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TIER I ECOLOGICAL EVALUATION FOR PHASE III CHANNEL IMPROVEMENTS TO THE JOHN F. BALDWIN SHIP CHANNEL

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SUMMARY

The John F. Baldwin Ship Channel (JFBSC) is part of the San Francisco Bay to Stockton, California, Navigation Project authorized by the River and Harbors Act of 1965 (Public Law 89-298). The JFBSC extends from the Golden Gate north of the city of San Francisco, through San Pablo Bay and the Carquinez Strait, and into Suisun Bay. The U.S. Army Corps of Engineers (USACE)-San Francisco District, is responsible for the construction and maintenance of the JFBSC.

Planned improvements to the JFBSC include deepening along an approximately 28-mi section of the channel in the West Richmond, Pinole Shoal, and Carquinez Strait reaches to a depth of -45 ft mean lower low water (MLLW). Disposal options for sediment proposed for removal from these improvement areas include aquatic disposal within San Francisco Bay or at an open-ocean site, marsh or wetlands construction, and uplands disposal.

To assist the USACE in determining whether the proposed dredged material is suitable for unrestricted, unconfined open-ocean disposal, Battelle/Marine Sciences Laboratory (MSL) prepared this Tier I report. Technical guidance for evaluating the suitability of dredged materials for ocean disposal is provided in the 1991 Testing Manual (*Evaluation of Dredged Material Proposed for Ocean Disposal - Testing Manual*, EPA-503/8-91/001), known as the "Green Book." The Green Book provides a tiered approach for testing the suitability of dredged materials through chemical, physical, and biological evaluations. The Tier I report primarily summarizes existing information on sediment contamination and toxicity potential, identifies contaminants of concern, and determines the need for further testing (i.e., Tiers II-IV).

Based on the findings of this Tier I report, sediments that would be removed during Phase III improvements to the JFBSC fail to meet the three suitability criteria for unrestricted, unconfined open-ocean disposal that are delineated in the Green Book. The first criterion is not met because fine-grained sediments comprise a significant fraction of the bottom material in some areas of the JFBSC, and because this material is not exposed to high current or wave energy. Dredged material from the JFBSC is not being proposed for beach nourishment; therefore, the second criterion is not met. JFBSC sediments do not meet the third criterion because, although they may be substantially similar to substrates at several of the proposed disposal sites, they are from an area that historically has experienced loading of contaminants, which toxicology studies have shown have the potential to result in acute toxicity or significant bioaccumulation.

Sufficient information on contaminant concentrations in JFBSC sediments exists to conclude that dredged materials from the JFBSC may pose a risk to sensitive marine organisms. Information on persistence, bioavailability, and relative bioaccumulation potential are lacking; therefore, additional testing of sediments under Tier III is warranted.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

The John F. Baldwin Ship Channel (hereafter referred to as "JFBSC" or the "Channel") is part of the San Francisco Bay to Stockton, California, Navigation Project authorized by the River and Harbors Act of 1965 (Public Law 89-298). The JFBSC extends from the Golden Gate north of the city of San Francisco, through San Pablo Bay and the Carquinez Strait, and into Suisun Bay. The U.S. Army Corps of Engineers (USACE)-San Francisco District, is responsible for the construction and maintenance of the JFBSC.

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1.1 THE TIERED PROCESS FOR EVALUATING DREDGED MATERIALS AND OBJECTIVES OF THE TIER I REPORT

Technical guidance for evaluating the suitability of dredged material for ocean disposal is provided in the 1991 Testing Manual (*Evaluation of Dredged Material Proposed for Ocean Disposal - Testing Manual*, EPA-503/8-91/001), known as the "Green Book." Suitability criteria presented in the Green Book are based on the biological testing requirements of the 1977 Ocean Dumping Regulations. The Green Book provides a tiered approach for testing the suitability of dredged materials through chemical, physical, and biological evaluations.

The four levels of investigation, or tiers, outlined in the Green Book provide a phased approach for evaluating compliance with the limiting permissible concentration (LPC), as defined in the U.S. Ocean Dumping Regulations. The LPC for the liquid-phase concentration of dredged material in the water column is the concentration that, after allowing for initial mixing, does not exceed applicable marine water-quality criteria or a toxicity threshold of 0.01 of the acutely toxic concentration. The first level of investigation, or Tier I evaluation, is used to determine whether a decision on LPC compliance can be made on the basis of readily available information. The Tier I report primarily summarizes existing information on sediment contamination and toxicity potential, identifies contaminants of concern, and determines the need for further testing (i.e., Tiers II-IV).

The goal of the information-gathering phase of a Tier I evaluation is to compile all reasonably available information for use in assessing the potential for contaminant-associated impacts following ocean disposal of the proposed dredged material. Specific guidelines have not been established for conducting Tier I evaluations, although the Green Book recommends the following as potential sources of information:

1. the available results of prior physical, chemical, and biological tests of the material proposed to be dumped
2. the available results of prior field monitoring studies of the proposed material to be dumped (e.g., physical characteristics, organic-carbon content, and grain size)
3. the available description of the source(s) of the contaminants contained in the proposed material to be dumped, which would be relevant for identifying potential contaminants of concern
4. the existing data in U.S. Environmental Protection Agency (EPA) or USACE files or otherwise available from public or private sources. Examples of potential sources include the following:
   - Selected Chemical Spill Listings (EPA)
   - Pesticide Spill Reporting System (EPA)
   - Pollution Incident Reporting System (U.S. Coast Guard)
   - Identification of In-Place Pollutants and Priorities for Removal (EPA)
   - hazardous waste sites and management facilities reports (EPA)
   - USACE studies of sediment pollution and sediments
   - federal STORET, BIOS, CETIS, and ODES computer databases (EPA)
   - water and sediment data on major tributaries (U.S. Geological Survey)
   - National Pollutant Discharge Elimination System (NPDES) permit records
   - CWA 404(b)(1) evaluations
   - pertinent and applicable research reports
   - Marine Protection, Research, Sanctuaries Act (MPRSA) 103 evaluations
   - port authorities
   - colleges/universities.

The next stage of the Tier I evaluation involves comparing information on the proposed dredged material to the three criteria in 40 CFR 227.13(b) that allow exclusion from further testing. Dredged material meeting one or more of the criteria listed below is considered environmentally acceptable for unrestricted, unconfined ocean dumping without further testing:

1. dredged material is composed predominantly of sand, gravel, rock, or any other naturally occurring bottom material with particle sizes larger than silt, and the material is found in areas of high current or wave energy such as streams with large bed loads or coastal areas with shifting bars and channels; or
2. dredged material is for beach nourishment or restoration and is composed predominantly of sand, gravel, or shell with particle sizes compatible with material on the receiving beaches; or
3. when - (i) the material proposed for dumping is substantially the same as the substrate at the proposed disposal site, and (ii) the site from which the material proposed for dumping is to be taken is far removed from known existing and historical sources of pollution so as to provide reasonable assurance that such material has not been contaminated by such pollution (40 CFR 227.1316).

If none of the exclusionary criteria is met, the LPC is evaluated based on available data on the proposed dredged material. This data must include an analysis of the toxicity and bioaccumulation potential of both the dredged material and reference sediments. If existing information is insufficient to determine whether the Water Quality Criteria (WQC) or 1% of the LC_{50} will be exceeded in the water column following the initial mixing period, then the evaluation process moves to Tier II.

Tiers II-IV represent increasingly more comprehensive levels of analysis involving sediment testing. Tier II consists of a model to evaluate marine WQC compliance and estimate the potential for benthic impact. Tier III consists of bioassays and bioaccumulation tests to determine whether the potential exists for the dredged material to have an unacceptable impact. Tier IV consists of bioassays and bioaccumulation tests to determine the long-term effects of exposure to dredged material. The level of testing required for a project is based on the degree of contamination expected from the sediments within a project area.

This Tier I report summarizes the existing information on chemical, physical, and biological characterization of the sediments in Oakland Inner and Outer Harbors and identifies contaminants of concern. In addition, this report provides justification for the selection of sites that were subjected to Tier III sediment testing.

1.2 BACKGROUND OF THE SITE

1.2.1 History of the Site

San Francisco Bay ("the Bay") and the Sacramento-San Joaquin Delta ("the Delta") form the largest estuary on the western coast of North America, with a surface area of 1240 km^2 and a drainage basin of 152,500 km^2 (Davis et al. 1991) (Figures 1.1 and 1.2). The physical nature of the San Francisco Estuary ("the Estuary") has been transformed dramatically since the rapid colonization of the Bay margins began during the gold rush years. Major factors contributing to physical changes in the Estuary include hydraulic gold mining in the late 1800s, reclamation of land from about 1850 to the present, and agricultural development of the Central Valley.

From 1853 to 1884, hydraulic gold mining technology brought an estimated 1 billion yd^3 of sediment into the northern reach of the Estuary (Suisun Bay/ San Pablo Bay) from the upper drainage basin, causing blockage of many waterways and flooding during heavy rainfalls. The mining process altered the volume, tidal prism, and circulation patterns of the northern reach of the Estuary to such an extent that hydraulic mining technology was prohibited by court injunction in 1884 (Gunther et al. 1990).

In the mid-1800s, new land was provided for human settlement and agriculture by filling subtidal and intertidal baylands. One of the first areas to be altered was the northern reach of the Estuary. Debris, derelict ships, and earth from the hillsides were used as fill to create moorage space and land area. During the period 1850 to 1957, 622 km^2 of marsh, tidelands, and subtidal lands were filled (USACE 1990). Only 125 km^2 of tidal marshland now exist in the Estuary (Gunther et al. 1990).

Today, the Bay and Estuary act as a critical thoroughfare for the nation's increasing role in international import and export. Over 5000 ships move through Bay ports annually. Navigation

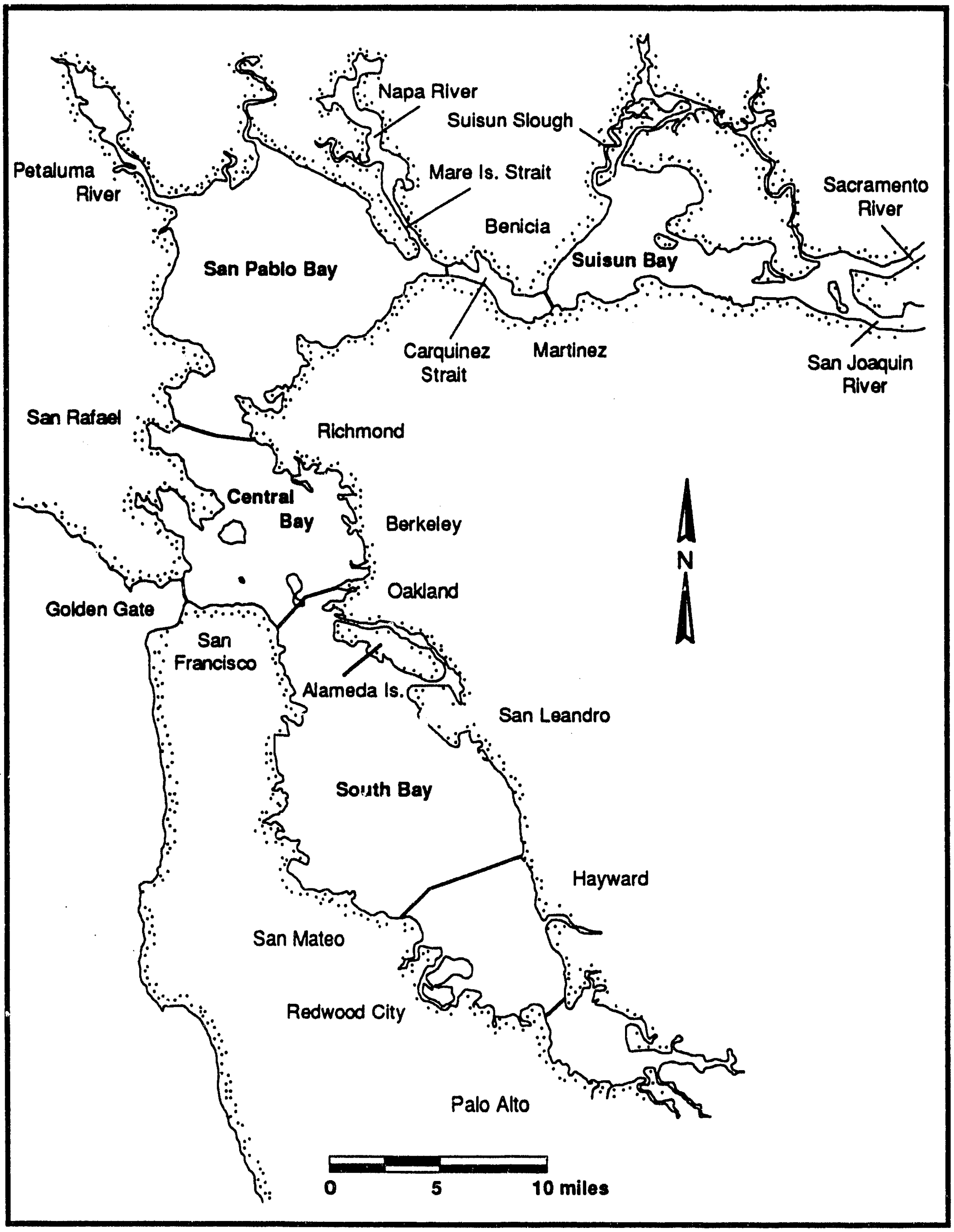

FIGURE 1.1. General Map of the San Francisco Bay Area

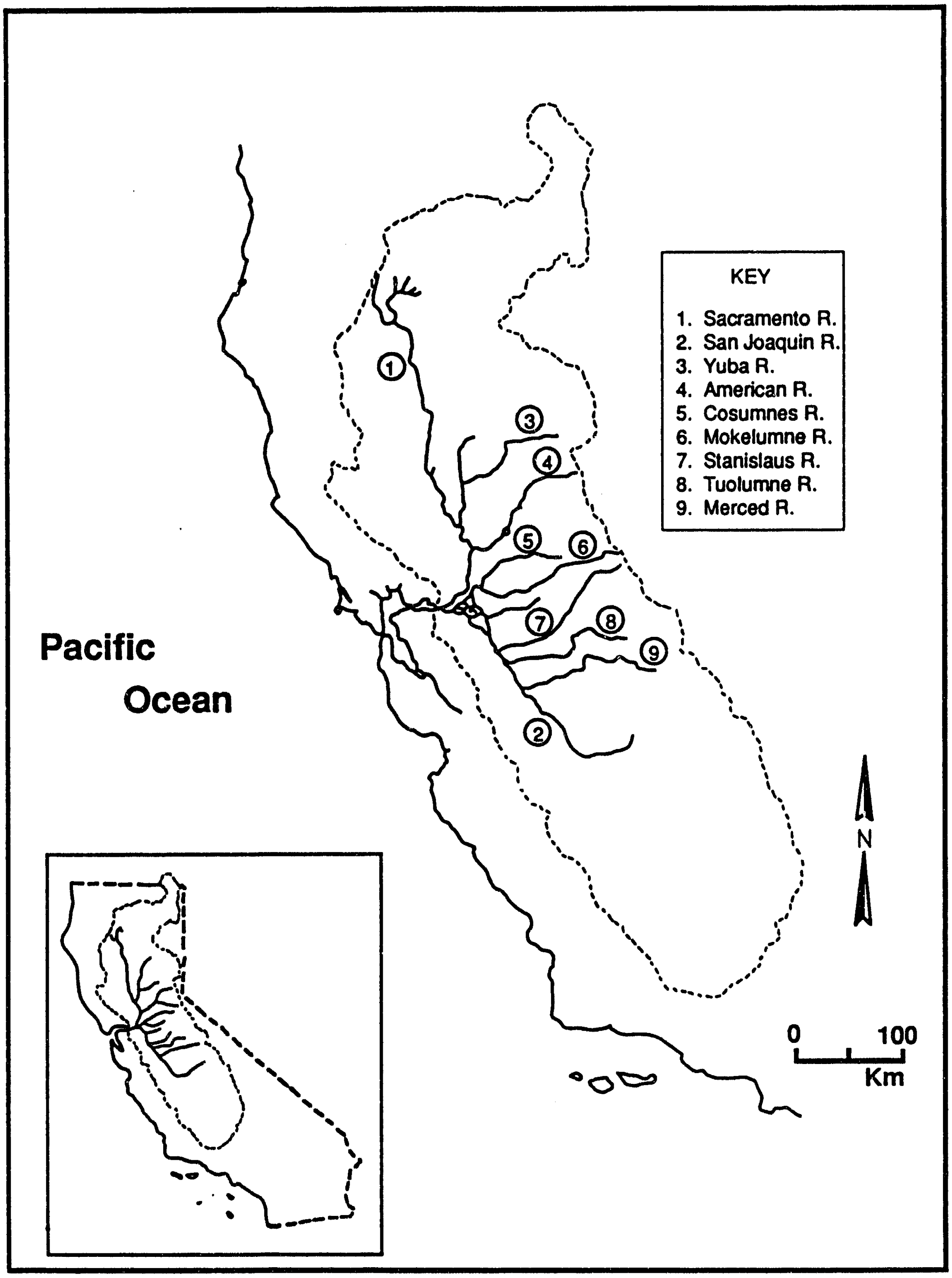

FIGURE 1.2. Map Showing Drainage Basin for the San Francisco Bay-Delta

channels are maintained and improved by federal and private parties. The USACE-San Francisco District currently dredges and disposes of over 4 million yd^3 of sediment annually from both deep- and shallow-draft federal navigation channels in the Bay region; another 3 million yd^3 of sediment are dredged and disposed of annually under USACE-issued permits (USACE 1990).

1.2.2 Physical Environment

The Bay is characterized by broad shallows carved by narrow channels, the depths of which are maintained by swiftly moving currents. The average depth of the Bay is 18 ft at MLLW, with a maximum depth of 360 ft in the Golden Gate area. The Central Bay has not only broad shallows (to 33 ft below MLLW) but also wide expanses of deep water (40 ft below MLLW to greater than 200 ft below MLLW). In San Pablo Bay, the average depth is less than 10 ft below MLLW. A narrow channel, 0.2 mi to 1 mi wide, which ranges in depth from 33 ft to 69 ft below MLLW, cuts through San Pablo Bay from the Central Bay to Carquinez Strait. Dredging maintains the depth of the channel at greater than 35 ft below MLLW at the Pinole Shoal, off Pinole Point (USACE 1990).

The San Joaquin and Sacramento rivers, the principal sources of fresh water input into the bay system, discharge at a rate of approximately 35,000 cubic feet per second (CFS) during the period of December through April and 14,000 CFS between July and October (Smith and Cheng 1987). These discharges and other natural runoff move 8.0 to 10.5 million yd^3 of sediment into the Bay annually as suspended load and bedload (USACE 1988). Krone (in Conomos, 1979) concluded that San Pablo Bay and Central Bay are depositional, while Suisun, Grizzly Bay, Carquinez Strait, and South Bay are erosional. Though relatively little is known about sediment deposition, resuspension, and transport in the Estuary, mounting evidence suggests that human activity has profoundly altered sediment processes (Gunther et. al. 1990).

Regional differences in water circulation in the Bay result from variations in freshwater inflow and wind-induced circulation and mixing. The northern reach of the Bay, which passes south and westward from the delta through Suisun and San Pablo bays, receives 90% of the riverine flow (USACE 1990). The northern reach is a partially mixed estuary with vertical salinity gradients on the order of 10 ppt during the winter high flow conditions and a well-mixed estuary with vertical salinity gradients of 3 ppt during summer low-flow conditions (Conomos 1979). Water residence times and replacement rates in the Bay depend on tidal diffusion and local phenomena such as wind stress, freshwater inflow, tidal currents, and bottom topography. In the northern reach, residence times are on the order of days during high river inflow and months during low-flow conditions (Walters et al. 1985).

1.2.3 Description of the John F. Baldwin Ship Channel

The JFBSC is part of the San Francisco Bay to Stockton, California, Navigation Project authorized by the River and Harbor Act of 1965. The JFBSC consists of five improvement or construction areas: the San Francisco Bar, West Richmond Channel, Pinole Shoal Channel, Carquinez Strait, and Suisun Channel. The USACE-San Francisco District, is responsible for the construction and maintenance of the JFBSC.

Planned improvements to the Channel were scheduled by the USACE to be completed in three phases. Under Phase I, completed in 1974, a 2000-ft-wide channel was built to a depth of -55 ft MLLW across the San Francisco Bar near the Golden Gate. Phase II, approved in 1984, provided channel improvements to -45 ft MLLW in Central Bay near Richmond, California. Phase III plans to improve approximately a 28-mi section of the JFBSC between San Francisco Bay, west of Richmond, and Suisun Bay.

Planned Phase III channel improvements include deepening the Channel to -45 ft MLLW in the West Richmond, Pinole Shoal, and Carquinez Strait reaches (Figure 1.3). Approximately 1,200,000 yd^3 of sediment will be removed from West Richmond, 7,000,000 yd^3 from Pinole Shoal, and 800,000 yd^3 from Carquinez Strait. The sediment proposed for removal from these project areas is being considered for use in creating wetlands or marshes, in-bay disposal at Alcatraz Island or Bay Farm Borrow Area, or offshore disposal.

1.2.4 Principal Regulatory Authorities

This section provides a brief introduction to the principal government agencies and legislation responsible for regulating water quality-related impacts to the San Francisco Estuary. A more exhaustive treatment of the evolution of environmental policies affecting the Estuary and the specific jurisdiction of each government agency, may be found in Davis et al. (1991).

The U.S. Environmental Protection Agency (USEPA) and the California Regional Water Quality Control Board (CRWQCB) are the principal authorities regulating sources of pollution to the San Francisco Estuary. This authority is derived primarily from the 1972 (and subsequent) amendments to the federal Water Pollution Control Act (or Clean Water Act). The USEPA is charged with administering provisions of the Clean Water Act (CWA), while actual implementation is through the CRWQCB. The CRWQCB shares authority for the implementation of both the CWA and Porter-Cologne Water Quality Control Act with nine regional water quality control boards. The San Francisco Estuary lies within the jurisdiction of two regional boards, the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB) and the Central Valley Regional Water Quality Control Board (CVRWQCB). The regional boards conduct planning, permitting, and enforcement activities under the direction and guidance of the CRWQCB.

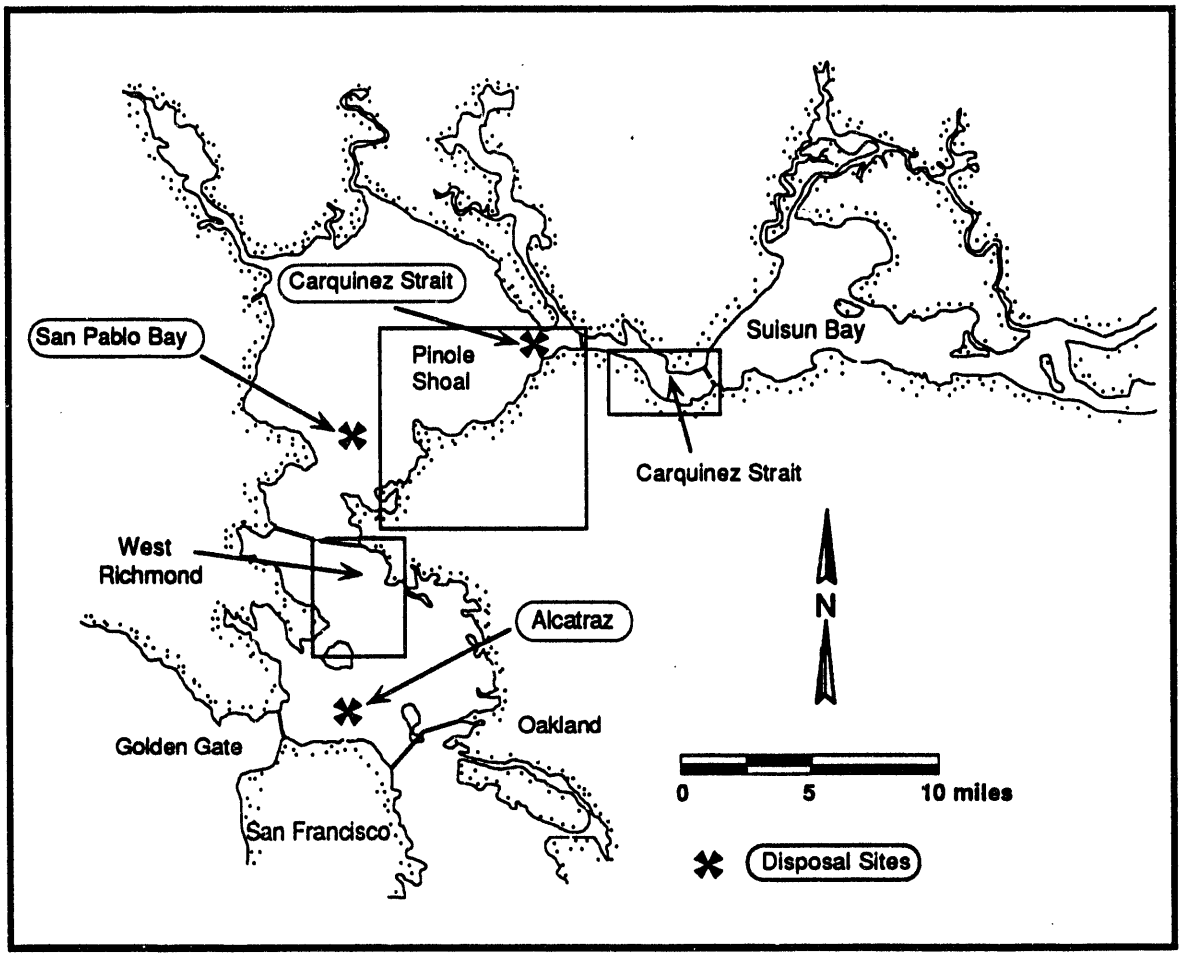

FIGURE 1.3. John F. Baldwin Ship Channel Study Areas and Locations of Currently Authorized In-Bay Dredged Material Disposal Sites

The 1972 CWA established the National Pollutant Discharge Elimination System (NPDES) program to regulate the discharge of municipal and industrial wastewater. The CRWQCB and nine regional boards manage the NPDES program for the State of California. The NPDES program requires all municipal and industrial facilities to obtain permits that specify allowable limits for pollutant levels in effluents. Recently proposed regulations also require NPDES permits for stormwater discharges associated with certain industrial and commercial activities and for municipal storm sewers serving populations greater than 100,000 (Gunther et al. 1990).

The USACE has primary responsibility for maintaining navigable waters throughout the United States. The River and Harbor Act of 1899 requires the USACE to issue permits for all dredging activities affecting navigable waters. The 1969 National Environmental Policy Act (NEPA) further requires assessment of each permit application for potential environmental impacts, and the preparation of an environmental impact statement (EIS) for cases in which proposed activities are likely to result in significant environmental effects, or a finding of no significant impact (FONSI) for proposed activities that are not likely to have significant environmental effects. Dredging conducted by the USACE is not covered by permits, but is subject to the same environmental reviews as permitted dredging projects, including water-quality certification by the regional boards. The 1972 Marine Protection, Research, and Sanctuaries Act (MPRSA) gives the USACE permitting authority over the transportation of dredged material for disposal into coastal waters and the open ocean. The regional boards also have independent authority under the California Water Code to regulate discharges of dredged materials. Additionally, the regional boards can require appropriate biological and chemical tests necessary to assess the potential for violation of water-quality objectives through dredging activities.

The San Francisco Bay Conservation and Development Commission (BCDC) was created by the 1965 State McAteer Act and has permitting authority for dredging and filling activities within the Bay. The BCDC derives additional authority from the 1972 federal Coastal Zone Management Act (CZMA). The BCDC's policies concerning dredging activities are outlined in the San Francisco Bay Plan (Bay Plan). The Bay Plan was the first coastal zone management program in the nation to be certified by the CZMA. The BCDC is charged with reviewing all proposed federal activities and licenses or permits for compliance with the Bay Plan.

The State Lands Commission (SLC) administers public trust lands in tidal and submerged areas and in coastal waters to within a three-mile state territorial limit. Dredging and filling activities on lands within SLC jurisdiction require prior written authorization. Authorization is provided in the form of a dredging permit or a mineral extraction lease (contingent upon compliance with the requirements of the California Environmental Quality Act).

Other government agencies such as the U.S. Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), U.S. Coast Guard (USCG), California Department of Fish and Game (CDFG), and the California Coastal Commission (CCC) have specific authority over dredging and filling activities and routinely participate in the review of dredging permits. The USFWS is authorized under the 1958 Fish and Wildlife Coordination Act (FWCA) to review federally funded, licensed, or permitted projects that potentially impact fish or wildlife habitat. The USFWS has additional authority under the Endangered Species Act when endangered or threatened species are involved. The NMFS is authorized under the FWCA, CWA, and NEPA to review federal projects that may affect marine, estuarine, or anadromous fisheries. The USCG reviews permit applications to assure that dredging activities will not impair the safe and orderly flow of maritime traffic. The USCG also assists the USACE in monitoring the activities of disposal barges throughout the Estuary using its "Vessel Traffic System." The CCC has authority to review the designation of ocean disposal sites and ensures that federally authorized activities are consistent with the California Coastal Management Program.

The National Estuary Program (NEP), established in 1987 under the federal Water Quality Act (WQA) and managed by the EPA, is dedicated to the protection of our national estuaries. The purpose of NEP is to identify nationally significant estuaries threatened by pollution, development, or overuse, and to promote preparation of comprehensive management plans to ensure their ecological integrity. The San Francisco Estuary Project (SFEP) was established in 1988 as part of the NEP. The SFEP has addressed a number of management issues in the Bay-Delta region, including the decline of biological resources, increased pollutants, freshwater diversion and altered flow regimes, increased waterway modification, and intensified land use. The SFEP is composed of representatives from the public and private sector and all levels of government, including elected officials from each of the Bay-Delta counties. Studies conducted through the SFEP have been summarized in a series of six "Status and Trends" reports: Wetlands and Related Habitats, Aquatic Resources, Wildlife, Pollutants, Dredging and Waterway Modification, and Land Use and Population.

The Aquatic Habitat Institute (AHI) is an independent, non-profit corporation established to evaluate the present and potential future effects of pollution on the Bay-Delta. The AHI is directed by a 10-member board of representatives from industrial and municipal dischargers, state and federal agencies, academic institutions, and the public. The AHI is funded through a variety of state and federal agencies, discharger associations, local governments and foundations, as well as membership fees and contributions. The AHI often works jointly with the SFEP on water quality issues and has published a number of reports on the loading, fate, and effects of contaminants in the Bay-Delta (Davis et al. 1991; Gunther et al. 1987; Phillips 1987).

Local governments and organizations representing specific interest groups also take an active role in the formation and review of regulatory policies established by the government agencies. For instance, two major associations, the Bay Area Dischargers Association (BADA) and the Bay Area League of Industrial Associations, represent the interests of dischargers to the Estuary in public review processes. Various environmental groups, including the Audubon Society, Citizens for a Better Environment, the Bay Institute of San Francisco, the Baykeeper, California Native Plant Society, Citizens Committee to Complete the Refuge, Friends of the River, the Sacramento River Preservation Trust, the Sierra Club, the Oceanic Society, the Pacific Coast Federation of Fishermen Association, Save San Francisco Bay Association, and United Anglers provide comments on proposed activities having potential environmental impacts. The U.S.

Department of Defense, port authorities, yachting associations, and other groups that depend on dredging to maintain navigable waterways also comment on dredging management decisions and policies.

1.3 OVERVIEW OF ENVIRONMENTAL RESOURCES

A general discussion of the environmental resources of the central and northern portions of the Bay is presented in this part of the report. This discussion is largely based on previous reviews appearing in Conomos (1979) and USACE (1990).

