	-	-	-
4,4'-DDD	2	6	4	0.08	0.09	2	0.77	0.975	0.975	1.18	0.2899	OR-28 0-2
4,4'-DDE	2	6	5	0.07	0.09	1	0.9	0.9	0.9	0.9	0	OR-28 0-2
4,4'-DDT	2	6	4	0.07	0.09	2	0.12	0.555	0.555	0.99	0.6152	OR-28 2-4

Table 4-14. Statistical Summary of Sediment Core Sample Data for Area IX (Oil Reclamation) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	2	6	0	-	-	6	68900	72830	72150	78100	3680	OR-28 2-4
Antimony	2	6	0	-	-	6	0.427	0.7577	0.615	1.33	0.3748	OR-28 0-2
Arsenic	2	6	0	-	-	6	11.2	13.2	13.2	15.3	1.367	OR-28 2-4
Barium	2	6	0	-	-	6	385	426.3	419	472	31.83	OR-28 2-4
Cadmium	2	6	0	-	-	6	0.341	0.3663	0.3675	0.4	0.02313	OR-28 0-2
Chromium	2	6	0	-	-	6	151	172.5	169	210	21.46	OR-28 0-2
Cobalt	2	6	0	-	-	6	16.1	18.52	18.7	20.8	1.777	OR-28 0-2
Copper	2	6	0	-	-	6	30.5	40.85	36.95	60.6	12.2	OR-28 0-2
Iron	2	6	0	-	-	6	46400	46780	46600	47800	545.6	OR-24 4-6
Lead	2	6	0	-	-	6	9.66	20.96	15.8	43.8	13.5	OR-28 0-2
Manganese	2	6	0	-	-	6	425	459.5	461	484	21.63	OR-24 0-2
Mercury	2	6	0	-	-	6	0.0555	0.27	0.181	0.589	0.2299	OR-28 2-4
Molybdenum	2	6	0	-	-	6	1.28	2.125	2.21	3.07	0.7523	OR-24 0-2
Nickel	2	6	0	-	-	6	84.8	96.22	95.75	116	11.28	OR-28 0-2
Selenium	2	6	0	-	-	6	0.429	0.486	0.481	0.581	0.0563	OR-28 4-6
Silver	2	6	0	-	-	6	0.13	0.2418	0.204	0.445	0.1189	OR-28 0-2
Vanadium	2	6	0	-	-	6	132	149.7	152	164	14.49	OR-28 2-4
Zinc	2	6	0	-	-	6	81.7	101.2	93.2	138	22.91	OR-28 0-2
Benzo(a)anthracene	2	6	0	-	-	6	1.512	199.4	73.23	727.4	284.4	OR-28 2-4
Benzo(a)pyrene	2	6	0	-	-	6	1.893	467.7	139	1749	689.9	OR-28 2-4
Benzo(b)fluoranthene	2	6	0	-	-	6	2.851	284.7	84.2	1067	420.2	OR-28 2-4
Benzo(g,h,i)perylene	2	6	0	-	-	6	2.875	464.5	132.3	1796	704.6	OR-28 2-4
Benzo(k)fluoranthene	2	6	0	-	-	6	1.316	264.2	86.39	958.5	379.1	OR-28 2-4
Chrysene	2	6	0	-	-	6	3.304	244.5	84.53	900.1	351.8	OR-28 2-4
Dibenzo(a,h)anthracene	2	6	0	-	-	6	0.4255	45.66	11.71	172.2	68.3	OR-28 2-4
Fluoranthene	2	6	0	-	-	6	3.449	406.6	153.9	1530	593.3	OR-28 2-4
Indeno(1,2,3-cd)pyrene	2	6	0	-	-	6	1.463	434	116	1686	663.8	OR-28 2-4
Pyrene	2	6	0	-	-	6	4.553	591.9	208.5	2224	866.2	OR-28 2-4
2-Methylnaphthalene	2	6	0	-	-	6	1.955	8.047	5.84	22	7.519	OR-28 2-4
Acenaphthene	2	6	1	0.34	0.34	5	0.1514	6.941	6.19	21.06	8.455	OR-28 2-4
Acenaphthylene	2	6	1	0.63	0.63	5	0.1601	18.1	8.68	58.08	23.82	OR-28 2-4
Anthracene	2	6	0	-	-	6	1.077	41.67	19.23	147.7	56.67	OR-28 2-4
Fluorene	2	6	0	-	-	6	1.467	10.23	5.615	32.92	12.06	OR-28 2-4
Naphthalene	2	6	1	1.842	1.842	5	3.454	40.59	16.84	129.6	52.72	OR-28 2-4
Phenanthrene	2	6	0	-	-	6	7.187	143.8	68.93	519.3	196.6	OR-28 2-4

Table 4-14. Statistical Summary of Sediment Core Sample Data for Area IX (Oil Reclamation) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	2	6	5	0.06	0.07	1	0.12	0.12	0.12	0.12	0	OR-28 0-2
Dieldrin	2	6	6	0.08	0.1	0	-	-	-	-	-	-
Endosulfan II	2	6	6	0.08	0.1	0	-	-	-	-	-	-
Endrin	2	6	6	0.07	0.09	0	-	-	-	-	-	-
Gamma-chlordane	2	6	5	0.06	0.08	1	0.09	0.09	0.09	0.09	0	OR-28 0-2
Heptachlor	2	6	6	0.07	0.08	0	-	-	-	-	-	-
Dibutyltin	2	6	5	1.618	1.996	1	6.21	6.21	6.21	6.21	0	OR-28 0-2
Monobutyltin	2	6	6	0.8559	1.056	0	-	-	-	-	-	-
Tetrabutyltin	2	6	6	2.027	2.502	0	-	-	-	-	-	-
Tributyltin	2	6	5	1.153	1.422	1	6.677	6.677	6.677	6.677	0	OR-28 0-2
Total organic carbon	2	6	0	-	-	6	9340	10210	10180	10900	598.1	OR-28 0-2

Table 4-15. Statistical Summary of Sediment Core Sample Data for Area X (South Basin)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aroclor-1016	8	24	24	9.02	13.7	0	-	-	-	-	-	-
Aroclor-1221	8	24	24	9.02	13.7	0	-	-	-	-	-	-
Aroclor-1232	8	24	24	9.02	13.7	0	-	-	-	-	-	-
Aroclor-1242	8	24	24	9.02	13.7	0	-	-	-	-	-	-
Aroclor-1248	8	24	24	9.02	13.7	0	-	-	-	-	-	-
Aroclor-1254	8	24	23	9.02	12.84	1	576.1	576.1	576.1	576.1	0	SB-20 2-4
Aroclor-1260	8	24	10	9.48	13.7	14	41.52	1250	909	4607	1463	SB-01 0-2
PCB101	8	24	3	0.09	0.09	21	0.07	55.27	16.42	346.7	93.12	SB-01 0-2
PCB105	8	24	9	0.07	0.1	15	0.08	16.91	10.5	68.4	20.76	SB-20 0-2
PCB110	8	24	3	0.1	0.1	21	0.1	48.34	12.82	229.1	70.03	SB-20 0-2
PCB118	8	24	3	0.1	0.1	21	0.09	38.03	8.47	217.8	62.54	SB-01 0-2
PCB126	8	24	24	0.12	0.18	0	-	-	-	-	-	-
PCB128	8	24	8	0.16	0.19	16	0.19	14.16	7.405	57.56	18.24	SB-20 0-2
PCB129	8	24	24	0.07	0.1	0	-	-	-	-	-	-
PCB138	8	24	3	0.08	0.09	21	0.22	82.88	25.46	445.1	130.8	SB-01 0-2
PCB153	8	24	3	0.12	0.13	21	0.22	119.5	31.67	736.9	200.7	SB-01 0-2
PCB170	8	24	3	0.08	0.08	21	0.12	31.51	6.83	184.1	52.96	SB-20 0-2
PCB18	8	24	10	0.06	0.08	14	0.07	1.049	0.77	2.56	0.8429	SB-20 0-2
PCB180	8	24	3	0.09	0.09	21	0.15	49.44	15.02	364	82.74	SB-01 0-2
PCB187	8	24	4	0.08	0.08	20	0.14	37.06	13.44	210.5	56.78	SB-01 0-2
PCB195	8	24	4	0.07	0.08	20	0.04	4.074	1.975	12.97	4.584	SB-01 0-2
PCB206	8	24	4	0.07	0.08	20	0.03	2.3	1.645	8.17	2.471	SB-12 0-2
PCB209	8	24	5	0.08	0.08	19	0.06	1.843	1.27	8.06	2.023	SB-12 0-2
PCB28	8	24	11	0.09	0.13	13	0.07	1.381	0.73	3.8	1.312	SB-12 0-2
PCB44	8	24	8	0.08	0.09	16	0.07	13.4	3.845	73.11	20.68	SB-01 0-2
PCB52	8	24	7	0.09	0.1	17	0.24	26.25	9.97	131.7	39.48	SB-01 0-2
PCB66	8	24	14	0.1	0.15	10	0.18	8.856	5.32	40.51	11.82	SB-01 0-2
PCB77	8	24	24	0.13	0.2	0	-	-	-	-	-	-
PCB8	8	24	16	0.13	0.2	8	0.22	1.112	1.11	1.95	0.7288	SB-03 0-2
2,4'-DDD	8	24	24	0.09	0.13	0	-	-	-	-	-	-
2,4'-DDE	8	24	24	0.11	0.16	0	-	-	-	-	-	-
2,4'-DDT	8	24	24	0.1	0.15	0	-	-	-	-	-	-
4,4'-DDD	8	24	10	0.08	0.11	14	0.57	12.01	6.83	65.35	16.95	SB-01 0-2
4,4'-DDE	8	24	6	0.07	0.08	18	0.04	26.82	13.62	146.3	37.52	SB-01 0-2
4,4'-DDT	8	24	15	0.07	0.11	9	0.4	16	0.74	135.3	44.76	SB-01 0-2

Table 4-15. Statistical Summary of Sediment Core Sample Data for Area X (South Basin) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Aluminum	8	24	0	-	-	24	63100	72520	73350	79400	3950	SB-12 2-4
Antimony	8	24	0	-	-	24	0.409	2.454	2.13	9.16	2.274	SB-20 0-2
Arsenic	8	24	0	-	-	24	11.3	15.03	15.2	17.5	1.656	SB-01 2-4
Barium	8	24	0	-	-	24	383	460.5	442.5	675	65.84	SB-01 0-2
Cadmium	8	24	0	-	-	24	0.223	1.643	1.45	4.69	1.298	SB-01 0-2
Chromium	8	24	0	-	-	24	154	305.1	248	792	165.8	SB-12 0-2
Cobalt	8	24	0	-	-	24	15.9	18.24	18.2	20.2	1.134	SB-20 0-2
Copper	8	24	0	-	-	24	28.8	87.67	76.9	242	60.44	SB-20 0-2
Iron	8	24	0	-	-	24	38900	49220	50000	53300	2924	SB-22 2-4
Lead	8	24	0	-	-	24	10.5	111.2	70.65	408	114.2	SB-01 0-2
Manganese	8	24	0	-	-	24	404	451.6	441.5	556	41.88	SB-16 0-2
Mercury	8	24	0	-	-	24	0.0734	0.611	0.5355	1.64	0.5054	SB-20 0-2
Molybdenum	8	24	0	-	-	24	0.805	2.691	2.675	3.4	0.5375	SB-20 4-6
Nickel	8	24	0	-	-	24	79.7	105.8	103.5	140	17.65	SB-12 0-2
Selenium	8	24	0	-	-	24	0.42	0.6188	0.5445	1.15	0.186	SB-01 0-2
Silver	8	24	0	-	-	24	0.113	0.5346	0.475	1.35	0.391	SB-20 2-4
Vanadium	8	24	0	-	-	24	125	153.5	154.5	180	14.08	SB-07 0-2
Zinc	8	24	0	-	-	24	77.3	224.1	185	481	143.1	SB-01 0-2
Benzo(a)anthracene	8	24	0	-	-	24	0.8043	118.9	119.9	278.2	97.07	SB-20 0-2
Benzo(a)pyrene	8	24	1	0.8595	0.8595	23	1.408	281.8	368.5	609.9	208.2	SB-22 4-6
Benzo(b)fluoranthene	8	24	0	-	-	24	2.273	181.9	219.3	385.1	140.4	SB-20 0-2
Benzo(g,h,i)perylene	8	24	0	-	-	24	2.287	270.4	307.5	671.6	208.5	SB-22 4-6
Benzo(k)fluoranthene	8	24	0	-	-	24	0.7565	164.7	186.2	370.2	129	SB-20 0-2
Chrysene	8	24	0	-	-	24	2.455	147.1	143.9	361.6	121.1	SB-20 0-2
Dibenzo(a,h)anthracene	8	24	0	-	-	24	0.2673	31.4	32.93	78.81	25.71	SB-20 0-2
Fluoranthene	8	24	0	-	-	24	1.764	217.4	231	504.6	178.8	SB-20 2-4
Indeno(1,2,3-cd)pyrene	8	24	0	-	-	24	0.9176	244.2	285.4	592.8	190.9	SB-22 4-6
Pyrene	8	24	0	-	-	24	2.633	402.9	395	885.1	332.4	SB-20 0-2
2-Methylnaphthalene	8	24	0	-	-	24	2.474	20.49	8.424	111.4	24.9	SB-01 0-2
Acenaphthene	8	24	0	-	-	24	0.1574	6.573	5.492	30.89	7.173	SB-20 2-4
Acenaphthylene	8	24	1	0.04449	0.04449	23	0.05954	13.67	14.03	28.53	10.52	SB-20 0-2
Anthracene	8	24	0	-	-	24	0.6198	35.57	28.75	138.6	36.54	SB-01 0-2
Fluorene	8	24	0	-	-	24	1.466	10.32	8.688	40.03	9.489	SB-20 2-4
Naphthalene	8	24	4	1.802	2.861	20	2.5	62.49	54.16	281.9	64.24	SB-20 2-4
Phenanthrene	8	24	0	-	-	24	6.048	76.69	74.71	230.4	62.56	SB-20 2-4

Table 4-15. Statistical Summary of Sediment Core Sample Data for Area X (South Basin) (continued)

Analyte	No. Cores	No. Samples	Non-detects			Detects						
			N	Minimum	Maximum	N	Minimum	Mean	Median	Maximum	Standard Deviation	Location of Max.
Alpha-chlordane	8	24	15	0.06	0.09	9	0.03	4.072	0.92	24.15	7.65	SB-01 0-2
Dieldrin	8	24	18	0.08	0.12	6	1.49	26.19	4.55	128.5	50.38	SB-01 0-2
Endosulfan II	8	24	24	0.08	0.12	0	-	-	-	-	-	-
Endrin	8	24	24	0.07	0.11	0	-	-	-	-	-	-
Gamma-chlordane	8	24	15	0.06	0.09	9	0.08	8.52	3.14	40.35	12.62	SB-01 0-2
Heptachlor	8	24	24	0.07	0.1	0						
Dibutyltin	8	24	18	1.587	2.435	6	3.001	10.58	10.75	16.63	5.269	SB-20 0-2
Monobutyltin	8	24	24	0.8395	1.288	0	-	-	-	-	-	-
Tetrabutyltin	8	24	24	1.989	3.051	0	-	-	-	-	-	-
Tributyltin	8	24	18	1.131	1.735	6	1.784	9.185	8.936	19.46	6.637	SB-20 0-2
Total organic carbon	8	24	0	-	-	24	9160	13640	12050	24200	4418	SB-20 2-4

Table 4-16. Summary of Metals Exceeding ER-Ms in Sediment Core Samples

Station	Depth	Unit	Concentration in mg/kg dry weight					
			Hg	Cu	Pb	Cr	Ni[(a)]	Zn
ER-M			0.71	270	218	370	112	410
Area I (India Basin)								
IB-56	0-5	cm	0.312	43.7 J	25.4 J	163	62.2	47 J
IB-56	0-2	ft	0.391 J	66.2	70.2	191	118	135
IB-56	2-4	ft	**0.719** J	68.5 J	83.2 J	182	112	138 J
IB-56	4-6	ft	0.324 J	46 J	34.4 J	151	90.5	88.4 J
Area III (Point Avisadero)								
PA-40	0-5	cm	0.257	57.7 J	23.6 J	163	90.5 J	115
PA-40	0-2	ft	0.369 J	**490** J	120 J	368	90.6	**425** J
PA-40	2-4	ft	0.433 J	**326** J	**583** J	**913**	***223***	214 J
PA-41	0-5	cm	0.478	**525** J	109 J	349	119 J	207
PA-41	0-2	ft	**2.09** J	**1980** J	153 J	**430**	***153***	**557** J
PA-41	2-4	ft	**1.84** J	**2150** J	103 J	205	131	260 J
PA-41	4-6	ft	**0.846** J	199 J	56.6 J	173	118	154 J
PA-44	0-5	cm	**1.51**	163 J	25.9 J	275	93.6 J	108
PA-44	0-2	ft	**2.1** J	125 J	161 J	167	105	93.8 J
PA-44	2-4	ft	0.0866 J	43.1 J	17.7 J	159	110	93.2 J
PA-44	4-6	ft	0.0739 J	43.9 J	**247** J	159	113	96.5 J
PA-47	0-5	cm	**7.47**	**1050** J	**275** J	291	117 J	322
PA-47	0-2	ft	**43.1** J	**780** J	101 J	330	***154***	367 J
PA-47	2-4	ft	0.124 J	31.2 J	11.2 J	152	96.3	83.5 J
PA-47	4-6	ft	0.082 J	29.6 J	11.1 J	175	136	79.7 J
Area X (South Basin)								
SB-01	0-5	cm	0.553 J	69.8	121	202	76.6	188
SB-01	0-2	ft	**1.11**	129 J	**408** J	336	96.2 J	**481**
SB-01	2-4	ft	0.709 J	84.3	149	278	106	268
SB-01	4-6	ft	0.0929	29.3 J	11 J	181	79.7 J	84.5
SB-03	0-5	cm	0.466 J	74.4	69.3	171	104	164
SB-03	0-2	ft	**0.845**	114 J	200 J	302	110 J	302
SB-03	2-4	ft	0.328 J	46.6	34.5	194	98.9	133
SB-03	4-6	ft	0.0734 J	30	10.7	170	85.4	84.5
SB-06	0-5	cm	0.497 J	76.9	65.3	198	104	185
SB-06	0-2	ft	**0.856** J	122	153	**466**	115	293
SB-06	2-4	ft	0.436 J	56.7	47.8	211	99.1	160
SB-06	4-6	ft	0.0749 J	30.7 J	10.5 J	161	93.5	81.8 J
SB-07	0-5	cm	0.647 J	80.1	88.9	209	104	186
SB-07	0-2	ft	**1.12** J	156	**284**	**448**	121	**451**
SB-07	2-4	ft	0.668 J	76.7	100	285	108	243
SB-07	4-6	ft	0.0827 J	30.7	11.1	160	86.1	84.5
SB-12	0-5	cm	0.620	95.5 J	90.8 J	212	107 J	199
SB-12	0-2	ft	**1.31** J	196 J	128 J	**792**	140	**430** J
SB-12	2-4	ft	**0.925** J	104 J	11.4 J	364	123	288 J
SB-12	4-6	ft	0.09 J	28.8 J	272 J	154	88.8	77.3 J

Table 4-16. Summary of Metals Exceeding ER-Ms in Sediment Core Samples (continued)

Station	Depth	Unit	Concentration in mg/kg dry weight					
			Hg	Cu	Pb	Cr	Ni	Zn
SB-16	0-5	cm	**0.79** J	173	139	451	199	228
SB-16	0-2	ft	0.314 J	92	46.2	218	106	137
SB-16	2-4	ft	0.111 J	34.5	15.7	208	90.1	89.7
SB-16	4-6	ft	0.200 J	41.3	25.6	198	101	109
SB-20	0-5	cm	**1.06** J	133	106	225	118	215
SB-20	0-2	ft	**1.64** J	242	**316**	**593**	138	**467**
SB-20	2-4	ft	**1.59** J	154	172	**576**	124	**441**
SB-20	4-6	ft	0.127 J	31	14.8	168	83.7	85.7
SB-22	0-5	cm	**1.26** J	163	142	256	130	243
SB-22	0-2	ft	**1.10** J	160	133	348	131	275
SB-22	2-4	ft	0.635 J	77.1	93.5	338	123	210
SB-22	4-6	ft	0.226 J	37.4	20.8	174	91.9	103

(a) All nickel values exceed the ER-M; bold italicized values exceed the ambient threshold value for San Francisco Bay.
Values above the ER-M are shown in bold.
J = estimated value.

location and with chemical. Metals concentrations generally were higher at Stations PA-41 and PA-47 than at Stations PA-40 and PA-44. At Station PA-47, the highest concentrations were found in the collocated 0-5 cm surface sediment sample with the exception of mercury, which was measured at a concentration of 7.47 mg/kg in the surface sample and 43.1 mg/kg in the 0-2 ft sample. The mercury concentration dropped to less than 0.2 mg/kg in the 2-4 ft sample.

Some metals exceeded the ER-M in the deepest interval analyzed (4-6 ft) at Stations PA-41 (mercury) and PA-44 (lead). Copper, lead, and chromium exceeded the ER-M in the 2-4 ft sample from PA-40; samples could not be collected below 4 ft because of the presence of a hard object (i.e., debris) below that depth.

In Area X, the highest metals concentrations were found in the 0-2 ft core interval with the exception of mercury at SB-16 and SB-22, where the highest concentrations were found in the collocated 0-5 cm surface sediment sample. Highest concentrations generally were found in the samples from Stations SB-20 on the eastern side of South Basin and SB-01 near the mouth of Yosemite Creek.

Metals concentrations in Area X did not exceed the ER-M in any of the 4-6 ft core samples, and few exceeded the ER-M below the 0-2 ft interval. Mercury was at or near the ER-M in the 2-4 ft samples from Stations SB-01 and SB-12; and mercury, chromium, and zinc exceeded the ER-M in the 2-4 ft sample from Station SB-20.

4.2.3 Organic Chemicals

Complete results for organic chemicals in sediment core samples are presented in Tables B-13 through B-18 (Appendix B). Calculated values for total PCBs, DDx, LPAH, and HPAH are provided in Table B-42 (Appendix B). Statistical summaries of organic constituents in sediment core samples are provided in Tables 4-11 through 4-15. Total PCBs, total DDx, dieldrin, and PAHs were found to exceed the ER-M in core samples at more than one HPS station. TBT was found to exceed the benchmark value of 25.1 µg/kg in core samples at more than one station. Table 4-17 summarizes the data for those chemicals in core samples where ER-Ms were exceeded (individual DDx compounds were not

Table 4-17. Summary of Organic Chemicals Exceeding ER-Ms in Sediment Core Samples

Station	Depth	Concentration in µg/kg dry weight					
		Total PCBs[a]	Total DDx[b]	Dieldrin	Total LPAH[c]	Total HPAH[d]	TBT
Area III (Point Avisadero)							
PA-40	0-5 cm	29.7	2.86	0.11 U	217	1,036	**72.9**
PA-40	0-2 ft	101	1.49	0.06 U	256	1,255	**850** D
PA-40	2-4 ft	122	1.28	0.06 U	202	961	**1008** D
PA-41	0-5 cm	**704**	3.86	0.1 U	1225	4,670	**208** D
PA-41	0-2 ft	**314**	8.89	0.08 U	775	3,177	**1024** D
PA-41	2-4 ft	**213**	5.58	0.09 U	1039	4,637	1.31 U
PA-41	4-6 ft	5.34	ND	0.09 U	898	4,175	1.33 U
PA-44	0-5 cm	67.6	3.09	0.08 UJ	560	2,554	**103**
PA-44	0-2 ft	10.5	0.20	0.09 U	118	400	**67.1**
PA-44	2-4 ft	ND	ND	0.09 U	7.75	2.24	1.30 U
PA-44	4-6 ft	1.10	ND	0.09 U	13.2	14.9	1.33 U
PA-47	0-5 cm	112	3.13	0.09 U	757	3,285	**114**
PA-47	0-2 ft	49.8	3.00	0.08 U	532	3,242	**138** D
PA-47	2-4 ft	0.08	ND	0.09 U	14.5	10.5	1.28 U
PA-47	4-6 ft	ND	ND	0.08 U	10.8	4.70	1.23 U
PA-52	0-5 cm	14.7	1.42	0.09 U	1187	4,329	1.26 U
PA-52	0-2 ft	8.26	1.36	0.08 U	1500	4,915	12.4
PA-52	2-4 ft	29.0	1.39	0.08 U	2611	8,192	20.1
PA-52	4-6 ft	30.9	1.71	0.08 U	2737	**10,027**	**33.1**
Area VIII (Eastern Wetland)							
EW-31	0-5 cm	11.8	0.2	0.06 U	46.8	347	0.85 U
EW-31	0-2 ft	26.2	0.19	0.06 U	694	1,853	0.90 U
EW-31	2-4 ft	0.80	ND	0.06 U	561	3,042	0.88 U
EW-31	4-6 ft	ND	ND	0.06 U	**18,070**	**33,458**	0.90 U
Area IX (Oil Reclamation)							
OR-24	0-5 cm	**425**	4.19	0.44 J	250	1,259	**65.9**
OR-24	0-2 ft	5.40	ND	0.08 U	52.8	199	1.19 U
OR-24	2-4 ft	ND	ND	0.08 U	12.0	15.1	1.15 U
OR-24	4-6 ft	24.8	ND	0.08 U	348	2,994	1.19 U
OR-28	0-5 cm	87.2	2.36	0.11 U	136	942	10.1
OR-28	0-2 ft	106	2.20	0.1 U	182	1,143	6.68
OR-28	2-4 ft	17.8	1.76	0.1 U	931	7,303	1.42 U
OR-28	4-6 ft	ND	ND	0.09 U	25.0	81.6	1.36 U
Area X (South Basin)							
SB-01	0-5 cm	557	17.2	4.21	241	1,257	3.08
SB-01	0-2 ft	**6,194**	**347**	**129** D	556	2,179	11.9
SB-01	2-4 ft	**780**	**48.6**	0.1 U	393	2,449	1.44 U
SB-01	4-6 ft	7.76	0.18	0.08 U	17.2	13.7	1.22 U
SB-03	0-5 cm	180	4.46	0.12 U	139	799	3.08

Table 4-17. Summary of Organic Chemicals Exceeding ER-Ms in Sediment Core Samples (continued)

Station	Depth	Concentration in µg/kg dry weight					
		Total PCBs	Total 4,4′-DDx	Dieldrin	Total LPAH	Total HPAH[(a)]	TBT
SB-03	0-2 ft	**1,706**	41.2	4.16	291	1,399	1.47 U
SB-03	2-4 ft	58.7	1.86	0.09 U	144	1,001	1.36 U
SB-03	4-6 ft	1.94	0.04	0.08 U	13.3	10.3	1.21 U
SB-06	0-5 cm	113	2.45	0.12 U	38.7	262	15.0
SB-06	0-2 ft	**1,278**	38.9	2.3	324	1,841	1.52 U
SB-06	2-4 ft	51.8	3.63	0.1 U	83.0	615	1.36 U
SB-06	4-6 ft	ND	ND	0.08 U	10.8	7.93	1.78
SB-07	0-5 cm	**425**	9.49	1.33	267	1,246	12.7
SB-07	0-2 ft	**1,262**	40.9	0.11 U	284	1,760	1.53 U
SB-07	2-4 ft	**332**	35.5	0.1 U	277	2,162	1.53 U
SB-07	4-6 ft	ND	ND	0.08 U	13.6	21.8	1.24 U
SB-12	0-5 cm	**681**	13.1	2.11	185	1,151	15.4
SB-12	0-2 ft	**2,577**	**101**	**15.8**	346	1,828	12.5
SB-12	2-4 ft	**204**	**55.0**	0.11 U	293	1,785	1.61 U
SB-12	4-6 ft	ND	ND	0.08 U	16.9	16.3	1.21 U
SB-16	0-5 cm	**1,786**	5.09	0.08 UR	276	2,409	11.1
SB-16	0-2 ft	**744**	3.26	0.08 U	57.3	316	3.53
SB-16	2-4 ft	52.9	ND	0.08 U	34.8	217	1.13 U
SB-16	4-6 ft	43.6	ND	0.09 U	63.0	357	1.29 U
SB-20	0-5 cm	**1,565**	15.8	3.63	281	1,666	**27.6**
SB-20	0-2 ft	**4,877**	34.8	1.49	532	2,632	19.5
SB-20	2-4 ft	**537**	20.6	0.12 U	733	2,252	1.73 U
SB-20	4-6 ft	8.24	0.14	0.09 U	42.2	241	1.25 U
SB-22	0-5 cm	**1,817**	10.2	2.75 J	235	1,583	**57.6**
SB-22	0-2 ft	**1,332**	22.4	4.94	244	2,098	6.02
SB-22	2-4 ft	144	0.42	0.11 U	153	1,052	1.59 U
SB-22	4-6 ft	6.08	ND	0.09 U	235	2,254	1.32 U

(a) Two times sum of 22 congeners.
(b) Sum of 4,4′-DDD, 4,4′-DDE and 4,4′-DDT.
(c) Sum of 7 individual LPAHs.
(d) Sum of 6 individual HPAHs.
U = not detected at or above the given detection limit.
D = Concentration measured in diluted sample.
ND = not detected.
Bold values exceed ER-M except for TBT, where they exceed screening value (Roy F. Weston, 1996).

tabulated). *alpha*-Chlordane was measured above the ER-M in a sample from Station SB-01 at the mouth of Yosemite Creek. All organic COPEC concentrations were below ER-Ms in core samples from Area I.

In Area III, organic COPECs were found to exceed the ER-M in samples from Stations PA-40, PA-41, PA-44, and PA-47, which are the same stations at which metals in core samples were elevated above ER-Ms. In addition, HPAHs and TBT levels exceeding the ER-M and TBT benchmark value, respectively, were found at depth at Station PA-52, at the eastern edge of Area III. As with the metals, the depth of the maximum concentration varied with location and chemical. All organic COPEC concentrations

were below the ER-M in the 4-6 ft samples except for HPAHs and TBT (measured above the screening value) at Station PA-52. Organic COPEC concentrations also were below the ER-M in the 2-4 ft samples except for PCBs at Station PA-41 and TBT (detected above the screening value) at Station PA-40.

In Area VIII, HPAH and LPAH concentrations exceeded the ER-M in the 4-6 ft sample from Station EW-31. In Area IX, total PCBs exceeded the ER-M and TBT exceeded the screening value in the station surface sediment sample from Station OR-24. All of the collocated core samples were below the threshold values. Total HPAHs exceeded the ER-M in the 2-4 ft sample from OR-28; concentrations above and below that interval were much lower.

In Area X, PCBs were measured at concentrations above the ER-M in all eight core samples. PCB concentrations were highest in the 0-2 ft samples except at Stations SB-16 and SB-22, where concentrations were highest in the collocated surface sediment sample. PCB concentrations decreased below 2 ft, and were below the ER-M in the 4-6 ft samples from all Area X stations.

PCB concentrations in the eight Area X cores are shown in Figure 4-13. The PCB concentration in each sample is proportional to the bubble size. This figure shows that the highest concentrations are found in the 0-2 ft interval with lower concentrations in the upper 5 cm. The highest concentrations are found along the eastern shore of South Basin and at the mouth of Yosemite Creek, with concentrations decreasing toward the center of Area X.

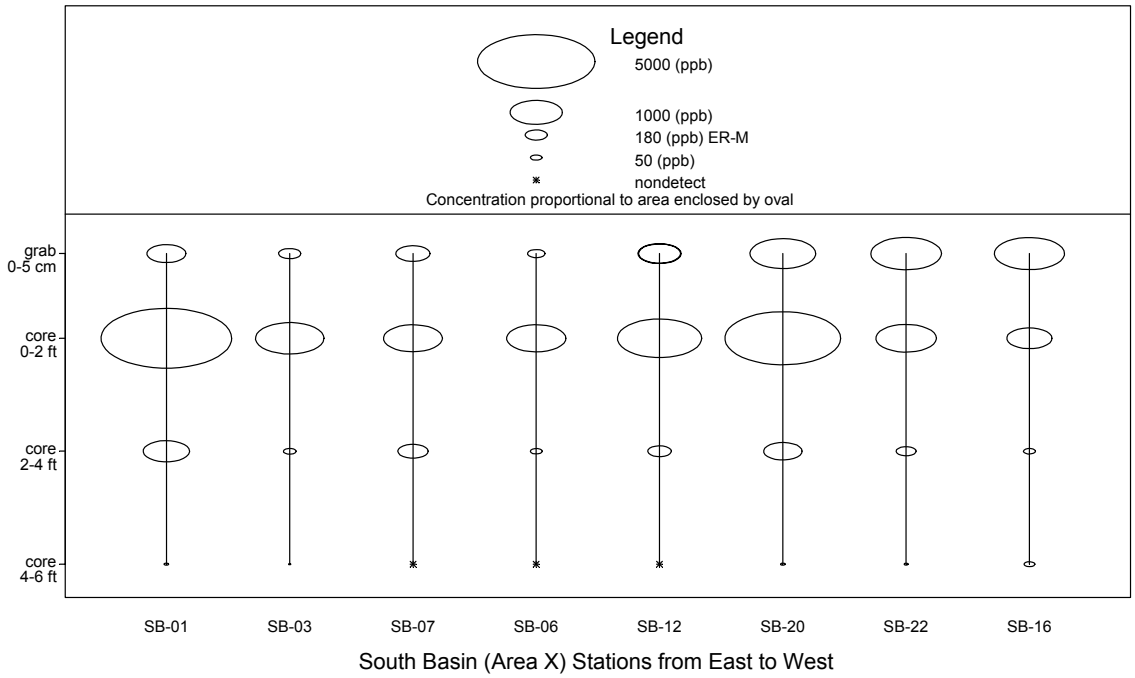


Figure 4-13. Total PCB Concentrations in Surface and Subsurface Sediment Samples from Area X

Total DDx and dieldrin concentrations in Area X were highest in the 0-2 ft sample from SB-01 near the mouth of Yosemite Creek. These pesticides also exceeded ER-Ms in the 0-2 ft and 2-4 ft samples from Station SB-12. TBT concentrations exceeded the screening value of 25.1 µg/kg in the collocated surface sediment samples from Stations SB-20 and SB-22 near the eastern shore of South Basin.

4.3 Nature and Extent of Contamination

Surface sediment chemistry results for the five study areas indicate that chemical concentrations generally are not elevated above ambient levels and ER-Ms in Areas I and VIII. The highest chemical concentrations (primarily PCBs, TBT, and metals) are found in Areas III and X. Some nearshore stations in Area IX showed elevated concentrations of PCBs, TBT, and chromium.

ERM-Qs were calculated for each sediment sample following the procedure outlined in Appendix F to provide a single indicator value for each station (Table 4-18). A box plot of ERM-Q values is presented in Figure 4-14, and the spatial distribution of ERM-Qs is shown in Figure 4-15. The threshold values of 0.3, 0.5, and 1.25 shown in the box plot are related to the WOE scoring criteria presented in Section 8.0. The distribution of ERM-Qs in surface sediment is consistent with the observations noted above: the highest chemical concentrations in sediment are found in Area III, Area X, and at a few stations in Area IX.

Table 4-18. ERM-Qs for Surface Sediment Samples

Area	Station	ERM-Q
Reference Sites		
Alameda Buoy	AB-67	0.209
Alcatraz Environs	AL-64	0.081
Bay Farm Borrow Pit	BF-66	0.202
Paradise Cove	PC-63	0.191
Red Rock	RR-65	0.128
Area I (India Basin)		
Area I	IB-54	0.191
Area I	IB-55	0.343
Area I	IB-56	0.196
Area I	IB-57	0.179
Area I	IB-58	0.181
Area I	IB-59	0.410
Area III (Point Avisadero)		
Area III	PA-38	0.527
Area III	PA-39	0.576
Area III	PA-40	0.327
Area III	PA-41	0.953
Area III	PA-42	0.775
Area III	PA-43	0.222
Area III	PA-44	0.553
Area III	PA-45	1.222
Area III	PA-46	0.692
Area III	PA-47	1.196
Area III	PA-48	0.236
Area III	PA-49	0.215
Area III	PA-50	0.222
Area III	PA-51	0.188
Area III	PA-52	0.211
Area III	PA-53	0.239

Table 4-18. ERM-Qs for Surface Sediment Samples (continued)

Area	Station	ERM-Q
Area VIII (Eastern Wetland)		
Area VIII	EW-30	0.152
Area VIII	EW-31	0.113
Area VIII	EW-32	0.220
Area VIII	EW-33	0.130
Area VIII	EW-34	0.134
Area VIII	EW-35	0.213
Area VIII	EW-36	0.129
Area VIII	EW-37	0.192
Area IX (Oil Reclamation)		
Area IX	OR-24	0.558
Area IX	OR-25	0.236
Area IX	OR-26	0.403
Area IX	OR-27	0.380
Area IX	OR-28	0.254
Area IX	OR-29	0.258
Area X (South Basin)		
Area X	SB-01	0.473
Area X	SB-02	0.706
Area X	SB-03	0.294
Area X	SB-04	0.359
Area X	SB-05	0.362
Area X	SB-06	0.293
Area X	SB-07	0.430
Area X	SB-08	0.402
Area X	SB-09	0.337
Area X	SB-10	0.605
Area X	SB-11	0.682
Area X	SB-12	0.526
Area X	SB-13	0.616
Area X	SB-14	0.568
Area X	SB-15	0.398
Area X	SB-16	1.069
Area X	SB-17	0.734
Area X	SB-18	0.497
Area X	SB-19	1.057
Area X	SB-20	0.854
Area X	SB-21	2.020
Area X	SB-22	0.989
Area X	SB-23	1.50

Chemical concentrations in sediments from Areas I and VIII are lower and generally similar to ambient conditions. Figure 4-16 shows the distribution of ERM-Qs in core samples. In general, the highest values are associated with the 0-2 ft core samples. The nature and extent of contamination in Areas III and X are discussed further below.

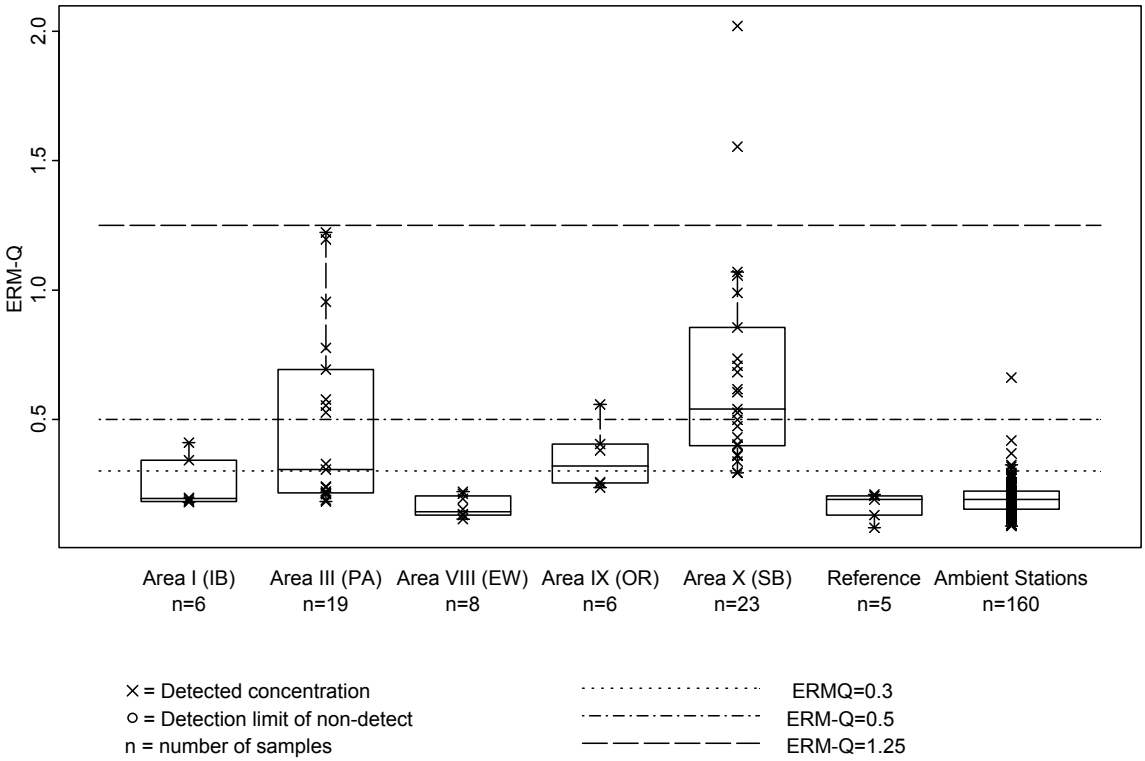


Figure 4-14. Box Plot of ERM-Qs in Surface Sediment Samples

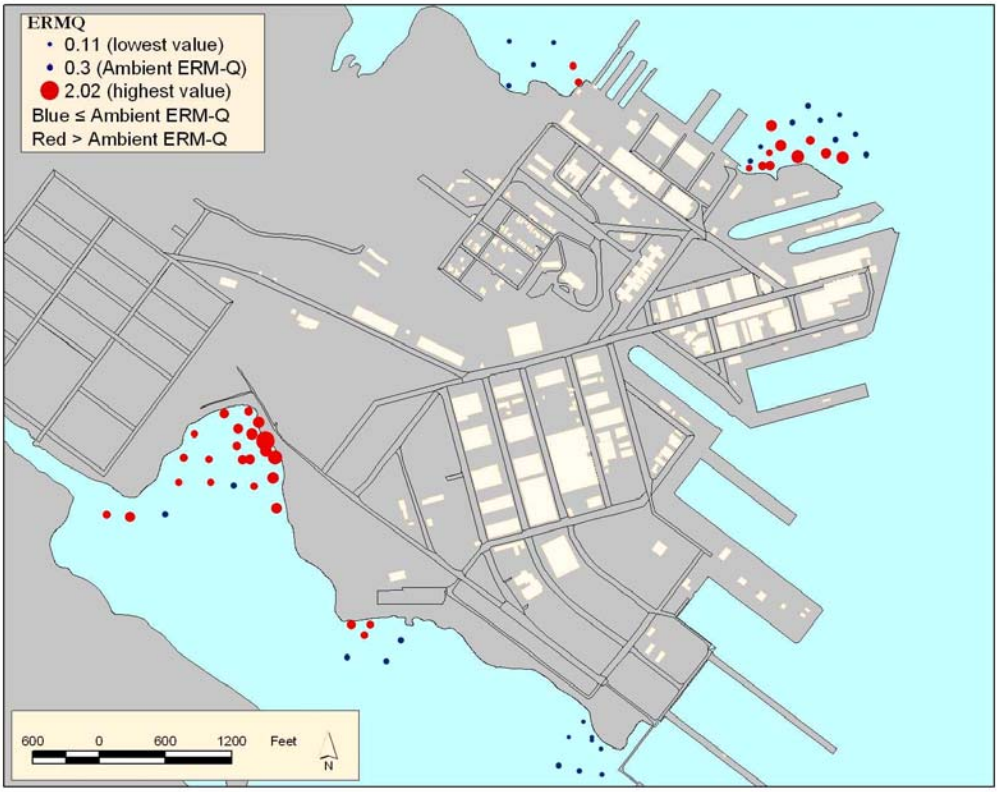


Figure 4-15. Distribution of ERM-Qs in Surface Sediment Samples

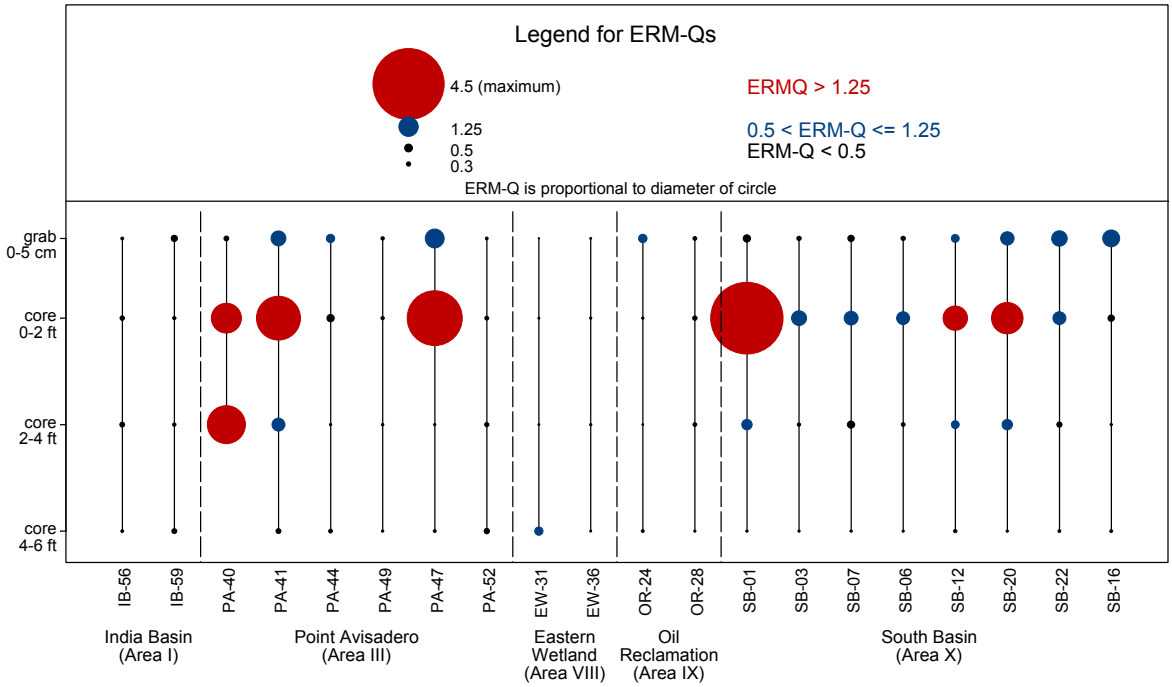


Figure 4-16. Distribution of ERM-Qs in Sediment Core Samples

4.3.1 Area III (Point Avisadero)

The primary COPECs detected at elevated concentrations in sediment samples from Area III include copper, lead, mercury, TBT, and PCBs. These chemicals most likely were derived from ship painting and maintenance activities associated with the adjacent dry docks. As noted in Section 1.2, a discharge tunnel leads north from Dry Docks 2 and 3 into Area III (see Figure 1-4). The two cores that were collected closest to the outfall from this tunnel (PA-40 and PA-41) contained black, gritty sand in the upper 2 ft, which indicates that sandblast grit may have been discharged from this tunnel. Some contaminants also may have been discharged into the offshore area from stormwater outfalls (see Figure 1-4). However, the horizontal and vertical distribution of chemicals in Area III sediments is patchy and discontinuous, rather than occurring as a gradient away from a well-defined source, and many COPECs do not co-occur. For example, the highest metals concentrations were found in samples from Station PA-47, whereas the highest PCB concentration was found in the surface sediment sample from Station PA-45. The highest surface concentrations of PAHs were found in samples from Stations PA-41, PA-52, and PA-53. The depth of the highest chemical concentrations was not consistent from one station to another or from one COPEC to another.

The variable and patchy distribution of contaminants at Area III suggests that this area is dynamic, and is affected by episodic input of contaminants and subsequent redistribution by waves and currents. The Parcel F sediment dynamics study (see Appendix L) measured significant resuspension and transport of sediment by spring tidal currents north of the drainage tunnel outlet (in the vicinity of Stations PA-41 and PA-42), with the direction of net transport to the east-southeast. If contaminants were discharged via the drainage tunnel from Dry Docks 2 and 3, they may have subsequently been transported in this direction.

4.3.2 Area X (South Basin)

In Area X, the highest concentrations of PCBs, TBT, and metals (primarily copper, mercury, and lead) are found along the eastern shoreline of South Basin. Chemical concentrations decrease with increasing

distance from this shoreline. The most likely sources of these contaminants appear to be the Site IR-01/21 landfill area, material used to fill the shoreline area from the 1940s to the 1960s, and/or a historical drum storage area used by the Triple A Machine Shop (see Figure 1-7). Contaminants most likely were transported to the offshore area via erosion and transport of contaminated Parcel E soils or fill material in and near the landfill and drum storage area. Shoreline debris is another possible source of contaminants to South Basin. As noted in Section 1.2, these potential sources were investigated further as part of the Parcel E data gap sampling in spring 2002 (TtEMI, 2003b). The Parcel E data gaps investigation confirmed that the highest PCBS concentrations along the Parcel E shoreline are located in the immediate vicinity of the highest concentrations of PCBs in Area X surface sediments.

Sediment core data indicate that the highest concentrations of PCBs and metals (copper, mercury, and lead) generally were found in the 0-2 ft core sample except at Stations SB-16 and SB-22, where the highest concentrations were measured in the collocated 0-5 cm surface sediment sample. Concentrations were significantly lower in the 2-4 ft and 4-6 ft core samples from all stations. The relatively lower concentrations in the surface (i.e., 0-5 cm) samples at most of the stations compared with concentrations in the 0-2 ft interval suggest that burial by relatively cleaner sediment has occurred.

Concentrations of PCBs, metals, and some pesticides were elevated in samples collected near the mouth of Yosemite Creek (Stations SB-01 and SB-02). The highest total PCB concentration on the site was measured in the 0-2 ft core sample from SB-01 (6.2 mg/kg); the highest concentrations of total DDx and dieldrin also were measured in this sample (Table 4-17). These contaminants most likely were transported into South Basin via Yosemite Creek and were not derived from activities near Parcel E based on the following observations:

- Chemical concentrations are lower in the area between Yosemite Creek and the eastern shoreline of South Basin (i.e., no concentration gradient leads to an obvious Navy-related source).

- Sediment transport measurements in South Basin indicate that currents are weak in South Basin (see Appendix L); therefore, significant upstream transport of sediment-associated contaminants is unlikely.

- Contamination has been detected previously in samples collected from Yosemite Creek upstream of HPS as part of the BPTCP (see Section 1.2).

- The composition of the PCBs in samples collected near and from Yosemite Creek appears to be different than the composition of PCBs occurring near the eastern shoreline of South Basin. These differences are discussed further in Section 4.3.3.

4.3.3 Composition of PCBs in South Basin

The patterns of specific PCB congeners in sediment samples can be compared to standard Aroclor formulations in order to provide information related to potential source(s), the environmental significance of the PCB contamination, and changes that may have occurred since the PCBs were released to the environment. A perfect or close match between the PCB composition of a field sample and an Aroclor formulation is rarely observed, because PCB contamination commonly is the result of multiple sources (including atmospheric deposition and runoff), and the PCB composition begins to change as soon as the material enters the environment. Also, selective PCB congener alterations occur due to weathering processes (e.g., as a result of selective water solubility, adsorption to solid matter, and evaporation), microbial degradation, and dechlorination processes. Typically, a given PCB congener composition changes over time substantially from the original Aroclor formulations that were released. However, a review and analysis

of the PCB composition of a field sample can provide insight into the nature of PCB contamination at a site.

Similarities and differences in the PCB compositions of samples from Area X (South Basin) and Yosemite Creek were evaluated using exploratory data analysis techniques, including principal component analysis (PCA). PCA algorithms reduce large and complex data sets to a suite of views that are used to explore the variability among the PCB composition in the samples. One type of PCA output is a two- or three-dimensional factor score plot, on which the principal component scores for each sample are cross-plotted. If a significant portion of the variance in the dataset is accommodated in the first few principal components, then the Euclidean distances between sample points on such plots (e.g., PC1 vs. PC2, or PC2 vs. PC3) provide a clear measure of their chemical similarity. Samples which visually "cluster" are chemically similar.

PCA analyses initially were conducted on surface sediment and cores samples from Area X using data from the Validation Study. The PCB congener data were normalized to the total PCB concentration of the sample, which formatted the data for strict relative compositional analysis independent of the absolute concentration. The analysis was performed using the 18 noncoplanar congeners used in the NOAA NS&T program and the Aroclor formulations included in the dataset. Selected parameters (i.e., PCB congeners 8 and 209, and Aroclors 1221, 1262, and 1268) were excluded from the analysis in order to focus on the most significant compositional differences. Two-dimensional factor score plots were generated, on which the principal component scores for each sample were cross-plotted. This analysis indicated an apparent difference between the relative concentrations of congeners in samples from the eastern shore of Area X and samples collected near the mouth of Yosemite Creek.

To validate this observation, recent data collected by the City of San Francisco were obtained and incorporated into the PCA analysis (ADL, 1999). The results of the PCA analysis are presented in Figure 4-17, with principal component 1 (PC1) plotted versus principal component 2 (PC2). The congener mixtures comprising technical-grade Aroclors also were plotted.

Overall, the PCA analyses indicate an apparent trend in compositional variation. The main body of data ranges from approximately a pure Aroclor 1260 composition to that of a 50/50 mix of Aroclors 1254 and 1260. Samples on the east side of Area X (near Station SB-23) plot closest to an Aroclor 1260 composition, and those from the west side of Area X near Yosemite Creek plot closest to the Aroclor 1254/1260 mixture. The highest concentrations of relatively pure Aroclor 1260 composition are present in surface samples along the eastern shore of Area X. An Aroclor 1254 composition appears to exist in the western side of Area X and in Yosemite Creek, although some of these compositional differences may be related to weathering and dechlorination of Aroclor 1260. Additional analysis of PCB composition in South Basin is included in the *Parcel F FS Data Gaps Technical Memorandum* (Battelle et al., 2005).

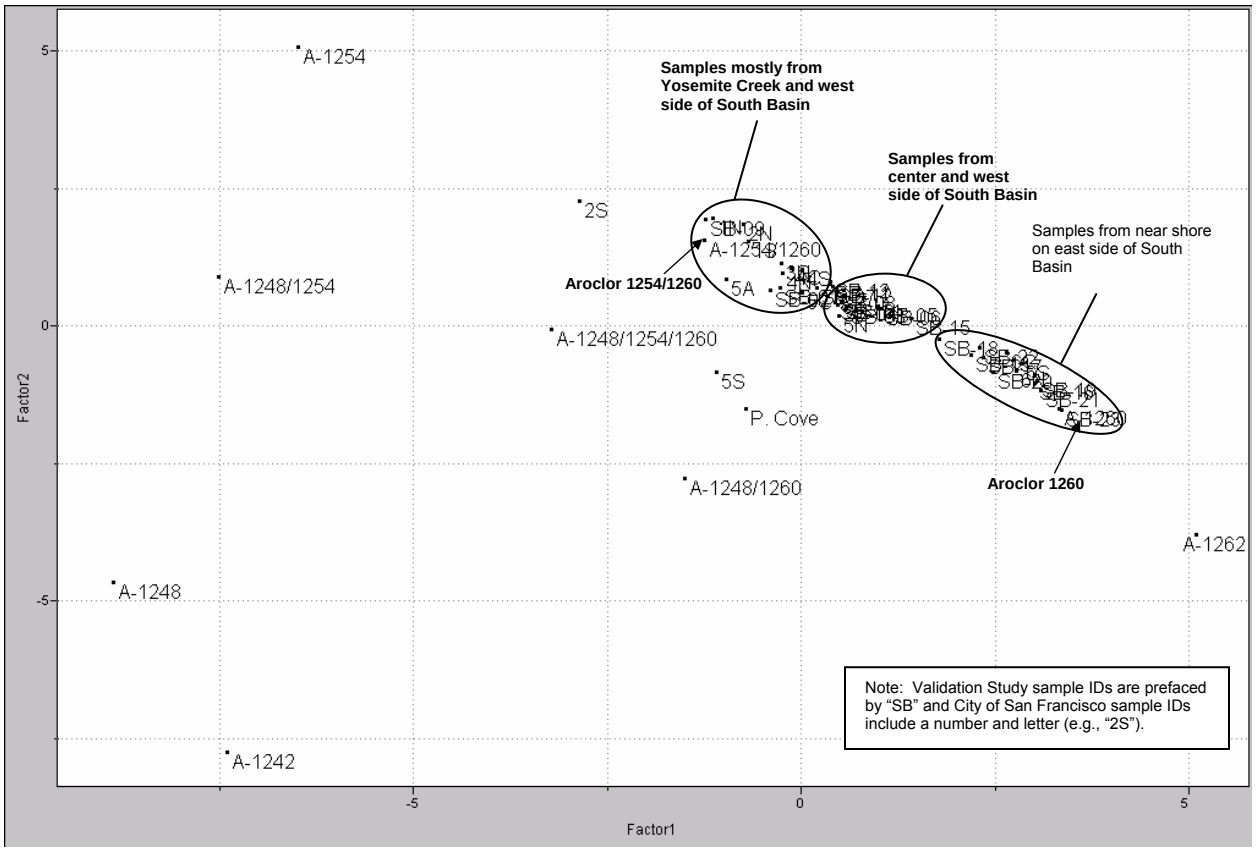


Figure 4-17. PCB Principal Component Analysis for Area X and Yosemite Creek

5.0 TOXICITY

Two toxicological tests were conducted to assess acute and sublethal effects associated with HPS sediment samples: a 10-day acute bulk sediment bioassay using the amphipod *E. estuarius*, and a 72-hour acute/sublethal SWI test using larvae of the purple urchin *S. purpuratus.* Each test provided the data needed to meet the DQOs outlined in Section 2.0. The results of the WOE evaluation are provided in Section 8.0.

5.1 Bulk Sediment Bioassay Results

Table 5-1 summarizes performance criteria and results for the bulk sediment bioassay using *E. estuarius.* Performance criteria were evaluated to assess overall test performance and suitability of subsequent bioassay results for decision-making. All four test organism batches were evaluated within the required holding time, and produced acceptable test organism survival and sensitivity. Organisms were acclimated slowly to test water quality conditions, and were held for at least 48 hours prior to testing. Interstitial water ammonia concentrations were measured at the beginning and end of each test. Total ammonia in interstitial water of all samples was below the 60 mg/L NOEC for *E. estuarius* (U.S. EPA, 1994a) (see Table 5-1). For most test batches, water quality parameters remained within target ranges specified in the QAPP. Slight exceedances of pH were noted in a few samples, but these exceedances did not appear to affect test results. Based on these results, test performance is considered acceptable, and no qualifications are associated with these data with respect to decision-making.

Table 5-2 summarizes the mean amphipod survival in HPS, reference, and control sediment samples. Control survival was above 90% in all batches, ranging from 94% to 100%. Amphipods exposed to HPS surface sediment samples exhibited 75% to 98% survival, and amphipods exposed to the five San Francisco Bay reference site samples exhibited 68% to 95% survival. Complete test data, including individual replicate endpoints, reference toxicant tests, and water quality data, are provided in Appendix D. Amphipod survival in all HPS surface sediment samples was greater than the reference envelope threshold value of 69.5% (SWRCB, 1998b).

5.2 Sediment-Water Interface Test Results

Table 5-3 summarizes performance criteria and results for the SWI test using *S. purpuratus* larvae. All test criteria specified in the QAPP (Battelle et al., 2001a) were met, with the exception of slight exceedances of salinity near the end of the testing period. The percentage of normally developed larvae in control was well above the 70% criteria, and copper reference toxicant exposures suggest acceptable test organism sensitivity. This test was conducted appropriately following the SWI test method (Anderson et al., 1999; Anderson et al., 2001), and the results are acceptable with few qualifications. Samples associated with laboratory observations of an unusual occurrence, such as low dissolved oxygen concentrations or holes in the screen tube, are identified in Table 5-4. Complete test data, including individual replicate endpoints, reference toxicant test results, and water quality data, are provided in Appendix D.

Table 5-4 presents mean larval normal development in SWICs from HPS sampling stations and San Francisco Bay reference site stations, as well as seawater control samples. Normal development in San Francisco Bay reference site samples was 86.7% to 98.1% except at Bay Farm, which had 60.1% normal development. The ambient threshold value for San Francisco Bay is 60% normal development relative to control (SWRCB, 1998b). Normal development of *S. purpuratus* larvae was greater than 60% in the majority (46 of 59) of HPS SWICs. Thirteen (13) HPS SWICs exhibited less than 60% normal larval development.

Table 5-1. Summary of Bulk Sediment Bioassay Using *E. estuarius*

Parameter	Acceptable Limit or Range	Batch 1	Batch 2	Batch 3	Batch 4
Sediment Collection Dates	not applicable	5/2/01 – 5/10/01	5/7/01 – 5/29/01	5/7/01 – 6/4/01	5/22/01 – 6/27/01
Organism Collection Date	not applicable	5/9/01	5/29/01	6/4/01	6/27/01
Organism Receipt Date	not applicable	5/11/01	5/31/01	6/6/01	6/28/01
Organism Acclimation period (days)	as needed to meet test water quality limits	1	2	1	1
Organism Holding period (days after acclimation)	>48 h (2 days) after acclimation	7	3	4	4
Bioassay Test Dates	–	5/19/01 – 5/29/01	6/4/01 – 6/14/01	6/11/01 – 6/21/01	7/2/01 – 7/12/01
Sediment Holding Time Limit Met?	Within 6 wks of collection	Limit Met	Limit Met	Limit Met	Limit Met
Organism Holding Time Limit Met?	Within 14 d of receipt at laboratory	Yes	Yes	Yes	Yes
Control Survival (%)	≥90	100	95	94	95
Reference Toxicant Response	Within MSL Control Chart Limits:				
Cadmium LC50 (mg/L)	2.9 – 18.5	7.9	9.4	9.7	8.9
Ammonia LC50 (mg/L)	77.8 –167.2	149.5	157.1	129.1	158.2
Water Quality Conditions					
Temperature (ºC)	13.0 – 17.0	14.3 – 15.5	14.3 – 15.8	14.3 – 16.1	14.6 – 15.9
Salinity (‰)	28 – 32	28.0 – 31.2	29.0 – 30.2	28.2 – 29.6	29.8 – 31.1
Dissolved Oxygen (mg/L)	3.4 – 8.4	6.0 – 8.5	5.6 – 8.5	6.3 – 8.6	5.8 – 9.0
pH (pH units)	7.3 – 8.3	7.2 – 8.2	7.4 – 8.2	7.4 – 8.5	7.6 – 8.2
Interstital Water Ammonia (mg/L)	<60 mg/L as total ammonia	0.1 – 12.7	0.3 – 42.4	1.2 – 20.8	1.3 – 20.1

LC50 = lethal concentration.

Table 5-2. Results of 10-Day Bulk Sediment Bioassay Using *E. estuarius*

Station ID	Test Batch	Mean Percent Survival	Standard Deviation
Area I (India Basin)			
IB-54	3	81.0	5.5
IB-55	2	93.0	5.7
IB-56	3	82.0	5.7
IB-57	3	76.0	9.6
IB-58	3	77.0	5.7
IB-59	3	76.0	10.8
Area III (Point Avisadero)			
PA-38	1	90.0	7.1
PA-39	1	86.0	8.9
PA-40	1	86.0	6.5
PA-41	1	75.0	6.1
PA-42	1	81.0	17.8
PA-43	1	85.0	8.7
PA-44	1	84.0	13.9
PA-45	1	94.0	4.2
PA-46	1	88.0	4.5
PA-47	1	89.0	7.4
PA-48	1	95.0	3.5
PA-49	1	83.0	4.5
PA-50	1	82.0	8.4
PA-51	1	94.0	5.5
PA-52	1	92.0	9.1
PA-53	1	89.0	9.6
Area VIII (Eastern Wetland)			
EW-30	2	97.0	4.5
EW-31	3	93.0	4.5
EW-32	2	89.0	8.9
EW-33	2	98.0	2.7
EW-34	2	97.0	2.7
EW-35	3	78.0	7.6
EW-36	2	95.0	3.5
EW-37	2	86.0	4.2
Area IX (Oil Reclamation)			
OR-24	2	92.0	5.7
OR-25	3	83.0	12.5
OR-26	2	88.0	11.0
OR-27	3	84.0	9.6
OR-28	3	80.0	10.0
OR-29	2	86.0	7.4

Table 5-2. Results of 10-Day Bulk Sediment Bioassay Using *E. estuarius* (continued)

Station ID	Test Batch	Mean Percent Survival	Standard Deviation
Area X (South Basin)			
SB-01	4	94.0	4.2
SB-02	4	90.0	8.7
SB-03	3	82.0	7.6
SB-04	4	91.0	11.9
SB-05	3	77.0	9.1
SB-06	3	82.0	5.7
SB-07	4	89.0	6.5
SB-08[(a)]	2	93.8	2.5
SB-09	3	79.0	17.1
SB-10	3	83.0	11.5
SB-11	2	87.0	13.0
SB-12	3	84.0	6.5
SB-13	2	89.0	8.2
SB-14	2	93.0	4.5
SB-15	3	89.0	5.5
SB-16	2	91.0	6.5
SB-17	2	87.0	5.7
SB-18	3	95.0	6.1
SB-19[(a)]	3	87.5	8.7
SB-20	2	89.0	6.5
SB-21	2	97.0	2.7
SB-22[(b)]	2	90.0	10.8
SB-23	2	96.0	4.2
Reference Sites			
Alameda Buoy	1	70.0	10.0
Alcatraz Environs	3	92.0	15.2
Bay Farm	1	68.0	12.5
Paradise Cove	1	90.0	3.5
Red Rock	1	95.0	5.0
Control Sediment			
E. estuarius Control	1	100.0	0.0
E. estuarius Control	2	95.0	5.0
E. estuarius Control	3	94.0	5.5
E. estuarius Control	4	95.0	5.0

(a) Mean survival calculation excluded one replicate that was not initiated (no animals recovered).
(b) Mean survival calculation excluded Replicate 4 (not initiated; one animal recovered).