1.3.1 Benthos

The benthos is a significant environmental resource, because it is ecologically important to the food web of the Bay. Benthic organisms can also influence erosion and sedimentation, and may cause some stirring or mixing of bay sediments through burrowing activities (bioturbation). Benthic organisms include filter feeders, deposit feeders, scavengers, and algae scrapers. Clams and crabs are examples of important benthic fisheries resources. Some species of fish, birds, and other animals use benthic organisms as a food source. Benthic organisms that are important as members of the food chain include amphipods (e.g., *Ampelisca abdita*, *Grandidierella japonica*, and *Corophium* spp.), molluscs (e.g., *Gemma gemma*, *Mytilus edulis*, and *Ostrea lurida*), and polychaetes (e.g., *Boccardia ligerica*, *Streblospio benedicti*, and *Mediomastus californiensis*) (CRWQCB, 1988).

Beginning with the Albatross Expedition of 1912 to 1913, numerous collections have been made of benthic invertebrates in the Bay. Nichols (in Conomos 1979) concluded that the major factors controlling infaunal community structure in the Bay are natural perturbations such as major fluctuations in salinity, biotic disturbances (e.g., by rays), and abiotic disturbance such as increased sediment loads on a seasonal basis and wind-generated wave disturbance. Anthropogenic influences are difficult to partition from natural influences. The conditions in the Bay favor species that rapidly colonize benthic environments. Several exotic species, which are adapted for rapid colonization of disturbed areas, have invaded the Bay and are now dominant in many areas. Recently, an exotic benthic species, the Asian clam, *Potamocorbula amurensis*, was discovered in the Bay. This clam, which was not found in the Bay before 1986, is now considered a major component of the benthic communities in areas of both the northern and southern portions of the Bay (Schemel 1989). Future changes in the biota may be expected with continued reduction in freshwater flow into the estuary.

Hopkins (1986) compiled 30 years of benthic invertebrate sampling data in an *Atlas of the Distributions and Abundances of Common Benthic Species in San Francisco Bay, California* and presented the distribution and relative density of the 24 most common infaunal taxa. There appeared to be no unusual occurrences or elevated densities of pollution-indicator species (e.g., *Capitella capitata*) in the vicinity of the JFBSC. Furthermore, pollution-sensitive taxa in the samples collected in the North Bay were not found in conspicuously lower densities compared to the remainder of the Bay.

Commercially and recreationally important benthic organisms include Dungeness crab (*Cancer magister*), red rock crab (*Cancer productus*), brown rock crab (*Cancer antennarius*), and the Franciscan bay shrimp (*Crangon franciscorum*). Dungeness crab are found on sandy and sand/mud bottoms from the low tideline to water depths of approximately 300 ft. Some individuals have been found as deep as 650 ft (Morris et al. 1980). Dungeness crab use San Pablo Bay as a nursery ground (CDFG 1987). Spawning (September to December) and hatching (December to March) occur in the Gulf of the Farallones and off the California coast in the vicinity of the Bay (Wild 1983; Morris et al. 1980). Post-larval Dungeness crabs (instars) are carried into the Bay by strong tidal currents with net transport to the Bay, and juvenile crabs spend one to two years in the Bay before migrating back to the open ocean. The distribution of Dungeness crabs in the Bay is a function of salinity. During low freshwater inflow conditions, crabs are found higher up in the estuary (i.e., toward the delta) than during high-flow conditions. Dungeness crabs prefer protected areas such as jetties, boat launches, and piers over more exposed areas (Tasto 1983).

Red rock crab and brown rock crab are harvested for sport. Both species are found throughout the Central Bay and San Pablo Bay. The red rock crab is more abundant in the Bay than the brown rock crab. Both species can spend their entire life cycles in the Bay, but some larvae are flushed from the Bay by outgoing tides (CDFG 1987). Red rock crab and brown rock crab inhabit rocky nearshore habitats (WESCO 1988).

There is a significant commercial and recreational fishery for Franciscan bay shrimp. Adult Franciscan bay shrimp move out of the Bay in winter, and young shrimp are hatched outside of the Bay. Larval and post-larval Franciscan bay shrimp move back into the Bay in near-bottom water. Larval and post-larval stages of the shrimp are found in their greatest concentrations in the Central Bay but are also found in San Pablo Bay from late winter to July. From April to August, juvenile Franciscan bay shrimp are most abundant in Suisun and San Pablo bays (WESCO 1988).

1.3.2 Aquatic Vegetation

Aquatic vegetation is a significant resource because it is the source of primary productivity in the Bay, provides important habitat for various life stages of fish and invertebrates, and plays a critical role in sediment stabilization. Important components of the Bay's aquatic vegetation include eelgrass, benthic algae, and phytoplankton.

Eelgrass (*Zostera* spp.) is the most prominent aquatic vascular plant type in the Bay system, but is apparently limited to the Central Bay region where salinity is highest (Nichols and Pamatmat 1988). Eelgrass beds host diverse epiphytes and invertebrates that provide forage for various species of juvenile and adult fish. In addition, eelgrass beds are an important spawning substrate and nursery habitat for some fish. Eelgrass is usually found in shallow areas with mud or mixed mud and sand substrates that are seldom exposed to the atmosphere. Because eelgrass is commonly found in relatively calm environments of bays and estuaries, it is extremely vulnerable to coastal urbanization that is heavily targeted at these environments (Zimmerman et al. 1991). Yet, despite the recognized importance of eelgrass, other than aerial observations of the distribution of eelgrass beds, little is known about the size of individual beds, total standing stock, seasonal and long-term fluctuations, eelgrass bed fauna, and the quantitative contribution of eelgrass to the organic matter budget of the Estuary (Nichols and Pamatmat 1988).

Benthic algae are another important component of aquatic vegetation with a critical position in the trophic structure of the Bay. There are approximately 170 species and subspecies of benthic algae in the Bay. Some of the more abundant species include red algae (*Cryptoplure violacea, Polyneura latissima, Gymnogongrus linearis*, and *Gracilaria sjoestedtii*) and brown algae (*Alaria marginata* and *Laminaria sinclairii*) (Silva, in Conomos 1979). *Gracilaria* spp. are used as a spawning substrate for several species of fish (WESCO 1988). Of particular relevance to the present Tier I report, Silva (in Conomos 1979) found that the benthic algae of the Central Bay were relatively free from the deleterious effects of urbanization.

Another important group of marine flora in the Bay is phytoplankton. As noted by Cloern (in Conomos 1979), the species composition and population density of phytoplankton are sensitive to environmental changes, and documentation of phytoplankton population dynamics can provide an invaluable record of water quality. Cloern defined gross spatial and temporal patterns of phytoplankton populations and found that phytoplankton dynamics in each major portion of the Bay are governed by a unique set of environmental factors. For example, Cloern speculated that the annual maximum abundance of phytoplankton in the Central Bay during spring may be a direct consequence of diatom blooms that occur in coastal waters during the upwelling season. In contrast, phytoplankton populations in San Pablo Bay and Suisun Bay appeared to be regulated by the physical accumulation of suspended particulates, the rapid growth of planktonic algae over shoals, and phytoplankton dynamics in coastal waters and tributaries. The distribution of phytoplankton within the Bay also varies seasonally. During winter months, when freshwater inputs to the bay system are greatest, flagellated green algae (*Chroomonas minutea, C. amphioxea, Cryptomonas* spp. and *Chrysochromulina kappa*) and several diatoms (*Melosira* spp. and *Cyclotella* spp.) are the predominant phytoplankton species. From March through September, oceanic species such as *Chaetocerus* spp., *Nitzschia* spp., *Rhizoselenia* spp., *Skeletonema costatum, Thalassiosira eccentrica, Coscinodiscus* spp., and *Cyclotella* spp. dominate (U.S. Navy 1987).

1.3.3 Wetland Vegetation

The Estuary once had abundant wetlands covering approximately 850 mi^2. Currently, only 50 mi^2 (about 6%) of the original wetlands remain in their original state (Wright and Phillips 1988). Approximately 97% of the Delta's 550 mi^2 of freshwater marsh was diked off and plowed for farms between 1860 and 1930. All that remains of the 300 mi^2 of brackish and salt marsh that fringed the Estuary's shores before 1850 is 50 mi^2 of undiked tidal marsh, along with 100 mi^2 of diked wetlands and 60 mi^2 of salt ponds (Cohen 1991). The largest remaining marsh in California (75 mi^2), Suisun Marsh, lies diked off from the tides on the northern shore of Suisun Bay. The majority of this marsh is owned by duck clubs that manipulate water levels to encourage plants favored by ducks and geese. Over 200 species of birds make use of Suisun Marsh, which provides important nesting, feeding, and resting areas for shorebirds and waterfowl (Cohen 1991). Elsewhere in Suisun Bay, freshwater ponds and lagoons, nontidal brackish and salt marshes, and seasonal wetland habitats provide 25 mi^2 of diked wetland habitat.

Wetland vegetation is important because it provides fish and wildlife habitat, primary productivity and nutrient export, and water purification. Many of the Estuary's rare or endangered species are dependent on or found only in specific wetland habitats (Cohen 1991). Impacts on wetland vegetation and fauna from shoreline or land disposal of dredged material are evaluated in terms of displacement or changes in the plant community.

Three predominant wetland types exist in close association within the Bay: tidal salt marshes, mudflats, and diked seasonal or managed wetlands. Tidal marshes of the Bay form the largest contiguous tidal marsh system on the Pacific coast of North America, and have been the subject of several review papers (Atwater et al. 1979; Josselyn 1983). Thirteen or 14 species of vascular plants characterize tidal salt marshes of the Bay. The dominant plant species are common pickleweed (*Salicornia pacifica*) and California cordgrass (*Spartina foliosa*). In the Delta, tidal marshes support about 40 species characteristic of freshwater marshes. Tules and bulrushes (*Scirpus* spp.), cat-tails (*Typha* spp.), and common reed (*Phragmites communis*) are the dominants, and these contrasting plant communities overlap around San Pablo Bay, Carquinez Strait, and Suisun Bay (Atwater et al. 1979). One of the major problems confronting tidal marshes is the inability of vegetation to expand landward because of dikes and upland development (Josselyn 1983).

1.3.4 Fish

Once the foremost fishing center on the West Coast, the San Francisco Bay-Delta region has changed dramatically over the past century (Smith and Kato, in Conomos 1979). Much of the decline in fishery resources has been attributed to human-induced changes including heavy exploitation between 1870 and 1915, extensive land reclamation, water development projects, water pollution, and dredging. Although the full impact of anthropogenic effects is unclear, the filling of shallow mud flats around the perimeter of the Bay has resulted in a dramatic reduction in habitat for many species. Many commercial fisheries that were once important to the Bay Area economy have disappeared, leading to the overall change in emphasis from commercial to recreational fishing. The only remaining commercial fisheries of note are those for Pacific herring, northern anchovy, and bay shrimp. The most important recreational fisheries of the Bay are those for striped bass, chinook salmon, steelhead, shad, sturgeon, English sole, herring, anchovy, halibut, starry flounder, brown rockfish, and shiner surfperch.

After reviewing the literature, Smith and Kato (in Conomos 1979) conclude that little quantitative data are available on the fishery resources of the Bay, or the life history of most of the animals which reside in the Bay, whether as seasonal migrants or residents. The brief summary on fishery resources of the Bay that follows is drawn from the 1990 Long Term Management Strategy (LTMS) report by the USACE-San Francisco District (USACE 1990). A more comprehensive review of the historical changes in the important fisheries of the Bay can be found in Smith and Kato (in Conomos 1979).

The introduced species of striped bass (*Morone saxatilis*) supported an important commercial fishery in the Sacramento/San Joaquin delta area from 1889 to 1935. Between 1889 and 1915, annual catches usually exceeded 500 tons, but catches dropped significantly between 1915 and 1935 when the striped bass fishery was closed (Smith and Kato, in Conomos 1979). The California Department of Fish and Game assesses the relative abundance of the young fish in the Bay and Delta through calculation of the "striped bass index." The index has been on a downward trend for the last several years, amounting to 4.6, 5.2 and 4.3 for the years 1988, 1989, and 1990, respectively. The 1990 index value is the lowest since the index was first computed in 1956. Prior to 1977, the striped bass index averaged 66.6 with a high of 117.2 in 1965. Since 1977, the index has averaged 23.1 (Stevens 1989).

Declines in striped bass abundances have been attributed at least partially to alterations in the freshwater/saltwater structure of the Estuary. For example, water diversions in the Delta have led to the loss of eggs, larvae, and young fish into export canals. Saltwater intrusion into the Delta has resulted in poor spawning in the San Joaquin River, and low river flows have been associated with poor year class survival and recruitment (Smith and Kato, in Conomos 1979). Other possible reasons for the decline of the San Francisco Bay striped bass fishery include the following: 1) increased adult mortality resulting in low egg production; 2) reductions in the planktonic prey of young striped bass in the western Sacramento/San Joaquin delta and Suisun Bay during the spring, aggravated by the invasion of several Asian species of copepods, including *Pseudodiaptomus forbesi* in 1987, which do not appear do be as good a food source as the native *Eurytemora* (Orsi 1989); 3) increased predation of young striped bass by the introduced clam, *Potamocorbula amurensis* (Orsi 1989); and 4) physiological stress to the population from toxic substances such as petroleum hydrocarbons and pesticides (Setzler-Hamilton et al. 1988). These impacts may have been exacerbated by recent droughts.

Chinook salmon (*Oncorhynchus tschawytscha*) are known to enter Bay Area spawning rivers during most of the year (Hart 1973). In the Sacramento River, the major spawning run occurs in the fall with minor runs in the spring and winter (Sasaki 1966). Chinook salmon are probably present somewhere in the Bay system at all times of the year. The peak migration of salmon smolts out of the Bay occurs between April and August. During outmigration, the juvenile salmonids tend to remain in the upper few yards of water (Goddard et al. 1985; Sasaki 1966).

River catches of salmon ranged from 5400 tons in 1880 to only 160 tons in 1957, the year all commercial salmon fishing was prohibited inside the Golden Gate (Smith and Kato, in Conomos 1979). Declines in Bay salmon populations have been attributed partially to loss in spawning habitat (loss of 80% of San Joaquin and Sacramento river spawning grounds by 1928) and water diversions (Smith and Kato, in Conomos 1979). Chinook salmon support an important sport fishery in the Bay Area.

Adult steelhead (*Oncorhynchus mykiss*) pass through Central Bay during their upstream and downstream migrations. The upstream spawning migration occurs during summer and fall (Hallock et al. 1961), and some adults return to the ocean after spawning. The greatest number of steelhead smolts migrate seaward in the fall and spring, although there is movement of smolts downstream during most months of the year (Hallock et al. 1961). Steelhead are harvested as a sportfish above the Carquinez Strait. There is no commercial fishery for steelhead in the Bay.

American shad (*Alosa sapidissima*) were introduced into the Bay system in 1871 when 10,000 fry were released into the Sacramento River (Smith and Kato, in Conomos 1979). Both juvenile and adult forms of American shad use the Bay and Delta as a migration pathway between the open ocean and the upper Sacramento, Feather, and American rivers where they spawn (USACE 1988). The spawning migration occurs during the spring, when shad is sought as a sportfish in the Sacramento, American and Feather rivers. Commercial fishing for American shad was banned in California in 1957 (Moyle 1976).

White sturgeon (*Acipenser transmontanus*) use the Bay and estuary in low to moderate numbers throughout the year. They spawn in the upper Sacramento River between February and June. The Feather River also may be used for spawning (Kohlhorst 1976; Moyle 1976; Wang 1986). Larval white sturgeon occupy the upper Sacramento River, while juveniles concentrate in Suisun Bay and associated sloughs and in the lower reaches of the Sacramento and San Joaquin rivers (Wang 1986). Adult sturgeon migrate from the upper estuary through

San Pablo Bay and the Central and South bays following the herring spawning in the latter two bays (USACE 1988). The white sturgeon, which is not harvested commercially, is a popular sportfish caught from South Bay to the lower Sacramento River near Rio Vista (USACE 1988).

English sole (*Parophrys vetulus*), formerly known as lemon sole, use the Bay as a nursery area. They prefer habitats with fine, sandy sediments and quiet waters. Their distribution within the Bay is related to freshwater inflow (Herrgesell et al. 1983). When freshwater inflow is low, the distribution of early life stage English sole is limited to the Central Bay. But when Delta outflow is high, large numbers of early life stage individuals are distributed well into the South and San Pablo bays. Juvenile English sole enter the Bay between March and May and leave in late fall (Cooper and Keller 1969; KLI/ANATEC 1982).

Pacific herring (*Clupea harngus pallasi*) migrate into the Bay between October and March to spawn. Pacific herring spawn intertidally and subtidally to depths of 25 ft or more, where they prefer substrates covered with seaweed, eelgrass, or rock (Smith and Kato, in Conomos 1979). Adult Pacific herring leave the Bay immediately after spawning (USACE 1988). Juvenile Pacific herring are distributed throughout the Bay, with the greatest concentrations in the Central Bay. Juveniles migrate to the ocean in late summer or early fall (Armor and Herrgesell 1985). Adult Pacific herring support an important commercial fishery in the Bay. Although they are fished for only a few months, the value of the herring catch is 10 million to 15 million dollars annually (USACE 1988).

The northern anchovy (*Engraulis mordax*) is probably the most abundant species of fish in the Bay. It is found in the Bay throughout the year but is most abundant from April through October. Adult and young-of-the-year anchovy are most prevalent in channels of Central Bay. Eggs are most abundant in San Pablo Bay, although larval forms are distributed throughout the Bay. Shoal habitats are important for all life stages but are most important for spawning and larval rearing. Anchovies are found in the upper two-thirds of the water column (Wang 1986; CDFG 1987). The northern anchovy supports an important bait and commercial fishery along the California coast (Messersmith 1969; Bane and Bane 1971; Talbot 1973; Wang 1986). Anchovies for the bait industry are normally caught in the Bay. But in some years, 10% of the catch may originate outside the Bay (Smith and Kato, in Conomos 1979). The commercial fishery in the vicinity of the Bay produces approximately 385 tons annually (Herrgesell et al. 1983).

Jacksmelt (*Atherinopsis californiensis*) migrate from the ocean to the Bay in March, and peak densities of these fish are seen in the Central Bay for one to two months after migration. From May until July, they are widely distributed throughout South, Central, and San Pablo bays. In July, the jacksmelt are again seen in high concentrations in the Central Bay during their seaward migration (CDFG 1987). Jacksmelt spawn in shallow waters in association with aquatic vegetation and hydroids (Bane and Bane 1971). Juveniles, found in shallow waters in early summer, begin moving into deeper waters by midsummer (USACE 1988). Jacksmelt are probably most important as a food source for other prey (Wang 1986).

Adult California halibut (*Paralicthhys californicus*) can be found on sandy bottoms on shoals and offshore of beaches during spring, summer, and early fall in the South, Central, and San Pablo bays. Larvae and juvenile forms of this fish have been collected in these bays during fall and winter (Wang 1986). California halibut are harvested as a commercial and sportfish in San Pablo and South bays.

Various life stages of the starry flounder (*Platichthys stellatus*) occur throughout the Bay system. The larval flounder is a pelagic stage found in the Central Bay during April and May (CDFG 1987). The young-of-the-year starry flounder become demersal (bottom-dwelling) when they reach a size of 0.27 in. to 0.31 in. Flounder are most numerous in the western Delta during June and July (Wang 1986). As they grow, starry flounder gradually move downstream toward more saline waters. The young-of-the-year starry flounder concentrate in the shoals of Suisun and San Pablo bays in September and October. By midwinter, the juvenile starry flounder reach lengths of 5 in. and are distributed at various depths throughout all embayments, with the exception of the South Bay (USACE 1988). Starry flounder that grow to 6 in. tend to concentrate in the Central Bay, whereas fish of 4 in. to 8 in. are more likely to be found in San Pablo Bay (CDFG 1987). Starry flounder are a popular sportfish, and are caught commercially, usually as a nontarget fish (CDFG 1987).

The adult brown rockfish (*Sebastes auriculatus*) is found in the Central Bay around piers, ledge outcroppings, and rocky crevices to depths of 65 ft (McConnaughey and McConnaughey 1986; Feder et al. 1974). Juvenile and larval rockfish are found in the Central Bay and San Pablo Bay. Brown rockfish are fished by individual anglers and anglers on sportfishing charters because of the ease with which they are caught (WESCO 1988). The brown rockfish makes up a small component of the commercial rockfish landings (Goddard et al. 1985).

Shiner surfperch (*Cymatogaster aggregata*) are abundant and widely distributed in the Bay system. Shiner surfperch are found in Suisun, San Pablo, and Central bays (Wang, 1986). These perch, which enter the Bay to give birth to live young, are commonly found in calm waters associated with eelgrass beds and the pilings of wharves and piers. Shiner surfperch do not migrate to the ocean until they are about two years of age (Bane and Richardson 1970). They are found in the deeper portions of the Bay during the winter months, migrating to the shallow water habitats in April (Herrgesell et al. 1983).

1.3.5 <u>Birds</u>

Over 75 species of aquatic birds reside in or are regular visitors to the Bay system. Aquatic birds use areas in the Bay system as nesting and breeding grounds. These birds depend on several habitat types for survival and breeding, including mud flats, salt marshes, beaches, and open water.

Some of the more common waterbirds and shorebirds in the Bay area include the double-crested cormorant (*Phalacrocorax auritus*), greater scaup (*Aythya marila*), surf scoter (*Melanitta perspicillata*), sanderling (*Calidris alba*), western sandpiper (*Calidris mauri*), California gull (*Larus californicus*), western gull (*Larus occidentalis*), and the brown pelican (*Pelecanus occidentalis*) (U.S. Navy 1987).

The California brown pelican (*P. occidentalis californicus*) is listed as an endangered species by both the California Department of Fish and Game and the U.S. Fish and Wildlife Service. The California brown pelican uses areas in and around the Bay waters as roosting and feeding grounds (U.S. Navy 1987). The California least tern (*Sterna antillarum browni*) and the peregrine falcon (*Falco peregrinus*) use the Bay area habitats and are listed as endangered or threatened by the California Department of Fish and Game and the U.S. Fish and Wildlife Service (U.S. Navy 1987).

The Bay Area serves as an important wintering area for a number of bird species, including the red knot, willet, semipalmated plover, western sandpiper, and least sandpiper. Typical birds found in freshwater marshes are ducks, gulls, terns, grebes, dowitchers, whimbrels, godwits, avocets, and stilts. It has been estimated that 60% of the canvasback duck population of the Pacific flyway use Bay wetlands (CDFG 1968).

1.3.6 Marine Mammals

Small colonies of harbor seals (*Phoca vitulina*) inhabit Bay waters where they feed on fish and shellfish. All marine mammals are protected from hunting, capture, killing, or harassment under the Marine Mammal Protection Act of 1972. Important hauling grounds for harbor seals are located at the mouths of Mowry and Newark sloughs and Calaveras Point in South Bay, on Castro Rocks at the east end of the Richmond-San Rafael Bridge, and on lower Tubbs Island in San Pablo Bay. Occasionally sea lions, harbor porpoises, and whales are also seen within the Bay. In the fall of 1985, the humpback whale (*Megaptera novaeangliae*) that came to be known popularly as "Humphrey" entered the Bay and made its way into the Sacramento River Delta (Magagnini 1985).

1.3.7 Threatened and Endangered Species

Several endangered animal species are native to the Bay region. Animals that have been designated threatened or endangered by the state of California, the U.S. Fish and Wildlife Service, or the National Marine Fisheries Service in the Bay include the salt marsh harvest mouse (*Reithrodontomys raviventris*), the Alameda striped racer (*Masticophis lateralis euryxanthus*), the California clapper rail (*Rallus longirostris obsoletus*), the California yellow-billed cuckoo (*Occyzus* *americanus occidentalis*), the California brown pelican (*Pelecanus occidentalis californicus*), the California least tern (*Sterna antillarum browni*), the peregrine falcon (*Falco peregrinus*), the California black rail (*Laterallus jamaicenisis coturniculus*), and the thicktail chub (*Gila crassicauda*) (CRWQCB 1982; U.S. Navy 1987). Any habitat identified as necessary for the continued existence of protected species is considered a significant resource.

On November 5, 1990, NMFS issued a final listing of the Sacramento River winter chinook as a threatened species under the Endangered Species Act (ESA). This was the first anadromous salmonid population to be protected under the ESA. Habitat loss and modification in the Sacramento River system, rather than overfishing, have been the primary causes of the decline (Williams and Williams 1991).

The gray whale (*Eschrichtius robustus*) and the humpback whale (*Megaptera novaeangliae*) are known to enter the Bay. The gray whale was formerly listed as an endangered species, but was removed from the list in 1992 because of promising population increases. The humpback whale is still listed as an endangered species (U.S. Navy 1987). The soft bird's beak (*Cordylanthus mollis*) is listed as a threatened plant by the state of California and is a candidate for federal listing as an endangered species (U.S. Navy 1987).

1.3.8 Introduced Species

This section is a brief synopsis of the extent and biological implications of introduced species in the Estuary, as presented in Cohen (1991).

More than 100 non-native, introduced species live and reproduce in the Estuary. The list of documented species that have been introduced includes 26 fish, 18 amphipods, 13 polychaetes, 12 gastropods, 11 bivalves, 10 isopods, 9 hydroids, 6 copepods, 5 sponges, 5 seaweeds, 4 anemones, 3 flatworms, 3 tunicates, 3 marsh plants, 2 crayfish, 2 barnacles, a Korean shrimp, the eastern bullfrog, and the muskrat.

Many of the fish species were deliberately introduced to establish commercial or sport fisheries (e.g., striped bass, American shad, catfish, largemouth bass). In contrast, most of the invertebrate introductions were accidental. Some species were transported in the ballast water of ships and others came in shipments of live oysters from the east coast or Japan.

Evidence from many ecosystems around the world suggests that introduced species typically reduce or eliminate populations of native species through predation or competition for limiting resources. However, in some rare cases, native species may actually benefit from the presence of introduced species. For example, in the Estuary introduced invertebrate species are the main food of migratory birds and of the endangered California clapper rail, and native hermit crabs frequently inhabit the shells of introduced snails.

2.0 EVALUATION OF EXISTING INFORMATION

2.1 POTENTIAL SOURCES OF CONTAMINATION

The following sections summarize the potential sources of contamination and available information on sediment chemistry, sediment bioassays, bioaccumulation studies, and fish histopathology for areas within and around the JFBSC. Contaminant sources and activities believed to be important in evaluating JFBSC sediments are municipal and industrial effluents, urban and nonurban runoff, dredging operations, riverine inputs, accidental spills, atmospheric inputs, discharges from marine vessels, and leakage from waste disposal sites.

2.1.1 Municipal and Industrial Effluents

The most comprehensive analysis of pollutant loading to the Estuary from municipal and industrial dischargers is found in the *Status and Trends Report on Pollutants in the San Francisco Estuary* published by the San Francisco Estuary Project (Davis et al. 1991). Data for this analysis were derived primarily from the AHI's 1984 to 1986 effluent monitoring database (Gunther et al. 1987). In order to analyze spatial patterns in municipal and industrial loadings the Estuary was divided into 10 major segments. Data for the three segments potentially affecting JFBSC, Central Bay, San Pablo Bay, and Suisun Bay will be discussed in this section.

Publicly Owned Treatment Works (POTWs) receive and treat wastewater from a variety of residential, commercial, and industrial sources. Seventy percent of the total wastewater flow into the Bay during 1984 to 1986 was contributed by eight POTWs (Gunther et al. 1987). Only three of these, Sacramento Regional, Central Contra Costa Sanitation District (Suisun Bay), and East Bay Municipal Utility District (Central Bay), were located in the central and northern reaches of the Bay-Delta area. Discharge of wastewater from POTWs during the dry season can represent a significant fraction of freshwater input to the Bay.

Trace metals was the only class of pollutants detected on a regular basis in POTW effluents. Of these, 10 elements (As, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, and Zn) were listed as "pollutants of concern." Only a few volatile organics (chloroform, bromodichloromethane, dichloromethane, tetrachloromethane, tetrachloroethene, toluene, and 1,1,1-trichloroethane) were commonly reported, and only toluene was classified as a pollutant of concern. Other pollutants, including semi-volatile organics, organochlorine pesticides, polychlorinated biphenyls (PCBs), and polynuclear aromatic hydrocarbons (PAHs), were detected infrequently in POTW effluents.

Petroleum refining is a major activity in the Bay area and results in the discharge of several categories of wastewater, including cooling water, stormwater runoff, and water used in processing crude oil into fuels, lubricants, asphalt, and other hydrocarbon products. Water used in processing crude oil ("process water") contains the highest contaminant loads and receives the greatest regulatory scrutiny. Process water generally contains contaminants that reflect the composition of the crude oil being refined; therefore, large numbers of hydrocarbon compounds and several trace elements (e.g., Se, Cr, Ni, Pb, Cu, Zn) are routinely reported in refinery effluents.

Table 2.1 summarizes the locations of all major POTWs and industrial (NPDES) dischargers into the Estuary that were identified by Gunther et al. (1987). According to Tom Gandesberry, a water-quality specialist with the San Francisco Bay Regional Water Quality Control Board (personal communication, October 1993), numerous unchecked, unregulated sewer outfalls are potentially a bigger source of contamination to the Estuary than industrial discharges.

Total municipal and industrial waste loads were calculated in Davis et al. (1991) using 1984 to 1986 average discharge data (monthly averages) compiled for each of the segments. A summary of the flows and mass loadings for selected trace elements is presented in Table 2.2. Mass loads were calculated by multiplying flow rates by the average trace-element concentrations in effluents. Although the pollutant loading data in Davis et al. (1991) is the most comprehensive available, their mass calculations should be treated as crude estimates only. This is due largely to infrequent sampling and chemical analysis undertaken by many of the dischargers. Moreover, other factors such as lack of uniformity in the use of analytical protocols, data sets with extremely high detection limits, and the general lack of quality assurance data, further confound interpretation.

Significant results from Davis et al. (1991) for selected trace metals are summarized below:

- Arsenic - Most of the total load to San Pablo Bay (1.2 kg to 2.8 kg As d^{-1}) was contributed by Chevron USA (refinery), Chevron Chemical (chemical plant), and Napa Sanitation District.
- Chromium - San Pablo Bay had the second highest loading rate of chromium (5.6 kg to 7.0 kg Cr d^{-1}) in the Estuary. Most of this was attributed to discharge from a power plant located on Mare Island.
- Lead - The third highest loading rate of lead in the Estuary came from discharges by Central Contra Costa Sanitation District (2.5 kg to 2.9 kg Pb d^{-1}) into Suisun Bay.
- Nickel - The second highest loading rate of Ni in the Estuary came from discharges by East Bay Municipal Utilities District (9.1 kg Ni d-1) into Central Bay. Chevron USA released significant quantities of Ni (3.1 kg to 4.1 kg Ni d^{-1}) into San Pablo Bay.
- Silver - San Pablo Bay received the highest load of silver (2.3 kg to 3.8 kg Ag d^{-1}) in the Estuary. Most of this was attributed to discharges into the Napa River from a small municipal treatment plant serving the City of Napa.
- Zinc - Discharge rates of 25 kg Zn d^{-1} into Central Bay by East Bay Municipal Utilities District were the second highest recorded within the Estuary.