Table 5-3. Summary of 72-Hour Acute/Sublethal SWI Test Using *S. purpuratus*

Parameter	Acceptable Limit Range	Batch 1	Batch 2	Batch 3	Batch 4	Batch 5	Batch 6
Sediment Collection Dates	Not applicable	5/2/01	5/4/01 – 5/6/01	5/4/01 – 5/9/01	5/14/01 – 5/17/01	5/18/01 – 5/19/01	5/21/01
Bioassay Test Dates	Not applicable	5/4/01 – 5/7/01	5/8/01 – 5/11/01	5/11/01 - 5/14/01	5/18/01 – 5/21/01	5/22/01 – 5/25/01	5/24/01 – 5/27/01
Holding Time Limit Met?	Within 6 wks of collection	Limit Met	Limit Met	Limit Met	Limit Met	Limit Met	Limit Met
Control Exposure Information							
Mean Percent Survival	-	93.0	80.7	83.1	83.6	89.5	78.6
Mean Percent Normal	≥ 70%	95.9	93.0	96.7	88.4	97.3	96.5
Reference Toxicant Response	Within Laboratory Control Chart Limits	IC-50 as Percent Normal	IC-50 as Percent Normal	IC-50 as Percent Normal	IC-50 as Percent Normal	IC-50 as Percent Normal	IC-50 as Percent Normal
Copper LC50 (µg/L)	16.3 – 24.9	16.9	19.4	17.2	22.4	17.2	17.3
Ammonia LC50 (mg/L total)	Not specified	3.59	3.28	2.30	3.86	2.90	3.11
Water Quality Conditions							
Temperature (ºC)	13-17	15.2 – 16.0	15.3 – 16.0	14.5 – 16.0	14.6 – 15.8	14.7 – 15.9	13.8 – 15.5
Salinity (‰)	30-34	31.9 – 33.7	32.3 – 33.9	32.1 – 34.1	32.6 – 34.4	32.0 – 34.2	31.4 – 33.7
Dissolved Oxygen (mg/L)	Not specified	4.3 – 7.6	1.7 – 8.1	2.9 – 7.5	4.0 – 7.5	4.6 – 7.6	3.6 – 7.5
pH (units)	Not specified	7.1 – 7.8	7.2 – 8.0	7.3 – 7.8	7.1 – 7.8	7.2 – 7.7	7.3 – 7.9
Overlying Water Ammonia							
Total (mg/L)	Not specified	0.000 – 0.094	0.000 – 5.290	0.000 – 3.520	0.000 – 3.070	0.000 – 4.900	0.000 – 2.610
Unionized (mg/L)	< 0.07 (SWRCB)	0.000 – 0.001	0.000 – 0.031	0.000 – 0.016	0.000 – 0.009	0.000 – 0.019	0.000 – 0.014

Table 5-4. Results of 72-Hour Acute/Sublethal SWI Test Using *S. purpuratus*

Sample ID	Test Batch	Mean Percent Normal Development	Standard Deviation	Coefficient of Variation	Surface Sediment ERM-Q
Area I (India Basin)					
IB-54[c]	1	45.9	23.0	50%	0.191
IB-55	1	95.9	4.0	4%	0.343
IB-56	1	90.2	5.7	6%	0.196
IB-57	1	94.8	3.1	3%	0.179
IB-58[c]	2	32.3	32.0	99%	0.181
IB-59[c]	2	40.1	31.8	79%	0.410
Area III (Point Avisadero)					
PA-38	3	88.4	6.1	7%	0.527
PA-39	3	96.0	2.8	3%	0.576
PA-40	3	97.7	2.0	2%	0.327
PA-41[b]	3	93.2	3.1	3%	0.953
PA-42[a,b,c]	2	25.9	31.4	121%	0.775
PA-43[b]	3	95.6	6.0	6%	0.222
PA-44	3	97.9	1.2	1%	0.553
PA-45	2	88.8	4.5	5%	1.222
PA-46[a]	2	95.7	5.7	6%	0.692
PA-47	3	97.0	2.7	3%	1.196
PA-48[b]	3	96.4	3.3	3%	0.236
PA-49[b,c]	2	41.6	44.7	107%	0.215
PA-50[a,b,c]	2	1.4	2.0	139%	0.222
PA-51[a,b,c]	2	38.7	31.2	81%	0.188
PA-52[a,b]	2	90.4	4.7	5%	0.211
PA-53[b]	3	96.8	2.8	3%	0.239
Area VIII (Eastern Wetland)					
EW-30	5	85.6	5.6	7%	0.152
EW-31	5	84.0	9.6	11%	0.113
EW-32[a,b,c]	4	52.1	33.5	64%	0.220
EW-33[b,c]	5	53.3	26.9	50%	0.130
EW-34[b]	3	94.4	2.9	3%	0.134
EW-35	3	95.9	0.7	1%	0.213
EW-36	5	88.1	12.9	15%	0.129
EW-37	3	90.5	6.6	7%	0.192
Area IX (Oil Reclamation)					
OR-24[b,c]	6	76.8	21.9	29%	0.558
OR-25[c]	5	8.5	11.7	138%	0.236
OR-26[c]	6	69.9	19.6	28%	0.403
OR-27	6	70.1	13.5	19%	0.380
OR-28	4	77.1	13.8	18%	0.254
OR-29[c]	6	72.0	25.0	35%	0.258

Table 5-4. Results of 72-Hour Acute/Sublethal SWI Test Using *S. purpuratus* (continued)

Sample ID	Test Batch	Mean Percent Normal Development	Standard Deviation	Coefficient of Variation	Surface Sediment ERM-Q
Area X (South Basin)					
SB-01[c]	5	71.7	20.3	28%	0.473
SB-02[d]	5	94.9	9.1	10%	0.706
SB-03	5	80.5	8.3	10%	0.294
SB-04	5	98.6	1.2	1%	0.359
SB-05	4	71.6	5.7	8%	0.362
SB-06[c]	5	55.4	23.8	43%	0.293
SB-07	5	95.7	3.2	3%	0.430
SB-08[c]	5	62.8	24.4	39%	0.402
SB-09[d]	5	90.9	11.8	13%	0.337
SB-10	5	85.9	11.6	13%	0.605
SB-11	4	78.4	9.9	13%	0.682
SB-12[c]	4	25.1	8.0	32%	0.526
SB-13	5	93.7	6.7	7%	0.616
SB-14[c]	4	55.2	21.2	38%	0.568
SB-15	5	93.2	4.3	5%	0.398
SB-16[b]	4	78.8	7.0	9%	1.069
SB-17[b]	5	89.3	8.2	9%	0.734
SB-18	4	87.2	8.4	10%	0.497
SB-19	6	74.9	9.2	12%	1.057
SB-20	4	88.1	6.2	7%	0.854
SB-21	4	92.6	3.6	4%	2.020
SB-22[d]	4	89.8	5.6	6%	0.989
SB-23	4	85.6	12.2	14%	1.50
Reference Sites					
Alameda Buoy	2	97.0	2.2	2%	0.209
Alcatraz Environs	4	86.7	4.0	5%	0.081
Bay Farm[b,c]	2	60.1	21.0	35%	0.202
Paradise Cove	1	98.1	1.5	2%	0.191
Red Rock	1	95.3	2.9	3%	0.128
Seawater Controls					
Batch 1 Control	1	95.9	0.9	1%	not applicable
Batch 2 Control	2	93.0	3.2	3%	not applicable
Batch 3 Control	3	96.7	1.2	1%	not applicable
Batch 4 Control	4	88.4	2.2	3%	not applicable
Batch 5 Control	5	97.3	0.7	1%	not applicable
Batch 6 Control	6	96.5	1.6	2%	not applicable

(a) Low dissolved oxygen observed (< 4.0 mg/L) during test.
(b) Overlying ammonia >2.0 mg/L total ammonia during test (measured in composite sample).
(c) Percentage normal larvae highly variable among true replicates (cv > 20%).
(d) Hole in Nytex screen observed in one or two replicates.

Seven of the SWICs with <60% normal development were collected from stations in the north (Areas I and III), and six were collected from stations in the south (Areas VIII, IX, and X), with no apparent spatial trend. Toxicity did not appear to be related to sediment COPEC concentrations: normal development was >70% at the stations with the highest overall COPEC concentrations (expressed as ERM-Qs), and the stations with lower normal development occurred where COPEC concentrations were generally low (Table 5-4, Figure 5-1). It is not unexpected for normal development to be high for stations where a high ERM-Q is driven by PCBs (which bioaccumulate but are not acutely toxic). However, urchin larvae are sensitive to dissolved metals, particularly copper which was elevated in surface sediments at a number of HPS stations.

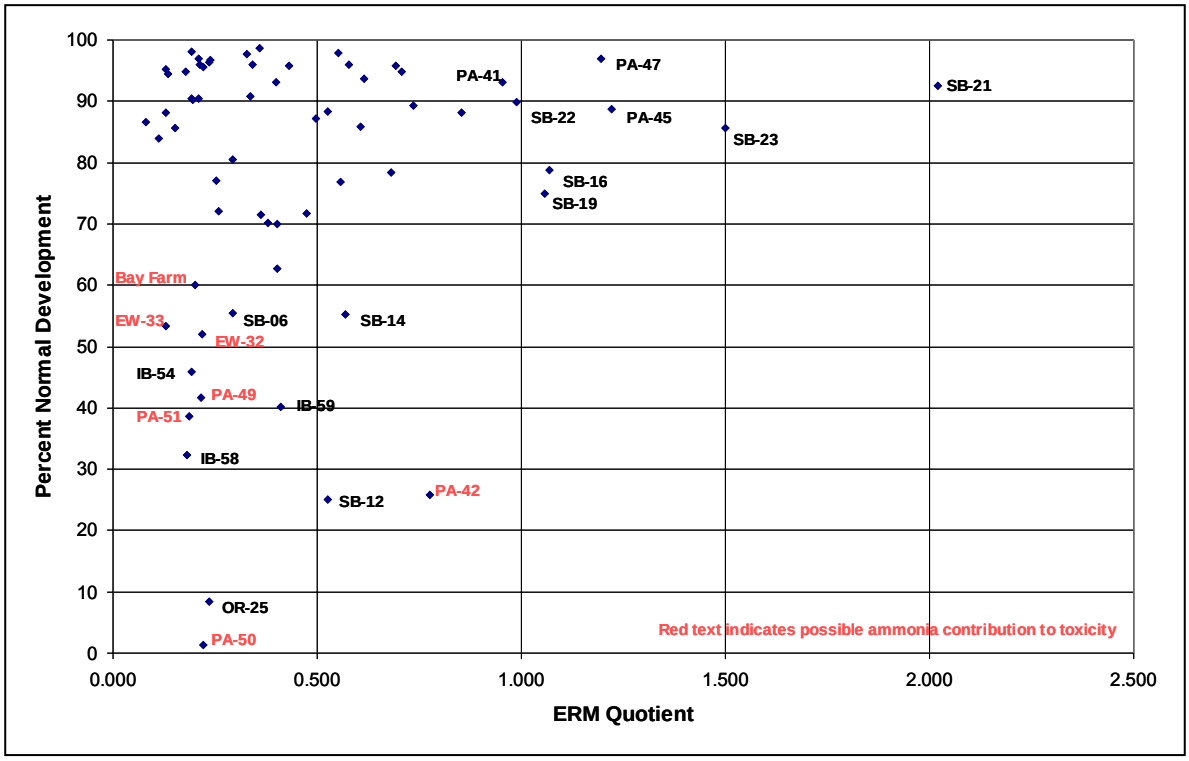


Figure 5-1. SWI Larval Response vs. Sediment ERM-Q

Plots of SWI against sediment concentrations of individual metals (i.e., cadmium, copper, and zinc) are shown in Figure 5-2. Results are similar to Figure 5-1, in that the plots show that toxicity does not increase with metal concentration, and the station samples with the highest sediment concentrations of copper and other metals (i.e., PA-47 and PA-41) were not toxic to urchin larvae. These results suggest that the metals were not fluxing from the sediment to the overlying water at those locations. Ancillary TIE data indicated that metals were suspected to be the primary toxicant in SB-19 and SB-20, and a secondary toxicant (after ammonia) at several other stations (Section 7.1), but exposure to the undisturbed SWI at these locations did not result in larval toxicity.

Because SWI larval toxicity did not correlate well with sediment chemistry, and low percentages of normal development were observed in some samples with low sediment COPEC concentrations, the potential influence of confounding factors was evaluated. Ammonia was suspected of contributing to toxicity at the stations that are shown as red in Figure 5-1. The potential ammonia contribution to toxicity was identified by plotting the Day 3 SWI ammonia concentration and mean SWI response on an

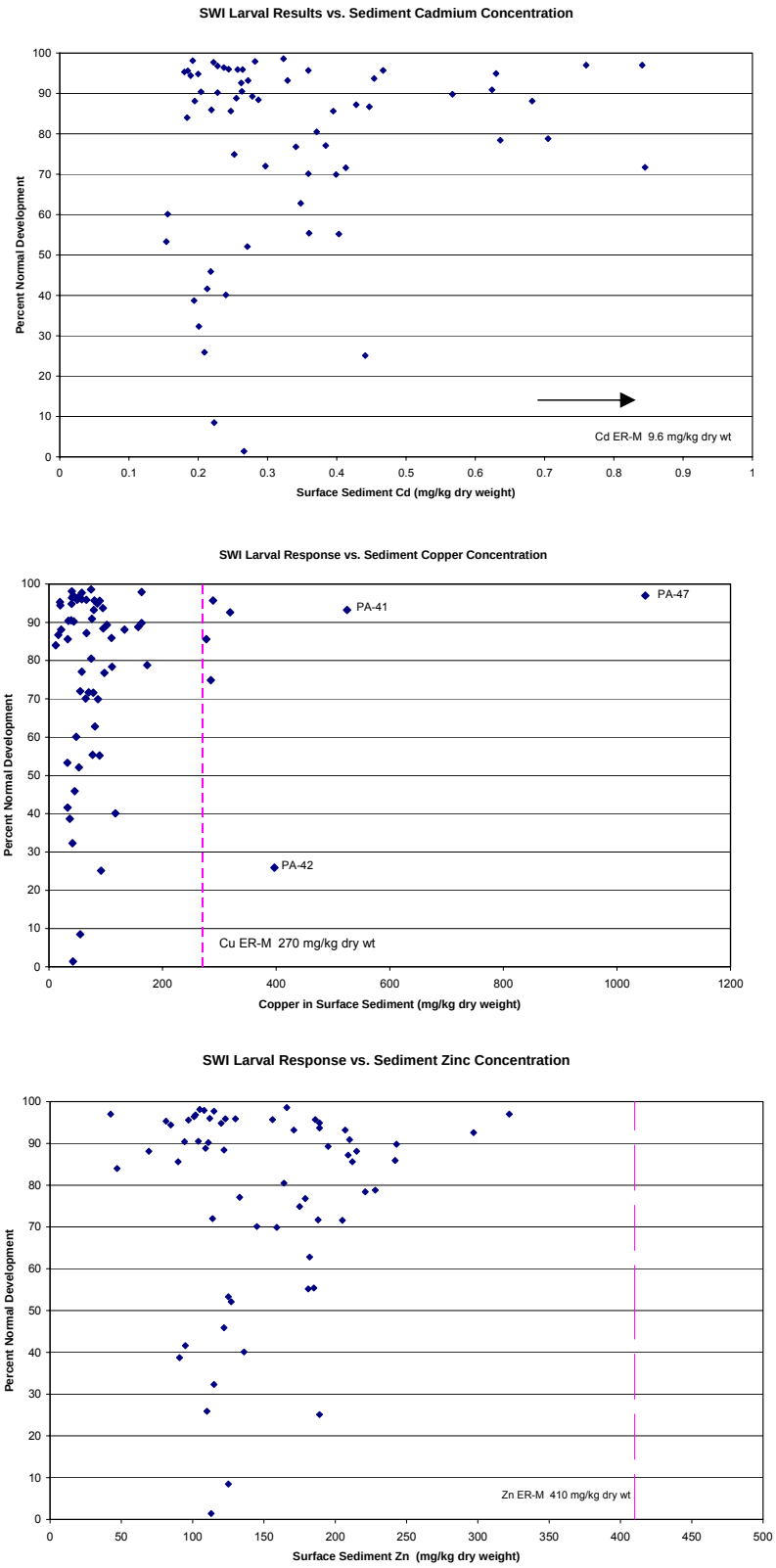
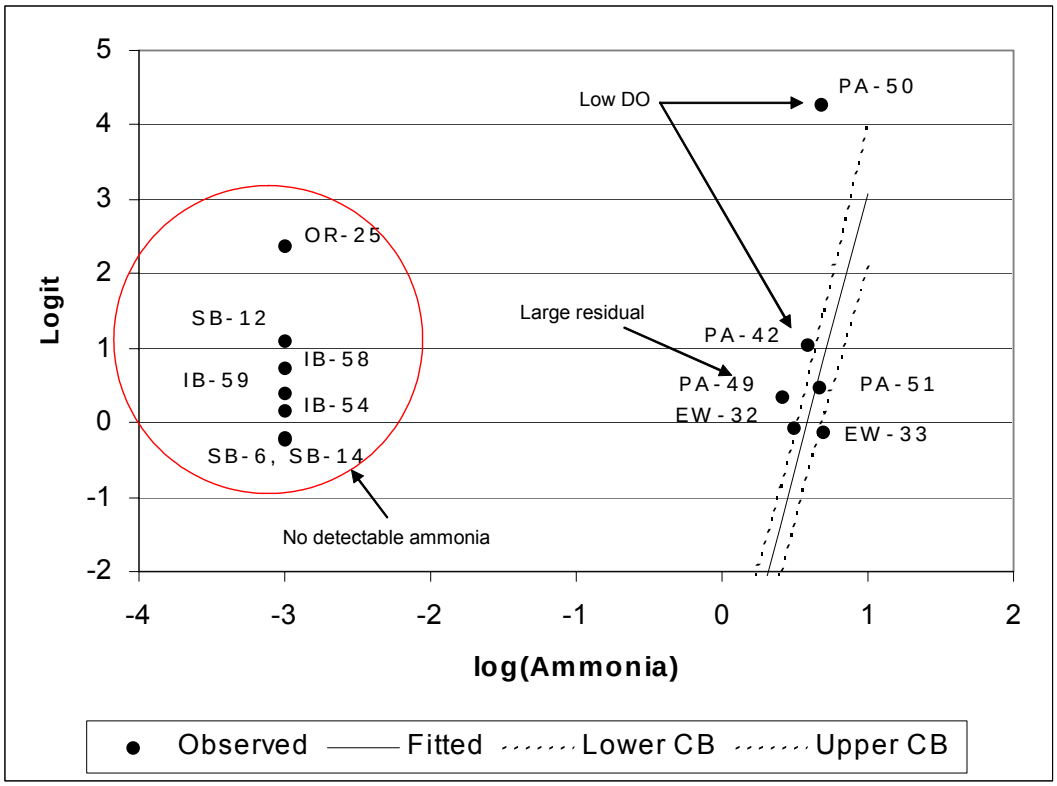


Figure 5-2. Plots of SWI Larval Development vs. Cadmium, Copper, and Zinc in Sediment

ammonia-only dose-response curve (Figure 5-3). The ammonia dose-response curve was developed from the ammonia reference toxicant tests with *S. purpuratus* larvae conducted by PERL with each batch of SWI samples. SWI sample results that fall in or on the confidence bands (dashed lines in Figure 5-3) exhibit the degree of toxicity that would be expected from exposure to ammonia alone (i.e., PA-51, EW-32, and EW-33). SWI results that fall outside and to the left of the confidence bands indicate greater toxicity than would be expected from ammonia alone (i.e., OR-25, SB-12, and the other stations on the left half of the plot). It should be noted that if *all* stations were plotted, there would be a number of results outside and to the right of the confidence bands, indicating less toxicity than expected from ammonia alone. Stations PA-42, PA-49, and PA-50 plot outside the confidence bands, indicating that toxicity is not attributable to ammonia alone. One possible contributor at PA-42 and PA-50 is low dissolved oxygen, which was noted in the water quality replicates associated with these two stations.



SWI larval responses with less than 60% normal development overlaid on the reference toxicity data dose-response relationship between the logit (1-proportion normal) corrected for the control against the log10 of total ammonia concentration + 0.001 (mg/L).

Figure 5-3. SWI Larval Response vs. Ammonia Reference Toxicity Results

Poor water quality may have contributed to some of the observed toxicity in the SWI test. Dissolved oxygen, temperature, pH, and salinity were monitored at the beginning and end of the SWI test. Water quality was measured in a sixth replicate SWIC that did not contain test organisms because the SWIC test containers that contain larvae are small and sensitive to disturbance. This replicate is expected to be, but may not always be, representative of the five test replicates; therefore, it was difficult to determine whether poor water quality could have contributed to observed toxicity in an individual replicate. For example, low dissolved oxygen was reported for some water quality replicates, but it is not known whether any particular test replicate had low dissolved oxygen.

Several other potential confounding factors are inherent to the SWI method. Unlike the amphipod bioassay, the SWI test is conducted with true field replicates (i.e., individual intact cores) from HPS stations. The variability that stems from testing five individual, unhomogenized, undisturbed core samples from each station can be significant. According to the authors of the SWI test method, the high variability observed in HPS samples was not unusual (Anderson, 2002); considerable spatial variability can occur between field replicates (especially those collected from multiple Van Veen grabs in deep water) due to changes in sediment types, amount of organic matter, and native fauna. Because the SWI is not disturbed during collection or laboratory exposure, other than to replace overlying water prior to testing, any algae or diatoms and other benthic infauna in the upper 5 cm become part of the bioassay test system. The native infauna can affect the bioassay in a number of ways, most obviously by increasing oxygen demand but also by generating ammonia, conditions that compound each other. Such effects can vary between replicates and over time, and are difficult to quantify. The presence of diatoms, amphipods and tubes, worm tubes, anemones, clams, and small crabs during SWI and sediment collection was recorded in the field notes (Appendix A).

5.3 Summary of Toxicity

Offshore sediments from Areas I, III, VIII, IX, and X were not acutely toxic to amphipods. Survival rates of the *E. estuarius* exposed to HPS surface sample sediments was similar to, and commonly higher than, survival rates of *E. estuarius* exposed to San Francisco Bay reference site sediments. The confounding factors that were suspected of influencing amphipod bioassay results in previous studies (e.g., organism acclimation and holding, appropriate organism sensitivity, monitoring and control of ammonia, monitoring and control of other water quality parameters) were successfully controlled during the Validation Study. The control of confounding factors, sensitivity of the test species, and overall data quality provide a high degree of certainty about the bulk sediment amphipod bioassay, which indicates that HPS surface sediments pose low to no risk to benthic invertebrates.

In general, offshore sediments from Areas I, III, VIII, IX, and X also were not acutely toxic to echinoderms, as indicated by normal development of purple urchin (*S. purpuratus*) larvae exposed to intact HPS SWICs. However, normal larval development was below the ambient threshold for San Francisco Bay in 20% of HPS SWICs (13 of 59). Larval toxicity did not appear to be related to elevated sediment COPEC concentrations, even at stations where metals rather than PCBs drove the ERM-Q. The HPS stations where larval toxicity occurred were distributed throughout the HPS offshore areas with no apparent spatial pattern.

The SWI test indicates that a small proportion of HPS surface sediments might pose some risk to echinoderms and other broadcast-spawning invertebrate species; however, the uncertainty associated with this test is greater than that of the amphipod bioassay. Ammonia may have contributed to SWI toxicity at some stations in Areas III and VIII. Other potential confounding factors were poor water quality, field replicate variability and the presence of native flora and fauna in the undisturbed cores.

6.0 BIOACCUMULATION

This section presents the results of the bioaccumulation line of evidence based on the laboratory bioaccumulation test. Field-collected tissue data are discussed in Section 7.0. The objectives of the bioaccumulation and dose assessment were as follows:

- To evaluate the bioavailability of sediment contaminants to benthic organisms, and
- To assess potential risk to upper trophic level receptors from sediment contaminants that accumulate in benthic organisms representing the prey of these receptors.

As described in Section 3.0, sediment samples were collected in 2001 from five HPS study areas and five reference site stations in San Francisco Bay. Bioavailability of sediment contaminants was evaluated with a 28-day flowthrough bioaccumulation exposure using *M. nasuta.* DQOs for the bioaccumulation test are provided in Table 2-6. The results of this test are presented in Section 6.1.

COPEC concentrations in *M. nasuta* tissue exposed to HPS sediments were compared to statistically derived reference threshold values. COPEC concentrations in tissue that exceeded the reference threshold concentration were evaluated for risk to upper trophic level receptors using a screening-level dose assessment, as described in Section 6.2 (dose calculations for all COPECs were performed). COPECs for which risk was indicated in the screening-level dose assessment were evaluated further using a refined approach, in which certain exposure parameters were adjusted. The refined dose assessment and its results are discussed in Section 6.3.

6.1 Laboratory Bioaccumulation Test Results

Performance results for the 28-day bioaccumulation test using *M. nasuta* are presented in Table 6-1. The bioaccumulation test was conducted within the required holding times, and exhibited acceptable control survival and sensitivity relative to BSL control chart limits. On some days, ambient salinity associated with Sequim Bay seawater produced slight elevations in this parameter above target limits, but this did not appear to influence test performance or results. Based on the test performance results, these data are unqualified and acceptable for decision-making.

Table 6-1. Summary Information for *M. nasuta* Bioaccumulation Test

Parameter	Acceptable Limit or Range	Test
Sediment Collection Dates	NA	5/2/01 – 5/22/01
Bioaccumulation Dates	NA	6/7/01 – 7/5/01
Holding Time Limits Met?	Within 6 Weeks of Collection	Limit Met
Control Survival (%)	≥ 80	87.3
Reference Toxicant Response	Within MSL Control Chart Limits:	
Copper LC50 (mg/L)	0.0 – 4.8	1.8 (1.1 – 3.1)
Water Quality Conditions		
Temperature (°C)	13 – 17	13.9 – 16.3
Salinity (‰)	28 – 32	28.9 – 32.5
Dissolved Oxygen (mg/L)	3.4 mg/L – 8.4	5.0 – 8.4
pH	7.3 – 8.3	7.2 – 7.8

NA = not applicable.

Although *M. nasuta* survival is not incorporated in the screening-level or refined ERA, these data are summarized in Table 6-2 to show observed trends among HPS stations and reference sites. Test organism survival was generally high, exceeding 80% for all but five of the HPS and reference site sampling stations. The lowest survival was associated with HPS stations EW-35 (64.4%), IB-56 (78.3%), SB-04 (77.8%), SB-19 (50.0%), and the Alcatraz Environs reference site AL-64 (74.7%). Sensitive bioassays using the amphipod *E. estuarius* and purple urchin larvae *S. purpuratus* conducted on the same sediment samples did not produce a toxic response (Section 5.0). Additionally, a plot of sediment concentration expressed as an ERM-Q versus *M. nasuta* survival (Figure 6-1) shows that there is no trend of increasing

Table 6-2. Percent Survival for *M. nasuta* Bioaccumulation Test

Station ID	Mean Percent Survival	Station ID	Mean Percent Survival
Area I		***Area IX***	
IB-54	90.0	OR-24	90.0
IB-55	94.4	OR-25	86.7
IB-56	78.3	OR-26	88.3
IB-57	87.8	OR-27	91.1
IB-58	81.1	OR-28	84.4
IB-59	85.6	OR-29	92.2
Area III		***Area X***	
PA-38	92.2	SB-01	93.3
PA-39	87.8	SB-02	90.0
PA-40	90.0	SB-03	93.3
PA-41	85.6	SB-04	77.8
PA-42	86.7	SB-05	86.7
PA-43	81.1	SB-06	82.2
PA-44	88.9	SB-07	88.9
PA-45	85.6	SB-08	88.9
PA-46	85.0	SB-09	96.7
PA-47	88.9	SB-10	88.9
PA-48	91.1	SB-11	93.3
PA-49	82.2	SB-12	95.6
PA-50	94.4	SB-13	95.6
PA-51	93.3	SB-14	87.8
PA-52	93.3	SB-15	94.4
PA-53	90.0	SB-16	94.4
Area VIII		SB-17	81.1
EW-30	93.3	SB-18	96.7
EW-31	91.1	SB-19	50.0
EW-32	93.3	SB-20	85.6
EW-33	86.7	SB-21	85.8
EW-34	85.6	SB-22	94.4
EW-35	64.4	SB-23	90.0
EW-36	86.7	***Reference***	
EW-37	84.4	AB-67	80.0
		AL-64	74.7
		BF-66	85.3
		PC-63	88.0
		RR-65	87.3
		Control	87.3

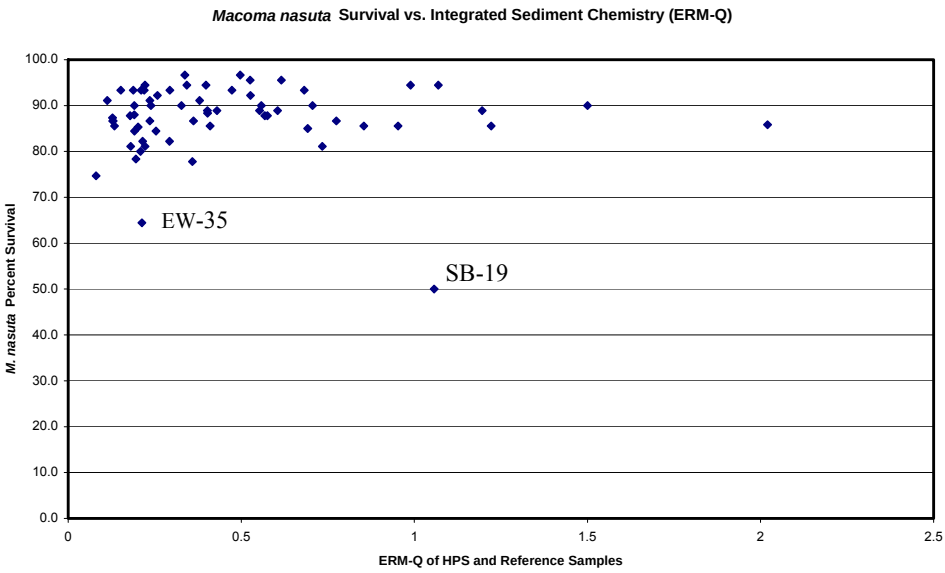


Figure 6-1. *M. nasuta* Survival vs. ERM-Q for Sediment

toxicity with increasing concentrations of chemicals in sediment, and that a number of stations with higher ERM-Qs did not exhibit low *M. nasuta* survival. Therefore, the reason for the reduced survival at some stations is not known.

6.2 Evaluation of Upper Trophic Level Risk

Potential risk to upper trophic level receptors from sediment contamination at HPS was assessed through a two-phase approach. First, a screening-level dose assessment was conducted that evaluated food-chain risk on a station-by-station basis using conservative exposure parameters that were likely to overestimate the risk potential. In the second phase, a refined dose assessment was conducted that assessed exposure over larger areas (e.g., both the whole site and the five HPS study areas) and took into account a range of possible site use factors. The refined evaluation more accurately reflects the actual exposure of the receptors to site contaminants at HPS.

6.2.1 Screening-Level Dose Assessment

A food-chain model was used to evaluate potential risk to upper trophic level receptors. The results presented in this section focus on the tissue COPECs for each station that exceed the reference threshold values although dose assessment results for all COPECs are provided. Tissue chemistry data for the *M. nasuta* samples from the laboratory bioaccumulation test are provided in Appendix C. Tissue concentrations for each HPS station were compared to reference threshold values developed from the reference tissue chemistry results (Table 6-3). The approach used to develop the reference threshold values is described in Appendix G.

The food-chain model focused on benthic invertebrate-eating birds. These birds are considered a conservative surrogate because they have significant potential for exposure to site COPECs both from incidental ingestion of sediment, based on their feeding behavior, and from their prey, which are usually resident in an area and closely associated with sediment. Based on discussions with ornithologists

Table 6-3. *M. nasuta* Tissue Reference Threshold Values

Inorganic Constituents (mg/kg dry weight)	90th percentile	Organic Constituents (mg/kg dry weight)	90th percentile
Aluminum	1,950	4,4′-DDD	0.00419
Antimony	0.187	4,4′-DDE	0.00750
Arsenic	22.9	4,4′-DDT	ND
Barium	20.2	*alpha*-Chlordane	0.00103
Cadmium[(a)]	0.369	Dieldrin	0.00157
Chromium	24.6	Endosulfan II	ND
Cobalt	3.63	Endrin	ND
Copper	14.8	*gamma*-Chlordane	0.00086
Iron	2,798	Heptachlor	ND
Lead	3.76	Dibutyltin	0.0126
Manganese	57.4	Tributyltin	0.0448
Mercury	0.174	Total 4,4-DDx	0.0119
Molybdenum	3.04	Total HPAH (sum of 10)	0.362
Nickel	9.60	Total LPAH	0.0421
Selenium	5.34	Total PCBs[(b)]	0.0686
Silver	0.252	–	–
Vanadium	11.5	–	–
Zinc	126	–	–

(a) Cadmium reference threshold value excludes data from Alcatraz Environs reference site.
(b) Total PCBs reference threshold value excludes data from Alameda Buoy reference site.
ND = not detected.

familiar with the HPS environs (Carol Bach, Port of San Francisco; Joelle Buffa, U.S. FWS; David Hayes, California Coastal Conservancy; Paul Jones, U.S. EPA; Louis Vincencio, U.S. FWS), the Navy selected the surf scoter, a diving duck, as the receptor for the following reasons:

- The scoter is present in large numbers from late fall through winter at HPS.
- The scoter is a benthic-feeding bird that forages primarily on mollusks (Vermeer and Bourne, 1984; Ohlendorf et al., 1986). As such, it is exposed directly to contaminated sediment. Additionally, because scoters feed primarily on bivalves, food-chain modeling using *M. nasuta* body burdens can be used in the exposure models.
- The scoter can feed in the intertidal zone during high tide and forages in the subtidal to depths in excess of 20 ft. Therefore, it can represent species potentially exposed to both intertidal and subtidal habitats. Many other species are only appropriate for one habitat or the other.
- There is a substantial body of relevant literature for scoters. Trace metal analyses of scoter tissue and scoter prey items have been reported from British Columbia (Vermeer and Peakall, 1979), and trace element and organochlorine residues in scoters have been reported from San Francisco Bay (Ohlendorf et al., 1991).

Doses were calculated for all COPECs using the methods described below and HQs were calculated for all COPECs with toxicity reference values (TRVs). Three COPECs (PCBs, mercury, and total 4,4′-DDx) were identified as priority COPECs for the purpose of the WOE evaluation because of their tendency to bioaccumulate.

6.2.1.1 Exposure Assessment

The purpose of the exposure assessment was to estimate the dose to which the selected receptor (the scoter) is exposed. It was assumed that scoters are exposed to site contaminants through consumption of contaminated prey and incidental ingestion of sediment. COPEC concentrations in prey tissue and sediment were represented by *M. nasuta* tissue and surface sediment sample data from each station. The dose equation used to characterize exposure to the scoter is as follows:

$$\text{Dose} = \{[(C_{sed} * IR_{sed}) + (C_{prey} * IR_{prey})] * SUF\}/BW \qquad (6\text{-}1)$$

where: Dose = daily dose resulting from ingestion of sediment and prey (milligrams COPEC per kilograms body weight per day)

C_{prey} = COPEC-specific concentration in depurated, laboratory *M. nasuta* tissue (milligrams COPEC per kilograms tissue [dry weight])

C_{sed} = COPEC-specific concentration in surface sediments (milligrams COPEC per kilograms sediment [dry weight])

IR_{prey} = estimate of daily ingestion rate of prey (kilograms prey [dry weight] per day)

IR_{sed} = estimate of daily incidental ingestion rate of surface sediments (kilograms sediment [dry weight] per day)

SUF = site use factor (unitless)

BW = body weight (kilograms).

For the screening-level dose assessment, C_{sed} and C_{prey} are the concentrations measured at each individual station. Concentrations for summed COPECs such as total PCBs, total 4,4′-DDx, LPAH, and HPAH were developed as described in Section 4.0.

The exposure parameter values used for these calculations are summarized in Table 6-4. The exposure parameters were presented and discussed by the Navy and agency technical group prior to data analysis; the rationale for the selected values is presented in Appendix G. A dose was calculated for each COPEC at each HPS station sampled for the Validation Study. Appendix H includes a table for each station summarizing the dose calculations for all COPECs.

Table 6-4. Screening-Level Exposure Parameters for the Surf Scoter

Parameter[(a)]	Value
Body Weight (BW)	1.1 kg
Prey Ingestion Rate (IR_{prey})	0.084 kg/day[(b)]
Sediment Ingestion Rate (IR_{sed})	0.0023 kg/day[(b)]
Site Use Factor (SUF)	1 (unitless)

(a) Exposure point concentrations are station-specific.
(b) In dry weight units

6.2.1.2 Effects Assessment

For the purpose of evaluating the potential effects associated with the doses calculated in the exposure assessment, chemical- and receptor-specific TRVs were compared to the calculated doses. In general, a TRV is defined as a dose level at which a particular biological effect may occur in an organism, based on laboratory toxicological investigations.

The Navy, in consultation with the U.S. EPA Region 9 Biological Technical Assistance Group (BTAG), developed effects-based TRVs. Each of these values represents a critical exposure level from a toxico-

logical study and is supported by a published dataset of toxicological exposures and effects (DON, 1998). Rather than derive a single point estimate associated with specific adverse biological effects, high and low TRVs were derived for each receptor and COPEC to reflect the variability of parameters within an ecological risk context. The low TRV is a conservative value consistent with a chronic, no observed adverse effects level (NOAEL). It represents a level at which adverse effects are not likely to occur, and is used to identify sites posing little or no risk. Conversely, the high TRV is a less conservative estimator of potential adverse effects, falling approximately mid-range of all of the reported adverse effects. The high TRV represents a level at which adverse effects are highly likely to occur, helping to identify sites posing immediate risks. In some cases, the high and low TRVs were derived using a NOAEL and lowest observed adverse effects level (LOAEL) from the same study; in other cases, independent NOAELs and LOAELs were selected as the low and high TRVs, respectively.

The Navy defines separate high TRVs for DDT (1.5 mg/kg-day) and DDE (0.60 mg/kg-day) (DON, 1998). For this evaluation, DDT and its metabolites, DDE and DDD, were evaluated as total 4,4′-DDx, which is the sum of the detected concentrations of 4,4′-DDT, 4,4′-DDE, and 4,4′-DDD in each sample (the 2,4′-DDx isomers were not detected at HPS). To be conservative, the lower of the two high TRVs applicable to the DDx (0.60 mg/kg-day) was used for the effects assessment.

For the purpose of the screening-level assessment, the TRVs developed by the Navy (DON, 1998) were scaled to account for differences in body weights between the organism used to establish the TRVs (high and low) and the ecological receptor chosen for evaluation. This was accomplished by using the following equation (Sample and Arenal, 1999):

$$TRV_w = TRV_l * (BW_s/BW_r)^{1-1.2} \qquad (6\text{-}2)$$

where: TRV_w = weight-adjusted TRV (mg/kg-day)
TRV_l = literature-based TRV (mg/kg-day)
BW_s = body weight of toxicity study receptor (kg)
BW_r = body weight of ecological receptor (kg).

Table 6-5 presents the weight-adjusted scoter TRVs for HPS COPECs.

6.2.1.3 Risk Characterization

The risk characterization combines the exposure and effects assessments to provide a quantitative estimate of the potential risks to the receptor. For the risk characterization, estimated daily doses were calculated for each COPEC and compared to the high and low TRVs (weight-adjusted for the surf scoter) according to the following equation:

$$HQ = \text{station-specific dose}/TRV \qquad (6\text{-}3)$$

Conservative exposure parameters were used to calculate doses for the screening-level dose assessment. These doses were used to derive two HQs for each COPEC at each station, an HQ_{low} using the low TRV and an HQ_{high} using the high TRV. When the dose is lower than the low TRV (i.e., $HQ_{low} < 1$), it is very likely that no risk is present from the specific COPEC. When the dose exceeds the low TRV (i.e., $HQ_{low} > 1$) in a screening-level dose assessment, it indicates that further evaluation is warranted. When the dose exceeds the high TRV (i.e., $HQ_{high} > 1$), it may indicate that remedial action is warranted; however, the HQ_{high} will change when conservative exposure parameters are adjusted in the refined dose assessment, and therefore should be re-evaluated. Because of differences in the degree of conservatism in selection of TRVs for various COPECs, resulting HQ values should not be compared between COPECs, but should be considered individually.

Table 6-5. Toxicity Reference Values for the Surf Scoter

COPEC	NOAEL Study Receptor Body Weight (kg)	Literature-Based Low Avian TRV (NOAEL) (mg/kg/day)	Scoter Weight-Adjusted Low TRV (mg/kg/day)	LOAEL Study Receptor Body Weight (kg)	Literature-Based High Avian TRV (LOAEL) (mg/kg/day)	Scoter Weight-Adjusted High TRV (mg/kg/day)
Aluminum	NA	NA	NA	NA	NA	NA
Antimony	NA	NA	NA	NA	NA	NA
Arsenic	1.17E+00	5.50E+00	5.43E+00	1.17E+00	2.20E+01	2.17E+01
Barium	NA	NA	NA	NA	NA	NA
Cadmium	7.99E-01	8.00E-02	8.53E-02	8.40E-02	1.04E+01	1.74E+01
Chromium	NA	NA	NA	NA	NA	NA
Cobalt	NA	NA	NA	NA	NA	NA
Copper	6.39E-01	2.30E+00	2.56E+00	4.09E-01	5.23E+01	6.37E+01
Iron	NA	NA	NA	NA	NA	NA
Lead	8.40E-02	1.40E-02	2.34E-02	8.00E-01	8.75E+00	9.33E+00
Manganese	NA	NA	NA	NA	NA	NA
Mercury	1.00E+00	3.90E-02	3.98E-02	1.00E+00	1.80E-01	1.83E-01
Molybdenum	NA	NA	NA	NA	NA	NA
Nickel	6.14E-01	1.38E+00	1.55E+00	5.80E-01	5.53E+01	6.28E+01
Selenium	1.11E+00	2.30E-01	2.30E-01	1.11E+00	9.30E-01	9.29E-01
Silver	NA	NA	NA	NA	NA	NA
Vanadium	NA	NA	NA	NA	NA	NA
Zinc	9.55E-01	1.72E+01	1.77E+01	9.55E-01	1.72E+02	1.77E+02
HPAH	NA	NA	NA	NA	NA	NA
LPAH	NA	NA	NA	NA	NA	NA
Total PCBs	8.00E-01	9.00E-02	9.59E-02	1.72E+00	1.27E+00	1.16E+00
Total 4,4′-DDx	3.50E+00	9.00E-03	7.14E-03	1.00E+00	6.00E-01	6.12E-01
alpha-Chlordane	NA	NA	NA	NA	NA	NA
Dieldrin	NA	NA	NA	NA	NA	NA
Endosulfan II	NA	NA	NA	NA	NA	NA
Endrin	NA	NA	NA	NA	NA	NA
gamma-Chlordane	NA	NA	NA	NA	NA	NA
Heptachlor	NA	NA	NA	NA	NA	NA
Dibutyltin	9.65E-02	7.30E-01	1.19E+00	0.0965	4.59E+01	7.46E+01
Monobutyltin	NA	NA	NA	NA	NA	NA
Tetrabutyltin	NA	NA	NA	NA	NA	NA
Tributyltin	9.65E-02	7.30E-01	1.19E+00	0.0965	4.59E+01	7.46E+01

NA = not available; TRV = toxicity reference value; COPEC = contaminant of potential ecological concern; LOAEL = lowest observed adverse effects level; NOAEL = no observed adverse effects level.

Summary tables for each station are provided in Appendix H, and include doses for all COPECs, and high and low TRVs and high and low HQs for each COPEC for which TRVs have been defined. The results of the screening-level dose assessment are discussed further in the following subsections.

Area I (India Basin). Overall, the results of the screening evaluation indicate that little or no risk is present to upper trophic level receptors feeding in Area I. Results of the reference tissue comparison and HQ calculations are summarized in Table 6-6. At two stations, tissue COPEC concentrations did not exceed reference threshold values. Tissue concentrations of PCBs and DDx exceeded reference at three

Table 6-6. Summary of Screening Level Dose Assessment Results for Area I (India Basin)

Station	HQ_{low}											
	Total PCBs[(a)]	Total 4,4′-DDx [(b)]	Dibutyltin	Tributyltin	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Selenium	Zinc
IB-54	**5.86E-02**	**1.56E-01**	5.90E-04	1.90E-03	2.58E-01	2.10E-01	4.48E-01	8.58E+00	1.42E-02	3.79E-01	1.03E+00	3.87E-01
IB-55	**1.24E-01**	**1.57E-01**	4.74E-04	1.49E-03	3.18E-01	2.19E-01	3.87E-01	2.16E+01	2.30E-02	6.00E-01	1.73E+00	3.62E-01
IB-56	4.26E-02	9.27E-02	6.76E-04	1.73E-03	3.01E-01	3.20E-01	4.70E-01	1.01E+01	2.41E-01	4.91E-01	1.72E+00	4.79E-01
IB-57	5.33E-02	1.15E-01	6.79E-04	1.89E-03	2.89E-01	1.97E-01	4.73E-01	1.05E+01	2.41E-01	**9.45E-01**	9.50E-01	3.79E-01
IB-58	4.44E-02	1.26E-01	4.49E-04	2.14E-03	3.08E-01	2.43E-01	3.46E-01	7.84E+00	1.48E-02	4.16E-01	1.55E+00	5.27E-01
IB-59	**1.11E-01**	**1.68E-01**	**9.17E-04**	**4.42E-03**	2.73E-01	1.93E-01	5.12E-01	1.01E+01	2.76E-01	6.55E-01	1.59E+00	3.69E-01

(a) Total PCBs are 2x the sum of detected congeners.
(b) Total 4,4′-DDx are the sum of 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT.
Bold: tissue concentration exceeds the reference threshold value.
HQ = hazard quotient.
All HQ_{high} values <1.0.

stations, and DBT, TBT, and nickel exceeded reference at one station each. However, the HQ_{low} values for these COPECs were all less than 1.0. HQ_{low} values were greater than 1.0 at all stations for lead, and were greater than 1.0 at all but one station for selenium. However, tissue concentrations for lead and selenium did not exceed reference threshold values. All of the HQ_{high} values were less than 1.0.

Area III (Point Avisadero). Results of the reference comparison and HQ calculations for Area III are summarized in Table 6-7. COPECs that most frequently exceeded reference threshold values were TBT, copper, DBT, PCBs, and mercury. Arsenic, cadmium, lead, nickel, selenium, zinc, and DDx also exceeded reference threshold values at some stations. Tissue COPEC concentrations did not exceed reference at two stations (PA-51 and PA-53).

HQ_{low} values for arsenic, cadmium, nickel, zinc, DBT, TBT, DDx, and PCBs did not exceed 1.0 at any station. The HQ_{low} value for copper exceeded 1.0 at six stations. At most stations, the copper HQ_{low} was 3 or lower. Figure 6-2 shows the distribution of copper in *M. nasuta* tissue at HPS. In these figures, bubble size is proportional to tissue concentration, and the values shown in red are above the reference threshold value. The most elevated copper concentrations in tissue were found in samples from Area III, and tend to be distributed in the central portion of Area III. They also tend to correspond with areas of highest sediment copper concentrations (Figure 4-4).

The mercury HQ_{low} exceeded 1.0 at four stations in Area III, but was always less than 10. At one of the four stations (PA-44), the HQ_{high} for mercury exceeded 1.0, with a value of 1.7. Figure 6-3 presents the bubble plot for mercury in *M. nasuta* tissue at HPS, and shows that the most elevated tissue concentrations of mercury are located in Area III. The elevated tissue mercury concentrations are generally located in the same areas as elevated sediment mercury concentrations (Figure 4-2).

In cases where tissue concentrations exceeded reference threshold values, the HQ_{low} values for lead and selenium exceeded 1.0 at two stations each, but not at the same stations. Because the low TRV for lead is very low, any lead tissue concentration that exceeds the reference threshold value will result in a HQ_{low} value of greater than 10. The HQ_{high} for lead did not exceed 1.0 at any station in Area III. In cases where tissue concentrations did not exceed reference threshold values, HQ_{low} values always exceeded 1.0 for lead, and exceeded 1.0 for selenium at all but two stations. Figures 6-4 and 6-5 show lead and selenium tissue concentrations at HPS, respectively. Neither of these COPECs had a strong, elevated tissue signature in Area III.

Area VIII (Eastern Wetland). Results of the reference comparison and HQ calculations for Area VIII are summarized in Table 6-8. PCB concentrations in tissue from this area exceeded reference threshold values at seven stations. Arsenic, cadmium, copper, lead, zinc, and DDx exceeded reference at up to three stations. In cases where tissue concentrations exceeded reference threshold values, cadmium and lead had HQ_{low} values above 1.0 at one and three stations, respectively (Figures 6-6 and 6-4, respectively). The HQ_{low} for cadmium at EW-33 was 1.2. Because the low TRV for lead is very low, any lead concentration that exceeds reference will result in a HQ_{low} greater than 10. The HQ_{high} for lead did not exceed 1.0 at any station in Area VIII. HQ_{low} values for lead and selenium exceeded one at all stations where tissue concentrations were below reference threshold values. All of the HQ_{high} values were less than 1.0. These results indicate that COPECs are not present in Area VIII at concentrations that are likely to pose significant risk to upper trophic level receptors.

Area IX (Oil Reclamation). Results of the reference comparison and HQ calculations for Area IX are summarized in Table 6-9. PCB and DDx tissue concentrations exceeded reference threshold values at all six stations. Copper and DBT tissue concentrations exceeded reference at four stations, and cadmium, lead, and TBT exceeded reference at three stations. Tissue concentrations of arsenic, nickel, and selenium exceeded reference at one or two stations.

Table 6-7. Summary of Screening Level Dose Assessment Results for Area III (Point Avisadero)

Station	HQ_{low}											
	Total PCBs[(a)]	Total 4,4′-DDx [(b)]	Dibutyltin	Tributyltin	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Selenium	Zinc
PA-38	**4.12E-01**	1.03E-01	**7.30E-03**	**3.86E-02**	3.22E-01	**3.83E-01**	**7.33E-01**	1.13E+01	2.48E-02	5.46E-01	**1.78E+00**	4.18E-01
PA-39	**2.11E-01**	9.66E-02	**1.74E-03**	**1.64E-02**	3.25E-01	1.95E-01	4.73E-01	9.69E+00	**2.82E+00**	4.92E-01	1.17E+00	5.53E-01
PA-40	**5.98E-02**	**1.36E-01**	**2.89E-03**	**3.36E-02**	2.88E-01	2.27E-01	**5.30E-01**	1.06E+01	2.94E-01	4.95E-01	9.58E-01	4.38E-01
PA-41	**1.32E-01**	1.17E-01	**7.25E-03**	**7.49E-02**	2.97E-01	2.48E-01	**1.49E+00**	2.05E+01	**5.34E-01**	5.63E-01	1.21E+00	4.17E-01
PA-42	**1.47E-01**	9.18E-02	**4.29E-03**	**5.43E-02**	2.73E-01	2.52E-01	**2.97E+00**	**1.56E+01**	**3.59E-01**	**5.97E-01**	1.12E+00	3.13E-01
PA-43	4.05E-02	7.35E-02	**2.24E-03**	**1.23E-02**	2.80E-01	2.22E-01	3.89E-01	7.59E+00	2.09E-01	4.32E-01	1.32E+00	4.47E-01
PA-44	**9.19E-02**	9.56E-02	**3.39E-03**	**3.87E-02**	3.12E-01	2.90E-01	**2.02E+00**	1.23E+01	**7.84E+00** [(c)]	4.99E-01	1.57E+00	**5.70E-01**
PA-45	**2.06E-01**	1.05E-01	**2.50E-03**	**2.92E-02**	2.80E-01	2.11E-01	**1.67E+00**	1.22E+01	**1.67E+00**	7.77E-01	1.08E+00	4.88E-01
PA-46	**9.24E-02**	8.95E-02	**2.13E-03**	**2.92E-02**	2.94E-01	2.34E-01	**1.67E+00**	1.67E+01	5.78E-02	7.68E-01	1.51E+00	4.03E-01
PA-47	**9.09E-02**	8.64E-02	**2.24E-03**	**2.99E-02**	2.62E-01	3.14E-01	**6.54E+00**	**4.25E+01**	**1.92E+00**	**8.18E-01**	**1.79E+00**	5.04E-01
PA-48	4.37E-02	1.03E-01	5.21E-04	**3.07E-03**	**3.28E-01**	2.67E-01	**5.45E-01**	8.21E+00	2.72E-01	4.15E-01	1.06E+00	4.21E-01
PA-49	4.80E-02	1.00E-01	6.72E-04	**3.07E-03**	2.88E-01	3.02E-01	**5.90E-01**	1.16E+01	2.56E-01	5.22E-01	1.13E+00	4.35E-01
PA-50	3.96E-02	**1.63E-01**	5.37E-04	2.36E-03	2.89E-01	2.52E-01	4.48E-01	1.02E+01	2.24E-02	5.49E-01	1.72E+00	4.58E-01
PA-51	4.50E-02	1.05E-01	6.65E-04	2.38E-03	3.09E-01	2.43E-01	3.93E-01	8.40E+00	2.07E-01	4.74E-01	9.99E-01	4.98E-01
PA-52	4.43E-02	9.59E-02	4.92E-04	1.82E-03	2.60E-01	2.35E-01	**5.43E-01**	1.00E+01	2.50E-01	**6.22E-01**	1.22E+00	4.95E-01
PA-53	4.76E-02	9.47E-02	5.58E-04	2.17E-03	2.23E-01	1.81E-01	4.01E-01	7.92E+00	1.97E-01	3.96E-01	1.06E+00	3.78E-01

(a) Total PCBs are 2x the sum of detected congeners.
(b) Total 4,4′-DDx are the sum of 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT.
(c) $HQ_{high} > 1$ (1.70E+00).
Bold: tissue concentration exceeds the reference threshold value.
Bold and shaded: tissue concentration exceeds the reference threshold value and $HQ_{low} > 1$.
HQ = hazard quotient.
All HQ_{high} values less than 1.0 except mercury at Station PA-44.

Table 6-8. Summary of Screening Level Dose Assessment Results for Area VIII (Eastern Wetland)

Station	HQ_{low}											
	Total PCBs[(a)]	Total 4,4′-DDx [(b)]	Dibutyltin	Tributyltin	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Selenium	Zinc
EW-30	**2.25E-01**	9.96E-02	5.43E-04	1.89E-03	**3.86E-01**	**4.83E-01**	**8.40E-01**	**1.78E+01**	3.29E-01	5.14E-01	1.71E+00	**6.28E-01**
EW-31	**1.38E-01**	1.10E-01	5.18E-04	1.44E-03	3.09E-01	2.18E-01	3.23E-01	8.75E+00	6.76E-03	3.48E-01	1.66E+00	3.75E-01
EW-32	**1.16E-01**	**1.53E-01**	6.32E-04	1.99E-03	2.73E-01	2.01E-01	4.12E-01	1.09E+01	1.66E-02	4.41E-01	1.41E+00	4.13E-01
EW-33	**1.99E-01**	8.86E-02	5.81E-04	1.67E-03	**3.68E-01**	**1.21E+00**	**6.33E-01**	**1.65E+01**	3.17E-01	4.68E-01	1.49E+00	4.34E-01
EW-34	**2.15E-01**	**1.40E-01**	5.68E-04	1.48E-03	**3.63E-01**	2.65E-01	3.38E-01	1.14E+01	6.46E-03	4.20E-01	1.43E+00	5.02E-01
EW-35	**1.00E-01**	1.19E-01	5.21E-04	1.40E-03	2.82E-01	2.35E-01	4.22E-01	8.80E+00	2.09E-01	4.08E-01	1.71E+00	5.50E-01
EW-36	**3.10E-01**	1.24E-01	5.35E-04	1.65E-03	2.95E-01	2.65E-01	**7.62E-01**	**1.63E+01**	6.37E-03	5.07E-01	1.63E+00	4.74E-01
EW-37	2.25E-02	2.49E-02	6.38E-04	1.90E-03	2.93E-01	1.99E-01	3.95E-01	8.11E+00	1.96E-01	4.25E-01	1.64E+00	4.53E-01

(a) Total PCBs are 2x the sum of detected congeners.
(b) Total 4,4′-DDx are the sum of 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT.
Bold: tissue concentration exceeds the reference threshold value.
Bold and shaded: tissue concentration exceeds the reference threshold value and $HQ_{low} > 1$.
HQ = hazard quotient.
All HQ_{high} values less than 1.0.

Table 6-9. Summary of Screening Level Dose Assessment Results for Area IX (Oil Reclamation)

Station	HQ_{low}											
	Total PCBs[(a)]	Total 4,4′-DDx [(b)]	Dibutyltin	Tributyltin	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Selenium	Zinc
OR-24	**1.09E+00**	**2.51E-01**	**2.32E-03**	**2.28E-02**	3.15E-01	**9.02E-01**	**7.94E-01**	**3.09E+01**	3.31E-01	**8.80E-01**	1.54E+00	5.05E-01
OR-25	**4.52E-01**	**2.00E-01**	7.91E-04	2.08E-03	2.78E-01	2.29E-01	4.71E-01	1.30E+01	2.33E-01	4.80E-01	1.77E+00	4.34E-01
OR-26	**7.35E-01**	**2.09E-01**	**9.74E-04**	**8.21E-03**	3.24E-01	**1.70E+00**	**7.11E-01**	**2.24E+01**	2.45E-01	**6.78E-01**	**1.82E+00**	5.45E-01
OR-27	**1.28E+00**	**3.41E-01**	**1.77E-03**	**9.61E-03**	2.68E-01	1.96E-01	**6.04E-01**	**1.93E+01**	2.53E-02	6.10E-01	1.41E+00	3.79E-01
OR-28	**2.73E-01**	**1.42E-01**	6.02E-04	1.71E-03	2.77E-01	**5.89E-01**	**4.91E-01**	1.14E+01	2.17E-01	3.95E-01	1.50E+00	4.31E-01
OR-29	**7.14E-01**	**2.34E-01**	**8.32E-04**	2.84E-03	**3.52E-01**	1.97E-01	4.47E-01	1.32E+01	2.87E-01	4.73E-01	1.43E+00	3.99E-01

(a) Total PCBs are 2x the sum of detected congeners.
(b) Total 4,4′-DDx are the sum of 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT.
(c) $HQ_{high} > 1$ (1.70E+00).
Bold: tissue concentration exceeds the reference threshold value.
Bold and shaded: tissue concentration exceeds the reference threshold value and $HQ_{low} > 1$.
HQ = hazard quotient.
All HQ_{high} values less than 1.0.

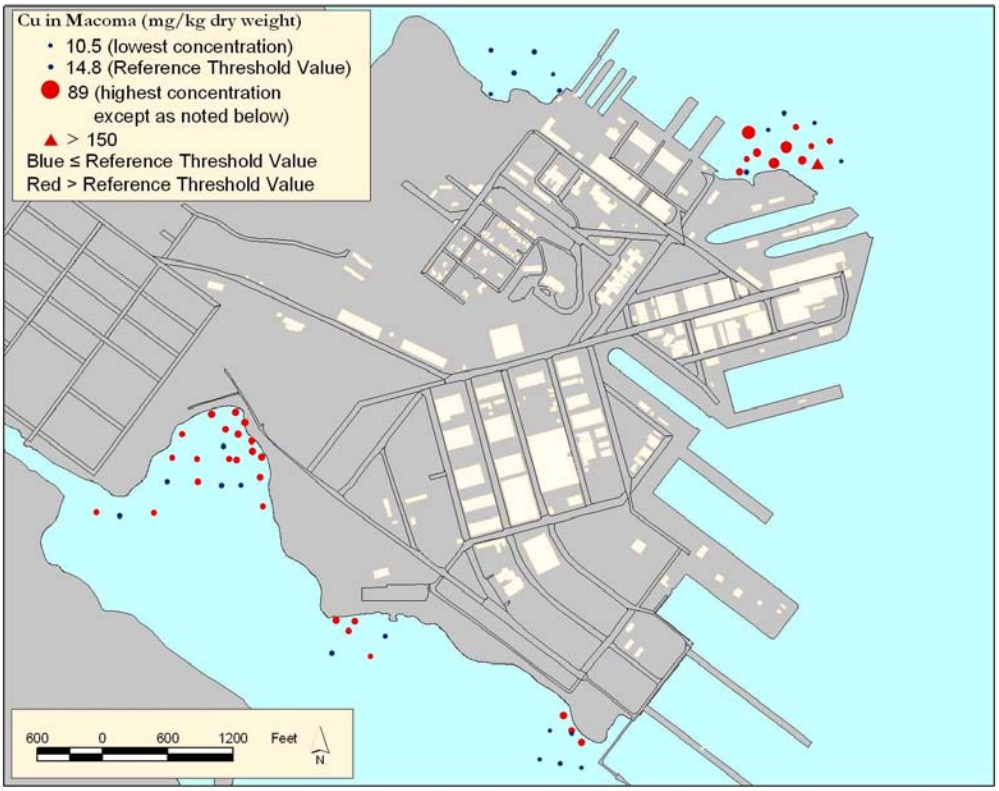


Figure 6-2. Map of Copper Concentrations in *M. nasuta* Tissue

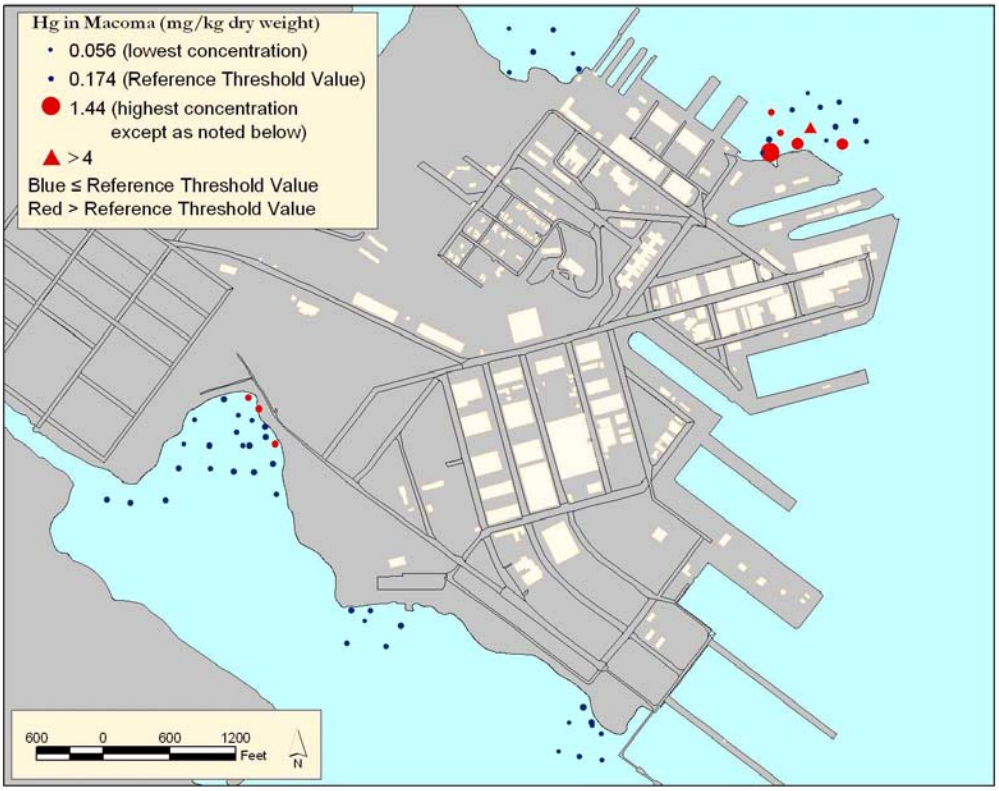


Figure 6-3. Map of Mercury Concentrations in *M. nasuta* Tissue

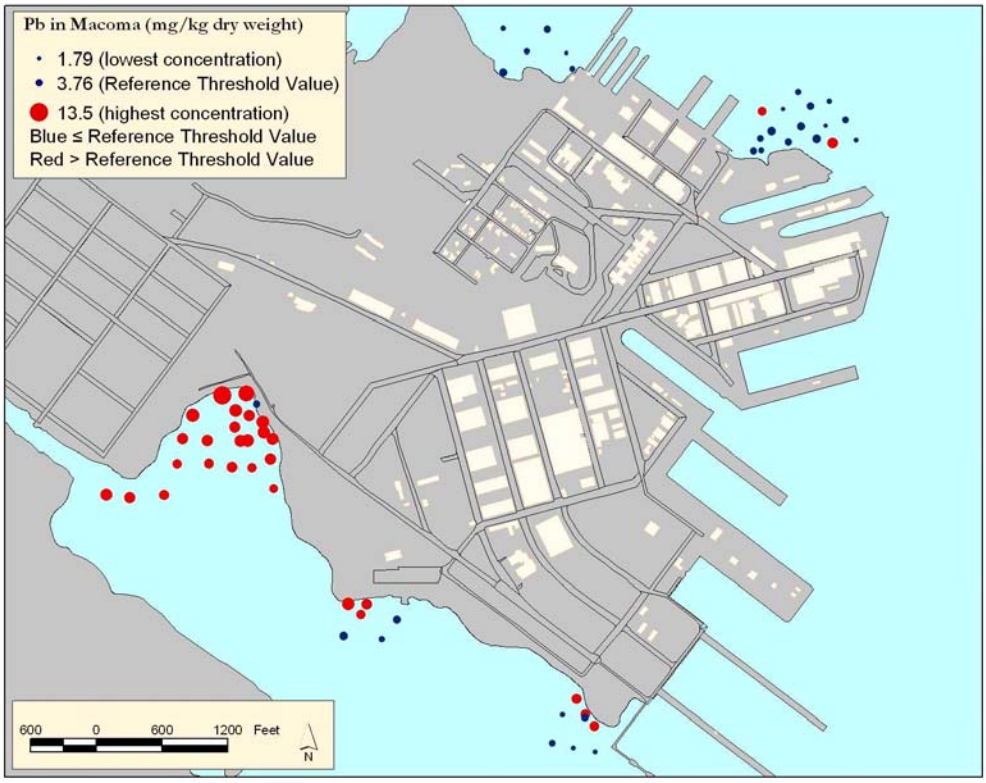


Figure 6-4. Map of Lead Concentrations in *M. nasuta* Tissue

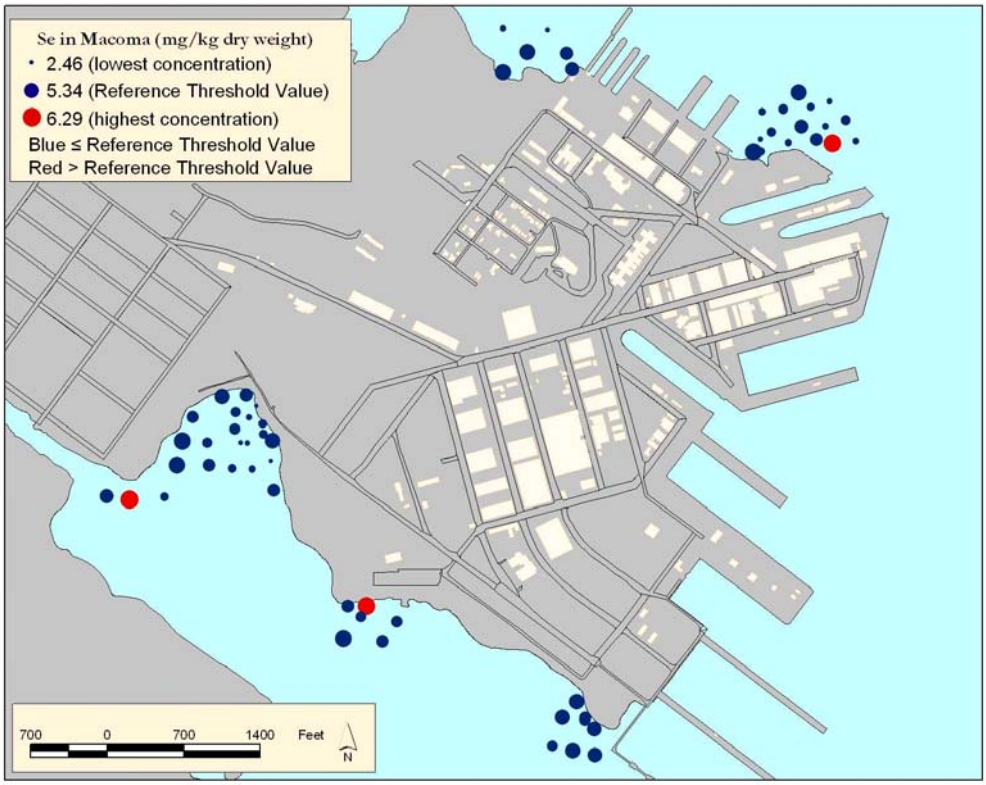


Figure 6-5. Map of Selenium Concentrations in *M. nasuta* Tissue

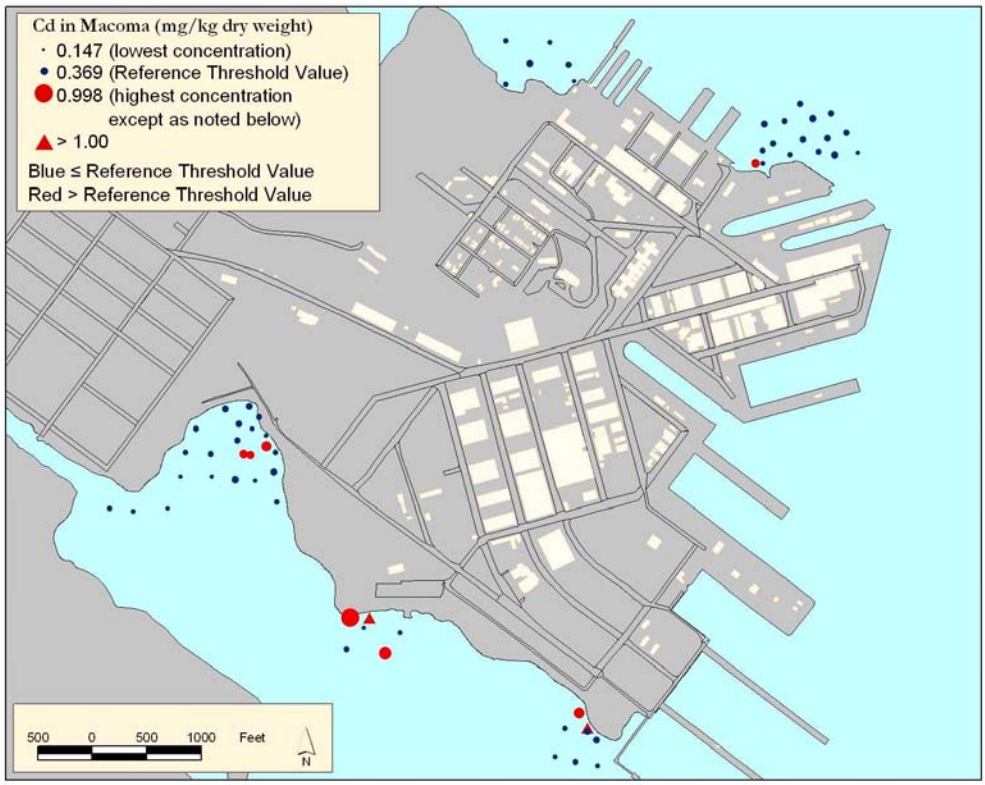


Figure 6-6. Map of Cadmium Concentrations in *M. nasuta* Tissue

In cases where tissue concentrations exceeded reference threshold values, HQ_{low} values were all below 1.0 at three stations. HQ_{low} values for PCBs, cadmium, and selenium were between 1.0 and 2.0 at one or more stations. Lead was the only COPEC with an HQ_{low} of greater than 10; however, the low TRV for lead is very low and any tissue lead concentration that exceeds reference will result in a HQ_{low} greater than 10. HQ_{high} values were below 1.0 at all Area IX stations. HQ_{low} values for lead and selenium exceeded 1.0 at stations where tissue concentrations did not exceed reference threshold values. Figures 6-4, 6-5, 6-6, and 6-7 show the distribution of *M. nasuta* tissue concentrations for lead, selenium, cadmium, and PCBs, respectively.