TABLE 2.1. Summary of the Location of All Major Publicly Owned Treatment Works (POTWs) and Industrial Dischargers Identified by Gunther et al. (1990)

Location	North Latitude	West Longitude	Segment
POTWs			
Benicia	30°02'30"	122°09'03"	SP 7
Calistoga	38°33'34"	122°33'28"	SP 9
Central CC Sanitary	38°02'44"	122°05'55"	SU 1
Central CC Sanitary #19			CD
Central Marin	37°56'54"	122°27'23"	CB 9
Davis			ND
Delta-Diablo			WD
EBDA	37°42'	122°48'	SB 11
EBMUD	37°49'02"	122°20'50"	CB 1
Fairfield-Suisun	38°12'33"	122°03'24"	SU 4
Hercules Rodeo	38°03'06"	122°15'55"	SP 6
Las Gallinas	38°01'32"	122°30'58"	SP 1
Lodi			ND
Mountain View			SU 1
Napa	38°13'45"	122°17'00"	SP 9
North Bayside	37°39'55"	122°21'41"	SB 6
Novalo-Ignacio	38°04'00"	122°29'00"	SP 1
Palo Alto	37°27'11"	122°06'36"	SB 2
Paradise Cove			CB 9
Port Costa			SP 7
Rio Vista			CD
Sacramento			ND
S.F. Southeast	37°44'58"	122°22'22"	SB 9
S.F. Northpoint			
San Jose-Santa Clara	37°26'06"	121°57'08"	SB 1
San Mateo	37°34'50"	122°14'45"	SB 7
Sausalito-Marin	37°50'37"	122°28'03"	CB 3
Sewage Agen. of S. Marin	37°53'40"	122°28'10"	CB 3
South Bayside	37°33'48"	122°12'55"	SB 4
Sonoma Valley	38°14'14"	122°25'51"	SP 2
Sunnyvale	37°26'	122°02'	SB 2
St. Helena	30°20'10"	122°26'15"	SP 9
Stockton			CD
Tracy			SD
Vacaville			ND
Vallejo	38°07'37"	122°16'00"	SP 7
Walnut Grove			ND
W. Sacramento			ND
West County Agency	37°54'41"	122°25'06"	CB 11
Yountville	38°24'24"	122°20'27"	SP 9
Industry			
C&H Sugar	--(a)	--	SP7
Chevron Oil	--	--	SP 5
Chevron Chemical	--	--	SP 5
Crown Zellerbach	--	--	WD
Dow Chemical	--	--	WD
Du Pont	--	--	WD
Exxon	--	--	SU 1
Fibreboard	--	--	WD

TABLE 2.1 (contd)

Location	North Latitude	West Longitude	Segment
Industry (contd)			
General Chemical	--	--	SU 1
Libbey-Owens Ford	--	--	SD
Mare Island Naval Shipyard	--	--	SP 9
McCormick and Baxter	--	--	CD
New United Motors	--	--	SB 1
Pacific Refining	--	--	SP 6
PG&E	--	--	
Contra Costa	--	--	WD
Hunters Point	--	--	SB 9
Oleum	--	--	SP 6
Pittsburg	--	--	WD
Potrero	--	--	SB 9
Shell Oil	--	--	SP 7
Stauffer Chemical	--	--	
Martinez	--	--	SU 1
Richmond	--	--	CB 7
Tosco	--	--	SU 1
Union Oil	--	--	SP 6
U.S. Steel	--	--	WD

(a) -- Not applicable.

TABLE 2.2. Summary of Average Daily Flows and Contaminant Loads from Municipal and Industrial Dischargers for Suisun Bay, San Pablo Bay, and Central Bay. Loading Rate Data are Expressed as Ranges (After Davis et al. 1991)

Title	Suisun Bay	San Pablo Bay	Central Bay
Flows (L/d)	220×10^6	261×10^6	450×10^6
	Loading Rates (kg/d)		
Arsenic	0.2-1.1	1.2-2.8	0.3-2.1
Cadmium	0.6-1.2	0.3-1.4	0.6-1.2
Chromium	2.3-2.9	5.6-7.0	5.1-5.5
Copper	4.3-5.1	4.3-7.2	7.8-13.0
Lead	3.1-4.6	2.5-6.9	2.4-4.0
Mercury	0.02-0.15	0.07-0.28	0.05-0.17
Nickel	4.1-5.3	6.7-9.8	9.5-12.0
Silver	0.3-1.1	2.3-3.8	1.0-2.4
Zinc	14-14	12-15	34-35

2.1.2 Urban and Nonurban Runoff

Urban and nonurban runoff are episodic and seasonally variable sources of contaminant loading to the Estuary. Pollutants in urban runoff originate from a variety of commercial, industrial, and residential operations and land-use practices. Sources for nonurban runoff include agricultural and pasture lands, natural range land, and forests. In general, the overall contribution of contaminant loads from urban and nonurban runoff to the Estuary is poorly known.

Loading rates of contaminants to the Estuary from both urban and nonurban sources are stongly influenced by regional patterns of precipitation. Pollutants often accumulate within drainages between individual storm events and between rainy seasons, only to be flushed out when the first rains appear. Scouring of urban and non urban surfaces following seasonal storms, therefore, may have a strong influence on temporal trends in pollutant loading.

Studies conducted under the Nationwide Urban Runoff Program (NURP) have detected a variety of contaminants in urban runoff, including all 13 EPA priority trace elements, solvents, pesticides, fuel oils, combustion products, lubricants, and synthesized polymers and resins (Davis et al. 1991). Insecticides used for mosquito and domestic pest control, as well as herbicides for maintaining golf courses, rights of way, and residential landscapes, contribute to contaminant loads in urban runoff. Illegal discharges to storm sewers and miscellaneous urban surfaces are believed to be an important source for some contaminants. Russell and Meiorin (1985) concluded from a survey of three communities in the Bay Area that at least 50% of used motor oil was being disposed of in this manner.

A review of studies on urban and nonurban sources of contaminants to the Estuary is provided in Gunther et al. (1987). However, high uncertainty is generally attached to estimates of pollutant loads due to the lack of information on the physical-chemical state (i.e., dissolved or particulate) and concentration of contaminants in runoff. Estimates of runoff coefficients (i.e., the fraction of rainfall that becomes runoff) are also poorly known. Gunther et al. provide ranges of pollutant loads in runoff, which they calculated by systematically varying the assumptions used in the calculations to create reasonable "high" and "low" estimates. Table 2.3 (reproduced from Gunther et al. 1987) shows Estuary-wide load estimates for selected pollutants. Gunther et al. report that despite high uncertainty, runoff contributes greater quantities of selected contaminants such as Pb than does effluent. It should be noted, however, that runoff estimates provided in Gunther et al. were primarily obtained using sources outside of the Bay-Delta region.

TABLE 2.3. Estimated Loading Rates of Selected Toxic Pollutants in the San Francisco Estuary from Urban Runoff (After Davis et al. 1991; table reproduced from Gunther et al. 1987)

Pollutant	Estimated Load[a] (tonnes/yr)	Estimated Range[b] (tonnes/yr)
Arsenic	6	1-9
Cadmium	2	0.3-3
Chromium	12	3-15
Copper	42	7-59
Lead	179	30-250
Mercury	0.1	0.03-0.15
Zinc	189	34-268
Total Hydrocarbons	8,260[c]	1,143-11,016[d]
PCBs	--	0.006-0.4
PAHs	--	0.5-5

(a) NOAA (1988).
(b) Gunther et al. (1987).
(c) Derived using concentrations of oil and grease.
(d) Minimum value derived using concentration data for petroleum hydrocarbons, maximum value using oil and grease data from (Gunther et al. 1987).

Data for pollutant loads in nonurban runoff have largely been compiled for drainage areas outside of the Estuary. Montoya et al. (1988) have measured trace elements in agricultural runoff for several locations in the Sacramento Valley. In general, metal loads were lower than those reported for urban runoff in Sacramento. A number of pesticides such as atrazine, simazine, fenthion, dacthal, diazinon, bidrin, phorsulfon, chloropropham, molinate, and thiobencarb, have been detected in drain waters originating from the Central Valley (DWR 1988). The National Oceanic and Atmospheric Administration (NOAA 1988) provides loading estimates to the Bay-Delta for selected trace metals and chlorinated hydrocarbons from croplands, forest land, other nonurban land, and irrigation return flows. The NOAA data has been reproduced in Table 2.4. These estimates should be viewed as high, as the NOAA data were collected during a single year, 1982, in which greater-than-average rainfall was reported.

2.1.3 Dredging Activities

As population growth exploded in the Bay area around the turn of the century, the Bay-Delta was developed as a major thoroughfare for commercial shipping, Naval operations, and recreational boating. There are currently six commercial ports serving the area: Benicia, Richmond, Oakland, San Francisco, Redwood City, and the Encinal terminals. In addition, there are six major defense installations in the Bay area that require free navigational access: Mare Island Naval Reservation, Naval Station Treasure Island, Hunters Point Annex, NAS Alameda, Naval Weapons Station Concord, and NAS Moffett Field. In 1986 there were approximately

18,350 berths in Bay area marinas (BCDC 1987), and the BCDC estimates that this number will increase to 30,300 to 42,640 by the year 2020 (BCDC 1982).

With increased urbanization of the Estuary, much attention has been focused on the impacts of turbidity, decreased dissolved oxygen, and the potential mobilization of contaminants resulting from dredging and dredged-material disposal operations (Davis et al. 1991). A principal concern is that dredging activities will result in the redistribution of contaminants and that under certain conditions this may lead to an increase in bioavailability. Greatest concern seems to be over new dredging or maintenance dredging of infrequently dredged areas, which contain greater quantities of deeply buried sediments, and thus potentially larger loads of contaminants that may have been introduced to the sediments over a period of decades (Gunther et al. 1987). Questions concerning bioavailability and potential toxicity of sediment components, however, are difficult to address in the absence of laboratory testing. In addition to physical fractionation and dispersion, which occur immediately after dumping, deposited sediments are continually subjected to an array of physical, chemical, and biological processes that can alter toxicity potential. Therefore, factors such as the physicochemical nature of the deposited sediments and conditions at the disposal site are important in determining potential contaminant mobility and bioavailability.

Naturally accumulating sediment is dredged from three types of areas in the Bay region: federally maintained navigation channels, large port facilities, and small project areas. The USACE, San Francisco District, maintains 13 congressionally authorized navigation and flood-control projects within the Bay region. An additional eight projects are maintained by the U.S. Navy, and a number of private dredging projects occur throughout the Bay to maintain ports,

TABLE 2.4. Loads (Tonnes/Yr) of Selected Trace Metals and Chlorinated Hydrocarbon Pesticides (CHP) from Cropland, Forest Land, Other Nonurban Land, and Irrigation Return Flows (After NOAA 1988 and Summary in Gunther et al. 1987)

Source(a)	As	Cd	Cr	Cu	Pb	Hg	Zn	CHP
Cropland	34	2	269	122	61	0.38	293	0.42
Forest Land	11	0	133	49	33	0.16	135	0.00
Other Nonurban Land	74	5	1,134	410	265	1.20	1,023	0.00
Irrigation Return Flows	0	0	2	0	0	2.00	2	0.08
Total	119	6	1,537	581	358	1.73	1,453	0.50

(a) Data are for 1982.

marinas, and shipyards. Locations of dredging areas under the jurisdiction of the USACE and the U.S. Navy, respectively, are presented in Figures 2.1 and 2.2.

The USACE estimates that its maintenance projects will generate a total of 17,025,788 yd^3 of material from 1989 through 1993 that will require in-bay disposal. The USACE currently dredges and disposes of over 4 million yd^3 of sediment each year from both deep- and shallow-draft federal navigation channels in the Bay; an additional 3 million yd^3 of sediment are dredged and disposed of under USACE issued permits.

Between the late 1800s and 1970 dredged material was disposed of at numerous sites throughout the Bay. A map showing locations of historical aquatic disposal sites in the Bay is presented in Figure 2.3. In many cases, little information exists regarding disposal practices at historical dredged material disposal sites. In addition to these locations, many diked, historic baylands were filled with dredged material up until the time in-bay aquatic disposal came under strict regulation (Gunther et al. 1990). Since 1975, in-bay disposal operations have been restricted to three locations: Alcatraz Island, San Pablo Bay, and Carquinez Strait (Figure 1.3). Disposal records (i.e., monthly schedules and disposal quantities) for the three active sites are provided in USACE (1990).

The most complete records on past dredge and fill activities for USACE and U.S. Navy projects are for the years 1975 to present. The USACE database contains records for all San Francisco District USACE Civil Works projects conducted from 1975 to 1985. Data for non-USACE and US Navy projects are obtained mostly from estimates listed on individual permit applications. Dredging records for the Pinole Shoal Channel section of the JFBSC for the years 1936 to 1987 are provided in Table 2.5. The Pinole Shoal Channel is dredged approximately every two years, although the channel has not been dredged since 1987. Materials from the Pinole Shoal Channel have been disposed of at the San Pablo Bay disposal site (Figure 1.3).

2.1.4 Riverine Inputs

A map of the principal rivers in the Bay-Delta drainage basin is provided in Figure 1.2. The Sacramento and San Joaquin rivers drain extensive agricultural areas and provide the largest source of freshwater to the Estuary. Collectively, the Sacramento and San Joaquin rivers drain approximately 40% of the total land area for the state of California (Gunther et al. 1987). Long-term average flows recorded by the USGS for the Sacramento and San Joaquin rivers, respectively, are 70 billion L d^{-1} (18.5 billion gal d^{-1}) and 9 billion L d^{-1} (2.4 billion gal d^{-1}).

The Sacramento Valley is considered to be one of the most productive agricultural regions in the world and is acknowledged as a world leader in pesticide application. Herbicides are also used extensively throughout the valley to control the invasion of aquatic plants in artificial wetland areas created for the culture of rice crops. Two herbicides, molinate and thiobencarb, are

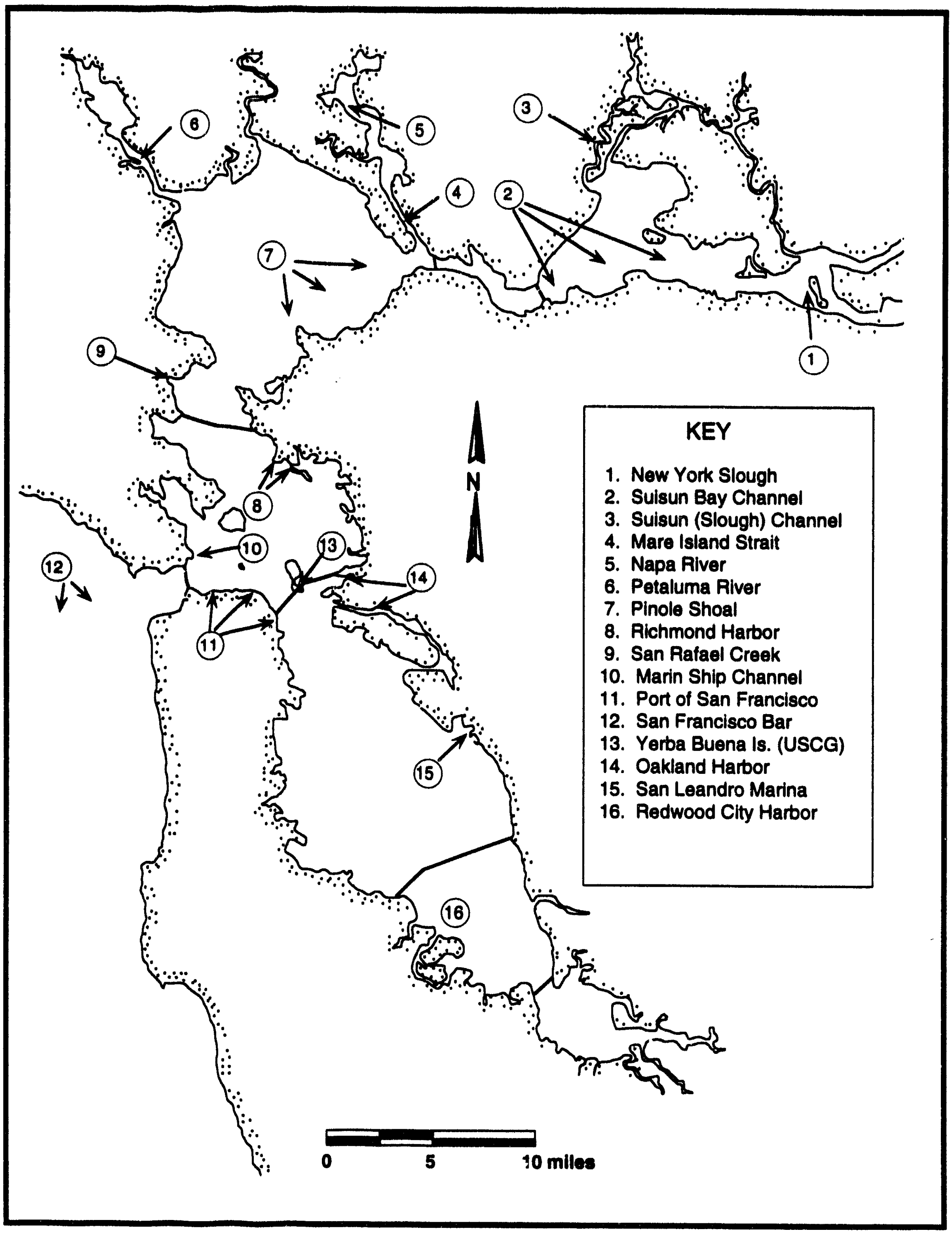

FIGURE 2.1. Locations of USACE Maintenance Dredging Projects

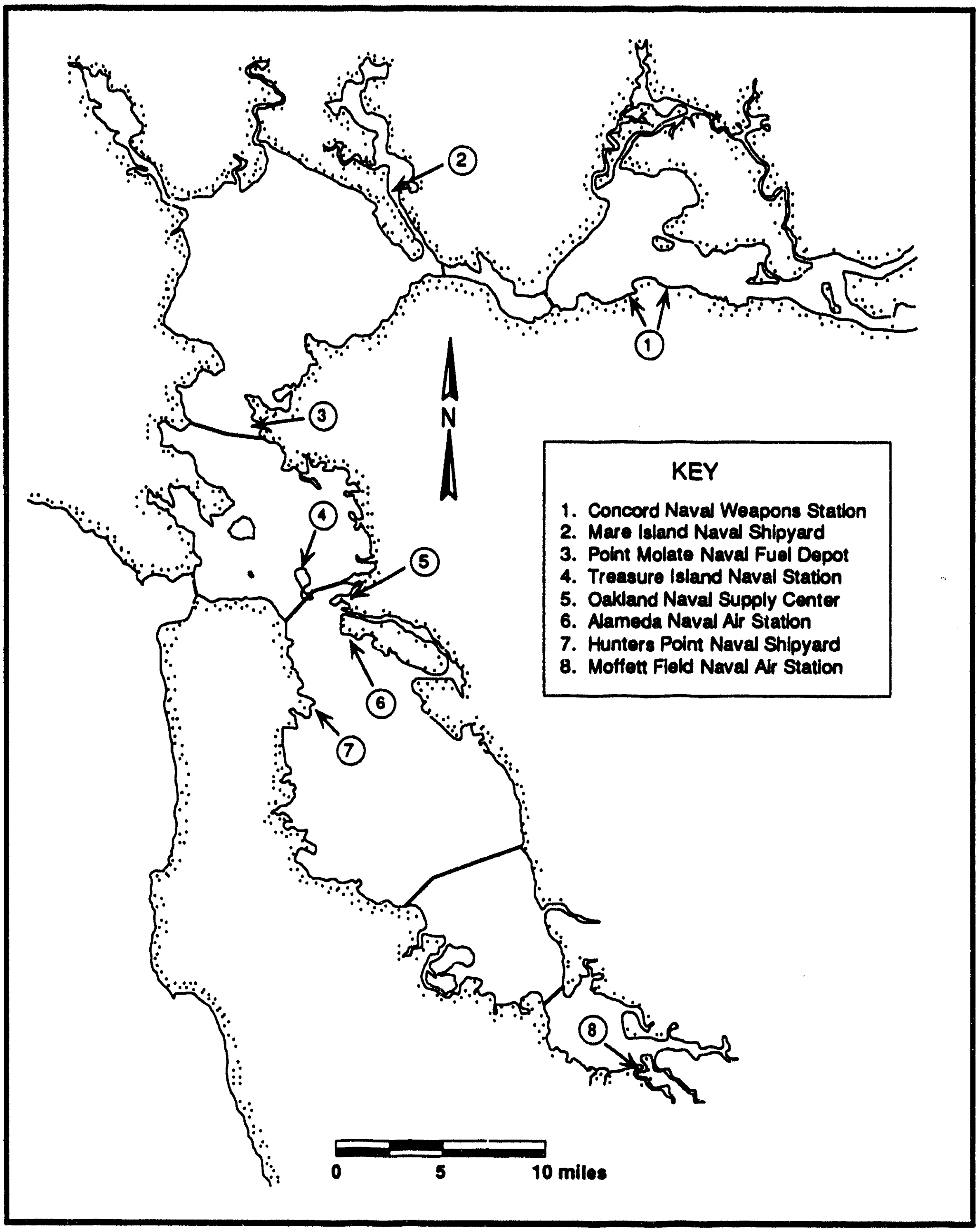

FIGURE 2.2. Locations of Naval Facilities Where Dredging Was Performed During 1975 to 1985

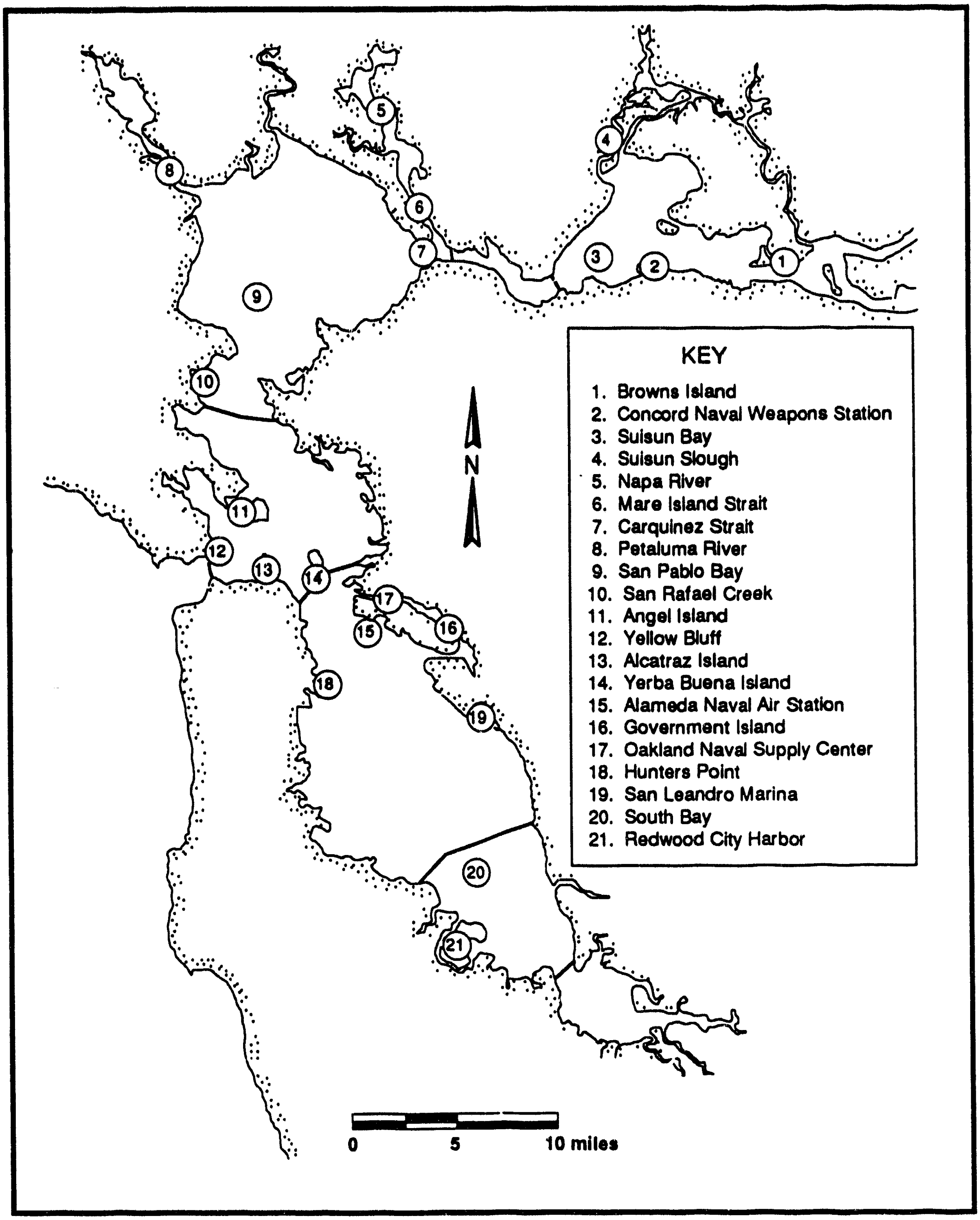

FIGURE 2.3. Locations of Historical In-Bay Dredged Material Disposal Sites

TABLE 2.5. Dredging Records for the Pinole Shoal Channel: 1936 to 1987

Fiscal Year	Quantity Removed (yd^3)
1936	181,700
1938	1,403,100
1939	733,200
1940	754,000
1941	1,024,800
1942	2,363,400
1943	1,122,100
1944	1,654,800
1947	420,100
1949	235,800
1950	381,100
1954	649,400
1957	231,500
1958	120,000
1959	315,000
1960	2,588,000
1961	843,000
1962	1,034,500
1967	218,200
1969	450,000
1970	290,500
1971	816,000
1972	665,000
1974	481,000
1976	46,900
1980	149,000
1982	386,927
1984	432,919
1987	309,386

the most commonly used and are of special significance due to their toxicity to aquatic organisms and high concentrations in various sections of the Sacramento River.

Mass transport of contaminant loads to the Estuary from major tributaries of the Delta is discussed in Gunther et al. (1987). Accurate estimates of loading rates are difficult to obtain, however, because of wide seasonal and interannual variation in river flows and large uncertainties in contaminant concentrations. Few monitoring programs sample frequently enough to adequately characterize temporal variation in contaminant concentrations. Significant contaminant loads are often transported in pulses that occur over periods as short as several days; therefore, considerable bias must be assumed when using average contaminant concentrations to estimate mass loads.

Water diversion to the southern portion of the Central Valley removes some of the flow from both the Sacramento and San Joaquin rivers. The volume of water diverted varies considerably among seasons and years. However, Gunther et al. (1987) conclude that on a time-averaged basis it is unlikely that contaminant loading to the Bay is more than 20% lower than estimates they have provided. This is largely because contaminant loading to the Bay is greatest during periods of high runoff and high river flow, and water diversions are generally less important at this time.

Whereas it is likely that potentially significant quantities of pesticides and herbicides enter the Bay from the Delta, the transport and fate of organic contaminants has been little studied in this region of the Estuary and reliable estimates of loading rates are unavailable. The lack of data on organic contaminants is at least partially due to the difficulty of detecting these compounds in water samples. Daily loading rates for selected trace metals (As, Cr, Cu, Ni, Zn, Se) have been summarized in Davis et al. (1991) and show wide variation between average and maximum estimates. However, average daily loading rates for each of the metals were at least one to two orders of magnitude higher than loading rate estimates reported for municipal and industrial discharges (Table 2.2). The best data for calculating pollutant loads from riverine sources come from the extensive work of Cutter (1989) on selenium.

2.1.5 Accidental Spills

Accidental spills are a potentially significant source of contaminant loading to the Bay. Spills of petroleum hydrocarbons, in particular, occur frequently and are of special concern. Most spills, however, are small and most often result from damaged ships, operator errors, handling accidents at terminals, and accidents involving materials carried on shoreline highways (Davis et al. 1991).

The National Oil and Hazardous Substance Response System is the federal government's mechanism for emergency response to discharges of oil into navigable waters of the United States. This system is described in the National Oil and Hazardous Substances Contingency Plan (NCP) (40 CFR, part 300). The NCP led to the creation of the National Response Center (NRC), which processes reports of all spills regulated by the Federal Water Pollution Control Act. The NRC is staffed by personnel from the U.S. Coast Guard. The NRC also maintains the Incident Reporting Information System (IRIS), an on-line relational database that provides the capability to collect, analyze, manage, and disseminate incident information.

Gunther et al. (1987) used data collected by the U.S. Coast Guard from 1984 to 1986 as the basis for a generalized estimate of pollutant loading to the estuary from spills. Their estimate of the average release of petroleum hydrocarbons into the Bay during this period was 17,000 L/yr (ca. 31,000 gal/yr or 94 tonnes/yr). However, it is likely that long-term estimates for pollutant loading from spills are influenced more by infrequent catastrophic events, which have the potential to release large quantities of contaminants at a single point in time.

Two major oil spills have occurred in the Bay within the last 21 years. In 1971 two oil tankers collided near the Golden Gate releasing approximately 3.2 million L (845,000 gal) of fuel oil. An accidental release of crude oil occurred at an above-ground holding tank at the Shell Oil refinery in Martinez in 1988. Approximately 1.4 million L (370,000 gal) of oil flowed into marshes near the release point and then eventually into Carquinez Strait and Suisun Bay. Overall 50 mi of shoreline were affected. Oil was detected as far east as Ryer and Roe islands and as far west as Pt. San Pablo downstream of the Carquinez Strait.

2.1.6 Additional Sources of Contamination

Additional sources of contamination to the Bay include atmospheric inputs, discharges from marine vessels, and leakage from waste disposal sites.

Although few data exist on the atmospheric deposition of toxic pollutants to the Bay-Delta area, estimates of the importance of atmospheric sources to pollutant loading vary depending on the contaminant (Gunther et al. 1987). Gunther et al. (1987) used deposition rates measured for other areas of the country to provide crude estimates of potential loading rates for the Bay-Delta area. They estimate that atmospheric deposition contributes 0.14 to 0.35 tons/yr of Cd, 1.9 to 3.1 tons/yr of Cu, and 6 to 21 tons/yr of Pb to the Estuary. Potentially significant loads were estimated for PAHs (0.8 to 4.8 tons/yr) and total hydrocarbons (2.1 to 45 tons/yr). Estimates for PCBs were based on flux rates calculated for the Great Lakes and ranged from 0.12 to 0.87 tons/yr.

Sewage and gray water (i.e., waste water from kitchen and bathing uses) are sources for coliform bacteria, substances which exert biochemical oxygen demand (BOD), suspended solids, oil and grease, and nutrients (BCDC 1987). These wastes generally have localized effects on water quality and public health in marinas and harbors with minimal flushing (Gunther et al. 1987).

Potential contamination of surface and ground water due to leakage from hazardous waste and municipal waste disposal sites has gained both local and national attention during the last decade. Nearly 2000 former municipal solid waste sites, hazardous waste disposal sites, and industrial waste disposal sites have been identified in the immediate Bay Area (SFBRWQCB 1988; CWMB 1989). There are currently 21 active solid waste landfills in the Bay area, some of which are considered potential threats to surface water due to their locations (ABAG 1985).

Older land disposal sites have the highest potential for leakage. The California regional water quality control boards have conducted Solid Waste Assessment Tests on only a small number of landfills. Management of municipal landfill sites is generally less rigorous than of hazardous material disposal sites due to the strict controls that now exist on hazardous materials transportation and disposal. Differences in the quantity and quality of contaminants present at various landfill sites and the poor availability of monitoring data generally confound efforts to estimate loading rates of toxic materials to the Bay.

2.2 OVERVIEW OF SEDIMENT CHEMISTRY DATA

The following section provides an overview of relevant physical and chemical evaluations that have been conducted on sediments within and in the vicinity of the JFBSC.

2.2.1 NOAA Status and Trends and Miscellaneous Studies on Contaminants in Bay Sediments

NOAA's Status and Trends (NS&T) Program was established to characterize the status and trends in environmental quality of selected portions of the nation's coastal and estuarine environments. Since 1984 the NS&T Program has analyzed surface sediment samples from approximately 200 coastal and estuarine sites throughout the United States (NOAA 1988).

NOAA released a comprehensive report in 1988 on the status and trends in contaminant concentrations and measures of biological stress in the Bay (Long et al. 1988). The intent of the San Francisco Bay Program was to track conditions in areas that integrate inputs from multiple sources such as municipal and industrial effluents, urban and rural runoff, and spills. Sampling sites were located in areas considered to be generally representative of the many hydrographic and pollution regimes in the Bay.

Long et al. (1988) report that contaminants are widespread throughout the Bay, with the highest concentrations generally occurring in peripheral areas such as harbors, waterways, and boat basins. However, considerable variation and patchiness in contaminant concentrations and the relative scarcity of basin-wide data (i.e., more studies have focused on basin margins) were cited as factors making it difficult to establish clear trends in contaminant distribution. Differences in the relative availability of data for different classes of contaminants were also reported. In general, sediment chemistry data for PAHs, PCBs, and pesticides are lacking for many areas of the Bay. The most complete data sets are for sediment metals, although few comprehensive monitoring studies have been performed; therefore, conclusions on temporal and spatial trends must be made on the pooled results from numerous investigations. Long et al. (1988) recommend that caution be exercised in evaluating the overall results produced from this type of analysis. Differences in sampling (especially sampling depth) and analytical protocols and method detection limits often confound efforts to interpret pooled data. Moreover, sediment characteristics that are often used in evaluating the potential availability of contaminants, such as grain size and organic matter content, are not provided in every data set.