Area X (South Basin). Results of the reference comparison and HQ calculations for Area X are summarized in Table 6-10. Tissue PCB concentrations exceeded reference threshold values at all stations, and tissue DDx concentrations exceeded reference at all but one station. Copper and lead tissue concentrations exceeded reference at most stations. Mercury exceeded reference at three stations. DBT, TBT, cadmium, nickel, selenium, and zinc each exceeded reference at some Area X stations.

The HQ_{low} values for PCBs were generally between 1.0 and 3.0. At the two stations where copper or selenium HQ_{low} values exceeded 1.0, no exceedances were above 2.1. The lead HQ_{low} values all exceeded 1.0, even in cases where tissue concentrations did not exceed reference threshold values. HQ_{low} values for selenium were above 1.0 at all but four stations where tissue concentrations were below reference threshold values. All HQ_{high} values were less than 1.0. As can be observed from the *M. nasuta* tissue concentration maps in Figures 6-2 through 6-7, only lead and PCBs in *M. nasuta* tissue are widely distributed at elevated concentrations at South Basin.

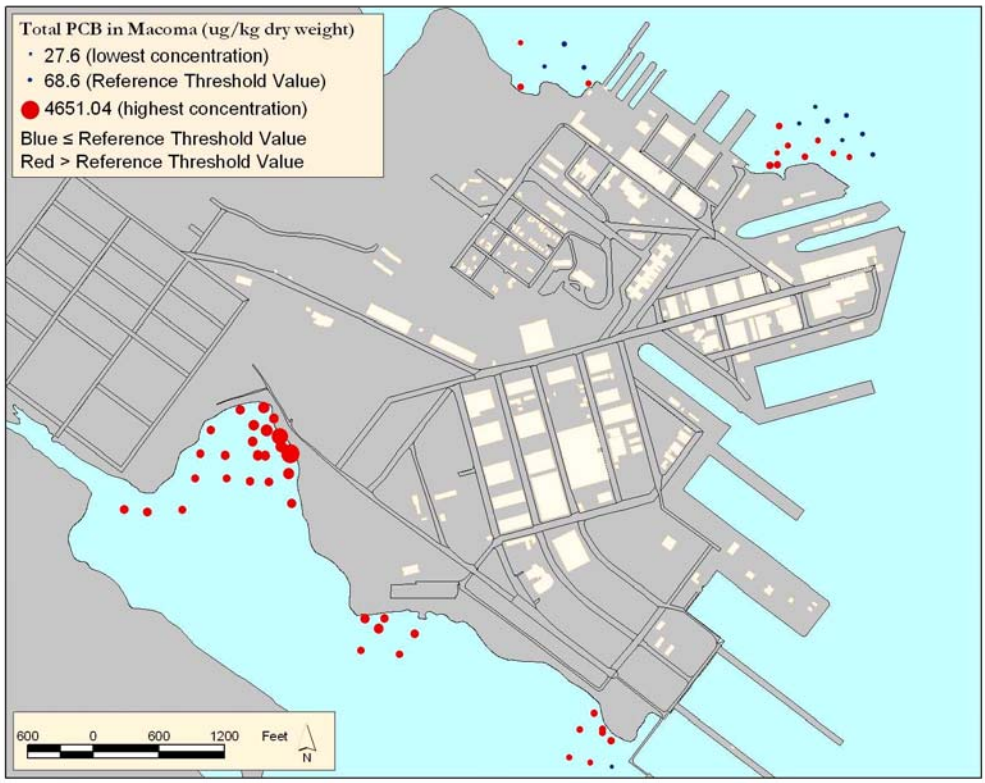


Figure 6-7. Map of Total PCB Concentrations in *M. nasuta* Tissue

6.2.2 Summary of Screening-Level Dose Assessment Results

Based on the results of the conservative screening-level risk assessment, stations in Area I appear to pose little to no risk to upper trophic level receptors. A greater proportion of stations in Areas III, VIII, IX, and X potentially pose a risk. Further evaluation of the five areas was conducted in a refined assessment, as discussed in Section 6.3.

6.3 Refined Dose Assessment

The screening-level dose assessment indicated that some risk to benthic-feeding birds (as modeled by the surf scoter) may be associated with individual sampling stations within the low-volume footprint. The screening-level dose assessment assumed that a receptor feeds at one sampling station 100%of the time. In fact, available data indicate that the typical scoter only spends the winter in San Francisco Bay, and its foraging area is larger than the HPS offshore areas included in the Validation Study (see Appendix G). To address this issue, quantitative refinements of prey concentrations and SUFs were applied to dose and HQ calculations. Results of these refinements are described in Sections 6.3.1 and 6.3.2 for tissue COPECs that exceeded reference threshold values.

6.3.1 Exposure Point Concentration Refinement

Exposure point concentrations (EPCs) were refined by using an estimate of the central tendency of the sediment and tissue concentrations for the entire site and for each of the five HPS study areas. The central tendency was estimated using both the arithmetic mean and the 95% upper confidence limit (UCL) of the mean. Complete results of the 95% UCL and arithmetic mean calculations are provided in Appendix H. To develop the 95% UCL, the lower of either the maximum sediment or tissue concentration

Table 6-10. Summary of Screening Level Dose Assessment Results for Area X (South Basin)

Station	HQ_{low}											
	Total PCBs[(a)]	Total 4,4′-DDx [(b)]	Dibutyltin	Tributyltin	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Selenium	Zinc
SB-01	**1.04E+00**	**8.01E-01**	6.62E-04	1.66E-03	2.97E-01	2.21E-01	**5.54E-01**	**3.41E+01**	2.63E-01	4.80E-01	1.56E+00	5.14E-01
SB-02	**8.89E-01**	**5.56E-01**	**3.80E-03**	1.23E-03	3.04E-01	2.12E-01	5.04E-01	**2.81E+01**	2.58E-01	3.99E-01	**2.09E+00**	3.24E-01
SB-03	**6.74E-01**	**3.31E-01**	6.17E-04	2.31E-03	2.51E-01	1.72E-01	**5.19E-01**	**2.35E+01**	2.51E-01	4.85E-01	1.20E+00	3.83E-01
SB-04	**5.31E-01**	**2.43E-01**	5.27E-04	1.61E-03	2.79E-01	1.72E-01	4.77E-01	**2.05E+01**	2.71E-01	4.19E-01	1.74E+00	4.46E-01
SB-05	**5.02E-01**	**2.15E-01**	4.37E-04	8.63E-04	2.32E-01	1.42E-01	**5.82E-01**	**2.13E+01**	2.52E-01	4.97E-01	1.50E+00	4.23E-01
SB-06	**8.18E-01**	**3.39E-01**	7.59E-04	2.76E-03	3.21E-01	3.10E-01	4.83E-01	**2.31E+01**	3.20E-01	4.80E-01	1.20E+00	**6.05E-01**
SB-07	**6.34E-01**	**2.67E-01**	7.14E-04	1.67E-03	2.50E-01	2.12E-01	**5.51E-01**	**2.64E+01**	3.56E-02	4.46E-01	1.74E+00	3.12E-01
SB-08	**8.61E-01**	**3.86E-01**	8.15E-04	2.16E-03	2.77E-01	2.37E-01	**5.54E-01**	**2.75E+01**	2.58E-01	5.07E-01	1.34E+00	4.44E-01
SB-09	**8.51E-01**	**7.67E-01**	5.79E-04	1.69E-03	2.19E-01	2.34E-01	**5.95E-01**	**4.02E+01**	1.89E-01	4.85E-01	1.49E+00	4.10E-01
SB-10	**1.07E+00**	**6.55E-01**	6.67E-04	1.94E-03	2.53E-01	2.52E-01	**8.37E-01**	**4.66E+01**	3.90E-01	**6.95E-01**	1.67E+00	3.90E-01
SB-11	**1.77E+00**	**8.03E-01**	7.21E-04	2.23E-03	3.17E-01	2.65E-01	**6.59E-01**	**3.88E+01**	3.94E-02	5.25E-01	1.32E+00	4.66E-01
SB-12	**1.34E+00**	**5.41E-01**	7.96E-04	2.22E-03	2.40E-01	2.48E-01	5.10E-01	**2.85E+01**	2.44E-01	4.18E-01	1.42E+00	5.20E-01
SB-13	**1.23E+00**	**5.12E-01**	**8.75E-04**	**3.77E-03**	3.18E-01	**3.42E-01**	**7.03E-01**	**3.29E+01**	3.26E-01	**6.75E-01**	9.81E-01	4.97E-01
SB-14	**1.37E+00**	**5.99E-01**	6.77E-04	2.42E-03	2.98E-01	**3.63E-01**	**6.33E-01**	**2.93E+01**	3.16E-02	5.52E-01	9.31E-01	**5.91E-01**
SB-15	**9.19E-01**	**3.74E-01**	**8.37E-04**	**3.15E-03**	2.65E-01	1.54E-01	4.69E-01	**2.05E+01**	2.96E-01	3.85E-01	1.10E+00	3.98E-01
SB-16	**1.89E+00**	**3.75E-01**	**1.08E-03**	**6.82E-03**	2.91E-01	3.09E-01	**7.70E-01**	**3.39E+01**	3.16E-01	6.61E-01	8.90E-01	5.66E-01
SB-17	**1.15E+00**	**3.12E-01**	**1.22E-03**	**7.89E-03**	2.63E-01	2.15E-01	**5.36E-01**	**1.92E+01**	2.52E-01	4.93E-01	1.51E+00	5.63E-01
SB-18	**2.00E+00**	**6.83E-01**	8.03E-04	**3.26E-03**	3.14E-01	3.01E-01	**7.60E-01**	**4.87E+01**	**3.58E-01**	5.79E-01	1.55E+00	5.21E-01
SB-19	**1.50E+00**	8.00E-02	**8.94E-04**	1.48E-03	2.04E-01	2.32E-01	**1.17E+00**	9.69E+00	**4.06E-01**	2.20E-01	8.18E-01	3.42E-01
SB-20	**2.05E+00**	**6.82E-01**	**3.95E-03**	**4.29E-03**	2.72E-01	2.06E-01	**7.93E-01**	**3.01E+01**	5.73E-02	4.51E-01	1.01E+00	4.92E-01
SB-21	**3.44E+00**	**4.92E-01**	**1.39E-03**	**1.08E-02**	2.68E-01	1.64E-01	**9.12E-01**	**2.78E+01**	3.77E-01	**7.07E-01**	1.20E+00	4.61E-01
SB-22	**2.01E+00**	**4.66E-01**	**1.89E-03**	**4.85E-03**	3.02E-01	**4.84E-01**	**7.88E-01**	**3.73E+01**	3.41E-01	5.38E-01	1.21E+00	3.81E-01
SB-23	**3.78E+00**	**4.45E-01**	**2.03E-03**	**1.56E-02**	2.45E-01	2.08E-01	**8.96E-01**	**3.19E+01**	**3.81E-01**	4.32E-01	1.70E+00	3.44E-01

(a) Total PCBs are 2x the sum of detected congeners.
(b) Total 4,4′-DDx are the sum of 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT.
(c) $HQ_{high} > 1$ (1.70E+00).
Bold: tissue concentration exceeds the reference threshold value.
Bold and shaded: tissue concentration exceeds the reference threshold value and $HQ_{low} > 1$.
HQ = hazard quotient.
All HQ_{high} values less than 1.0.

or the 95% UCL was used in the calculation. Both the 95% UCL and the arithmetic mean were calculated based on the distribution of the dataset (normal, lognormal or non-normal).

Table 6-11 summarizes the results of the EPC refinement using the 95% UCLs of the sediment and tissue data sets. For a scoter foraging over all five HPS study areas, the HQ_{low} values indicate site-related potential risks from copper, lead, and mercury. For a scoter foraging exclusively at Area I, none of the HQ_{low} values exceeded 1.0 for tissue concentrations that exceeded reference. For Area III, HQ_{low} values for copper and mercury exceeded 1.0. For Area VIII, the HQ_{low} for lead exceeded 1.0, and for Area IX, the HQ_{low} values for cadmium, lead, and PCBs exceeded 1.0. For Area X, HQ_{low} values for lead and PCBs exceeded 1.0. All HQ_{high} values were less than 1.0.

The site-wide and area-specific evaluations using the 95% UCL EPCs indicate that Area I is not associated with excess risk; therefore this area was not evaluated further. The assessments for the entire site (copper, lead, and mercury), Area III (copper and mercury), Area VIII (lead), Area IX (cadmium, lead, and PCBs) and Area X (lead and PCBs) were refined further as discussed in Section 6.3.2.

6.3.2 Refinement of SUF

All dose calculations conducted to this point were performed using an SUF of 1.0, which assumes that a receptor feeds solely within the designated location (e.g., individual station, area, or entire site). As noted in Appendix G, data are not available to define the foraging area for the scoter in San Francisco Bay. However, the highest possible SUF for a scoter at HPS is 0.5 because they are winter migrants and spend only six months of the year in San Francisco Bay. A SUF of 0.5 implies that over the winter, scoters forage solely at HPS. This is unlikely to be the case based on what is known about scoters in other habitats such as Puget Sound, Washington (Mahaffy et al., 1995) and Chesapeake Bay (Perry and Lohnes, 2001-2004).

Due to the uncertainty associated with the foraging range data available for the scoter, a range of SUFs are presented so that the impact of the SUF on the resulting HQ can be evaluated. As the SUF was reduced below one, the remaining (i.e., non-HPS) exposure was assumed to be at reference concentrations. This scenario assumes that the scoters' entire exposure occurs within San Francisco Bay, and does not account for seasonal migration. The dose was calculated using the following equation:

$$Dose = \frac{\left\{\left[\left(C_{sed-HPS} * IR_{sed}\right) + \left(C_{prey-HPS} * IR_{prey}\right)\right] \times SUF_{HPS}\right\} + \left\{\left[\left(C_{sed-ref} * IR_{sed}\right) + \left(C_{prey-ref} * IR_{prey}\right)\right] \times SUF_{ref}\right\}}{BW} \quad (6\text{-}4)$$

where:
- $C_{sed-HPS}$ = 95% UCL COPEC-specific concentration in surface sediments (milligrams COPEC per kilograms sediment [dry weight]) for the entire HPS site or an individual area
- $C_{sed-ref}$ = 95% UCL COPEC-specific concentration in surface sediments (milligrams COPEC per kilograms sediment [dry weight]) for all reference stations
- $C_{prey-HPS}$ = 95% UCL COPEC-specific concentration in depurated, laboratory *M. nasuta* tissue (milligrams COPEC per kilograms tissue [dry weight]) for the entire HPS site or an individual area (e.g., Area III)
- $C_{prey-ref}$ = 95% UCL COPEC-specific concentration in depurated, laboratory *M. nasuta* tissue (milligrams COPEC per kilograms tissue [dry weight]) for all reference stations
- IR_{sed} = sediment ingestion rate (milligrams sediment per day [dry weight])
- IR_{prey} = prey tissue ingestion rate (milligrams tissue per day [dry weight])
- SUF_{HPS} = site use factor (unitless) for HPS
- SUF_{ref} = site use factor (unitless) for reference (equivalent to 1 minus the site use factor for HPS).

Table 6-11. Summary of HPS Hazard Quotients for the Surf Scoter – 95% UCL Sediment and Tissue Concentrations

COPEC	Site-wide 95% UCL			Area I 95% UCL			Area III 95% UCL			Area VIII 95% UCL			Area IX 95% UCL			Area X 95% UCL		
	[tissue]>ref	HQ low	HQ high	[tissue]>ref	HQ low	HQ high	[tissue]>ref	HQ low	HQ high	[tissue]>ref	HQ low	HQ high	[tissue]>ref	HQ low	HQ high	[tissue]>ref	HQ low	HQ high
Arsenic	N	2.97E-01	7.42E-02	N	3.10E-01	7.74E-02	N	3.02E-01	7.56E-02	Y	3.52E-01	8.79E-02	Y	3.31E-01	8.26E-02	N	2.85E-01	7.13E-02
Cadmium	Y	4.49E-01	2.20E-03	N	2.70E-01	1.32E-03	N	2.79E-01	1.36E-03	Y	9.16E-01	4.48E-03	Y	1.12E+00	5.50E-03	N	2.77E-01	1.35E-03
Copper	Y	1.31E+00	5.25E-02	N	5.28E-01	2.13E-02	Y	3.26E+00	1.31E-01	Y	7.15E-01	2.88E-02	Y	7.03E-01	2.83E-02	Y	7.68E-01	3.09E-02
Lead	Y	2.70E+01	6.78E-02	N	1.94E+01	4.87E-02	N	2.12E+01	5.33E-02	Y	1.54E+01	3.87E-02	Y	2.48E+01	6.23E-02	Y	3.35E+01	8.42E-02
Mercury	Y	1.10E+00	2.39E-01	N	2.52E-01	5.46E-02	Y	4.15E+00	9.00E-01	N	2.67E-01	5.78E-02	N	2.99E-01	6.47E-02	N	3.14E-01	6.80E-02
Nickel	N	6.22E-01	1.53E-02	Y	9.66E-01	2.38E-02	N	6.78E-01	1.67E-02	N	5.15E-01	1.27E-02	Y	7.33E-01	1.81E-02	N	5.49E-01	1.36E-02
Selenium	N	1.46E+00	3.62E-01	N	1.71E+00	4.23E-01	N	1.43E+00	3.53E-01	N	1.67E+00	4.13E-01	N	1.72E+00	4.26E-01	N	1.47E+00	3.64E-01
Zinc	N	4.70E-01	4.70E-02	N	4.75E-01	4.75E-02	N	4.88E-01	4.88E-02	N	5.34E-01	5.34E-02	N	5.02E-01	5.02E-02	N	4.84E-01	4.84E-02
Total PCBs[(a)]	Y	8.78E-01	7.25E-02	Y	1.07E-01	8.79E-03	Y	2.58E-01	2.13E-02	Y	2.29E-01	1.89E-02	Y	1.07E+00	8.84E-02	Y	1.77E+00	1.46E-01
Total 4,4′-DDx [(b)]	Y	3.14E-01	3.67E-03	Y	1.62E-01	1.89E-03	N	1.15E-01	1.34E-03	Y	1.36E-01	1.59E-03	Y	2.87E-01	3.35E-03	Y	5.48E-01	6.40E-03
Dibutyltin	Y	2.22E-03	3.54E-05	N	7.81E-04	1.24E-05	Y	4.94E-03	7.86E-05	N	6.03E-04	9.61E-06	Y	1.78E-03	2.83E-05	Y	2.03E-03	3.23E-05
Tributyltin	Y	2.09E-02	3.32E-04	Y	3.44E-03	5.48E-05	Y	5.73E-02	9.12E-04	N	1.84E-03	2.92E-05	Y	1.45E-02	2.32E-04	Y	5.15E-03	8.20E-05

COPECs in bold are priority COPECs **(Hg, DDx, and PCBs).**
(a) Total PCBs are 2x the sum of detected congeners.
(b) Total 4,4′-DDx are the sum of 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT.
(c) Gray cells correspond to HQ >1.
COPEC = contaminant of potential ecological concern; HQ = hazard quotient; UCL = upper confidence limit.

Doses and HQs were calculated using SUFs of 0.5, 0.1, 0.05, and 0.01 for tissue COPECs that were elevated above reference and had HQ_{low} values greater than 1.0 based on 95% UCLs as EPCs. These SUFs span a wide range of possible exposure scenarios. These calculations were run for five scenarios: over the entire site, and individually for Areas III, VIII, IX, and X. In addition, doses and HQs were calculated for a scoter that is only exposed to reference conditions. This allowed for a comparison of potential risk associated with 100% ambient exposure compared to 100% exposure to HPS sediments. HQs calculated for SUFs of 0.5, 0.1, 0.05, and 0.01 are summarized in Tables 6-12 through 6-16. Figures 6-8 through 6-18 illustrate the relative contributions of HPS and ambient concentrations for COPECs with HQ_{low} values greater than 1.0.

6.3.2.1 Sitewide Hazard Quotients with Refined SUF

Refined SUF results for copper, lead, and mercury for sitewide exposure are presented in Table 6-12. The reference contribution to the copper HQ_{low} increases significantly as the SUF decreases (Figure 6-8). At a SUF of 0.5 or less, the HQ_{low} is less than 1.0 and becomes dominated by the reference contribution. The same pattern is observed for lead (Figure 6-9), although the low lead TRV results in HQ_{low} much higher than 1.0 even for 100% reference exposure. A similar pattern is also observed for mercury (Figure 6-10), where the reference contribution is dominant for all SUFs of 0.1 or less.

6.3.2.2 Area III Hazard Quotients with Refined SUF

Refined SUF results for copper and mercury at Area III are provided in Table 6-13. Results indicate that the 95% UCLs for copper and mercury tissue concentrations exceed reference threshold values, and that the associated HQ_{low} values are higher than 1.0. The patterns for copper and mercury (Figures 6-11 and 6-12, respectively) are similar to those observed for the sitewide HQ_{low} values, although the Area III contribution to the Area III HQ_{low} values is greater than the sitewide contribution to the sitewide HQ_{low} values. The Area III HQ_{low} values for copper and mercury are less than 1.0 when lower SUFs are used (i.e., $\leq$0.1).

6.3.2.3 Area VIII Hazard Quotients with Refined SUF

Refined SUF results for lead are provided in Table 6-14 for Area VIII exposure. As observed in the sitewide results for lead, the low TRV for lead results in HQ_{low} values much higher than 1.0 even for 100% reference exposure. As shown in Figure 6-13, as the Area VIII SUF decreases, the HQ_{low} values decrease and then level off as they approach the reference SUF of 1.0.

6.3.2.4 Area IX Hazard Quotients with Refined SUF

Refined SUF results for cadmium, lead, and PCBs at Area IX are provided in Table 6-15. The HQ_{low} values for cadmium and PCBs slightly exceeded 1.0. The HQ_{low} for lead is much higher than 1.0 even for 100% reference exposure. Figures 6-14 (cadmium) and 6-15 (lead) show a similar pattern of a significant reference contribution and a leveling of the HQ_{low} as the SUF decreases. In contrast, Figure 6-16 shows that the Area IX contribution to the PCB HQ_{low} remains significant even at a low SUF. However, the HQ_{low} for PCBs is only slightly above 1.0 at a SUF of 1.0; the HQ_{low} drops below 1.0 at lower SUFs.

6.3.2.5 Area X Hazard Quotients with Refined SUF

Refined SUF results for lead and PCBs at Area X are provided in Table 6-16. The HQ_{low} for lead is much higher than 1.0, even for 100% reference exposure, whereas the HQ_{low} for PCBs slightly exceeds 1.0.

Figure 6-17 shows a similar pattern for lead as previously observed, with a significant reference contribution and leveling of the HQ_{low} as the SUF decreases. The pattern for PCBs (Figure 6-18) is similar to that observed for Area IX, with a major contribution to the HQ_{low} from Area X for most SUFs. As was the case for Area IX, the HQ_{low} for PCBs drops below 1.0 at a SUF of 0.5 and less.

6.3.2.6 Summary of Results of SUF Refinement

Based on this analysis, refining the SUF to more realistic values (i.e., <0.5) results in HQ_{low} of less than 1.0 for all COPECs except lead. However, because of the low avian TRV for lead, HQ_{low} values are greater than 1.0 even for scenarios evaluating ambient exposure only. Ambient concentrations of copper, lead, and mercury provide a significant contribution to the overall risk for scenarios with a SUF of less than 0.5. For PCBs, reduction of the SUF decrease the HQ_{low} to less than 1.0, but the majority of PCB exposure is still from the portion of the diet obtained at HPS.

6.4 Summary of Bioaccumulation and Dose Assessment

To evaluate potential risk to benthic-invertebrate eating birds (i.e., surf scoter) exposed to HPS sediments, a two-phase dose assessment was conducted. In the first phase, a station-by-station screening-level evaluation was conducted. Of the five areas evaluated, Area I appeared to pose little to no risk to surf scoters; at Areas III, VIII, IX, and X, a higher proportion of the stations potentially posed a risk. For most COPECs, the estimated dose to the scoter is associated with an HQ_{low} slightly above 1.0.

In the second phase, a refined exposure evaluation was performed and average exposures (using the 95% UCL for sediment and tissue) over an entire area (i.e., the entire HPS site or Areas I, III, VIII, IX, and X) were evaluated. Additionally, ranges of SUFs were applied to take into account foraging range in relation to the area of offshore sediments at HPS. Integrating exposure over each individual area identified the following COPECs that exceeded tissue reference threshold values and had HQ_{low} values above 1.0: none in Area I; copper and mercury in Area III; lead in Area VIII; cadmium, lead, and PCBs in Area IX; and lead and PCBs in Area X.

The results of the SUF refinement indicate that reducing the SUF to less than 0.5 results in the reduction of the HQ_{low} values to less than one for all COPECs except lead. However, because of the low avian TRV for lead, HQ_{low} values are high even for scenarios evaluating ambient exposure only. Consequently, the ecological significance of the lead HQ_{low} values calculated for HPS is unclear. In general, concerns about the Navy/BTAG TRV (DON, 1998) make it difficult to adequately assess the risk to birds from lead. The Navy/BTAG TRV for lead is significantly lower than other widely accepted TRVs such as those from Oak Ridge National Laboratory (Sample et al., 1996) or the U.S. EPA (2003). For example, if the U.S. EPA lead TRV for birds (1.6 mg lead/kg bw-day) is used to assess effects from lead to the scoter at HPS, potential risk from lead throughout HPS would be considered negligible.

Ambient concentrations of lead, copper and mercury provide a significant contribution to the overall risk when SUFs of less than 1.0 are used in the calculation. However, the majority of the potential risk from PCBs in Areas IX and X can be attributed to the portion of the diet obtained at HPS. Based on the results of the refined dose assessment, the main bioaccumulative risk drivers at HPS were found to be copper, mercury, and PCBs.

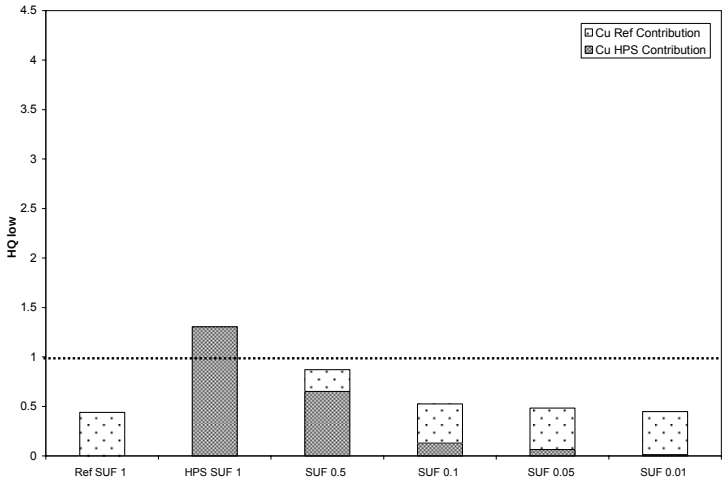


Figure 6-8. Contribution of Reference and HPS 95% UCL Exposure to Copper HQ_{low}

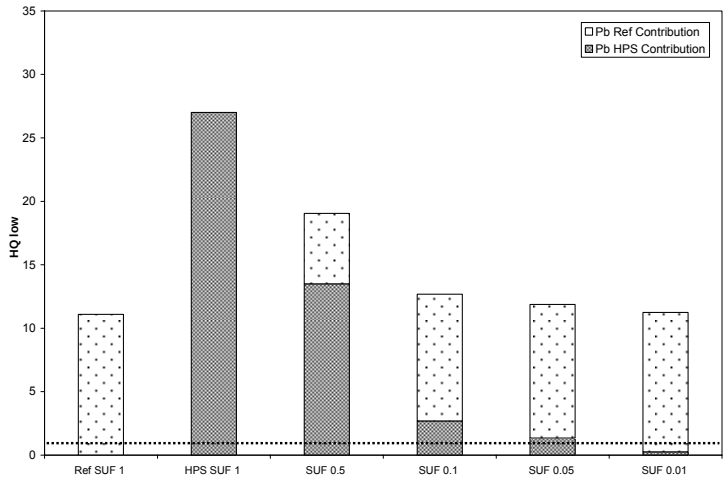


Figure 6-9. Contribution of Reference and HPS 95% UCL Exposure to Lead HQ_{low}

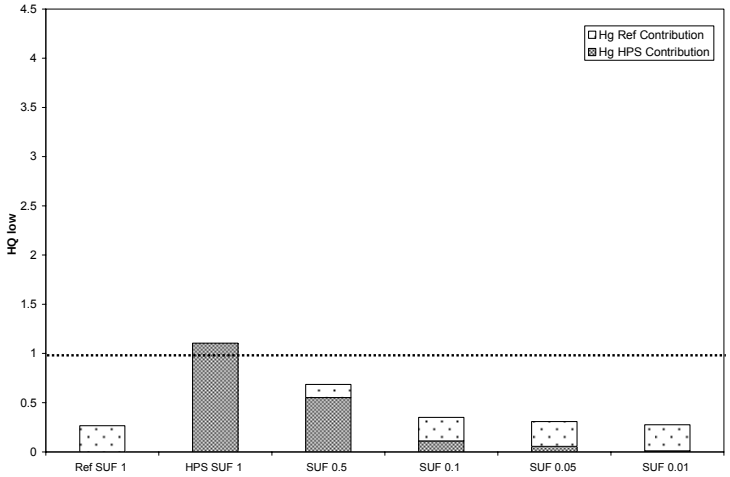


Figure 6-10. Contribution of Reference and HPS 95% UCL Exposure to Mercury HQ_{low}

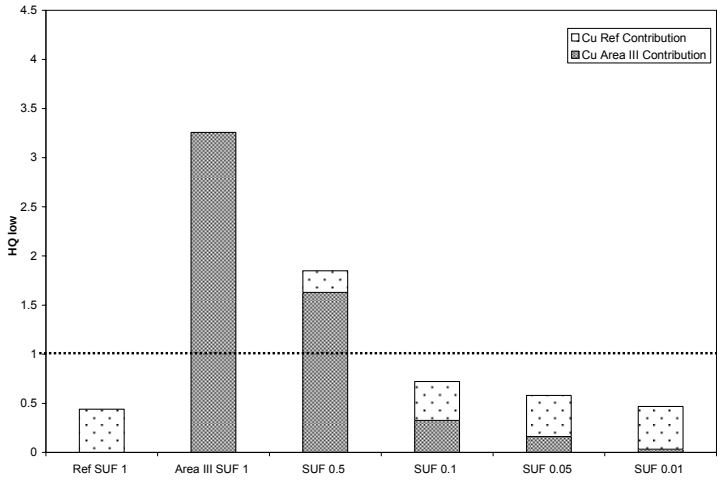


Figure 6-11. Contribution of Reference and Area III 95% UCL Exposure to Copper HQ_{low}

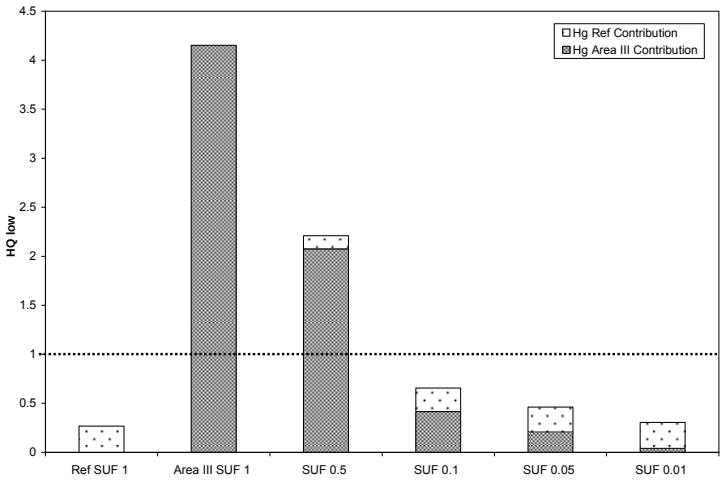


Figure 6-12. Contribution of Reference and Area III 95% UCL Exposure to Mercury HQ_{low}

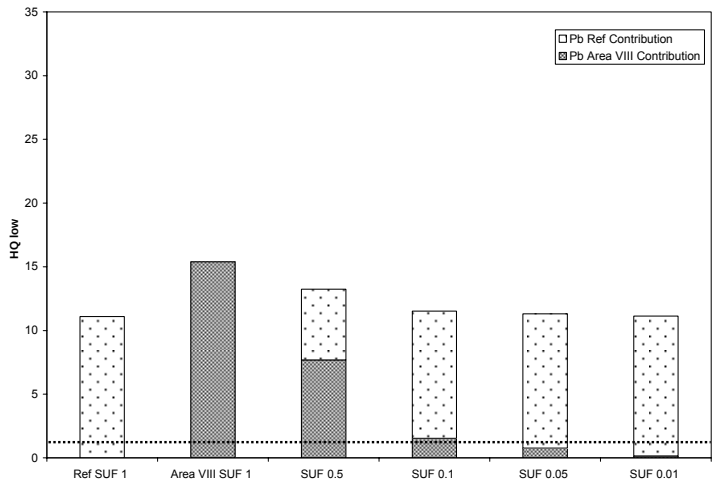


Figure 6-13. Contribution of Reference and Area VIII 95% UCL Exposure to Lead HQ_{low}

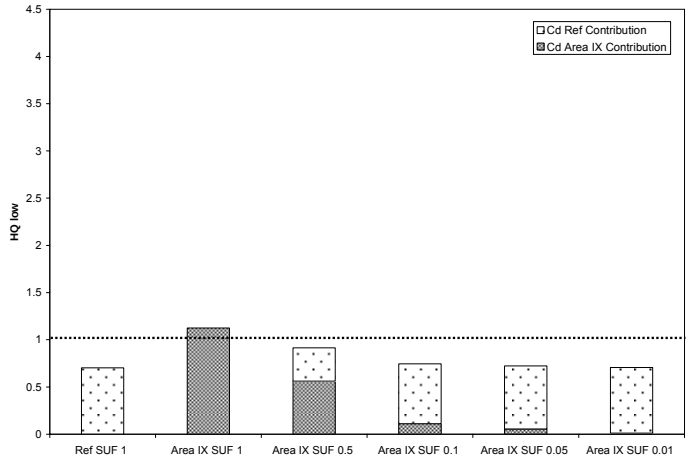


Figure 6-14. Contribution of Reference and Area IX 95% UCL Exposure to Cadmium HQ_{low}

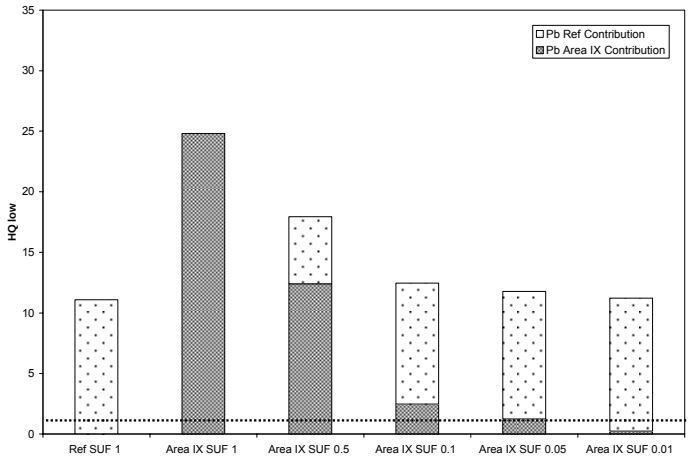


Figure 6-15. Contribution of Reference and Area IX 95% UCL Exposure to Lead HQ_{low}

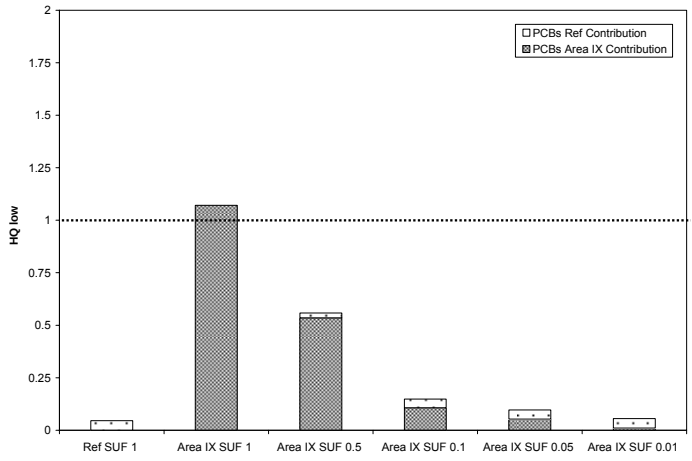


Figure 6-16. Contribution of Reference and Area IX 95% UCL Exposure to PCB HQ_{low}

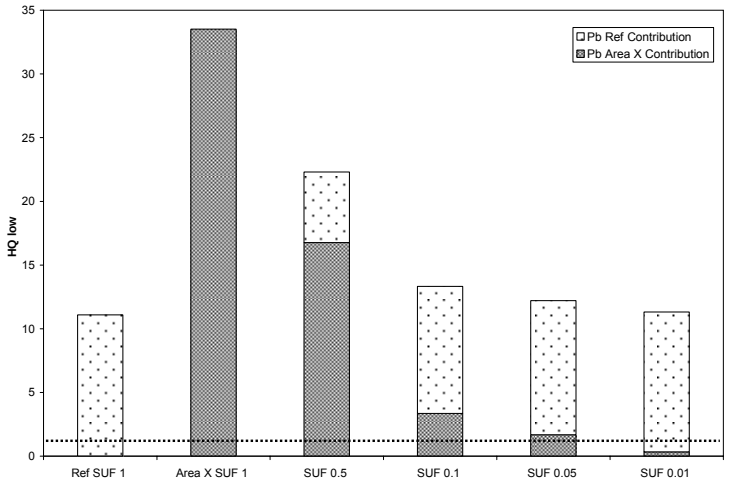


Figure 6-17. Contribution of Reference and Area X 95% UCL Exposure to Lead HQ_{low}

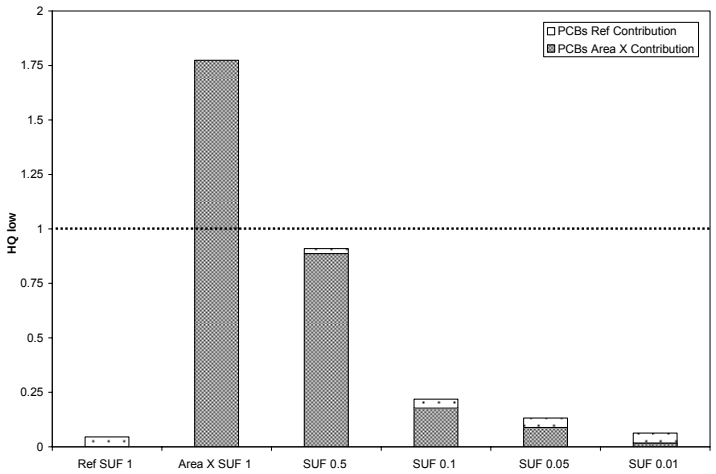


Figure 6-18. Contribution of Reference and Area X 95% UCL Exposure to PCB HQ_{low}

Table 6-12. HQ Results for HPS using 95% UCL Sediment and Tissue Concentrations and Refined SUF

Copper

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	4.39E-01	4.39E-01
1	0	1.31E+00	0	1.31E+00
0.5	0.5	6.53E-01	2.20E-01	8.72E-01
0.1	0.9	1.31E-01	3.95E-01	5.26E-01
0.05	0.95	6.53E-02	4.17E-01	4.83E-01
0.01	0.99	1.31E-02	4.35E-01	4.48E-01

Lead

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	1.11E+01	1.11E+01
1	0	2.70E+01	0	2.70E+01
0.5	0.5	1.35E+01	5.54E+00	1.90E+01
0.1	0.9	2.70E+00	9.98E+00	1.27E+01
0.05	0.95	1.35E+00	1.05E+01	1.19E+01
0.01	0.99	2.70E-01	1.10E+01	1.12E+01

Mercury

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	2.67E-01	2.67E-01
1	0	1.10E+00	0	1.10E+00
0.5	0.5	5.52E-01	1.34E-01	6.86E-01
0.1	0.9	1.10E-01	2.40E-01	3.51E-01
0.05	0.95	5.52E-02	2.54E-01	3.09E-01
0.01	0.99	1.10E-02	2.64E-01	2.76E-01

Gray cells correspond to HQ_{low} >1
SUF = site use factor; HQ = hazard quotient

Table 6-13. HQ Results for Area III using 95% UCL Sediment and Tissue Concentrations and Refined SUF

Copper

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	4.39E-01	4.39E-01
1	0	3.26E+00	0	3.26E+00
0.5	0.5	1.63E+00	2.20E-01	1.85E+00
0.1	0.9	3.26E-01	3.95E-01	7.21E-01
0.05	0.95	1.63E-01	4.17E-01	5.80E-01
0.01	0.99	3.26E-02	4.35E-01	4.68E-01

Mercury

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	2.67E-01	2.67E-01
1	0	4.15E+00	0	4.15E+00
0.5	0.5	2.08E+00	1.34E-01	2.21E+00
0.1	0.9	4.15E-01	2.40E-01	6.56E-01
0.05	0.95	2.08E-01	2.54E-01	4.61E-01
0.01	0.99	4.15E-02	2.64E-01	3.06E-01

Gray cells correspond to HQ >1.
SUF = site use factor; HQ = hazard quotient

Table 6-14. HQ Results for Area VIII using 95% UCL Sediment and Tissue Concentrations and Refined SUF

Lead

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	1.11E+01	1.11E+01
1	0	1.54E+01	0	1.54E+01
0.5	0.5	7.70E+00	5.54E+00	1.32E+01
0.1	0.9	1.54E+00	9.98E+00	1.15E+01
0.05	0.95	7.70E-01	1.05E+01	1.13E+01
0.01	0.99	1.54E-01	1.10E+01	1.11E+01

Gray cells correspond to HQ > 1.
SUF = site use factor; HQ = hazard quotient

Table 6-15. HQ Results for Area IX using 95% UCL Sediment and Tissue Concentrations and Refined SUF

Cadmium

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	7.03E-01	7.03E-01
1	0	1.12E+00	0	1.12E+00
0.5	0.5	5.62E-01	3.52E-01	9.14E-01
0.1	0.9	1.12E-01	6.33E-01	7.45E-01
0.05	0.95	5.62E-02	6.68E-01	7.24E-01
0.01	0.99	1.12E-02	6.96E-01	7.07E-01

Lead

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	1.11E+01	1.11E+01
1	0	2.48E+01	0	2.48E+01
0.5	0.5	1.24E+01	5.54E+00	1.80E+01
0.1	0.9	2.48E+00	9.98E+00	1.25E+01
0.05	0.95	1.24E+00	1.05E+01	1.18E+01
0.01	0.99	2.48E-01	1.10E+01	1.12E+01

PCBs

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	4.57E-02	4.57E-02
1	0	1.07E+00	0	1.07E+00
0.5	0.5	5.36E-01	2.28E-02	5.58E-01
0.1	0.9	1.07E-01	4.11E-02	1.48E-01
0.05	0.95	5.36E-02	4.34E-02	9.69E-02
0.01	0.99	1.07E-02	4.52E-02	5.59E-02

Gray cells correspond to HQ >1.
SUF = site use factor; HQ = hazard quotient

Table 6-16. HQ Results for Area X using 95% UCL Sediment and Tissue Concentrations and Refined SUF

Lead

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	1.11E+01	1.11E+01
1	0	3.35E+01	0	3.35E+01
0.5	0.5	1.68E+01	5.54E+00	2.23E+01
0.1	0.9	3.35E+00	9.98E+00	1.33E+01
0.05	0.95	1.68E+00	1.05E+01	1.22E+01
0.01	0.99	3.35E-01	1.10E+01	1.13E+01

PCBs

SUF		HQ_{low}		
HPS	**Reference**	**HPS**	**Reference**	**Total**
0	1	0	4.57E-02	4.57E-02
1	0	1.77E+00	0	1.77E+00
0.5	0.5	8.87E-01	2.28E-02	9.10E-01
0.1	0.9	1.77E-01	4.11E-02	2.19E-01
0.05	0.95	8.87E-02	4.34E-02	1.32E-01
0.01	0.99	1.77E-02	4.52E-02	6.30E-02

Gray cells correspond to HQ >1.
SUF = site use factor; HQ = hazard quotient

7.0 ANCILLARY DATA

The Validation Study was designed primarily to provide data for three lines of evidence (sediment chemistry, toxicity, and bioaccumulation) at 59 sampling stations in the five HPS study areas. These data form the basis for the WOE evaluation. However, ancillary data also were collected to evaluate various sources of uncertainty associated with the WOE approach and to support identification of areas for evaluation in the FS. Ancillary data include the following:

- TIE studies to support evaluation of the toxicity line of evidence;
- Analysis of nondepurated *M. nasuta* tissue samples and field-collected invertebrate and forage fish samples to support the bioaccumulation line of evidence; and
- Evaluation of potential risk to a piscivorous bird using field-collected forage fish tissue data.

Results of these ancillary data evaluations are presented below. These data are integrated with the WOE results to identify risk drivers and pathways at HPS in Section 10.0.

7.1 Toxicity Identification Evaluation Studies

Toxicity identification evaluation (TIE) tests were conducted on sediment samples from a subset of stations from HPS. Two environmental media were assessed: suspended particulate phase (SPP) and porewater.

1. SPP testing was conducted by BSL as part of the Validation Study, and assumed that ammonia was the primary cause of larval abnormality at HPS stations with historically high levels of this constituent. It was expected that these exposures would represent potential toxicity associated with dredging or storm events, thus creating an exposure scenario that was less conservative than a porewater exposure and more conservative than the passive diffusion represented by a SWI exposure.

2. Testing was conducted by SAIC/EFANE as part of an independent technology demonstration program to determine the relative contribution to observed toxicity by multiple environmental constituents (including ammonia, sulfides, metals, and/or organics) using porewater derived from HPS sediment samples.

The SAIC/EFANE exposure scenario is not directly relevant to the evaluation of ecological risk at HPS because echinoderm larvae would not be directly exposed to porewater in the environment. However, the SAIC/EFANE study provided information on potential toxicity drivers associated with sediment porewater.

The results of the BSL and SAIC/EFANE TIE studies are presented below, followed by a summary that suggests potential toxicity drivers associated with the SPP and porewater environmental compartments. Complete results of the BSL TIE study are presented in Appendix I, including a description of modifications to the original experimental design included in the VS Work Plan (Battelle et al., 2001a). The complete SAIC/EFANE TIE report is provided in Appendix P.

7.1.1 Battelle TIE Experiment

BSL's TIE study evaluated 16 sediment samples originally proposed for TIE testing in the VS Work Plan (Battelle et al., 2001a). Prior to testing, the stations were screened to determine whether they contained sufficient amounts of porewater ammonia to produce toxicity. Sediments from seven of these stations

exhibited levels of ammonia in interstitial water that either exceeded the NOEC for *S. purpuratus* (SWRCB, 1998b), or appeared to cause decreased survival or a high proportion of abnormal larvae in SWI tests conducted by PERL (Table 7-1). These samples were divided into two batches and tested according to the methodology presented in the VS Work Plan. During Batch 1 testing, high ammonia levels in the 50% and 100% concentrations resulted in 100% abnormal larval development. Consequently, the concentration series for Batches 2 and 3 were changed to increase the likelihood of observing a dose-response. The sediment samples in Batch 1 were retested as Batch 3.

Table 7-1. Experimental Design for TIE

TIE Test Batch	Stations Tested	SPP Concentrations	Test Volume (mL)	Comments
Batch 1	EW-33 SB-21 SB-23	0%, 10%, 50%, 100%	500 mL	100% abnormality in 50% and 100% treatments. Chemistry analysis on 100% SPP.
Batch 2	OR-24 SB-22 SB-19 SB-20 (0-5 cm)	0%, 5%, 10% 20%, 40%, 80%	500 mL	Dose-response observed. Chemistry analysis on 100% SPP.
Batch 3	EW-33 SB-21 SB-23 (After 25-day purge)	0%, 5%, 10% 20%, 40%, 80%	10 mL	Dose-response observed. Tested in scintillation vials. Chemistry analysis on 100% SPP.

TIE = toxicity identification evaluation; SPP = suspended particulate phase.

For Batch 1 testing, HPS Stations EW-33, SB-21, and SB-23 were evaluated using the purple urchin, *S. purpuratus*. The selected SPP concentrations (0%, 10%, 50%, and 100%) did not produce a useful dose-response because adverse effects were observed at 50% and 100% concentrations. These samples were retested in Batch 3.

HPS Stations SB-19, SB-20, SB-22, and OR-24 were tested in Batch 2. Results are presented in Figure 7-1. Based on the results of Batch 1, the concentration series was altered to include effects expected to occur at lower percentages of SPP, with a final concentration series of 0%, 5%, 10%, 20%, 40%, and 80% SPP. This concentration series produced reasonable dose-response profiles. Based on these results, Station SB-19 appeared to have toxicity not completely attributable to ammonia because it fell well below the dose-response line for ammonia based on reference toxicant results. In contrast, Stations OR-24, SB-22, and SB-20 fell along the ammonia dose-response line, suggesting that the observed toxicity in SPP prepared with sediment from these stations is due primarily to ammonia (Figure 7-1).

Figure 7-2 presents the results of Batch 3 testing, which was a retest of Batch 1 sediments using the modified SPP concentration series described for Batch 2: 0%, 5%, 10%, 20%, 40%, and 80% SPP. In this batch, the dose-response profiles for Stations EW-33 and SB-23 suggested that ammonia was not solely responsible for observed toxicity. This effect is less pronounced for Station SB-21.

Summary information for analytical chemistry conducted on 100% SPP samples for each TIE test sediment is presented in Table 7-2. Although a full suite of COPEC chemistry analyses were conducted, only selected COPECs are listed in Table 7-2 because many COPECs were not detected. The highest COPEC concentrations were observed in SPP created from the sediment sample from Station SB-19. This station also produced the most pronounced adverse effect observed in the TIE test, with essentially no normal

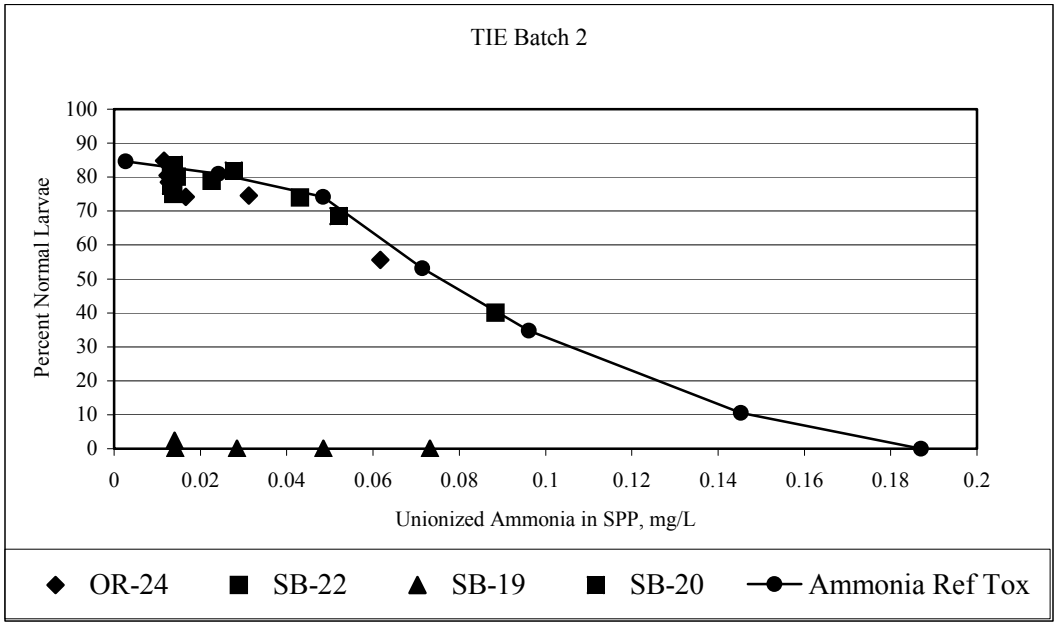


Figure 7-1. Summary Dose-Response Results for TIE Batch 2 Test

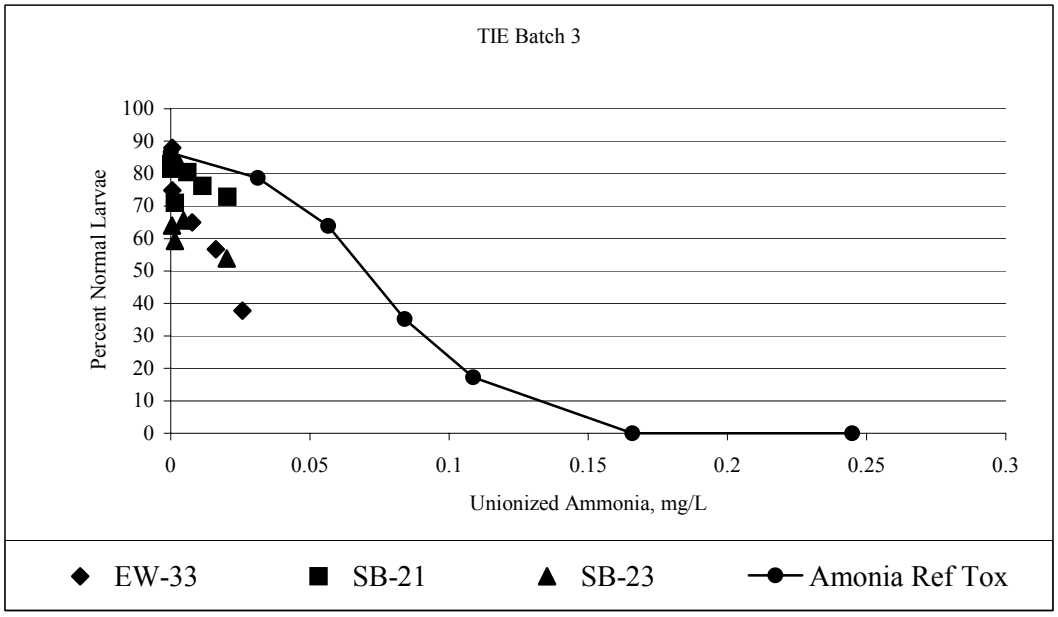


Figure 7-2. Summary Dose-Response Results for TIE Batch 3 Test

larvae in any SPP concentration except the control. At least two metals (cadmium and copper) were found to be present in the SPP water at levels well above the median effective concentration (EC50) concentrations determined during reference toxicant exposures. Thus, acute toxicity observed in SB-19 SPP likely is associated with those metals. It is interesting to note that the undisturbed SWI cores from Station SB-19 were not acutely toxic to *S. purpuratus* larvae, suggesting that the difference in exposure scenarios (SPP vs. SWI core) resulted in a difference in observed toxicity. The mechanism for toxicity observed in Stations SB-23 and EW-33 is less clear.

Table 7-2. COPEC Concentrations in 100% SPP for TIE Stations

Analyte	SB-19	SB-20	SB-21	SB-22	SB-23	EW-33	OR-24
Metals (µg/L)							
Silver	0.110	0.0381	0.039	0.0219	0.0308	0.0227	0.0307
Aluminum	330	137	390	155	233	151	240
Arsenic	2.11	4.83	3.45	3.57	5.01	5.61	13.3
Barium	40.1	16.6	18.1	17.2	17.3	28.3	19.7
Cadmium[(a)]	9.95	0.0229	0.0268	0.0362	0.0249	0.0335	0.0237
Cobalt	12.0	0.433	0.923	0.478	0.435	1.01	0.514
Chromium	1.90	0.420	0.967	0.615	0.794	0.208	0.344
Copper[(b)]	473	0.780	3.79	0.955	3.69	0.648	0.878
Iron	244	99.2	239	132	265	437	151
Mercury	0.445	0.004	0.0218	0.0042	0.0182	0.0077	0.0041
Manganese	2980	597	1280	871	473	4.10	716
Molybdenum	17.6	12.1	14.5	14.7	13.7	19.4	15.5
Nickel	18.8	1.41	2.16	1.43	1.90	2.08	2.01
Lead	3.30	0.898	2.66	0.978	2.32	0.614	0.832
Antimony	3.50	1.8	5.23	4.03	7.19	6.50	3.25
Selenium	0.304	0.096	0.163	0.103	0.188	0.144	0.0988
Vanadium	9.92	3.76	6.14 J	5.43	6.44	3.27	3.08
Zinc	91.4	2.08	5.45	2.74	2.60	3.03	2.36
Organics (ng/L)							
Aroclor 1260	2305	362 U	209 J	68 J	264	176 U	177 U
Fluoranthene	19.48	4.46 J	14.02	3.52 J	23.0	6.21 J	3.21 J
Pyrene	23.52	5.44 J	19.28 J	6.02 J	21.76	5.9 J	1.02 U
4′4′-DDT	0.35 U	0.73 U	0.67 U	0.35 U	0.36 U	0.35 U	0.36 U
TBT	23.5	22.2 U	11.1 U	11.1 U	20.8	0 U	11.1 U

(a) Mean EC50 for cadmium reference toxicant exposures (BSL and PERL) was <0.06 µg/L.
(b) Mean EC50 for copper reference toxicant exposures (BSL and PERL) was 7.42 mg/L.

Figure 7-3 presents the dose-response with 95% confidence bands for *S. purpuratus* larvae developed for ammonia in reference toxicant tests conducted by PERL. This dose-response is expressed in terms of total ammonia, as the water quality measurements needed to convert data to the unionized form of ammonia were not always available. Comparison to the data obtained for Batch 3 SPP Stations EW-33, SB-21, and SB-23 shows that all three stations produced a dose-response curve that fell outside the confidence bounds, suggesting that toxicants other than ammonia might be influencing observed toxicity. This dose-response relationship also suggests that adverse effects might be suspected whenever total ammonia concentrations exceed 2 mg/L, because this concentration can reduce the percentage of normal larvae approximately 20% relative to control. As discussed in Section 5.2, this dose-response relationship also was used to determine whether ammonia could be suspected of influencing the SWI bioassay results.

7.1.2 SAIC/EFANE TIE Testing

SAIC/EFANE performed TIE testing on samples from ten HPS study area stations, one San Francisco Bay reference site (Paradise Cove), and one spiked sample. The test medium was sediment porewater. Three test species were evaluated: larvae of the purple sea urchin, *S. purpuratus*; the Atlantic silverside, *Menidia menidia*; and larvae of the sand dollar, *Dendraster excentricus*. Although porewater testing is useful because it is likely to produce an acutely toxic response useful for toxicant identification, the exposure may not represent true environmental conditions because larval forms typically live in the water column rather than in sediment. The SAIC/EFANE study consisted of a sequential series of toxicity tests

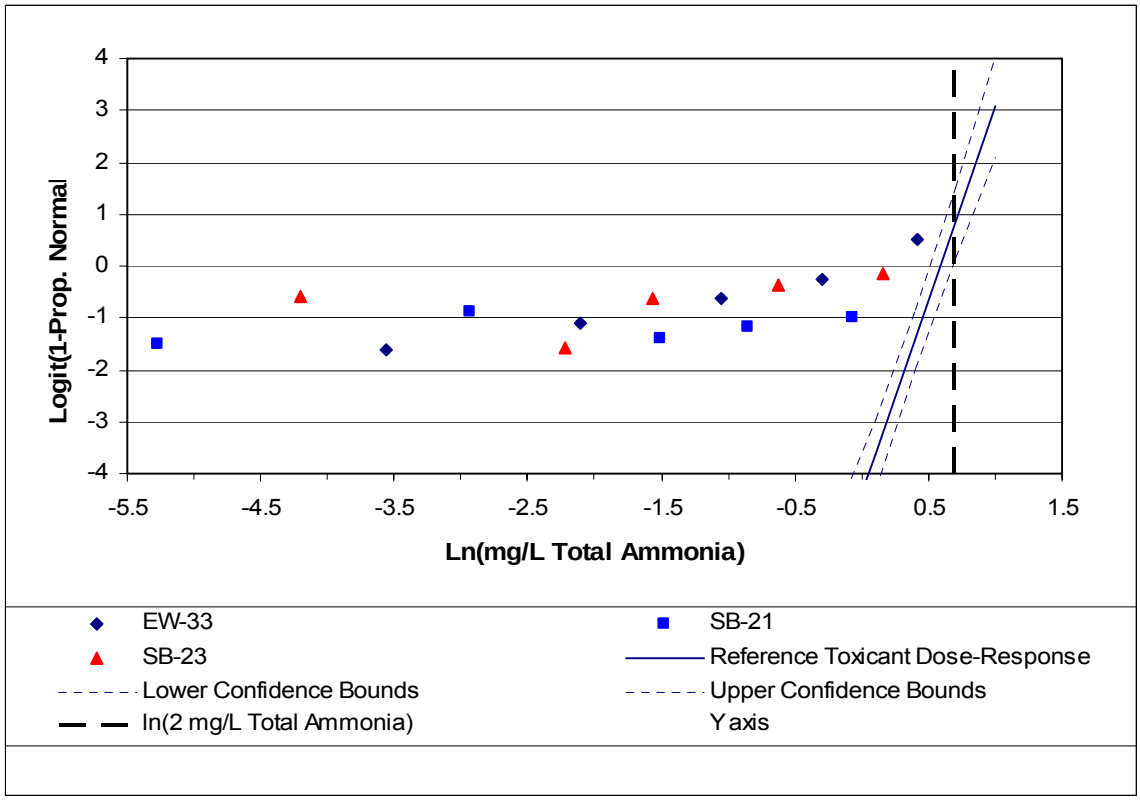


Figure 7-3. Ammonia Dose-Response Relationship for BSL and PERL Laboratory Reference Toxicant Exposures with HPS Batch 3 Stations Included

that included exposures to serial dilutions of porewater. Porewater samples underwent manipulations to remove or reduce the concentrations of various constituents, including ammonia, metals, and organic chemicals. A compete description of the study is presented in Appendix P. General study conclusions were as follows:

- Ammonia was the predominant cause of toxicity;
- Toxicity reduction was observed when metals bioavailability was reduced;
- Toxicity did not differ substantially between surface (0-5 cm) and subsurface (5-10 cm) samples;
- Levels of toxicity observed in porewater TIE exposures were dramatically higher than those observed in bulk sediment evaluations and SWI tests conducted by BSL and PERL. This was expected because it the aggressive extraction method used to obtain porewater was likely to result in relatively higher levels of COPECs in the test medium compared to bulk sediment or SPP.

7.1.3 Comparison of TIE Testing Results among Studies

A comparison of testing results from the Battelle and SAIC/EFANE TIE studies is presented in Table 7-3. In general, the TIE results were consistent for HPS stations tested by both laboratories, as both studies identified ammonia as the primary toxicity driver for *S. purpuratus* larvae exposures. Although both studies also identified metals as a potential contributor to observed toxicity, in most cases the extent of the

Table 7-3. Comparison of Results for BSL and SAIC/EFANE TIE Studies

HPS Station	SWI Bioassay Result (% Normal Development)	Primary Toxicity Driver(s) Associated with Observed Dose-response in TIE with Urchin Larvae	
		Battelle TIE	SAIC/EFANE TIE
Area III (Point Avisadero)			
PA-41 (0-5 cm)	93.2	Not tested	Ammonia primary, metals secondary
PA-41 (5-10 cm)	Not tested	Not tested	Ammonia primary, metals secondary
Area VIII (Eastern Wetland)			
EW-33	53.3	Ammonia primary, COPECs suspected	Ammonia primary, metals secondary
Area IX (Oil Reclamation)			
OR-24	76.8	Ammonia	Ammonia primary, metals secondary
Area X (South Basin)			
SB-18	87.2	Not tested	Ammonia primary, metals secondary (Al, Cu, Zn)
SB-19	74.9	Cd, Cu suspected primary, ammonia secondary	Not tested
SB-20 (0-5 cm)	88.1	Ammonia	Ammonia primary, metals secondary
SB-20 (5-10 cm)	Not tested	Not tested	Metals primary, ammonia and particulates secondary
SB-21	92.6	Ammonia primary, metals suspected	Ammonia
SB-22	89.8	Ammonia	Ammonia primary, metals secondary
SB-23	85.6	Ammonia primary, metals suspected	Ammonia primary, metals secondary

Note: Exposure media for SWI test is undisturbed SWI core, exposure media for Battelle TIE is suspended-particulate phase, exposure media for SAIC/EFANE TIE is porewater.

BSL = Battelle Sequim Laboratory; SAIC/EFANE = Science Applications Internation Corporation/Engineering Field Activity Northeast; TIE = toxicity identification evaluation; SWI = sediment water interface.

contribution or the metal(s) responsible could not be identified. The general conclusion drawn from the TIE studies is that, under certain conditions, ammonia or metals can exert a toxic influence on larvae of certain species. However, under the nondisruptive environmental conditions represented by amphipod or SWI exposures during the HPS study, toxicity generally was reduced or not observed at all. This result suggests that both TIE tests created conditions that increased COPEC bioavailability, a phenomenon that is unlikely unless the sediment bed is significantly disturbed. A major storm event that causes sediment resuspension could be considered a significant disturbance, depending upon the depth to which the sediment bed is eroded (the depth of erosion was not determined in the Sediment Dynamics Study provided in Appendix L). Resuspension of loosely consolidated surficial sediment is not likely to result in a significant increase in bioavailability because the highest COPEC concentrations are typically found at depth. It should be noted that the SAIC/EFANE TIE study was conducted using porewater samples and a testing scenario that does not represent potential storm conditions. The Battelle TIE study was conducted using SPP samples, which more closely approximates resuspended material.

7.2 Ancillary Data to Support the Bioaccumulation Line of Evidence

This section presents the ancillary data for nondepurated *M. nasuta* tissue samples and field-collected invertebrate and forage fish tissue samples. In the WOE evaluation, chemistry data for depurated *M. nasuta* tissues from the laboratory bioaccumulation study were used to evaluate food-chain risk at HPS. The ancillary data were collected to evaluate the validity of using depurated *M. nasuta* tissue data from the laboratory to represent prey tissue concentrations. Dose calculations also were performed using field-collected tissue data.

7.2.1 Nondepurated *M. nasuta* Tissue

In the dose assessment presented in Section 6.2, depurated *M. nasuta* tissues were used to represent trophic transfer via prey ingestion. The dose model discussed in Section 6.2 has separate terms for exposure through contaminated tissue (C_{prey}), and contaminated sediment ingestion (C_{sed}). The sediment ingestion component of the exposure term takes into account both exposure to sediment contaminants in the gut of prey and through incidental sediment ingestion via foraging or preening. Because all exposure to sediment contaminants is incorporated in the sediment ingestion exposure term, the prey exposure term focuses solely on the tissue body burden, which is represented by the depurated *M. nasuta* tissue data. This approach ensures that exposure to prey gut contents is only factored in once.

To address any uncertainty introduced into the assessment by using depurated organisms, five non-depurated *M. nasuta* tissue replicate samples were added to the 28-day bioaccumulation test design (one in each of the five HPS study areas) and evaluated for all COPECs. These stations spanned the expected range of COPEC concentrations. Complete analytical results for nondepurated samples are presented in Appendix C. Plots comparing paired tissue concentrations in depurated and nondepurated *M. nasuta* tissue samples are presented in Figures 7-4 through 7-9 (the dotted diagonal lines represent one-to-one correspondences). For example, aluminum concentrations in nondepurated *M. nasuta* tissue are higher than in depurated tissue (Figure 7-4). In contrast, molybdenum concentrations are higher in depurated tissue (Figure 7-6). A nearly one-to-one relationship is observed for some COPECs, with most of the points falling close to the diagonal line (see PCBs on Figure 7-9). Overall, no prevailing trend was apparent.

A dose assessment was conducted using the nondepurated *M. nasuta* tissue data to evaluate the significance of differences between the depurated and nondepurated tissue concentrations. Results of the dose calculations are presented in Appendix H and summarized in Table 7-4. In general, although a few additional COPECs exceed reference tissue thresholds for the nondepurated tissue, the HQs for COPECs in depurated and nondepurated tissues are similar. In fact, the depurated samples tended to result in slightly more conservative estimates (e.g., Stations OR-26 and SB-21) and only one nondepurated sample (Station IB-56) resulted in a more conservative estimate for nickel (Table 7-4). The generally good agreement between depurated and nondepurated tissue concentrations supports the use of depurated tissue for the WOE evaluation.

7.2.2 Field-Collected Invertebrate and Fish Tissue Data

To further evaluate the validity of using the depurated laboratory *M. nasuta* data to evaluate bioaccumulation, tissue samples of invertebrate prey items were collected in all five HPS study areas. Samples from each area were separated into hard-bodied invertebrate (HBI) and soft-bodied invertebrate (SBI) composites. As described in the field summary report (Battelle, 2001), polychaete worms (such as *Nephtys caecoides* and *Nereis* sp.) were the most abundant SBI collected at all five areas. The HBI composites consisted of clams (such as *Macoma nasuta* and *Tapes japonica*); these were not as abundant as worms, and were not found at all in Area III (Point Avisadero). No HBI or SBI invertebrate tissues were collected from reference stations.

Composite samples of forage fish (FF) also were collected and analyzed at all five HPS study areas. Species targeted as representative prey to avian predators included the bay goby (*Lepidogobius lepidus*), arrow goby (*Clevelandia ios*), Cheekspot goby (*Ilypnus gilberti*), yellowfin goby (*Acanthogobius flavimanus*), and staghorn sculpin (*Leptocottus armatus*). Sufficient tissue from these target species were collected at all areas except Area VIII where English sole (*Parophrys vetulus*) and speckled sanddab (*Citharichthys stigmaeus*) were added to goby tissue to provide sufficient mass for the composite analysis. Similar species of forage fish were collected from five reference stations (Alcatraz Environs,

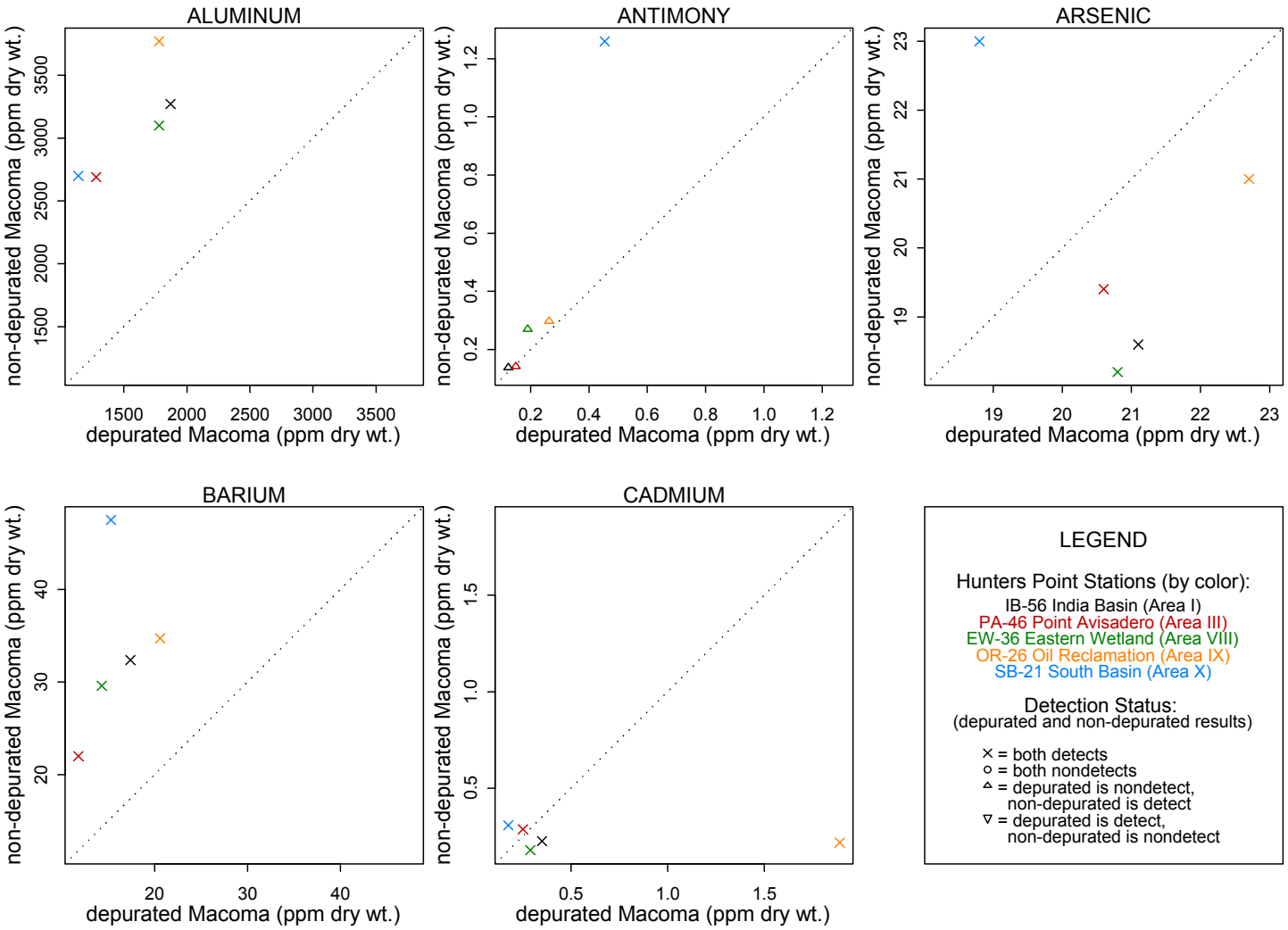


Figure 7-4. Depurated and Nondepurated *M. nasuta* Tissue Concentrations of Aluminum, Antimony, Arsenic, Barium, and Cadmium

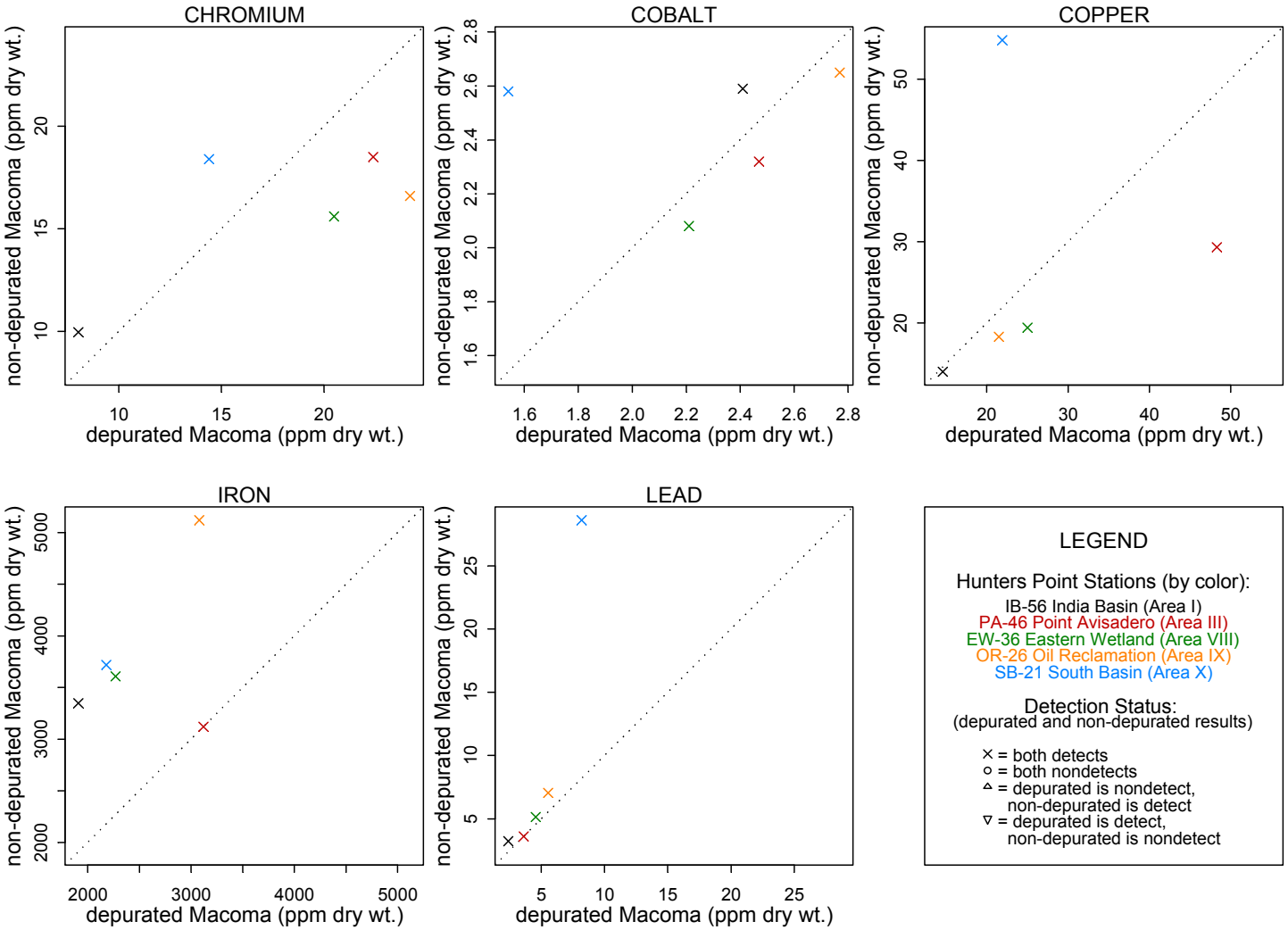


Figure 7-5. Depurated and Nondepurated *M. nastua* Tissue Concentrations of Chromium, Cobalt, Copper, Iron, and Lead

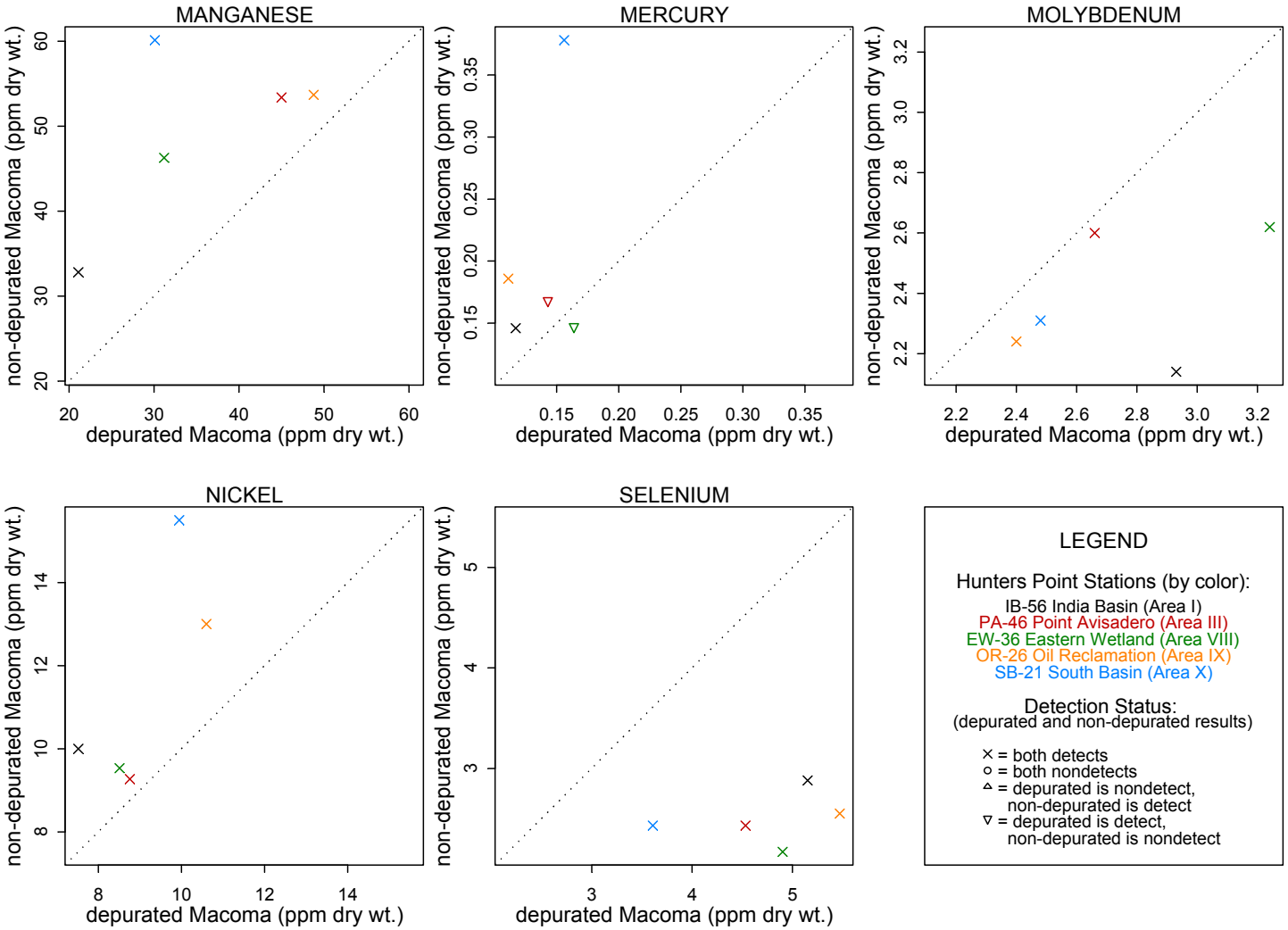


Figure 7-6. Depurated and Nondepurated *M. nastua* Tissue Concentrations of Manganese, Mercury, Molybdenum, Nickel, and Selenium

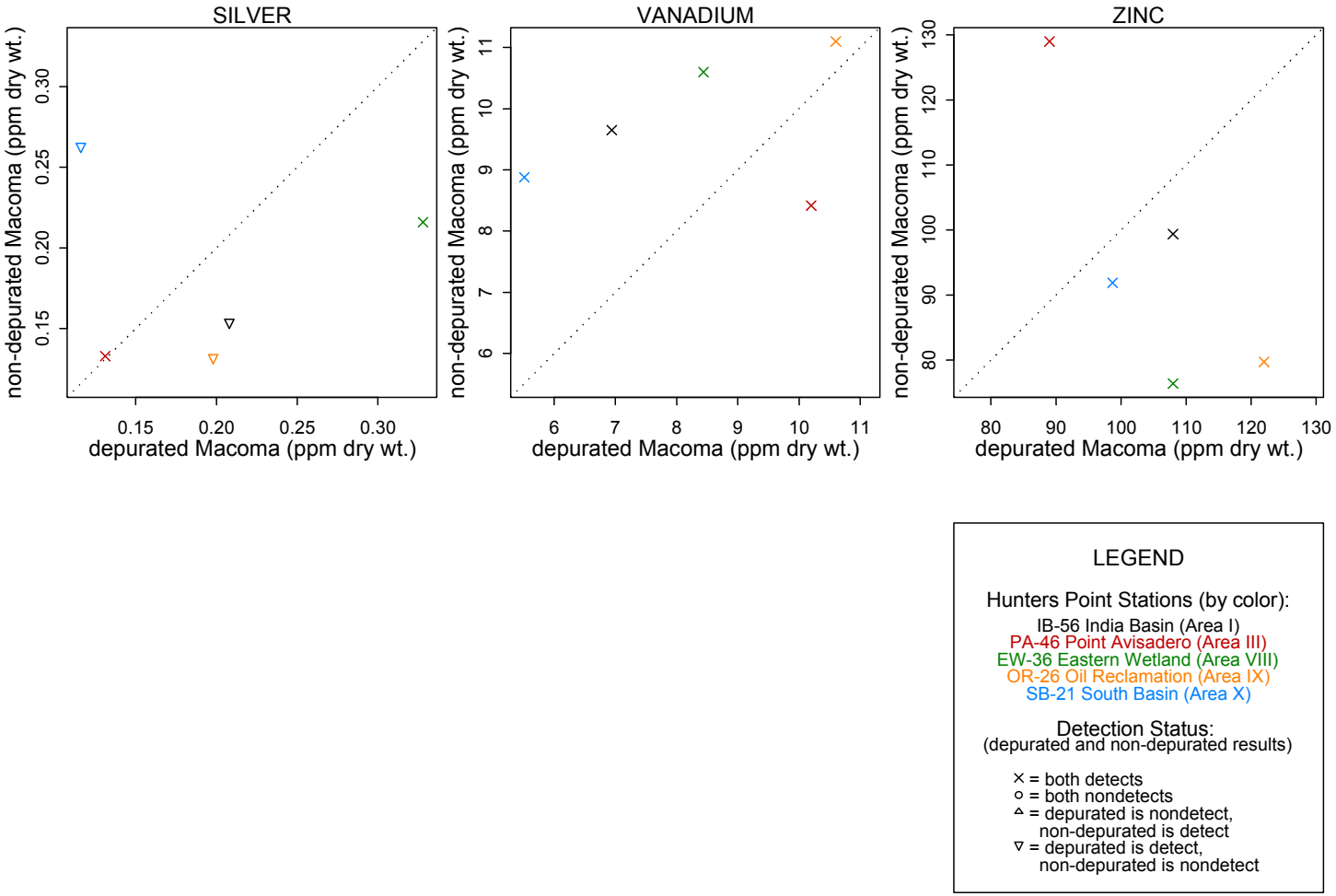


Figure 7-7. Depurated and Nondepurated *M. nastua* Tissue Concentrations of Silver, Vanadium, and Zinc

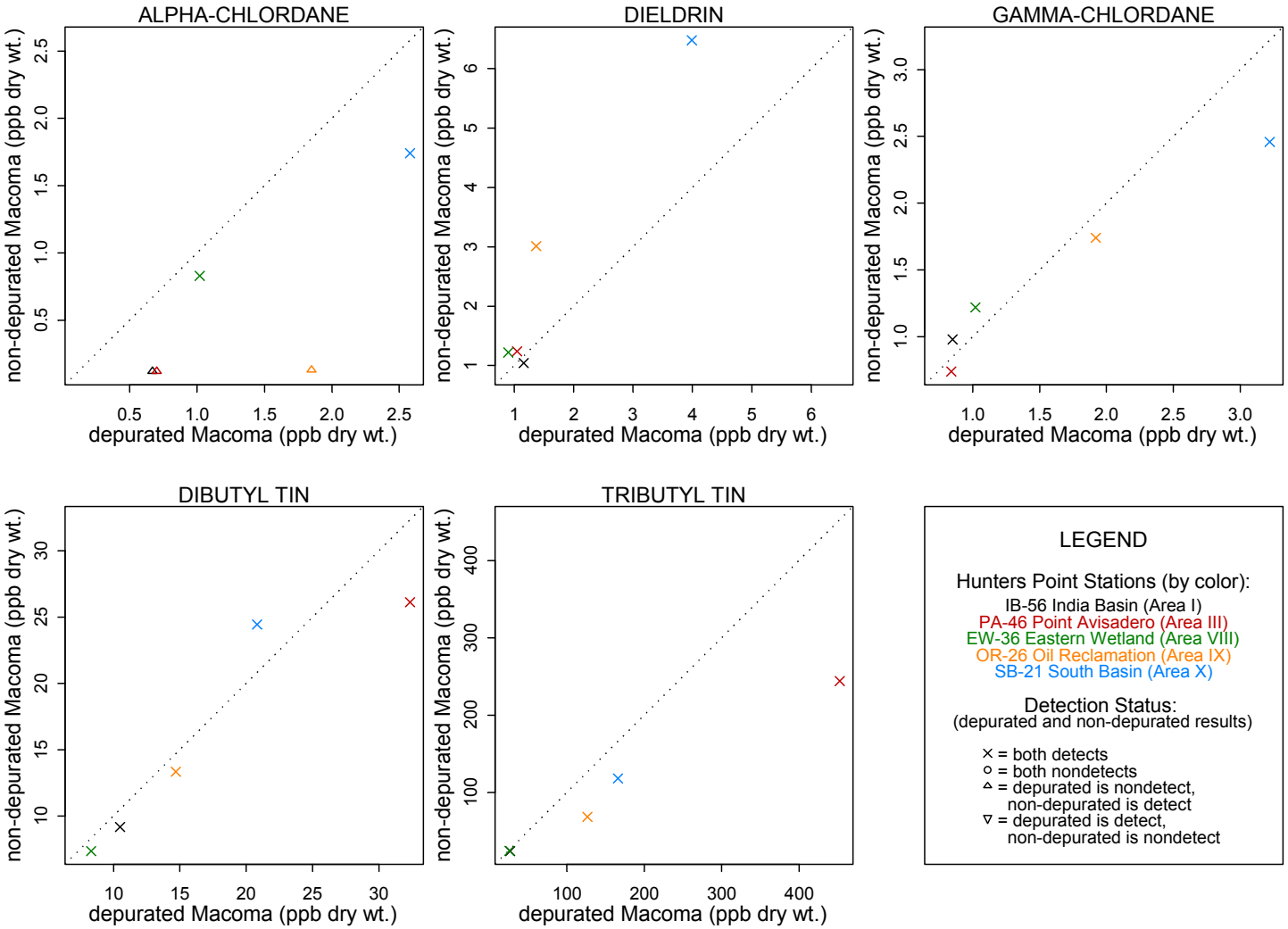


Figure 7-8. Depurated and Nondepurated *M. nastua* Tissue Concentrations of *alpha*-Chlordane, Dieldrin, *gamma*-Chlordane, Dibutyltin, and Tributyltin

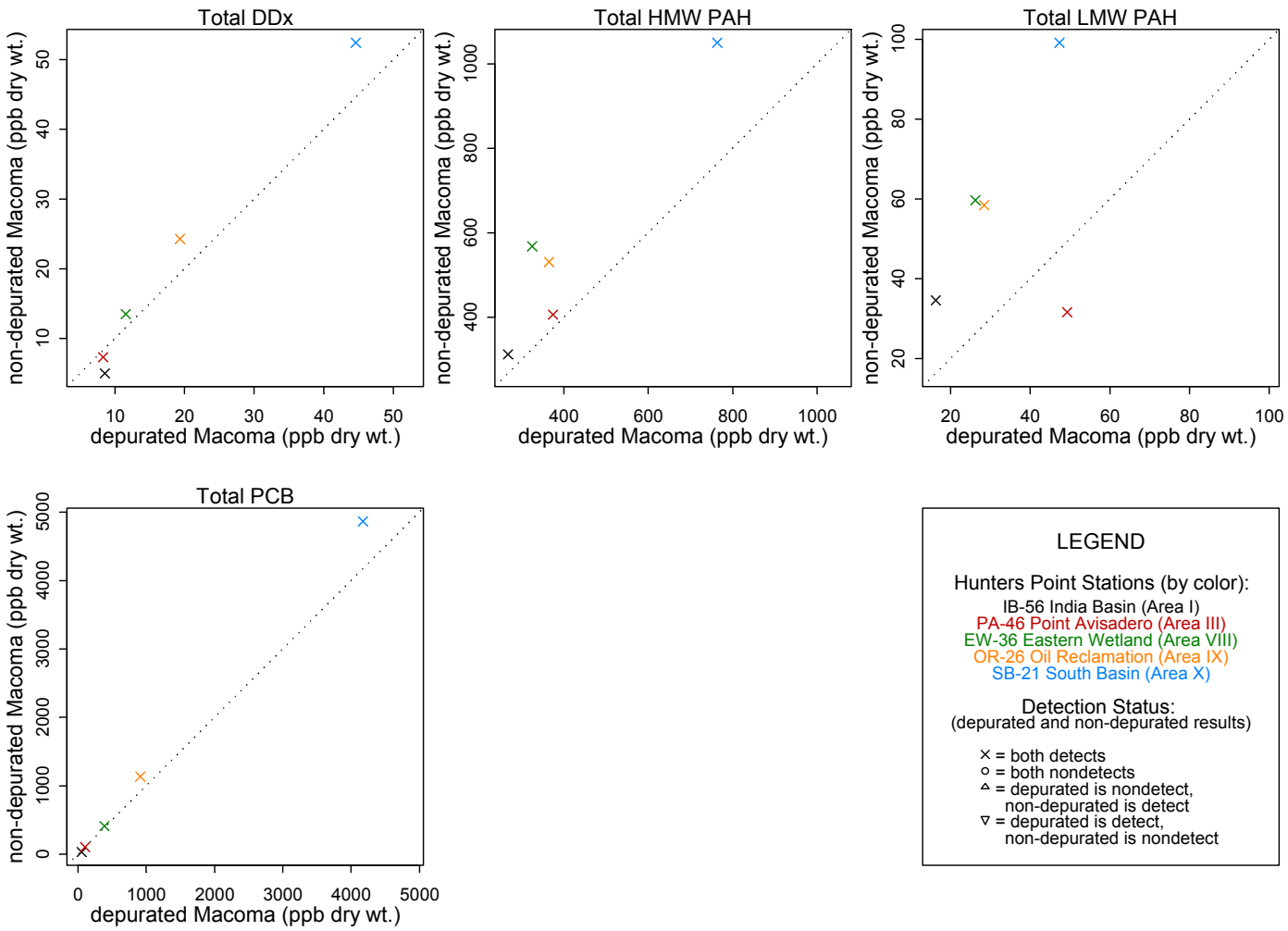


Figure 7-9. Depurated and Nondepurated *M. nastua* Tissue Concentrations of Total DDx, Total HPAH, Total LPAH, and Total PCB

Table 7-4. Summary of Dose Assessment for Surf Scoter using Depurated and Nondepurated *M. nasuta* Tissue Data

Station ID	Tissue Type	COPECs > Reference	HQ low <1	HQ low >1	HQ low >10	HQ high >1
EW-36	Depurated	Cu, Pb, **PCBs**	Cu, **PCBs**	Pb	Pb	none
	Nondepurated	Cu, Pb, **PCBs**, **DDx**	Cu, **PCBs**, **DDx**	Pb	Pb	none
IB-56	Depurated	none	None	none	none	none
	Nondepurated	Ni	Ni	none	none	none
OR-26	Depurated	Cd, Cu, Pb, Ni, Se, DBT, TBT, **PCBs**, **DDx**	Cu, Ni, DBT, TBT, **PCBs**, **DDx**	Cd, Pb, Se	Pb	none
	Nondepurated	Cu, Pb, **Hg**, Ni, DBT, **PCBs**, **DDx**	Cu, **Hg**, Ni, DBT, **PCBs**, **DDx**	Pb	Pb	none
PA-46	Depurated	Cu, DBT, TBT, **PCBs**	DBT, TBT, **PCBs**	Cu	none	none
	Nondepurated	Cu, Zn, DBT, TBT, **PCBs**	Zn, DBT, TBT, **PCBs**	Cu	none	none
SB-21	Depurated	Cu, Pb, Ni, DBT, TBT, **PCBs**, **DDx**	Cu, Ni, DBT, TBT, **DDx**	Pb, **PCBs**	Pb	none
	Nondepurated	As, Cu, Pb, **Hg**, Ni, DBT, **PCBs**, **DDx**	As, **Hg**, Ni, DBT, **DDx**	Cu, Pb, **PCBs**	Pb	none

COPECs in **bold** are priority COPECs (**Hg**, **DDx**, and **PCBs**).
DDx = sum of 4,4′-DDD; 4,4′-DDE; and 4,4′-DDT.
HQ = hazard quotient.

Alameda Buoy, Red Rock, Paradise Cove, and Bay Farm) as part of the RI for Seaplane Lagoon at Alameda Point (Battelle et al., 2001c).

Analytical data from the field-collected tissue composites are provided in Appendix C. Scatter plots that compare field-collected tissue data with laboratory *M. nasuta* data from adjacent stations are presented in Figures 7-10 through 7-15. Bivariate plots of COPEC concentrations in HBI and SBI versus sediment concentrations from adjacent stations are provided in Appendix F. Observed data trends include the following:

- Field-collected HBI samples have very similar tissue concentrations to the laboratory-exposed *M. nasuta* collected at adjacent stations;
- COPEC concentrations generally are higher in SBI composite samples than in any of the other tissue types;
- Inorganic COPEC concentrations generally are lower in forage fish than in SBIs or HBIs;
- Concentrations of bioaccumulative organic COPECs (e.g., PCBs and the chlorinated pesticides) generally are higher in forage fish than in the bivalves (both laboratory exposed and field-collected HBIs).

A dose assessment was conducted using the field-collected invertebrate tissue. Results of the dose calculations are presented in Appendix H and summarized in Tables 7-5 and 7-6. Because collocated sediment data were not available for each composite field-collected tissue sample, the 95% UCLs of the sediment concentrations in each area were used as the sediment EPCs. With a few exceptions, the HQ_{low} values developed using the field-collected HBI data were similar to those based on laboratory *M. nasuta* data (Table 6-11). However, HQ_{low} values developed using the field-collected SBI data tended to be of higher magnitude than those using the laboratory *M. nasuta* data. All HQ_{high} values were less than 1.0.

Based on these results, laboratory exposed, depurated *M. nasuta* appear to be a reasonable surrogate for field-collected bivalves because of the close correlation in tissue concentrations. However, it is not clear whether COPEC concentrations in depurated *M. nasuta* tissue adequately represent concentrations in field-collected polychaete tissue. The higher body burdens measured in the field-collected SBI could be due to a number of factors. One hypothesis is that polychaetes bioaccumulate at a faster rate than bivalves; thus, the concentrations measured represent increased uptake into tissue. This may be because the SBI composite samples included polychaete species with a wide-range of feeding types, resulting in higher uptake of contaminants and a greater potential for biomagnification than *M. nasuta*. A second hypothesis is that because polychaetes are in intimate contact with sediment, and many of these species are sediment ingesters or detrital deposit feeders, they may ingest more sediment than surface-deposit or filter-feeding bivalves. Therefore, higher COPEC concentrations measured in the field-collected SBI composite samples (higher than either the depurated and nondepurated laboratory exposed *M. nasuta* or the field collected bivalves) may be a result of COPECs sorbed to sediment in the guts and not because of a higher uptake rate into tissue.

This second hypothesis is supported by data collected in South Basin in 2001 and 2002 (USACE, 2002). Biota-sediment accumulation factors (BSAFs) were developed for polychaetes and amphipods based on laboratory-controlled studies using South Basin sediments and allowing the test organisms to depurate before analysis. BSAFs for PCBs based on depurated *Neanthes* ranged from 0.155 to 0.181 and were lower than the BSAFs developed for the other test species *Leptocheirus* (an amphipod) (BSAFs ranging from 0.386 to 1.334). These BSAFs for *Neanthes* were also lower than BSAFs developed for South Basin using the depurated *M. nasuta* data collected for the Validation Study (0.418 for stations with sediment concentrations <2,000 ppb PCBs). Thus, in South Basin sediments, depurated polychaete tissue reflected lower uptake on a normalized lipid basis than either amphipods or bivalves.

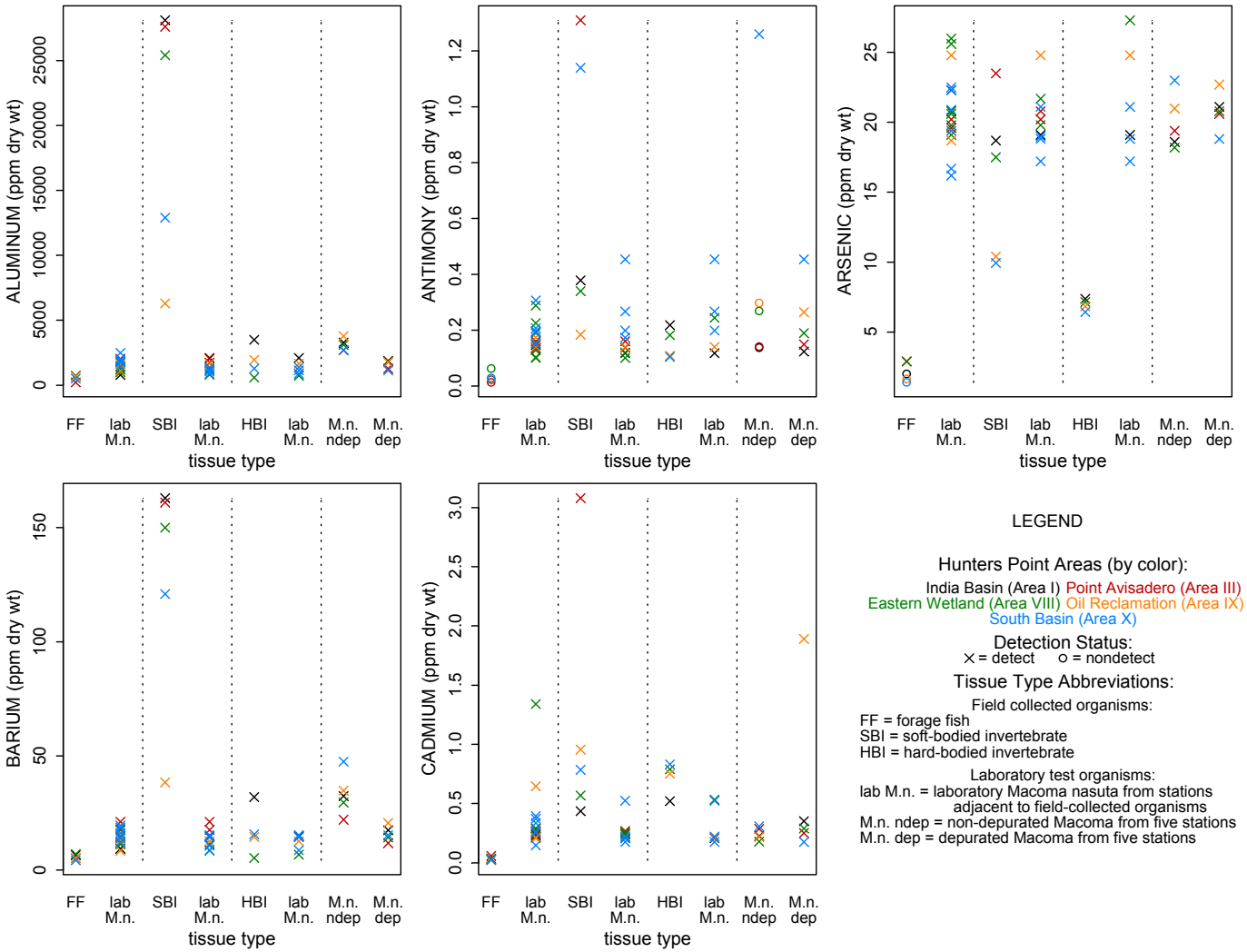


Figure 7-10. Field-Collected and Laboratory Test Organism Tissue Concentrations of Aluminum, Antimony, Arsenic, Barium, and Cadmium

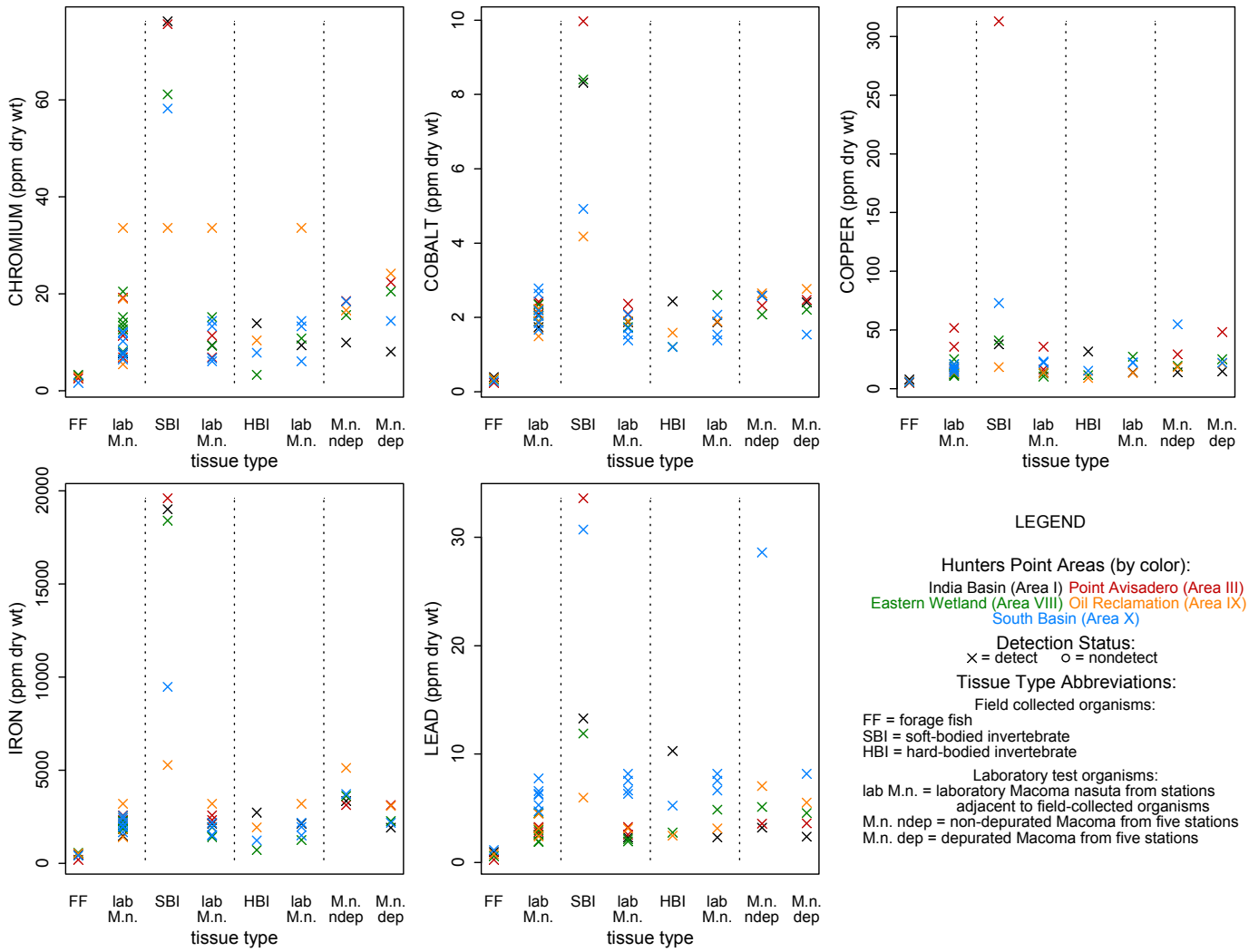


Figure 7-11. Field-Collected and Laboratory Test Organism Tissue Concentrations of Chromium, Cobalt, Copper, Iron, and Lead

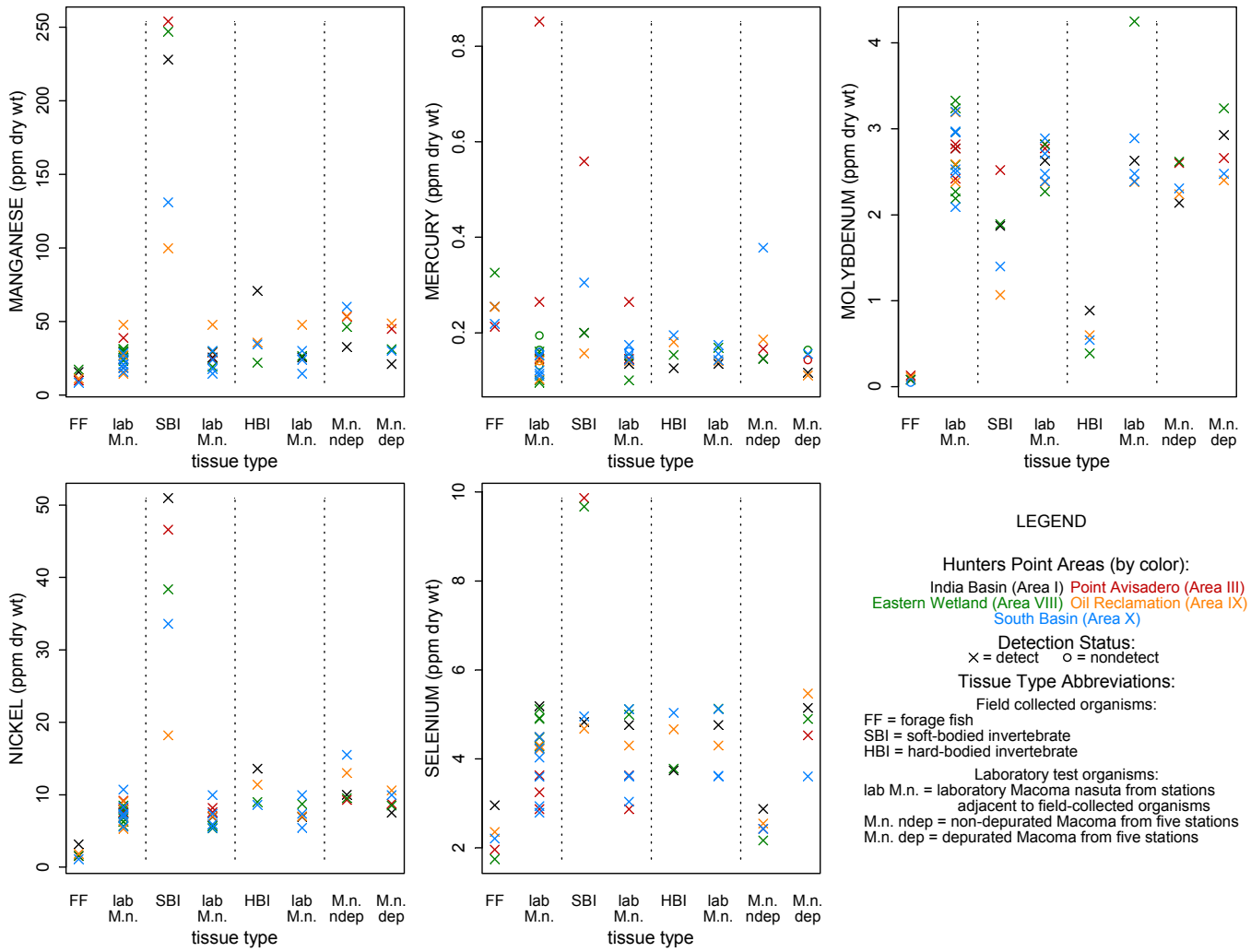


Figure 7-12. Field-Collected and Laboratory Test Organism Tissue Concentrations of Manganese, Mercury, Molybdenum, Nickel, and Selenium

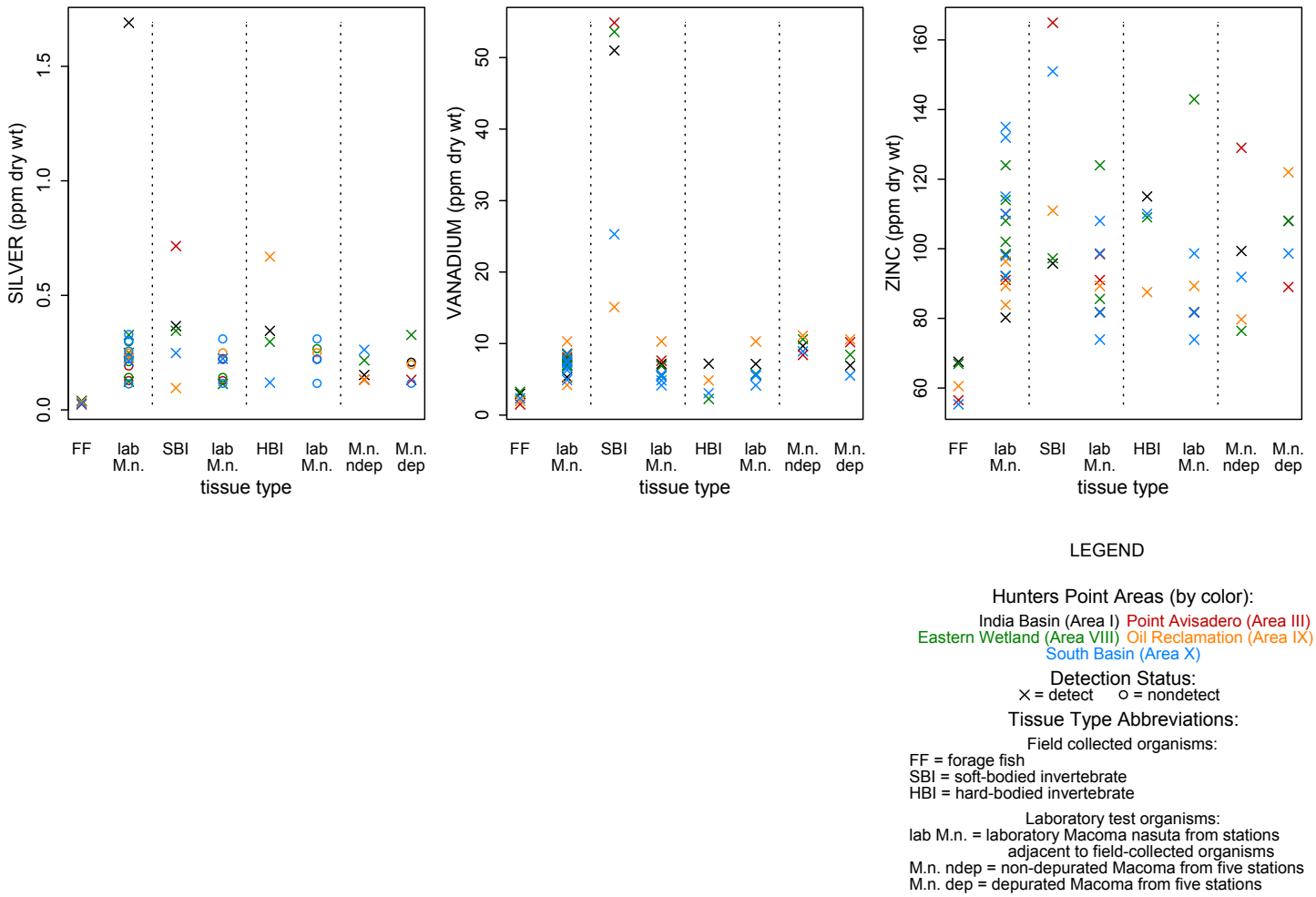


Figure 7-13. Field-Collected and Laboratory Test Organism Tissue Concentrations of Silver, Vanadium, and Zinc

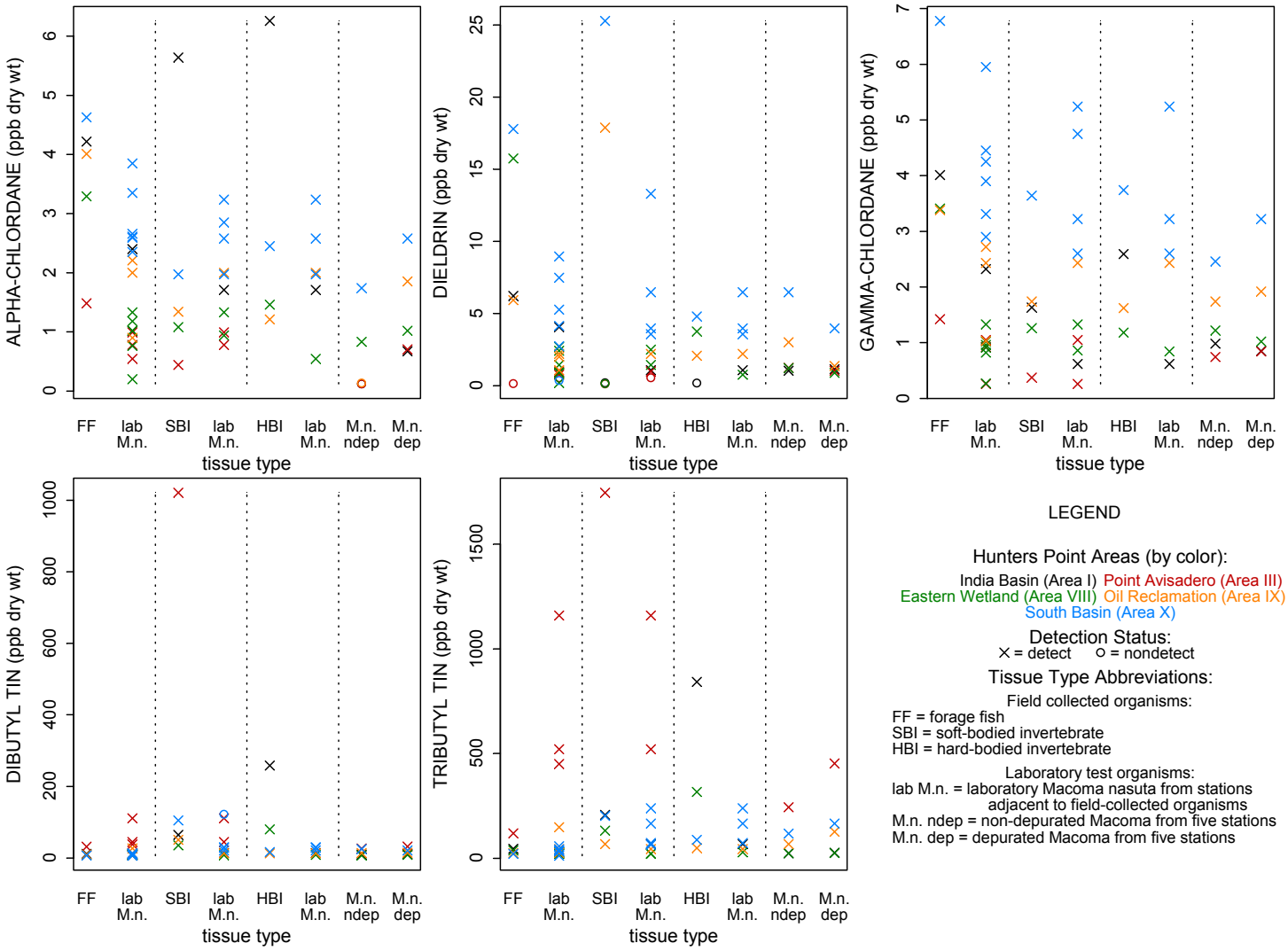


Figure 7-14. Field-Collected and Laboratory Test Organism Tissue Concentrations of *alpha*-Chlordane, Dieldrin, *gamma*-Chlordane, Dibutyltin, and Tributyltin

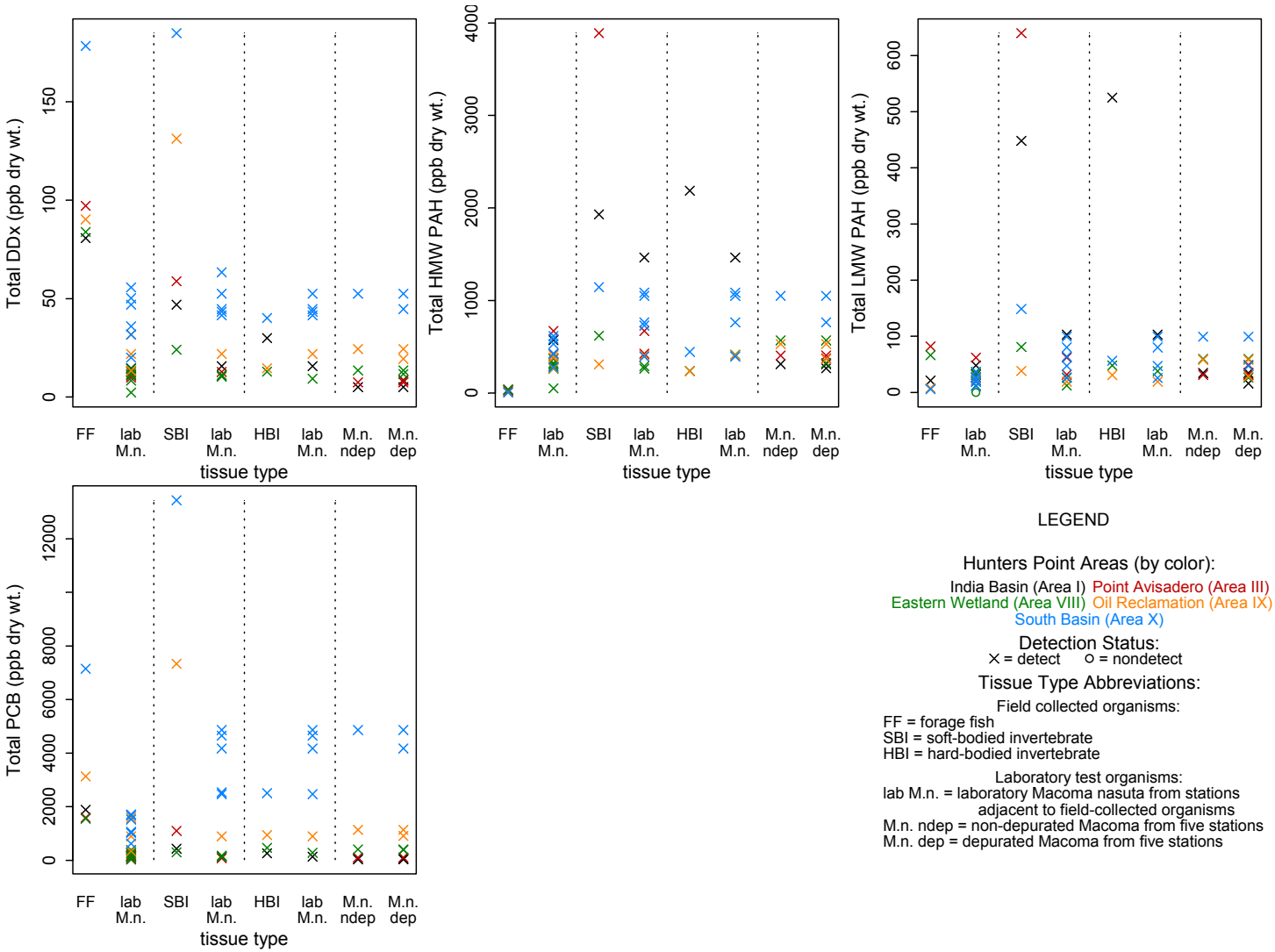


Figure 7-15. Field-Collected and Laboratory Test Organism Tissue Concentrations of Total DDx, Total HPAH, Total LPAH, and Total PCB

Table 7-5. Summary of Hazard Quotients for the Surf Scoter Based on HBI Tissue Concentrations

COPEC	HQ_{low} Based on 95% UCL Sediment Concentrations				
	Area I	**Area VIII**	**Area IX**	**Area X**	**Sitewide**
	AAB-369	**AAB-377**	**AAB-404**	**AAB-399**	**95% UCL**
Arsenic	1.08E-01	1.04E-01	1.01E-01	9.48E-02	1.08E-01
Cadmium	4.72E-01	7.13E-01	6.84E-01	7.56E-01	7.54E-01
Copper	1.03E+00	3.73E-01	3.40E-01	6.07E-01	1.03E+00
Lead	4.39E+01	1.12E+01	1.30E+01	2.59E+01	3.84E+01
Mercury	2.61E-01	3.10E-01	3.75E-01	4.20E-01	4.37E-01
Nickel	9.82E-01	5.74E-01	7.44E-01	5.91E-01	8.38E-01
Selenium	1.25E+00	1.26E+00	1.56E+00	1.68E+00	1.68E+00
Zinc	5.12E-01	4.83E-01	3.97E-01	5.00E-01	5.16E-01
Total PCBs	2.06E-01	3.71E-01	7.58E-01	2.03E+00	1.82E+00
Total 4,4′-DDx	3.21E-01	1.39E-01	1.56E-01	4.34E-01	4.27E-01
Dibutyltin	1.66E-02	5.13E-03	8.54E-04	1.09E-03	1.46E-02
Tributyltin	5.42E-02	2.04E-02	3.26E-03	5.73E-03	4.86E-02

Area values include 95% UCL sediment and individual station tissue concentrations for each HPS study area.
Site-wide value includes 95% UCL sediment and 95% UCL tissue concentrations of four study areas.
Gray cells correspond to HQ_{low} >1.0. COPECs in **bold** are priority COPECs **(Hg, total 4,4′-DDx, and PCBs).**
COPEC = contaminant of potential ecological concern; HQ = hazard quotient; UCL = upper confidence limit.
All HQ_{high} values less than 1.0.

Table 7-6. Summary of HPS Hazard Quotients for the Surf Scoter Based on SBI Tissue Concentrations

COPEC	HQ_{low} Based on 95% UCL Sediment Concentrations					
	Area I	**Area III**	**Area VIII**	**Area IX**	**Area X**	**Sitewide**
	AAB-398	**AAB-460**	**AAB-372**	**AAB-456**	**AAB-453**	**95% UCL**
Arsenic	2.67E-01	3.36E-01	2.50E-01	1.51E-01	1.44E-01	3.07E-01
Cadmium	3.95E-01	2.77E+00	5.15E-01	8.66E-01	7.16E-01	2.77E+00
Copper	1.21E+00	9.90E+00	1.26E+00	6.11E-01	2.33E+00	9.49E+00
Lead	5.37E+01	1.20E+02	4.10E+01	2.44E+01	1.09E+02	1.08E+02
Mercury	4.03E-01	1.16E+00	3.98E-01	3.29E-01	6.31E-01	9.07E-01
Nickel	2.82E+00	2.52E+00	2.02E+00	1.08E+00	1.82E+00	2.63E+00
Selenium	1.61E+00	3.28E+00	3.22E+00	1.56E+00	1.65E+00	3.28E+00
Zinc	4.29E-01	7.35E-01	4.33E-01	4.98E-01	6.77E-01	6.87E-01
Total PCBs	3.46E-01	9.28E-01	2.42E-01	5.84E+00	1.07E+01	8.02E+00
Total 4,4′-DDx	5.02E-01	6.30E-01	2.57E-01	1.41E+00	1.98E+00	1.64E+00
Dibutyltin	4.19E-03	6.57E-02	2.26E-03	3.25E-03	6.80E-03	6.57E-02
Tributyltin	1.34E-02	1.13E-01	8.50E-03	4.54E-03	1.31E-02	1.12E-01

Area values include 95% UCL sediment and individual station tissue concentrations for each HPS study area.
Site-wide value includes 95% UCL sediment and 95% UCL tissue concentrations of five study areas.
Gray cells correspond to HQ_{low} >1.0. COPECs in **bold** are priority COPECs **(Hg, total 4,4′-DDx, and PCBs).**
COPEC = contaminant of potential ecological concern; HQ = hazard quotient; UCL = upper confidence limit.
All HQ_{high} values less than 1.0.

A BSAF for PCBs developed using the field-collected SBI tissue data was approximately 2.4, which is an order of magnitude higher than those developed for *Neanthes* in the laboratory by the USACE. The BSAFs for polychaetes based on field and laboratory data sets may be different because the field-collected tissue and sediment samples were not collocated, and/or the field tissue samples were not depurated, which introduced the potential artifact of sediment in the gut. However, it is likely that BSAFs generated from field-collected polychaetes would be similar to those generated under careful laboratory conditions by the USACE if these factors were controlled.

7.3 Dose Assessment for Piscivorous Birds

The upper trophic level assessment for the bioaccumulation line of evidence focused on an invertebrate-eating species, the surf scoter. To evaluate potential risk to piscivorous avian receptors that may feed at HPS, an additional dose assessment was performed and HQs were calculated using the field-collected forage fish data. The double-crested cormorant (DCCO) was selected as the appropriate piscivorous receptor for the following reasons:

- The species is widespread in San Francisco Bay with nesting colonies potentially within foraging distance of HPS (located on the Oakland-San Francisco Bay Bridge and the Dumbarton Bridge; Ainley et al., 1981); as such, they are found year round in San Francisco Bay.

- DCCO have been observed at HPS (Harding Lawson Associates [HLA], 1991).

- Because the DCCO forage in shallow waters overlying bottoms of flat relief (<8 m deep) (Hatch and Weseloh, 1999; Ainley, 2000), the birds could be exposed to most areas addressed in the Validation Study. This is contrasted with piscivorous wading birds [e.g., the great blue heron (*Ardea herodias*) or the snowy egret (*Egretta thula*)] that are restricted to the shallow intertidal zone, which makes up only a small portion of the area addressed in the Validation Study.

The exposure parameters used in the dose assessment for the DCCO are described in Appendix G and summarized in Table 7-7.

As described in Section 6.2.1.2, the low and high TRVs developed by the Navy in consultation with the U.S. EPA Region 9 BTAG were scaled to account for differences in body weights between the organism used to establish the TRV and the receptor of concern (ROC). Table 7-8 presents the weight-adjusted TRVs for the DCCO.

Table 7-7. Exposure Parameters for the Double-Crested Cormorant

Parameter	Double-Crested Cormorant	Units
IR_{prey}	0.091	kg/day dry weight
C_{prey} Screen	COPEC concentration in field-collected fish composite for each HPS study area	mg/kg dry weight
IR_{sed}	0.0018	kg/day dry weight
C_{sed} Screen	• 95% UCL and mean of sediment stations in each HPS study area	mg/kg dry weight
Foraging Range	227	km^2
SUF Screen	• 1	unitless
Body weight	1.67	kg

COPEC = contaminant of potential ecological concern; UCL = upper confidence limit; IR = ingestion rate; C = concentration; SUF = site use factor.

Table 7-8. Weight-Adjusted TRVs for the Double-Crested Cormorant

COPEC	NOAEL Study Receptor Body Weight (kg)	Literature-Based Low Avian TRV (NOAEL) (mg/kg/day)	Cormorant Weight-Adjusted Low TRV (mg/kg/day)	LOAEL Study Receptor Body Weight (kg)	Literature-Based High Avian TRV (LOAEL) (mg/kg/day)	Cormorant Weight-Adjusted High TRV (mg/kg/day)
Aluminum	NA	NA	NA	NA	NA	NA
Antimony	NA	NA	NA	NA	NA	NA
Arsenic	1.17E+00	5.50E+00	5.90E+00	1.17E+00	2.20E+01	2.36E+01
Barium	NA	NA	NA	NA	NA	NA
Cadmium	7.99E-01	8.00E-02	9.27E-02	8.40E-02	1.04E+01	1.90E+01
Chromium	NA	NA	NA	NA	NA	NA
Cobalt	NA	NA	NA	NA	NA	NA
Copper	6.39E-01	2.30E+00	2.79E+00	4.09E-01	5.23E+01	6.92E+01
Iron	NA	NA	NA	NA	NA	NA
Lead	8.40E-02	1.40E-02	2.55E-02	8.00E-01	8.75E+00	1.01E+01
Manganese	NA	NA	NA	NA	NA	NA
Mercury	1.00E+00	3.90E-02	4.32E-02	1.00E+00	1.80E-01	1.99E-01
Molybdenum	NA	NA	NA	NA	NA	NA
Nickel	6.14E-01	1.38E+00	1.69E+00	5.80E-01	5.53E+01	6.83E+01
Selenium	1.11E+00	2.30E-01	2.50E-01	1.11E+00	9.30E-01	1.01E+00
Silver	NA	NA	NA	NA	NA	NA
Vanadium	NA	NA	NA	NA	NA	NA
Zinc	9.55E-01	1.72E+01	1.92E+01	9.55E-01	1.72E+02	1.92E+02
HPAH	NA	NA	NA	NA	NA	NA
LPAH	NA	NA	NA	NA	NA	NA
Total PCBs	8.00E-01	9.00E-02	1.04E-01	1.72E+00	1.27E+00	1.26E+00
Total 4,4′-DDx	3.50E+00	9.00E-03	7.76E-03	1.00E+00	6.00E-01	6.65E-01
alpha-Chlordane	NA	NA	NA	NA	NA	NA
Dieldrin	NA	NA	NA	NA	NA	NA
Endosulfan II	NA	NA	NA	NA	NA	NA
Endrin	NA	NA	NA	NA	NA	NA
gamma-Chlordane	NA	NA	NA	NA	NA	NA
Heptachlor	NA	NA	NA	NA	NA	NA
Dibutyltin	9.65E-02	7.30E-01	1.29E+00	0.0965	4.59E+01	8.11E+01
Monobutyltin	NA	NA	NA	NA	NA	NA
Tetrabutyltin	NA	NA	NA	NA	NA	NA
Tributyltin	9.65E-02	7.30E-01	1.29E+00	0.0965	4.59E+01	8.11E+01

NA = not available; TRV = toxicity reference value; COPEC = contaminant of potential ecological concern; LOAEL = lowest observed adverse effects level; NOAEL = no observed adverse effects level.

Dose assessment results for each composite forage fish sample are provided in Appendix H. Both the arithmetic mean and the 95% UCL of the mean sediment concentration for a given area were used as the sediment exposure point concentration in Appendix H. Table 7-9 summarizes the calculated HQ_{low} values using the 95% UCL of the sediment concentrations. For the sitewide exposure scenario, the HQ_{low} for lead, total 4,4′-DDx and PCBs exceeded 1.0. For the individual area, the HQ_{low} for lead exceeded 1.0 at all areas, and the HQ_{low} for PCBs exceeded 1.0 at Areas IX and X. Additionally, the HQ_{low} for total 4,4′-DDx slightly exceeded 1.0 at Area X (South Basin). All HQ_{high} values were less than 1.0.

Table 7-9. Summary of HPS Hazard Quotients for the Double-Crested Cormorant – Sediment 95% UCL and FF Tissue Concentrations

COPEC	HQ_{low} Based on 95% UCL Sediment Concentrations					
	Area I	**Area III**	**Area VIII**	**Area IX**	**Area X**	**Site-Wide**
Arsenic	2.43E-03	2.94E-02	2.84E-02	2.74E-03	2.50E-03	2.90E-02
Cadmium	1.97E-02	3.91E-02	2.43E-02	1.74E-02	2.07E-02	3.31E-02
Copper	1.95E-01	3.70E-01	1.24E-01	1.55E-01	1.87E-01	2.18E-01
Lead	6.95E+00	5.57E+00	2.33E+00	4.01E+00	6.63E+00	5.90E+00
Mercury	3.31E-01	3.10E-01	4.18E-01	3.33E-01	2.98E-01	4.03E-01
Nickel	2.50E-01	1.58E-01	1.12E-01	1.46E-01	1.15E-01	1.68E-01
Selenium	6.48E-01	4.29E-01	3.84E-01	5.17E-01	4.84E-01	5.88E-01
Zinc	1.99E-01	1.71E-01	1.96E-01	1.80E-01	1.69E-01	1.99E-01
Total PCBs	9.88E-01	8.59E-01	8.15E-01	1.64E+00	3.75E+00	3.75E+00
Total 4,4′-DDx	5.67E-01	6.82E-01	5.89E-01	6.34E-01	1.25E+00	1.25E+00
Dibutyltin	4.95E-04	1.36E-03	3.62E-04	4.16E-04	3.04E-04	1.34E-03
Tributyltin	1.93E-03	5.23E-03	1.59E-03	1.16E-03	9.36E-04	5.11E-03

Area values include 95% UCL sediment and individual station tissue concentrations for each HPS study area. Site-wide value includes 95% UCL sediment and 95% UCL tissue concentrations of five study areas.
Gray cells correspond to HQ_{low} >1.0. COPECs in **bold** are priority COPECs **(Hg, total 4,4′-DDx, and PCBs).**
COPEC = contaminant of potential ecological concern; HQ = hazard quotient.
All HQ_{high} values less than 1.0.