Table 2.6 presents a summary of the data compiled by Long et al. (1988) for metals found in surface sediments from selected areas of the Bay. The data summarized in Table 2.6 were extracted from multiple studies conducted from 1970 through 1986. Data sources included dredging studies conducted by the USACE, studies of sewage and industrial discharges

TABLE 2.6. Summary of Metal Concentrations in Surface Sediments for Selected Areas Within San Francisco Bay (All units ppm dry wt) (After Long et al. 1988)

Area	Years Sampled	Mean ±S.D.	Median	Range	N[(a)]
Mercury					
San Pablo Bay	70-73, 75, 76, 84-86	0.45 ±0.53	0.30	<0.01-2.80	112
Carquinez Str./Suisun Bay	70, 71 73, 74, 76	0.23 ±0.26	0.11	0.02-1.25	57
Mare Island Strait	70-79	0.43 ±0.22	0.42	0.02-1.30	199
Central Bay	70,71, 73, 74, 76, 84-86	0.35 ±0.44	0.26	<0.01-3.90	111
Cadmium					
San Pablo Bay	73, 75, 76, 84-86	0.71 ±0.54	0.53	0.04-2.0	51
Carquinez Str./Suisun Bay	73, 74, 76, 83	0.52 ±0.57	0.24	0.03-2.1	46
Mare Island Strait	71-79	1.54 ±1.32	1.20	0.20-8.3	194
Central Bay	71, 73, 74, 76, 80, 81, 84-86	0.79 ±0.40	0.75	0.02-2.2	77
Copper					
San Pablo Bay	70, 73, 84-86	45 ±24	41	5-131	58
Carquinez Str./Suisun Bay	70, 73, 74, 83	39 ±24	39	5-100	78
Mare Island Strait	70-74	83 ±16	62	44-128	124
Central Bay	70, 71, 73, 74, 80, 81, 84-86	33 ±20	30	5-86	114
Lead					
San Pablo Bay	70-73, 75-76, 84-86	32 ±40	27	5-421	112
Carquinez Str./Suisun Bay	70, 73, 74, 83	29 ±18	30	1-100	89
Mare Island Strait	70-79	47 ±13	46	22-124	196
Central Bay	70, 71, 73, 74, 76, 80, 81, 84-86	34 ±27	30	3-170	134
Chromium					
San Pablo Bay	73, 84-86	280 ±219	190	33-769	17
Mare Island Strait	71-73	153 ±117	91	62-387	28
Central Bay	71, 73, 80, 81, 84-86	81 ±94	44	13-383	48
Silver					
San Pablo Bay	84-86	0.45 ±0.44	0.27	<0.01-1.60	15
Mare Island Strait	73, 74	2.12 ±0.91	2.15	0.50-4.90	82
Central Bay	80, 81, 84-86	0.72 ±0.58	0.50	0.13-2.00	35

(a) N Number of samples.

conducted by numerous environmental consulting firms, and miscellaneous studies conducted by or funded through NOAA, EPA, U.S. Navy, and the U.S. Geological Survey. Again, because these studies all had specific and often quite different sampling and analysis objectives, the overall means presented in Table 2.6 should be interpreted cautiously. It should also be noted that most of the sampling locations for these studies are concentrated in peripheral areas (i.e., near harbors and outfalls); therefore, the means reported in Table 2.6 may not accurately reflect basin-wide averages. Since the focus of this report is the JFBSC, data collected by the USACE connected with dredging operations are treated separately in Section 2.22.

Few data are available for PAH concentrations in Bay sediments. Prior to 1983 there are no data for individual PAH compounds (Long et al. 1988). Many studies only report concentrations of oil and grease (i.e., a measure of vegetable oils, animal fats, soaps, waxes and other hydrocarbons extractable by freon solvent) or total petroleum hydrocarbons (the mineral fraction of oil and grease). The major sources of PAH data include NOAA's NS&T Program (Boehm et al. 1987; Chapman et al. 1986; NOAA 1987) and research largely sponsored by NOAA and conducted at the Lawrence Livermore National Laboratory (Spies et al. 1985a,b). Sampling locations and summarized data for total PAH in San Pablo Bay and Central Bay are provided in Figure 2.4 and Table 2.6, respectively. Only NS&T and data from Spies et al. (1985a,b) are included in this summary. Stations within harbors and along basin margins have been excluded from the summary for Central Bay.

Wide ranges in PAH concentrations were reported in Long et al. (1988), reflecting high spatial variability in the distribution of hydrocarbon contamination. The highest total PAH concentration (the sum of 10 individual PAHs common to the NOAA and Spies data sets) within San Francisco Bay was 90.4 ppm and was found in Islais Creek. The Bay-wide mean for the 10 sites included in NOAA's NS&T Program (Figure 2.5) was 2.38 ppm (1.64 ppm if Islais Creek is excluded). San Pablo Bay contained four of the five Bay sites with the lowest total PAH concentrations. Mean total PAH concentrations in surface samples from San Pablo Bay and Central Bay, respectively, based on 18 individual PAHs (data from NOAA NS&T and Spies) were 0.2 ppm to 5.8 ppm and 0.8 ppm to 3.3 ppm. The lowest value reported from San Pablo Bay was for a site located near the northeastern portion of the JFBSC. The highest mean PAH concentration in Central Bay was found at a site just west of Richmond Harbor.

Sampling for dichlorophenyltrichlorethane (DDT) and PCBs in surface sediments has taken place at irregular intervals since 1971 (Long et al. 1988). Long et al. (1988) provide a historical overview of DDT and PCB concentrations in sediments and animal tissues for the entire Bay. Sampling locations and summarized data for DDT and PCBs in surface sediments from San Pablo Bay and Central Bay are provided in Figure 2.5 and Table 2.7, respectively. Again, only NS&T and data from Spies et al. (1985a, 1985b) are considered. Total DDT in Table 2.7 is the sum of the isomers for DDT, dichlorodiphenyldichloroethane (DDD), and dichlorodiphenyldichoroethylene (DDE).

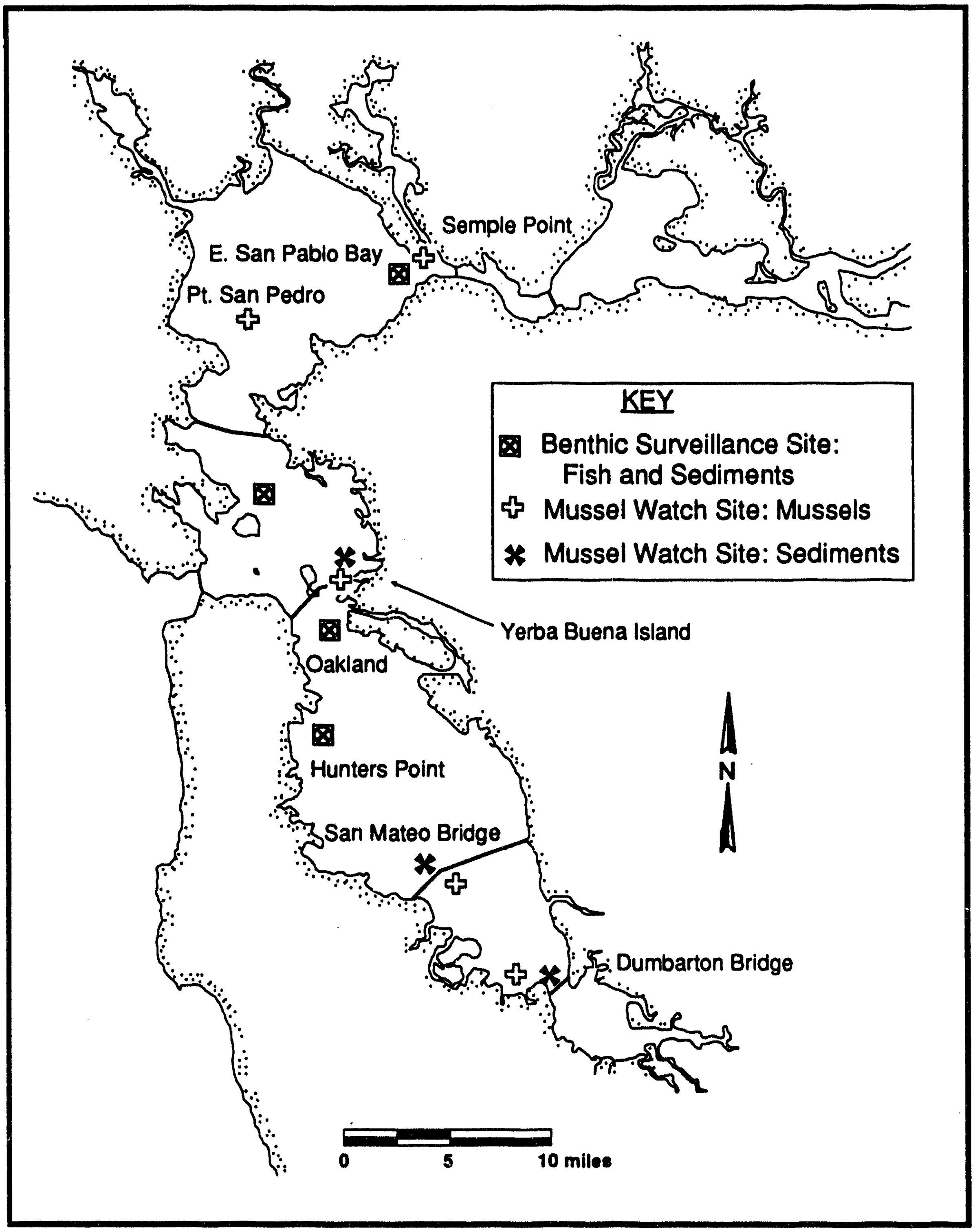

FIGURE 2.4. NOAA NS&T Program Sampling Locations (After Long et al. 1988)

TABLE 2.7. Total PAH, DDT, and PCB Concentrations in Sediments at Selected Locations within San Pablo Bay and Central Bay (After Long et al. 1988 for the Years 1984 to 1986)

Sites	Total PAH (ppm)	DDT (ppb)	PCB[a] (ppb)
San Pablo Bay Sites:			
San Pablo Bay (SP[b])	5.8	--	56
San Pablo Bay (T)	0.8	0.4	11
San Pablo Bay (BS[c])	0.2	0.8	12
Point San Pedro (MW[d])	1.3	11.0	33
Semple Point (MW)	1.1	23.0	29
Central Bay Sites:			
Richmond (SP)	33.0	--	51
Southhampton Shoal (BS)	0.8	0.4	12

(a) NOAA (T,BS,MW) values are the sum of eight levels of chlorination of the biphenyls (dichlorobiphenyl through nonachlorobiphenyl). Data from Spies use the sum of three aroclors (1242,1254, and 1260).
(b) SP Spies (1987) (ref. in Long et al. 1988).
(c) T Sediment Quality Triad Study.
(d) BS NOAA Benthic Surveillance Program.
(e) MW NOAA Mussel Watch Program.

Mean total DDT ranged from 0.4 ppb to 23 ppb in San Pablo Bay. A mean of 0.4 ppb was reported for the Southhampton Shoal site in Central Bay. The average DDT concentration reported by Long et al. (1988) for the entire Bay (excluding Lauritzen Canal) for the years 1971 through 1987 was 100 ±280 ppb (range 0.25 ppb to 1,960 ppb). Mean total PCB ranged from 11 ppb to 56 ppb in San Pablo Bay and 12 ppb to 51 ppb in Central Bay.

2.2.2 Chemical Evaluations on JFBSC Sediments Conducted as Part of Maintenance Dredging Operations

Pollutant samples have been obtained by the USACE for all active maintenance dredging projects since 1970. Additional sampling has occurred for all proposed navigation projects during the performance of feasibility studies. Table 2.8 provides a summary of contaminant concentrations for Carquinez Strait and Suisun Bay and the Pinole Shoal and West Richmond channels for the years 1970 to 1974. Five metals (Pb, Zn, Hg, Cd, Cu), oil and grease, total volatile solids (TVS), chemical oxygen demand (COD), and total kjeldahl nitrogen (TKN) were analyzed from bulk sediment samples. Means include the pooled values from all sampling depths. Table 2.8 also compares means for each of the JFBSC sites with mean values for all dredging projects within the Bay.

In April 1972, the San Francisco District of the USACE initiated a study to quantify the impact of dredging and dredged sediment-disposal operations on the environment of the Bay and Estuary. In 1973 a series of holes varying in depth from 9 ft to 22 ft below Bay bottom were drilled in the San Pablo Bay-Carquinez Strait area in conjunction with the USACE' s Pollutant

TABLE 2.8. Bulk Sediment Chemistry Results for Studies Conducted by the USACE During 1970 to 1974 (All Units in ppm) (After USACE 1979)

Title	Carquinez Str. and Susuin Bay	Pinole Shoal Channel	West Richmond Channel	All Dredged Channels
Lead:				
N	--[a]	28	54	30869
Mean	26.7	20.4	16.7	35.5
S.D.	16.6	8.8	4.1	33.1
Range	9-66	7-43	9-28	1-286
Zinc:				
N	28	54	30	869
Mean	72.7	72.2	55.3	108.1
S.D.	34.5	24.0	8.9	68.1
Range	45-174	35-123	39-73	1-624
Mercury:				
N	31	54	30	872
Mean	0.21	0.29	0.31	0.55
S.D.	0.22	0.54	0.21	0.92
Range	0.01-0.80	0.05-4.0	0.03-1.1	0.002-10.0
Cadmium:				
N	–	–	17	567
Mean	–	–	0.56	1.59
S.D.	–	–	0.14	1.37
Range	–	–	0.3-0.80	0.05-15.6
Copper:				
N	–	–	17	380
Mean	–	–	20.2	41.6
S.D.	–	–	3.5	25.5
Range	–	–	14-27	4-117
Oil & Grease:				
N	31	54	30	727
Mean	500	400	100	800
S.D.	400	200	100	800
Range	100-1600	100-1100	30-200	10-8400
TVS:				
N	31	49	13	425
Mean	5.41	5.11	3.39	6.03
S.D.	2.47	1.70	0.80	2.22
Range	1.1-9.3	1.7-8.5	2.2-4.4	0.7-16.6
COD:				
N	31	49	13	541
Mean ($X 10^4$)	4.35	3.02	2.14	4.12
S.D.	3.19	1.28	1.32	2.19
Range	0.3-13.3	0.5-5.0	0.5-5.4	0.10-21.4
TKN:				
N	31	49	13	527
Mean	900	900	400	1000
S.D.	700	500	100	900
Range	100-2200	200-2300	200-600	50-9600

(a) -- Not applicable.

Distribution Study (PDS). Three to six samples from each core were analyzed for particle-size distribution, TVS, COD, TKN, oil and grease, and five metals (Hg, Pb, Zn, Cd, Cu). The locations of PDS sites within the West Richmond and Pinole Shoal channels, respectively, are presented in Figures 2.5 and 2.6. Results of chemical analyses conducted for the PDS are presented in Table 2.9.

Sediment samples were collected from six potential dredging areas along the Pinole Shoal in December 1988 (E.V.S. 1989). Sampling locations were approximately equidistant along the length of the Channel, extending from the opening of Carquinez Strait to a point just southeast of the San Pablo Disposal Area. Sediments were collected to a depth of -37 ft MLLW from six stations within each area using a 5-ft oceanographic gravity corer (I.D. 3 in.). Sediments were analyzed for 10 metals (As, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Zn), organotin, total sulfides and water soluble sulfides, total organic carbon (TOC), oil and grease, phenols, PAHs, and chlorinated pesticides. Analytical results for Pinole Shoal sediments and a reference site located within the San Pablo Disposal Area, are presented in Table 2.10.

2.2.3 Chemical Evaluations of JFBSC Sediments Conducted Prior to Phase III Channel Improvements

Battelle/Marine Sciences Laboratory (MSL) conducted sampling, geological characterization, and chemical evaluation studies on sediment from the JFBSC in October 1989 (Word and Kohn 1990) and in August 1990 (Kohn et al. 1991). The study area included an approximately 28-mi portion of the JFBSC that extended from West Richmond to and including Carquinez Strait (Figure 1.3). The objective of the 1989 study was to determine physical characteristics and chemical contaminant levels in sediment to the proposed project depth of -47 ft MLLW (-45 ft MLLW plus 2 ft of overdepth). The objective of the 1990 study was to further examine the characteristics of sediments in the West Richmond area by collecting and analyzing core samples from five new sites from this reach. The data from the new sites were then compared to data from the West Richmond sites that were sampled in 1989.

In 1989, sediment core samples were collected at 48 locations throughout the JFBSC using a vibratory hammer core sampler. Nine of these locations were from West Richmond (Figure 2.7), 30 from San Pablo Bay (Figure 2.8), and 9 from Carquinez Strait (Figure 2.9). The five sites sampled during 1990 in the West Richmond Channel were located just outside and to the east of the existing channel, while the 1989 stations were inside the existing channel (Figure 2.9). Core sampling and compositing information are summarized in Table 2.11 for 1989 sampling and in Table 2.12 for 1990 sampling. The geological properties of the sediment core samples were described, the sediment from the cores composited into separate samples based on those descriptions, and chemical analyses conducted for 13 metals, 16 PAHs, 18 pesticides, 7 PCB aroclors, 3 butyltins, and 4 conventional sediment characteristics (Table 2.13). These data were then compared with sediment values from Oakland and Richmond harbors, reference values from Point Reyes fine- and coarse-grained sediments, and from typical shale sediment.

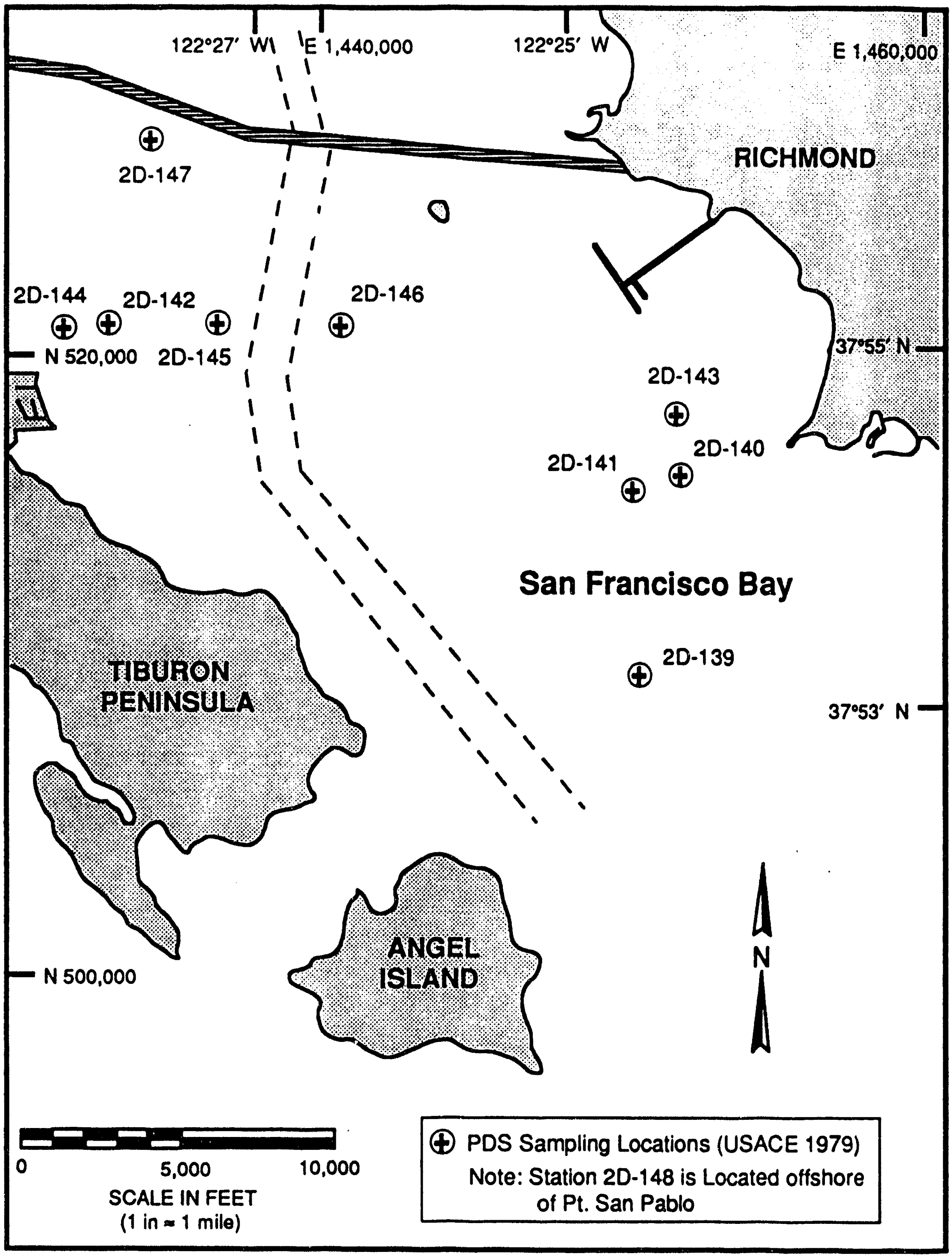

FIGURE 2.5. USACE Pollutant Distribution Study (PDS) Sampling Locations in the West Richmond Channel Area

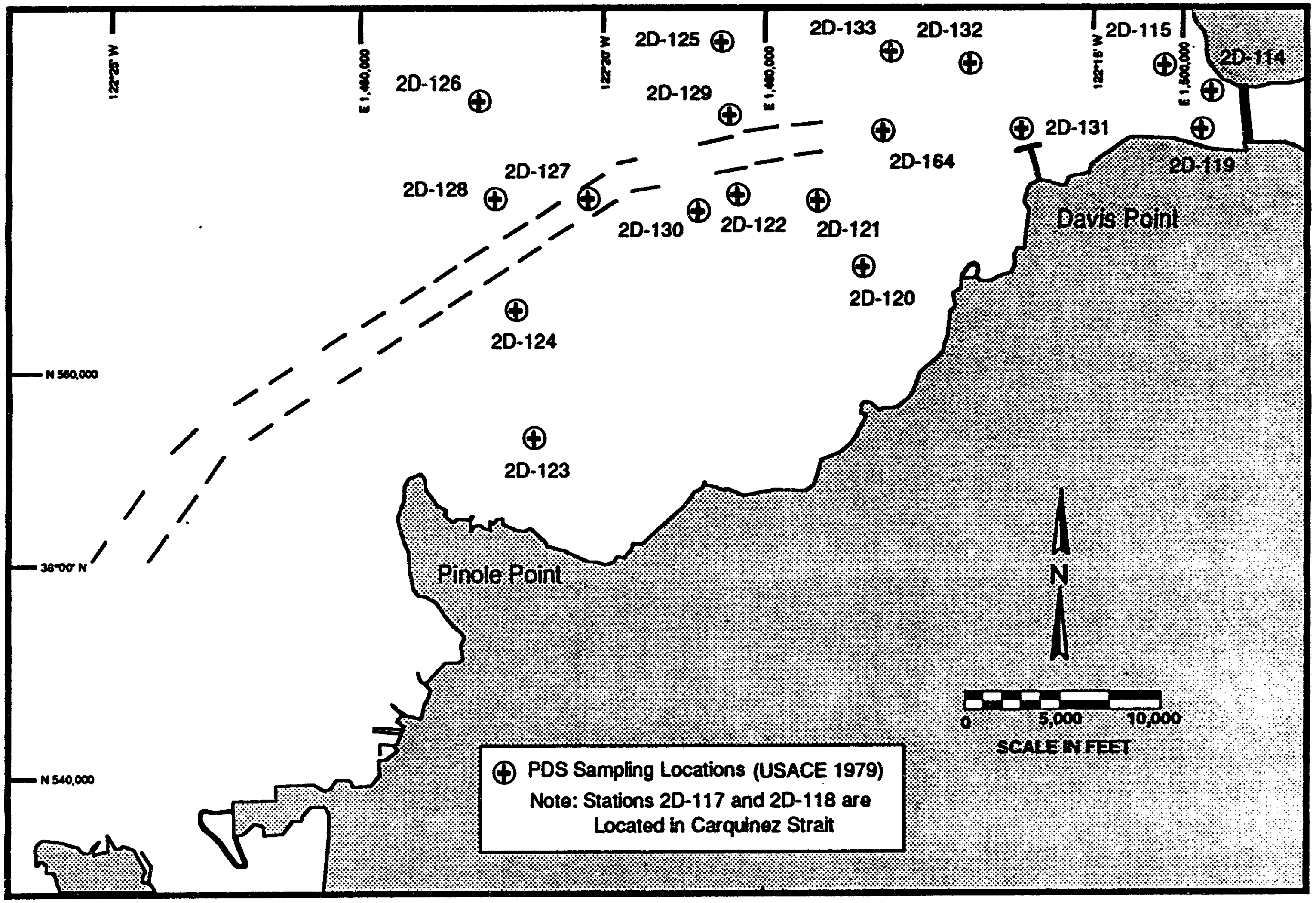

FIGURE 2.6. USACE Pollutant Distribution Study (PDS) Sampling Locations in the Pinole Shoal Area

TABLE 2.9. Results of Chemical Analyses from USACE Pollutant Distribution Study (PDS)

Location	Depth (ft)	TVS (% dry weight)	COD	TKN	O & G	Hg (ppm)	Pb	Zn	Cd	Cu
Pinole Shoal										
2D-114	0-0.6	7.0	4.3	0.16	0.06	1.5	50	151	1.40	51
	4.0-4.6	6.6	3.2	0.12	0.11	0.7	42	158	1.40	43
	6.0-6.6	8.1	3.9	0.19	0.10	0.7	45	171	1.50	54
	7.5-8.1	8.0	4.1	0.16	0.14	0.7	55	168	1.60	52
	11.9-12.5	8.0	3.8	0.15	0.04	0.7	47	165	1.50	53
	17.5-18.1	8.2	4.3	0.20	0.10	0.6	47	176	1.50	53
2D-115	0-0.6	9.3	4.7	0.16	0.20	0.5	421	328	1.60	61
	6.0-6.6	8.8	4.7	0.22	0.14	0.2	140	236	1.70	62
	8.9-9.5	9.1	3.2	0.14	0.03	2.4	325	297	1.40	49
2D-117	0-0.6	7.2	4.6	0.15	0.08	0.6	52	154	1.30	53
	2.5-3.1	7.4	3.7	0.15	0.04	0.8	46	151	1.20	57
	6.5-7.1	7.5	4.0	0.18	0.09	0.7	55	181	1.10	57
	7.7-8.3	7.7	3.6	0.17	0.04	0.7	38	110	1.10	48
	9.1-9.7	6.7	3.0	0.13	0.03	0.5	32	100	1.00	41
2D-118	0-0.6	3.8	2.1	0.07	0.03	0.2	32	99	0.90	28
	1.6-2.2	8.1	6.3	0.16	0.12	0.5	49	122	1.10	43
	2.5-3.1	16.5	15.7	0.34	0.04	0.4	58	136	1.80	54
	4.0-4.6	5.8	4.2	0.12	0.06	0.3	35	101	1.10	36
	6.9-7.5	6.4	4.6	0.14	0.09	0.4	37	121	1.00	37
	9.4-10.0	6.8	5.3	0.14	0.07	0.4	32	79	0.80	35
	13.0-13.6	13.2	12.3	0.29	0.20	0.7	41	88	1.20	51
	16.9-17.5	6.9	3.5	0.13	0.03	0.4	32	88	0.90	35
	18.0-18.6	7.0	4.0	0.11	0.04	0.4	26	107	0.60	33
2D-119	0-0.6	2.1	0.6	0.03	-0.01	0.1	24	93	0.50	13
	2.5-3.1	6.0	3.5	0.12	0.04	1.4	61	182	0.80	37
	5.0-5.6	6.0	2.6	0.08	0.03	0.8	63	197	0.70	35
	7.5-8.1	5.3	1.5	0.05	0.02	0.5	67	143	0.20	32
	10.0-10.6	6.4	4.2	0.13	0.05	2.1	40	173	0.70	37
	13.8-14.4	4.9	1.7	0.06	0.03	1.0	22	84	0.60	24
2D-120	0-0.6	7.4	4.2	0.12	0.07	1.7	62	139	1.00	37
	2.5-3.1	7.0	1.7	0.05	0.02	1.6	22	67	0.60	26
	3.2-3.8	13.1	3.0	0.08	0.04	0.6	28	65	1.10	24
	6.9-7.5	5.9	5.6	0.16	0.02	0.3	17	106	0.50	45
	7.5-8.1	8.5	5.1	0.12	0.02	0.3	17	90	0.70	33
	14.4-15.0	5.8	5.1	0.14	0.02	0.5	20	111	0.70	40
2D-121	0-0.6	7.0	4.3	0.14	0.07	1.3	54	179	0.08	78
	2.5-3.1	7.7	2.6	0.08	0.07	0.5	27	124	0.05	62
	7.5-8.1	8.0	2.6	0.10	0.04	0.9	20	103	0.05	52
	10.0-10.6	5.7	5.0	0.14	0.05	0.3	24	99	0.03	32
	11.4-12.1	3.5	3.1	0.07	0.02	0.4	17	94	0.04	27
	17.5-18.1	2.2	0.4	0.03	-0.01	0.2	12	63	0.03	15
	21.9-22.5	2.9	1.6	0.04	0.01	0.3	16	72	0.03	21

Table 2.9 (contd)

Location	Depth (ft)	TVS	COD	TKN	O & G	Hg	Pb	Zn	Cd	Cu
		(% dry weight)				(ppm)				
Pinole Shoal (contd)										
2D-122	0-0.6	3.8	2.7	0.10	-0.01	0.3	21	86	0.30	26
	3.4-4.0	3.6	2.6	0.06	0.01	0.5	14	79	0.60	26
	11.9-12.5	2.2	0.9	0.04	0.02	0.2	15	54	0.10	18
	14.1-14.7	3.2	2.1	0.07	0.01	0.3	14	72	0.60	21
	20.0-20.6	3.8	2.6	0.08	0.01	0.3	16	80	0.40	27
2D-123	0-0.6	8.4	5.1	0.17	0.06	1.2	59	169	0.80	71
	3.4-4.0	7.7	2.8	0.08	0.02	1.3	27	89	0.50	37
	5.7-6.3	4.8	5.1	0.11	0.04	0.6	15	146	0.50	25
	18.4-19.0	6.2	5.1	0.18	0.04	0.7	21	173	0.50	31
	21.9-22.5	6.5	4.6	0.18	0.05	0.5	21	175	0.40	30
2D-124	0-0.6	7.9	2.6	0.09	0.05	1.8	28	152	0.40	39
	1.9-2.5	7.9	5.1	0.18	0.11	0.7	30	176	0.70	36
	4.4-5.0	4.8	4.8	0.12	0.04	0.2	24	75	0.70	26
	11.2-11.8	2.5	1.5	0.03	0.02	0.1	14	70	0.50	13
	21.9-22.5	4.0	2.4	0.08	0.03	0.3	18	87	0.80	25
2D-125	0-0.6	8.0	4.8	0.15	0.18	2.4	48	175	1.50	49
	6.4-7.0	8.4	2.8	0.14	0.08	1.8	30	117	0.50	37
	11.9-12.5	8.5	2.3	0.08	0.07	1.9	34	101	0.80	38
	13.8-14.4	8.4	3.2	0.15	0.15	1.4	24	90	0.70	34
2D-126	0-0.6	8.2	4.9	0.14	0.12	2.0	53	179	1.20	46
	2.5-3.1	8.0	4.4	0.15	0.14	3.0	38	166	0.40	39
	7.5-8.1	8.9	2.9	0.16	0.04	2.0	32	109	0.60	34
	16.9-17.5	8.5	2.4	0.10	0.07	0.8	19	86	0.70	30
2D-127	0-0.6	3.7	2.2	0.07	0.03	1.7	32	120	0.70	22
	5.0-5.6	3.7	3.2	0.11	0.02	0.4	17	76	0.60	14
	11.9-12.5	2.7	1.5	0.07	0.01	0.3	17	73	0.60	12
2D-128	0-0.6	7.7	4.8	0.16	0.06	2.8	39	126	1.40	26
	3.7-4.3	3.2	1.3	0.04	0.04	1.0	20	90	0.80	15
	10.0-10.6	6.2	5.2	0.18	0.01	0.9	20	98	0.90	17
	14.0-14.6	4.8	3.7	0.13	0.02	0.4	15	86	0.70	18
	18.4-19.0	4.6	4.4	0.12	-0.01	0.5	17	91	1.00	18
	21.9-22.5	3.8	2.5	0.08	-0.01	0.4	13	61	1.00	14
2D-129	0-0.6	4.2	1.9	0.04	0.06	1.2	21	91	1.00	20
	6.4-7.0	2.6	1.4	0.05	0.02	0.2	8	56	0.30	32
	13.3-13.9	2.6	1.3	0.06	0.02	0.2	7	62	0.50	24
	19.0-19.6	2.3	1.0	0.04	0.01	0.3	9	64	0.40	25
	21.9-22.5	3.1	1.4	0.06	0.01	0.9	10	73	0.50	32
2D-130	0-0.6	2.4	1.2	0.05	0.02	0.4	12	61	0.50	24
	1.9-2.5	4.0	3.7	0.10	0.01	0.4	22	82	0.30	27
	3.4-4.0	2.6	1.5	0.05	-0.01	0.6	17	55	0.50	17
	6.5-7.1	1.9	0.5	0.04	0.01	0.2	16	48	0.50	12
	10.0-10.6	2.6	1.1	0.05	0.01	0.4	19	52	0.50	16
2D-131	0-0.6	3.1	1.2	0.05	0.01	0.6	30	73	0.60	18
	2.5-3.1	6.6	1.8	0.10	0.05	0.6	30	62	0.30	39
	6.9-7.5	7.8	1.7	0.11	0.03	0.7	27	65	0.70	41

Table 2.9 (contd)

Location	Depth (ft)	TVS	COD	TKN	O & G	Hg	Pb	Zn	Cd	Cu
		(% dry weight)				(ppm)				
Pinole Shoal (contd)										
2D-132	0-0.6	7.0	3.8	0.13	0.16	0.7	48	99	0.60	60
	4.2-4.8	5.1	3.1	0.12	0.14	0.9	31	73	0.30	37
	8.8-9.4	2.5	0.9	0.04	0.03	0.8	17	42	0.30	18
	10.0-10.6	3.6	2.9	0.10	0.05	0.4	16	55	0.40	19
	11.9-12.5	2.4	1.0	0.05	0.03	0.5	21	38	0.40	11
2D-133	0-0.6	5.3	2.7	0.12	0.08	0.5	51	93	0.70	41
	3.4-4.0	3.6	2.7	0.10	0.05	0.4	16	44	0.50	18
	5.7-6.3	2.1	1.0	0.05	0.02	0.3	14	44	0.50	14
	10.8-11.4	2.2	1.2	0.04	0.01	0.3	14	45	0.50	18
	15.7-16.3	2.7	1.8	0.05	0.02	0.3	14	51	0.70	21
2D-164	0-0.6	6.3	1.6	0.07	0.01	0.4	12	84	0.70	40
	4.4-5.0	3.6	2.3	0.07	0.01	0.5	14	103	0.70	26
	8.0	3.7	2.5	0.08	0.03	0.4	13	107	0.90	30
	10.7-11.3	3.3	1.8	0.09	0.02	0.3	12	100	0.70	30
West Richmond										
2D-139	0-0.6	2.6	1.1	0.08	0.01	0.3	13	77	0.8	16
	3.0-3.6	2.0	0.7	0.06	0.01	0.3	11	77	0.6	13
2D-140	0-0.6	6.9	3.7	0.06	0.04	0.7	51	188	2.2	67
	2.5-3.1	6.5	2.5	0.08	0.02	0.4	26	108	1.8	47
	6.9-7.5	5.1	4.3	0.12	0.02	0.7	18	98	1.7	25
	12.5-13.1	5.3	4.4	0.11	0.02	0.9	14	105	1.0	33
	16.9-17.5	5.1	5.0	0.11	0.03	0.7	17	111	1.2	39
2D-141	0-0.6	6.9	3.4	0.07	0.05	0.9	42	179	1.5	70
	4.4-5.0	4.7	3.4	0.07	0.01	0.5	14	97	1.1	23
	5.7-6.3	4.6	4.5	0.07	0.01	0.6	13	87	1.2	23
	15.4-16.0	4.3	3.6	0.10	-0.01	0.3	15	107	1.3	31
	23.7-24.3	4.3	2.0	0.08	0.01	0.4	15	52	1.7	12
2D-142	0-0.6	7.9	4.2	0.08	0.09	1.8	54	205	1.6	61
	6.1-6.7	7.2	4.2	0.16	0.09	1.9	40	203	1.0	89
	10.0-10.6	7.4	4.1	0.11	0.05	0.8	30	173	1.0	44
	15.7-16.3	5.9	3.1	0.06	0.05	0.6	22	152	0.9	52
2D-143	0-0.6	7.4	4.1	0.16	0.03	0.3	29	175	1.0	59
	5.0-5.6	6.5	3.8	0.11	0.05	0.5	28	157	1.0	60
	10.7-11.3	6.8	3.2	0.11	0.06	0.9	19	109	0.9	44
	13.4-14	6.1	3.3	0.10	0.03	0.7	19	106	1.0	40
	21.1-21.7	7.5	2.6	0.13	0.04	0.8	14	75	0.7	35
2D-144	0-0.6	7.6	3.9	0.14	-0.01	0.7	29	145	0.9	42
	5.4-6.0	7.1	4.2	0.10	0.06	0.5	31	148	0.8	41
	10.7-11.3	7.5	4.0	0.14	0.05	0.7	25	150	0.8	50
	19.0-19.6	5.7	3.1	0.10	0.04	0.5	19	98	0.8	31
	21-21.6	7.0	3.6	0.16	0.14	1.3	25	121	1.0	53
2D-145	0-0.6	7.2	3.8	0.09	0.07	0.7	37	148	0.9	49
	5.0-5.6	7.1	4.2	0.12	0.05	0.6	25	130	0.8	47

Table 2.9 (contd)

Location	Depth (ft)	TVS	COD	TKN	O & G	Hg	Pb	Zn	Cd	Cu
		(% dry weight)				(ppm)				
West Richmond (contd)										
	6.9-7.5	5.7	3.4	0.11	0.05	1.4	24	99	0.7	32
	9.4-10.0	4.7	3.8	0.09	-0.01	0.8	10	74	0.6	18
	10.0-10.6	3.7	3.2	0.11	0.02	0.4	11	57	0.6	12
	13.6-14.2	5.4	5.2	0.08	0.04	0.6	14	83	0.7	13
2D-146	0-0.6	3.7	1.2	0.06	0.01	0.4	12	53	0.6	10
	3.2-3.8	3.7	1.6	0.08	0.01	0.4	10	52	0.5	8
	6.9-7.5	5.4	2.5	0.06	0.03	0.4	12	43	0.8	7
	8.4-9.0	3.8	2.2	0.06	0.01	0.4	10	87	0.9	27
	13.7-14.3	3.9	2.7	0.04	0.01	0.7	11	90	0.7	31

TABLE 2.10. Pinole Shoal Sediment Chemistry Results for Study Conducted by E.V.S. Consultants, Inc. (1989) (All Units in mg/kg Dry Weight)

	Pinole Shoal Channel			San Pablo Disposal Site (Reference)
Metals	Mean	S.D.	Range	Mean
As	8.29	1.080	6.54-10.1	7.86
Cd	0.29	0.060	0.24-0.42	0.31
Cr	140.00	12.300	120-159	163
Cu	37.80	11.200	25.6-61.2	42.0
Pb	18.50	2.800	16.4-23.4	21.7
Hg	0.13	0.042	0.075-0.18	0.21
Ni	80.10	9.030	69.2-96.6	75.9
Se	0.24	0.038	0.21-0.31	0.29
Ag	0.19	0.070	ND-0.35	0.24
Zn	94.10	15.600	79.8-128	112
Organics				
Oil and Grease	449.00	91.000	298-598	887
TOC	0.69	0.210	0.46-1.12	1.15
Phenol				
Total Phenol	0.23	0.130	0.12-0.51	0.14
Phenol	0.15	0.059	0.091-0.26	0.10
Pentachlorophenol	0.08	0.072	ND-0.22	0.034
Total Chlorinated Phenol	0.17	0.033	ND-0.24	--[b]
PAHs				
Benzo (a) anthracene	0.027	0.029	ND-0.093	-
Benzo (a) pyrene	0.110	0.110	ND-0.30	0.34
Benzo (b) Fluoranthene[a] Benzo (k) fluoranthene[a]	0.057	0.042	ND-0.13	-
Chrysene	0.032	0.028	ND-0.074	-
Fluoranthene	0.063	0.032	0.023-0.12	0.22
Phenanthrene	0.024	0.010	ND-0.045	0.056
Pyrene	0.012	0.007	ND-0.026	-
Chlorinated Pesticides				
4,4'-DDD	0.002	0.001	ND-0.004	0.003
4,4'-DDE	0.0017	0.001	ND-0.0039	-
Dieldrin	0.0009	0.0003	ND-0.0017	-

(a) Benzo (b) fluoranthene and Benzo (k) fluoranthene coelute under test conditions.
(b) -- Not applicable.

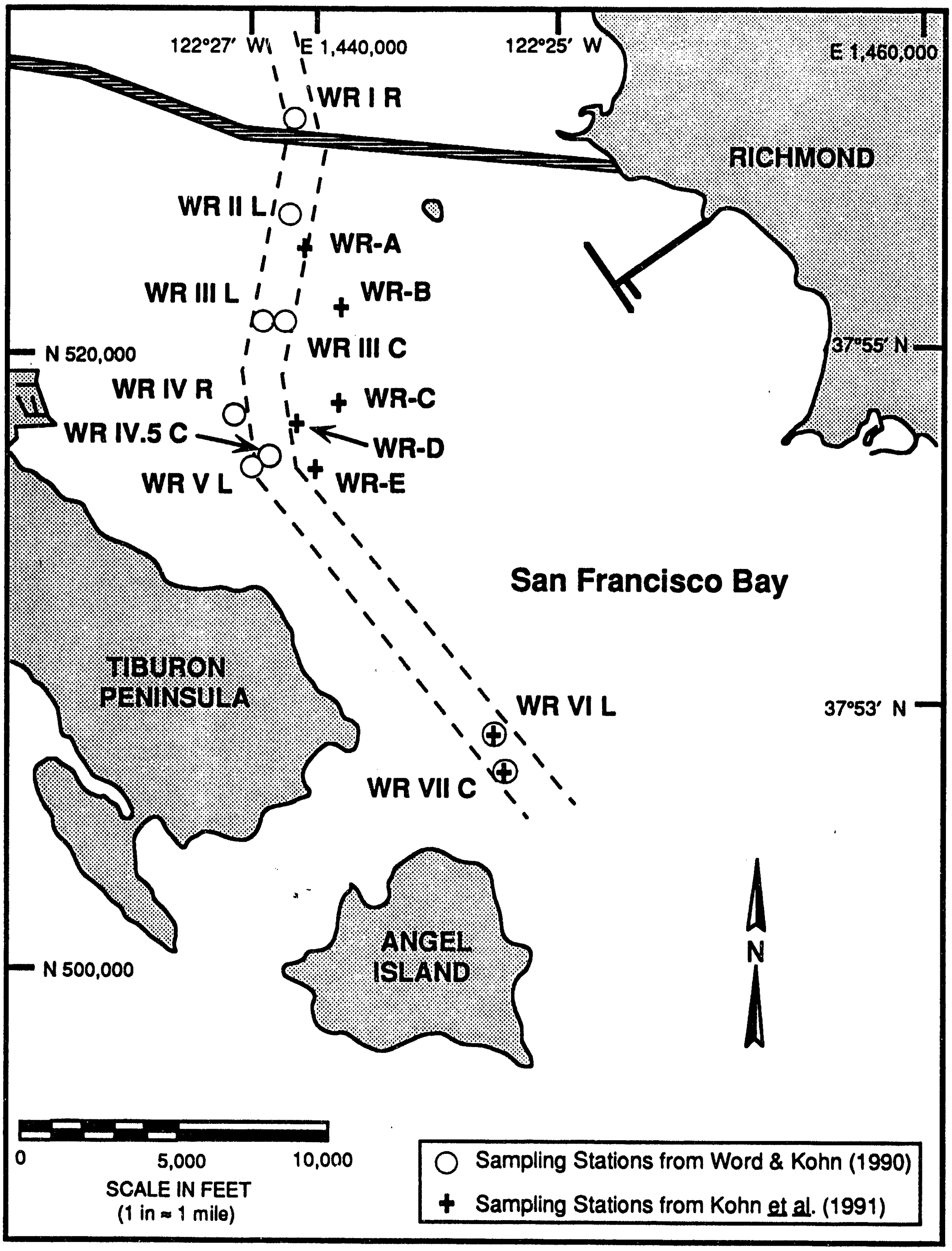

FIGURE 2.7. Sampling Locations for Studies Performed by Battelle/Marine Sciences Laboratory in the West Richmond Channel

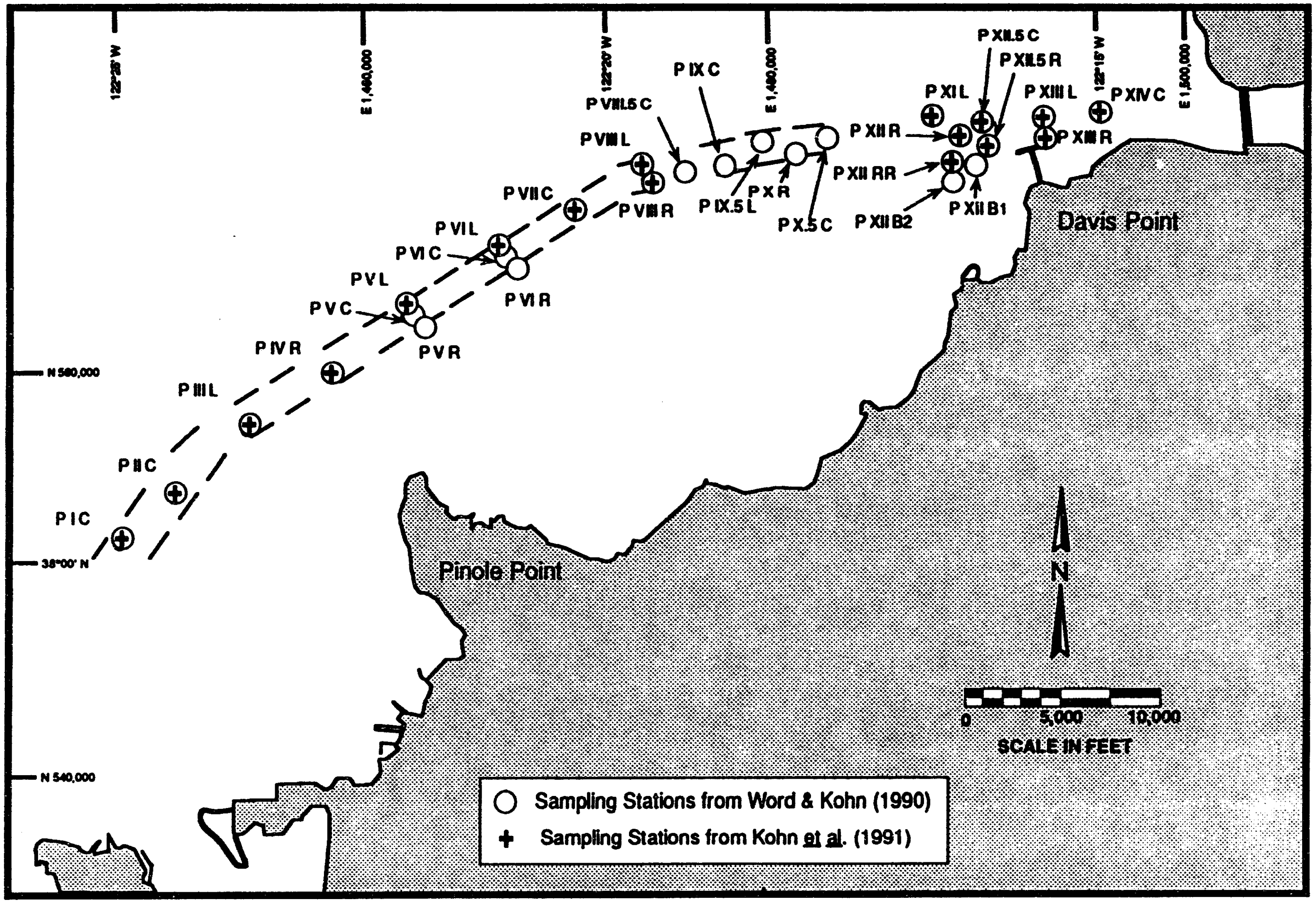

FIGURE 2.8. Sampling Locations for Studies Performed by Battelle/Marine Sciences Laboratory in the Pinole Shoal Channel

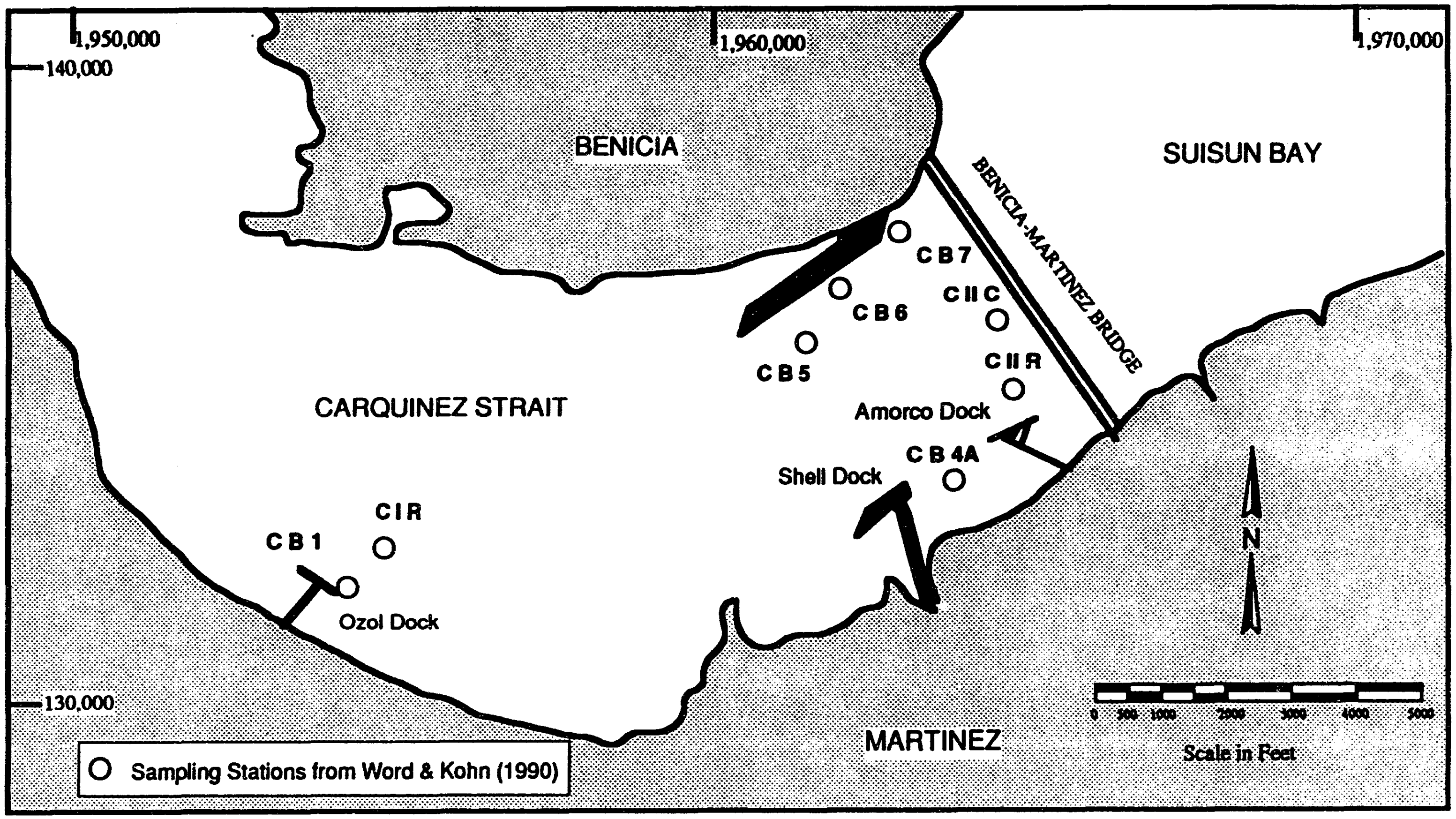

FIGURE 2.9. Sampling Locaitons for a Study Performed by Battelle/Marine Sciences Laboratory in Carquinez Strait

TABLE 2.11. Core Sampling Locations and Compositing Information for Studies Conducted by Battelle/Marine Sciences Laboratory in 1989

Station	California State Plane Coordinates Y. Northing	X. Easting	Date Sampled	Water Depth, ft MLLW	Ft Core Required to -47 ft MLLW	Ft Core Collected	Comments	Date Composited	Number Samples
West Richmond (California State Zone III)									
WR VII C	506,490	1,446,650	09-07-89	41.5	5.5	6.5	7 attempts before success	09-14-89	
WR VI L	507,710	1,446,070	09-07-89	43.0	4.0	8.2	Kept upper 5 ft	09-14-89	
WR V L	517,103	1,438,724	09-07-89	41.0	6.0	6.5		09-14-89	
WR IV.5 C	517,495	1,438,847	09-07-89	39.7	7.3	10.5		09-14-89	2
WR IV R	518,178	1,438,369	09-12-89	35.5	11.5	14.0		09-19-89	2
WR III L	520,991	1,438,861	09-12-89	40.4	6.6	13.0	Kept upper 7.6 ft	09-19-89	
WR III C	520,992	1,439,072	09-12-89	40.6	6.4	10.0	Kept upper 7.4 ft	09-19-89	
WR II L	524,226	1,439,379	09-12-89	40.1	6.9	11.5	Kept upper 8 ft	09-19-89	
WR I R	528,590	1,439,299	09-12-89	41.9	5.1	7.0	Kept upper 6.5 ft	09-19-89	
Pinole Shoal (California State Zone III)									
P I C	551,186	1,448,210	09-11-89	44.0	3.0	7.2	Kept upper 4 ft	09-19-89	
P II C	554,048	1,450,768	09-11-89	42.7	4.3	8.4	Kept upper 5.3 ft	09-19-89	
P III L	557,302	1,454,274	09-11-89	44.0	3.0	8.0	Kept upper 4 ft	09-19-89	
P IV R	560,115	1,458,253	09-11-89	39.0	8.0	13.5	Kept upper 9 ft	09-19-89	
P V L	563,465	1,461,846	09-11-89	38.6	8.4	12.5	Kept upper 9.5 ft	09-19-89	
P V C	563,244	1,461,981	09-11-89	38.3	8.7	14.0	Kept upper 10 ft	09-19-89	
P V R	563,059	1,462,094	09-11-89	36.5	10.5	13.9	Kept upper 11.5 ft	09-19-89	2
P VI L	566,244	1,466,551	09-11-89	35.4	11.6	14.0	Kept upper 11.6 ft	09-18-89	2
P VI C	566,069	1,466,624	09-11-89	38.0	9.0	13.0	Kept upper 10 ft	09-18-89	
P VI R	565,870	1,466,777	09-11-89	35.3	11.7	13.7	Kept upper 12.7 ft	09-18-89	2
P VII C	568,105	1,470,198	09-11-89	36.9	10.1	14.5	Kept upper 11.5 ft	09-18-89	2
P VIII L	570,249	1,473,544	09-10-89	37.5	9.5	14.0	Kept upper 10.5 ft	09-18-89	2
P VIII R	569,775	1,473,806	09-10-89	36.5	10.5	14.5	Kept upper 11.5 ft	09-18-89	2
P VIII.5 C	570,630	1,476,526	09-10-89	36.6	10.4	11.5		09-18-89	2
P IX C	570,933	1,478,421	09-10-89	36.2	10.8	13.0	Kept upper 11.8 ft	09-18-89	2
P IX.5 L	571,551	1,480,937	09-10-89	36.9	10.1	14.0	Kept upper 11.5 ft	09-18-89	2
P X R	571,519	1,482,791	09-10-89	35.5	11.5	12.2		09-18-89	2
P X.5 C	572,236	1,485,358	09-10-89	36.6	10.4	13.9		09-15-89	2

TABLE 2.11. (contd)

Station	California State Plane Coordinates Y. Northing	X. Easting	Date Sampled	Water Depth, ft MLLW	Ft Core Required to -47 ft MLLW	Ft Core Collected	Comments	Date Composited	Number Samples
P XI L	572,663	1,487,604	09-10-89	43.5	3.5	6.7	Kept upper 4.5 ft	09-15-89	
P XII R	571,423	1,489,548	09-09-89	38.5	8.5	12.0	Kept upper 10 ft	09-15-89	
P XII RR	571,167	1,489,570	09-09-89	37.8	9.2	9.9		09-15-89	
P XII B2	570,683	1,489,481	09-09-89	34.5	12.5	14.0		09-19-89	3
P XII B1	571,051	1,490,122	09-09-89	35.9	11.1	12.5		09-19-89	2
P XII.5 C	571,863	1,490,801	09-09-89	41.0	6.0	10.0	Kept upper 7 ft	09-15-89	
P XII.5 R	571,342	1,490,814	09-09-89	31.0	16.0	14.5	Peat layer, bottom 1.5 ft	09-15-89	2
P XIII L	572,670	1,493,016	09-09-99	40.7	6.3	9.8	Kept upper 7.5 ft	09-15-89	
P XIII R	571,963	1,493,176	09-09-89	37.2	9.8	10.7		09-15-89	2
P XIII B3	571,540	1,492 640	09-09-89	35.3	11.7	11.7		09-15-89	2(a)
P XIII B4	571,700	1,493 300	09-09-89	39.0	8.0	9.0	Very abrupt slope, 10 attempts	09-15-89	2(a)
P XIV C	573,010	1,495,892	09-09-89	42.6	4.4	6.9	Kept upper 5.5 ft	09-15-89	
Carquinez Strait (California State Zone II)									
CB I	131,972	1,953,947	09-08-89	40.4	6.6	6.9		09-19-89	
C I R	132,351	1,954,498	09-08-89	39.0	8.0	9.0		09-14-89	
CB 2	132,656	1,961,899	09-08-89	40.2	6.8	9.0		09-14-89	1(a)
CB 3	Station Rejected		09-08-89	> 48	NA(b)	NA	Below project depth	N/A	0
CB 4	Station Rejected		09-08-89	> 48	NA	NA	Below project depth	N/A	0
CB 4 A	133,565	1,963,508	09-08-89	35.6	11.4	11.7		09-19-89	2
CB 5	135,907	1,961,546	09-08-89	43.0	4.0	3.8	4 attempts before success	09-14-89	
CB 6	136,606	1,962,079	09-08-89	40.5	6.5	8.3	Kept upper 7.5 ft	09-14-89	
CB 7	137,509	1,963,057	09-08-89	43.9	3.1	5.0		09-15-89	
C II C	135,914	1,964,338	09-08-89	40.7	6.3	6.8		09-14-89	2
C II R	134,760	1,964,403	09-08-89	44.6	2.4	6.0	Kept upper 3.4 ft	09-14-89	

(a) This number of samples was composited, but were not chemically analyzed because of their location in berthing areas not maintained by USACE.
(b) NA Not applicable.

TABLE 2.12. Core Sampling Locations for Studies Conducted by Battelle/Marine Sciences Laboratory in 1990

Station	Rep	California Zone III State Plane Coordinates Y (Northing)	X (Easting)	Date Sampled	Water Depth (ft MLLW)	Core Required (ft to -47 ft MLLW)	Core Collected (ft)
WR-A	1	523,268	1,439,718	08-14-90	36.8	10.2	14.0
WR-B	1	521,019	1,440,107	08-14-90	34.8	12.2	17.0
WR-C	1	518,602	1,440,857	08-14-90	34.5	12.5	18.5
WR-D	1	518,308	1,439,457	08-14-90	42.4	4.6	6.5
WR-E	1	517,380	1,439,924	08-14-90	40.9	6.1	6.5

Table 2.13. Sampling Parameters for 1989 and 1990 Studies Conducted by Battelle/Marine Sciences Laboratory

Conventionals

Total Organic Carbon (TOC)
Total Oil and Grease
Total Petroleum Hydrocarbon (HC)
Total Volatile Solids (TVS)
Grain Size

Metals

Ag
Al[(a)]
As
Cd
Co[(a)]
Cr
Cu
Hg
Ni
Pb
Se
Tl
Zn

Butyltins

Chlorinated Pesticides

Polychlorinated Biphenyls (PCB)

PAHs

Napthalene
Acenaphthylene
Acenaphthene
Fluorene
Phenanthrene
Anthracene
Fluoranthene
Pyrene
Benzo(a)anthracene
Chrysene
Benzo(b)fluoranthene
Benzo(k)fluoranthene
Benzo(a)pyrene
Indeno(1,2,3-c,d)pyrene
Dibenz(a,h)anthrazene
Benzo(g,h,i)perylene

(a) Not analyzed in Kohn et al. (1991).

Conventional Sediment Characteristics

The results of oil and grease and petroleum hydrocarbon analyses are presented in Table 2.14. Oil and grease concentrations ranged from 5.5 mg/kg to 178 mg/kg. On average, concentrations found in sediments from Pinole Shoal were lower than concentrations found in sediment from West Richmond. The petroleum hydrocarbon (PH) concentrations were similar to, although somewhat lower than, those measured for oil and grease. Concentrations measured for PAHs ranged from 3.5 mg/kgto 131 mg/g.

Compared to the 1989 sediments, sediments collected in 1990 showed comparable or lower concentrations of oil and grease and petroleum hydrocarbons (Table 2.15).

Metals

The results of metal analyses conducted in 1989 are presented in Table 2.16. In the West Richmond reach of the Channel, arsenic (As) from the lower 4 ft to 8 ft of cores from Station WR IV.S C and Ag, Pb, and Zn within the upper 4 ft to 6 ft of cores from Stations WR V L, WR IV.5 C, and WR IV R were elevated compared with Point Reyes reference sediment or typical shale soils.

Elevated concentrations of metals, notably Ag, As, Al, Cr, Cu, Hg, Pb, and Zn, were present at some stations within the northeastern Pinole Shoal area. Elevated levels of As, Hg, and Al were located near the opening of the Carquinez Strait and at one of two berthing areas (Stations PXII B 1 or PXII B 2). Elevated levels of Ag and Pb were located at Station P XIV C. The As and Hg levels are potentially of more concern than the slightly elevated levels of Al. The availability of As and Hg are, however, unknown, and it is possible that they were a part of the mineral matrix rather than the bioavailable fraction of the sediment.

In the Central Pinole shoal reach, the upper 5 ft to 8 ft of Stations P VI L and P VIII R had consistently higher concentrations of metals than the surrounding area. The consistency of the elevated concentrations of metals at these two stations was most likely related to the higher levels of organic carbon that were also reported.

Each of the metals, Al, As, and Hg,were found at higher concentrations at the easternmost Carquinez Strait stations, with the highest concentrations for any of the JFBSC stations occurring at Station C II R. These high concentrations of potentially toxic metals occurred in sediment at levels not predicted based on grain size, TOC, or the proximity to a berthing area.