Forage fish tissue samples were collected at the five reference site stations (Alcatraz Environs, Alameda Buoy, Red Rock, Paradise Cove, and Bay Farm) as part of the RI for Seaplane Lagoon at Alameda Point (Battelle et al., 2001c). Figures 7-16 through 7-18 compare forage fish tissue concentrations for lead, total DDx, and total PCBs from HPS with those from reference areas within San Francisco Bay. Lead (except in Area III) and PCB concentrations in forage fish from HPS are elevated relative to reference concentrations; however, total DDx concentrations are similar to reference except in Area X.

The results of the piscivorous bird evaluation support the conclusions of the scoter assessment using the depurated, laboratory *M. nasuta* data. When SUFs of $\leq$0.1 are used, the HQ_{low} values for both the scoter and the DCCO are less than 1.0. In both evaluations, the highest HQs were associated with lead; however, concerns about the Navy/BTAG TRV for lead make it difficult to adequately assess the risk from lead. For example, if the proposed U.S. EPA TRV for birds (1.6 mg lead/kg bw-day; U.S. EPA, 2003) is used to assess effects from lead to the DCCO at HPS, risk throughout HPS would be considered negligible. As with the scoter evaluation based on laboratory *M. nasuta* data, the fish tissue from South Basin (Area X) contributed the highest PCB exposure to the DCCO.

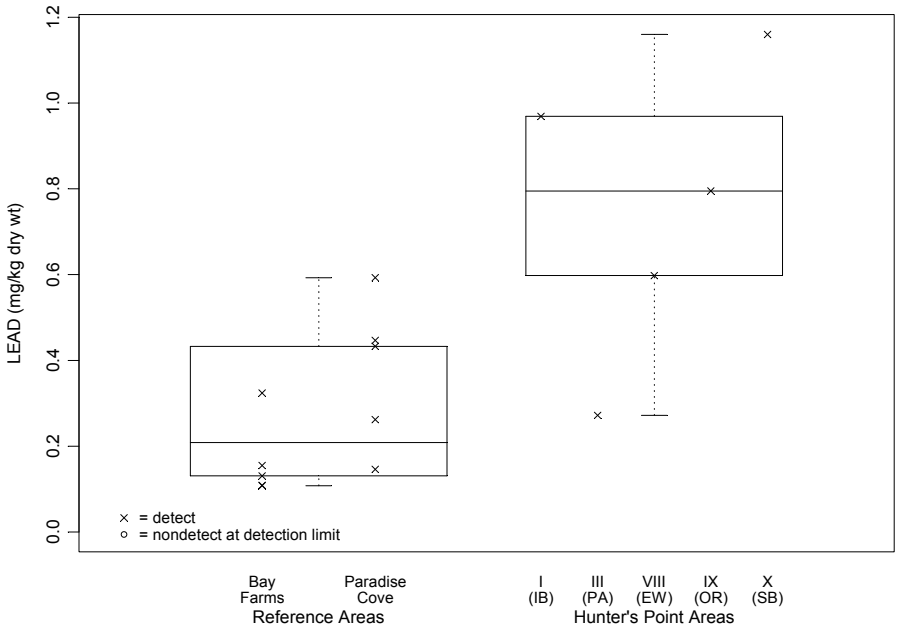


Figure 7-16. Forage Fish Tissue Concentrations at HPS and Reference Areas: Lead

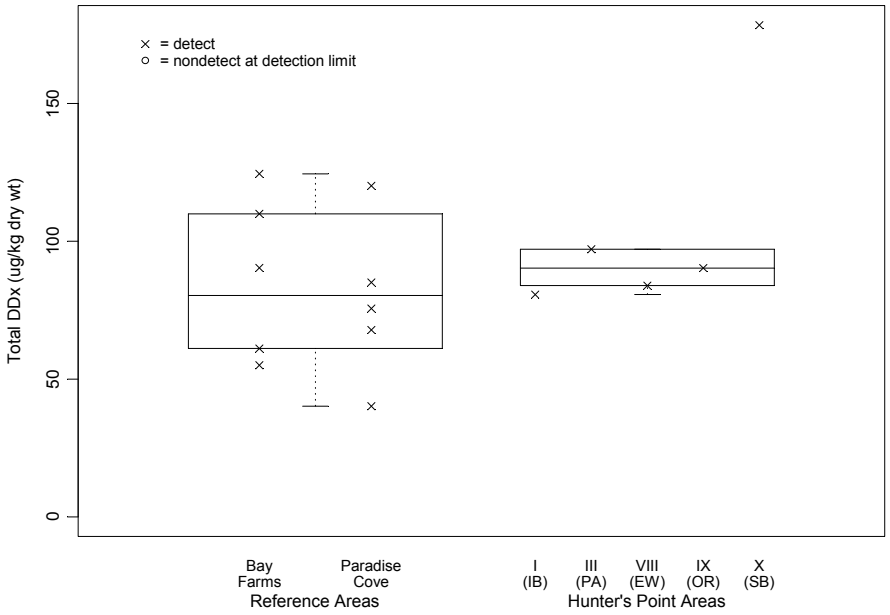


Figure 7-17. Forage Fish Tissue Concentrations at HPS and Reference Areas: Total DDx

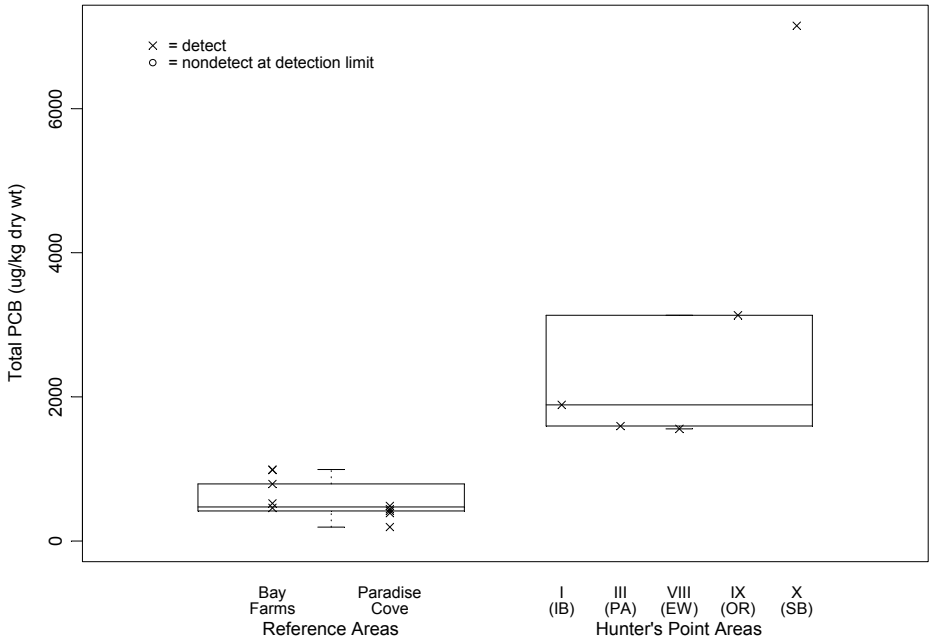


Figure 7-18. Forage Fish Tissue Concentrations at HPS and Reference Areas: Total PCBs

7.4 Summary of Ancillary Data Evaluation

The ancillary data provide insights into specific uncertainties associated with the three lines of evidence collected for the Validation Study (uncertainty is discussed further in Section 11.0). These uncertainties include concerns about potential confounding factors associated with the SWI test, and the validity of using depurated *M. nasuta* tissue from a laboratory exposure as a measure of bioaccumulation in the field. Additionally, the results of the ancillary data evaluation are used in conjunction with the results of the WOE to define risk drivers and pathways at the site.

In general, the results of the two TIE studies were consistent, and identified ammonia as the predominant source of toxicity in both SPP and porewater exposures. Both studies also identified metals as a primary or suspected contributor to observed toxicity in the TIE tests at some stations. The SAIC/EFANE study, by virtue of its experimental design, was able to identify particular classes of metals that might have contributed to observed toxicity. In addition, the SAIC/EFANE study also detected low dissolved oxygen levels in some porewater tests; this phenomenon also was observed in some of the SWI exposures conducted by PERL in support of the Validation Study. The Battelle TIE results were used to support evaluation of SWI test results as they relate to the potential influence of ammonia.

The nondepurated *M. nasuta* data and the field-collected tissue data (both invertebrate and forage fish tissue) showed similar spatial patterns and trends as observed in the depurated, laboratory *M. nasuta* data. Even in instances where differences in COPEC concentrations occurred among the different tissue types, the conclusions drawn from the analyses conducted using the data were similar. Several inorganic constituents (mainly copper and mercury, and potentially lead) and PCBs appear to be the contaminants that are contributing most significantly to estimates of potential risk.

8.0 WEIGHT OF EVIDENCE EVALUATION

This section presents the results of the WOE evaluation using the data for the three lines of evidence (sediment chemistry, toxicity, and bioaccumulation) and the decision criteria specified in the VS Work Plan (Battelle et al., 2001a). The WOE approach is described in Section 2.1.6 and the decision criteria are presented in Table 2-8. Integration of the different lines of evidence into a WOE framework is meant to facilitate identification of areas that should or should not be evaluated in the FS. Thus, "bright line criteria" were established in the VS Work Plan as a starting point for interpreting WOE results. The WOE results are integrated with the ancillary data and human health evaluation results in Section 10.0 to identify areas for consideration in the FS.

The WOE scores for each line of evidence are summarized below (and presented in Table 8-1), followed by the integration of scores for each station and development of the WOE map. The integrated WOE map shows areas that either (1) should be included in the FS footprint; (2) should be excluded from the FS footprint; or (3) require additional evaluation.

8.1 Sediment Chemistry WOE Scores

The WOE scoring criteria for the sediment chemistry line of evidence are presented in Table 8-2. When scoring this line of evidence, it became clear that none of the HPS or reference site stations could receive a high negative (-2) score because the category required as one condition that all COPEC concentrations be below ER-Ms. However, ambient sediment concentrations of nickel exceed the ER-M throughout San Francisco Bay. Consequently, the WOE criteria for the low negative (−1) category were modified slightly as follows:

- ERM-Q ≤0.5 but >UTL of ambient ERM-Q (0.3); **or**
- 1-3 COPECs >ER-Ms **excluding** nickel.

Because of the ERM-Q condition, stations with nickel concentrations elevated significantly above ambient were still scored as low negative (−1).

The WOE scores for the sediment chemistry endpoint for all HPS stations are presented in Table 8-1 and are summarized by area in Table 8-3. Reference site station scores also are provided for comparison. All stations in Area I (India Basin) and Area VIII (Eastern Wetland) and all but one station in Area IX (Oil Reclamation) had negative findings for sediment chemistry. In Areas I and VIII, the majority of the stations had a high magnitude negative findings (scores of −2). Approximately half of the stations in Area III (Point Avisadero) and Area X (South Basin) had positive findings. Five stations in Area III and two in Area X showed a high magnitude negative finding (−2 score), and several in each of these areas showed a high magnitude positive finding (+2 score).

WOE scores for the sediment chemistry endpoint were mapped spatially and are presented in Figure 8-1. Areas of elevated COPEC concentrations in sediment are found mainly on the eastern shoreline of South Basin in Area X, near the mouth of Yosemite Creek, and in several areas at Area III (Point Avisadero).

Table 8-1. WOE Scores for HPS and Reference Site Stations

Station	Sediment Chemistry WOE Score	Bulk Sediment Bioassay WOE Score	SWI Test WOE Score	Bioaccumulation WOE Score	Integrated WOE Score[(a)]	Footprint Map
India Basin Area I						
IB-54	-2	-2	2	1	-0.25	gray
IB-55	-1	-2	-2	1	-1	white
IB-56	-2	-2	-2	-2	-2	white
IB-57	-2	-2	-2	-1	-1.75	white
IB-58	-2	-2	2	-2	-1	white
IB-59	-1	-2	2	1	0	gray
Point Avisadero Area III						
PA-38	1	-2	-2	1	-0.5	gray
PA-39	1	-2	-2	1	-0.5	gray
PA-40	-1	-2	-2	1	-1	white
PA-41	1	-1	-2	1	-0.25	gray
PA-42	1	-2	2	1	0.5	gray
PA-43	-1	-2	-2	1	-1	white
PA-44	1	-2	-2	2	-0.25	gray
PA-45	2	-2	-2	1	-0.25	gray
PA-46	1	-2	-2	1	-0.5	gray
PA-47	2	-2	-2	1	-0.25	gray
PA-48	-1	-2	-2	1	-1	white
PA-49	-2	-2	2	1	-0.25	gray
PA-50	-2	-2	2	1	-0.25	gray
PA-51	-2	-2	2	-2	-1	white
PA-52	-2	-2	-2	1	-1.25	white
PA-53	-2	-2	-2	-2	-2	white
Eastern Wetland Area VIII						
EW-30	-1	-2	-2	1	-1	white
EW-31	-2	-2	-2	1	-1.25	white
EW-32	-2	-2	1	1	-0.5	gray
EW-33	-2	-2	1	1	-0.5	gray
EW-34	-2	-2	-2	1	-1.25	white
EW-35	-2	-2	-2	1	-1.25	white
EW-36	-2	-2	-2	1	-1.25	white
EW-37	-2	-2	-2	-2	-2	white
Oil Reclamation Area IX						
OR-24	1	-2	-1	1	-0.25	gray
OR-25	-2	-2	2	1	-0.25	gray
OR-26	-1	-2	-1	1	-0.75	gray
OR-27	-1	-2	-1	1	-0.75	gray
OR-28	-2	-2	-2	1	-1.25	white
OR-29	-1	-2	-1	1	-0.75	gray

Table 8-1. WOE Scores for HPS and Reference Site Stations (page 2 of 2)

Station	Sediment Chemistry WOE Score	Bulk Sediment Bioassay WOE Score	SWI Test WOE Score	Bioaccumulation WOE Score	Integrated WOE Score[(a)]	Footprint Map
South Basin Area X						
SB-01	-1	-2	-1	1	-0.75	gray
SB-02	1	-2	-2	1	-0.5	gray
SB-03	-2	-2	-2	1	-1.25	white
SB-04	-1	-2	-2	1	-1	white
SB-05	-1	-2	-2	1	-1	white
SB-06	-2	-2	1	1	-0.5	gray
SB-07	-1	-2	-2	1	-1	white
SB-08	-1	-2	-1	1	-0.75	gray
SB-09	-1	-2	-2	1	-1	white
SB-10	1	-2	-2	1	-0.5	gray
SB-11	1	-2	-2	1	-0.5	gray
SB-12	1	-2	2	1	0.5	gray
SB-13	1	-2	-2	1	-0.5	gray
SB-14	1	-2	-1	1	-0.25	gray
SB-15	-1	-2	-2	1	-1	white
SB-16	1	-2	-2	1	-0.5	gray
SB-17	1	-2	-2	1	-0.5	gray
SB-18	-1	-2	-2	1	-1	white
SB-19	2	-2	-1	1	0	gray
SB-20	1	-2	-2	1	-0.5	gray
SB-21	2	-2	-2	1	-0.25	gray
SB-22	2	-2	-2	1	-0.25	gray
SB-23	2	-2	-2	1	-0.25	gray
Alameda Buoy						
AB-67	-2	-1	-2	-2	-1.75	white
Alcatraz Environs						
AL-64	-2	-2	-2	1	-1.25	white
Bay Farm						
BF-66	-2	1	-1	-2	-1	white
Paradise Cove						
PC-63	-2	-2	-2	-1	-1.75	white
Red Rock						
RR-65	-2	-2	-2	1	-1.25	white

(a) white ≤−1, −1< gray ≤0.5, black >0.5.
SWI = sediment water interface; WOE = weight of evidence.

Table 8-2. WOE Scoring Criteria for the Sediment Chemistry Endpoint

WOE Score	Attribute	Sediment Chemistry
+2	High Positive	• ERM-Q >1.25 **or** • 7 or more COPECs >ER-Ms **or** • Any one COPEC >10 times its ER-M
+1	Low Positive	• ERM-Q >0.5 but ≤1.25 **or** • 4-6 COPECs >ER-Ms **or** • Any one COPEC >5 times its ER-M
–1	Low Negative	• ERM-Q ≤0.5 but >UTL of ambient ERM-Q (0.3)[(a)] **or** • 1-3 COPECs >ER-Ms
–2	High Negative	• ERM-Q ≤UTL of ambient ERM-Q (0.3)[(a)] **or** • All individual COPECs <ER-Ms

(a) Ambient ERM-Qs calculated from 1993-1997 RMP and BPTCP reference site data, using HPS COPEC list for which there are ER-Ms. UTL of 0.3 represents the 95% upper confidence interval on the 95th percentile of the ERM-Qs calculated for the reference site data.

WOE = weight of evidence; ER-M = Effects Range – Median; ERM-Q = ER-M quotient; COPEC = contaminant of potential ecological concern; UTL = upper tolerance limit.

Table 8-3. Summary of WOE Scores for the Sediment Chemistry Endpoint

WOE Score	Number of Stations per Area					
	I	III	VIII	IX	X	Total
+2	0	2	0	0	4	6
+1	0	6	0	1	9	16
-1	2	3	1	3	8	17
-2	4	5	7	2	2	20

WOE = weight of evidence.

8.2 Bulk Sediment Bioassay WOE Scores

The bulk sediment bioassay was conducted using the amphipod *E. estaurius*. Finding and magnitude criteria for this endpoint are summarized in Table 8-4. The threshold between a positive and negative finding was based on comparison to the reference envelope tolerance limit for *E. estuarius*, which is expressed as survival relative to control (SWRCB, 1998a). Magnitude criteria were based on the magnitude of the response observed in the bioassay.

Table 8-1 presents the WOE scores for each HPS and reference site station. All of the HPS stations received a high magnitude negative finding (–2 score) except for Station PA-41, which received a low negative finding (–1 score). A low magnitude positive finding (+1 score) was noted at the Bay Farm reference site (BF-66), where survival was just below the reference envelope threshold. The negative WOE scores for HPS sediments support the conclusion that HPS sediments are not acutely toxic to benthic invertebrates. WOE scores for the bulk sediment bioassay endpoint are mapped in Figure 8-2.

8.3 SWI Test WOE Scores

The SWI test was conducted on larvae of the purple sea urchin *S. purpuratus*. The WOE scoring criteria for this endpoint are presented in Table 8-5. As with *E. estuarius*, this endpoint (percentage normal sea urchin larvae) was normalized to the control for comparability with the San Francisco Bay minimum significant difference (MSD) reference threshold (SWRCB, 1998a). The MSD is the percentage of control response at which a significant difference from control was observed 90% of the time at San Francisco Bay ambient stations.

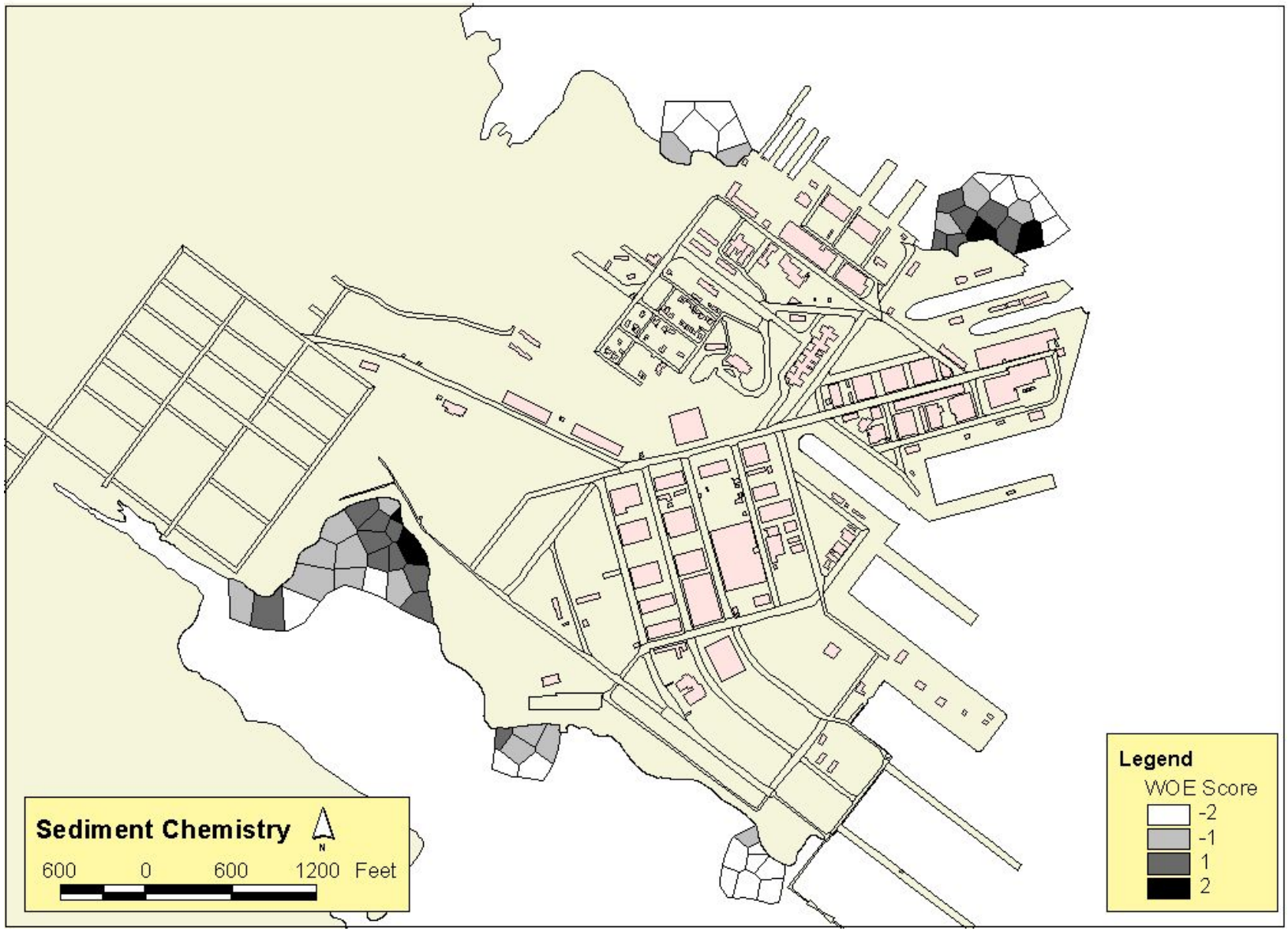


Figure 8-1. WOE Map for the Sediment Chemistry Endpoint

Table 8-4. WOE Scoring Criteria for the Bulk Sediment Bioassay Endpoint

WOE Score	Attribute	Amphipod Bioassay
+2	High Positive	≤50% survival relative to control response
+1	Low Positive	>50% but ≤69.5% survival relative to control response
–1	Low Negative	>69.5% but ≤80% survival relative to control response
–2	High Negative	>80% survival relative to control response

WOE = weight of evidence.

WOE scores for each HPS and reference site station are provided in Table 8-1. Scores are summarized by area in Table 8-6. The majority of HPS stations (47 of 59) received negative findings (scores of –1 and –2). Positive findings (scores of +1 or +2) were assigned to 12 HPS stations due to lower than ambient normal larval development. For stations with positive WOE scores, laboratory data were examined to identify the potential cause of toxicity. In some cases, toxicity did not appear to be associated with high COPEC concentrations. Elevated ammonia and native infauna were identified as potential confounding factors.

Figure 8-3 provides a spatial presentation of the WOE scores for the SWI test larvae endpoint. Stations with negative findings are distributed throughout the five areas and do not always correspond with stations identified as having high sediment COPEC concentrations.

8.4 Bioaccumulation WOE Scores

Depurated, laboratory-exposed *M. nasuta* tissue concentrations were compared to reference tissue thresholds and HQs developed for the surf scoter were calculated at each station (see Section 6.2). PCBs, mercury, and DDx were identified as priority COPECs because of their tendency to bioaccumulate. Table 8-7 summarizes the finding and magnitude criteria for this endpoint.

An error in the WOE logic was encountered when scoring the bioaccumulation endpoint. A WOE category did not exist for a station with the following characteristics:

- No priority COPECs in tissue exceeded reference, and
- One nonpriority COPEC exceeded reference and had an HQ between 1 and 10.

This condition did not meet either the low negative (–1) nor the low positive (+1) criteria. One station (IB-57) fell into this category, and was assigned the higher WOE score (+1).

Bioaccumulation WOE scores for all HPS and reference site stations are provided in Table 8-1 and an area-by-area summary is presented in Table 8-8. Dose assessment details for each station can be found in Appendix H. The majority of the HPS stations had a low magnitude positive finding (+1 score). Five stations (in Areas I, III and VIII) had negative findings (–1 and –2 scores). One station (in Area III) had a high positive finding (+2 score) for this endpoint. Figure 8-4 maps the WOE scores for the bioaccumulation endpoint.

8.5 Integrated Weight of Evidence Results

The integrated WOE scores for each of the five study areas and WOE maps based on the integrated scores are presented below.

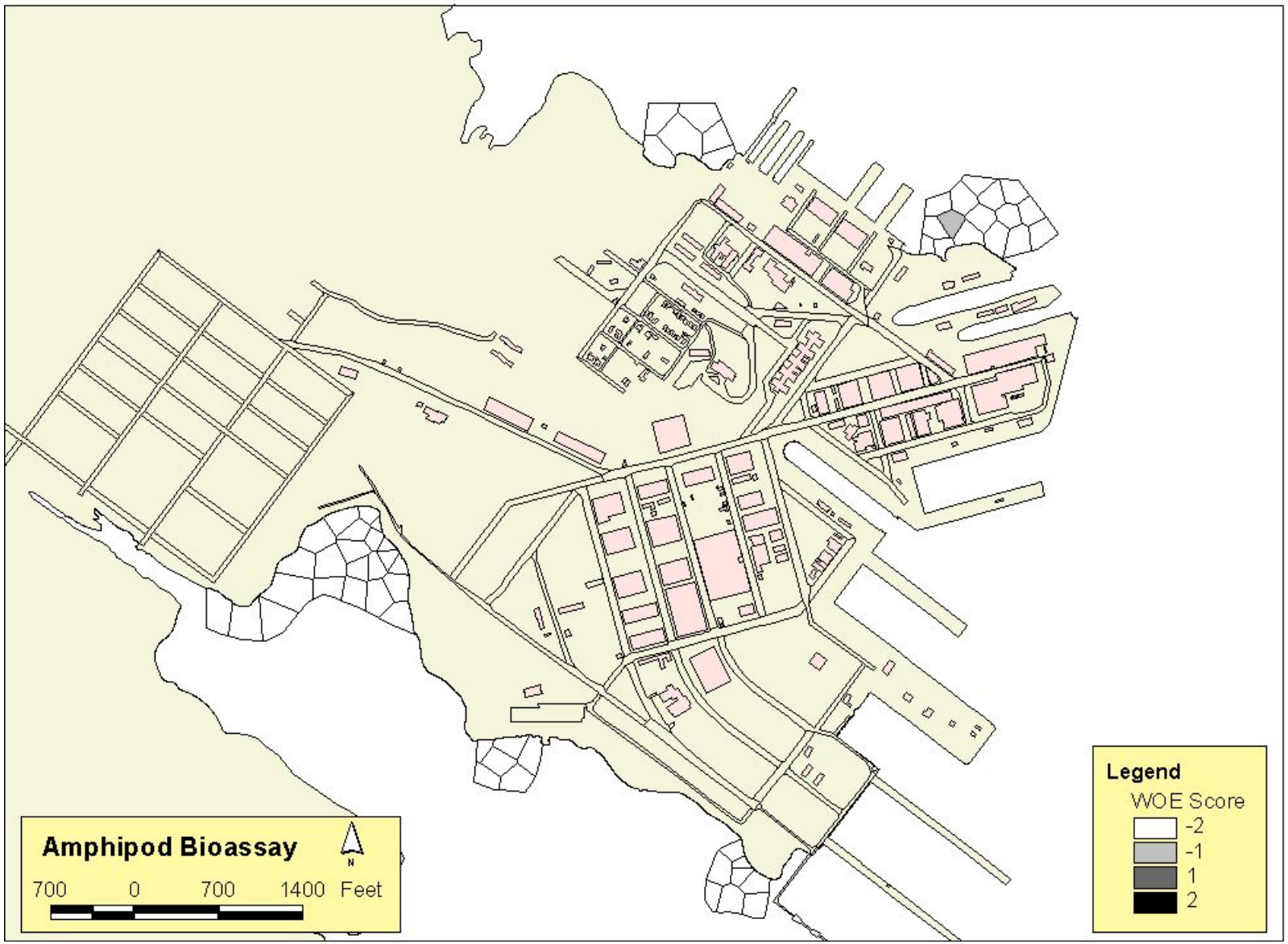


Figure 8-2. WOE Map for the Bulk Sediment Bioassay Endpoint

Table 8-5. WOE Scoring Criteria for the SWI Test Endpoint

WOE Score	Attribute	Echinoderm Larvae SWI Bioassay
+2	High Positive	≤50% normal development relative to control response
+1	Low Positive	>50% but ≤60% normal development relative to control response
–1	Low Negative	>60% but ≤80% normal development relative to control response
–2	High Negative	>80% normal development relative to control response

WOE = weight of evidence; SWI = sediment water interface.

Table 8-6. Summary of WOE Scores for the SWI Test Endpoint

WOE Score	Number of Stations per Area					
	I	III	VIII	IX	X	Total
+2	3	4	0	1	1	9
+1	0	0	2	0	1	3
–1	0	0	0	4	4	8
–2	3	12	6	1	17	39

WOE = weight of evidence; SWI = sediment water interface.

8.5.1 Integrated WOE Scores

Integration of the weight, finding, and magnitude for each endpoint was conducted to determine whether and how strongly the result supports inclusion or exclusion of a station from the FS footprint. Weight, finding, and magnitude were integrated by multiplying the scaled weight (0.25) by the numerical score for finding and magnitude (–2, –1, +1 or +2). This value, the integrated score, was represented by a value on a bar chart, where the height of the bar reflects the magnitude of the response and its position in relation to zero corresponds with a positive or negative finding. The charts show each individual score (separate colored bars) as well as the integrated score. The wide black bar is the integrated WOE score for each station; that is, the sum of the scaled scores for each individual endpoint. Bar charts for Areas I, III, VIII, IX, and X are provided as Figures 8-5 through 8-9, respectively.

8.5.2 WOE Maps

"Bright line" criteria for inclusion or exclusion of a station from the FS footprint were defined in the VS Work Plan as follows:

- WOE score >0.5 validates inclusion in the FS footprint (map as black)
- WOE score ≤0.5 and >–1 indicates that data require further evaluation (map as gray)
- WOE score <–1 validates exclusion from the FS footprint (map as white).

Figure 8-10 maps the integrated WOE scores for each station using these "bright-line" criteria. None of the station scores exceeded 0.5; therefore, none were categorically included in the FS footprint based on these criteria. Some stations in each of the five areas mapped as white, indicating that they would be excluded from the FS footprint based on the "bright-line" criteria. The majority of the stations mapped as gray, which indicates that further evaluation is required to determine whether the station should be included or excluded from the footprint.

Figure 8-3. WOE Map for SWI Test Endpoint

Table 8-7. WOE Scoring Criteria for the Bioaccumulation Endpoint

WOE Score	Attribute	*M. nasuta* Bioaccumulation
+2	High Positive	One or more priority[(a)] COPECs or two or more nonpriority COPECs exceed reference[(b)] and • HQ_{low} >10 **or** • HQ_{high} >1.
+1	Low Positive	One or more priority[(a)] COPECs or two or more nonpriority COPECs exceed reference[(b)] and • HQ_{low} ≤10 • HQ_{high} ≤1.
–1	Low Negative	No priority[(a)] COPECs or no more than one nonpriority COPEC exceeds reference and HQ_{low} ≤1.
–2	High Negative	No COPEC concentrations in HPS tissues exceed reference.

(a) Priority COPECs are PCBs, mercury, and DDx.
(b) Tissue concentrations in one replicate tissue sample were compared with reference threshold values derived from the reference site distribution.
WOE = weight of evidence; COPEC = contaminant of potential ecological concern; HQ = hazard quotient.

Table 8-8. Summary of WOE Scores for the Bioaccumulation Endpoint

WOE Score	Number of Stations per Area					
	I	III	VIII	IX	X	Total
+2	0	1	0	0	0	1
+1	3	13	7	6	23	52
−1	1	0	0	0	0	1
−2	2	2	1	0	0	5

WOE = weight of evidence.

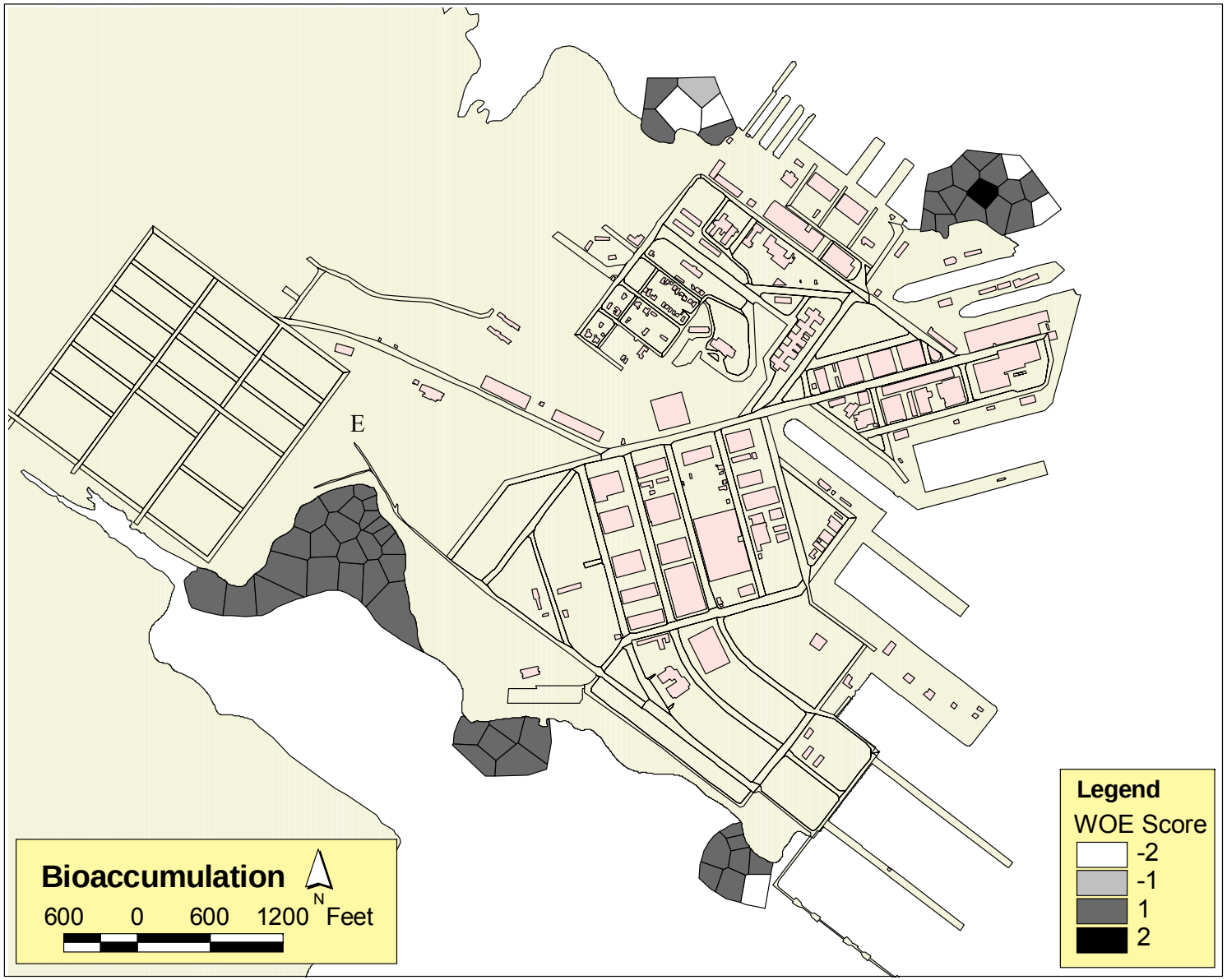


Figure 8-4. WOE Map for the Bioaccumulation Endpoint

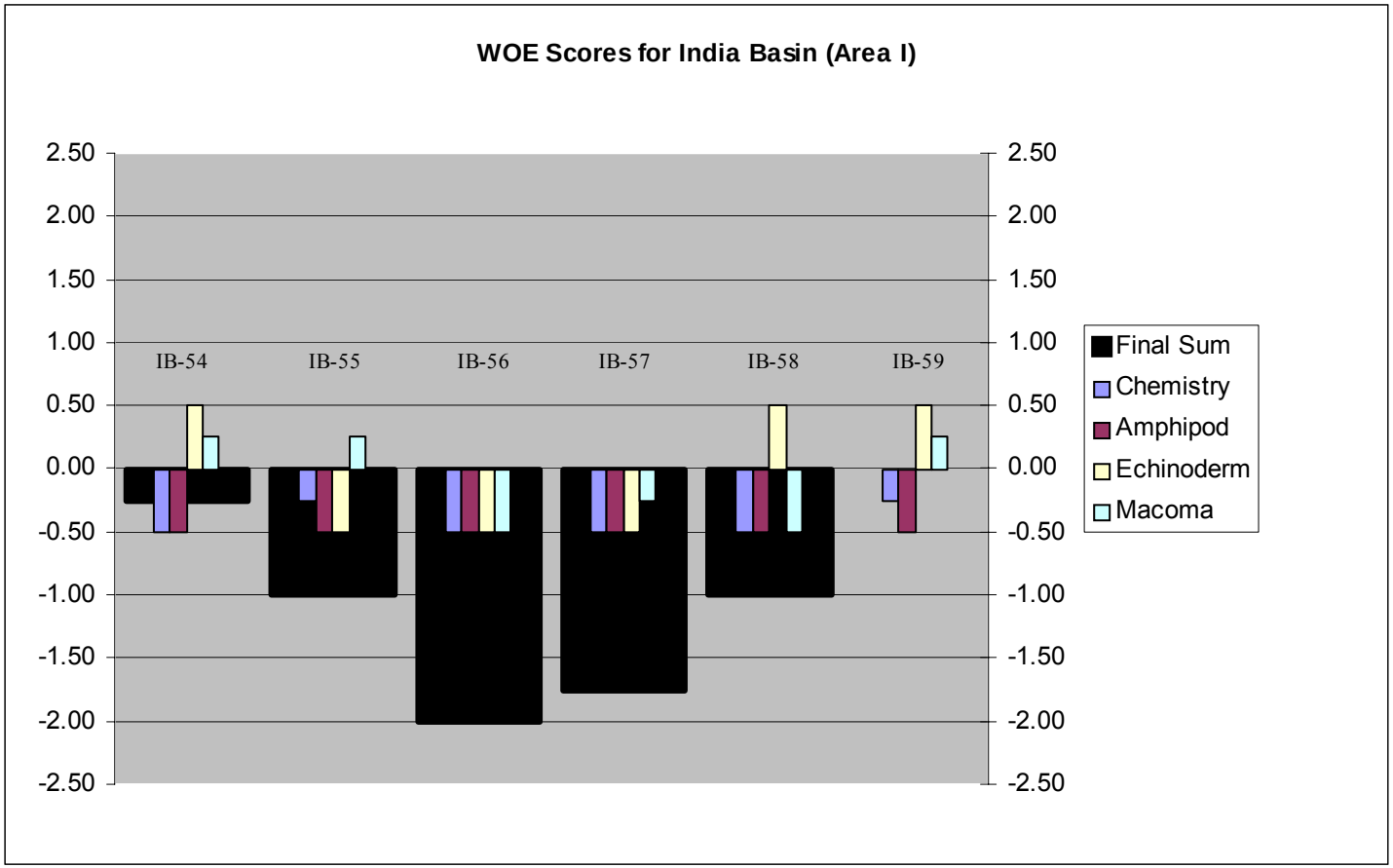


Figure 8-5. Integrated WOE Scores for Area I (India Basin)

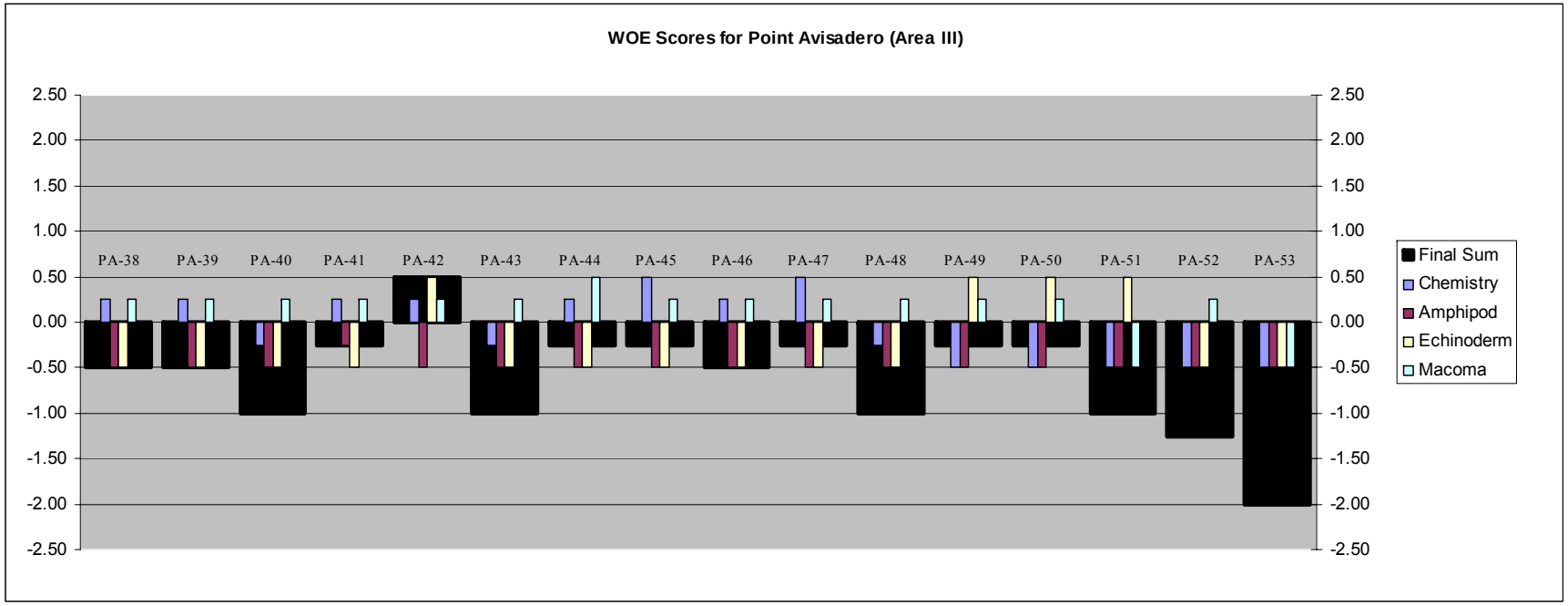


Figure 8-6. Integrated WOE Scores for Area III (Point Avisadero)

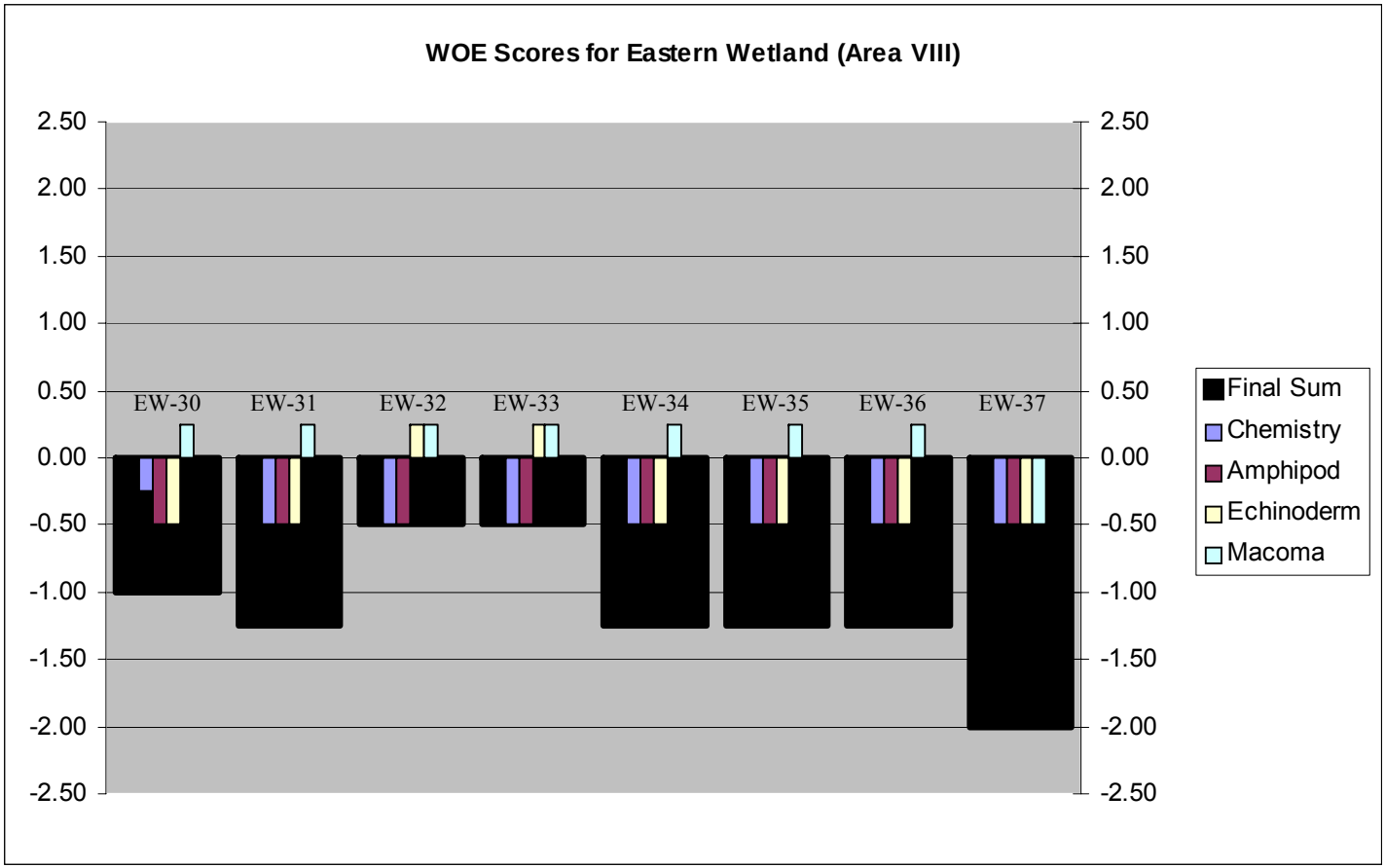


Figure 8-7. Integrated WOE Scores for Area VIII (Eastern Wetland)

Figure 8-8. Integrated WOE Scores for Area IX (Oil Reclamation)

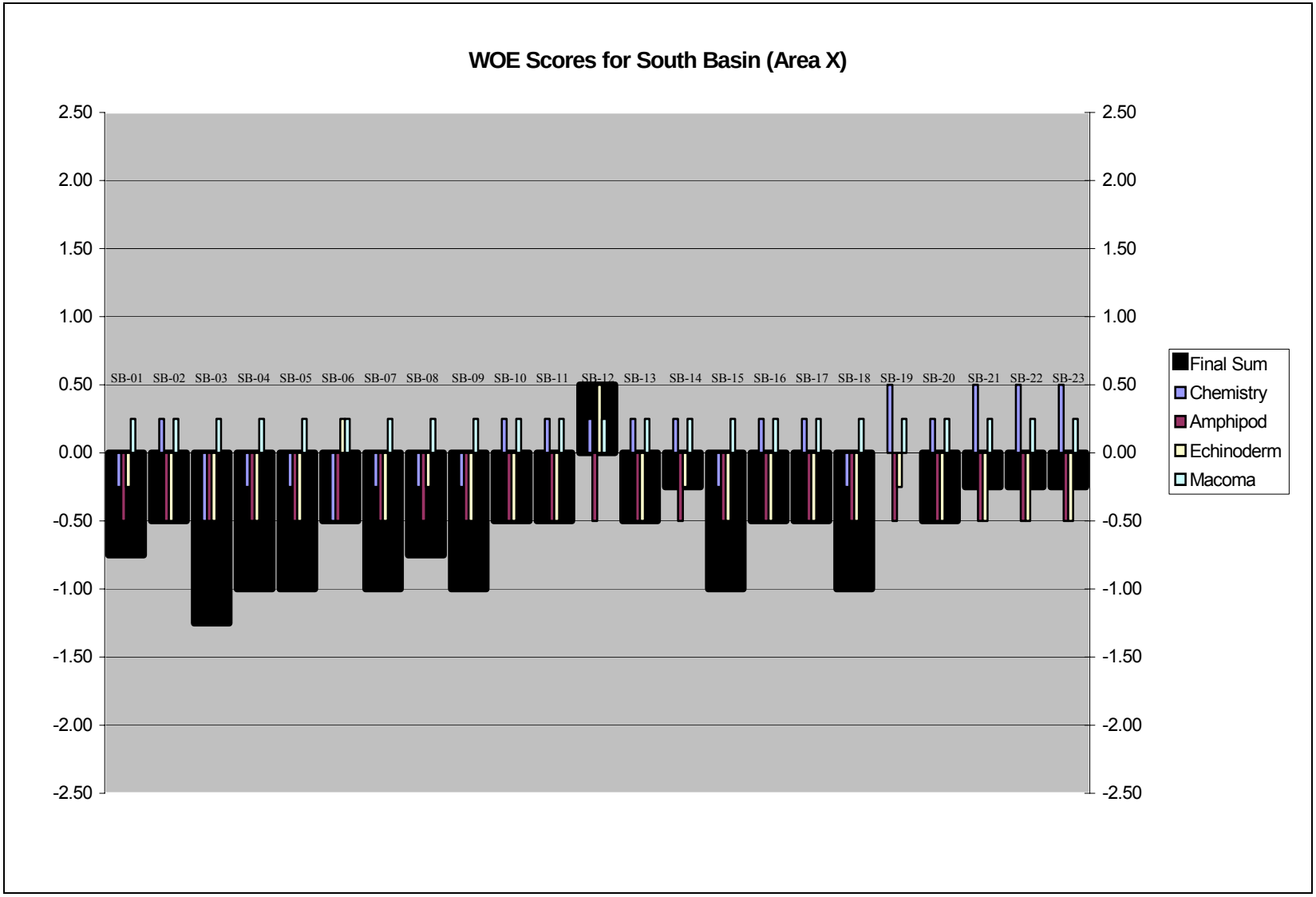


Figure 8-9. Integrated WOE Scores for Area X (South Basin)

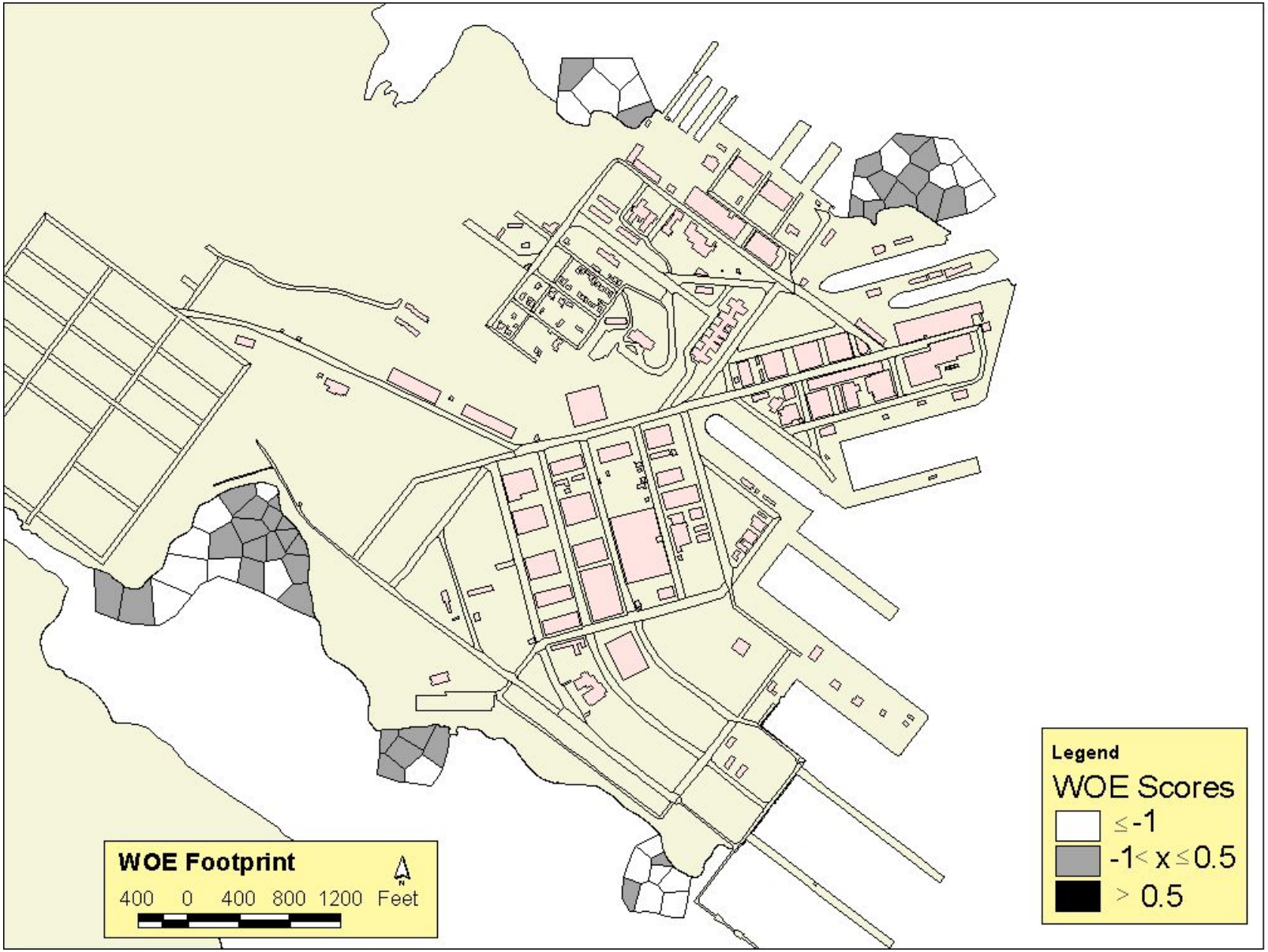


Figure 8-10. Map of WOE Footprint

9.0 HUMAN HEALTH EVALUATION

This section presents the results of the human health evaluation of Parcel F sediments. As discussed in Section 2.2, the human health evaluation consisted of two parts, a site-specific human health risk assessment and a statistical evaluation of fish tissue concentrations for risk communication purposes. The human health risk assessment (Section 9.1) follows the methodology presented in U.S. EPA's Risk Assessment Guidance for Superfund (U.S. EPA, 1989 and 1992) and the approach described in the HHE Work Plan (Battelle et al., 2001b). A more complete description of the methods used is provided in Appendix J. Standard dose relationships were incorporated and default or conservative values for the exposure assumptions were selected to ensure that risks were not underestimated. Cumulative risks and comparisons to reference conditions also were evaluated. The results of this investigation will be integrated with the ecological evaluation to identify areas that require evaluation in the Parcel F FS (Section 10.0).

Section 9.2 presents a statistical evaluation of fish tissue concentrations in sport fish from throughout San Francisco Bay. As discussed in the HHE Work Plan (Battelle, 2001b), it is difficult to attribute measured tissue concentrations in recreationally preferred sport fish to one specific source due to the relative mobility of these species. Although these fish tissue concentrations cannot be directly related to site-specific remedial goals for sediment, concerns have been raised by the U.S. EPA Region 9 and DTSC regarding the relative risks associated with consuming sport fish caught in the vicinity of HPS compared to other locations within San Francisco Bay. Preliminary evaluations based on existing data (RWQCB et al., 1995; SFEI, 1999) indicated that levels of chemicals in fish from the vicinity of HPS were similar to those collected elsewhere in the bay; however, additional data were required for a statistically defensible comparison. To address this issue, fish tissue samples were collected from the vicinity of HPS and from designated locations throughout the bay according to a statistically based sampling design. Section 9.2 presents a statistical comparison of these data, for risk communication purposes only.

9.1 Human Health Risk Assessment

The human health risk assessment was performed according to standard U.S. EPA risk assessment guidance (U.S. EPA, 1989 and 1992). Details regarding risk assessment methodology are provided in Appendix J. The sources of uncertainties associated with each of the steps and the potential biases in the results are presented in Section 11.0. The uncertainty analysis is a qualitative assessment of the sources, magnitude, and effects of uncertainty and variability in the exposure and toxicity parameters, assumptions, and models used.

9.1.1 Data Evaluation

The human health evaluation focused on body burden data analyzed for the 28-day *M. nasuta* bioaccumulation test. Section 6.0 provides a description of this test. Sediment chemistry data for surface sediment samples collected from 59 stations at HPS were also used to evaluate risks associated with dermal contact and incidential ingestion of sediment. A description of the surface sediment chemistry data is provided in Section 4.1. The *M. nasuta* and surface sediment samples were analyzed for a broad suite of chemicals, and all detected bioaccumulative chemicals were considered COPCs for the purpose of this evaluation. The depurated tissue chemistry and sediment chemistry results from both the HPS and reference locations were prepared for interpretation as follows:

- A concentration equivalent to half of the method detection limit was assumed for sample concentrations that were reported as below the detection limit;
- Total PCB concentrations were estimated as two times the sum of the 22 PCB congeners;

- Wet weight tissue concentrations were evaluated per U.S. EPA (1989) guidance for ingestion scenarios. All of the data were provided from the laboratory on a wet weight basis except for metals. Metal concentrations were converted from dry weight basis to wet weight using the following equation:

$$\text{Wet Weight} = \left[\frac{100 - \%\,\text{moisture}}{100}\right] \times \text{Dry Weight} \qquad (9\text{-}1)$$

Complete analytical results for *M. nasuta* tissue samples associated with the HPS and reference site sampling stations are provided in Appendix C. Sediment chemistry results are presented in Appendix B.

In addition to the suite of chemicals evaluated at all stations, 2,3,7,8-TCDD (dioxin) was included as a COPC in the tissue analysis performed at the five reference locations as well as for representative sampling locations identified in offshore Areas VIII (EW-30 and EW-33), IX (OR-24 and OR-28), and X (SB-16 and SB-17). These stations were selected based on their proximity to a possible onshore source. For the purpose of this evaluation, dioxin was evaluated using TEFs. Specifically, 17 individual 2,3,7,8-substituted dioxin and furan congeners were measured and their toxicity expressed as 2,3,7,8-dioxin using TEFs reported by Van den Berg et al. (1998). TEFs define the toxicity of an individual congener relative to the toxicity of 2,3,7,8-TCDD. The TEF of each congener present in a mixture is multiplied by the respective mass concentration and the products are summed to derive the 2,3,7,8-TCDD toxic equivalence quotient (TEQ) of the mixture. The calculated TEF values for each dioxin and furan congener are shown in Table 9-1.

Table 9-1. Toxic Equivalency Factors for Dioxin-Like Compounds

Dioxin (D) Congener	TEF[(a)]	Furan (F) Congener	TEF[(a)]
2,3,7,8-TCDD	1.0	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDD	1.0	1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDD	0.1	2,3,4,7,8-PeCDF	0.5
1,2,3,6,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,7,8,9-HxCDF	0.1
1,2,3,4,6,7,8,9-OCDD	0.001	2,3,4,6,7,8-HxCDF	0.1
		1,2,3,4,6,7,8-HpCDF	0.01
		1,2,3,4,7,8,9-HpCDF	0.01
		1,2,3,4,6,7,8,9-OCDF	0.01

(a) TEF values proposed by Van den Berg et al., 1998.
TEF = toxic equivalence factor.

9.1.2 Exposure Assessment

The objective of the exposure assessment is to identify relevant routes of exposure and populations likely to be exposed. Based on this information, the magnitude, frequency, and duration of current and reasonably anticipated future human exposure to COPCs associated with HPS was estimated.

9.1.2.1 Exposure Pathways and Populations

Based on available information, existing and potential sediment-associated risks to human receptors at HPS generally are limited to exposures occurring within the intertidal area. The primary receptor

identified for this evaluation was a current or future adult resident that collects and consumes locally caught shellfish. Therefore, the pathways evaluated include direct contact (i.e., ingestion and dermal contact) with sediment during clamming and indirect contact through the consumption of shellfish. The exposure parameters associated with direct contact during shellfish collection are similar to those for a wading scenario. Most shellfish collected and consumed by humans at HPS are likely to be mussels present along the shoreline or attached to piers. Use of the clam *M. nasuta* as a surrogate for all shellfish species at HPS is believed to be a conservative approach because *M. nasuta* actively filter detritus from sediment and as a result are more highly exposed to sediment-associated contaminants than mussels, which passively filter from the water column. In addition, individuals collecting *M. nasuta* would have more direct contact with sediment than those collecting mussels from the shoreline. Therefore, the risks estimated for this receptor are anticipated to be higher than or consistent with those for less exposed individuals including recreational users, children, occasional visitors, and on-site workers. A summary of the rationale for focusing on this receptor and associated pathways is provided below.

It is assumed that any risks associated with direct contact to sediment via ingestion, inhalation, and dermal contact (e.g. from wading) would be accounted for by evaluating exposures from direct contact with sediments during clamming activities. Direct exposure to sediment by recreational users and future residents via swimming was considered minimal. Anecdotal evidence indicates that a small group of individuals swims in or near the site; however, in general, the low ambient temperature of the bay waters is not conducive for recreational use without sufficient protective gear including wet suit, boots, gloves, and hood, which minimize available skin surface area for dermal contact to sediment and surface water. In addition, most of the intertidal shoreline at HPS does not offer sufficient water depth to engage in active water sports (i.e., surfing, windsurfing, swimming, etc.).

During redevelopment of HPS, construction workers may potentially be exposed to sediment-associated contaminants via direct contact (i.e., dermal contact and incidental ingestion) to COPCs in sediment and porewater. However, because these exposures would be of limited duration and would likely involve minimal contact with offshore sediments, it is assumed that evaluation of exposures associated with consumption of shellfish and direct contact with sediments during clamming activities would capture any risks associated with this pathway.

Risks to children associated with consumption of shellfish were not calculated because as observed by SFEI (2002), children under the age of 6 years are unlikely to consume shellfish. Only thirteen percent (13%) of the SFEI study (2001) participants reported that children under the age of six eat locally caught fish and only 2% reported that pregnant or breastfeeding woman eat a portion of their catch. Given that only 5% of the overall seafood consumption among San Francisco anglers is comprised of shellfish (Wong, 1997), it can be assumed that less than 1% of Bay-area children under the age of six are consuming shellfish from San Francisco Bay. However, risks to children associated with direct contact to sediment during collection of shellfish were estimated to ensure that evaluation of the adult receptor was adequately protective.

9.1.2.2 Exposure Point Concentrations

EPCs were developed based on the chemical concentrations found in the *M. nasuta* tissue. In accordance with U.S. EPA guidance (U.S. EPA, 1989; 1992), both a Reasonable Maximum Exposure (RME) and a Central Tendency Exposure (CTE) were evaluated. The RME relies on conservative exposure factors to estimate the reasonable maximum exposures anticipated for the site, whereas the CTE describes a more typical or average exposure to an individual.

This evaluation considered individual concentrations of COPCs at each sampling location; however, total risks for each area were also evaluated to focus the investigation on those areas of higher concern. The HPS data sets for each area initially were tested using the Shapiro-Wilk (Gilbert, 1997) goodness-of-fit test to

determine if the underlying distributions were lognormal or normal. The results of the test were inconclusive due to the limited number of samples and variability in the data; however, graphic presentation of the combined HPS and reference data set indicated a normal trend. Therefore, the 95% UCL of the arithmetic mean for each area was estimated using the following equation (Gilbert, 1987):

$$95\%\,\mathrm{UCL} = x + t_{1-\alpha,n-1}\frac{s}{\sqrt{n}} \qquad (9\text{-}2)$$

where: x = arithmetic mean;
s = standard deviation of the arithmetic mean;
t = critical value for n-1 degrees of freedom at the 95th level of confidence; and
n = number of samples.

The maximum concentration or 95% UCL for each constituent was also used as the EPC for the CTE scenario as recommended by U.S. EPA guidance (1992). Additional discussion is presented in Appendix J. In addition, Table J-4 (Appendix J) presents the EPCs for the HPS data, and Table J-5 (Appendix J) presents the reference location EPCs.

9.1.2.3 Estimation of Chemical Intake

Table 9-2 summarizes the specific exposure factors used to derive the dose calculated for each exposure scenario using the equations described in Appendix J. The doses derived in this manner for each scenario were then summed to estimate a lifetime average daily dose (LADD) and average daily dose (ADD) for each constituent by HPS sampling area based on the adult RME and CTE exposure scenarios, respectively (see Appendix J). Doses estimated for the reference locations are shown in Table J-8 for adult RME and Table J-9 for the adult CTE. Identical exposure factors were utilized for both areas within HPS and reference locations. A summary of each of the key exposure parameters and the rationale for their selection is provided below.

Table 9-2. Exposure Factors

Exposure Parameters	Acronym	Units	Average Adult/Child	RME Adult/Child	Reference
Target Risk	TR	unitless	1.0E-06	1.0E-06	U.S. EPA, 2002a
Target Hazard Index	THI	unitless	1	1	U.S. EPA, 2002a
Ingestion Rate - bivalves	IR	kg/day	1.6E-02 / NA	4.8E-02 / NA	SFEI, 2002
Fraction Ingested from Source	FI	unitless	0.5	1	Professional judgment
Exposure Frequency – bivalves	EF	days/year	365	365	U.S. EPA, 1989
Exposure Duration	ED	years	9 / 6	30 / 6	U.S. EPA, 1989 & 1991
Ingestion Rate - sediment	IR	mg/day	50	100	U.S. EPA, 2002a
Exposure Frequency – sediment	EF	days/year	13	26	Professional judgment
Skin Surface Area	SA	cm^2/day	5700 / 2800	5700 / 2800	U.S. EPA, 2002a
Adherence Factor	AF	mg/cm^2	0.07 / 0.2	0.07 / 0.2	U.S. EPA, 2002a
Dermal Absorption Factor	DAF	unitless	chemical-specific	chemical-specific	U.S. EPA, 2002a
Body Weight	BW	kg	70 / 15	70 / 15	U.S. EPA, 2002a
Averaging Time- cancer	AT_c	days	25,550	25,550	U.S. EPA, 2002a
Averaging Time – noncancer	AT_{nc}	days	3,285 / 2,190	10,950 / 2,190	U.S. EPA, 2002a

Shellfish Ingestion Rate (IR). The Office of Environmental Health Hazard Assessment (OEHHA, 1994) summarized the results of the United States Food and Drug Administration (FDA) study on shellfish consumption, reporting an average of 12 g/day and a maximum of 18 g/day nationwide. However, these values do not reflect regional variation in consumption. For the purpose of this assessment, a seafood consumption study conducted by the San Francisco Estuary Institute (SFEI, 2002) was used to estimate consumption rate for shellfish ingestion. Based on the data provided in this study, the median fish consumption rate of all participants was 16 g/day and the 90th percentile was 48 g/day. Although these values refer primarily to sport fish consumption rather than shellfish consumption, they were applied to illustrate the risks associated with the CTE and RME scenarios. It is assumed that they represent conservative estimates of shellfish consumption because Wong (1997) found that shellfish typically comprises less than 5% of total seafood consumption among San Francisco anglers.

Sediment Ingestion (IR). To estimate incidential ingestion of sediment as a result of clamming activities, daily ingestion rates of 50 mg/day for the CTE and 100 mg/day for the RME were assumed for both adult and child scenarios. These rates were based on incidental ingestion rates of soil recommended by U.S. EPA (2002a) for evaluating adult residential exposures.

Fraction Ingested (FI). For the RME and CTE, it was assumed that 100 and 50 percent, respectively of the shellfish consumed was obtained from HPS for both adult and child scenarios. As discussed previously, mussels are the only bivalves found at HPS.

Exposure Frequency (EF). The shellfish ingestion rates are annualized and presented on a daily basis. Therefore, the exposure frequency for the shellfish ingestion pathway is assumed to be 365 days per year (U.S. EPA, 1989).

It was assumed that individuals harvesting shellfish from HPS would engage in this activity one day per week for six months of the year (RME) or one day every two weeks for six months of the year (CTE). Therefore, for the purpose of calculating risks associated with direct sediment exposures (i.e., dermal contact and incidental ingestion), the exposure frequency was assumed to be 13 days per year for the CTE and 26 days per year for the RME.

Exposure Duration (ED). An assumed exposure duration of 9 years was used for typical individuals. For the RME, an exposure duration of 30 years was assumed. These assumptions were based on recommendations by U.S. EPA (1989) and represent median and 90th percentile estimates of residential tenure at a single location, respectively. For the child scenario, an exposure duration of 6 years was used (U.S. EPA, 1989).

Body Weight (BW). Based on information presented by U.S. EPA (1989), a body weight of 70 kg for adult and 15 kg for child was assumed for both the typical exposure and the RME.

Skin Surface Area (SA). To evaluate dermal exposures, it was assumed that individuals would wear a short-sleeve shirt and shorts, exposing hands, forearms, lower legs, and feet (i.e., 5,700 cm^2/day for adult and 2,800 cm^2/day for child) (U.S. EPA, 2002a).

Adherence Factor (AF). An adherence factor of 0.07 mg/cm^2 for adult and 0.20 mg/cm^2 for child was assumed for both the CTE and RME (U.S EPA, 2002a).

Dermal Absorption Factor (DAF). Dermal absorption factors were based on data reported by U.S. EPA Region 9 in the development of PRGs (U.S. EPA, 2002a). In the absence of available information, a DAF of 0.01 was assumed for metals, and 0.1 for organics.

Averaging Time (AT). Averaging time is equal to the lifetime of the individual (70 years × 365 days per year) when evaluating risks to carcinogens. For noncarcinogens, the averaging time is equal to the exposure duration (U.S. EPA, 2002a).

9.1.2.4 Exposure to Lead

Exposure to lead in environmental media cannot be evaluated by calculating a chemical intake or dermal dose. Lead presents an exception to the paradigm that noncarcinogenic effects of chemicals occur only at exposure levels exceeding some physiological threshold at which natural defense mechanisms are overwhelmed. Some of the effects of lead exposures, particularly changes in the levels of certain blood enzymes, appear to occur at blood lead levels so low as to be essentially without a threshold. Studies have shown that the absorption of lead through food ingestion by infants up to six months old is known to be very high, and is much lower in adults. Less information is available regarding the potential absorption of lead through ingestion of affected food for older infants, toddlers, and children. As a result, the U.S. EPA has deemed it inappropriate to estimate toxicity-based dose levels. Instead, potential risk associated with lead exposure is assessed by means of blood lead levels.

The U.S. EPA (1994b) and DTSC (2002) have established a target blood lead level for children less than eight years of age, who are particularly susceptible to lead toxicity, of no more than 10 µg/dL (micrograms of lead per deciliter of blood) for both short- and long-term exposures. However, the models proposed by these agencies are designed to estimate blood-lead level in children based on lead contamination of soil, drinking water, homegrown vegetables, respirable dust, and air. Because these models are not designed to predict lead levels associated with seafood uptake from sediment, estimates of risk associated with lead ingestion were not quantified. The maximum tissue concentrations for lead varied from 2.35 mg/kg to 0.45 mg/kg at the HPS sampling locations. The lead concentrations for HPS were slightly above lead levels measured in the reference stations (0.88 mg/kg to 0.43 mg/kg). For comparison purposes, U.S. EPA Region 9 recommends a PRG of 400 mg/kg of lead in soil based on acceptable blood-lead levels in children under six years of age. Assuming a bioaccumulation factor of 1, the lead concentrations in HPS is 200 times lower than concentrations determined to be health-protective for children. Consequently, further modeling of lead uptake by children through consumption of seafood was not warranted.

9.1.3 Toxicity Assessment

The toxicity assessment determines the relationship between the magnitude of exposure to a COPC and the nature and magnitude of adverse health effects that may result from such exposure. For purposes of risk assessment, COPCs are classified into two broad categories: noncarcinogens and carcinogens. The toxicity for most of the COPCs at HPS is relatively well-known and their toxicity criteria have been well established. If available, toxicity criteria were selected (in order of preference) from the following sources: (1) California DTSC Office of Environmental Health Hazard Assessment (OEHHA) Criteria for Carcinogens (DTSC, 2001); (2) U.S. EPA's Integrated Risk Information System (IRIS) (U.S. EPA, 2002b); and (3) U.S. EPA's Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 1994c). Table 9-3 presents the cancer slope factors (CSFs) and noncarcinogenic chronic reference doses (RfDs) for all of the HPS COPCs.

Compounds that did not have DTSC or U.S. EPA-approved toxicity criteria were not evaluated quantitatively. There are a variety of reasons why a chemical may not have a toxicity criterion. U.S. EPA may withdraw values due to lack of consensus among their scientists regarding the toxicity of particular compounds. This is not an indication by U.S. EPA that the compounds were nontoxic, but that the degree of toxicity is questionable. Other compounds (including organotins) have no U.S. EPA-accepted toxicity assigned to them and consequently, dose and risks estimates were not evaluated for these compounds.

Table 9-3. Summary of Toxicity Criteria

COPC	Carcinogen Classification[a]	Dermal Absorption Factor	Oral Cancer Slope Factor[b] $(mg/kg\text{-}day)^{-1}$	Oral Reference Dose (mg/kg-day)
		Inorganics		
Ag	D	1.0E-02	NA	5.0E-03 [2]
Al	NA	1.0E-02	NA	NA
As	A	3.0E-02	1.5E+00 [2]	3.0E-04 [2]
Ba	NA	1.0E-02	NA	NA
Cd	B1	1.0E-02	3.8E-01 [1]	5.0E-04 [2]
Co	NA	1.0E-02	NA	NA
Cr	A (CrVI), NA (CrIII)	1.0E-02	1.9E-01 [1]	3.0E-03 [2]
Cu	D	1.0E-02	NA	3.7E-02 [3]
Fe	NA	NA	NA	NA
Hg	NA	1.0E-02	NA	1.0E-04 [2,4]
Mn	D	1.0E-02	NA	NA
Mo	NA	1.0E-01	NA	NA
Ni	NA	1.0E-02	NA	2.0E-02 [2]
Pb	B2	1.0E-02	8.5E-03 [1]	NA
Sb	NA	1.0E-02	NA	4.0E-04 [2]
Se	D	1.0E-02	NA	5.0E-03 [2]
V	NA	1.0E-02	NA	NA
Zn	D	1.0E-02	NA	3.0E-01 [2]
		SVOCs		
Acenaphthene	NA	1.0E-01	NA	6.0E-02 [2]
Acenaphthylene	NA	1.0E-01	NA	NA
Anthracene	D	1.0E-03	NA	3.0E-01 [2]
Benzo(a)anthracene	B2	1.3E-01	1.2E+00 [1]	NA
Benzo(a)pyrene	B2	1.3E-01	1.2E+01 [1]	NA
Benzo(b)fluoranthene	B2	1.3E-01	1.2E+00 [1]	NA
Benzo(g,h,i)perylene	D	1.3E-01	NA	NA
Benzo(k)fluoranthene	B2	1.3E-01	1.2E+00 [1]	NA
Chrysene	B2	1.3E-01	1.2E-01 [1]	NA
Dibenz(a,h)anthracene	B2	1.3E-01	4.1E+00 [1]	NA
Fluoranthene	D	1.3E-01	NA	4.0E-02 [2]
Fluorene	D	1.0E-01	NA	4.0E-02 [2]
Indeno(1,2,3-cd)pyrene	B2	1.3E-01	1.2E+00 [1]	NA
2-Methylnaphthalene	NA	NA	NA	NA
Naphthalene	D	1.0E-01	NA	2.0E-02 [2]
Phenanthrene	D	1.0E-01	NA	NA
Pyrene	D	1.0E-01	NA	3.0E-02 [2]

Table 9-3. Summary of Toxicity Criteria (continued)

COPC	Carcinogen Classification[(a)]	Dermal Absorption Factor	Oral Cancer Slope Factor[(b)] $(mg/kg\text{-}day)^{-1}$	Oral Reference Dose (mg/kg-day)
PCBs/Pesticides				
alpha-Chlordane	B2	4.0E-02	1.3E+00 [1]	5.0E-04 [2]
gamma-Chlordane	B2	4.0E-02	1.3E+00 [1,2]	5.0E-04 [2]
2,4′-DDD	B2	3.0E-02	2.4E-01 [2]	NA
2,4′-DDE	B2	3.0E-02	3.4E-01 [2]	NA
2,4′-DDT	B2	3.0E-02	3.4E-01 [2]	5.0E-04 [2]
4,4′-DDD	B2	3.0E-02	2.4E-01 [2]	NA
4,4′-DDE	B2	3.0E-02	3.4E-01 [2]	NA
4,4′-DDT	B2	3.0E-02	3.4E-01 [2]	5.0E-04 [2]
Dieldrin	B2	1.0E-01	1.6E+01 [1,2]	5.0E-05 [2]
Endosulfan II	NA	1.0E-01	NA	6.0E-03 [2]
Endrin	D	1.0E-01	NA	3.0E-04 [2]
Heptachlor	B2	1.0E-01	4.1E+00 [1]	5.0E-04 [2]
Total Congeners (PCBs)	B2	1.4E-01	5.0E+00 [1]	NA
Organotins				
DBT	NA	1.0E-01	NA	NA
MBT	NA	1.0E-01	NA	NA
TBT	NA	1.0E-01	NA	NA
TTBT	NA	1.0E-01	NA	NA
Total Dioxin	B2	3.0E-02	1.30E+05 [1]	NA

(a) Carcinogen Classification defined as: (A) human carcinogen, (B2) probable human carcinogen based on human epidemiological studies, (B2) probable human carcinogen based on animal studies, and (D) not classifiable as a human carcinogen

(b) Toxicity values are referenced as follows: (1) Cal-EPA OEHHA Cancer Slope Factors (DTSC, 2001); (2) U.S. EPA IRIS (U.S. EPA, 2002b); (3) U.S. EPA HEAST (1994c); and (4) oral RfD for methylmercury.

NA = not applicable (no U.S. EPA-acceptable toxicity values are provided for this compound).

However, because toxicity criteria are available for most of the chemicals with known or documented effects, it is assumed that the majority of the potential risk at the site is captured in this evaluation.

9.1.4 Risk Characterization

The estimated LADD and ADD for the RME and CTE scenarios were combined with the available toxicity data to derive area-specific risks and noncarcinogenic hazards for each of COPC evaluated at HPS (see Appendix J). Site-specific risks and hazards were compared to the risks and hazards associated with the reference locations in order to provide a perspective of the relative risk associated with HPS. In addition, cumulative risks were determined by summing the risks associated with each COPC.

9.1.4.1 Summary of Cancer Risks

Tables 9-4a though 9-4g present the risks estimated for the future adult resident using the RME and CTE scenarios. Cancer risks derived in this assessment can be compared to U.S. EPA's risk management range (i.e., 10^{-6} to 10^{-4}) for health protectiveness at Superfund sites. Based on this range, U.S. EPA typically considers 10^{-6} as the "point of departure" for taking action at Superfund sites (U.S. EPA, 1989).

Table 9-4a. Summary of Cumulative RME Risk and Identification of Risk Drivers for Adult Shellfish Consumption

Area	Cumulative Risk at HPS		Cumulative Risk from Reference		Exceedance Above Safe Risk Level (10^{-6})?		Exceedance Above Reference Levels?	
	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Risk	CTE Risk	RME Risk	CTE Risk
Eastern Wetland Area	2.2E-02	1.1E-03	3.3E-02	1.6E-03	Yes	Yes	No	No
India Basin Area I	1.7E-03	8.5E-05	3.3E-02	1.6E-03	Yes	Yes	No	No
Oil Reclamation Area	3.9E-02	1.9E-03	3.3E-02	1.6E-03	Yes	Yes	Yes	Yes
Point Avisadero Area	1.8E-03	9.1E-05	3.3E-02	1.6E-03	Yes	Yes	No	No
South Basin Area X	4.3E-02	2.2E-03	3.3E-02	1.6E-03	Yes	Yes	Yes	Yes

Table 9-4b. RME Risk Drivers by Area for Adult Shellfish Consumption

Area	Individual Risk at HPS				Individual Risk at Reference			
	Arsenic	Chromium	Total Congeners	Dioxin	Arsenic	Chromium	Total Congeners	Dioxin
Eastern Wetland Area	1.9E-03	1.5E-04	6.9E-05	1.9E-02	1.7E-03	1.6E-04	1.2E-05	3.1E-02
India Basin Area I	1.5E-03	9.0E-05	2.5E-05	–	1.7E-03	1.6E-04	1.2E-05	3.1E-02
Oil Reclamation Area	1.6E-03	1.3E-04	5.8E-04	3.6E-02	1.7E-03	1.6E-04	1.2E-05	3.1E-02
Point Avisadero Area	1.6E-03	1.8E-04	3.8E-05	–	1.7E-03	1.6E-04	1.2E-05	3.1E-02
South Basin Area X	1.5E-03	1.1E-04	4.7E-04	4.1E-02	1.7E-03	1.6E-04	1.2E-05	3.1E-02

Table 9-4c. Percent Contribution by Area and Ratio of Individual RME Risk for Adult Shellfish Consumption

Area	% Contribution to Cumulative HPS RME Risk				Ratio of Individual Risk from HPS Site to Reference			
	Arsenic	Chromium	Total Congeners	Dioxin	Arsenic	Chromium	Total Congeners	Dioxin
Eastern Wetland Area	9%	0.7%	0.3%	90%	1.1	1.0	6.0	0.6
India Basin Area I	90%	5%	1.5%	–	0.9	0.6	2.2	–
Oil Reclamation Area	4%	0.3%	1.5%	94%	1.0	0.8	50.1	1.2
Point Avisadero Area	86%	10%	2.1%	–	0.9	1.2	3.3	–
South Basin Area X	3%	0.3%	1.1%	95%	0.9	0.7	41.1	1.3

Table 9-4d. CTE Risk Drivers by Area for Adult Shellfish Consumption

Area	Individual Risk at HPS				Individual Risk at Reference Locations			
	Arsenic	Chromium	Total Congeners	Dioxin	Arsenic	Chromium	Total Congeners	Dioxin
Eastern Wetland Area	9.4E-05	7.6E-06	3.5E-06	9.7E-04	8.3E-05	7.9E-06	5.8E-07	1.5E-03
India Basin Area I	7.6E-05	4.5E-06	1.3E-06	–	8.3E-05	7.9E-06	5.8E-07	1.3E-03
Oil Reclamation Area	8.0E-05	6.5E-06	2.9E-05	1.8E-03	8.3E-05	7.9E-06	5.8E-07	1.3E-03
Point Avisadero Area	7.8E-05	9.2E-06	1.9E-06	–	8.3E-05	7.9E-06	5.8E-07	1.3E-03
South Basin Area X	7.5E-05	5.6E-06	2.4E-05	2.1E-03	8.3E-05	7.9E-06	5.8E-07	1.3E-03

Table 9-4e. Summary of Cumulative RME Risk and Identification of Risk Drivers for Direct Contact with Sediment

Area	Cumulative Risk at HPS		Cumulative Risk from Reference		Exceedance Above Safe Risk Level (10^{-6})?		Exceedance Above Reference Levels?	
	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Risk	CTE Risk	RME Risk	CTE Risk
Eastern Wetland Area	3.4E-06	1.4E-07	2.6E-06	1.1E-07	Yes	No	Yes	Yes
India Basin Area I	3.4E-06	1.4E-07	2.6E-06	1.1E-07	Yes	No	Yes	Yes
Oil Reclamation Area	4.9E-06	2.0E-07	2.6E-06	1.1E-07	Yes	No	Yes	Yes
Point Avisadero Area	3.8E-06	1.6E-07	2.6E-06	1.1E-07	Yes	No	Yes	Yes
South Basin Area X	3.7E-06	1.5E-07	2.6E-06	1.1E-07	Yes	No	Yes	Yes

Table 9-4f. RME Risk Drivers by Area for Direct Contact with Sediment

Area	Individual Risk at HPS				Individual Risk at Reference			
	Arsenic	Chromium	Benzo(a)pyrene	Total Congeners	Arsenic	Chromium	Benzo(a)pyrene	Total Congeners
Eastern Wetland Area	7.1E-07	2.5E-06	1.0E-07	6.1E-09	8.9E-07	1.5E-06	1.5E-07	4.9E-09
India Basin Area I	8.0E-07	2.3E-06	1.9E-07	1.6E-08	8.9E-07	1.5E-06	1.5E-07	4.9E-09
Oil Reclamation Area	9.3E-07	3.7E-06	1.6E-07	6.0E-08	8.9E-07	1.5E-06	1.5E-07	4.9E-09
Point Avisadero Area	9.1E-07	2.2E-06	3.8E-07	9.8E-08	8.9E-07	1.5E-06	1.5E-07	4.9E-09
South Basin Area X	8.3E-07	2.2E-06	2.1E-06	2.8E-07	8.9E-07	1.5E-06	1.5E-07	4.9E-09

Table 9-4g. CTE Risk Drivers by Area for Direct Contact with Sediment

Area	Individual Risk at HPS				Individual Risk at Reference Locations			
	Arsenic	Chromium	Benzo(a)pyrene	Total Congeners	Arsenic	Chromium	Benzo(a)pyrene	Total Congeners
Eastern Wetland Area	2.9E-08	9.7E-08	5.7E-09	3.1E-10	3.7E-08	5.9E-08	7.4E-09	2.5E-10
India Basin Area I	3.3E-08	8.9E-08	9.8E-09	8.1E-10	3.7E-08	5.9E-08	7.4E-09	2.5E-10
Oil Reclamation Area	3.9E-08	1.4E-07	7.8E-09	3.1E-09	3.7E-08	5.9E-08	7.4E-09	2.5E-10
Point Avisadero Area	3.8E-08	8.6E-08	1.9E-08	5.0E-09	3.7E-08	5.9E-08	7.4E-09	2.5E-10
South Basin Area X	3.5E-08	8.4E-08	1.3E-08	1.4E-08	3.7E-08	5.9E-08	7.4E-09	2.5E-10

Note: Direct contact pathways contributed less than 5% to the overall cumulative risk at HPS. Exposure parameters for a wading scenario are similar to those for direct contact during shellfish collection.

RME Risks. The area-specific cumulative risks based on RME exposure scenario through ingestion of shellfish ranged from 1.7×10^{-3} in Area I to 4.3×10^{-2} in Area X (Table 9-4a), whereas risks from direct contact with sediment were on the order of 1×10^{-6} for all areas (Table 9-4e). The combined cumulative risks from both exposure pathways (i.e., ingestion of shellfish and direct contact with sediment) exceeded the U.S. EPA risk management range at all locations at HPS, with the majority of the risk associated with shellfish ingestion. However, they were comparable to risks predicted for the reference locations, indicating that potential exposure to sediments at HPS are not significantly higher than those associated with conditions elsewhere in the Bay. Evaluating risks associated with individual chemicals, it can be determined that the primary risk drivers at each of the five HPS areas are arsenic, chromium, total PCB congeners, and dioxin (Tables 9-4b and 9-4f). At those areas where dioxin was analyzed (i.e., Areas VIII, IX, and X), it accounted for more than 90% of the risks (Table 9-4c). For Areas I and III, arsenic and chromium are the primary drivers for the RME scenario, accounting for more than 95% of the risk, followed by total PCB congeners. Risks associated with arsenic, chromium, and dioxin at HPS were comparable to the risks from these chemicals at the reference location.

CTE Risks. The area-specific risks based on the CTE exposure scenario via ingestion of shellfish ranged from 9×10^{-5} for Areas I and III to 2×10^{-3} for Areas IX and X (Table 9-4a) while risks from direct contact with sediment were on the order of 1×10^{-7} for all areas (Table 9-4e). The combined cumulative risks within the U.S. EPA risk management range except for Areas VIII (Eastern Wetland), IX (Oil Reclamation) and X (South Basin). As noted for the RME, the cumulative risks at HPS were consistent with those from the reference locations (i.e., 2×10^{-3}). Also consistent with the RME risks, the majority of the risk was attributed to arsenic, chromium, total PCB congeners, and dioxin (as indicated in Table 9-4d). More than 90% of the risks are associated with dioxin at Areas VIII, IX, and X, whereas the majority of risk is attributed to arsenic at Areas I and III.

9.1.4.2 Noncarcinogenic Hazard

Table 9-5a through 9-5d presents the hazards estimated for the future resident using the RME and CTE scenarios. Hazards associated with the reference locations also are presented for comparison.

RME Hazard. The hazards estimated for the each of the HPS areas were consistent with the reference locations (Table 9-5). The area-specific hazard index based on RME exposure scenario ranged from 9 to 11 based on ingestion of shellfish (Table 9-5a). The hazard index based on direct contact with sediment was below one for each of the areas of concern as indicated in Table 9-5d. Although the combined hazards from ingestion of shellfish and direct contact at HPS were above the U.S. EPA and DTSC benchmark of one, all HPS hazard indexes (HIs) were below 10 except for Eastern Wetland. A majority of the hazards at HPS are attributed to inorganic chemicals including arsenic, chromium, cadmium, and mercury (see Table 9-5b). Comparisons of individual chemical concentrations from HPS to reference indicate that the metal concentrations at HPS are consistent or below those found at the reference locations, with the exception of mercury in Area III.

CTE Hazard. Using average exposure assumptions, the HPS area-specific hazard indices based on ingestion of shellfish were slightly above the U.S. EPA and DTSC benchmark of 1.0, with HI less than two (see Table 9-5a). Table 9-5d indicates that all of the hazards related to direct contact with sediment were below one. The HI associated with the reference location was two.

Hazard Associated with Mercury Exposure. Although mercury was not identified as a primary risk driver, a summary of the hazards associated with exposure to mercury via ingestion of shellfish at each station is provided in Table 9-6 per the request of the RWQCB. All of the stations have

Table 9-5a. Summary of Hazard Index for Exposure to Shellfish

Area	Hazard Index at HPS		Hazard Index from Reference		Exceedance Above Benchmark (1.0)?		Exceedance Above Reference Levels?	
	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Risk	CTE Risk	RME Risk	CTE Risk
Eastern Wetland Area	1.1E+01	1.9E+00	9.8E+00	1.6E+00	Yes	Yes	Yes	Yes
India Basin Area I	8.8E+00	1.5E+00	9.8E+00	1.6E+00	Yes	Yes	No	No
Oil Reclamation Area	9.6E+00	1.6E+00	9.8E+00	1.6E+00	Yes	Yes	No	No
Point Avisadero Area	1.0E+01	1.7E+00	9.8E+00	1.6E+00	Yes	Yes	Yes	Yes
South Basin Area X	8.9E+00	1.5E+00	9.8E+00	1.6E+00	Yes	Yes	No	No

Table 9-5b. RME Hazard Drivers by Area

Area	Individual Hazard at HPS				Individual Hazard at Reference			
	Arsenic	Chromium	Mercury	Cadmium	Arsenic	Chromium	Mercury	Cadmium
Eastern Wetland Area	9.8E+00	6.3E-01	1.6E-01	1.6E-01	8.6E+00	6.4E-01	1.6E-01	1.2E-01
India Basin Area I	7.9E+00	3.7E-01	1.3E-01	6.5E-02	8.6E+00	6.4E-01	1.6E-01	1.2E-01
Oil Reclamation Area	8.3E+00	5.3E-01	1.8E-01	7.8E-02	8.6E+00	6.4E-01	1.6E-01	1.2E-01
Point Avisadero Area	8.1E+00	7.5E-01	1.1E+00	6.8E-02	8.6E+00	6.4E-01	1.6E-01	1.2E-01
South Basin Area X	7.8E+00	4.6E-01	1.6E-01	6.8E-02	8.6E+00	6.4E-01	1.6E-01	1.2E-01

Table 9-5c. Percent Contribution by Area and Ratio of Individual Hazard

Area	% Contribution to Cumulative HPS RME Hazard				Ratio of Individual Hazard from HPS Site to Reference			
	Arsenic	Chromium	Mercury	Cadmium	Arsenic	Chromium	Mercury	Cadmium
Eastern Wetland Area	88%	6%	1%	2%	1.1	1.0	1.0	1.3
India Basin Area I	90%	4%	2%	1%	0.9	0.6	0.8	0.5
Oil Reclamation Area	87%	6%	2%	1%	1.0	0.8	1.1	0.6
Point Avisadero Area	77%	7%	11%	1%	0.9	1.2	6.9	0.6
South Basin Area X	88%	5%	2%	1%	0.9	0.7	1.0	0.6

Table 9-5d. Summary of Hazard Index for Exposure via Direct Contact with Sediment

Area	Hazard Index at HPS		Hazard Index from Reference		Exceedance Above Benchmark (1.0)?		Exceedance Above Reference Levels?	
	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Risk	CTE Risk	RME Risk	CTE Risk
Eastern Wetland Area	2.7E-02	3.6E-03	2.6E-02	3.5E-03	No	No	Yes	Yes
India Basin Area I	2.8E-02	3.7E-03	2.6E-02	3.5E-03	No	No	Yes	Yes
Oil Reclamation Area	3.7E-02	4.9E-03	2.6E-02	3.5E-03	No	No	Yes	Yes
Point Avisadero Area	3.3E-02	4.4E-03	2.6E-02	3.5E-03	No	No	Yes	Yes
South Basin Area X	3.5E-02	4.9E-03	2.6E-02	3.5E-03	No	No	Yes	Yes

Table 9-6. Summary of Mercury Hazards based on Ingestion of Shellfish

Area	Station ID	RME Hazard from Ingestion of Shellfish	CTE Hazard from Ingestion of Shellfish
Eastern Wetland Area	EW-30	0.21	0.04
	EW-31	0.08	0.01
	EW-32	0.07	0.01
	EW-33	0.19	0.03
	EW-34	0.11	0.02
	EW-35	0.12	0.02
	EW-36	0.10	0.02
	EW-37	0.10	0.02
India Basin Area I	IB-54	0.07	0.01
	IB-55	0.07	0.01
	IB-56	0.13	0.02
	IB-57	0.14	0.02
	IB-58	0.09	0.01
	IB-59	0.14	0.02
Oil Reclamation Area	OR-24	0.20	0.03
	OR-25	0.13	0.02
	OR-26	0.12	0.02
	OR-27	0.08	0.01
	OR-28	0.11	0.02
	OR-29	0.16	0.03
Point Avisadero Area	PA-38	0.08	0.01
	PA-39	1.64	0.27
	PA-40	0.17	0.03
	PA-41	0.31	0.05
	PA-42	0.21	0.03
	PA-43	0.12	0.02
	PA-44	4.55	0.76
	PA-45	0.77	0.13
	PA-46	0.08	0.01
	PA-47	0.91	0.15
	PA-48	0.14	0.02
	PA-49	0.14	0.02
	PA-50	0.07	0.01
	PA-51	0.12	0.02
	PA-52	0.14	0.02
	PA-53	0.12	0.02
South Basin Area X	SB-01	0.14	0.02
	SB-02	0.12	0.02
	SB-03	0.12	0.02
	SB-04	0.16	0.03
	SB-05	0.14	0.02
	SB-06	0.19	0.03
	SB-07	0.08	0.01
	SB-08	0.15	0.03
	SB-09	0.12	0.02
	SB-10	0.20	0.03
	SB-11	0.10	0.02
	SB-12	0.12	0.02
	SB-13	0.18	0.03

Table 9-6. Summary of Mercury Hazards based on Ingestion of Shellfish (continued)

Area	Station ID	RME Hazard from Ingestion of Shellfish	CTE Hazard from Ingestion of Shellfish
South Basin Area X (cont'd)	SB-14	0.10	0.02
	SB-15	0.17	0.03
	SB-16	0.17	0.03
	SB-17	0.13	0.02
	SB-18	0.21	0.04
	SB-19	0.18	0.03
	SB-20	0.10	0.02
	SB-21	0.19	0.03
	SB-22	0.16	0.03
	SB-23	0.19	0.03

hazards associated with the RME scenario below the U.S. EPA benchmark of 1.0 except for stations PA-39 and PA-44 in Area III (Point Avisadero). The hazard associated with the reference stations ranged from 0.16 for the RME scenario to 0.027 for the CTE scenario. The CTE hazards at all HPS stations were below the benchmark of one (1.0). It should be noted that clams were not found in Area III (Section 3.2.3.1).

9.1.4.3 Risks and Hazards Associated with Child Exposures

Risks and hazards to children were slightly higher than those calculated for adult only exposures (Table 9-7), and were comparable to risks calculated for the reference area based on exposure through direct contact with sediment.

9.1.5 Station by Station Evaluation of Risks

In addition to the risks for each of the five areas, cumulative risks and HI associated with each of the 59 sampling stations also were evaluated (Table 9-8 and Figure 9-1). Stations where the cumulative risk exceeded 1×10^{-6} for carcinogenic effects and the HI was greater than 1 were compared to reference concentrations. Risks associated with dioxin were removed from this comparison because it was not measured at each of the stations sampled.

It is important to note that although arsenic, chromium, and dioxin were the primary risk drivers for cumulative risks at HPS, concentrations of these chemicals in shellfish tissue were comparable to those reported for the reference stations. As indicated on Table 9-4c, risks from exposure to total PCB congeners via ingestion of shellfish were elevated above reference at Area IX (Oil Reclamation) and Area X (South Basin). For all other compounds, the chemical concentrations in shellfish were found to be consistent with or below levels measured at the reference locations.

9.1.6 Human Health Risk Assessment Summary

The objective of the human health risk assessment was to calculate potential carcinogenic risks and non-carcinogenic hazards associated with sediment exposures via collection and ingestion of shellfish from HPS. The risk evaluation incorporated default and/or conservative exposure factors into standard regulatory dose relationships with the objective of not underestimating risks. For purposes of this assessment, future residents were assumed to harvest and consume shellfish from the intertidal areas of HPS and be incidentally exposed to sediment while harvesting. The direct contact exposure scenario also is representative of wading at the site. Risks from direct contact with sediment were more than 100 times

Table 9-7. Cumulative Risks and Hazards Estimated for Child Exposures

	Risk at HPS		Risk from Reference Locations	
Area	**Direct Contact RME**	**Direct Contact CTE**	**Direct Contact RME**	**Direct Contact CTE**
Eastern Wetland Area	5.2E-06	5.16E-07	3.7E-06	3.7E-07
India Basin Area I	4.9E-06	4.90E-07	3.7E-06	3.7E-07
Oil Reclamation Area	7.0E-06	7.00E-07	3.7E-06	3.7E-07
Point Avisadero Area	5.2E-06	5.50E-07	3.7E-06	3.7E-07
South Basin Area X	5.2E-06	5.4E-07	3.7E-06	3.7E-07

	Hazard at HPS		Hazard from Reference Locations	
Area	**Direct Contact RME**	**Direct Contact CTE**	**Direct Contact RME**	**Direct Contact CTE**
Eastern Wetland Area	8.2E-02	1.1E-02	5.9E-02	8.0E-03
India Basin Area I	7.3E-02	9.80E-03	5.9E-02	8.0E-03
Oil Reclamation Area	1.1E-01	1.5E-02	5.9E-02	8.0E-03
Point Avisadero Area	8.4E-02	1.1E-02	5.9E-02	8.0E-03
South Basin Area X	7.8E-02	1.1E-02	5.9E-02	8.0E-03

Table 9-8. Station by Station Evaluation of Cumulative Risks

Station Identification	Cumulative Risk		HPS Reference Sites		Exceedance Above Safe Risk Level (10^{-6})?		Exceedance Above Reference Levels?	
	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Risk	CTE Risk	RME Risk	CTE Risk
Eastern Wetland								
EW-30 Total	2.4E-03	1.2E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
EW-31 Total	1.5E-03	7.6E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
EW-32 Total	1.5E-03	7.3E-05	2.0E-03	1.04E-04	Yes	Yes	No	No
EW-33 Total	2.2E-03	1.1E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
EW-34 Total	2.1E-03	1.0E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
EW-35 Total	1.7E-03	8.7E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
EW-36 Total	2.0E-03	1.0E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
EW-37 Total	1.6E-03	7.8E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
India Basin								
IB-54 Total	1.4E-03	7.0E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
IB-55 Total	1.4E-03	7.0E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
IB-56 Total	1.6E-03	8.0E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
IB-57 Total	1.7E-03	8.0E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
IB-58 Total	1.7E-03	8.7E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
IB-59 Total	1.5E-03	7.6E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
Oil Reclamation Area								
OR-24 Total	2.4E-03	1.2E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
OR-25 Total	1.8E-03	8.8E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
OR-26 Total	2.0E-03	1.0E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
OR-27 Total	1.8E-03	8.9E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
OR-28 Total	1.5E-03	7.6E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
OR-29 Total	2.3E-03	1.2E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
Point Avisadero Area								
PA-38 Total	1.7E-03	8.5E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-39 Total	1.8E-03	9.1E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-40 Total	1.7E-03	8.3E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-41 Total	1.7E-03	8.6E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-42 Total	1.6E-03	8.2E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-43 Total	1.5E-03	7.7E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-44 Total	1.9E-03	9.6E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-45 Total	1.4E-03	6.8E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-46 Total	1.8E-03	9.1E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-47 Total	1.6E-03	8.2E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-48 Total	1.9E-03	9.4E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-49 Total	1.8E-03	9.2E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-50 Total	1.9E-03	9.5E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-51 Total	1.7E-03	8.4E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-52 Total	1.7E-03	8.4E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
PA-53 Total	1.3E-03	6.7E-05	2.0E-03	1.0E-04	Yes	Yes	No	No

Table 9-8. Station by Station Evaluation of Cumulative Risks (continued)

Station Identification	Cumulative Risk		HPS Reference Sites		Exceedance Above Safe Risk Level (10^{-6})?		Exceedance Above Reference Levels?	
	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Risk	CTE Risk	RME Risk	CTE Risk
South Basin Area X								
SB-01 Total	2.0E-03	9.8E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-02 Total	1.7E-03	8.2E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-03 Total	1.5E-03	7.5E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-04 Total	1.8E-03	9.2E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-05 Total	1.5E-03	7.4E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-06 Total	2.1E-03	1.0E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-07 Total	1.6E-03	8.1E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-08 Total	1.9E-03	9.6E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-09 Total	1.8E-03	9.0E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-10 Total	1.9E-03	9.5E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-11 Total	2.4E-03	1.2E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-12 Total	1.7E-03	8.5E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-13 Total	2.2E-03	1.1E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-14 Total	2.3E-03	1.1E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-15 Total	1.8E-03	9.0E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-16 Total	2.3E-03	1.2E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-17 Total	1.9E-03	9.3E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-18 Total	2.5E-03	1.3E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-19 Total	1.3E-03	6.3E-05	2.0E-03	1.0E-04	Yes	Yes	No	No
SB-20 Total	2.2E-03	1.1E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-21 Total	2.6E-03	1.3E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-22 Total	2.2E-03	1.1E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes
SB-23 Total	2.2E-03	1.1E-04	2.0E-03	1.0E-04	Yes	Yes	Yes	Yes

lower compared to risks associated with shellfish ingestion. The HHE determined that cumulative health risks to future residents are consistent with or below reference levels at Areas I (India Basin), Area III (Point Avisadero), and Area VIII (Eastern Wetland). Areas IX (Oil Reclamation) and Area X (South Basin) appear to contain slightly higher risks than those associated with the reference areas; this increased risk appears to be attributable to concentrations of Total PCBs, which were found to be significantly above concentrations measured at the reference locations in both Area IX and X stations. However, the actual contribution of Total PCBs to the overall cumulative area-wide risk is minimal (about 1 percent).

9.2 Statistical Comparison of Fish Tissue for Risk Communication

Health concerns associated with fish consumption have been identified as a regional issue during the last decade due to multiple chemical sources in San Francisco Bay. Available data from the RMP (RWQCB et al., 1995; SFEI, 1999) indicate that concentrations of six chemicals or groups of chemicals (including PCBs, dioxins, mercury, dieldrin, DDT, and chlordane) in fish collected from throughout the San Francisco Bay are elevated enough to pose a potential risk to recreational anglers (OEHHA, 1994) and cause health advisory warnings. Although this is a regional issue, concerns have been raised regarding

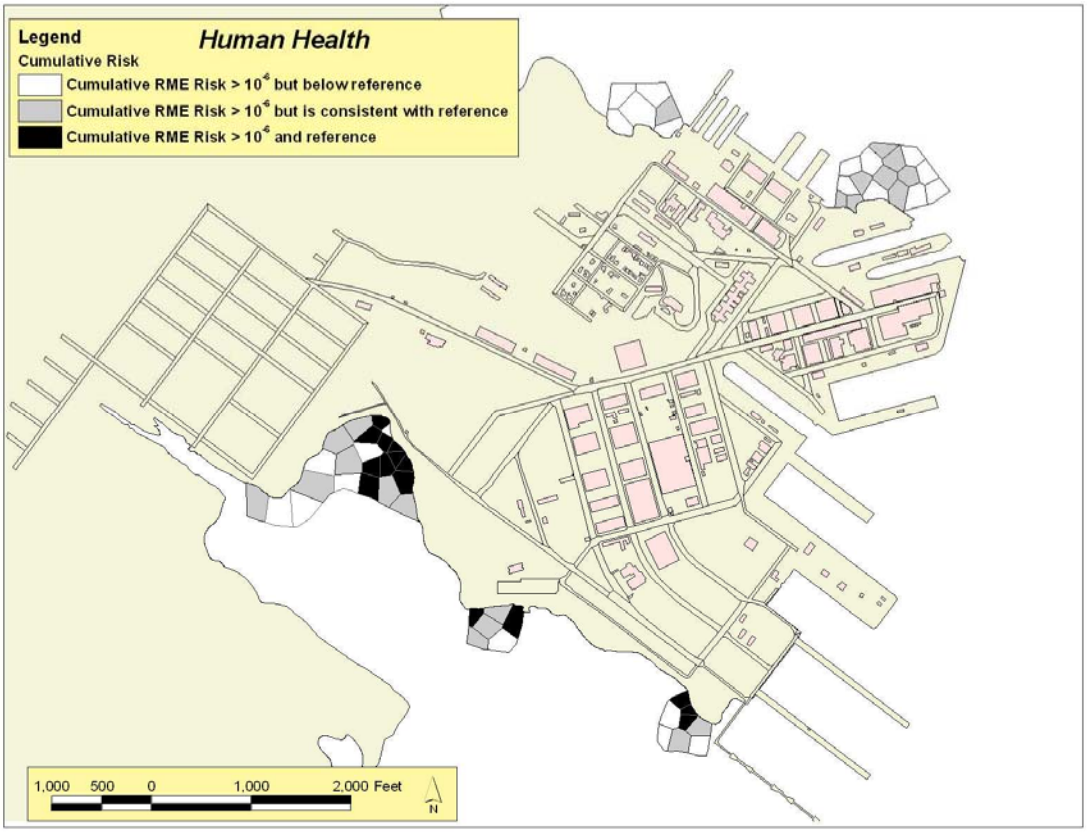


Figure 9-1. Map of Human Health Risk Assessment Results for Individual Stations

the relative risks of consuming locally caught fish in HPS. Due to the mobility of most recreationally preferred fish species, it is difficult to attribute measured tissue concentrations in fish to one specific source. Preliminary evaluations based on existing data (RWQCB et al., 1995; SFEI, 1999) indicate that levels of chemicals in fish from the vicinity of HPS are similar to those collected elsewhere in the bay; however, additional data were required to support a statistically defensible comparison. The purpose of this evaluation was to collect additional data according to a statistically designed sampling program to determine if real differences exist, not to derive an estimate of risks associated with the site for the purpose of identifying areas for evaluation in the Parcel F FS.

For the purpose of this evaluation, it was assumed that all exposure parameters relevant to the estimation of risk associated with fish consumption (e.g., ingestion rates, exposure duration, etc.) are the same for anglers at both HPS and ambient locations with the exception of fish tissue concentration. Based on this assumption, a statistically significant difference in tissue concentration would imply a corresponding difference in risk. Consequently, the objective of this evaluation was to determine if the concentrations of chemicals in fish tissue near HPS is significantly elevated above the reference locations. In order to determine if the data sets were "significantly" different, they were statistically compared to discern with 95% confidence whether the mean of the HPS data is consistent with the mean gathered from the reference locations.

Representative tissue concentrations of COPCs at each sampling location were compared to chemical concentrations found in fish tissue measured at ambient locations and during the SFEI studies. The fish evaluation was designed to mirror the sampling methods and analysis used by the RMP for comparison purposes.

9.2.1 Fish Tissue Data Preparation

As discussed in the HHE Work Plan (Battelle et al., 2001b), this evaluation focused on the collection of equal numbers of each of three species from the vicinity of HPS and from ambient locations within the Bay. Specifically, six composites each of surfperch and jacksmelt were collected from areas around HPS and from ambient locations (i.e., two composites of each species from each of three locations within the Bay). These species were selected based on information indicating that they have relatively limited foraging ranges and, therefore, are more likely to be better indicators of spatial variations within the Bay. White croaker also were targeted; however, efforts to collect this species were not successful. Ambient locations sampled included San Mateo Bridge, Bay Farm, and San Francisco Pier 7.

Sampling and analytical methods were designed to match those used by the RMP (SFEI, 1999) as closely as possible to ensure comparability of data. The field summary report (Battelle, 2001) describes the sampling methods used, and the analytical methods are outlined in the HHE Work Plan (Battelle et al., 2001b).

Fish tissue composites were grouped by species and areas combining different age, size, and sexes of fishes. In addition, several different species of perch (e.g., walleye, black, etc.) were captured during the sampling events and composited under the general category of perch. The fish tissue results from both the HPS and ambient locations were prepared for interpretation following the procedures described below:

- A concentration equivalent to half of the method detection limit was assumed for samples that were reported as below the detection limit;
- The total PCB concentration was estimated as two times the sum of the 22 PCB congeners;
- Lipophilic compounds were lipid-normalized for the purpose of the statistical evaluation (i.e., DDx, PCBs, chlordanes).

All of the data were provided in wet weight basis. The statistical comparisons were performed by pooling all data from HPS locations and assuming that all bioaccumulative compounds were identified as COPCs. A similar methodology was applied to the ambient locations. A summary of the fish tissue concentrations from HPS and ambient locations are presented in Table K-1 (Appendix K).

9.2.2 Statistical Comparisons to Reference

In order to determine if fish tissue associated with HPS is "significantly" different as compared to ambient concentrations, the data sets were statistically compared. The tests were designed to discern with 95% confidence whether the mean of the HPS data is consistent with the mean gathered from the reference locations.

Distributional comparisons were used to determine whether a statistical difference exists between the HPS and ambient locations. Two methods were used to compare the HPS concentrations to reference levels. The first method used a standard Student's t-test for evaluating differences in tissue chemical concentrations between Hunters Point and the ambient locations. The t statistic is based on the underlying assumption that the observations are random samples drawn from normally distributed populations and that the variances of the two groups being compared (e.g., tissue copper concentrations at HPS and ambient locations) are equal. The test compares the means of the two populations and based on a specified confidence limit, determines if the means are statistically similar. Prior to performing the statistical comparisons, the data sets were tested for fitting either a standard normal or lognormal distribution using

the Shapiro-Wilk test (Snedecor and Cochran, 1980). Chemicals fitting a lognormal distribution were log transformed and then examined using the standard Student's t-test. Contaminant data not fitting either distribution were examined using a nonparametric technique (Kruskal-Wallis). Equality of variance was evaluated using the Folded form F statistic (Steel and Torrie, 1980). Variances found to be equal are processed with pooled degrees of freedom, whereas unequal variance pairs are processed using the Cochran and Cox approximation of the probability level of the approximate t statistic.

Table K-2 (Appendix K) presents the result of the distribution fitting and statistical testing. The majority of the chemical concentrations found in fish tissue were determined to be statistically similar to the ambient stations. For the jacksmelt, the mean concentrations for copper, 4,4′-DDD, *alpha*- and *gamma*-chlordane, tributyltin, and total PCBs at HPS were statistically higher than mean concentrations detected in the ambient locations. The comparison of perch tissue concentrations yielded different results with the mean concentrations for arsenic, *gamma*-chlordane, anthracene, benzo(a)anthrancene, benzo(k)fluoranthene, and chrysene higher than ambient levels.

9.2.3 Comparisons to RMP

Fish tissue concentrations also were compared to data collected from the two previous RMP sampling events (1997 and 2000). Data collected from stations in close proximity to Oakland Inner Harbor (Fruitvale) and Hunters Point (Double Rock) were excluded from the data set prior to performing the comparisons in order to reduce any biases resulting from outliers. These data are presented in Table K-3 (Appendix K). Because of differences in sampling times and number of replicates, statistical analysis of the data sets from HPS and RMP was not considered appropriate. Instead, box plots of the lipophilic compounds measured in fish tissues from the RMP, ambient, and HPS stations are presented for comparison purposes only. Data collected from 1994 pilot study were not included in the analysis because no jacksmelt were captured during that year. All the wet weight concentrations are lipid standardized, as these compounds are lipophilic and tend to bioaccumulate in the fat. Figure 9-2 presents a comparison of the percent lipids measured from the various field investigations. There is a slight difference in the percent lipids measured at the RMP data (average of 2%) and HPS and ambient stations (average of 1%).

Figures 9-3 through 9-6 show HPS, ambient, and RMP data box plots for mercury, dieldrin, total DDx, and total PCBs by fish species, respectively. All the plots are presented in lipid normalized wet weight concentrations except for mercury where chemical concentration was not found to be correlated to percent lipids. For additional comparisons, foraging fish data were included in the comparisons to determine if a bioaccumulation effect is occurring that would indicate potential magnification of contaminants through the aquatic food chain.

The box plots confirm the results of the statistical evaluation. For example, Figure 9-3 depicts no discernable difference between the mean concentrations of mercury found at HPS and the ambient stations and clearly shows low variability in the data sets. As determined in SFEI (1999), length of the fish is the primary factor controlling mercury bioaccumulation. Because of the smaller sizes of foraging fish, the mercury concentrations in these species are relatively low in comparisons to those measured in sports fish from all locations. Conversely, concentrations of dieldrin and total PCB congeners (Figures 9-4 and 9-6, respectively) were higher in the smaller fish,indicating that size alone was not determining the total body burden. However, statistical comparisons of dieldrin from HPS and ambient locations showed that there was no discernable difference between the data sets. The average RMP concentration for dieldrin is consistent with concentrations at HPS and ambient locations stations for both perch and jacksmelt. There was a smaller variability in total PCB concentrations found in the ambient locations and RMP for jacksmelt, and the comparisons for perch showed both HPS and ambient were below concentrations measured at RMP. The foraging fish indicated the highest variability from the southern sampling locations at HPS.

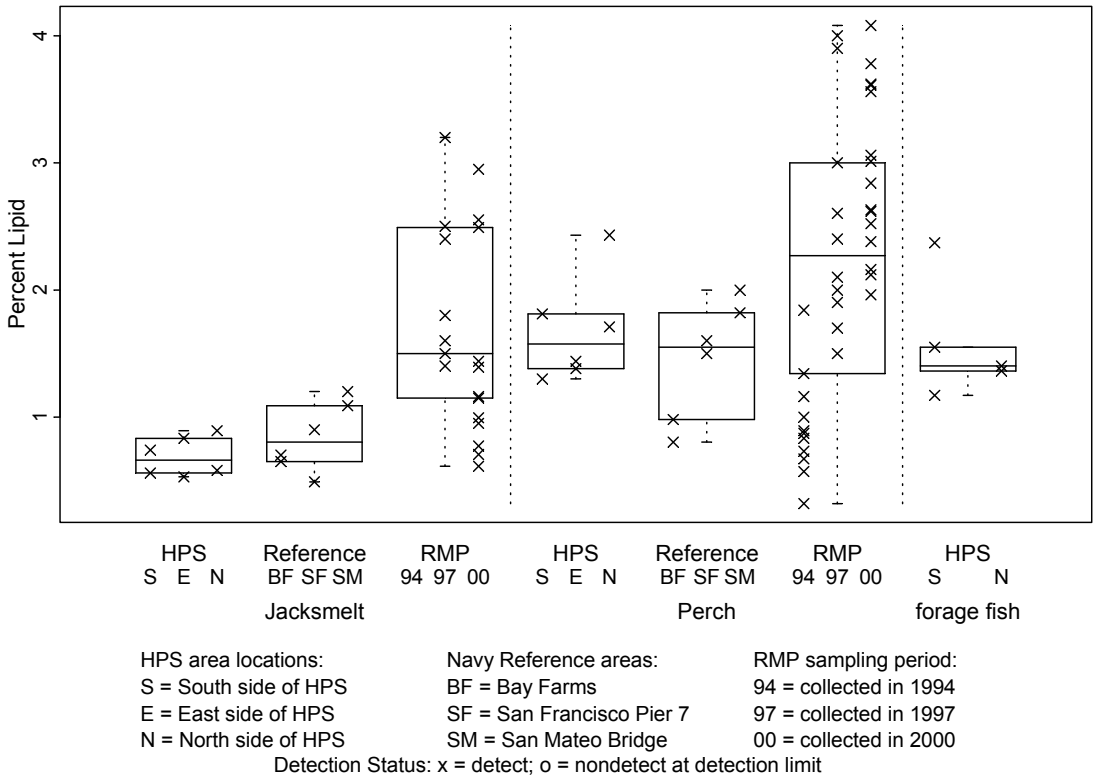


Figure 9-2. Percent Lipid in Sport Fish and Forage Fish Tissue Samples

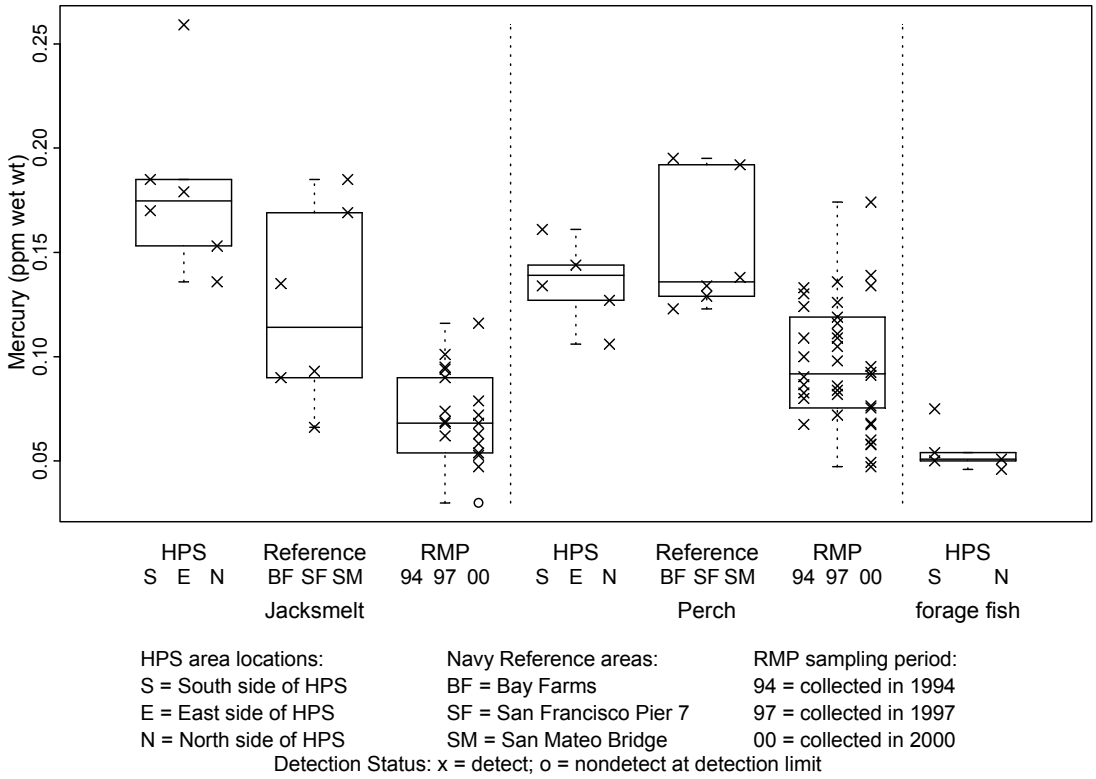


Figure 9-3. Mercury Concentrations in Sport Fish and Forage Fish Tissue Samples

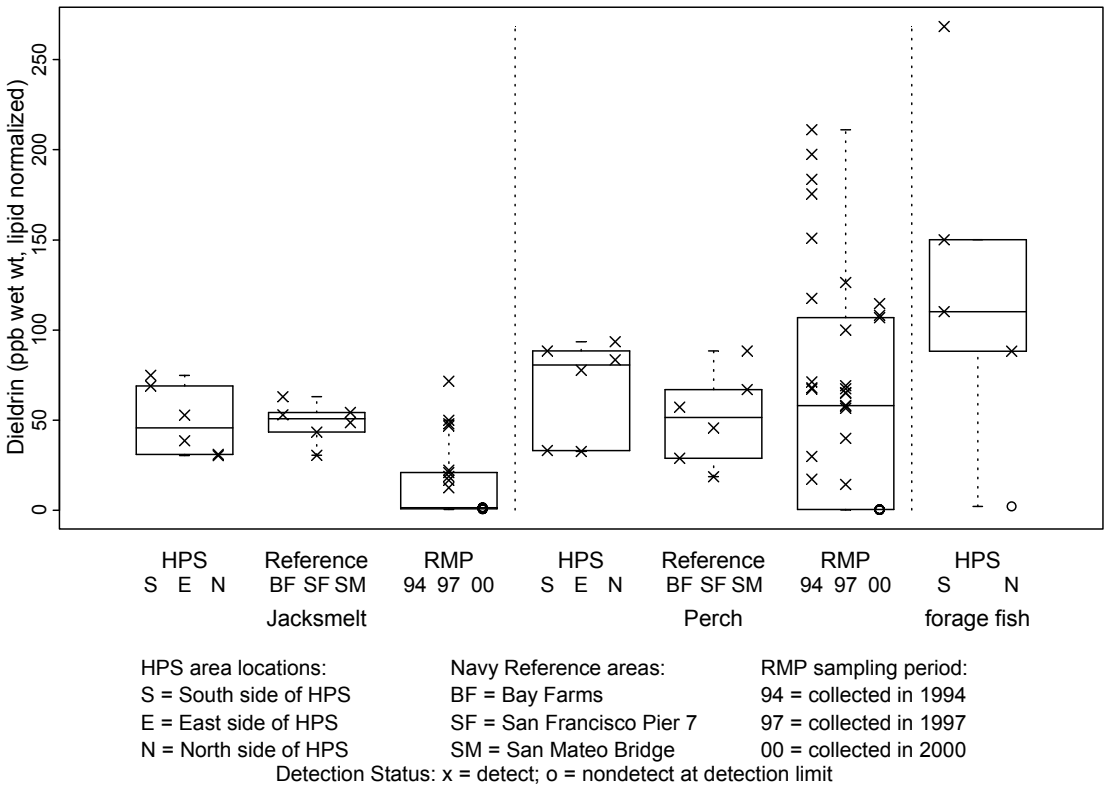


Figure 9-4. Dieldrin Concentrations in Sport Fish and Forage Fish Tissue Samples

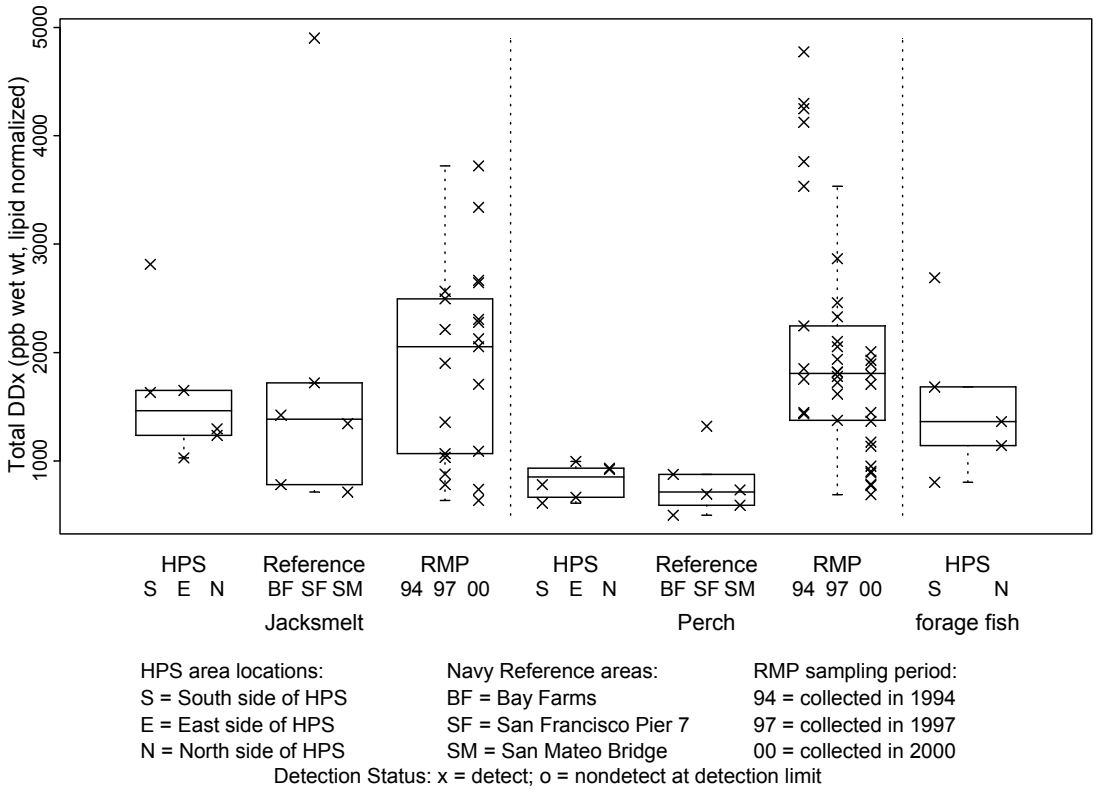


Figure 9-5. Total DDx Concentrations in Sport Fish and Forage Fish Tissue Samples

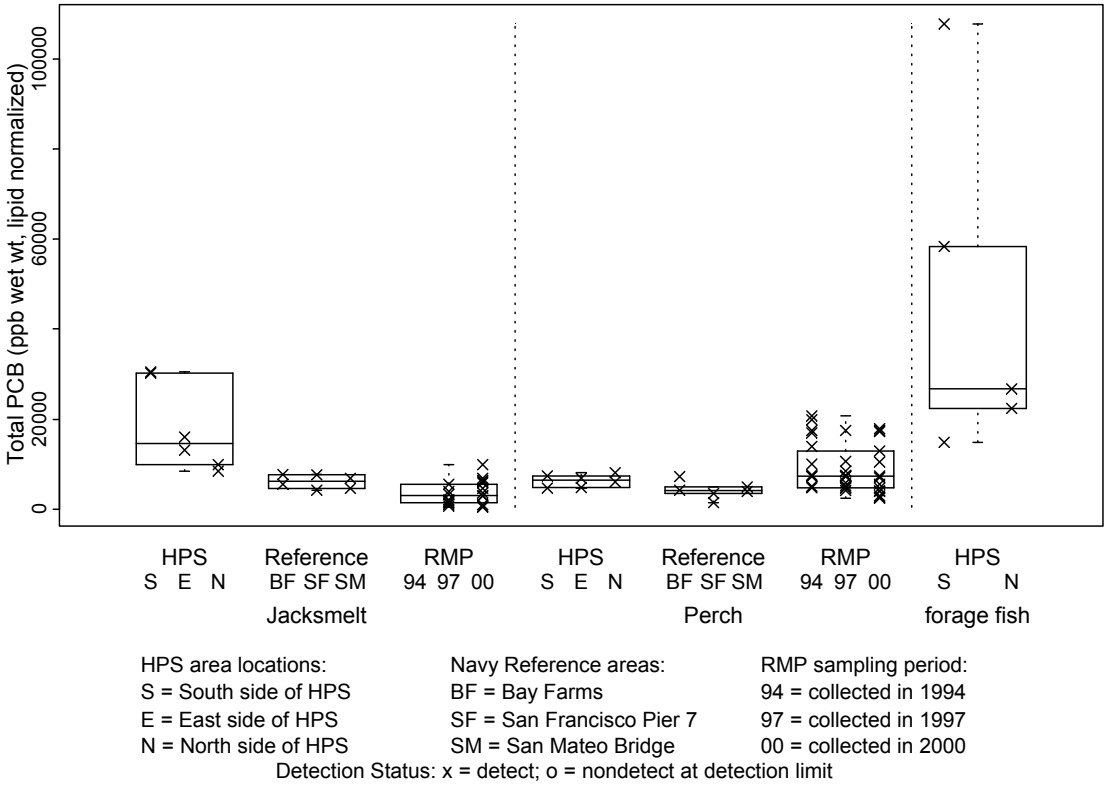


Figure 9-6. Total PCB Concentrations in Sport Fish and Forage Fish Tissue Samples

This result is further illustrated in the higher total PCB concentrations in sports fish captured near the Oil Reclamation Area. In Figure 9-5, DDx from HPS and ambient are consistent with those measured for jacksmelt and significantly below RMP concentrations for perch.

Overall, perch captured as part of the RMP had consistently higher concentrations of lipophilic compounds than those measured at either HPS or ambient locations. The RMP data also showed higher variability in perch concentrations for all analytes than those measured at HPS and ambient. For the jacksmelt, the RMP concentrations for lipophilic compounds were consistent with those measured at HPS and ambient stations. Slightly higher concentrations for total PCBs where seen in the southern area of HPS. Overall, the RMP data from 2000 are consistently lower than those measured in 1997.

9.2.4 Risk Evaluation

In order to quantify the potential risks to local anglers consuming their own catch, a standard risk assessment methodology was applied consistent with U.S. EPA's *Risk Assessment Guidance for Superfund* (1989) as described in Appendix J. The purpose of this risk assessment is to determine if there is an additional body burden on local anglers who fish at HPS as compared to the ambient locations. Following the methodology discussed for the shellfish consumption pathway (see Section 9.1), the sport fish risk assessment applies all the same exposure assumptions and toxicity factors to determine excess cancer risk and hazard.

In accordance with the HHE Work Plan (Battelle, 2001b), risk estimates were calculated only for chemicals found to be statistically higher at HPS than at the ambient locations. For the jacksmelt, copper, 4,4′-DDD, *alpha*- and *gamma*-chlordane, tributyltin, and total PCBs were identified as COPCs. For the

perch, arsenic, *gamma*-chlordane, anthracene, benzo(a)anthrancene, benzo(k)fluoranthene, and chrysene were found to be statistically higher than ambient and were retained as COPCs. Risks were estimated based on both the RME and CTE exposure scenarios. Table K-4 (Appendix K) presents the EPCs used in the risk assessment. EPCs for the RME and CTE were the lower value between the 95% UCL of the mean and the maximum measured concentrations. Because of the many conservative assumptions applied in the RME scenario and the lack of subsistence fishermen at HPS, it is assumed that the CTE scenario is more representative of actual risks associated with ingestion of locally captured fish from HPS. However, risks from both scenarios are presented for comparison purposes.

The objective of the risk assessment was to determine if fish captured near HPS pose a risk to local anglers based on conservative default exposure factors. Similar risks were also predicted using data collected from the ambient locations and RMP studies. The exposure factors used in this analysis are identical to those used to evaluate the shellfish consumption pathway (see Table 9-2). As noted in SFEI (2002), approximately 15% of the fishermen do not eat their own catch and only one in ten eats above the health advisory limit.

ADD for noncarcinogenic compounds and LADD for carcinogenic compounds were determined for each COPC by fish species Using the toxicity values shown in Table 9-3, the risks and hazards are shown in Tables 9-9 and 9-10 for the RME and CTE, respectively. For the jacksmelt, individual risks from each COPC were below U.S. EPA's risk range and target risk of 1×10^{-6} for both the RME and CTE scenarios except for total PCBs. Risk from PCBs in jacksmelt was 3×10^{-4} for the RME and 2×10^{-5} for CTE. For the ambient stations, the total PCB risk for jacksmelt was 1×10^{-4} for RME and 5×10^{-6} for CTE. To put these risks into perspective, risks were estimated using the RMP fish tissue data collected from 1997 and 2001. As presented in Table 9-11, PCB risk for jacksmelt based on the RMP data was 8×10^{-5} for RME and 4×10^{-6} for the CTE. Based on these comparisons, the PCB concentrations in jacksmelt are consistent with the variability seen in the RMP monitoring. Taking the ratio of individual PCB concentrations to the ambient indicates that the PCBs concentrations were three times higher than the ambient stations and four times higher than the RMP in 1997 and four times higher than the 2000 RMP data. Individual hazards for each compound were below U.S. EPA's benchmark of one for both the RME and CTE scenarios.

For the perch, risks were below 1×10^{-6} for all COPCs except for arsenic. HPS risks for arsenic based on the RME scenario were consistent with the ambient stations at a risk level of 3×10^{-4}. For the CTE, the risk from HPS was 2×10^{-5}, whereas risk from ambient was 1×10^{-5}. Because arsenic is naturally elevated in the Bay and the concentrations in sediment at HPS were found to be consistent with the reference stations, the risks found in HPS fish tissue were determined to be consistent with ambient stations. For noncarcinogenic effects, the hazard quotients for all COPCs were below U.S. EPA's benchmark of one.

Risks were also calculated for children based on ingestion rates from the U.S. EPA's *Exposure Factors Handbook* (1997a; Table 10-61), which estimates a total fish consumption rate for children under the age of six of 11.4 g/day and a recreational fish intake of 5.6 g/day. By applying these ingestion rates for children in conjunction with the adult fish ingestion rates estimated from SFEI (2002), it was found that risks and hazards to children were only slightly higher than those calculated for adult only exposures (Table 9-12), which were comparable to risks calculated for the reference area. The hazards associated with direct contact with sediment and ingestion of jacksmelt were below U.S. EPA's benchmark of 1.0, whereas hazards from arsenic were above 1.0 at both the site and reference stations.