All of the metal concentrations measured in West Richmond sediment during 1990 (Table 2.17) were comparable to the low end of the concentration range of West Richmond sediments sampled during 1989.

TABLE 2.14. Total Oil and Grease and Petroleum Hydrocarbons in JFBSC Sediments From Battelle/Marine Sciences Laboratory 1989 Study

Station	Section, ft	Oil & Grease, mg/kg dry wt	Petroleum Hydrocarbons, mg/kg dry wt	Petroleum Fraction, %
West Richmond				
WR VII C	0-5.5	37	27	73
WR VI L	0-4	73	55	75
WR V L	0-6	79	74	94
WR IV.5 C	0-4	82	70	85
WR IV.5 C	4-8	18	16	89
WR IV R	0-6	167	112	67
WR IV R	6-11.5(a)	38	19	51
WR III L	0-6.6	61	11	18
WR III C	0-6.4	26	12	46
WR II L	0-6.9	20	5.8	29
WR I R	0-5.1	91	49	54
Pinole Shoal				
P I C	0-3	44	21	48
P II C	0-4.3	39	25	64
P III L	0-3	45	24	53
P IV R	0-8	34	22	65
P V L	0-8.4	53	40	75
P V C	0-8.7	33	24	73
P V R	0-5	45	28	62
P V R	5-10.5	93	21	23
P VI L	0-5	114	50	44
P VI L	5-11.6	41	24	59
P VI C	0-9	21	8.5	40
P VI R	0-5	63	39	62
P VI R	5-11.7	25	11	44
P VII C	0-5	98	32	33
P VII C	5-10.1	48	12	25
P VIII L	0-6.6	136	65	48
P VIII L	6.6-9.5	17	6.7	39
P VIII R	0-8	83	52	63
P VIII R	8-10.5	30	7.6	25
P VIII.5 C	0-3.6	41	13	32
P VIII.5 C	3.6-10.4(a)	9.4	7	74
P IX C	0-5	9.1	6	66
P IX C	5-11.8	8.5	8.6	101
P IX.5 L	0-5(a)	16	13	78
P IX.5 L	5-10.1	7.3	5.5	75
P X R	0-6	15	11	73
P X R	6-11.5	5.5	3.5	64

TABLE 2.14. (contd)

Station	Section, ft	Oil & Grease, mg/kg dry wt	Petroleum Hydrocarbons, mg/kg dry wt	Petroleum Fraction, %
Pinole Shoal (contd)				
P X.5 C	0-5	9.3	7	75
P X.5 C	5-11	12	7.6	63
P XI L	0-3.5	17	13	76
P XII R	0-8.5	19	9.1	48
P XII RR	0-9.2	45	33	73
P XII B2	0-2	17	15	88
P XII B2	2-7.5(a)	76	28	37
P XII B2	7.5-12.5	23	14	61
P XII B1	0-5	178	131	74
P XII B1	5-11.1	102	43	42
P XII.5 C	0-6(a)	15	8.7	58
P XII.5 R	0-5.3	21	14	67
P XII.5 R	5.3-11.1	24	15	63
P XIII L	0-6(a)	18	14	75
P XIII R	0-5	7.3	1	14
P XIII R	5-10	10	10	100
P XIV C	0-4.5	62	38	61
Carquinez Strait				
CB 1	0-6.6	61	32	52
C I R	0-8(a)	15	12	86
CB 4 A	0-3.8	111	59	53
CB 4 A	3.8-11.4	31	20	65
CB 5	0-4	33	23	70
CB 6	0-6.5	16	18	113
CB 7	0-3.1	104	62	60
C II C	0-4	9.1	14	154
C II C	4-6.8	55	52	95

(a) Reported concentration is the mean concentration of the compositing duplicates.

TABLE 2.15. Total Volatile Solids (TVS), Total Organic Carbon (TOC), Oil and Grease, and Total Petroleum Hydrocarbons (TPH) in JFBSC Sediments from Battelle/Marine Sciences Laboratory 1990 Study

Sample	TVS (%dry wt)	TOC (%dry wt)	Oil and Grease (µg/kg dry wt)	TPH (µg/kg dry wt)	Petroleum Fraction
Method Blank	N/A[a]	N/A	0.7 U[b]	0.7 U	N/A
WR-A	5.11	0.53	17.0	14.0	82%
WR-B	5.58	0.62	8.8	9.9	100%
WR-C	5.43	1.17[c]	4.3	0.7 U	< 16%
WR-D	6.29	0.86	18.0	1.7	9.4%
WR-E	4.79[d]	0.71	17.2[e]	4.3[f]	25%

(a) U Undetected above given detection limit.
(b) N/A Not applicable.
(c) Mean of three replicates, S.D.=0.11.
(d) Mean of three replicates, S.D.=0.39.
(e) Mean of three replicates, S.D.=6.1.
(f) Mean of two replicates, S.D.=0.49.

TABLE 2.16. Metals in JFBSC Sediments from Studies Conducted by Battelle/Marine Sciences Laboratory in 1989

Station, Section, ft		Concentration (mg/kg dry wt except Al)												
		Ag	Al (%)	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	Tl	Zn
Shale soil[a]		0.10	8.0	6.6	0.30	20	100	57.0	0.4	95	20.0	0.60	1	80
Point Reyes coarse[b]		0.04	NA[c]	6.9	1.67	NA	315	9.8	0.09	42	7.7	0.31	0.44	36
Point Reyes fine[d]		0.04	NA	7.2	0.63	NA	341	12.3	0.07	51	7.5	0.34	0.34	55
Detection Limits														
Target DL		0.1	0.001	2	0.1	0.1	2	2	0.02	2	2	0.1	0.1	2
Lowest achieved DL		0.03	0.83	1.0	0.01	0.67	9	1	0.02	2	1.9	0.42	0.27	0.9
Maximum achieved DL		0.03	0.83	1.0	0.01	0.67	9	1	0.02	2	1.9	0.89	0.42	0.9
West Richmond														
WR VII C	0-5.5	0.07	6.09	9.0	0.17	14.3	210	25.4	0.16	68	16.5	0.66	<0.42	73
WR VI L	0-4	0.11	6.53	11.6	0.22	15.6	197	28.9	0.26	73	13.3	<0.58	0.48	82
WR V L	0-6	0.24	6.89	11.5	0.33	17.4	207	41.3	0.25	87	28.1	<0.62	<0.42	114
WR IV.5 C	0-4	0.22	7.47	10.6	0.25	17.7	236	41.6	0.28	90	26.1	<0.61	<0.42	111
WR IV.5 C	4-8	0.04	6.58	14.4	0.17	19.6	171	24.6	0.07	87	7.6	<0.61	<0.42	69
WR IV R	0-6	0.36	7.45	12.3	0.30	15.2	226	48.5	0.38	102	32.3	<0.86	0.46	127
WR IV R	6-11.5(e)	0.09	6.93	10.9	0.14	17.6	225	24.9	0.08	95	10.4	<0.87	0.47	78
WR III L	0-6.6	0.05	7.27	8.9	0.10	17.6	205	23.8	0.02	94	7.2	<0.85	0.62	74
WR III C	0-6.4	0.04	6.02	10.3	0.12	16.6	220	24.1	0.02	93	7.7	<0.85	0.46	71
WR II L	0-6.9	0.04	5.86	8.7	0.10	16.6	208	22.1	0.25	91	5.6	<0.88	0.61	74
WR I R	0-5.1	0.19	7.38	9.4	0.23	17.9	375	38.0	0.20	98	23.8	<0.86	0.46	106
Pinole Shoal														
P I C	0-3	0.08	7.06	10.9	0.18	16.1	191	39.0	0.06	105	9.6	<0.85	0.46	96
P II C	0-4.3	0.09	7.70	11.2	0.19	11.1	179	45.0	0.05	108	8.3	<0.84	0.61	104
P III L	0-3	0.09	7.69	9.6	0.20	10.7	206	47.3	0.06	113	8.8	0.88	0.46	100
P IV R	0-8	0.08	7.09	8.4	0.17	11.3	253	33.7	0.06	103	8.9	<0.86	0.77	90

TABLE 2.16. (contd)

Station, Section, ft		Ag	Al (%)	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	Tl	Zn
		Concentration (mg/kg dry wt except Al)												
Pinole Shoal (contd)														
P V L	0-8.4	0.16	8.48	10.0	0.27	12.1	237	56.1	0.16	117	17.1	<0.52	0.62	119
P V C	0-8.7	0.09	8.08	8.4	0.22	13.0	218	49.1	0.06	123	11.9	<0.52	0.47	102
P V R	0-5	0.12	8.15	13.2	0.25	12.5	247	58.8	0.18	124	13.1	<0.52	0.62	118
P V R	5-10.5	0.10	8.12	10.0	0.18	11.8	249	43.5	0.06	113	8.4	0.62	0.46	100
P VI L	0-5	0.27	8.70	17.0	0.48	15.4	278	77.7	0.38	146	28.5	<0.51	0.62	162
P VI L	5-11.6	0.10	8.06	8.6	0.18	12.3	207	48.0	0.06	117	9.7	<0.50	0.60	102
P VI C	0-9	0.08	7.14	8.5	0.13	13.4	239	31.3	0.02	105	10.4	<0.51	0.77	82
P VI R	0-5	0.15	7.80	10.4	0.22	13.8	256	44.8	0.14	116	18.2	<0.50	0.61	115
P VI R	5-11.7	0.08	8.48	9.6	0.16	13.6	239	44.0	0.05	112	7.8	<0.52	0.77	98
P VII C	0-5	0.12	7.36	12.0	0.23	14.2	267	47.4	0.16	113	15.7	<0.51	0.61	106
P VII C	5-10.1	0.07	7.42	9.4	0.15	14.6	210	36.6	0.03	106	7.9	<0.51	0.46	88
P VIII L	0-6.6	0.24	8.74	13.9	0.32	18.2	213	65.3	0.24	129	26.6	<0.86	0.77	140
P VIII L	6.6-9.5	0.04	7.09	8.6	0.09	18.5	281	25.6	0.03	98	9.3	<0.85	0.46	70
P VIII R	0-8	0.18	9.22	14.1	0.31	16.5	273	60.3	0.19	134	18.7	<0.88	0.62	133
P VIII R	8-10.5	0.06	6.74	18.7	0.13	15.5	242	30.8	0.03	97	8.2	<0.51	0.46	79
P VIII.5 C	0-3.6	0.05	6.58	12.1	0.10	18.0	248	24.0	0.04	100	13.5	<0.89	0.31	80
P VIII.5 C	3.6-10.4(e)	0.06	7.30	8.8	0.12	15.8	267	34.0	0.04	106	8.0	<0.86	0.54	84
P IX C	0-5	0.05	6.11	12.0	0.09	18.8	288	25.1	0.02	96	8.6	<0.85	0.62	75
P IX C	5-11.8	0.04	7.31	11.7	0.08	17.4	270	23.5	0.02	104	7.2	<0.88	0.31	71
P IX.5 L	0-5(e)	0.06	6.57	9.6	0.10	17.7	311	23.9	0.06	96	13.6	<0.86	0.39	75
P IX.5 L	5-10.1	0.04	7.61	8.1	0.08	19.9	276	21.9	0.02	105	9.5	<0.84	0.61	68
P X R	0-6	0.05	7.12	9.4	0.11	18.3	312	24.8	0.05	105	11.1	<0.84	0.62	83
P X R	6-11.5	0.04	7.36	13.2	0.08	18.9	393	25.6	0.02	113	8.2	<0.83	0.31	72
P X.5 C	0-5	0.07	7.16	12.4	0.09	18.3	313	23.8	0.03	99	9.2	<0.41	0.62	76
P X.5 C	5-11	0.04	6.85	9.9	0.09	18.2	333	29.3	0.03	99	7.2	<0.81	0.31	71
P XI L	0-3.5	0.14	8.13	10.2	0.17	18.7	345	39.7	0.10	112	10.2	<0.42	0.46	96
P XII R	0-8.5	0.05	9.06	14.3	0.13	17.2	331	46.5	0.26	108	11.8	<0.42	0.77	90
P XII RR	0-9.2	0.12	8.68	13.5	0.22	17.5	280	55.8	0.24	114	13.2	<0.41	0.31	115
P XII B2	0-2	0.04	6.21	8.6	0.10	18.2	307	21.0	0.06	91	16.4	<0.86	0.31	83
P XII B2	2-7.5(e)	0.11	9.30	17.1	0.15	19.3	284	58.5	0.32	106	14.3	0.93	0.54	89
P XII B2	7.5-12.5	0.08	8.26	8.2	0.13	21.4	561	38.7	0.06	114	7.7	<0.86	0.62	92
P XII B1	0-5	0.23	8.86	14.0	0.43	22.9	247	75.0	0.24	122	24.0	<0.85	0.62	152

TABLE 2.16. (contd)

Station	Section, ft	Ag	Al (%)	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	Tl	Zn
		Concentration (mg/kg dry wt except Al)												
Pinole Shoal (contd)														
P XII B1	5-11.1	(f)	7.53	12.6	0.26	20.8	377	51.6	0.13	110	12.9	1.02	0.31	113
P X11.5 C	0-6(e)	0.08	9.35	16.9	0.19	16.4	242	53.9	0.37	97	16.4	<0.41	0.46	95
P X11.5 R	0-5.3	0.08	10.31	14.6	0.15	18.5	241	60.8	0.33	106	15.9	0.42	0.62	92
P X11.5 R	5.3-11.1	0.07	8.67	9.6	0.14	19.3	435	39.9	0.05	107	7.8	<0.41	0.61	93
P XIII L	0-6(e)	0.09	10.19	17.1	0.19	17.9	189	53.5	0.30	86	16.3	0.58	0.62	92
P XIII R	0-5	0.08	9.62	17.4	0.16	15.7	195	52.3	0.29	76	13.6	<0.42	0.61	88
P XIII R	5-10	0.08	9.50	18.8	0.16	17.1	207	55.0	0.37	95	12.2	<0.39	0.77	88
P XIV C	0-4.5	0.26	8.54	17.2	0.46	20.5	275	55.8	0.30	104	61.9	<0.63	0.31	136
Carquinez Strait														
CB 1	0-6.6	0.14	10.07	19.1	0.24	19.2	243	60.3	0.41	93	24.8	<0.83	0.77	102
C I R	0-8(e)	0.26	10.22	18.8	0.22	18.8	184	56.5	0.38	90	22.0	<0.60	0.69	102
CB 4 A	0-3.8	0.16	7.52	17.8	0.28	20.5	269	56.2	0.27	103	22.1	0.85	0.46	126
CB 4 A	3.8-11.4	0.09	9.75	19.1	0.15	20.6	230	67.3	0.38	120	15.0	<0.87	0.61	101
CB 5	0-4	0.05	7.59	9.9	0.15	19.8	204	29.4	0.13	89	14.7	<0.60	<0.42	88
CB 6	0-6.5	0.22	8.83	14.7	0.57	20.5	223	66.5	0.44	108	34.8	<0.59	<0.42	147
CB 7	0-3.1	0.27	8.00	14.1	0.36	19.2	206	61.7	0.22	108	24.9	0.96	0.62	132
C 11 C	0-4	0.03	6.16	8.4	0.09	18.2	190	17.6	0.06	81	10.4	<0.59	<0.42	71
C 11 C	4-6.8	0.07	7.26	16.4	0.34	20.6	249	33.1	0.18	99	17.5	<0.60	<0.42	104
C 11 R	0-2.4	0.06	11.21	21.4	0.19	19.4	164	54.2	0.45	80	13.6	<0.59	<0.42	84

(a) Krauskopf (1967).
(b) Mean of values reported by Word et al. (1988, 1990a,b).
(c) NA Not applicable
(d) Mean of values reported by Word et al. (1989b) and Word et al. (1990a,b).
(e) Reported concentration is the mean concentration of compositing duplicate samples.
(f) Sample currently being reanalyzed.

TABLE 2.17. Metals in JFBSC Sediments from Studies Conducted by Battelle/Marine Sciences Laboratory in 1990

Sample	Metal Concentrations (mg/kg dry wt)										
	Ag	As	Cd	Cr	Cu	Hg	Ni	Pb	Se	Tl	Zn
WR-A	0.055	7.0	0.10	196.0	20.7	0.027	76.3	8.8	0.23	< 0.12	63.6
WR-B	0.061	10.4	0.12	216.0	21.8	0.027	80.5	7.1	0.19	< 0.12	64.7
WR-C	0.055	15.0	0.13	208.0	20.2	0.033	86.3	4.1	0.27	< 0.12	62.3
WR-D	0.058	12.8	0.16	145.0	21.6	0.031	72.9	5.4	0.27	< 0.12	60.5
WR E[a]	0.054	10.4	0.11	199.0	19.6	0.034	83.3	7.3	0.15	< 0.12	65.5

(a) Mean of three replicates.

PAHs

The results of PAH analyses for sediments collected in 1989 are presented in Table 2.18. The concentrations and types of PAH compounds found in the West Richmond sediments distinguished this reach of the JFBSC from the Pinole Shoal area and Carquinez Strait. Sediment from the southernmost station, WRVII, contained both low molecular weight (LPAH) and high molecular weight (HPAH) compounds. Lower molecular weight PAH compounds were sequentially lost from stations farther north of Station WRVII. The highest concentrations of LPAH and total PAH occurred in the southern part of the channel (Stations WR VII C, WR VI L, and WR V L). Examination of the PAH chromatograms of West Richmond samples also showed that more volatile compounds were present, indicating a possible source of petroleum hydrocarbons near Station WR VII.

In the Pinole Shoal reach of the JFBSC, PAHs were detected at Stations P VI L, P VIII L, P XII B1, and P XIV C. Most PAH compounds were the HPAHs, fluoranthene, pyrene, and chrysene. At Station P VI L, phenanthrene, benzo(b)fluoranthene, and benzo(a)pyrene were also present. In all cases, the total concentration of these higher molecular weight PAH compounds was at least 30 times lower than the concentrations observed in the West Richmond channel area.

In Carquinez Strait, the PAH levels from sediments at two berthing areas, Stations CB 7 and CB 4A, were higher than those of any other sampled areas in Pinole Shoal and second highest to the elevated West Richmond levels. More than 90% of PAHs were the higher molecular weight PAHs with nearly all these compounds represented.

The most noticeable difference between 1989 and 1990 sediment samples was for PAH values of sediment cores from the central part of the West Richmond reach of the Channel, where the upchannel direction changes from northwest to north. No PAHs were detected in any 1990 West Richmond sediments, while the sum of PAH concentrations ranged from 1 mg/kg to 3 mg/kg (ppm) at the three 1989 stations (WR IV R, WR IV.5 C, and WR V L).

TABLE 2.18. Total PAH and High Molecular Weight (HPAH) Fraction in JFBSC Sediments from Battelle/Marine Sciences Laboratory 1989 Study

Station, Section, ft		Total PAH (µg/kg)	HPAH (µg/kg)	% HPAH	Comment
WR VII C	0-5.5	3538	2977	84	NC[a]
WR V L	0-6	3075	2366	77	NC
WR VI L	0-4	2740	2256	82	NC
WR IV R	0-6	1829	1580	86	NC
WR IV R	6 11.5(b)	474	366	77	NC
WR IV.5 C	0-4	1783	1417	79	PAH in upper 4 ft of core only
WR IV.5 C	4-8	0	0	NA[c]	NC
WR I R	0-5 .1	878	776	88	NC
CB 4 A	0-3.8	392	358	91	PAH in upper 3.8 ft of core only
CB 4 A	3.8-11.4	0	0	NA	NC
CB 7	0-3.1	260	239	92	NC
P XIV C	0-4.5	179	179	100	NC
CB 6	0-6.5	167	152	91	NC
P VI L	0-5	166	148	89	PAH in upper 5 ft of core only
P VI L	5-11.6	0	0	NA	NC
P XII B1	0-5	66	49	74	PAH in upper 5 ft of core only
P XII B1	5-11.1	0	0	NA	NC
P VIII L	0-6.6	55	55	100	PAH in upper 6.6 ft of core only
P VIII L	6.6-9.5	0	0	NA	NC
P XIII L	0-6(a)	26	26	100	NC
C II C	0-4	0	0	NA	NC
C II C	4-6.8	26	26	100	PAH in lower part of core
P VI II R	0-8	18	18	100	NC
P VIII R	8-10.5	0	0	NA	NC
P V R	0-5	17	17	100	PAH in upper 5 ft of core only
P V R	5-10.5	0	0	NA	NC
P VII C	0-5	11	11	100	PAH in upper 5 ft of core only
P VII C	5-10.1	0	0	NA	NC

(a) NC No comment.
(b) Reported concentration is the average concentration of compositing duplicates, or the detected value if found in only one of the duplicates.
(c) NA Not applicable.
Note: Table only includes stations where PAHs were detected.

Kohn et al. (1991) suggest that detection of PAH in WR IV R, WR IV.5 C, and WR V L may be correlated with a higher proportion of fine-grained sediments (clay). The relationship of PAH to organic carbon showed no such correlation, as the 1990 sediment samples showed TOC values as high as those 1989 samples where PAH was detected. Further north in the channel, PAHs were undetected at both 1989 and 1990 stations (WR III L, WR III C, WR II L, WR-A, and WRB).

Chlorinated Pesticides and PCBs

Chlorinated pesticide results for sediments collected in 1989 are presented in Table 2.19. Only two pesticides, ß-BHC and ∂-BHC, were detected in six sediment samples from four locations in Pinole Shoal and two locations in Carquinez Strait. Pesticides were not detected in sediments collected in 1990 (Table 2.20). PCBs were not detected in sediment samples collected in either 1989 (Table 2.19) or 1990 (Table 2.21).

Butyltins

Butyltin concentrations for sediments collected in 1989 are summarized in Table 2.22. Total butyltin concentrations from West Richmond sediments ranged from undetected to as high as 19.3 µg/kg (dry wt), with the more toxic tributyltin form ranging from 8.6% to 37.8% of the total butyltins. This more toxic form ranged from undetected (<1 µg/kg dry weight) to 7.3 µg/kg dry weight. Using the equation of Valkirs et al. (1986), the concentration of tributyltins in the interstitial water was estimated to be approximately 0.004 µg/L, which is less than 1% of the acute and approximately 6% of the chronic marine water quality criteria of 0.22 µg/L and 0.069 µg/L, respectively.

The highest concentrations of butyltins occurred in the Carquinez Strait sediments at two berthing areas, Stations CB 4A and CB 7. The concentration of tributyltin at station CB 7 was 29 µg/kg dry weight.

Butyltin levels were low throughout the Pinole Shoal part of the channel. The highest concentrations of tributyltin in Pinole Shoal occurred at Station P VIII L (4 µg/kg) and Station P VIII R (3.9 µg/kg). The highest total of butyltin species was found at Station P VII C (10.1 µg/kg) followed by P VI R (8.7 µg/kg), P VIII R (7.9 µg/kg), and P VIII L (7.1 µg/kg). These relatively low concentrations of tributyltin were approximately one-half of the highest levels observed in the West Richmond sediment. Levels of tributyltin in West Richmond sediment were characterized through an organic carbon normalization formula (Valkirs et al. 1986) and were found to be from 1% to <6% of the acute and chronic marine water quality criteria. Concentrations of butyltin compounds in 1990 West Richmond sediments were comparable to or lower than concentrations found in 1989 sediments (Table 2.23).

TABLE 2.19. Chlorinated Pesticides and Polychlorinated Biphenyls (PCB) in JFBSC Sediments from Battelle/Marine Sciences Laboratory 1989 Study (All units in µg/kg Dry Weight)

Station, Section, ft	ß-BHC	∂-BHC
DL	4.0	8.0
West Richmond		
No Pesticides or PCBs Detected		
Pinole Shoal		
P XII R	0-8.5	1026
P XII B2 2-7.5	ND[a]	31
P XII B1 0-5	ND	29
P XII.5 R 5.3-11.1	ND	13
Carquinez Strait		
CB 1 0-6.6	ND	17
CB 4 A 3.8-11.4	ND	19

(a) ND Not detected above given detection limit.
Note: Table only includes stations where chlorinated pesticides were detected

TABLE 2.20. Pesticides in West Richmond Sediments from Battelle/Marine Sciences Laboratory 1990 Study

Sample	Recovery	Pesticide (ug/kg dry weight) Aldrin	A-BHC	B-BHC	D-BHC	Chlordane	4.4' DDD	4.4' DDE	4.4' 'DDT	Dieldrin
Detection Limit	N/A	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Method Blank	110%	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U
WR-A(a)	130%	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U
WR-B	100%	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U
W R-C	130%	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U
WR-D	140%	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U
WR-E	140%	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U

Sample	Pesticide (ug/kg dry weight) Endosulfan I	Endosulfan II	Endosulfan Sulfate	Endrin	Endrin Aldehyde	Heptachlor	Heptachlor Epoxide	Lindane (G-BHC)	Methoxy-chlor	Endrin Ketone	Toxaphene
Detection Limit	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.0	2.0	20.0
Method Blank	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	2.0 U	4.0 U	2.0 U	20.0 U
WR-A(a)	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	5.6 U	2.8 U	27.9 U
WR-B	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	2.8 U	5.6 U	2.8 U	28.0 U
WR-C	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	5.5 U	2.8 U	27.3 U
WR-D	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	2.9 U	5.8 U	2.9 U	29.2 U
WR-E	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	2.7 U	5.4 U	2.7 U	27.2 U

(a) Mean of three replicates.

TABLE 2.21. Polychlorinated Biphenyls (PCB) in West Richmond Sediments from Battelle/Marine Sciences Laboratory 1990 Study

		PCB Concentration (ug/kg dry weight)						
Sample	Surrogate (DBC) Recovery	Aroclor-1016	Aroclor-1221	Aroclor-1232	Aroclor-1242	Aroclor-1248	Aroclor-1254	Aroclor-1260
Detection Limit	NA[a]	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Method Blank	110%	20.0 U[b]	20.0 U	20.0 U	20.0 U	20.0 U	20.0 U	20.0 U
WR-A[c]	130%	27.9 U	27.9 U	27.9 U	27.9 U	27.9 L	27.9 U	27.9 U
WR-B	100%	28.0 U	28.0 U	28.0 U	28.0 U	28.0 U	28.0 U	28.0 U
WR-C	130%	27.2 U	27.2 U	27.2 U	27.2 U	27.2 U	27.2 U	27.2 U
WR-D	140%	29.2 U	29.2 U	29.2 U	29.2 U	29.2 U	29.2 U	29.2 U
WR-E	140%	27.2 U	27.2 U	27.2 U	27.2 U	27.2 U	27.2 U	27.2 U
WR-E	100%	27.4 U	27.4 U	27.4 U	27.4 U	27.4 U	27.4 U	27.4 U

(a) NA Not applicable.
(b) U Undetected above given detection limit.
(c) Mean of three replicates, S.D.=0.0 (compounds below detection in all samples).

TABLE 2.22. Butyltins in JFBSC Sediments from Battelle/Marine Sciences Laboratory 1989 Study

Station, Section, ft		Propyl Tin Recovery, %	Butyltin Species (µg/kg) Tri-	Di-	Mono-	Total
Detection Limits						
Target DL		NA(a)	10	10	10	NA
Lowest achieved DL		NA	0.40	0.41	0.42	NA
Maximum achieved DL		NA	0.80	0.83	2.3	NA
West Richmond						
WR VII C	0-5.5	36	1.8	15	1.2	18
WR VI L	0-4	56	0.82	7.1	1.6	9.5
WR V L	0-6	43	7.3	12	<2.3	19.3
WR IV.5 C	0-4	48	<0.74	2.1	<0.76	2.1
WR IV.5 C	4-8	36	<0.62	0.74	<0.63	0.74
WR IV R	0-6	82	2.3	5.1	<2.0	7.4
WR IV R	6-11.5 rep 1	45	0.81	<0.55	<0.56	0.81
WR IV R	6-11.5 rep 2	63	0.49	0.97	<0.46	1.46
WR III L	0-6.6	45	0.53	<0.55	<0.56	0.53
WR III C	0-6.4	45	<0.56	0.71	<0.57	0.71
WR II L	0-6.9	51	<0.49	<0.50	<0.50	NA
WR I R	0-5.1	45	2.1	7.9	3.0	13.0
Pinole Shoal						
P I C	0-3	54	0.83	<0.72	<0.73	0.83
P II C	0-4.3	31	1	3.5	1.1	5.6
P III L	0-3	38	0.74	0.68	<0.69	1.42
P IV R	0-8	68	0.96	1.3	1.0	3.3
P V L	0-8.4	39	0.93	1.7	0.83	3.5
P V C	0-8.7	57	<0.80	<0.83	<0.84	NA
P V R	0-5	63	<0.63	0.66	<0.41	0.66
P V R	5-10.5	58	<0.66	<0.68	<0.70	NA
P VI L	0-5	55	0.71	<0.67	<0.68	0.71
P VI L	5-11.6	42	0.63	3.2	<0.66	4.5
P VI C	0-9	49	0.81	1.7	0.81	3.3
P VI R	0-5	53	1.6	1.2	0.69	3.5
P VI R	5-11.7	97	2.7	4.5	1.5	8.7
P VII C	0-5	39	0.63	2.5	0.68	3.8
P VII C	5-10.1	83	2.6	6.5	0.97	10.1
P VIII L	0-6.6	68	4.0	0.71	2.4	7.1
P VIII L	6.6-9.5	53	<0.40	<0.41	<0.42	NA
P VIII R	0-8	70	3.9	2.1	1.9	7.9
P VIII R	8-10.5	52	<0.54	1.5	0.57	1.5
P VIII.5 C	0-3.6	46	2.1	0.74	<0.47	2.8
P VIII.5 C	3.6-10.4 rep 1	58	<0.49	0.57	<0.52	0.57
P VIII.5 C	3.6-10.4 rep 2	54	<0.59	1.1	<0.62	1.1

TABLE 2.22. (contd)

Station, Section, ft		Propyl Tin Recovery, %	Butyltin Species (µg/kg) Tri-	Di-	Mono-	Total
Pinole Shoal (contd)						
P IX C	0-5	47	<0.50	<0.51	<0.52	NA
P IX C	5-11.8	48	<0.46	<0.47	<0.48	NA
P IX.5 L	0-5 rep 1	53	<0.48	<0.48	<0.49	NA
P IX.5 L	0-5 rep 2	71	0.55	0.56	0.47	1.58
P IX.5 L	5-10.1	63	0.58	0.72	<0.49	1.3
P X R	0-6	80	2.0	2.8	1.2	6.0
P X R	6-11.5	42	0.48	<0.47	<0.48	0.48
P X.5 C	0-5	43	0.53	0.57	<0.50	1.10
P X.5 C	5-11	43	0.48	<0.47	<0.48	0.48
P XI L	0-3.5	63	<0.59	<0.58	<0.60	NA
P XII R	0-8.5	31	<0.62	<0.62	<0.64	NA
P XII RR	0-9.2	125	3.7	1.7	1.3	6.7
P XII B2	0-2	46	1.5	1.3	<0.92	2.8
P XII B2	2-7.5 rep 1	45	0.89	1.0	2.0	3.9
P XII B2	2-7.5 rep 2	79	2.7	11	3.1	17.0
P XII B2	7.5-12.5	69	0.75	3.1	0.95	4.8
P XII B1	0-5	66	2.1	5	2.4	9.5
P XII B1	5-11.1	46	0.89	3.1	<0.58	4.0
P XII.5 C	0-6 rep 1	42	0.67	1.4	0.88	2.9
P XII.5 C	0-6 rep 2	60	0.87	<0.77	<0.59	0.87
P XII.5 R	0-5.3	22	2.5	0.88	0.78	4.2
P XII.5 R	5.3-11.1	92	3.0	<0.69	1.0	4.0
P XIII L	0-6 rep 1	36	3.1	6.5	1.5	11.1
P XIII L	0-6 rep 2	43	<0.57	1.3	0.74	2.0
P XIII R	0-5	72	2.1	1.9	<0.67	4.0
P XIII R	5-10	45	1.5	1.2	0.66	3.4
P XIV C	0-4.5	45	<0.59	0.59	0.71	1.30
Carquinez Strait						
CB 1	0-6.6	81	2.5	2.1	1.3	5.9
C I R	0-8 rep 1	41	1.7	2.6	0.74	5.0
C I R	0-8 rep 2	64	2.9	1.8	1.1	5.8
CB 4 A	0-3.8	37	6.1	12	3.3	21
CB 4 A	3.8-11.4	37	0.57	1.5	<0.55	2.1
CB 5	0-4	42	0.57	1.4	<0.56	2.0
CB 6	0-6.5	86	2.8	3.5	1.1	7.4
CB 7	0-3.1	33	29	3.5	4.1	37
C II C	0-4	39	<0.51	1.3	<0.52	1.3
C II C	4-6.8	40	<0.61	5.8	1.0	6.8
C II R	0-2.4	40	1.2	1.3	0.97	3.5

(a) NA Not applicable.

TABLE 2.23. Butyltins in JFBSC Sediments from Battelle/Marine Sciences Laboratory 1990 Study

Sample	Propyltin Surrogate Recovery	Butyltin Concentration (µg/kg dry weight) Tri-	Di-	Mono-	Total
Method Blank	19.7 %	0.9	0.6 U[a]	0.6	1.5
WR-A	29.3 %	0.5	0.4	0.4 U	0.9
WR-B	41.8 %	0.8	0.8	0.4 U	1.6
WR-C	35.2 %	0.6	0.5 U	0.4 U	0.6
WR-D	33.7 %	0.9	0.4 U	0.4 U	0.9
WR-E Rep 1	35.9 %	0.9	0.5 U	0.6	1.5
WR-E Rep 2	36.0 %	0.8	0.5 U	0.5 U	0.8

(a) U Undetected above given detection limit.

2.3 OVERVIEW OF SEDIMENT TOXICITY STUDIES

Long and Markel (1992) provide a thorough summary and discussion of historical sediment toxicity data for the Bay. Their summary includes a review of 60 toxicity studies conducted since 1985 and a 1990 synoptic survey (45 sites) funded through NOAA and conducted by ToxScan, Inc. (Watsonville, California). Studies showing evidence of lesions and other histopathological abnormalities in fish were also reviewed in Long and Markel (1992) and are briefly discussed in Section 2.5 of this report.

Long and Markel's review of sediment toxicity studies is generally restricted to two types of tests: solid phase bioassays using the amphipod, *Rhepoxynius abronius*, and suspended phase bioassays using embryos of either the oyster, *Crassostrea gigas,* or the bay mussel, *Mytilus edulis*. Mussel and oyster bioassays were treated as equivalent tests and results from both tests were merged in the summaries produced in Long and Markel (1992) and in this report. Bivalve embryo tests using the Green Book and Puget Sound Protocols (PSP) were treated independently. Most of the data were generated during pre-dredging studies and, therefore, pertain to peripheral waterways and harbors. The synoptic survey conducted in 1990 consisted of bivalve embryo bioassays (survival and abnormal development), tests for cytogenetic endpoints in bivalve and echinoderm embryos, and tests using bioluminescent bacteria (Microtox). Sampling for the synoptic survey was restricted to San Pablo Bay (1 sample), Central Bay (10 samples), and South Bay (34 samples).

The data presented in Long and Markel (1992) clearly show toxicant-related impacts to at least some of the resident species in the Bay. Figure 2.10 shows locations that were identified as being most toxic based on a fixed toxicity threshold (i.e., 75% amphipod mortality or abnormal development in bivalve larvae). With the exception of a single site in the northeastern portion of

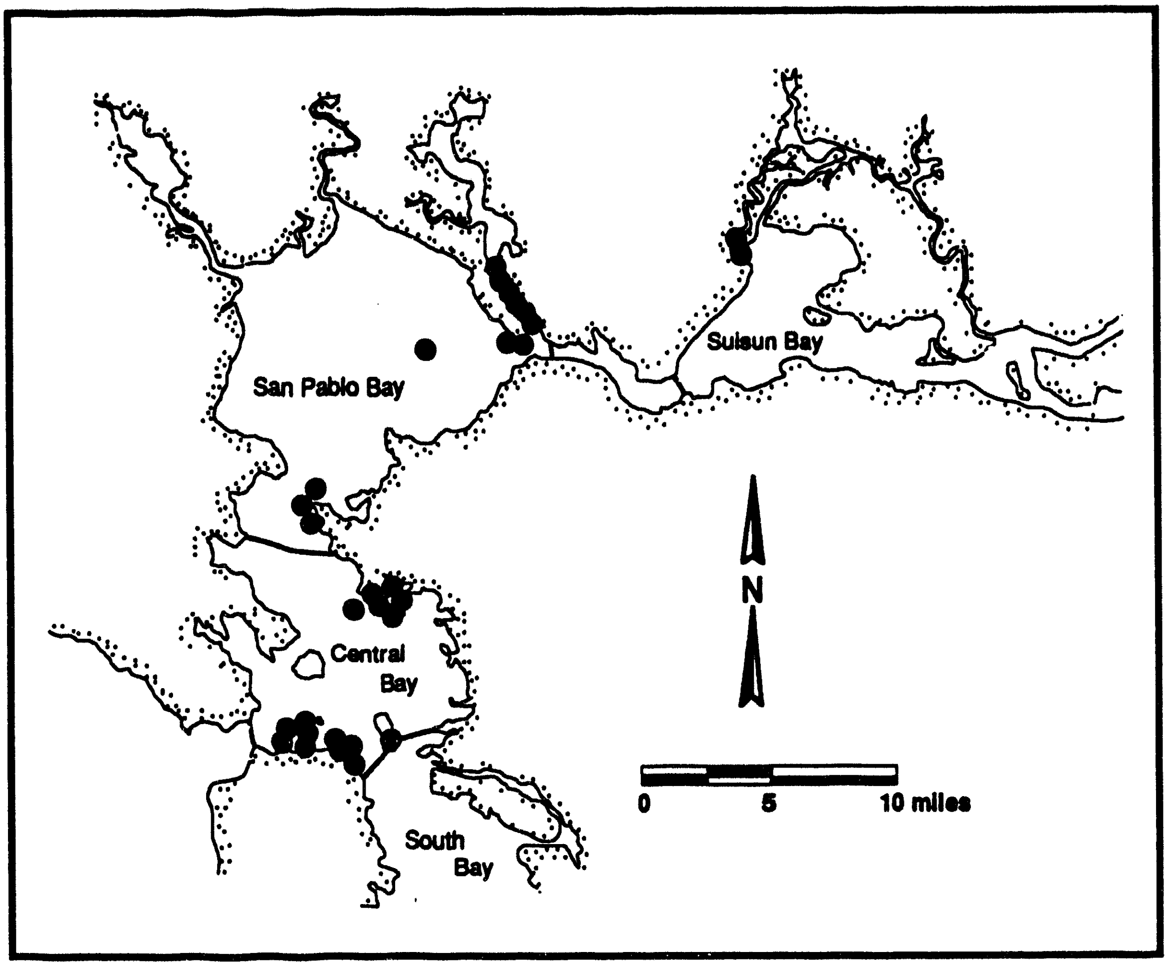

FIGURE 2.10. Locations of Historical Sediment Toxicity Studies Showing ≥75% Amphipod Mortality or ≥75% Abnormal Development in Bivalve Larvae (After Long and Markel 1992)

the Pinole Shoal Channel, all of these locations are located along bay margins, and most of these are near major harbors. A similar plot of the most toxic locations from the 1990 synoptic survey is presented in Figure 2.11. In this study, sediment toxicity based on cytogenetic and larval testing was found at a single site near the center of San Pablo Bay and at three locations within Richmond Harbor.

A listing of all toxicity studies conducted within San Pablo Bay from 1985 to 1990 is presented in Table 2.24. This table includes references for the original studies cited and a summary of both the methods used in each study and the study results. Table 2.25 summarizes the results of amphipod and bivalve larvae tests performed using sediments from southwest San Pablo Bay. The southwest San Pablo Bay location has historically been a common reference-sediment site. However, it should be noted that 4 of the 10 samples analyzed from 6 separate studies showed significant toxicity to either bivalve larvae or amphipods. Sediment toxicity results for the San Pablo Bay and Carquinez Strait dredged material disposal sites have been summarized in Table 2.26. All of the results are for suspended phase bioassays employing bivalve larvae. Two out of seven studies conducted using sediments from the Carquinez disposal site showed toxicity when embryos were exposed to undiluted sediment suspensions. No toxicity was shown for the 50% sediment suspensions. Only one study was cited for the San Pablo Bay disposal site, and it did not show toxicity in either the undiluted or 50% sediment suspension.

Amphipod and bivalve larvae (100% sediment suspensions) toxicity studies for all regions of the Bay have been summarized in Tables 2.27 and 2.28, respectively. The summary of amphipod toxicity results includes studies that have used *Eohaustorius estuarius* and *Hyalella azteca*, in addition to *Rhepoxynius*. Samples taken from basins and peripheral areas have been listed separately in both tables. The San Pablo Bay disposal site has been included as a peripheral site in Table 2.28 because its sediments are largely derived from peripheral locations.

San Pablo Bay exhibited the lowest average percent amphipod mortality among the basins examined. Only two peripheral sites (Alcatraz disposal site, Guadalupe Slough Channel) had average amphipod mortalities that were less than those of San Pablo Bay, although relatively few studies were conducted at the peripheral locations. The highest average amphipod mortality was found in Oakland Outer Harbor (75.5%), followed by Castro Cove (60.3%), Islais Creek Waterway (53.0%), and Treasure Island Naval Base (48.3%).

In contrast to the amphipod results, San Pablo Bay exhibited the highest average percentage of abnormal bivalve larvae (based on data for 100% sediment suspensions) among the basin locations. However, only one data point was presented for Central Bay and no data were presented for northern South Bay. The highest percentage of abnormal larvae for a peripheral site (Point Molate at 100%) was approximately five times that reported for San Pablo Bay. Overall, San Pablo Bay was ranked the 16th most toxic site out of 23 sites based on the mean incidence of bivalve abnormalities.

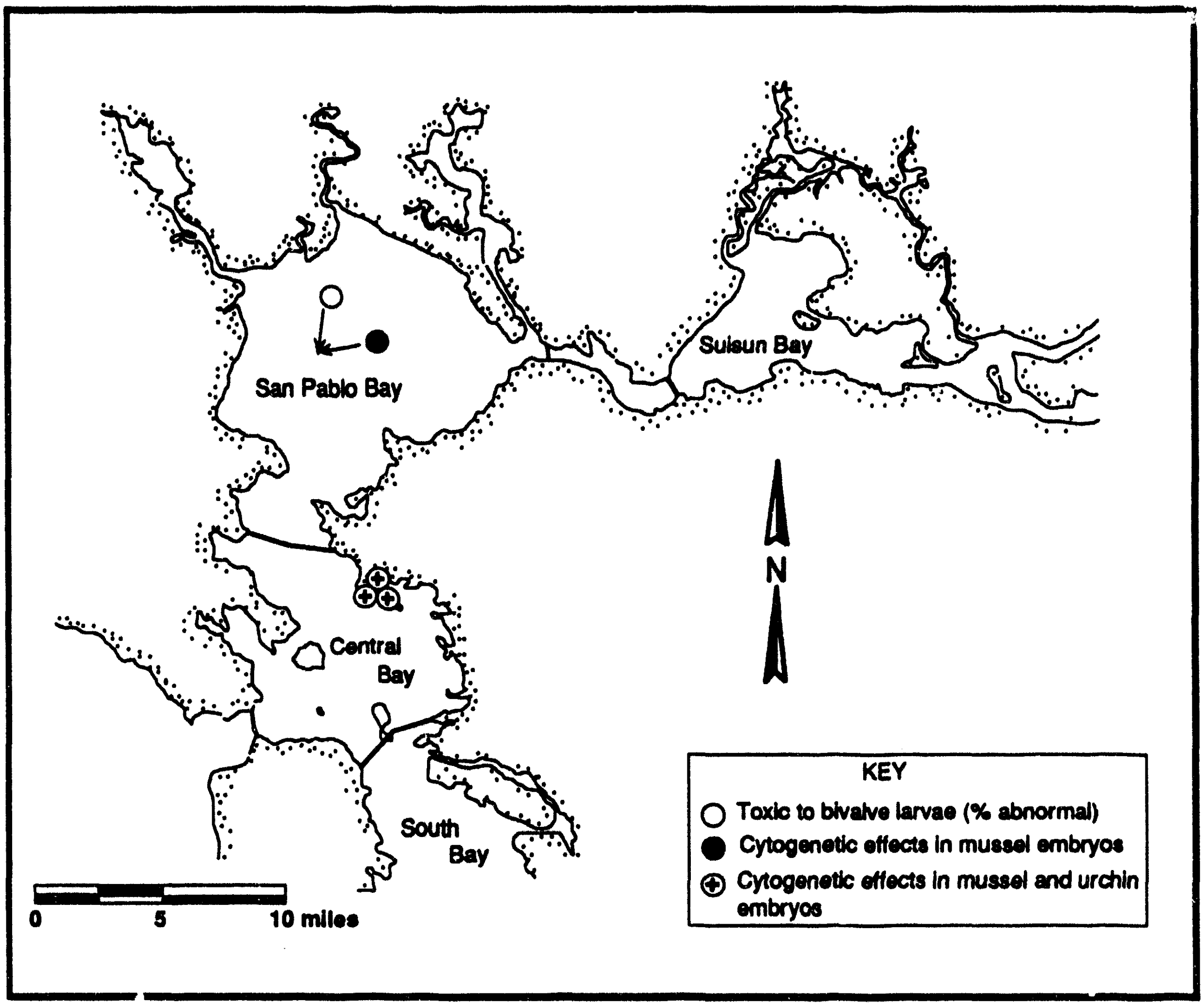

FIGURE 2.11. Sampling Sites from Synoptic Survey Performed by ToxScan, Inc. that Showed Significant Sediment Toxicity (After Long and Markel 1992)

TABLE 2.24. Summary of Historical Sediment Toxicity Studies for Selected Sites Within Central and San Pablo Bay (After Long and Markel 1992)

Source	Survey/Location	Station I.D.	Sampling Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y) No Hit (N)	Amphipod % Mortality/ Bivalve % Abnormal
Long & Buchman (1989)	San Pablo Bay	SP-1	2/22/87	2 cm grab	Rhepoxynius	amphipod	Y	9
Long & Buchman (1989)	San Pablo Bay	SP-2	2/22/87	2 cm grab	Rhepoxynius	amphipod	Y	54
Long & Buchman (1989)	San Pablo Bay	SP-3	2/22/87	2 cm grab	Rhepoxynius	amphipod	Y	17
Long & Buchman (1989)	San Pablo Bay	SP-1	2/22/87	2 cm grab	PSP[(a)]	bivalve	Y	7.4
Long & Buchman (1989)	San Pablo Bay	SP-2	2/22/87	2 cm grab	PSP	bivalve	Y	14
Long & Buchman (1989)	San Pablo Bay	SP-3	2/22/87	2 cm grab	PSP	bivalve	Y	7.9
Long & Buchman (1989)	off Vallejo, Semple Pt.	VA-1	2/20/87	2 cm grab	Rhepoxynius	amphipod	Y	69
Long & Buchman (1989)	off Vallejo, Semple Pt.	VA-2	2/20/87	2 cm grab	Rhepoxynius	amphipod	N	10
Long & Buchman (1989)	off Vallejo, Semple Pt.	VA-3	2/20/87	2 cm grab	Rhepoxynius	amphipod	N	16
Long & Buchman (1989)	off Vallejo, Semple Pt.	VA-1	2/20/87	2 cm grab	PSP	bivalve	Y	13.3
Long & Buchman (1989)	off Vallejo, Semple Pt.	VA-2	2/20/87	2 cm grab	PSP	bivalve	N	6.5
Long & Buchman (1989)	off Vallejo, Semple Pt.	VA-3	2/20/87	2 cm grab	PSP	bivalve	Y	9.1
Chapman et al. (1985)	San Pablo Bay	SP 02	7/7/85	2 cm grab	Rhepoxynius	amphipod	N	9
Chapman et al. (1985)	San Pablo Bay	SP 05	7/7/85	2 cm grab	Rhepoxynius	amphipod	N	4
Chapman et al. (1985)	San Pablo Bay	SP 09	7/7/85	2 cm grab	Rhepoxynius	amphipod	N	24
Chapman et al. (1985)	San Pablo Bay	SP 02	7/7/85	2 cm grab	PSP	bivalve	N	13.4
Chapman et al. (1985)	San Pablo Bay	SP 05	7/7/85	2 cm grab	PSP	bivalve	N	7.7
Chapman et al. (1985)	San Pablo Bay	SP 09	7/7/85	2 cm grab	PSP	bivalve	N	15.3
McPherson & Power (1989)	Pinole Shoal Channel	Section 3	Dec-88	composited core	100%	bivalve	Y	15.1
McPherson & Power (1989)	Pinole Shoal Channel	Section 4	Dec-88	composited core	100%	bivalve	Y	100
McPherson & Power (1989)	San Pablo Bay Disposal Site	Ref.	Dec-88	composited core	100%	bivalve	N	6.9
McPherson & Power (1989)	Pinole Shoal Channel	Section 3	Dec-88	composited core	50%	bivalve	N	5.3
McPherson & Power (1989)	Pinole Shoal Channel	Section 4	Dec-88	composited core	50%	bivalve	N	47.2
McPherson & Power (1989)	San Pablo Bay Disposal Site	Ref.	Dec-88	composited core	50%	bivalve	N	7.5
E.V.S. (1987)	Southwest San Pablo Bay	Ref.	May-87	comp. 2' core	100%	bivalve	Y	13.9
E.V.S. (1987)	Southwest San Pablo Bay	Ref.	May-87	comp. 2' core	50%	bivalve	Y	9.6
E.V.S. (1987)	Southwest San Pablo Bay	Ref.	May-87	comp. 2' core	Rhepoxynius	amphipod	N	9
ToxScan (1989)	S.F. Bay Ref. Sediment	R-3	Oct-89	NA[(b)]	20 g/L	bivalve	N	3.8
ToxScan (1989)	S.F. Bay Ref. Sediment	R-3	Oct-89	NA	Rhepoxynius	amphipod	--[(c)]	15

TABLE 2.24. (contd)

Source	Survey/Location	Station I.D.	Sampling Date	Sample Type	Amphipod Species or Suspended Sediment Concentration	Bioassay Type	Significant Hit (Y) No Hit (N)	Amphipod % Mortality/ Bivalve % Abnormal
	UNOCAL Terminal:							
M.E.C. (1990a)	off Rodeo, Area 1	1	Jul-90	composited core	100%	bivalve	--	9
M.E.C. (1990a)	off Rodeo, Area 2	2	Jul-90	composited core	100%	bivalve	--	11
M.E.C. (1990a)	off Rodeo, Area 4	4	Jul-90	composited core	100%	bivalve	--	8.6
M.E.C. (1990a)	off Rodeo, Area 1	1	Jul-90	composited core	50%	bivalve	--	9.6
M.E.C. (1990a)	off Rodeo, Area 2	2	Jul-90	composited core	50%	bivalve	--	19.5
M.E.C. (1990a)	off Rodeo, Area 4	4	Jul-90	composited core	50%	bivalve	--	19.6
	Pacific Refinery Pier:							
M.E.C. (1990b)	San Pablo Bay	1	Feb-90	composited core	100%	bivalve	Y	26.4
M.E.C. (1990b)	San Pablo Bay	2	Feb-90	composited core	100%	bivalve	Y	25.7
M.E.C. (1990b)	San Pablo Bay	3	Feb-90	composited core	100%	bivalve	Y	19.9
M.E.C. (1990b)	San Pablo Bay	1	Feb-90	composited core	50%	bivalve	Y	15.8
M.E.C. (1990b)	San Pablo Bay	2	Feb-90	composited core	50%	bivalve	Y	15.8
M.E.C. (1990b)	San Pablo Bay	3	Feb-90	composited core	100%	bivalve	Y	17
	Pacific Refinery Pier:							
Anonymous	San Pablo Bay	1	NA	composited core	100%	bivalve	Y	19.2
Anonymous	San Pablo Bay	1	NA	composited core	50%	bivalve	Y	23.1
ToxScan (1989)	S.F. Bay Ref. Sediment	R-3	Oct-89	NA	100%	bivalve	N	3.8
ToxScan (1989)	S.F. Bay Ref. Sediment	R-3	Oct-89	NA	Rhepoxynius	amphipod	--	15
ToxScan (1990)	S.F. Bay Ref. Sediment	R-3	Jan-90	NA	100%	bivalve	N	7.2
ToxScan (1990)	S.F. Bay Ref. Sediment	R-3	Jan-90	NA	Rhepoxynius	amphipod	N	37
ToxScan (1990)	S.F. Bay Ref. Sediment	R-3	Mar-90	NA	100%	bivalve	N	1.8
ToxScan (1990)	S.F. Bay Ref. Sediment	R-3	Mar-90	NA	Rhepoxynius	amphipod	N	29

(a) PSP Puget Sound Protocols.
(b) NA Not available.
(c) -- No data.

TABLE 2.25. Summary of Results for Amphipod Bioassays and Bivalve Larve Tests Performed Using Sediments from Southwest San Pablo Bay (After Long and Markel 1992)

Amphipod Bioassays:

Investigator	Sampling Date	*R. abronius* % Mortality Mean ±S.D.	Ratio of Toxic Samples to Total
E.V.S.	07/85	12.3 ±10.4	0/3
E.V.S.	02/87	26.7 ±24.0	3/3
E.V.S.	05/87	9.0	0/1
ToxScan	10/89	15.0	--
ToxScan	01/90	37.0	0/1
ToxScan	03/90	29.0	0/1

Suspended Phase Bivalve Larvae Tests:

Investigator	Sampling Date	Bivalve Larvae % Abnormal Mean ±S.D.	Ratio of Toxic Samples to Total
E.V.S.	07/85	21.1 ±4.0	0/3
E.V.S.	02/87	9.8 ±3.8	3/3
E.V.S.	05/87	13.9	1/1
ToxScan	10/89	3.8	0/1
ToxScan	01/90	7.2	0/1
ToxScan	03/90	1.8	0/1

TABLE 2.26. Summary of Bivalve Toxicity Data for the Carquinez Strait and San Pablo Bay Disposal Sites (All Results are for Suspended Phase Bioassays Using Either *M. edulis* or *C. gigas* [After Long and Markel 1992])

Site/Data Source	Sampling Date	Sample Type	Dilution	Significant Hit (Y) No Hit (N)	% Abnormal Embryos
Carquinez Disposal Site:					
Power et al. (1989)	Oct-88	composited core	50%	N	7.6
E.V.S. (1990)	Nov-89	composited core	50%	--[b]	26.1
M.B.L. (1987)	Dec-87	composited core	50%	N	98
M.E.C. (1990)	Jul-90	composited core	50%	--	13.1
M.E.C. (1990)	Feb-90	composited core	50%	N	16.2
Anonymous	NA[b]	composited core	50%	N	7.7
			Mean=28.1		S.D.=34.9
Power et al. (1989)	Oct-88	composited core	0%	Y	98.7
E.V.S. (1990)	Apr-90	composited core	0%	Y	96.5
E.V.S. (1990)	Nov-89	composited core	0%	--	30.9
M.B.L. (1987)	Dec-87	composited core	0%	N	99.7
M.E.C. (1990)	Jul-90	composited core	0%	--	18.8
M.E.C. (1990)	Feb-90	composited core	0%	N	15.3
Anonymous	NA	composited core	0%	N	44.7
			Mean=57.8		S.D.=39.0
San Pablo Bay Disposal Site:					
McPherson & Power (1989)	Dec-88	composited core	0%	N	6.9
McPherson & Power (1989)	Dec-88	composited core	50%	N	7.5

(a) "--" Not provided in Long and Markel (1992).
(b) NA Not available from original source.

TABLE 2.27. Summary of Amphipod Toxicity Studies for all Regions within San Francisco Bay (After Long and Markel 1992)

Area	% Mortality Mean ± S.D.(a)	No. of Samples(a)	Area Rank(a)	Ratio of Toxic Samples to Total(b)	Area Rank(b)
Basins					
San Pablo Bay	23.4 ±17.5	17	14	4/15	11
Central Bay	33.3 ±7.5	3	9	3/3	1
South Bay, southern	32.0 ±14.4	13	11	6/12	10
South Bay, central	55.4 ±22.6	14	3	ND(c)	ND
South Bay, northern	25.0 ±14.3	9	13	0/3	13
Peripheral Areas					
Oakland Outer Harbor	75.5 ±5.0	2	1	2/2	1
Castro Cove	60.3 ±26.5	3	2	3/3	1
Islais Creek Waterway	52.0 ±37.8	3	4	2/3	8
Hunters Point Naval Base	37.2 ±15.1	8	6	6/6	1
Oakland Inner Harbor	36.0 ±17.1	24	7	14/25	9
Alameda Naval Base	33.5 ±3.5	2	8	2/2	1
Southern South Bay Channels	33.0 ±11.4	9	10	6/23	12
Richmond Harbor	27.0 ±15.6	2	12	2/2	1
Guadalupe Slough Channel	21.5 ±3.4	4	15	0/4	13
Alcatraz disposal site	11.5 ±13.4	2	16	0/2	13
Treasure Island Naval Base	48.3 ±18.3	6	5	6/6	1

(a) *Rhepoxynius abronius*, area ranks based on average mortailities.
(b) Ratio of samples identified in tests with *R. abronius*, *Eohaustorius estuarius*, or *Hyalella azteca* as siginficantly more toxic than controls versus the total number of samples that were tested and area ranks based upon the ratios.
(c) ND No Data.

TABLE 2.28. Summary of Bivalve Toxicity Tests (100% Sediment Suspensions) for all Regions within San Francisco Bay (After Long and Markel 1992)

Area	%Abnormal Mean ±S.D.(a)	No. of Samples(a)	Area Rank(a)	Ratio of Toxic Samples to Total(b)	Area Rank(b)
Basins					
San Pablo Bay	19.1 ±31.0	9	16	9/16	15
Central Bay	2.4	1	23	0/3	21
South Bay, southern	14.9 ±30.6	8	19	2/9	20
South Bay, northern	ND(c)	ND	ND	2/3	11
Peripheral Areas					
San Pablo disposal site	6.9	1	21	0/1	21
Carquinez disposal site	57.8 ±39.0	7	8	2/5	18
Mare Island Strait	76.2 ±28.7	10	5	8/10	8
Suisun Slough Channel	98.5 ±1.1	2	2	2/2	1
UNOCAL	9.5 ±1.3	3	20	ND	ND
Point Molate	100.0 ±0	2	1	2/2	1
Islais Creek	ND	ND	ND	4/4	1
Guadalupe Slough Channel	98.0 ±4.2	8	3	8/8	1
Redwood Creek	84.4 ±21.4	2	4	2/2	1
Richmond Harbor	63.8 ±40.9	13	6	10/13	9
Hunters Point	59.1 ±36.7	6	7	4/6	11
Port of San Francisco	55.0 ±43.5	19	9	5/7	10
Oakland Middle Harbor	43.1 ±18.3	6	10	6/6	1
Alcatraz disposal site	35.5 ±39.3	30	11	13/27	17
Oakland Inner Harbor	31.9 ±35.4	23	12	15/29	16
Treasure Island	29.0 ±17.5	11	13	11/11	1
Pacific Refining	22.8 ±3.8	4	14	ND	ND
Castro Cove	21.3 ±10.9	3	15	2/3	11
Alameda Naval Base	19.0 ±15.3	3	17	2/3	11
Oakland Outer Harbor	18.9 ±29.2	18	18	7/18	19
South Bay, south channels	5.1 ±5.4	16	22	0/14	21

(a) Tests using *Mytilus edulis* or *Crassostrea gigas*, Area Ranks based upon the average abnormalities.
(b) Ratios of number of samples identified as significantly more toxic than controls to the total number of samples tested, Area Ranks based upon ratios.
(c) ND No data.

2.4 OVERVIEW OF BIOACCUMULATION STUDIES

Long et al. (1988) provide a summary of bioaccumulation studies conducted within the Bay from approximately 1970 to present. Their summary includes results from NOAA's Mussel Watch and Benthic Surveillance Projects, and various studies conducted by state and local agencies, universities, and consulting firms. They provide detailed summaries from over 20 different surveys or programs describing the levels of six metals (Hg, Cd, Cu, Pb, Cr, As), PAHs, DDT, and PCBs in the tissues of bivalves, fish, and crustaceans. A brief overview of the trends noted in Long et al. (1988) is presented in this section.

Tissue burdens of selected contaminants have been reported for a variety of bivalve species from different areas of the Bay. The most commonly used species included the clams, *Macoma nasuta*, *Macoma balthica*, *Tapes japonica*, and *Mya arenaria*, the oysters, *Crassostrea gigas*, *Ostrea lurida*, and the mussels, *Mytilus edulis*, *Mytilus californianus*, and *Ischadium demissum*. Sampling and analytical protocols varied among the different studies. The most important difference noted for bioaccumulation studies employing mussels was the use of transplanted versus resident species. Transplanted mussels were usually *Mytilus californianus* collected at Bodega Head and deployed at sampling sites using either buoyed or anchored arrays. Studies of bioaccumulation in resident mussels used *Mytilus edulis*.

Long et al. (1988) caution that natural sources of variability, such as lipid content, age, sexual maturity, trophic level, and feeding habits can have a pronounced effect on levels of contaminants measured in tissues. For example, animals with high lipid content tend to accumulate relatively higher levels of lipophilic organic compounds. Also, because lipids accumulated during gametogenesis are expelled in reproductive products (eggs, sperm), the concentrations of certain contaminants may vary dramatically depending on whether sampling occurrs before or after spawning. Because ingestion is a major pathway for contaminants in tissues, feeding habits play an important role in determining the relative level of contaminants in different species. In general, deposit feeding bivalves accumulate relatively higher levels of contaminants compared to suspension- or filter-feeding species (Long et al. 1988).

A summary of metal bioaccumulation data from Long et al. (1988) for mussels sampled from San Pablo Bay and Central Bay is presented in Table 2.29. Summary statistics are presented separately for the basins and peripheral areas of each bay. For comparison, data have also been included for the entire Bay and for two reference locations outside of the Bay (Tomales Bay and Bodega Head).

In general, mean tissue burdens for all six metals from the Bay (Bay-wide averages) and both the basin and peripheral sites from San Pablo and Central Bay exceeded concentrations found at the Tomales Bay and Bodega Head reference sites. However, it should be noted that there is wide scatter in the data for most metals at each of the sites. Also, the distribution of sampling locations is not even across the major basins of the Bay. In many cases there is also a wide difference in the number of samples collected from basin versus peripheral areas within a given bay. Long et al. (1988) provide a more detailed discussion of the spatial and temporal variability in the distribution of each of the metals. The reader is urged to consult this reference for details concerning the individual study results that have been compiled and summarized in this report.

Relatively few studies have analyzed PAH concentrations in the tissues of either fish or bivalves. Long et al. (1988) only reference five surveys (11 sites) since 1975 that have reported tissue-PAH concentrations. Moreover, sampling and analytical protocols varied among studies, making it difficult to report on geographic and temporal trends. Ranges in total PAH for fish and mussels, respectively, were reported as 0.017 ppm to 14 ppm wet weight and 0.025 ppm to 13 ppm wet weight.

In contrast to PAH concentrations, the biota of the Bay have been well characterized for DDT concentrations. Long et al. (1988) report that 25 surveys since 1965 have analyzed for DDT in the tissues of fish, bivalves, or crustaceans. Total DDT (sum of DDT, DDD, and DDE isomers) concentrations in 189 mussel samples collected throughout the Bay averaged 0.33 ppm with a range of 0.01 ppm to 22.47 ppm. The Bay-wide mean exceeded levels reported in the Tomales Bay and Bodega Head reference areas by a factor of 15. The means for San Pablo Bay and Central Bay, respectively, were 0.10 ppm (range <0.2 ppm to 0.23 ppm) and 0.12 ppm (range 0.01 ppm to 2.6 ppm). A total of 448 tissue samples (muscle, liver, gonad, or other tissue) have been analyzed for DDT from fish collected in the Bay. Most sampling has focused on two species, the starry flounder (*Platichthys stellatus*) and the striped bass (*Morone saxatilis*). Sampling has been most intense in the Sacramento-San Joaquin Delta. Long et al. (1988) report total DDT concentrations in starry flounder livers collected from San Pablo Bay (NOAA NS&T Program) in 1984 and 1985 of 1.001 ppm and 1.325 ppm dry weight, respectively.