Table 9-9. Dose and Risk Calculation for Sport Fish Exposure to RME at HPS Stations

Area	Species	Chemical	EPC [(a)] (mg/kg)	LADD for RME (mg/kg-day)	ADD for RME (mg/kg-day)	Oral CSF (mg/kg-day)$^{-1}$	Oral RfD (mg/kg-day)	RME Risk	RME Hazard
HPS	Jacksmelt	Cu	1.32E+00	3.87E-04	9.02E-04	NA	3.70E-02	–	2.4E-02
		4,4′-DDD	1.95E-03	5.73E-07	1.34E-06	2.40E-01	NA	1.4E-07	–
		alpha-Chlordane	5.81E-04	1.71E-07	3.99E-07	1.30E+00	5.00E-04	2.2E-07	8.0E-04
		gamma-Chlordane	2.20E-04	6.47E-08	1.51E-07	1.30E+00	5.00E-04	8.4E-08	3.0E-04
		TBT	8.96E-03	2.63E-06	6.14E-06	NA	NA	–	–
		Total PCB	2.24E-01	6.58E-05	1.53E-04	5.00E+00	NA	3.3E-04	–
Reference	Jacksmelt	Cu	5.27E-01	1.55E-04	3.61E-04	NA	3.70E-02	–	9.8E-03
		4,4′-DDD	1.70E-03	5.00E-07	1.17E-06	2.40E-01	NA	1.2E-07	–
		alpha-Chlordane	5.60E-04	1.65E-07	3.84E-07	1.30E+00	5.00E-04	2.1E-07	7.7E-04
		gamma-Chlordane	1.90E-04	5.58E-08	1.30E-07	1.30E+00	5.00E-04	7.3E-08	2.6E-04
		TBT	3.77E-03	1.11E-06	2.59E-06	NA	NA	–	–
		Total_PCB	7.05E-02	2.07E-05	4.83E-05	5.00E+00	NA	1.0E-04	–
HPS	Perch	*gamma*-Chlordane	2.51E-04	7.37E-08	1.72E-07	1.30E+00	5.00E-04	9.6E-08	3.4E-04
		Anthracene	5.01E-04	1.47E-07	3.43E-07	NA	3.00E-01	–	1.1E-06
		As	8.36E-01	2.46E-04	5.73E-04	1.50E+00	3.00E-04	3.7E-04	1.9E+00
		Benzo(a)anthracene	1.62E-04	4.77E-08	1.11E-07	1.20E+00	NA	5.7E-08	–
		Benzo(k)fluoranthene	2.60E-04	7.64E-08	1.78E-07	1.20E+00	NA	9.2E-08	–
		Chrysene	4.07E-04	1.20E-07	2.79E-07	1.20E-01	NA	1.4E-08	–
Reference	Perch	*gamma*-Chlordane	1.34E-04	3.94E-08	9.20E-08	1.30E+00	5.00E-04	5.1E-08	1.8E-04
		Anthracene	1.61E-04	4.72E-08	1.10E-07	NA	3.00E-01	–	3.7E-07
		As	6.38E-01	1.87E-04	4.37E-04	1.50E+00	3.00E-04	2.8E-04	1.5E+00
		Benzo(a)anthracene	7.13E-05	2.10E-08	4.89E-08	1.20E+00	NA	2.5E-08	–
		Benzo(k)fluoranthene	7.11E-05	2.09E-08	4.87E-08	1.20E+00	NA	2.5E-08	–
		Chrysene	2.51E-04	7.38E-08	1.72E-07	1.20E-01	NA	8.9E-09	–

Note: all concentrations are presented on wet weight basis.
(a) Exposure Point Concentration is the lower value between the maximum concentration and 95% UCL of the mean.

Table 9-10. Dose and Risk Calculation for Sports Fish Exposure to CTE at HPS Stations

Area	Species	Chemical	EPC[(a)] (mg/kg)	LADD for CTE (mg/kg-day)	ADD for CTE (mg/kg-day)	Oral CSF (mg/kg-day)-1	Oral RfD (mg/kg-day)	CTE Risk	CTE Hazard
HPS	Jacksmelt	Cu	1.32E+00	1.93E-05	1.50E-04	NA	3.70E-02	–	4.1E-03
		4,4′-DDD	1.95E-03	2.86E-08	2.23E-07	2.40E-01	NA	6.9E-09	–
		alpha-Chlordane	5.81E-04	8.54E-09	6.65E-08	1.30E+00	5.00E-04	1.1E-08	1.3E-04
		gamma-Chlordane	2.20E-04	3.24E-09	2.52E-08	1.30E+00	5.00E-04	4.2E-09	5.0E-05
		TBT	8.96E-03	1.32E-07	1.02E-06	NA	NA	–	–
		Total PCBs	2.24E-01	3.29E-06	2.56E-05	5.00E+00	NA	1.6E-05	–
Reference	Jacksmelt	Cu	5.27E-01	7.74E-06	6.02E-05	NA	3.70E-02	–	1.6E-03
		4,4′-DDD	1.70E-03	2.50E-08	1.94E-07	2.40E-01	NA	6.0E-09	–
		alpha-Chlordane	5.60E-04	8.23E-09	6.40E-08	1.30E+00	5.00E-04	1.1E-08	1.3E-04
		gamma-Chlordane	1.90E-04	2.79E-09	2.17E-08	1.30E+00	5.00E-04	3.6E-09	4.3E-05
		TBT	3.77E-03	5.55E-08	4.31E-07	NA	NA	–	–
		Total PCBs	7.05E-02	1.04E-06	8.06E-06	5.00E+00	NA	5.2E-06	–
HPS	Perch	*gamma*-Chlordane	2.51E-04	3.68E-09	2.86E-08	1.30E+00	5.00E-04	4.8E-09	5.7E-05
		Anthracene	5.01E-04	7.36E-09	5.72E-08	NA	3.00E-01	–	1.9E-07
		As	8.36E-01	1.23E-05	9.56E-05	1.50E+00	3.00E-04	1.8E-05	3.2E-01
		Benzo(a)anthracene	1.62E-04	2.38E-09	1.85E-08	1.20E+00	NA	2.9E-09	–
		Benzo(k)fluoranthene	2.60E-04	3.82E-09	2.97E-08	1.20E+00	NA	4.6E-09	–
		Chrysene	4.07E-04	5.98E-09	4.65E-08	1.20E-01	NA	7.2E-10	–
Reference	Perch	*gamma*-Chlordane	1.34E-04	1.97E-09	1.53E-08	1.30E+00	5.00E-04	2.6E-09	3.1E-05
		Anthracene	1.61E-04	2.36E-09	1.83E-08	NA	3.00E-01	–	6.1E-08
		As	6.38E-01	9.37E-06	7.29E-05	1.50E+00	3.00E-04	1.4E-05	2.4E-01
		Benzo(a)anthracene	7.13E-05	1.05E-09	8.15E-09	1.20E+00	NA	1.3E-09	–
		Benzo(k)fluoranthene	7.11E-05	1.04E-09	8.12E-09	1.20E+00	NA	1.3E-09	–
		Chrysene	2.51E-04	3.69E-09	2.87E-08	1.20E-01	NA	4.4E-10	–

Note: all concentrations are presented on wet weight basis.

(a) Exposure Point Concentration is the lower value between the maximum concentration and 95% UCL of the mean.

Table 9-11. Summary of Risk and Identification of Risk Drivers for Sports Fish

Individual Risk

Fish Species	Chemical	Risk at HPS		Risk from Reference Locations		Risk from RMP in 1997		Risk from RMP in 2000	
		RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors
Jacksmelt	Cu	–	–	–	–	–	–	–	–
	4,4′-DDD	1.4E-07	6.9E-09	1.2E-07	6.0E-09	3.6E-06	1.8E-07	2.7E-06	1.3E-07
	alpha-Chlordane	2.2E-07	1.1E-08	2.1E-07	1.1E-08	–	–	–	–
	gamma-Chlordane	8.4E-08	4.2E-09	7.3E-08	3.6E-09	–	–	–	–
	TBT	–	–	–	–	–	–	–	–
	Total PCB	3.3E-04	1.6E-05	1.0E-04	5.2E-06	7.9E-05	4.0E-06	8.8E-05	4.4E-06
Perch	*gamma*-Chlordane	9.6E-08	4.8E-09	5.1E-08	2.6E-09	–	–	–	–
	Anthracene	–	–	–	–	–	–	–	–
	As	3.7E-04	1.8E-05	2.8E-04	1.4E-05	–	–	–	–
	Benzo(a)anthracene	5.7E-08	2.9E-09	2.5E-08	1.3E-09	–	–	–	–
	Benzo(k)fluoranthene	9.2E-08	4.6E-09	2.5E-08	1.3E-09	–	–	–	–
	Chrysene	1.4E-08	7.2E-10	8.9E-09	4.4E-10	–	–	–	–

Table 9-11. Summary of Risk and Identification of Risk Drivers for Sports Fish (page 2 of 3)

RME Comparison to Risk Benchmark

Fish Species	Chemical	Exceedance Above 10^{-6} Risk?							
		HPS RME	HPS CTE	Reference RME	Reference CTE	RMP RME	RMP CTE	RMP RME	RMP CTE
Jacksmelt	Cu	–	–	–	–	–	–	–	–
	4,4′-DDD	No	No	No	No	Yes	No	Yes	No
	alpha-Chlordane	No	No	No	No	–	–	–	–
	gamma-Chlordane	No	No	No	No	–	–	–	–
	TBT	–	–	–	–	–	–	–	–
	Total PCB	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Perch	*gamma*-Chlordane	No	No	No	No	–	–	–	–
	Anthracene	–	–	–	–	–	–	–	–
	As	Yes	Yes	Yes	Yes	–	–	–	–
	Benzo(a)anthracene	No	No	No	No	–	–	–	–
	Benzo(k)fluoranthene	No	No	No	No	–	–	–	–
	Chrysene	No	No	No	No	–	–	–	–

Table 9-11. Summary of Risk and Identification of Risk Drivers for Sports Fish (page 3 of 3)

RME Comparison to Reference and RMP

		Comparison of HPS Data to Reference		Comparison of HPS Data to RMP		Ratio of Individual Risk from HPS Site to Reference and RMP		
Fish Species	**Chemical**	**Exceeds RME Reference?**	**Exceeds CTE Reference?**	**Exceeds RME RMP?**	**Exceeds CTE RMP?**	**Reference**	**RMP 1997**	**RMP 2000**
Jacksmelt	Cu	–	–	–	–	–	–	–
	4,4′-DDD	Yes	Yes	No[(a)]	No[(a)]	1.15	0.035	0.05
	alpha-Chlordane	Yes	Yes	–	–	1.04	–	–
	gamma-Chlordane	Yes	Yes	–	–	1.16	–	–
	TBT	–	–	–	–	–	–	–
	Total PCB	Yes	Yes	Yes	Yes	3.17	4.14	3.74
Perch	*gamma*-Chlordane	Yes	Yes	–	–	1.87	–	–
	Anthracene	–	–	–	–	–	–	–
	As	Yes	Yes	–	–	1.31	–	–
	Benzo(a)anthracene	Yes	Yes	–	–	2.27	–	–
	Benzo(k)fluoranthene	Yes	Yes	–	–	3.66	–	–
	Chrysene	Yes	Yes	–	–	1.62	–	–

(a) Risks and Hazards estimated for DDT from RMP data are presented for comparison purposes to risks from DDD at HPS and reference stations

Table 9-12. Summary of Child Risks and Hazards Associated with Consumption of Sport Fish

Risks to Children

Fish Species	Chemical	Risk at HPS		Risk from Reference Locations		Risk from RMP in 1997		Risk from RMP in 2000	
		RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors
Jacksmelt	Cu	NC	NC	NC	NC	NA	NA	NA	NA
	4,4′-DDD	1.4E-07	9.8E-09	1.2E-07	8.6E-09	3.6E-06	1.8E-07	2.7E-06	1.3E-07
	alpha-Chlordane	2.3E-07	1.6E-08	2.2E-07	1.5E-08	NA	NA	NA	NA
	gamma-Chlordane	8.5E-08	6.0E-09	7.4E-08	5.2E-09	NA	NA	NA	NA
	TBT	NC	NC	NC	NC	NA	NA	NA	NA
	Total PCB	3.3E-04	2.3E-05	1.1E-04	7.4E-06	7.9E-05	4.0E-06	8.8E-05	4.4E-06
Perch	*gamma*-Chlordane	9.7E-08	6.8E-09	5.2E-08	3.7E-09	NA	NA	NA	NA
	Anthracene	NC	NC	NC	NC	NA	NA	NA	NA
	As	3.7E-04	2.6E-05	2.8E-04	2.0E-05	NA	NA	NA	NA
	Benzo(a)anthracene	5.8E-08	4.1E-09	2.6E-08	1.8E-09	NA	NA	NA	NA
	Benzo(k)fluoranthene	9.3E-08	6.6E-09	2.5E-08	1.8E-09	NA	NA	NA	NA
	Chrysene	1.5E-08	1.0E-09	9.0E-09	6.3E-10	NA	NA	NA	NA

Hazards to Children

Fish Species	Chemical	Hazard at HPS		Hazard from Reference Locations	
		RME Exposure Factors	CTE Exposure Factors	RME Exposure Factors	CTE Exposure Factors
Jacksmelt	Cu	2.6E-02	6.7E-03	1.0E-02	2.7E-03
	4,4′-DDD	NC	NC	NC	NC
	alpha-Chlordane	8.5E-04	2.2E-04	8.2E-04	2.1E-04
	gamma-Chlordane	3.2E-04	8.3E-05	2.8E-04	7.1E-05
	TBT	NC	NC	NC	NC
	Total PCB	NC	NC	NC	NC
Perch	*gamma*-Chlordane	3.7E-04	9.4E-05	2.0E-04	5.0E-05
	Anthracene	1.2E-06	3.1E-07	3.9E-07	1.0E-07
	As	2.0E+00	5.2E-01	1.6E+00	4.0E-01
	Benzo(a)anthracene	NC	NC	NC	NC
	Benzo(k)fluoranthene	NC	NC	NC	NC
	Chrysene	NC	NC	NC	NC

NA = chemicals that were not analyzed in the RMP study.
NC = chemicals lacking toxicity criteria.

9.2.5 Summary of Risk

The results of the statistical comparisons of fish tissue data indicated that the majority of compounds present at HPS were statistically similar to ambient. Using conservative exposure assumptions, only total PCBs in jacksmelt and arsenic in perch were present at risks above U.S. EPA's risk threshold and target residential risk of 1×10^{-6}. Further comparisons of the risks from HPS to ambient locations and RMP data showed that for the jacksmelt, PCB concentrations were three times higher than the ambient stations and four times higher than the RMP in 1997 and 2000. Based on the statistical evaluation, total PCBs in jacksmelt were the only chemicals that were found to be above ambient. Although arsenic is not measured as part of the RMP, the risks from arsenic at HPS were found to be consistent with risk found at the ambient stations. Arsenic is naturally elevated throughout the bay and measured concentrations of arsenic at HPS sampling stations were determined to be consistent with the reference site stations.

9.3 Summary of Human Health Evaluation

Based on the results of the human health evaluation, risks to humans from chemicals in Parcel F sediments appear to be similar to risks from ambient conditions with the exception of exposure to PCBs. In general, risks associated with PCBs appear to be highest on the south side of HPS, particularly in Area X. This conclusion is supported by both the shellfish/direct contact evaluation and the statistical comparison of recreationally preferred sport fish from HPS and elsewhere in San Francisco Bay. However, the contribution of total PCBs to the area-wide cumulative risk in Areas IX and X is minimal (about 1%) due to the presence of other chemicals (e.g., arsenic, dioxin) that are comparable to ambient conditions.

10.0 IDENTIFICATION OF THE PARCEL F FS STUDY AREA

The objective of this section is to identify areas that should be evaluated in the Parcel F FS, and to develop PRGs for the chemicals that are driving risk at the site. The WOE results were not used directly to identify the FS footprint because the integrated results for many stations indicated that additional evaluation was needed to determine whether or not the station should be included in the footprint. Therefore, all results were evaluated, including the three lines of evidence (sediment chemistry, toxicity, and bioaccumulation), ancillary data, and the human health evaluation, to identify pathways and contaminants driving ecological and human health risk in each of the five Parcel F study areas (Section 10.1). Based on this evaluation, ranges of PRGs were developed for the chemicals and pathways driving risk at the site (Section 10.2).

10.1 Identification of Pathways and Contaminants Driving Risk

The following approach was used to identify the chemicals and pathways driving risk at each of the five Parcel F areas (Areas I, III, VIII, IX, and X):

- Evaluate individual lines of evidence (sediment chemistry, toxicity, and bioaccumulation) and ancillary data, and identify relationships between chemical concentrations in sediment and adverse biological effects.

- Review area-wide human health risk assessment results.

- Summarize the status of source control in each area and evaluate the potential for future contamination from onsite sources.

Some aspects of the data evaluation are common to all five areas. These site-wide considerations are discussed below, followed by the individual evaluations for each area.

In all five areas, acute toxicity was not observed in the bulk sediment bioassay using the amphipod *E. estuarius*. Some toxicity was observed in the acute/sublethal SWI test using larvae of the purple urchin *S. purpuratus.* The 13 HPS stations where larval toxicity occurred were distributed throughout the HPS offshore areas with no apparent spatial pattern or relationship to chemical concentrations in sediment. Ammonia might have contributed to SWI toxicity at some stations; other factors that could have contributed to toxicity were poor water quality, field replicate variability and the presence of native flora and fauna in the undisturbed cores. Although small areas of HPS surface sediments throughout the site might pose some risk to echinoderms and other broadcast-spawning invertebrate species, this pathway does not appear to be responsible for the majority of ecological risk at the site. Therefore, the discussions for each area in the sections below focus on sediment chemistry, dose assessment results, and potential human health risk.

Dose assessments based on field-collected tissue data for hard-bodied and soft-bodied invertebrates were performed in response to comments on the Draft Validation Study Report (Section 7.2.2), although the DQOs for field-collected tissue data were not designed to support this assessment. These dose assessment results have a higher degree of uncertainty than the assessments based on depurated *M. nasuta* tissue from the laboratory bioaccumulation test because of the small number of samples (one per area for each tissue type) and lack of reference site data. Additionally, the field-collected tissue samples were not depurated prior to analysis. The chemical concentrations measured in the field-collected tissue samples may represent tissue burdens plus residual sediment in the guts of the organisms, and the food chain model used in the dose assessment assumes that the prey concentration represents tissue burdens only. Because reference samples of field-collected invertebrates were not collected, it is not known whether or

to what degree invertebrate tissue concentrations from HPS are elevated compared to reference conditions, and potential risks assuming SUFs of less than 1.0 cannot be estimated. Therefore, when evaluating risk to the scoter, greater weight was given to the results based on the depurated *M. nasuta* tissue from the laboratory bioaccumulation test.

Lead was identified as a potential contributor to risk at the site based on dose assessment results; however, it cannot be definitively identified as a primary risk driver because of the uncertainty associated with evaluating risk associated with exposure to lead. As discussed in Section 6.0, the avian TRV for lead used in the dose assessment (DON, 1998) is low compared with other widely accepted TRVs such as those from Oak Ridge National Laboratory (Sample et al., 1996) or the U.S. EPA (2003). Therefore, HQ_{low} values exceed 1.0 even for scenarios evaluating ambient exposure only. Consequently, the ecological significance of the lead HQ_{low} values calculated for HPS is unclear. For example, if the U.S. EPA lead TRV for birds (1.6 mg lead/kg bw-day) is used to assess effects from lead to the scoter at HPS, potential risk from lead throughout HPS would be considered negligible. However, chemical concentrations of lead in sediment exceed reference and ambient levels in Area I (one sample), Area III (several samples), and in Areas IX and X, and lead concentrations in *M. nasuta* tissue from the laboratory bioaccumulation test exceed the reference threshold value at several stations in Areas III, VIII, and IX, and most of Area X (particularly along the Parcel E shoreline). Ultimately, ecological concerns about lead can be qualitatively addressed because it is co-located with other risk drivers (see Section 10.2.2).

10.1.1 Area I (India Basin)

A review of all available ecological data indicates a low potential for ecological risk associated with exposure to sediments in Area I. Chemical concentrations in sediment were similar to ambient concentrations with the exception of lead at one station and nickel at two stations. Dose assessment results are summarized in Table 10-1. HQ_{low} values for the refined dose assessment for the scoter based on laboratory *M. nasuta* data were below 1.0 for all COPECs with tissue concentrations above reference threshold values. HQ_{low} values for the scoter dose assessments based one HBI and one SBI tissue sample were greater than 1.0 for copper, lead, nickel, and selenium assuming a SUF of 1.0. However, it is not known whether tissue concentrations for these COPECs are higher than reference concentrations because field-collected invertebrate tissues were not collected at reference sites. The dose assessment for the double-crested cormorant based on forage fish tissue data indicated a HQ_{low} of greater than 1.0 for lead, assuming a SUF of 1.0. All HQ_{high} values were less than 1.0. As discussed in Section 10.1, a higher degree of uncertainty is associated with (1) assessing risk using field-collected invertebrate tissue – especially the SBI tissue, and (2) assessing risk from exposure to lead.

The results of the HHE (Section 9.0) indicated that potential risks to humans from Area I sediments are similar to risks from exposure to San Francisco Bay ambient conditions. Specifically, the cumulative risk and hazard to future residents from harvesting and consuming shellfish in Area I are similar to or below reference levels (Tables 9-4a and 9-5a).

The presence of potentially-contaminated shoreline and nearshore fill and debris in Parcel B is an ongoing concern because it may act as a future source of contamination to offshore sediments. A recently completed Parcel B shoreline investigation characterized the boundaries and levels of contamination in the debris field (TtEMI, 2003a). The shoreline fill and debris will be evaluated as a potential source of contamination to offshore sediments as part of the Parcel B ROD amendment process.

10.1.2 Area III (Point Avisadero)

The ecological evaluation for Area III (Point Avisadero) indicates potential risk to upper trophic level receptors from exposure to several chemicals. Concentrations of some COPECs exceeded ambient con-

Table 10-1. Summary of Dose Assessment and Sediment Chemistry Results

Dose Assessment: HQ_{low} > 1; Site Use Factor = 1.0					95% UCL Sediment Concentration (mg/kg dry wt) (SF Bay ambient threshold value)
Receptor	**Scoter**	**Scoter**	**Scoter**	**Double-crested cormorant**	
Prey concentration data	**Depurated lab *Macoma* tissue**	**Field-collected hard-bodied invertebrate tissue**	**Field-collected soft-bodied invertebrate tissue**	**Field-collected forage fish tissue**	
India Basin (Area I)					
Copper	5.28E-01	**1.03E+00**	**1.21E+00**	1.95E-01	112 (68.1)
Lead	**1.94E+01**	**4.39E+01**	**5.37E+01**	**6.95E+00**	115 (43.2)
Mercury	2.52E-01	2.61E-01	4.03E-01	3.31E-01	0.36 (0.43)
Nickel	9.66E-01	9.82E-01	**2.82E+00**	2.50E-01	232 (112)
Selenium	**1.71E+00**	**1.25E+00**	**1.61E+00**	6.48E-01	0.39 (0.64)
Total PCBs	1.07E-01	2.06E-01	3.46E-01	9.88E-01	0.09 (0.015)
Point Avisadero (Area III)					
Cadmium	2.79E-01	N/A	**2.77E+00**	3.91E-02	0.43 (0.33)
Copper	***3.26E+00***	N/A	**9.90E+00**	3.70E-01	708 (68.1)
Lead	**2.12E+01**	N/A	**1.20E+02**	**5.57E+00**	118 (43.2)
Mercury	***4.15E+00***	N/A	**1.16E+00**	3.10E-01	1.66 (0.43)
Nickel	6.78E-01	N/A	**2.52E+00**	1.58E-01	171 (112)
Selenium	**1.43E+00**	N/A	**3.28E+00**	4.29E-01	0.38 (0.64)
Total PCBs	2.58E-01	N/A	9.28E-01	8.59E-01	2.44 (0.015)
Eastern Wetland (Area VIII)					
Copper	7.15E-01	3.73E-01	**1.26E+00**	1.24E-01	41.1 (68.1)
Lead	***1.54E+01***	**1.12E+01**	**4.10E+01**	**2.33E+00**	24.7 (43.2)
Mercury	2.67E-01	3.10E-01	3.98E-01	4.18E-01	0.26 (0.43)
Nickel	5.15E-01	5.74E-01	**2.02E+00**	1.12E-01	97.5 (112)
Selenium	**1.67E+00**	**1.26E+00**	**3.22E+00**	3.84E-01	0.46 (0.64)
Total PCBs	2.29E-01	3.71E-01	2.42E-01	8.15E-01	0.03 (0.015)
Oil Reclamation (Area IX)					
Cadmium	***1.12E+00***	6.84E-01	8.66E-01	1.74E-02	0.39 (0.33)
Lead	***2.48E+01***	**1.30E+01**	**2.44E+01**	**4.01E+00**	54.5 (43.2)
Mercury	2.99E-01	3.75E-01	3.29E-01	3.33E-01	0.52 (0.43)
Nickel	7.33E-01	7.44E-01	**1.08E+00**	1.46E-01	135 (112)
Selenium	**1.72E+00**	**1.56E+00**	**1.56E+00**	5.17E-01	0.38 (0.64)
Total PCBs	***1.07E+00***	7.58E-01	**5.84E+00**	**1.64E+00**	0.34 (0.015)
Total 4,4'-DDX	2.87E-01	1.56E-01	**1.41E+00**	6.34E-01	0.004 (0.007)
South Basin (Area X)					
Copper	7.68E-01	6.07E-01	**2.33E+00**	1.87E-01	189 (68.1)
Lead	***3.35E+01***	**2.59E+01**	**1.09E+02**	**6.63E+00**	98.0 (43.2)
Mercury	3.14E-01	4.20E-01	6.31E-01	2.98E-01	0.86 (0.43)
Nickel	5.49E-01	5.91E-01	**1.82E+00**	1.15E-01	124 (112)
Selenium	**1.47E+00**	**1.68E+00**	**1.65E+00**	4.84E-01	0.42 (0.64)
Total PCBs	***1.77E+00***	**2.03E+00**	**1.07E+01**	**3.75E+00**	1.61 (0.015)
Total 4,4'-DDX	5.48E-01	4.34E-01	**1.98E+00**	1.25E+00	0.019 (0.007)

Notes:

1. Dose assessments are based on a site use factor (SUF) = 1 and 95% UCL sediment and tissue EPCs, except those based on field collected tissue data where the tissue EPC is a single value.
2. Bold text: HQ_{low} value exceeds one. Bold italicized text: *Macoma* tissue concentration exceeds the reference threshold value.
3. Yellow shading: chemical identified as a primary risk driver.
4. Results for lead are shaded blue because of uncertainty regarding toxicity reference value (TRV).
5. All HQ_{high} values less than 1.0.

centrations at one or more stations, primarily mercury, copper, PCBs, and TBT (Section 4.0). In general, a positive relationship was observed between COPEC concentrations in sediment and laboratory-exposed *M. nasuta* tissue (Figures F-29 through F-34, Appendix F). Although PCBs in sediment were elevated at some Area III stations, PCBs did not significantly bioaccumulate into *M. nasuta* tissue (Figure 10-1). Dose assessment results for Area III indicated that PCBs pose minimal risk to upper trophic level receptors.

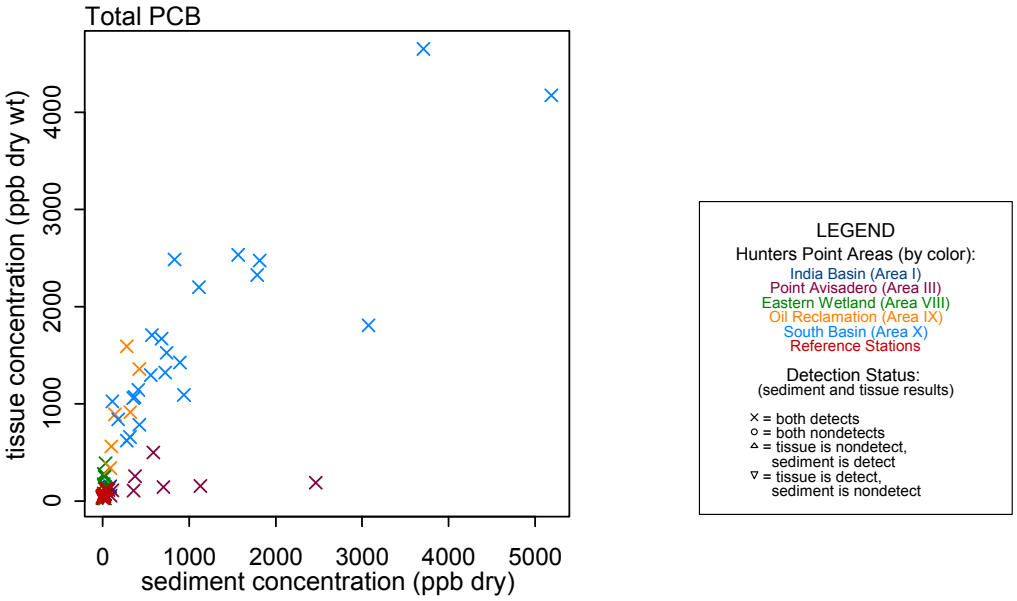


Figure 10-1. Sediment and Depurated *M. nasuta* Tissue Total PCB Concentrations

Dose assessment results are summarized in Table 10-1. For the refined dose assessments for the scoter based on laboratory *M. nasuta* data and a SUF of 1.0, tissue concentrations exceeded reference threshold values and HQ_{low} values exceeded 1.0 for copper and mercury. HQ_{low} values for the scoter dose assessment based on one SBI tissue sample were greater than 1.0 for six metals (cadmium, copper, lead, mercury, nickel and selenium) assuming a SUF of 1.0. The dose assessment for the double-crested cormorant based on forage fish tissue data indicated a HQ_{low} of greater than 1.0 for lead, assuming a SUF of 1.0. All HQ_{high} values were less than 1.0. As discussed in Section 10.1, a higher degree of uncertainty is associated with assessing risk using field-collected invertebrate tissue and from exposure to lead. Therefore, based on these results, copper and mercury were identified as the primary risk drivers in Area III.

The results of the HHE (Section 9.0) indicated that potential risks to humans from Area III sediments are similar to risks from exposure to San Francisco Bay ambient conditions. The cumulative risk and hazard to future residents from harvesting and consuming shellfish in Area III are similar to or below reference levels.

The primary historical source of contamination to Area III appears to be the drainage tunnel from Dry Docks 2 and 3, and possibly storm drains. Surface drainage from Parcel B has been controlled and the storm drains and outfalls have been cleaned. The drainage tunnel has not been investigated recently, although a steel door currently blocks the tunnel about 25 ft from the Area III shoreline. Options for investigating and/or decommissioning this tunnel will be evaluated as part of the Parcel B ROD amendment process.

10.1.3 Area VIII (Eastern Wetland)

Ecological data for Area VIII (Eastern Wetland) indicate a low potential for ecological risk associated with exposure to soft sediments. Sediment COPEC concentrations were similar to ambient concentrations (Section 4.0). Dose assessment results are summarized in Table 10-1. For the refined dose assessments for the scoter based on laboratory *M. nasuta* data, lead was the only COPEC with tissue concentrations exceeding the reference threshold value and a HQ_{low} value above 1.0. HQ_{low} values for the scoter dose assessments based on one HBI and one SBI tissue sample were greater than 1.0 for copper, lead, nickel, and selenium, assuming a SUF of 1.0. The dose assessment for the double-crested cormorant based on forage fish tissue data indicated a HQ_{low} of greater than 1.0 for lead, assuming a SUF of 1.0. All HQ_{high} values were less than 1.0. As discussed in Section 10.1, a higher degree of uncertainty is associated with assessing risk using field-collected invertebrate tissue and from exposure to lead.

The results of the HHE (Section 9.0) indicated that potential risks to humans from Area VIII sediments are similar to risks from exposure to San Francisco Bay ambient conditions. Specifically, the cumulative risk and hazard to future residents from harvesting and consuming shellfish in Area VIII are similar to reference levels (Tables 9-4a and 9-5a).

Metal slag and other debris along the shoreline in Parcel E adjacent to Area VIII poses an ongoing concern because it may act as a future source of contamination to offshore sediments. Removal of this material is currently being evaluated, including investigation of the material underneath the slag that will be exposed if the slag is removed. The Area VIII shoreline will be evaluated as a potential ongoing source of contamination to offshore sediments.

10.1.4 Area IX (Oil Reclamation)

Ecological data for Area IX (Oil Reclamation Area) indicate potential risk to upper trophic level receptors. Sediment chemistry results indicate that PCB concentrations are elevated above ambient levels (Section 4.0). Several metals are also elevated at one or more stations (e.g., lead, chromium, and mercury). Dose assessment results are summarized in Table 10-1. COPEC concentrations in *M. nasuta* tissue exceeded reference threshold values and HQ_{low} values for the refined dose assessments for the scoter based on laboratory *M. nasuta* data exceeded 1.0 for PCBs, cadmium, and lead, assuming a SUF of 1.0. HQ_{low} values for the scoter dose assessment based on SBI and HBI tissue data were greater than 1.0 for five COPECs (lead, nickel, selenium, PCBs, and DDx) assuming a SUF of 1.0. The dose assessment for the double-crested cormorant based on forage fish tissue data indicated a HQ_{low} of greater than 1.0 for lead and PCBs, assuming a SUF of 1.0. As discussed above, a higher degree of uncertainty is associated with assessing risk using field-collected invertebrate tissue and from exposure to lead. Based on these results, PCBs appear to be the primary risk driver in Area IX.

The results of the HHE (Section 9.0) indicated that potential risks to humans from Area IX sediments are similar to or slightly higher than risks from exposure to San Francisco Bay ambient conditions. The cumulative risk to future residents from harvesting and consuming shellfish in Area IX is slightly higher than reference levels (Table 9-4a). Cumulative hazards are similar to reference conditions (Table 9-5a). Of the individual chemicals contributing to risk, only the risk from PCBs is elevated above reference levels (Table 9-4b).

The primary historical source of contamination to Area IX may be the Parcel E shoreline, or transport of PCB-contaminated sediment from Area X. Recent sampling along the Parcel E shoreline indicates that the onshore area adjacent to Area IX is not likely to be an ongoing source of PCBs to the offshore (TtEMI, 2003b). Sediment transport from Area X to Area IX will be evaluated as part of the Parcel F FS.

10.1.5 Area X (South Basin)

Evaluation of Area X (South Basin) ecological data indicated potential for adverse effects to site receptors. Sediment chemistry results (Section 4.0) indicated that a number of COPECs (primarily PCBs, mercury, copper, and lead) are elevated above ambient and reference concentrations, particularly along the eastern shoreline of South Basin adjacent to the Parcel E landfill area. In general, a positive relationship was observed between COPEC concentrations in sediment and laboratory-exposed *M. nasuta* tissue (Figures F-29 through F-34, Appendix F). Dose assessment results are summarized in Table 10-1. COPEC concentrations in *M. nasuta* tissue exceeded reference threshold values and HQ_{low} values for the refined dose assessments for the scoter based on laboratory *M. nasuta* data exceeded 1.0 for PCBs and lead. HQ_{low} values for the scoter dose assessment based on one SBI and one HBI tissue sample were greater than 1.0 for six COPECs (PCBs, lead, copper, nickel, selenium, and DDx) assuming a SUF of 1.0. The dose assessment for the DCCO based on forage fish tissue data indicated a HQ_{low} of greater than 1.0 for PCBs, lead and DDx, assuming a SUF of 1.0. All HQ_{high} values were less than 1.0. As discussed in Section 10.1, a higher degree of uncertainty is associated with assessing risk using field-collected invertebrate tissue and from exposure to lead. Risk to the DCCO from exposure to DDX was similar to reference exposure. Based on these results, PCBs were identified as the primary risk driver in Area X.

The results of the HHE (Section 9.0) indicated that potential risks to humans from Area X sediments are similar to or higher than risks from exposure to San Francisco Bay ambient conditions. The cumulative risk to future residents from harvesting and consuming shellfish in Area IX is higher than reference levels (Table 9-4a). Cumulative hazards are similar to reference conditions (Table 9-5a). Of the individual chemicals contributing to risk, only the risk from PCBs is significantly elevated above reference levels (Table 9-4b).

The primary source of contamination to Area X appears to be the Parcel E shoreline and landfill area on the east side of South Basin. Fill material from shoreline filling activities from the 1940s through the 1960s may have contributed to contamination. Active remediation along the shoreline is currently being planned as part of Parcel E activities. Contamination affecting sediments near Yosemite Creek appears to be derived from a different source area. The source of this contamination is under evaluation. Source control in Area X will be evaluated as part of the Parcel F FS.

10.2 Development of Preliminary Remediation Goals

The refined evaluation of the Validation Study results (Section 10.1) identified PCBs, mercury, and copper as the primary ecological risk drivers at HPS, with several other metals (i.e., lead) potentially contributing to risk. The human health risk assessment results showed that consumption of shellfish potentially poses an additional excess cancer risk relative to reference conditions, with PCBs in Areas IX and X posing the greatest site-associated potential risk.

PRGs based on risk to benthic invertebrate-feeding birds (i.e., the scoter) from PCBs, mercury, and copper were developed using the collocated sediment and laboratory-exposed *M. nasuta* tissue data. These data provide a strong, direct link between sediment-associated contaminants and tissue and allowed development of quantitative PRGs. These PRGs were then compared to PRGs developed for a piscivorous bird receptor (i.e., the DCCO) to ensure that they are sufficiently protective.

10.2.1 Calculation of Preliminary Remediation Goals for PCBs, Mercury, and Copper

PRGs for PCBs, mercury and copper in sediment were developed by back-calculating a safe sediment concentration in the following way.

$$\frac{\text{Dose}}{\text{TRV}} = \text{HQ}_{\text{low}} \tag{10-1}$$

set HQ_{low} to 1

$$\frac{\left[\left(\text{IR}_{\text{sed}} * \text{C}_{\text{sed}}\right) + \left(\text{IR}_{\text{prey}} * \text{C}_{\text{prey}}\right)\right] * \text{SUF}}{\text{BW}} = \text{TRV} \tag{10-2}$$

Solve for PRG by setting C_{sed} = X.

$$\frac{\left[\left(\text{IR}_{\text{sed}} * \text{X}\right) + \left(\text{IR}_{\text{prey}} * \text{X} * \text{BAF}\right)\right] * \text{SUF}}{\text{BW}} = \text{TRV} \tag{10-3}$$

$$\left[\left(\text{IR}_{\text{sed}} * \text{X}\right) + \left(\text{IR}_{\text{prey}} * \text{X} * \text{BAF}\right)\right] = \frac{\text{TRV} * \text{BW}}{\text{SUF}} \tag{10-4}$$

$$\frac{\text{IR}_{\text{sed}} * \text{X}}{\text{X}} + \frac{\text{IR}_{\text{prey}} * \text{X} * \text{BAF}}{\text{X}} = \frac{\left(\frac{\text{TRV} * \text{BW}}{\text{SUF}}\right)}{\text{X}} \tag{10-5}$$

$$\text{X} = \left(\frac{\text{TRV} * \text{BW}}{\text{SUF} * \left(\text{IR}_{\text{sed}} + \left[\text{IR}_{\text{prey}} * \text{BAF}\right]\right)}\right) \tag{10-6}$$

where: Dose = Daily dose resulting from ingestion of sediment and prey (milligrams COPEC per kilograms body weight per day [dry weight])

C_{sed} = COPEC-specific concentration in surface sediments (milligrams COPEC per kilograms sediment [dry weight]).

C_{prey} = COPEC-specific concentration in depurated, laboratory *M. nasuta* tissue (milligrams COPEC per kilograms tissue [dry weight])

IR_{prey} = Estimate of daily ingestion rate of prey (kilograms prey per day [dry weight])

IR_{sed} = Estimate of daily incidental ingestion rate of surface sediments (kilograms sediment per day [dry weight])

SUF = site use factor (unitless)

BW = body weight (kilograms)

X = PRG (milligrams COPEC per kilograms sediment [dry weight])

BAF = $\frac{C_{prey}}{C_{sed}}$.

The exposure parameters described above were used for the surf scoter as discussed in Section 6.2.1.2. Bioaccumulation factors (BAFs) were estimated for copper, mercury, and PCBs accumulating into *M. nasuta* tissue by using the collocated sediment and tissue data collected at HPS. Field-collected HBI and SBI tissue data and non-depurated *M. nasuta* laboratory data could not be used to estimate BAFs because of the small sample number and absence of collocated sediment data. In general, BAFs were estimated as the ratio of the mean sediment to mean *M. nasuta* tissue concentration. Using all the collocated laboratory *M.nasuta* and sediment data collected in Parcel F, this resulted in a BAF ratio of 0.22 for copper (Figure 10-2).

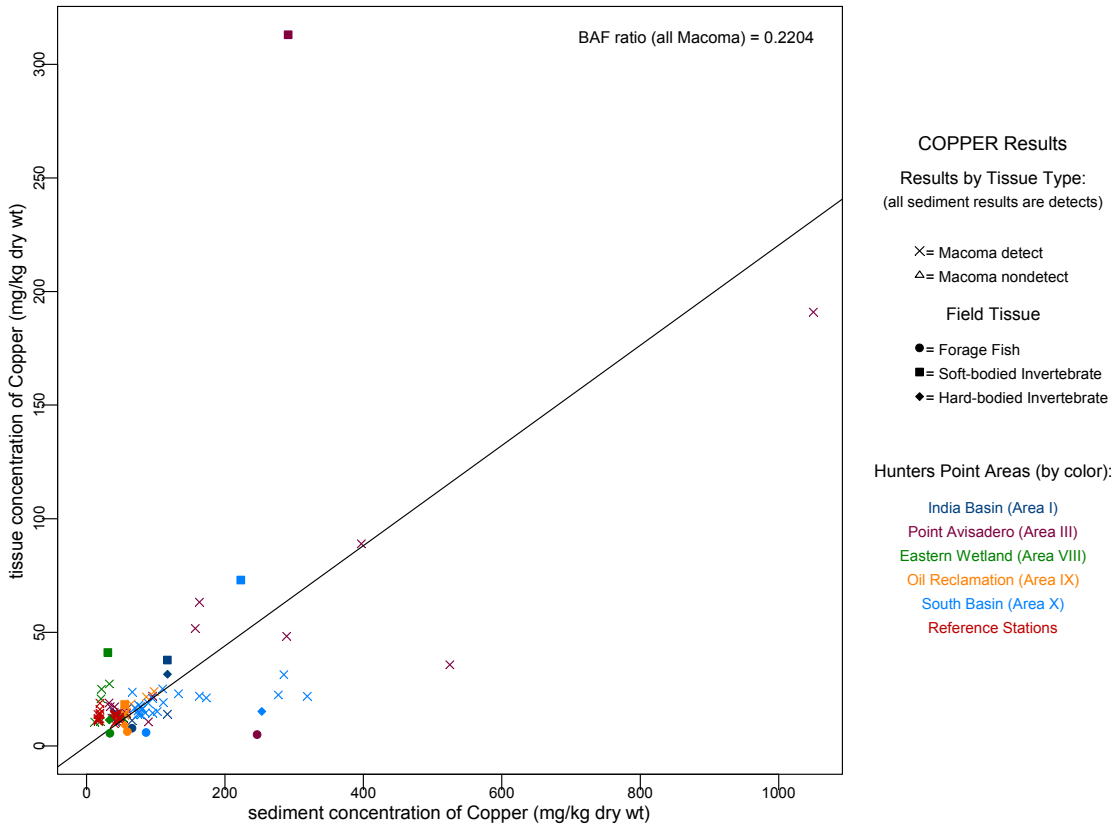


Figure 10-2. Development of Copper BAF

For mercury, uptake into tissue was more complicated because two distinct populations exhibited different rates of uptake (see top plot in Figure 10-3). One population exhibited low rates of uptake and consisted of stations in Area I, VIII, IX, X, and most of Area III. The second population had higher rates of uptake and consisted of a few stations in Area III (see middle plot in Figure 10-3). Because mercury is a primary risk driver in Area III, a BAF for mercury was developed using only stations from Area III (see bottom plot in Figure 10-3). This resulted in a BAF ratio of 0.53, which was slightly higher than if all the stations in Parcel F were used, but is assumed to conservatively represent uptake in Area III.

As with mercury, two distinct relationships were observed for PCBs. PCBs in Area III sediments appear to be less bioavailable than in other HPS sediments (see top plot in Figure 10-4). Because PCBs are the primary risk driver in Area X, the BAF ratio for PCBs was developed using data from Area X.

The middle plot in Figure 10-4 shows the Area X data in the concentration range of the *M. nasuta* samples. The Area X data show a curvilinear pattern, with higher uptake at low sediment concentrations (i.e., less than 2,000 µg/kg). Only the data below sediment concentrations of 2,000 µg/kg were used to calculate a BAF because this is the concentration range with the highest uptake rates. This is a conservative estimate of uptake, as it best represents the rapid uptake observed in the lower sediment concentrations.

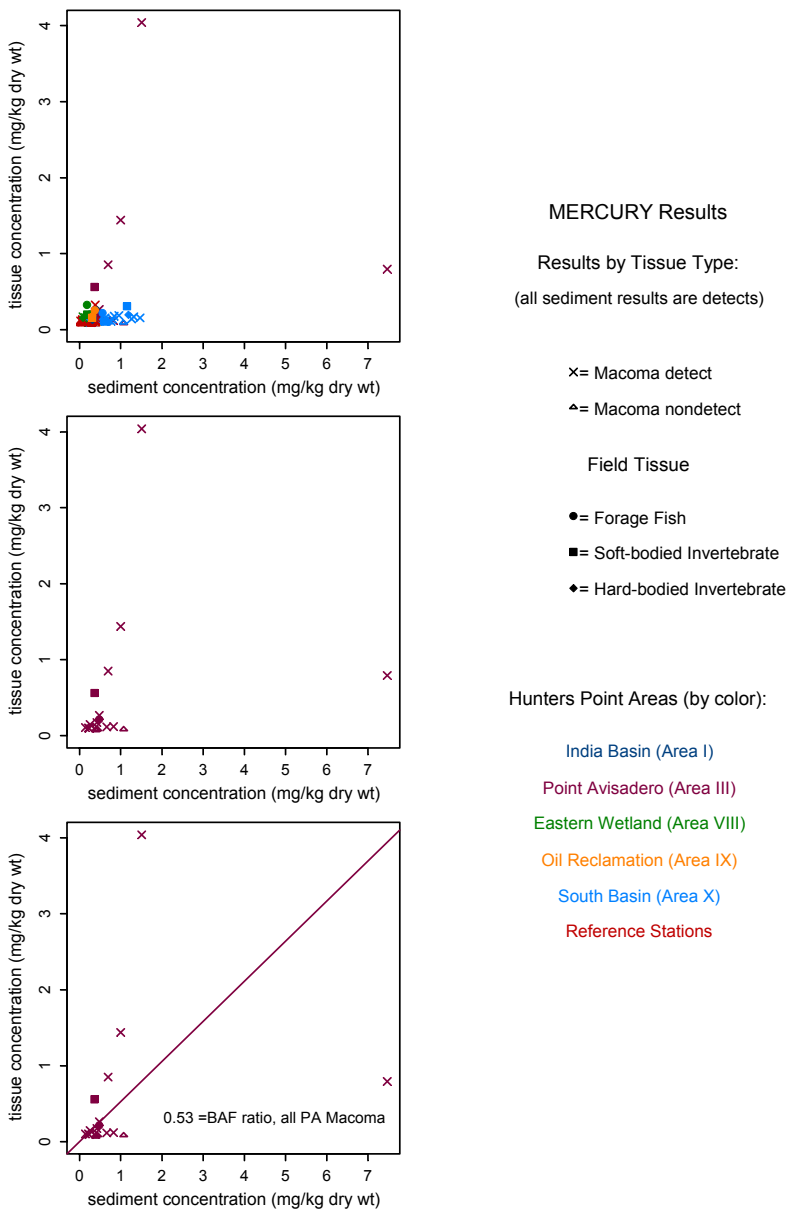


Figure 10-3. Development of Mercury BAF

The BAF ratios for copper (0.22), mercury (0.53) and PCBs (2) were used in Equation 10-6 to develop PRGs protective of scoters for a range of SUFs (Table 10-2). For copper, PRGs range from 135 mg/kg at a SUF of 1 to 13,500 mg/kg at a SUF of 0.01. For mercury, PRGs range from 0.94 mg/kg to 94 mg/kg. For PCBs, PRGs range from 0.62 mg/kg to 62 mg/kg. The highest reasonable SUF for a scoter (or any other winter migrant species) is 0.5 because scoters only spend half of the year in San Francisco Bay. A SUF of 0.5 corresponds with spending 100% of their time foraging in Area X during the half of the year that they are in the Bay, although as discussed in Section 6.0, the available information on the surf scoter indicates that a realistic SUF is lower than 0.5. However, due to the uncertainty inherent in the PRG model and in the development of a SUF for the scoter, ranges of PRGs are proposed for consideration in the FS. A realistic range of SUFs to consider is between 0.5 (the maximum based on their migratory behavior) and 0.02 (the minimum based on foraging range data for scoters from Puget Sound).

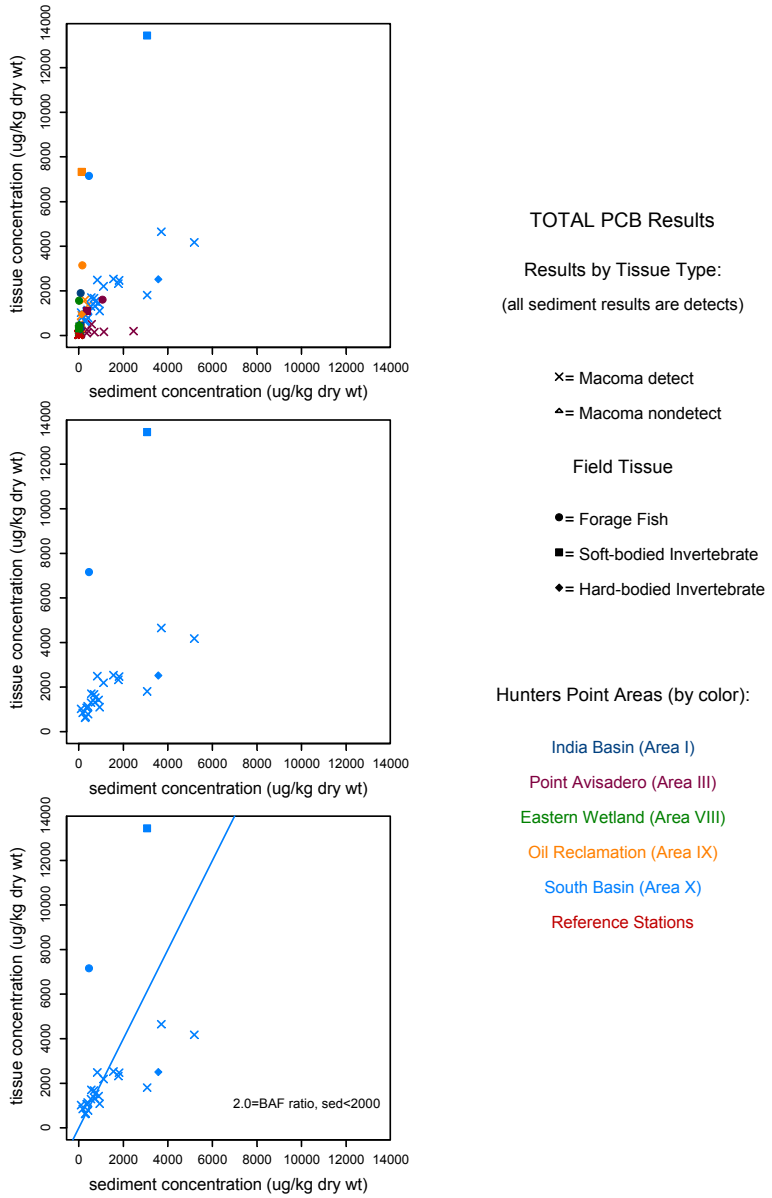


Figure 10-4. Development of PCB BAF

Table 10-2. Preliminary Remediation Goals for the Surf Scoter

SUF	PRGs (mg/kg dry weight)		
	Copper	Mercury	PCBs
1	135	0.94	0.62
0.5	271	1.87	1.24
0.4	339	2.34	1.55
0.3	452	3.12	2.07
0.2	677	4.69	3.10
0.1	1350	9.37	6.20
0.05	2710	18.8	12.4
0.02	6770	46.9	31.0
0.01	13500	93.7	62.0

10.2.2 Confirmation of the Protectiveness of the Proposed PRGs for PCBs

To confirm the protectiveness of proposed PRGs based on exposure to the scoter, a similar set of calculations was performed for the DCCO for PCBs (Table 10-3). PCBs were the only risk driver identified for the DCCO that required development of a PRG (lead will be qualitatively addressed, and risk to the DCCO from exposure to DDX is similar to reference conditions). A BAF representing PCB uptake from sediment into forage fish also was developed using a ratio estimator (Figure 10-5). This evaluation resulted in a BAF of 8.4 for PCBs. Because the actual sediment concentrations to which the fish are exposed are unknown (i.e., sediment and forage fish samples were not collocated), this value has a higher degree of uncertainty relative to the BAF based on laboratory-exposed *M. nasuta.*

Table 10-3. Preliminary Remediation Goals for the Double-Crested Cormorant

SUF	PRGs (mg/kg dry weight)
	PCBs
1	0.23
0.5	0.45
0.4	0.56
0.3	0.75
0.2	1.13
0.1	2.25
0.05	4.51
0.02	11.3
0.01	22.5

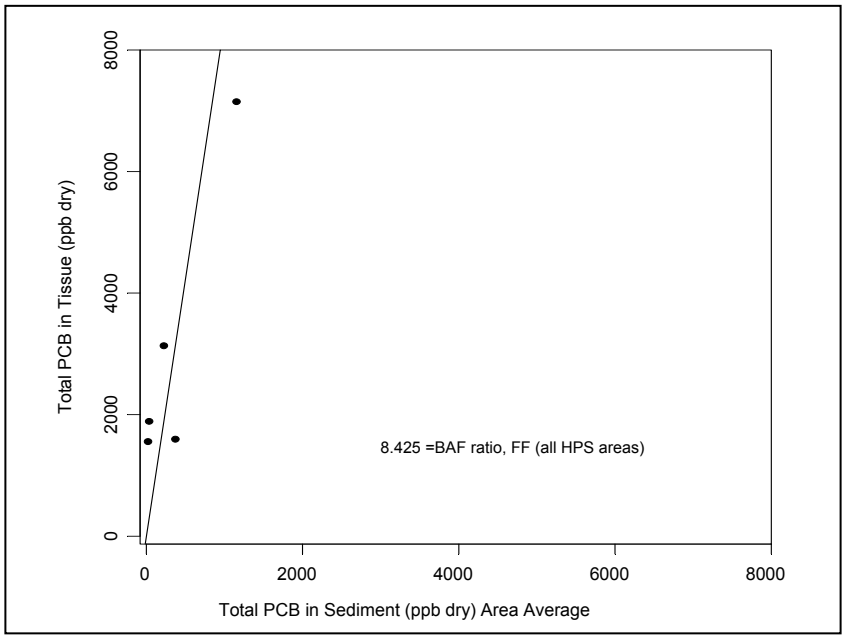


Figure 10-5. Development of Forage Fish BAF for PCBs

Using the exposure parameters for the DCCO (Section 7.4) and the BAF developed above, PRGs protective of piscivorous birds were estimated and ranged from 0.23 mg/kg to 23 mg/kg PCBs (Table 10-3). Due to the biomagnifying properties of PCBs, sediment PRGs protective of DCCO feeding on forage fish result in lower PRGs than those protective of scoters feeding on bivalves at the same SUF. However, because the DCCO is likely to forage over larger areas than the scoter, PRGs for the DCCO should be based on smaller SUFs than those for the scoter. As such, PRGs based on the scoter should be adequately protective of piscivorous birds such as the DCCO.

10.2.3 Qualitative Evaluation of Lead

As discussed in Section 10.1, lead was identified as a potential contributor to risk at Parcel F. However, because of uncertainty associated with evaluating risk from lead, it cannot be definitively identified as a primary risk driver. Lead concentrations in sediment at the site are highest in Area X (Figures 4-5 and 4-6). To qualitatively address lead, its distribution in Area X was compared with the distribution of PCBs, which are the primary risk driver. Figure 10-6 is a bivariate plot of lead vs. PCBs in Area X. Sample stations are shown in Figure 10-7. This plot indicates that the highest lead concentrations in Area X generally co-occur with the highest PCB concentrations, with the exception of several stations along the western side of South Basin. Because of the tendency for lead and PCBs to co-occur, remediation based on PCB concentrations in sediment also will reduce lead concentrations.

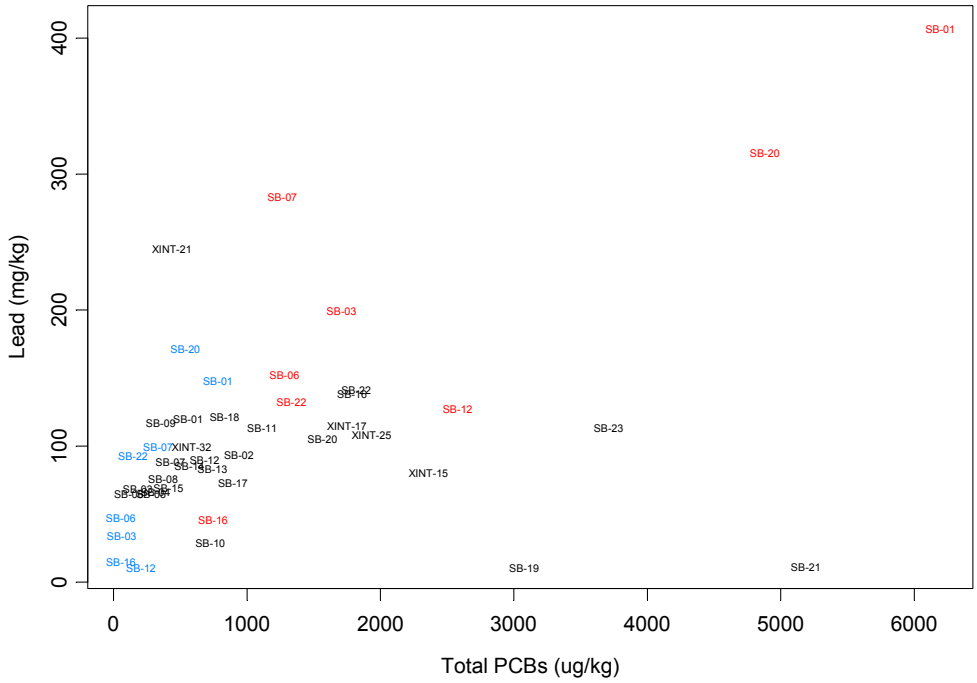


Figure 10-6. Bivariate Plot of Lead and Total PCB Concentrations in Area X Surface and Subsurface Sediment Samples by Station. Black=Surface sediment sample; Red=Core 0- 2-ft section; Blue=Core 2- 4-ft section.

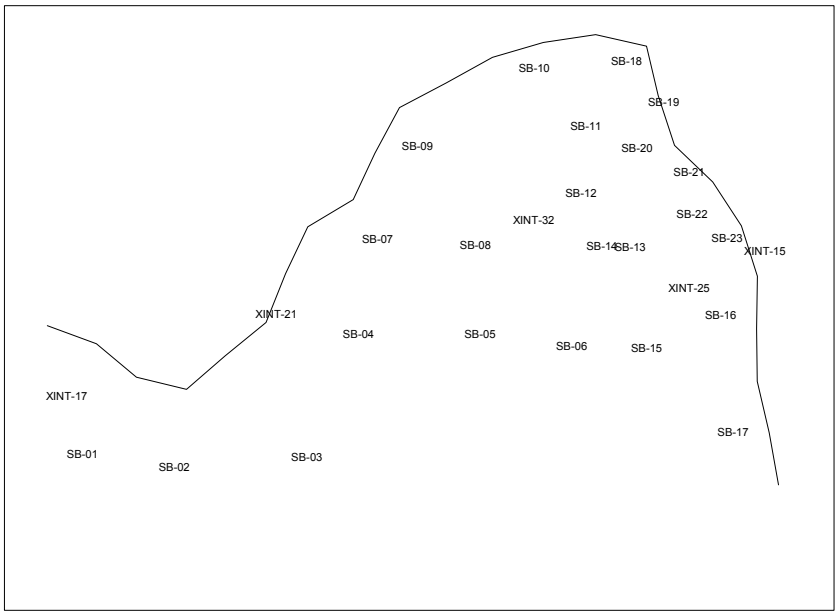


Figure 10-7. Area X Sampling Station Locations from 2000 and 2001 Sampling Activities

10.3 Identification of the Proposed FS Study Area

Based on the evaluation presented in Section 10.1, potential ecological risks are greatest and of most concern in Area III (Point Avisadero) and Areas IX and X (South Basin). Potential human health risks are associated with exposure to PCBs in Areas IX and X (South Basin). All five of the areas have potential shoreline source control issues that should be addressed. Therefore, all of the areas (Areas I, III, VIII, IX and X) will be evaluated in the Parcel F FS. Mercury, copper and PCBs were identified as the primary risk drivers; several other chemicals may also contribute to risk (see Table 10-1). The significance of the risk findings will be assessed during the FS scoping process to ensure development of a protective FS footprint. Remedial action objectives (RAOs) will be developed during the FS scoping process to address ecological and human health risk concerns as well as source control issues.

11.0 UNCERTAINTY

This section discusses the uncertainty associated with the data and methods used in the Validation Study to estimate risk to ecological receptors and human health from chemicals present in offshore sediments at HPS. As with all evaluations, there is uncertainty associated with this assessment. Uncertainty can be introduced through the use of assumptions in the absence of scientific data or through interpretation of the data itself, and can lead to either underestimates or overestimates of potential risk. The Validation Study evaluation was conducted with a conservative bias in an attempt to favor an overestimation, rather than underestimation, of potential risks to site receptors.

11.1 Uncertainty Associated with Ecological Assessment

Sources of uncertainty associated with sediment chemistry, toxicity, and bioaccumulation and their potential influence on the conclusions of the ecological assessment are presented below. It is important to note that, although the ecological risk evaluation included very conservative exposure and toxicity assumptions, the very nature of uncertainty means that the assessment may underestimate an individual element of the exposure and effect being modeled. The Navy is confident, however, that the conservative assumptions made as part of the assessment assure that any inaccuracies regarding risk estimates are biased toward an overestimation, not an underestimation, of risk.

11.1.1 Uncertainties Associated with Sediment Chemistry

In general, the sediment chemistry data generated for the Validation Study were of high quality, with good sensitivity, and good spatial coverage. The data were reviewed by an independent data validator to reduce the uncertainty associated with the analyses. A few potential uncertainties exist, but overall, the data are adequate to support the Validation Study.

First, in Area III, sediment chemistry values are very heterogeneous. Agreement between analytical results in field and laboratory duplicates was quite good, so it is likely that the heterogeneity is the result of small-scale spatial variability. Patterns of contamination are not as clearly linked to the shore, as observed in Area X; however, this may be due to the high velocity discharge from the dry docks at Area III, a greater degree of sediment disturbance from tidal action, or other conditions at Area III that differ from Area X.

In addition to higher variability in Area III, it should be noted that some of the highest concentrations of metals were measured at Station PA-47, on the southeastern edge of the sampled area. This indicates that the sampling design might not completely bound areas of elevated chemical concentrations. Five sediment samples were collected from the area south and east of Station PA-47 in previous investigations: three in the Phase 1B ERA (Stations TFST01, TFSS02, and TFSM03; PRC, 1996) and two in the sediment screening survey completed as part of the VS Work Plan (Battelle et al., 2001a). Copper concentrations in these samples ranged from 43 to 481 mg/kg, which is significantly lower than the 1,050 mg/kg measured in the sample from PA-47. Lead concentrations ranged from 12 to 58.6 mg/kg, compared with 275 mg/kg at Station PA-47; and mercury concentrations ranged from 0.03 to 0.31 mg/kg, compared with 7.47 mg/kg at Station PA-47 (mercury was not measured in the screening samples). These data indicate that metals concentrations decrease to the south of Station PA-47, and that the contamination around Station PA-47 appears to be patchy as observed elsewhere in Area III.

Data analysis revealed a few values that did not follow the general trend in a particular area, and could be considered outliers. Outliers may be due to either measurement variability, or very small-scale variability of contaminants in the sediment itself. Focused validation of outliers was performed in those cases where it was determined that a change in the value might alter a conclusion about an area.

11.1.2 Uncertainty Associated with Bulk Sediment Bioassay and SWI Test

The bioassays conducted for the Validation Study were selected and designed to address many of the uncertainties associated with previous bioassays conducted at Navy facilities in San Francisco Bay. For the amphipod bioassay, the primary issues were acclimation of test organisms, sensitivity of the organisms to confounding factors (particularly ammonia but also grain size), and appropriate monitoring and control of water quality parameters (including ammonia). For the larval development bioassay, the primary issue was selection of an appropriate test species, exposure medium, and endpoint. Other important issues were sensitivity to ammonia, appropriate water quality monitoring, and enumeration methods consistent with ongoing San Francisco Bay monitoring programs.

11.1.2.1 Bulk Sediment Bioassay

Confounding factors were successfully controlled and monitored during the bulk sediment bioassay with *E. estuarius.* Test organisms were procured from one supplier and appropriately acclimated prior to testing. Consistent control performance and reference toxicant test results indicate appropriate health and sensitivity of the test organisms. Sensitivity to grain size was addressed through exposure to reference sites with grain size distributions spanning the range of expected HPS grain size distributions. Ammonia was monitored in bulk sediment prior to testing, and on test days 0, 3, and 10, to ensure that total ammonia never exceeded the toxicity threshold for *E. estuarius*. These controls allow a high degree of certainty that the amphipod bioassay distinguished COPEC effects from confounding factor effects.

11.1.2.2 SWI Test

In the context of providing relevant site-specific data with an endpoint that is comparable to the San Francisco Bay-wide reference envelope tolerance limit, many of the uncertainties plaguing previous studies were addressed in the SWI test. The SWI exposure was selected as the most appropriate site-specific medium for assessing the effects of contaminant flux from sediment on a sensitive organism in the water column just above the sediment surface. The test species (larvae of the purple urchin, *S. purpuratus*) and the normal development endpoint were specifically agreed upon as appropriately sensitive and comparable to the SWRCB ambient MSD threshold, which is based on the same test organism and was used as the criteria for finding. However, the SWI method itself, even when followed precisely, is the source of uncertainty that must be considered when evaluating these bioassay results.

Uncertainty associated with the SWI method is described in detail in Sections 6.2 and 9.3. The most significant source of uncertainty is the collection and testing of true field replicates, which can vary in several ways: proximity to each other, sediment and porewater characteristics, and presence of native infauna. Because SWI core disturbance and manipulation are kept to a minimum, sediment, porewater, and native infauna characteristics of each core are preserved throughout the test exposure, and their influences cannot be distinguished easily in the laboratory. Although water quality and ammonia monitoring were implemented at appropriate frequencies using appropriate calibrated instruments for reliable data quality, the representativeness of the water quality and ammonia measurements were identified as another source of uncertainty. Water quality is measured in a separate SWI replicate than the ones containing test organisms, so that the instrument probes do not interfere with the larvae in the small screen tube. This part of the SWI protocol is fairly routine procedure for bioassays, but it does not provide data to assess replicate-specific effects if they are observed. The ammonia measurement also does not allow for evaluation of replicate-specific effects because it is a composite sample; however, it is more representative in that the sample is collected from actual test chambers. That ammonia measurements were made, along with multiple ammonia reference toxicant tests to assess larval sensitivity, represents significant progress toward understanding the results of larval development bioassays in general.

11.1.3 Uncertainty Associated with the Evaluation of Risk via Bioaccumulation

The screening-level assessment of risk via bioaccumulation at HPS was designed to be conservative, addressing uncertainty by overestimating risk. This approach results in increased confidence that contaminated sites will not be removed from further assessment when, in fact, risk actually exists. Results of the screening-level dose assessment were used to focus the refined assessment, which more accurately reflects exposure of the receptors to site contaminants at HPS. As with all ecological assessments, there are inherent uncertainties. The discussion of these uncertainties as they apply to either or both the screening level and refined assessment is organized according to the steps of the assessment:

1. Uncertainties associated with comparison of site tissue concentrations to reference threshold values,
2. Exposure assessment uncertainties,
3. Effects assessment uncertainties, and
4. Risk characterization uncertainties.

11.1.3.1 Uncertainties Associated with Comparison of Site Tissue Concentrations to Reference Threshold Values

The sources of uncertainty associated with the first step in the bioaccumulation evaluation, the comparison of laboratory *M. nasuta* site tissue concentrations to reference threshold values, include:

- **Representativeness of ambient conditions by reference values generated for the HPS Validation Study for tissue.** This source of uncertainty is believed to be minimal, because sediment samples were found to be representative of ambient sediment conditions within San Francisco Bay. The two exceptions (cadmium from Alcatraz Environs and total PCBs from Alameda Buoy) were excluded from the reference threshold value calculation for those COPECs.

- **Potential differences in bioaccumulation by organisms associated with coarse-grained vs. fine-grained sediments.** This source of uncertainty is believed to be minimal, because generally there were few statistical differences in tissue concentrations between fine-grained and coarse-grained samples.

- **Appropriateness of method used to develop threshold values from the reference data.** This source of uncertainty is believed to be minimal because the use of the 90th percentile value of the reference distribution for each COPEC minimized the possibility of overestimating reference tissue conditions.

11.1.3.2 Exposure Assessment Uncertainties

Uncertainties associated with input parameters used in the dose assessment model for the surf scoter in the screening-level assessment and the DCCO in the ancillary data assessment are discussed below:

Bioaccumulation Test Results. Results of the 28-day *M. nasuta* laboratory bioaccumulation tests have some inherent level of uncertainty associated with them, including test organism health and varying uptake rates between individuals. Use of standard procedures; close monitoring of test chamber conditions; and use of organisms of the same age and size range, from the same source, collected at the same time with standard handling to maintain organism health minimizes these sources of uncertainty.

Sources of uncertainty in the chemical analysis of the tissue samples are minimized by the use of established methods, analysis of quality control samples to assess accuracy and precision of the measurements, a thorough data quality review, and independent data validation. (Data validation results are summarized in Appendix E.)

The remaining area of uncertainty involves the representativeness of the results. Three replicates were run for each HPS station, but only one replicate was analyzed for chemistry. For the reference stations, five replicates were run for each station, and each replicate was analyzed and included in derivation of reference threshold values. As a result, data were available to assess variability among reference replicates, but not for HPS replicates. Therefore, some uncertainty is associated with the representativeness of the tissue chemistry results for the HPS stations.

Species-Specific Exposure Parameters. In calculating dose estimates for receptors of concern, several species-specific exposure parameters must be considered. For example, the relationship between a receptor's size and the magnitude of its dietary intake is a critical determinant of exposure. Although literature data exist from which information such as body weight, daily ingestion rate, and dietary composition can be estimated, there is a natural level of variability in these parameters within a population of receptors that cannot be expressed through the selection of a single representative value. In addition, uncertainty is inherent in the use of literature-derived values to calculate potential risks to receptors of concern (ROCs) specific to HPS rather than relying on more site- or region-specific data. Although based on the most relevant scientific data available, using literature-derived exposure parameters will add an unknown degree of uncertainty that may over- or underestimate exposure at HPS.

To evaluate the potential impact of this variability in exposure parameters, a sensitivity analysis was performed that determined that the three most sensitive parameters influencing the magnitude of the HQs are: (1) TRVs, (2) bioaccumulation factors, and (3) SUFs (Battelle et al., 1999). Although body weights, ingestion rates, and diet are components of the dose assessment, it was determined that the range of these values found within the literature would not significantly impact the receptors' dose. Therefore, it was determined that uncertainties associated with body weights, ingestion rates, and diet are minor, and that further investigations to refine them would not make major contributions to refining the dose assessment.

Treatment of Nondetect Data. An important consideration in the evaluation of site chemistry data is the manner in which results reported below the detection limit (i.e., nondetect data) are handled. The ability of an analytical method to detect chemical concentrations is a function of the method used, the sample preparation method, and the sample matrix. Uncertainty is inherently associated with nondetect chemistry results because associated chemical concentrations can only be quantitatively described as being less than the sample-specific detection limit.

Traditionally, nondetect data points have been assigned a value of one-half the sample-specific detection limit, acknowledging that the "true" concentration is somewhere between zero and the full value of the detection limit (U.S. EPA, 1989). Although using one-half of the detection limit may have little effect on assessment of individual COPECs, this practice becomes more problematic when assessing risk related to classes of compounds such as PCBs, PAHs, and DDT and its degradation products. Due to the assumed additive effects of these compounds, results for individual chemicals within a specific class (e.g., PCBs) typically are added together for assessment. If a large number of the individual compounds are reported as nondetect, summing the results based on assigned values of one-half the detection limit can result in a highly uncertain estimate of potential risk.

For the bioaccumulation assessment at Validation Study, nondetects were handled differently depending on whether the COPEC was assessed individually or as part of a sum. Individually assessed COPECs (metals, non-DDT pesticides, and organotins) had nondetected values and were assessed at one-half the detection limit. For the four classes of compounds that were summed (HPAH, LPAH, PCBs [as congeners], and DDx and its degradation products), only individual constituents that were detected were included in the sum (i.e., nondetects were assumed to be zero). All summed classes at each station contained one or more detects. Handling nondetects in this manner provided values for comparison of individual COPECs at each station to reference threshold values. By not including nondetects in the sums, it is likely that the result is closer to the actual concentration, but it is possible that summed concentrations were underestimated.

Bioavailability of Sediment-Associated COPECs. The uptake of a COPEC from sediment by ROCs is affected by its bioavailability in sediment, which is largely controlled by site-specific chemical and physical factors such as pH, the presence of simultaneously extractable metals/acid volatile sulfides (SEM/AVS), exchangeable cations, sediment organic carbon content, and grain size. Although data for some of these sediment characteristics were available, for the purpose of the screening-level and refined dose assessments, it was conservatively assumed that all sediment-associated COPECs were 100% bioavailable. Direct exposures to sediment (i.e., incidental sediment ingestion) account for a small percentage of the total dose to the surf scoter and cormorant (i.e., less than 3%); therefore, this assumption, although very conservative, is not likely to significantly impact the final dose estimate for these ROCs and further refinements were not conducted.

Variation in COPEC Uptake by Prey Species. Each species absorbs, metabolizes, and excretes COPECs in a different manner, affecting the transfer of COPECs to higher-level receptors. Because *M. nasuta* data is used as a surrogate for all prey, prey species variation is not accounted for in the exposure model. This variation is likely to have a minimal impact on the dose assessment for surf scoters, because they feed primarily on bivalves such as *M. nasuta*. Scoters are a surrogate species for birds that feed on benthic invertebrate feeding birds, some of which also eat soft-bodied invertebrates. Uptake of COPECs by SBI may or may not be similar to that of HBI such as *M. nasuta*. Sources of uncertainty in the dose assessment for benthic-feeding birds include:

- The use of laboratory-exposed, depurated *M. nasuta* to estimate the magnitude of receptor exposure to COPECs at HPS: These data are adequate to support the WOE and development of the FS footprint. Comparison of depurated and nondepurated *M. nasuta* showed no consistent bias, and HQs and WOE scores were similar between paired tests. Additionally, field-collected HBIs had similar tissue concentrations to the laboratory-reared *M. nasuta* collected at adjacent stations. The close correlation between the field-collected HBIs, the nondepurated *M. nasuta* tissue and the laboratory-reared, depurated *M. nasuta* support the assumption that the laboratory-depurated *M. nasuta* are a reasonable surrogate for bioaccumulation in bivalves in the field.

- The use of laboratory-exposed, depurated *M. nasuta* to estimate the dose for benthic-feeding birds that consume prey other than or in addition to bivalves: Doses to scoters preying on SBI were estimated in the ancillary data evaluation (Section 7.0) and tended to be of higher magnitude than those developed using laboratory *M. nasuta* tissue concentrations. Although the SBI collected in the field had higher tissue concentrations than any of the other tissue types, it is unclear whether the field-collected SBI sample results represent tissue concentrations alone, or whether they reflect concentrations in tissue plus sediment present in the gut. If the field-collected SBI tissue is representative of tissue

concentrations of other prey types, then the dose estimated using only laboratory-exposed, depurated *M. nasuta* for benthic-feeding birds that consume prey other than or in addition to bivalves is underestimated. Although a preliminary evaluation suggests that the field-collected data may overestimate polychaete tissue concentrations, sufficient data do not exist to quantitatively address this uncertainty.

Additional sources of uncertainty in evaluation of the field-collected invertebrate data include:

- Only one sample was collected per area and may not be representative of the area;
- The sample in each area was collected over a large area and could not be collocated with specific HPS Validation Study stations;
- HBI could not be collected at Area III;
- Organisms were not depurated prior to analysis.

It is unknown whether field-collected HBI and SBI tissue concentrations are elevated as compared to field-collected HBI and SBI from reference sites in SF Bay because no field-collected invertebrates were collected from reference sites. Because the HBI tissue samples had similar COPEC concentrations as the laboratory *M. nasuta* tissue samples, some predictions can be made regarding comparisons to reference. However, SBI tissue sample concentrations are not comparable to *M. nasuta* laboratory tissue sample concentrations and similar predictions cannot be made. Assuming that all SBI tissue concentrations at HPS are elevated as compared to reference concentrations in San Francisco Bay is a conservative assumption and is likely to overestimate contributions from the site.

Estimation of Exposure Point Concentrations (C_{sed} and C_{prey}). In the screening-level dose assessment, risk was evaluated on a station-by-station basis, which does not accurately reflect the feeding behavior of the scoter which integrates exposure over a larger area. To address this bias, a refinement was conducted using the arithmetic mean and 95% UCL of the mean to calculate sediment and tissue concentrations on a site-wide and area-by-area basis. The large sample size, collected sediment and tissue data, and a sampling strategy based on a previous data resulted in a solid dataset on which to base the exposure point concentrations. Although both the arithmetic mean and the 95% UCL were estimated, the main focus of the evaluation in the refined assessment was conducted using the 95% UCL, which provided a more conservative estimate of the population mean. Therefore, the refined exposure point concentrations are likely to be adequate representations of the average conditions in different areas.

Site Use Factors. San Francisco Bay is a large, rich ecosystem that supports a variety of habitats and numerous species of plants and animals that coexist in a complex and widespread food web. It is probable that most species of benthic-feeding and piscivorous birds forage in areas much larger than the area included in the Validation Study. Additionally, the surf scoter, like many species of birds, is only in San Francisco Bay for a portion of the year. Therefore, the assumption that the birds forage at HPS 100% of the time (as was assumed in the screening level assessment) greatly overestimates their true exposure. This exposure parameter was adjusted in the refined assessment, and a range of values evaluated.

11.1.3.3 Effects Assessment Uncertainties

Development of TRVs requires acquisition and integration of toxicity data from numerous sources in an attempt to define a daily dose (mg/kg-day) that is protective of a particular receptor. Because results of toxicity studies can vary due to a wide range of experimental factors, the TRVs developed for specific species have a level of uncertainty associated with them. Sources of uncertainty in TRVs are discussed below:

Quantity and Quality of Toxicity Data Used to Derive the Toxicity Reference Values. Uncertainties are associated with the quantity and variable quality of literature-derived toxicity data. In order to reduce the uncertainties in the toxicity data set, an extensive search of primary, peer-reviewed literature and secondary literature (e.g., government reports and technical conference proceedings) was performed. The number and types of databases searched were believed to be adequate to capture the majority of relevant sources of ecotoxicological literature. However, it is practically impossible to verify that all applicable data have been identified and evaluated.

Confidence Rating of the Literature Sources Used to Derive the Toxicity Reference Values. To qualitatively evaluate uncertainty associated with literature resources, the Navy's *Interim Final Toxicity Reference Document* (DON, 1998) developed a method to characterize the confidence level of TRVs. Although TRVs can be rated based on confidence, several sources of uncertainty are still associated with the derivation and application of these TRVs. For example, PCBs have the high confidence rating, but a large degree of uncertainty is still associated with this TRV. The confidence rating for the TRV for PCBs does not take into account differences between studies based on Aroclor data and studies based on individual congener data. Furthermore, the TRV is not differentially applied based on the type of site data available. Comparing a dose based on congener data to a TRV based on Aroclor data, or vice-versa, may create a large degree of uncertainty. Likewise, the TRV for lead has a relatively "certain" rating, but several sources of uncertainty are still associated with this TRV. Studies on which the lead TRV is based employed lead acetate, a form of lead not commonly found in nature. Lead acetate is highly soluble and more bioavailable than inorganic lead or other lead salts, making it more toxic than other forms of lead.

Exposure Conditions of Literature Derived Toxicity Reference Values. The majority of the toxicity data that were evaluated were derived from laboratory studies and conducted in settings that do not mimic true field conditions. Laboratory studies typically control various factors in order to isolate one parameter in particular. Although such controlled experiments result in a more valid interpretation of the isolated parameters or relationship, uncertainty is associated with assuming laboratory exposure conditions are equivalent to in-field exposure conditions. As discussed in the following paragraphs, exposure duration and toxicity characterization are two parameters that exemplify the difficulty in translating literature-derived data to data representing the exposure conditions for receptors at HPS.

In development of TRVs, the use of chronic data is preferred. Available toxicological data were not always associated with chronic exposure durations. Therefore, uncertainties were introduced in extrapolating nonchronic test results to chronic receptor toxicity values. These uncertainties were partially handled through the application of uncertainty factors in the derivation of low TRVs.

Uncertainty is associated with the extrapolation of literature-derived toxicity endpoints (especially laboratory-based studies) to equivalent endpoints for receptors at HPS due to discrepancies in exposure conditions. For example, the stressors affecting a receptor exposed to COPECs in the

wild can be very different than those affecting an organism exposed in a laboratory setting. However, the direction, magnitude, and effect of this uncertainty are not known.

Magnitude of Difference between Low TRV and High TRV. Low TRVs derived by the Navy/BTAG process represent a no effect level, whereas the high TRVs represent the mid-range of effects levels found in the literature. There is a critical point on the dose-response curve at which effects will first be seen, but that dose is not known. The difference between the low and high TRVs is typically an order of magnitude, and HQs between 1 and 10 give an indication of how close the dose may be to the no effect or low effects levels represented by the TRVs. When the difference between the low and high TRV for a COPEC is very great, there is a high degree of uncertainty regarding where effects may first be seen.

The difference between the low and high TRVs is greater than an order of magnitude for some COPECs, such as copper and lead. The high TRV for copper is about 23 times the low TRV. The difference in the high and low TRV for copper increases the uncertainty of risk conclusions based on the magnitude of the HQ_{low} because it is unknown whether the dose estimated is approaching where first-effects may be found.

A more extreme case is lead, for which the high TRV is 625 times the low TRV. The screening-level dose assessment for lead resulted in high HQ_{low} values for lead, even at reference stations. The HQ_{high} for lead at HPS never exceeded 1.0. Although such a high HQ at reference sites makes it likely that there would be widespread effects on receptors in San Francisco Bay, these effects are not actually observed. Thus the ecological significance of the lead HQ_{low} calculated for HPS is unclear. In general, concerns about the Navy/BTAG TRV make it difficult to adequately assess the risk to birds from lead. The Navy/BTAG TRV for lead is significantly lower than other widely accepted TRVs such as those from Oak Ridge National Laboratory (Sample et al. 1996) or the U.S. EPA (2003). For example, if the U.S. EPA TRV for birds (1.6 mg lead/kg bw-day) is used to assess effects from lead to the scoter at HPS, risk to lead throughout HPS would be considered negligible.

Use of Surrogate Species Data. In the absence of toxicity data specific to the ROCs (i.e., surf scoter and DCCO), it is preferable to develop TRVs based on data from species that are phylogenetically similar to the scoter. For several COPECs, avian TRVs were developed using data for species that are not similar to the scoter and DCCO in terms of diet or feeding activity. This represents a primary source of uncertainty associated with applying the avian TRVs to dissimilar species. Without species-specific data, it is impossible to determine whether the data from surrogate species appropriately reflect the sensitivity of surf scoters and DCCO. However, for the main risk driver at Area X (PCBs), gallinaceous birds (specifically chickens) have been observed to be among the most sensitive avian species tested, respective to the reproductive and developmental effects of PCBs (Bosveld and Van den Berg 1994; Kennedy et al., 1996). Thus the PCB TRV based on a chicken study should be a conservatively appropriate TRV for scoters and DCCOs.

Conversion of Laboratory TRVs to Receptor TRVs. Test species TRVs were converted to receptor TRVs using an allometric conversion equation based on the ratio of test species and receptor species body weights. This practice is based on scaling theory and is applied to correct for differential food ingestion and metabolism rates that depend on the size of the organism. This theory, as applied to absorption, transport, metabolism, and excretion, assumes that the site ROC and the laboratory study receptors metabolize COPECs in the same manner physiologically and biochemically. However, significant differences exist in these areas that relate to the metabolic activity and physiological processes of individual organisms and species. Therefore, a degree of

uncertainty exists whenever an allometric conversion is applied to adjust a TRV from a test organism to a receptor species. This uncertainty is not quantifiable (and is of unknown magnitude and effect) without conducting toxicity studies on the specific receptors assessed for HPS.

With respect to the uncertainty associated with selecting the appropriate allometric equation for TRV conversion, it is important to note that the seminal research group in this field (Sample et al., 1996) continues to revise their models for interspecies extrapolation. Even apparently small modifications to the recommended allometric equation (e.g., the changes recommended in Sample and Arenal [1999] vs. Sample et al. [1996]) can have substantial effects on TRVs and, thus, risk calculations. For example, HQs go slightly up or down, and for COPECs that have HQs close to one (e.g., copper, nickel and cadmium) this slight difference can be the difference between a finding of risk or no risk. Although the Validation Study evaluation used TRVs based on the latest allometric scaling equations (Sample and Arenal, 1999), it is possible that future models for interspecies toxicity extrapolation may yield different TRVs. However, it cannot be predicted whether such changes will suggest that the risk evaluation presents an overestimate or underestimate of risks.

11.1.3.4 Risk Characterization Uncertainties

Uncertainties associated with the characterization of risk to for the surf scoter in the screening-level dose assessment and the DCCO in the ancillary data assessment are discussed below:

Application of TRVs. Because varying degrees of uncertainty are associated with the TRVs used in this study, equivalent or similar HQs for different COPECs may not indicate a similar level of risk, and risk conclusions should not be extrapolated from one COPEC to another. Ambient concentrations of some COPECs resulted in doses that either were close to the low TRV (e.g., copper) or exceeded it (e.g., lead, nickel, and selenium). These results indicate that, based on the Navy/BTAG TRVs, ambient concentrations of lead, nickel, and selenium are potentially high enough to pose risk.

In addition to the uncertainty associated with application of TRVs from laboratory studies to receptors in the wild, the characterization of risk to avian receptors at HPS is inherently uncertain because a number of constituents were detected for which little or no avian toxicity data are available. For those constituents for which no avian toxicity data were available, neither a quantitative nor a qualitative assessment of ecological risk was possible. For a number of COPECs, even though some toxicity data were available, the quality and/or quantity of these data precluded development of TRVs. The exclusion of these COPECs from the risk characterization process is a source of uncertainty, and potentially resulted in an underestimate of ecological risk.

Species Representativeness. The Validation Study evaluated potential risk to benthic invertebrates through two different toxicity bioassays and bioaccumulation risk to scoters. Other taxa (including benthic fish, marine mammals and other species of birds) were not quantitatively evaluated. Although this results in uncertainty, its impact on the conclusions of the Validation Study are likely to be low for the following reasons.

Fish: Available toxicity data for various fish and invertebrate endpoints were compiled to assess the relative sensitivity of invertebrates vs. fish. For many contaminants, invertebrate endpoints were found to be more sensitive than fish endpoints. Additionally, ecotoxicity reference values (ERVs) based on effects-based critical body residues developed for the Navy for the *Baseline Ecological Risk Assessment at Pearl Harbor* (DON, 2002) were used to evaluate potential toxicity to fish. Except for aluminum (which is likely to be an anomaly), there is no evidence that

tissue concentrations of any COPEC measured in forage fish tissue at HPS exceed the LOAEL ERV concentrations. Only one COPEC, PCBs at Area X, exceeds the NOAEL ERV (the LOAEL ERV is not exceeded). Although an exceedance of the NOAEL ERV is not by itself an indication that there is risk to the forage fish population at Area X, it does lend an additional line of evidence supporting the identification of PCBs as the primary risk driver at Area X.

Marine mammals: Based on an analysis of potential exposure routes to harbor seals (e.g., dermal exposure while at haul-outs, incidental ingestion of sediment while foraging, and ingestion of prey that have accumulated contaminants from sediments), contribution of potential contaminants in sediment at HPS to the overall exposure of the harbor seal is considered to be minimal (Battelle et al. 2001a). Therefore, the exclusion of a quantitative evaluation of the harbor seal is not expected to result in an underestimate of risk.

Birds: Focusing solely on the avian evaluation, the uncertainty associated with characterizing risk solely to benthic-feeding birds was evaluated by conducting a dose assessment on piscivous birds (the double-crested cormorant) using field-collected forage fish. The outcome of the dose assessment on the double-crested cormorant was similar to that of the scoter. Even for the bioaccumulative organic COPECs that tended to be in higher concentrations in forage fish, the magnitude of the HQs resulted in similar conclusions to that of the scoter. Thus, decisions made based on the scoter also are protective of the cormorant. Therefore, results of the scoter risk characterization should be representative of risks to upper trophic level avian receptors at HPS.

Great care was taken to select avian ROCs that were: (a) present in large numbers at HPS and (b) possessed life history characteristics that would expose them to the highest concentrations of contaminants through readily identifiable and complete exposure routes. However, because not all species potentially exposed to site contaminants are represented by these ROCs, uncertainty exists as to whether the risks calculated for the surf scoter and double-crested cormorant underestimate or overestimate site-related risks to other avian species.

Linkage Between Results of Validation Study and Regional Species Information. It is uncertain how the results of the Validation Study relate to regional information on scoter and DCCO populations in San Francisco Bay. Currently, available information on scoters in San Francisco Bay is lacking and data on DCCO populations in San Francisco Bay are equivocal concerning the health of the population (e.g., Stenzel et al., 1995; Davis, 1997). Impacts at the level of the individual, as evaluated using the simple HQ approach, can be difficult to extrapolate to the population level. This extrapolation becomes even more complicated when there is natural variability in the demographic parameters of the population of interest and the potential that stochastic environmental effects are significant. Although this is a source of uncertainty, the issue can be conservatively addressed by assuming that impacts to these species are sufficiently large that they require further evaluation in a FS.

Effects of Exposure to Chemical Mixtures and Noncontaminant Stressors. Exposure to a mixture of chemicals can result in additive, synergistic, or antagonistic toxicity. The toxicological concept of additivity is defined as the effect of two or more chemicals that, when given simultaneously, will produce a response that is additive of their individual responses at the target (Amdur et al., 1991). Thus, two compounds that are hepatotoxic may have additive toxicity on the liver. Conversely, if two chemicals bind at the same site, or produce opposite effects on the same function, they may have a combined effect that is less than their individual responses resulting in an antagonistic effect (Amdur et al., 1991). Synergistic toxicity can occur in cases where one compound may interfere with the toxicokinetics of another (e.g., by inhibiting its detoxification pathway), resulting in a potentiation of toxicity.

A hazard index approach can be used to address the additive toxicity of chemical mixtures. The main purpose of addressing exposure to a chemical mixture by using a hazard index is to conservatively identify potential contaminants of concern that individually may not pose a potential risk, but in combination with other compounds has additive interactions. This approach minimizes the possibility that a site may be identified as requiring no further action when it really does pose a risk (because individual HQs are less than 1 but additive contaminants have a hazard index greater than one).

The challenge of using a hazard index with ecological receptors is that one needs to know what COPECs impact similar targets and should be added together. The U.S. EPA's *Ecological Risk Assessment Guidance for Superfund* (U.S. EPA, 1997b, page 2-4) recommends that a HI only be developed for those contaminants that produce toxicity by the same toxic mechanism.

A HI approach was not used at HPS to evaluate exposure of birds to a mixture of compounds. Although this may underestimate potential toxicity, it is unlikely to result in a significant underestimation of risk, because once an individual compound is identified as posing a potential risk, it becomes a risk driver to be evaluated in the FS. Copper, mercury, and PCBs were all individually identified as posing potential risk to birds at Parcel F and will be evaluated in the FS. Because Parcel F will be evaluated in an FS, there should be no concern that the site will be incorrectly identified as not posing a potential risk.

Another source of uncertainty concerns the potential combined effects of contaminant exposure and non-contaminant stressors such as changes in habitat, prey abundance, and reproductive state. Noncontaminant stressors can adversely affect physiological processes involved in limiting toxicity through, for example, metabolic detoxification and/or increased rates of excretion. Because the presence and magnitude of non-contaminant stressors are extremely difficult to quantify, they are not directly reflected in the Validation Study risk calculations. Although this represents a potential source of uncertainty in the assessment, this uncertainty is commonly understood to be accounted for through the use of conservative exposure and toxicity assumptions used in the risk evaluation.

11.2 Uncertainty Associated with Human Health Assessment

The sources of uncertainty associated with the HHE and the potential biases in the results are presented in this section. Quantitative risk estimates derived in this assessment are conditional (contingent estimates), and include a number of assumptions about local fishing practice, land use, exposure, and toxicity. None of the risk estimates can be separated from these assumptions of the uncertainties inherent in the numerical values of the parameters used to calculate them. The calculated cancer risks and noncancer hazards are contingent on the assumptions and parameter assignments made in deriving them. With respect to the data evaluation, the major uncertainties include:

- The use of *M. nasuta* as surrogates to simulate tissue concentrations representative of other shellfish species is conservative because *Macoma* are aggressive filter feeders, particularly in comparison to the mussels typically found at HPS that passively filter the water rather than the sediment to obtain their food. As a result, it is probable that *M. nasuta* tissue concentrations would overestimate concentrations in the mussels for many chemicals.

- Estimates of exposure point concentrations were based on either the maximum measured tissue concentrations or 95% UCL of the mean, and were assumed to stay constant indefinitely without allowing for decreasing concentrations over time. For environmental

media with time-varying chemical concentrations, the current levels found in sediment may not accurately characterize long-term exposure conditions.

- One-half the method detection limit was used for chemicals not detected in tissue.

- The total PCB concentration was estimated by either summing the Aroclor concentrations or summing the individual detected congener concentration and multiplying by two. Comparisons of the total congener concentration to the sum of the total Aroclors indicate a relationship that is less than two. Therefore, the use of the congener data may overestimate the actual risks associated with exposure to PCBs.

Quantitative estimates of dose were derived to estimate the RME and are conditional estimates that include numerous assumptions on the type of exposures that may occur, the frequency and duration of those exposures, and the concentration of constituents at the point of exposure. Hypothetical future residential exposures were evaluated to comply with regulatory policy, but it is unclear if they will actually occur with any regularity at the site. Relatively conservative assumptions are used for many of the exposure parameters, resulting in a compounding effect. No attempt is made in this assessment to quantify this compounding effect on the cumulative risk estimates. The overall approach was intended to provide a conservative estimate of dose to avoid underestimating the risk. The following discussion provides a list of uncertainties associated with the exposure assessment.

- Activities that differ from the assumptions made for a particular exposure pathway could lead to exposures different than those quantified. In addition, the probability of occurrence was not included in the quantification of risk.

- One major area of uncertainty in the exposure assessment is the prediction of human activities that may lead to consumption of shellfish. The degree to which a future resident is assumed to be harvesting and consuming shellfish captured off the shoreline of HPS is conservative. Because of the habitat along the shoreline, only limited mussel burrows actually exist at a few of the areas. Therefore, the mussel population at the site may not be large enough to support the assumed consumption rate.

- The RME was estimated for all pathways quantified. Parameters were selected to estimate the reasonable maximum; however, the use of multiple conservative parameters in this scenario can result in an estimate of intake above the upper 95 percent confidence interval. The average or central tendency exposure was presented as well, which likely represents a more typical level of risk related to consumption of seafood by future residents.

- An assumed exposure duration of 9 years was used for typical individuals. For the RME, an exposure duration of 30 years was assumed. These assumptions were based on recommendations by U.S. EPA (1989) and represent upper bound and average residential tenure at a single location.

- Use of RfDs and carcinogenic slope factors in the toxicity assessment is subject to several types of uncertainties. The studies from which these values are derived typically involve conditions that are not identical to the type of exposures of interest involving chemicals in the environment. Extrapolations from animal experiments are frequently required to derive toxicity values for use in risk assessments. Uncertainty can be associated with extrapolations involving:

— High experimental doses to low environmental exposure doses.

— Animals used in experimental studies to humans.

— Short-term exposure to long-term exposure.

— Homogenous animal populations to heterogeneous human populations, which can vary substantially in their individual dose-response actions.

— Continuous experimental doses to intermittent human exposures.

The methods used to derive slope factors and RfDs are intended to be conservative in recognition of these types of uncertainties. For noncarcinogens, uncertainty factors are applied to either the NOEL or LOEL; for carcinogens, a slope factor at the estimated 95 percent upper confidence limit is used. The resulting toxicity values used in quantitative risk assessment calculations are likely to overestimate the true risk. Carcinogenic slope factors assume no threshold for effects; if thresholds for carcinogenicity exist, the true risks could be zero at sufficiently low doses.

The overall quality of the toxicology database also contain numerous uncertainties resulting from:

- Lack of consistency between different experimental studies.
- Limited numbers of studies.
- Lack of available information on multiple species and multiple exposure routes.
- Lack of demonstrable dose-response relationships.
- Lack of plausible biological mechanisms of action.
- Lack of direct evidence of effects in humans.

For ingestion exposures, the bioavailability of chemicals in the human body is assumed to be the same as that in the study organism from which toxicity factors were developed. Most toxicity parameter values are calculated to be used with administered rather than absorbed doses; however, there values still reflect the bioavailability of the as-administered form. Risks are likely to be overestimated if chemical bioavailability from environmental media is less than that from the experimentally administered doses in toxicological studies.

- The toxicity of each chemical was assumed to be additive. Interactions between chemicals, synergism, or antagonisms were not accounted for due to the limited toxicity information on these types of interactions. Interactions could result in overestimates or underestimates of risk.

- Risks associated with exposure to lead were not quantified in this assessment due to the lack of specific algorithms in U.S. EPA and DTSC lead uptake models to adequately model this exposure pathway. Lead concentrations at HPS were found to be below those measured at the reference stations. In addition, the lead concentrations were significantly below U.S. EPA Region 9 PRGs for soil which are based on exposure to children through ingestion, dermal contact, inhalation of lead from soil, groundwater, and air. Based on these comparisons, levels of lead at HPS do not appear to be significant.

Uncertainties associated with estimating cancer risk and noncancer hazard are primarily those that have been built into the process of deriving the estimates, as previously discussed.

- Multiple constituent, multiple pathway risks were evaluated assuming additivity of risks. Possible interactions (antagonistic or synergistic) that could occur among the various

constituents present are not included in this assessment. Interactions could result in over- or underestimates of the risks.

In summary, because the majority of assumptions regarding EPCs and contact rates made in this assessment are conservative, and tend to overestimate exposure and risk, the incremental risks to the defined receptor populations from exposure to COPCs at HPS are likely to be overestimated.

12.0 SUMMARY AND CONCLUSIONS

This section summarizes the major findings of the Validation Study and provides conclusions regarding the proposed study area for the Parcel F FS.

12.1 Summary

This report presents the results of a Work Plan developed in a collaborative effort between the Navy and agency technical group. Data for three lines of evidence (i.e., sediment chemistry, toxicity, and bioaccumulation) were collected at 59 HPS sampling stations and evaluated in a WOE framework. Ancillary data, including field-collected tissue data and TIE study results, were used in conjunction with results for the three lines of evidence to identify contaminants and pathways driving ecological risk at the site. Subsurface sediment samples were analyzed to characterize the vertical extent of contamination. A human health evaluation also was performed to evaluate potential health risks from the consumption of shellfish at HPS and to determine whether chemical concentrations in sport fish caught at HPS with fish are higher than those in fish caught elsewhere in San Francisco Bay. Site-specific data were used to develop PRGs and identify areas for consideration in the Parcel F FS.

FS-related data also were collected as part of the Validation Study to support the evaluation of remedial alternatives. This information included a sediment dynamics study, analysis of ^{210}Pb and ^{137}Cs radio-isotopes in sediment cores, and physical and chemical sediment characterization. This information will be incorporated into the FS for Parcel F. Validation Study results are summarized below.

12.1.1 Three Lines of Evidence

The primary findings for the sediment chemistry, toxicity and bioaccumulation lines of evidence are provided below.

12.1.1.1 Sediment Chemistry

Surface sediment chemistry results indicate that chemical concentrations generally are not elevated above ambient levels and ER-Ms in Areas I (India Basin) and VIII (Eastern Wetland). The highest chemical concentrations (primarily PCBs, metals, and TBT) are found in Areas III (Point Avisadero) and X (South Basin). Concentrations of several chemicals were elevated above ambient levels and ER-Ms at some nearshore stations in Area IX (Oil Reclamation).

In Area III, the primary COPECs in sediment samples were copper, mercury, PCBs, and TBT. The horizontal and vertical distribution of chemicals in Area III sediments is patchy and discontinuous, and many COPECs do not co-occur. The depths of the highest chemical concentrations are not consistent from one station to another or from one COPEC to another. The chemicals detected in Area III sediments were most likely derived from historical ship painting and maintenance activities that were carried out in the adjacent dry docks. Some of the waste materials appear to have been discharged into the offshore area via a drainage tunnel that leads north from Dry Docks 2 and 3 into Area III. Some contaminants also may have been discharged from stormwater outfalls, particularly on the eastern side of Point Avisadero. The variable and patchy distribution of contaminants appears to reflect an episodic input of contaminants and subsequent redistribution of nearshore sediments by waves and currents.

In Area X, the highest concentrations of PCBs, TBT, and metals (primarily copper, mercury, and lead) are found along the eastern shoreline of South Basin. Chemical concentrations decrease with increasing distance from this shoreline. The highest concentrations of PCBs and metals were found in the 0-2 ft core sample at all but two stations. Concentrations were significantly lower below 2 ft. The relatively lower

concentrations in the surface (i.e., 0-5 cm) samples at most of the stations compared with the 0-2 ft samples suggests that burial by relatively cleaner sediment has occurred. Additional data on the vertical distribution of contaminants were collected as part of the FS data gaps investigation to determine the depth of maximum chemical concentrations with greater certainty (Battelle et al., 2005).

The most likely sources of the contaminants in Area X are the Site IR-01/21 landfill area, Parcel E fill material, and/or a historical drum storage area used by the Triple A Machine Shop. Contaminants most likely were transported to the offshore area via erosion and transport of contaminated Parcel E soils in and near the landfill and drum storage area. Additional investigation of the Site IR-01/21 landfill is underway and Parcel E shoreline sampling has been performed to further characterize these potential sources (TtEMI, 2003b).

Concentrations of PCBs, metals, and some pesticides were elevated in samples collected near the mouth of Yosemite Creek. These contaminants most likely were transported into South Basin via Yosemite Creek and were not derived from Parcel E because (1) chemical concentrations are lower in the area between Yosemite Creek and the eastern shoreline of South Basin (i.e., a concentration gradient from an identified Parcel E source does not exist; (2) currents in South Basin are weak and significant upstream transport of sediment-associated contaminants from the Parcel E shoreline is unlikely; (3) contamination was detected previously in samples collected from Yosemite Creek upstream of HPS as part of the BPTCP; and (4) the composition of the PCBs in samples collected near and from Yosemite Creek appears to be different than the composition of PCBs occurring near the eastern shoreline of South Basin.

12.1.1.2 Toxicity

Sediment samples from Areas I, III, VIII, IX, and X were not acutely toxic to amphipods based on a 10-day bulk sediment bioassay. Survival of the *E. estuarius* exposed to HPS surface sediments was similar to, and often higher than, survival of *E. estuarius* exposed to San Francisco Bay reference site sediments. The confounding factors that were suspected of influencing amphipod bioassay results in previous studies (e.g., organism acclimation and holding, appropriate organism sensitivity, monitoring and control of ammonia, monitoring and control of other water quality parameters) were controlled successfully during the Validation Study.

Sediment samples from Areas I, III, VIII, IX, and X generally were not acutely toxic to echinoderms, as indicated by normal development of purple urchin (*S. purpuratus*) larvae exposed to intact SWICs. However, normal larval development was below the ambient threshold for San Francisco Bay at 13 of the 59 HPS sampling stations. Larval toxicity did not appear to be related to elevated sediment COPEC concentrations. Ammonia might have contributed to observed toxicity at some stations in Areas III and VIII. Other potential confounding factors that could have contributed to toxicity were poor water quality, field replicate variability, and the presence of native flora and fauna in the undisturbed cores.

12.1.1.3 Bioaccumulation

A laboratory bioaccumulation test was conducted to evaluate the uptake of sediment contaminants into the tissue of the clam *M. nasuta*. Screening and refined dose assessments were performed using depurated *M. nasuta* tissue data to evaluate potential risk to benthic-invertebrate eating birds (i.e., surf scoter) exposed to HPS sediments. The screening assessment consisted of a station-by-station evaluation of upper trophic level risk. Screening results indicated that most stations in Areas I and VIII pose little to no risk to surf scoters. A higher proportion of stations in Areas III, IX, and X showed a potential risk.

The refined assessment was performed using average exposures over the entire HPS site and over Areas I, III, VIII, IX, and X. Additionally, a range of SUFs was considered. The refined assessment identified

copper, mercury, lead, and PCBs as upper trophic level risk drivers when higher SUFs (i.e., ≥0.5) were considered; HQ_{low} values for all COPECs except lead were below 1.0 when SUFs of <0.1 were used. HQ_{low} values for lead were high for all scenarios, including consideration of ambient exposure only. Ambient concentrations of lead, copper, and mercury provide a significant contribution to the overall risk when SUFs of less than 1.0 are used for HPS Parcel F. However, the majority of the potential risk from PCBs can be attributed to the portion of the diet obtained at HPS even when lower SUFs are used. Bioaccumulation of mercury and copper in Area III appeared to be elevated over ambient. Based on these findings, PCBs, mercury and copper were identified as the primary risk drivers and were used as the basis for developing PRGs. Lead was identified as a potential contributor to risk; however, it cannot be definitively identified as a primary risk driver because of the uncertainty associated with evaluating risk associated with exposure to lead. Areas with potential risk from exposure to lead are qualitatively addressed because the highest lead concentrations in Area X sediment generally co-occur with high PCB concentrations.

12.1.2 Ancillary Data

Ancillary data were evaluated in conjunction the results of the three lines of evidence (Sections 4.0-6.0) and the Human Health Evaluation (Section 9.0) to identify primary risk drivers and develop PRGs. Results of ancillary data collection are summarized below.

12.1.2.1 TIE Studies

TIE studies were conducted by BSL as part of the Validation Study and by SAIC/EFANE as part of a broader technology demonstration program. The Battelle TIE focused on the effects of ammonia in a SPP exposure, whereas the SAIC/EFANE TIE focused on the relative contribution of various groups of chemicals to toxicity from porewater exposures. In general, the results of the two TIE studies were consistent, and identified ammonia as the predominant source of toxicity. Both studies also identified metals as a suspected contributor to observed toxicity for some stations, although in most cases the extent of the contribution or identity of a specific toxic metal could not be determined. The general conclusion drawn from the TIE studies is that under certain environmental conditions, ammonia or metals could exert a toxic influence on larvae of some species. However, under the conditions represented by the Validation Study toxicity tests (i.e., bulk sediment and SWI exposures), toxicity was generally reduced or not observed at all.

12.1.2.2 Nondepurated **M. nasuta** *and Field-Collected Tissue Data*

Nondepurated *M. nasuta* data and the field-collected tissue data (both invertebrate and forage fish tissue) were compared with depurated *M. nasuta* tissue data in order to support the bioaccumulation line of evidence. COPEC concentrations in nondepurated *M. nasuta* and field-collected tissue samples generally showed similar spatial patterns and trends as observed in the depurated, laboratory-exposed *M. nasuta* samples, although concentrations in soft-bodied invertebrate (i.e., polychaete) tissue were higher than those in other tissue types.

12.1.3 WOE Evaluation

The results for the three lines of evidence were evaluated using decision criteria specified in the VS Work Plan (Battelle et al., 2001a). The WOE approach was not intended to be prescriptive; rather, it was used as a tool to assist in data interpretation. The WOE results were not used directly to identify areas for consideration in the FS because integrated results for many stations indicated that additional evaluation was needed to determine whether or not the station should be included in the FS footprint. Therefore, all results were evaluated, including the three lines of evidence (sediment chemistry, toxicity, and

bioaccumulation), ancillary data, and the human health evaluation to identify pathways and contaminants driving ecological and human health risk in each of the five areas included in the Validation Study.

12.1.4 Human Health Evaluation

Potential human health risks from shellfish consumption and direct contact with sediment during shellfish collection were evaluated on a station-by-station basis and on an area-wide basis using *M. nasuta* tissue data from the laboratory bioaccumulation test. The exposure parameters for direct contact with sediment are similar to those for a wading scenario. Risks from direct contact with sediment were more than 100 times lower than risks from shellfish ingestion. On an area-wide basis, cumulative risks to humans from Parcel F sediments were comparable to risks from ambient conditions in San Francisco Bay with the exception of exposure to PCBs. In general, risks associated with PCBs were highest on the south side of HPS, particularly in Areas IX and X. This conclusion is supported by both the shellfish evaluation and the statistical comparison of recreationally preferred sport fish from HPS and elsewhere in San Francisco Bay. However, the contribution of total PCBs to the area-wide cumulative risk in Areas IX and X is minimal (about 1%) due to the presence of other chemicals (e.g., arsenic, dioxin) that are comparable to ambient conditions.

12.1.5 Identification of Areas for Evaluation in the Parcel F FS

Areas I, III, VIII, IX, and X will be evaluated in the Parcel F FS. RAOs will be developed during the FS scoping process to address ecological and human health risk concerns as well as source control issues. Area III (Point Avisadero) and Areas IX-X (South Basin) pose the greatest potential risk to ecological receptors. Mercury and copper were identified as the primary risk drivers in Area III, and PCBs were identified as the primary risk driver in Areas IX-X. Potential human health risks from consumption of shellfish from Area III are similar to reference. Cumulative human health risk from consuming shellfish in Areas IX-X exceeds reference levels; of the individual chemicals contributing to risk, only the risk from PCBs is elevated above reference levels. Sediments in Areas I (India Basin) and VIII (Eastern Wetland) pose a low potential ecological or human health risk. However, shoreline material in both areas may act as potential future sources of contamination to offshore areas. In addition, radiological surveys will be performed in areas as recommended by the Historical Radiological Assessment (DON, 2004).

12.1.6 Development of PRGs

Sediment PRGs based on risk to benthic invertebrate-feeding birds (i.e., the surf scoter) from PCBs, mercury and copper were developed using the collocated sediment and laboratory-exposed *M. nasuta* tissue data. These data provide a strong, direct link between sediment-associated contaminants and tissue. Ranges of PRGs for sediment based on SUFs of 1 to 0.01 are 135 mg/kg to 13,500 mg/kg dry weight for copper, 0.94 mg/kg to 94 mg/kg dry weight for mercury, and 0.62 mg/kg to 62 mg/kg dry weight for PCBs.

PCB PRGs also were developed for a piscivorous bird receptor (i.e., the DCCO). The PCB PRGs for sediment based on SUFs of 1 to 0.1 for the DCCO range from 0.23 mg/kg to 23 mg/kg dry weight. Because the DCCO is likely to forage over larger areas than the scoter, PRGs for the DCCO should be based on smaller SUFs than those for the scoter. Therefore, PRGs based on the scoter should be adequately protective of piscivorous birds such as the cormorant.

These PRGs will be evaluated in conjunction with contaminant distribution data as part of the FS scoping process to help identify areas for consideration in the FS.

12.1.7 FS-Related Data

Results of the FS-related data collected as part of the Validation Study are summarized below. These data will be combined with additional data collected for the FS data gaps investigation (Battelle et al., 2005) in the Parcel F FS.

12.1.7.1 Sediment Dynamics Study

The sediment dynamics study characterized sediment transport patterns around HPS based on site-specific field measurements and modeling (Appendix L). The study focused on Area III (Point Avisadero) and Area X (South Basin). The study found that near-bottom tidal currents on the north side of Point Avisadero are strong and will resuspend loosely consolidated surficial sediments. Residual circulation in South Basin is weak and highly variable, and the basin appears to be an area of sediment accumulation. Tidal circulation in South Basin does not erode sediments, although infrequent winter storms result in wave-induced sediment resuspension. However, resuspended sediments are not likely to be transported out of South Basin because of the weak residual circulation. Although not quantified by the study, model predictions indicate that extreme storms from the southeast will result in the erosion of sediments in South Basin. Additional data regarding the site-specific erosional properties of the sediment bed were collected as part of the FS Data Gaps investigation.

12.1.7.2 Radioisotope Data

Profiles of the radioisotopes ^{210}Pb and ^{137}Cs were measured in seven cores from HPS and Yosemite Creek. Cores collected in Areas I and X were determined to be the most suitable for age dating because they exhibited a uniform fine-grained texture and homogeneous structure, indicating a relatively uniform depositional environment. The radioisotope profiles from the Area X cores most closely approximated the ideal profiles that would result from deposition in undisturbed conditions, although all cores indicated some degree of deviation from the ideal. The average sediment accumulation rate for the three cores collected in South Basin was estimated to be about 1 cm/yr. Sediment accumulation rates determined for other areas are less reliable because of evidence that either sedimentation processes were not uniform or subsequent disturbance of the sediment column occurred. The presence of polychaetes in the upper 1-2 ft of sediment in many cores from South Basin indicates that some mixing of surface and subsurface sediments to these depths may occur.

12.1.7.3 Physical and Chemical Sediment Characterization

Sediment samples collected from Areas III and X were analyzed to evaluate upland disposal and beneficial reuse options and to establish dewatering and stabilization characteristics. Results indicate that the sediments most likely to require remediation would be classified as nonhazardous but are unlikely to be suitable for beneficial reuse. Air-drying and plate-and-frame compression were equally effective in dewatering sediments; centrifuge dewatering was the least effective method. Addition of fly ash or hydrated high calcium lime slightly increased the strength of the Area III sediment; however, neither additive had an appreciable effect on Area X sediment, which was a clayey sand. The physical characteristics of the treated sediment indicate that it would only be suitable for lightly loaded subgrade applications with relatively flat, if any, exposed side slopes. The treated material would not be suitable for reuse in any application where a high degree of stability or strength is required.

12.2 Conclusions

The primary objective of the Validation Study was to identify the area of offshore sediments that require evaluation in the Parcel F FS. The primary conclusions of the Validation Study are as follows:

- Based on the pathways evaluated in the Validation Study, ecological risk associated with offshore sediments at HPS can be attributed primarily to bioaccumulation and food-chain transfer to upper trophic level receptors. The data collected in the Validation Study are insufficient for fully characterizing risks to upper trophic level receptors that forage primarily on polychaetes. Sediments in Area III (Point Avisadero) and Areas IX-X (South Basin) pose the greatest potential risk to ecological receptors.

- Potential sources of contamination along the shoreline in all areas (i.e., Areas I, III, VIII, IX, and X) should be evaluated and addressed as part of Parcel B and E activities.

- Cumulative human health risks are comparable to risks from ambient conditions in San Francisco Bay with the exception of exposure to PCBs in South Basin (Areas IX and X). Potential human health concerns should be addressed in the RAOs for Parcel F.

- PCBs, copper and mercury are the primary ecological risk drivers. The significance of risk estimates associated with the evaluation of field-collected tissue data is uncertain. These uncertainties should be addressed in the FS scoping process to ensure that a protective FS footprint is developed.

Information on sediment dynamics and sediment characteristics also was collected in the Validation Study to support the Parcel F FS. The FS-related data indicate that South Basin is an area of sediment accumulation with an average sedimentation rate of about 1 cm/yr. The occurrence of lower chemical concentrations in the 0-5 cm samples than in the collocated 0-2 ft samples at most stations supports the hypothesis that natural burial by relatively cleaner sediment is occurring. Higher-resolution data on the distribution of contamination in the upper 2 ft were collected as part of the FS data gaps investigation to provide a more detailed three-dimensional CSM for the FS. Infrequent winter storms cause wave-induced resuspension of sediments in South Basin, and extreme event storms may erode the sediment bed. Site-specific data on the erosional properties of the sediment bed were collected as part of the FS data gaps investigation to predict the effects of extreme erosional events with greater certainty (Battelle et al., 2005).

13.0 REFERENCES

ADL, see Arthur D. Little.

Ainley, D.G. 2000. "Double-Crested Cormorant." In: P.R. Olofson (ed.), *Baylands Ecosystem Species and Community Profiles: Life Histories and Environmental Requirements of Key Plants, Fish and Wildlife*. Prepared for the San Francisco Bay Regional Water Quality Control Board.

Ainley, D.G., D.W. Anderson, and P.R. Kelly. 1981. "Feeding Ecology of Marine Cormorants in Southwestern North America." *Condor, 83*: 120-131.

Amdur, M.O., J. Doull, and C. Klaassen. 1991. *Casarett and Doull's Toxicology: The Basic Science of Poisons*. 4th Edition. Pergamon Press.

American Society for Testing and Materials. 1984. *Standard Practice for Description and Identification of Soils*. ASTM D 2488-84. Philadelphia, PA.

American Society for Testing and Materials. 1992. *Standard Guide for Conducting 10-Day Static Sediment Toxicity Tests with Marine and Estuarine Amphipods*. ASTM E 1367-92. Philadelphia, PA.

Anderson, B.S., J.W. Hunt, M. Hester, and B.M. Phillips. 1999. "Assessment of Sediment Toxicity at the Sediment-Water Interface." *Techniques in Aquatic Toxicology.* CRC Press, Inc., Boca Raton, FL.

Anderson, B.S., J.W. Hunt, B.M. Phillips, R. Fairey, H.M. Puckett, M. Stephenson, K. Taberski, J. Newman, and R.S. Tjeerdema. 2001. "Influence of Sample Manipulation on Contaminant Flux and Toxicity at the Sediment-Water Interface." *Marine Environmental Research, 51*(3): 191-211.

Anderson, B.S. 2002. Personal communication: Letter to Jeff Ward, Battelle Sequim Laboratory, from Brian Anderson, Marine Pollution Studies Laboratory, Santa Cruz, CA. January 29.

Aplin, J.A. 1967. *Biological Survey of San Francisco Bay, 1963-1966.* California Department of Fish and Game. Mar. Resour. Oper. MRO Ref. 67-4. 131 pp.

Aqua Terra Technologies. 1991. *Environmental Sampling and Analysis Plan for Naval Station Treasure Island, Hunters Point, San Francisco, California*. July.

Arthur D. Little. 1999. *Phase II Sampling and Analysis Plan, Sediment Studies at Islais, Mission and Yosemite Creeks, Fall 1999*. Prepared for the City and County of San Francisco Public Utilities Commission. November 8.

ASTM, see American Society for Testing and Materials.

ATT, see Aqua Terra Technologies.

Battelle. 2001. *Hunters Point Shipyard Parcel F Validation Study and Human Health Evaluation Field Summary Report.* Prepared for Southwest Division, Naval Facilities Engineering Command. July 26.

Battelle. 2004. *Hunters Point Shipyard Parcel F Feasibility Study Data Gaps Investigation Field Summary Report.* Prepared for Southwest Division, Naval Facilities Engineering Command. February.

Battelle, ENTRIX Inc., and Neptune and Co. 1999. *Hunters Point Shipyard Parcel F Data Summary Memorandum*. Working Draft. Prepared for Engineering Field Activity West, Naval Facilities Engineering Command. November.

Battelle, ENTRIX Inc., and Neptune and Co. 2001a. *Hunters Point Shipyard Parcel F Validation Study Work Plan. Final.* Prepared for Southwest Division, Naval Facilities Engineering Command. April 23.

Battelle, ENTRIX Inc., and Neptune and Co. 2001b. *Hunters Point Shipyard Parcel F Human Health Evaluation Work Plan. Final.* Prepared for Southwest Division, Naval Facilities Engineering Command. May 2.

Battelle, ENTRIX Inc., and Neptune and Co. 2001c. *Seaplane Lagoon (IR Site 17) Fish Tissue Evaluation Work Plan, Alameda Point.* Prepared for Southwest Division, Naval Facilities Engineering Command. May 18.

Battelle, Sea Engineering Inc., and Neptune & Company. 2005. *Draft Hunters Point Shipyard Parcel F Feasibility Study Data Gaps Investigation Technical Memorandum.* Prepared for Southwest Division, Naval Facilities Engineering Command. February.

Bosveld, A.T.C., and M. Van Den Berg. 1994. "Effects of Polychlorinated Biphenyls, Dibenzo-p-dioxins and Dibenzofurans on Fish-Eating Birds." *Environ. Rev., 2*: 147-166.

Davis, J.A., D.M. Fry, and B.W. Wilson. 1997. "Hepatic Ethoxyresofurin-o-deethylase Activity and Inducibility in Wild Populations of Double-Crested Cormorants (*Phalacrocorax auritus*)." *ET&C, 16*(7): 1141-1449.

Department of Toxic Substances Control. 2001. California Cancer Potency Values. Available at: www.oehha.ca.gov/risk/chemicalDB/index.asp.

Department of Toxic Substances Control. 2002. LeadSpread Version 7. Available at: www.cwo.com/~herd1/ledspred.htm.

DON, see United States Department of Navy.

DTSC, see Department of Toxic Substances Control.

Gilbert, R.O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. Van Nostrand Reinhold, New York, NY.

Harding Lawson Associates. 1991. *Preliminary Draft Ecological Risk Assessment Data Summary Report*. November.

Hatch, J.J., and D.V. Weseloh. 1999. "Double-Crested Cormorant." In: A. Poole and F. Gill (eds.), *The Birds of North America*. pp 1-35.

HLA, see Harding Lawson Associates.

Kennedy, S.W., A. Lorenzen, S.P. Jones, M.E. Hahn, and J.J. Stegman. 1996. "Cytochrome P4501A Induction in Avian Hepatocyte Cultures: A Promising Approach for Predicting the Sensitivity of Avian Species to Toxic Effects of Halogenated Aromatic Hydrocarbons." *Toxicol. Appl. Pharmacol., 141*: 214-230.

Long, E.R., and L.G. Morgan. 1991. *The Potential for Biological Effects of Sediment-Sorbed Contaminants Tested in the National Status and Trends Program*. NOAA Technical Memorandum NOS OMA 52. Seattle, WA. March.

Long, E.R., D.D. MacDonald, S.L. Smith, and F.D. Calder. 1995. "Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments." *Environmental Management, 19*(1): 81-97.

Madenjian, C.P., T.J. DeSorcie, R.M. Stedman, E.H. Brown, G.W. Eck, L.J. Schmidt, R.J. Hasselberg, S.M. Chernyak, and D.R. Passino-Reader. 1999. "Spatial Patterns in PCB Concentrations of Lake Michigan Lake Trout." *J. Great Lakes Res., 25*(1): 149-159.

Mahaffy, M.S., C.R. Bennett, and W. Parsons. 1995. "Puget Sound Waterbirds as Contaminant Monitors." *Puget Sound Research '95, Proceedings*. Puget Sound Water Quality Authority. January 12-14.

Moffet and Nichols Engineers. 1981. "Facility Certification Reports Triple A Shipyard – Dry Docks 2 and Dry Dock 4." September 1.

Moss Landing Marine Laboratories. 2001. *Draft Standard Operating Procedures for Field and Laboratory Processing of Fish Tissue Samples*. Prepared for the San Francisco Estuary Institute.

National Oceanographic and Atmospheric Administration. 1998. *Sampling and Analytical Methods of the National Status and Trends Program Mussel Watch Project: 1993-1996 Update*. NOAA Technical Memorandum NOS/ORCA/CMBAD 130. National Oceanographic and Atmospheric Administration, Silver Springs, MD.

NOAA, see National Oceanographic and Atmospheric Administration.

OEHHA, see Office of Environmental Health Hazard Assessment.

OEHHA. 1994. Health advisory on catching and eating fish: Interim sport fish advisory for San Francisco Bay. Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, Sacramento, CA. http://www.OEHHA.ca.gov/fish/nor_cal/int-ha.html.

Ohlendorf, H.M., R.W. Lowe, P.R. Kelly, and T.E. Harvey. 1986. "Selenium and Heavy Metals in San Francisco Bay Diving Ducks." *J. Wild. Manage., 50*(1): 64-71.

Ohlendorf, H.M., K.C. Marois, R.W. Lowe, T.E. Harvey, and P.R. Kelly. 1991. "Trace Elements and Organochlorines in Surf Scoters from San Francisco Bay, 1985." *Environmental Monitoring and Assessment, 18*: 105-122.

Perry, M.C., and E.J.R. Lohnes. 2001-2004. "Atlantic Seaduck Project, Patuxent Wildlife Research Center, Laurel, MD." http://www.pwrc.usgs.gov/resshow/perry/scoters/default.htm.

PRC, see PRC Environmental Management, Inc.

PRC Environmental Management, Inc. 1994. *Phase IA Ecological Risk Assessment, Naval Station Treasure Island, Hunters Point Annex, San Francisco, California*. July.

PRC Environmental Management, Inc. 1996. *Phase IB Ecological Risk Assessment, Hunters Point Shipyard, San Francisco, California. Volume I, Part 1: Nature and Extent of Contamination, and Part 2: Risk Characterization to Aquatic Receptors*. Draft. November 15.

RWQCB, see Regional Water Quality Control Board.

Regional Water Quality Control Board (San Francisco Bay Region). 1997. *San Francisco Bay Protection and Toxic Hot Spot Cleanup Program Proposed Regional Toxic Hot Spot Cleanup Plan.* December.

Regional Water Quality Control Board (San Francisco Bay Region). 1998. *Ambient Concentrations of Toxic Chemicals in Sediments*. Prepared by T. Gandesbery and F. Hetzel. April.

Regional Water Quality Control Board (San Francisco Bay Region). 2000. *Draft Staff Report: Beneficial Reuse of Dredged Materials: Sediment Screening and Testing Guidelines.* May.

Regional Water Quality Control Board (San Diego Region). 2001. *Guidelines for Assessment and Remediation of Contaminated Sediments in San Diego Bay at NASSCO and Southwest Marine Shipyards.* June 1.

Regional Water Quality Control Board (San Francisco Bay Region), State Water Resources Control Board, and California Department of Fish and Game. 1995. *Contaminant Levels in Fish Tissue from San Francisco Bay. Final Report*. June.

Roy F. Weston. 1996. *Recommendations for a Screening Level for Tributyltin in Puget Sound Sediments*. Prepared for the U.S. Environmental Protection Agency Region X. April.

Sample, B., and C. Arenal. 1999. "Allometric Models for Interspecies Extrapolation of Wildlife Toxicity Data." *ET&C, 62*: 653-663.

Sample, B.E., D.M. Opresko, and G.W. Suter. 1996. *Toxicological Benchmarks for Wildlife: 1996 Revision*. ES/ER/TM-86/R3.

San Francisco Estuary Institute. 1999. *Contaminant Concentrations in Fish from San Francisco Bay 1997*. A technical report of the San Francisco Estuary Regional Monitoring Program for Trace Substances. May. Available at: http://www.sfei.org/rmp/index.html

San Francisco Estuary Institute. 2001. *Public Summary of the San Francisco Bay Seafood Consumption Study*. March.

San Francisco Estuary Institute. 2002. Technical Report: *San Francisco Seafood Consumption Report. Conducted by Environmental Health Investigators Branch (EHIB) of the California Department of Health Services*.

SFEI, see San Francisco Estuary Institute.

Snedecor, G.W., and W.G. Cochran. 1980. *Statistical Methods*, 6th ed. Iowa State UP, Ames, IA.

State Water Resources Control Board. 1998a. *The Evaluation and Use of Sediment Reference Sites and Toxicity Tests in San Francisco Bay*. Prepared by SWRCB Division of Water Quality. 132 pp.

State Water Resources Control Board. 1998b. *Sediment Quality and Biological Effects in San Francisco Bay: Bay Protection and Toxic Cleanup Program Final Technical Report*. Prepared by SWRCB Division of Water Quality. 188 pp. August.

Steel, G.D., and J.H. Torrie. 1980. *Principles and Procedures of Statistics*, 2nd ed. McGraw-Hill, New York, NY.

Stenzel, L.E., H.R. Carter, R.P. Henderson, S.D. Emslie, M.J. Rauzon, G.W. Page, P. O'Brien. 1995. "Breeding Success of Double-Crested Cormorants in the San Francisco Bay Area, California." *Colonial Waterbirds, 18* (Special Publication 1): 216-224.

SWRCB, see State Water Resources Control Board.

Tetra Tech EM, Inc. 1997. *Parcel E Remedial Investigation Draft Final Report, Hunters Point Shipyard, San Francisco, California*. Prepared for Engineering Field Activity West, Naval Facilities Engineering Command. October 27.

Tetra Tech EM, Inc. 2001. *Draft Landfill Closeout Report, Parcel E, Hunters Point Shipyard, San Francisco*. Prepared for Southwest Division, Naval Facilities Engineering Command.

Tetra Tech EM, Inc. 2002. *Draft Final Field Sampling Plan and QAPP for Parcel E Landfill Data Gaps Investigation, Hunters Point Shipyard, San Francisco, California.* Prepared for Southwest Division, Naval Facilities Engineering Command. January 8.

Tetra Tech EM, Inc. 2003a. *Draft Parcel B Shoreline Characterization Technical Memorandum, Hunters Point Shipyard, San Francisco, California.* Prepared for Southwest Division, Naval Facilities Engineering Command. October 3.

TetraTech EM, Inc. 2003b. *Parcel E Standard Data Gaps Investigation, Phase I Data Package, Hunters Point Shipyard, San Francisco CA*. Prepared for Southwest Division Naval Facilities Engineering Command. January.

Tetra Tech EM, Inc. and Levine-Fricke-Recon, Inc. 1998. *Parcel F Feasibility Study Draft Report, Hunters Point Shipyard, San Francisco, California*. Prepared for Engineering Field Activity West, Naval Facilities Engineering Command. April 3.

Torok, M.L. 1994. "Movements, Daily Activity Patterns, Dive Behavior, and Food Habits of the Harbor Seals (*Phoca Vitulina richardsii*) in the San Francisco Bay, California." M.S. Thesis, California State University, Stanislaus, CA.

TtEMI, see Tetra Tech EM, Inc.

United States Army Corps of Engineers. 2002. "Biota-Sediment Accumulation Factors: Hunters Point, CA." July 1.

United States Environmental Protection Agency and United States Army Corps of Engineers. 1991. *Evaluation of Dredged Material Proposed for Ocean Disposa –Testing Manual.* EPA 503/8-91/001. U.S. EPA Office of Water, Washington, DC. February.

United States Department of Navy. 1998. Interim Final, *Development of Toxicity Reference Values as Part of a Regional Approach for Conducting Risk Assessments at Naval Facilities in California*. Prepared by Engineering Field Activity West, Naval Facilities Engineering Command.

United States Department of the Navy. 2002. *Ecotoxicity Reference Values for Bioaccumulation Risk Estimates in the Baseline Ecological Risk Assessment for Pearl Harbor Sediments*. Draft Document.

United States Department of the Navy. 2004. *Hunters Point Shipyard Historical Radiological Assessment, Volume II.* Draft Final Document.

United States Environmental Protection Agency. 1986. *Superfund Public Health Evaluation Manual*. EPA/540/1-86/060. Prepared by Office of Emergency and Remedial Response, Washington, DC.

United States Environmental Protection Agency. 1989. *Risk Assessment Guidance for Superfund Volume I, Human Health Evaluation Manual (Part A)*. EPA/540/1-89/002. Prepared by Office of Emergency and Remedial Response, Washington, DC.

United States Environmental Protection Agency. 1991. *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual, Supplemental Guidance Standard Exposure Factors, Draft Final.* OSWER 9285.6-03. Prepared by Office of Solid Waste and Emergency Response, Washington, DC. March 25.

United States Environmental Protection Agency. 1992. *Supplemental Guidance to RAGS: Calculating the Concentration Term*. OSWER 9285.7-08I. Prepared by Office of Emergency and Remedial Response, Washington, DC.

United States Environmental Protection Agency. 1994a. *Methods for Assessing the Toxicity of Sediment-Associated Contaminants with Marine and Estuarine Amphipods*. Prepared by Office of Research and Development, Washington, DC. EPA/600/R-94/025.

United States Environmental Protection Agency. 1994b. *Guidance Manual for the Integrated Exposure Uptake Biokinetic Model for Lead in Children*. EPA/540/R-93/081. Prepared by Office of Emergency and Remedial Response, Washington, DC.

United States Environmental Protection Agency. 1994c. Health Effects Assessment Summary Tables. FY-1994 Annual. Office of Research and Development, Office of Emergency and Remedial Response, Washington, DC. EPA/540/R-94/020. March 1994.

United States Environmental Protection Agency. 1997a. *Exposure Factors Handbook, Volume II: Food Ingestion Factors*. EPA/600/P-95/002Fb. Prepared by Office of Research and Development, Washington DC.

United States Environmental Protection Agency. 1997b. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments*. Interim Final. EPA/540/R-97/006. Prepared by U.S. EPA Environmental Response Team, Edison, NJ. June 5.

United States Environmental Protection Agency. 2000. *Guidance for the Data Quality Objectives Process*. EPA/600/R-96/055. August.

United States Environmental Protection Agency. 2002a. United States Environmental Protection Agency Region 9 Preliminary Remediation Goal Tables. Available at: www.epa.gov/region09/waste/sfund/prg. October 1.

United States Environmental Protection Agency. 2002b. *Integrated Risk Information System (IRIS). Database*. Environmental Criteria and Assessment Office. Available at: http://www.epa.gov/iris.

United States Environmental Protection Agency. 2002c. "Radionuclide Carcinogenicity Slope Factors (Health Effects Assessment Summary Tables [HEAST])." Updated September 12. Available at: www.epa.gov/radiation/heast.

United States Environmental Protection Agency. 2003. *Ecological Soil Screening Levels for Lead. Interim Final*. OSWER Directive 9285.7-70.

USACE, see United States Army Corps of Engineers

U.S. EPA, see United States Environmental Protection Agency.

USGS, see United States Geological Survey.

Van den Berg, M., L. Birnbaum, A.T.C. Bosveld, B. Brunstrom, P. Cook, M. Freeley, J.P. Giesy, A. Hanberg, R. Hasegawa, S.W. Kennedy, T. Kubiak, J.C. Larsen, F.X.R. van Leeuwen, A.K.D. Liem, C. Nolt, R.E. Petersen, L. Poellinger, S. Safe, D. Schrenk, D. Tillet, M. Tysklind, M. Younes, F. Waern, and T. Zacharewski. 1998. "Toxic Equivalency Factors (TEFs) for PCBs, PCDDs, PCDFs for Humans and Wildlife." *Environ. Health Persp., 106*(12): 775-792.

Vermeer, K., and N. Bourne. 1984. "White Winged Scoter Diet in British Columbia Waters: Resource Partitioning with Other Scoters." In: D.N. Nettleship, G.A. Sanger, and P.F. Springer (eds.), *Marine Birds: Their Feeding Ecology and Commercial Fisheries Relationships*.

Vermeer, K., and D.B. Peakall. 1979. "Trace Metals in Seaducks of the Fraser River Delta Intertidal Area, British Columbia." *Mar. Poll. Bull., 10*: 189-193.

Wang, J.C.S. 1986. *Fishes in the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to Early Life Histories.* A cooperative study by the California Department of Water Resources, California Department of Fish and Game, U.S. Bureau of Reclamation, and U.S. Fish and Wildlife Service. Technical Report 9 (FS/B10-4ATR 86-9). Prepared for the Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. January.

Wong, K. 1997. *Fishing for Food in San Francisco Bay: Part II. An Environmental Health and Safety Report*. Prepared by the Save San Francisco Bay Association. Oakland, CA.