Since 1972, 19 surveys have determined PCB concentrations in biota from the Bay. Long et al. (1988) report a Bay-wide mean concentration of PCB in mussel tissues (193 samples) collected from 1975 to 1986 of 0.65 ppm dry weight (range 0.06 ppm to 4.60 ppm dry weight). The Bay-wide mean was approximately 13 times that reported for the Tomales Bay and Bodega Head reference sites. They caution, however, that this is only an estimate, because many studies they reviewed reported relatively high detection limits, and many surveys reported PCB concentrations only in wet weight. A total of 402 tissue samples (muscle, liver, gonad, or other tissue) have been analyzed for PCBs from fish collected in the Bay. As noted for DDT, most of the sampling has concentrated on starry flounder and striped bass collected from the Sacramento-San Joaquin Delta. The highest levels of PCBs have been reported in striped bass, where mean concentrations have ranged from 0.47 ppm wet weight in muscle tissue to 2.13 ppm in gonads.

TABLE 2.29. Summary of Metal Concentrations (ppm Dry Weight) in Mussels (*Mytilus edulis* or *M. californianus*) for Selected Years and Areas Within San Francisco Bay (After Long et al. 1988)

Metals	Mean ± S.D.	Median	Range	N	Range Factor
Mecury[a]					
San Pablo Bay					
Basin	0.38±0.16	0.35	0.16-0.74	33	4.6
Mare Island Strait	0.35±0.01	0.31	0.23-0.49	25	2.1
Central Bay					
Basin	0.31±0.08	0.30	0.09-0.73	105	8.1
All Peripheral sites	0.63±0.47	0.51	0.19-1.90	18	10.0
San Francisco Bay (all)	0.40±0.25	0.33	0.09-3.22	311	35.8
Tomales Bay	0.23±0.08	0.23	0.12-0.41	22	3.4
Bodega Head	0.21±0.10	0.18	0.09-0.45	22	5.0
Cadmium[b]					
San Pablo Bay					
Basin	10.83±7.77	9.90	2.4-34.4	33	14.3
Mare Island Strait	4.81±2.49	3.90	2.2-10.9	24	5.0
Central Bay					
Basin	6.10±2.2	5.60	1.8-15.0	105	8.3
All Peripheral sites	5.19±2.23	5.31	1.4-10.8	18	7.7
San Francisco Bay (all)	7.41±4.39	6.00	0.8-34.4	332	43.0
Tomales Bay	3.86±1.43	3.70	1.7-7.2	37	4.2
Bodega Head	9.71±3.27	9.50	2.5-16.3	53	6.5
Copper[b]					
San Pablo Bay					
Basin	11.33±5.69	9.65	5.3-30.7	24	5.8
Mare Island Strait	14.19±4.13	14.60	8.74-19.5	6	2.2
Central Bay					
Basin	9.23±1.92	9.20	4.9-15.0	105	3.1
All Peripheral sites	8.86±3.24	8.00	5.1-16.2	18	3.2
San Francisco Bay (all)	10.02±3.64	9.40	2.2-30.7	305	14.0
Tomales Bay	9.36±4.36	7.75	3.8-22.3	28	5.9
Bodega Head	6.51±2.23	6.10	2.1-13.7	53	6.5
Lead[b]					
San Pablo Bay					
Basin	2.45±1.92	2.15	1.1-10.4	32	9.5
Mare Island Strait	2.89±2.85	1.85	<0.1-11.8	24	118.0
Central Bay					
Basin	7.57±35.5	3.7	1.0-366.4	105	366.4
All Peripheral sites	30.62±122.0	<0.2	<0.2-519.2	18	2596.0
San Francisco Bay (all)	6.23±34.9	2.9	<0.2-519.2	331	2596.0
Tomales Bay	0.41±0.56	<0.2	0.4-3.1	36	7.8
Bodega Head	0.93±0.38	0.9	0.3-2.2	53	7.3

Table 2.29. (contd)

Metals	Mean ± S.D.	Median	Range	N	Range Factor
Chromium[b]					
San Pablo Bay					
Basin	2.79±1.28	2.15	1.5-6.1	16	4.1
Mare Island Strait	5.58±2.53	5.58	3.8-7.4	2	1.9
Central Bay					
Basin	1.92±1.20	1.90	0.1-6.5	105	6.5
All Peripheral sites	5.33±4.29	3.45	0.8-14.7	18	18.4
San Francisco Bay (all)	2.72±2.30	2.20	0.1-14.8	288	148.0
Tomales Bay	0.71±1.11	<0.1	0.7-3.9	28	5.6
Bodega Head	2.05±1.11	1.73	0.9-6.6	23	7.3
Silver[b]					
San Pablo Bay					
Basin	0.37±0.23	0.40	0.02-1.1	33	55.0
Mare Island Strait	0.41±0.13	<1.0	0.08-<1	24	11.2
Central Bay					
Basin	1.00±1.05	0.90	0.03-1.9	103	63.3
All Peripheral sites	0.11±0.15	<0.1	0.03-0.61	18	20.3
San Francisco Bay (all)	0.97±1.94	0.64	0.02-22.5	317	1125.0
Tomales Bay	0.20±0.27	<0.1	0.03-1.3	37	43.3
Bodega Head	0.14±0.11	0.11	0.02-0.7	53	35.0

(a) 1973 to 1986.
(b) 1971 to 1986.

2.5 OVERVIEW OF FISH HISTOPATHOLOGY DATA

Demersal fish, which are either in frequent physical contact with sediments or feed on benthic prey, receive a relatively high exposure to mixtures of sediment-associated chemicals in contaminated areas (Long et al. 1988). Hence, demersal fish are thought to be reasonable integrators of contaminant exposure throughout their migratory range. Exposure to certain chemicals is known to induce cancerous growths and other pathological and histopathological disorders in fish (Long et al. 1988). Consequently, histopathological examinations of tissue lesions in fish have become a standard practice in many regional pollution assessments. The following brief summary of fish histopathology data for San Francisco Bay draws heavily on the more thorough review by Long et al. (1988).

2.5.1 English Sole

In 1953, Hesteroff found a 16% to 32% prevalence in trawls from Central Bay (in Kelly 1971). Cooper and Keller (1969) examined 15,739 English sole during a year-long study (1965 to 1966) and found that the prevalence of tumors among Central Bay fish was nearly twice that of the South Bay fish: 15.5% versus 8.9%. Kelly (1971) collected over 5000 fish during 1969 to 1970 and found a 9.65% incidence in a Central Bay site, and an incidence of only 1.7% at a more northerly site. He also noted a clear tendency for smaller fish in shallow water to have a higher prevalence of tumors than older fish in deeper waters: 13% of fish in 1 to 1.5 fathoms versus 5.7% of fish in 1.5 to 2.0 fathoms. No tumors were found in fish captured in 4 to 6 fathoms of water. Given the differences among sampling designs of these studies, Long et al. (1988) conclude that rigorous testing of the data to assess temporal trends was not possible.

2.5.2 Starry Flounder

From 1982 through 1987, NOAA supported research performed by the Lawrence Livermore National Laboratory on the effects of organic contaminants in the Bay on the reproductive system of starry flounder. Spies et al. (1985a, 1985b, 1988) provide strong evidence that lipid-soluble organic contaminants had sublethal effects on the reproductive success of starry flounder. Laboratory-spawned females captured at variously-contaminated sites showed a highly significant negative relationship between hepatic mixed-function oxidase (MFO) activity and fertilization success. Environmental induction of MFO activity by xenobiotic contaminants is apparently widespread in coastal fish populations of North America. MFO activity in the liver is a measure of the enzymatic response of the fish to organic pollutant exposure, and it is inducible by xenobiotic contaminants. Bay sediments are extensively contaminated with xenobiotic compounds, including PAHs, PCBs, phthalates, and benzthiazole-2 (4-mopholinyl), which can accumulate in fish tissues. The results of these studies suggested the following: 1) that there is a direct toxic (sublethal) effect of chlorinated biphenyls on both fertilization success and viable hatching of flounder eggs (Spies et al. 1985a, 1985b), 2) that some females living in contaminated conditions may experience complete reproductive inhibition (Spies et al. 1988), 3) that concentrations of PCBs in spawned eggs were good predictors of embryological success (Spies et al. 1988), 4) that immunoassays for P-450E could be incorporated into NOAA's NS&T program as a sensitive and potentially inexpensive measure of the biochemical response of fishes to contaminants (Spies et al. 1988), 5) that starry flounder collected in Oakland Outer Harbor had greater liver concentrations of PCBs and PAHs than those collected at a site in northern San Pablo Bay or Central Bay near Berkeley (Spies and Rice 1988), 6) that gamete viability, zygote formation, and embryological development decrease with increasing hepatic MFO activity of spawning females (Spies and Rice 1988), and 7) that reproductive problems may be associated with only moderate environmental concentrations of chlorinated hydrocarbons. Thus, the xenobiotic compounds accumulated in the Bay had, and may continue to have, measurable effects on starry flounder reproductive and development processes (Spies et al. 1988b).

2.5.3 White Croaker

Based on data collected by the Benthic Surveillance Project (NOAA 1987), the prevalence of proliferative disorders of the kidney in white croaker was 3% at Southhampton Shoal, 10% at Oakland, and about 7% at Bodega Bay. Since no other studies have been conducted, insufficient data presently exist to determine potential temporal trends in histopathological conditions in white croaker.

2.5.4 Summary

A major implication of these histopathological studies relative to the JFBSC is that better sediment contamination information is needed as a measure of the potential impacts on reproductive success of demersal fish populations. Few consistent statistical relationships between sediment chemistry and histopathological disorders have been demonstrated, largely because demersal fish are mobile and thus exposed to numerous, synergistic and potentially adverse, stimuli. Histopathological disorders may be the result of environmental factors other than bulk chemistry that have not yet been adequately researched.

3.0 IDENTIFICATION OF CONTAMINANTS OF CONCERN

The preceding sections of this report identified potential sources of contamination to JFBSC sediments and presented an overview of sediment chemistry, sediment toxicity, and bioaccumulation studies that have been performed on sediments either within or in the vicinity of the West Richmond, Pinole Shoal, and Carquinez Strait reaches of the Channel. This section provides a summary of contaminants that are potentially present in JFBSC sediments and identifies contaminants that, because of their concentration and/or toxicological importance, are judged to be of particular concern.

The following studies presented sediment chemistry and toxicity data that were judged to be relevant for examining the potential toxicological importance of JFBSC sediments:

Sediment Chemistry:

- USACE (1979)
- USACE (1970 to 1983, unpublished dredging data sheets)
- Long et al. (1988)
- E.V.S. (1989)
- Word and Kohn (1990)
- Kohn et al. (1991)

Sediment Toxicity:

- Long et al. (1988)
- E.V.S. (1989)
- Long and Markel (1992)

Because of the variable nature of dredged materials, the Green Book specifies that contaminants of concern be identified on a case-by-case basis. Contaminants specifically addressed in §227.6 of the Ocean Dumping Regulations must be considered as part of this evaluation. These contaminants are organohalogen compounds; mercury or mercury compounds; cadmium or cadmium compounds; oil of any kind or in any form; known carcinogens, mutagens or teratogens or materials suspected to be carcinogens, mutagens, or teratogens by responsible scientific opinion. Other contaminants to be included are those that might reasonably be expected to cause an unacceptable adverse impact if the dredged material in question were placed in the ocean. Contaminants of concern are further identified on the basis of their concentration in dredged materials relative to their concentration in reference sediments, toxicological importance, persistence in the environment, and propensity to bioaccumulate.

A list of potential contaminants in JFBSC sediments is presented in Table 3.1. This list includes contaminants that have been verified in JFBSC sediments as well as those that might reasonably be expected to be present based on current and historical sources of contaminant loading. Contaminant sources that are likely to be of importance relative to JFBSC sediments, have been summarized in the preceding sections of this report.

Table 3.2 presents a list of contaminants of concern within the West Richmond, Pinole Shoal and Carquinez Strait reaches of the Channel. This list is based on sediment analysis conducted in 1989 (Word and Kohn 1990) and 1990 (Kohn et al. 1991) by Battelle/Marine Sciences Laboratory. All of the contaminants in this table have verified concentrations that are at least two to four times higher than concentrations of the same contaminants in reference sediments (i.e., typical shale sediment, Point Reyes coarse and fine sediments). Ten metals (Ag, As, Cu, Cr, Hg, Ni, Pb, Se, Tl, and Zn), oil and grease, petroleum hydrocarbons, PAHs, PCBs, pesticides and organotin are included on this list.

Elevated concentrations of metals were detected in sediments throughout the Channel. Cu, Zn, Ni, and Cr were the four metals most often found at elevated concentrations. Over 80% of the stations sampled had elevated levels of at least one of these metals. Ag was also widely distributed, with 32 out of 53 stations reporting elevated concentrations. Hg was found at elevated concentrations at 7 out of 9 stations in Carquinez Strait, 16 out of 30 stations in Pinole Shoal, and 7 out of 14 stations in West Richmond. Concentrations of Cd at most stations were generally below levels found in reference sediments.

Word and Kohn (1990) found good agreement between sediment metal concentrations and TOC, although they identified several metals that were found at higher than expected levels based on sediment organic matter concentrations. Ag was enriched in the lower 4 ft to 8 ft of sediment at West Richmond station WR IV.5 C and As, Pb, and Zn were found at elevated concentrations within the upper 4 ft to 6 ft of sediment in West Richmond stations WR V L, WR IV.5C, and WR IV R. In the central portion of Pinole Shoal, the upper 5 ft to 8 ft of sediment at stations P VI L and P VIII R were identified as having metal concentrations that were consistently higher than sediments in the surrounding area. Sediments from northeastern Pinole Shoal were shown to have generally higher levels of most metals, with the highest concentrations of As, Hg, and Al found at stations near the opening of Carquinez Strait.

Word and Kohn (1990) used a model based on partitioning coefficients to predict potential water column concentrations of As, Ag, Pb, and Zn from their concentrations in sediment. They reported that maximum predicted water column concentrations for each of the metals would not be expected to exceed the corresponding 4-day average EPA Goldbook Criteria for acute toxicity. However, they concluded that sediment metal concentrations at selected stations in Carquinez Strait and the central and northeastern sections of Pinole Shoal, were high enough to pose a risk to sensitive marine organisms. Word and Kohn (1990) recommend that toxicity testing be performed to determine the bioavailable fraction of sediment metals.

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TABLE 3.1. Potential Contaminants in JF Baldwin Sediments

Contaminant	Reference
West Richmond	
Ag	Word & Kohn (1990), Davis et al. (1991), USACE (1973), Long et al. (1988), USACE [a]
As	Word & Kohn (1990), Kohn et al. (1991), Davis et al. (1991)
Cd	Long et al. (1988)
Cu	Word & Kohn (1990), Kohn et al. (1991), Davis et al. (1991), USACE (1973), Long et al. (1988)
Cr	Word & Kohn (1990), Kohn et al. (1991), Davis et al. (1991), Long et al. (1988)
Hg	Word & Kohn (1990), Davis et al. (1991), Long et al. (1988)
Ni	Word & Kohn (1990), Kohn et al. (1991), Davis et al. (1991)
Pb	Word & Kohn (1990), Kohn et al. (1991), Davis et al. (1991)
Se	Word & Kohn (1990)
Zn	Word & Kohn (1990), Davis et al. (1991)
Oil and Grease	Word & Kohn (1990)
PH	Word & Kohn (1990)
PAH	Word & Kohn (1990), Long et al. (1988)
Pesticides	Long et al. (1988)
PCB	Long et al. (1988)
Organotin	Word & Kohn (1990)
Pinole Shoal	
Ag	E.V.S. (1989), Word & Kohn (1990), Davis et al. (1991), Long et al. (1988)
As	E.V.S. (1989), Word & Kohn (1990), Davis et al. (1991)
Cd	E.V.S. (1989), Davis et al. (1991), USACE (1973), Long et al. (1988)
Cu	E.V.S. (1989), Word & Kohn (1990), Davis et al. (1991), USACE (1973), Long et al. (1988)
Cr	E.V.S. (1989), Word & Kohn (1990), Davis et al. (1991), Long et al. (1988)
Hg	E.V.S. (1989), Word & Kohn (1990), Davis et al. (1991), USACE (1973), Long et al. (1988)
Ni	Word & Kohn (1990), Davis et al. (1991)
Pb	E.V.S. (1989), Word & Kohn (1990), Davis et al. (1991), USACE (1973), Long et al. (1988)
Se	E.V.S. (1989), Word & Kohn (1990)
Tl	Word & Kohn (1990)
Zn	E.V.S. (1989), Word & Kohn (1990), USACE (1973)
Oil and Grease	E.V.S. (1989), Word & Kohn (1990), USACE (1973)
PH	Word & Kohn (1990)
PAH	E.V.S. (1989), Word & Kohn (1990)
Pesticides	E.V.S. (1989), Word & Kohn (1990)
Organotin	E.V.S. (1989), Word & Kohn (1990)

TABLE 3.1. (contd)

Contaminant	Reference
Carquinez Strait	
Ag	Word & Kohn (1990), Davis et al. (1991), Long et al. (1988)
As	Word & Kohn (1990), Davis et al. (1991)
Cd	Davis et al. (1991), Long et al. (1988)
Cu	Word & Kohn (1990), Davis et al. (1991), Long et al. (1988)
Cr	Word & Kohn (1990), Davis et al. (1991), Long et al. (1988)
Hg	Word & Kohn (1990), Davis et al. (1991), Long et al. (1988)
Ni	Word & Kohn (1990), Davis et al. (1991)
Pb	Word & Kohn (1990), Davis et al. (1991), Long et al. (1988)
Se	Word & Kohn (1990)
Tl	Word & Kohn (1990)
Zn	Word & Kohn (1990), Davis et al. (1991)
Oil and Grease	Word & Kohn (1990)
PH	Word & Kohn (1990)
PAH	Word & Kohn (1990)
Pesticides	Word & Kohn (1990)
Organotin	Word & Kohn (1990)

TABLE 3.2. Summary of Contaminants of Concern at Individual Sampling Locations Within the JFBSC (Data are from Word and Kohn 1990 and Kohn et al. 1991)

West Richmond	Depth (ft)	Contaminant[a]
Word and Kohn		
WR VII C	0-5.5	Cr, Cu, Hg, Pb, Se, Zn, **PAH**
WR VI L	0-4	Ag, Cu, Hg, Zn, O&G[b], PH, **PAH**
WR V L	0-6	**Ag**, Cr, Cu, Hg, Ni, Pb, Zn, O&G, PH, **PAH**
WR IV.5 C	0-4	**Ag**, Cr, **Cu**, **Hg**, Ni, Pb, Zn, **O&G**, PH, **PAH**
WR IV.5 C	4-8	As, Cu, Ni
WR IV R	0-6	**Ag**, Cr, **Cu**, **Hg**, Ni, **Pb**, Zn, **O&G**, **PH**, **PAH**
WR IV R	6-11.5	Ag, Cr, Cu, Ni, Zn, **PAH**
WR III L	0-6.6	Cr, Cu, Ni, Zn, O&G
WR III C	0-6.4	Cr, Cu, Ni
WR II L	0-6.9	Cr, Cu, Hg, Ni, Zn
WR I R	0-5.1	**Ag**, Cr, Cu, Hg, Ni, Pb, Zn, **O&G**, PH, **PAH**
Kohn et al.		
WR-A		Cu
WR-B		Cr, Cu
WR-C		As, Cr, Cu, Ni
WR-D		Cu
WR-E		Cu
Pinole Shoal		
P I C	0-3	Ag, Cu, Ni, Zn, O&G
P II C	0-4.3	Ag, **Cu**, Ni, Zn
P III L	0-3	Ag, Cr, **Cu**, Ni, Se, Zn, O&G
P IV R	0-8	Ag, Cr, Cu, Ni, Tl, Zn
P V L	0-8.4	**Ag**, Cr, **Cu**, Hg, Ni, Pb, Zn, O&G, PH
P V C	0-8.7	Ag, Cr, **Cu**, Ni, Zn
P V R	0-5	Ag, As, Cr, **Cu**, Hg, Ni, Zn, O&G
P V R	5-10.5	Ag, Cr, **Cu**, Ni, Se, Zn, **O&G**
P VI L	0-5	**Ag**, As, Cr, **Cu**, **Hg**, Ni, Pb, Zn, **O&G**
PVI L	5-11.6	Ag, Cr, **Cu**, Ni, Zn, O&G, PH, **PAH**
P VI C	0-9	Ag, Cr, Cu, Ni, Tl, Zn
P VI R	0-5	Ag, Cr, **Cu**, Hg, Ni, Pb, Zn, O&G
P VI R	5-11.7	Ag, Cr, **Cu**, Ni, Tl, Zn
P VII C	0-5	Ag, Cr, **Cu**, Hg, Ni, Pb, Zn, **O&G**
P VII C	5-10.1	Cr, Cu, Ni, Zn, O&G
P VIII L	0-6.6	**Ag**, Cr, **Cu**, Hg, Ni, Pb, Tl, Zn, **O&G**, PH
P VIII L	6.6-9.5	Cr, Cu, Ni
P VIII R	0-8	**Ag**, Cr, **Cu**, Hg, Ni, Pb, Zn, O&G, PH
P VIII R	8-10.5	As, Cr, Cu, Ni, Zn

TABLE 3.2. (contd)

West Richmond	Depth (ft)	Contaminant[a]
Pinole Shoal		
P VIII.5 C	0-3.6	Cr, Cu, Ni, Zn, O&G
P VIII.5 C	3.6-10.4	Cr, Cu, Ni, Zn
P IX C	0-5	Cr, Cu, Ni, Zn
P IX C	5-11.8	Cr, Cu, Ni
P IX.5 L	0-5	Cr, Cu, Ni, Zn
P IX.5 L	5-10.1	Cr, Cu, Ni
P X R	0-6	Cr, Cu, Ni, Zn
P X R	6-11.5	As, Cr, Cu, Ni, Zn
P X.5 C	0-5	Cr, Cu, Ni, Zn
P X.5 C	5-11	Cr, Cu, Ni
P XI L	0-3.5	Ag, Cr, **Cu**, Ni, Zn
P XII R	0-8.5	Cr, **Cu**, Hg, Ni, Tl, Zn
P XII RR	0-9.2	Ag, As, Cr, **Cu**, Hg, Ni, Zn, O&G
P XII B2	0-2	Cr, Cu, Ni, Pb, Zn
P XII B2	2-7.5	Ag, As, Cr, **Cu**, **Hg**, Ni, Se, Zn, O&G
P XII B2	7.5-12.5	Ag, Cr, **Cu**, Ni, Zn
P XII B1	0-5	**Ag**, As, Cr, **Cu**, Hg, Ni, Pb, Zn, **O&G**, **PH**
P XII B1	5-11.1	Cr, **Cu**, Ni, Se, Zn, **O&G**
P XII.5 C	0-6	Ag, As, Cr, **Cu**, **Hg**, Ni, Pb, Zn
P XII.5 R	0-5.3	Ag, As, Cr, **Cu**, **Hg**, Ni, Pb, Zn
PXII.5 R	5.3-11.1	Cr, **Cu**, Ni, Zn
P XIII L	0-6	Ag, As, **Cu**, **Hg**, Ni, Pb, Zn
P XIII R	0-5	Ag, As, **Cu**, **Hg**, Zn
P XIII R	5-10	Ag, As, Cr, **Cu**, **Hg**, Ni, Tl, Zn
P XIV C	0-4.5	Ag, As, Cr, **Cu**, **Hg**, Ni, **Pb**, Zn, O&G, **PAH**
Carquinez Strait		
CB 1	0-6.6	Ag, As, Cr, **Cu**, **Hg**, Ni, Pb, Tl, Zn, O&G
C I R	0-8	**Ag**, As, **Cu**, **Hg**, Ni, Pb, Tl, Zn
CB 4 A	0-3.8	**Ag**, As, Cr, **Cu**, Hg, Ni, Pb, Se, Zn, **O&G**, PH, **PAH**
CB 4 A	3.8-11.4	Ag, As, Cr, **Cu**, **Hg**, Ni, Zn
CB 5	0-4	Cr, Cu, Ni, Zn
CB 6	0-6.5	**Ag**, As, Cr, **Cu**, **Hg**, Ni, **Pb**, Zn, **PAH**
CB 7	0-3.1	**Ag**, As, Cr, **Cu**, Hg, Ni, Pb, Se, Zn, **O&G**, PH, **PAH**, TBT
C II C	0-4	
C II C	4-6.8	As, Cr, Cu, Hg, Ni, Pb, Zn, O&G, PH
C II R	0-2.4	As, **Cu**, **Hg**, Zn

(a) All contaminants listed exceeded reference sediment (shale, Point Reyes coarse and fine sediment) concentrations by a factor of two. Contaminants in bold exceeded reference concentrations by a factor of four.

(b) Oil and grease.

PAHs were detected in sediments from all regions of the Channel; however, concentrations in West Richmond sediments were greatly elevated relative to that of either Carquinez Strait or Pinole Shoal. Concentrations of PAHs were either not detected or very low in the southwestern portion of Pinole Shoal. Only two stations from central Pinole Shoal and two stations from berthing areas in northeastern Pinole Shoal had detectable levels of PAHs. Sediments collected in West Richmond during 1989 contained levels of total PAH that were from 9 to over 300 times higher than stations from Carquinez Strait and Pinole Shoal. Stations in the southern portion of West Richmond contained both low and high molecular weight PAHs. LPAHs were sequentially lost in the northern sections of the channel. Word and Kohn (1990) suggest that an unweathered source of petroleum hydrocarbons may be present in the vicinity of station WR VII. Additional sampling of stations in West Richmond during 1990 did not detect PAHs in sediments. Stations sampled in 1990 were located approximately 1000 ft to 2000 ft east of the 1989 stations. Kohn et al. (1991) conclude that while concentrations of PAHs in sediments collected during 1990 do not represent a significant hazard, there is reason to believe that dredging could have a negative impact on marine life if the source of PAHs in the 1990 sediments is still active. Concentrations of PAHs reported by Word and Kohn (1990) warrant further testing of sediments in the West Richmond section of the Channel.

Although pesticides and PCBs were considered to be likely contaminants in JFBSC sediments, they were undetected by Word and Kohn (1990) and Kohn et al. (1991). E.V.S. (1989) did not detect PCBs and only reported low concentrations of three chlorinated pesticides in Pinole Shoal sediments. Organotin concentrations were low or not detected in Pinole Shoal sediments, except for an area within the Channel approximately due north of Pinole Pt. where concentrations of dibutyltin and tributyltin, respectively, of 0.011 mg/kg dry weight and 0.027 mg/kg dry weight were reported (E.V.S. 1989). Word and Kohn (1990) report non-detectable to low levels of organotins in sediments from West Richmond and Pinole Shoal, but slightly elevated concentrations in Carquinez Strait. Using the Valkirs et al. (1986) formulation, they predict that water column concentrations of tributyltin could reach 8% and 25%, respectively, of the acute and chronic marine water quality criteria values. They conclude that levels of tributyltin in sediments of at least one berthing area (CB 7) may be high enough to contribute to toxicity or bioaccumulation.

Information on bioavailability and the relative bioaccumulation potential of sediment contaminants from the JFBSC is generally lacking. While bioassays have been performed on sediments from many regions of Central Bay and San Pablo Bay, only one study (i.e., E.V.S. 1989) has presented toxicity data where potential dredged material from the JFBSC was evaluated. This study conducted mussel larvae bioassays using sediments from two sites in the central region of the Pinole Shoal Channel. Moderate toxicity (EC50= 50.9% v/v) was reported at one of the sites, while the percentage of abnormal larvae at the other site did not differ significantly from reference sediments.

A number of contaminants of concern have been found in Channel sediments at elevated concentrations relative to reference areas. The presence of these contaminants, coupled with the fact that uncertainty exists regarding their bioavailability and bioaccumulation potential, leads to the conclusion that further testing of Channel sediments is required. Further testing of sediments is needed for areas within Carquinez Strait, Pinole Shoal, and West Richmond. Testing should include sediment analysis for chemicals of concern, Tier III solid phase and suspended sediment toxicity testing, and bioaccumulation testing for chemicals of concern. The chemicals of concern are conventional parameters (TOC, grain size, oil and grease, petroleum hydrocarbons, and ammonia), metals (Ag, As, Cr, Cu, Hg, Ni, Pb, Se, Tl, and Zn), PAHs (16 EPA priority pollutants), and organotins. A cursory evaluation of pesticides and PCBs should also be performed.

4.0 DETERMINATION OF COMPLIANCE

Existing physical, chemical, and biological data on sediments proposed for dredging from the JFBSC have been compiled in Section 2 of this report. Section 3 identified contaminants that, because of their concentration and/or toxicological importance, have the greatest potential to adversely impact sensitive marine life. The purpose of this section is to determine whether sufficient information exists to determine compliance with the limiting permissible concentration (LPC).

Sediments that meet one or more of the following criteria are considered environmentally acceptable for ocean disposal without further testing:

1) dredged material is composed predominantly of sand, gravel, rock, or any other naturally occurring bottom material with particle sizes larger than silt, and the material is found in areas of high current or wave energy such as streams with large bed loads or coastal areas with shifting bars and channels; or

2) dredged material is for beach nourishment or restoration and is composed predominantly of sand, gravel, or shell with particle sizes compatible with material on the receiving beaches; or

3) when - (i) The material proposed for dumping is substantially the same as the substrate at the proposed disposal site, and (ii) The site from which the material proposed for dumping is to be taken is far removed from known existing and historical sources of pollution so as to provide reasonable assurance that such material has not been contaminated by such pollution.

Sediments that would be removed during Phase III improvements to the JFBSC fail to meet the exclusionary criteria outlined above. The first criterion is not met because fine-grained sediments comprise a significant fraction of the bottom material in some areas of the Channel, and because this material is not exposed to high current or wave energy. Dredged material from the JFBSC is not being proposed for beach nourishment; therefore, the second criterion is not met. JFBSC sediments do not meet the third criterion because, although they may be substantially similar to substrates at several of the proposed disposal sites, they are from an area that historically experienced loading of contaminants, which toxicology studies have shown have the potential to result in acute toxicity or significant bioaccumulation.

Sufficient information on contaminant concentrations in JFBSC sediments exists to conclude that dredged materials from the Channel may pose a risk to sensitive marine organisms. Information on persistence, bioavailability, and relative bioaccumulation potential are lacking; therefore, additional testing of sediments under Tier III is warranted.

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APPENDIX

DEFINITIONS OF ACRONYMS AND ABBREVIATIONS

AHI	Aquatic Habitat Institute
BADA	Bay Area Dischargers Association
BCDC	San Francisco Bay Conservation and Development Commission
BOD	biological oxygen demand
CRWQCB	California Regional Water Quality Control Board
CCC	California Coastal Commission
CDFG	California Department of Fish and Game
COD	chemical oxygen demand
CVRWQCB	Central Valley Regional Water Quality Control Board
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
DDD	dichlorodiphenyldichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorophenyltrichlorethane
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FONSI	Finding of No Significant Impact
FWCA	Fish and Wildlife Coordination Act
IRIS	Incident Reporting Information System
JFBSC	JF Baldwin Ship Channel
km	kilometer
L	liter
LPC	Limiting Permissible Concentration
m	meter
mg	milligrams
MLLW	Mean Lower Low Water
MPRSA	Marine Protection, Research, and Sanctuaries Act
NCP	National Contingency Plan
NEP	National Estuary Program
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NS&T	National Status and Trends
NURP	National Urban Runoff Program
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SFEP	San Francisco Estuary Project
SLC	State Lands Commission
TKN	total kjeldahl nitrogen
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TVS	total volatile solids
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
V/V	volume to volume
WQA	Water Quality Act
WQC	water quality criteria

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