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Review of Sediment Quality Investigations in San Francisco Bay

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Glossary of Acronyms

AVS	Acid Volatile Sulfides
BADA	Bay Area Dischargers Association
BOD	Biochemical Oxygen Demand
BPTCP	Bay Protection and Toxic Cleanup Program
CMBAD	Coastal Monitoring and Bioeffects Assessment Division
DFG	California Department of Fish and Game
DOC	Dissolved Organic Carbon
EA	Ecological Assessment
EIS	Environmental Impact Statement
ERA	Environmental Risk Assessment
IAS	Initial Assessment Study
km	Kilometer
LEMP	Local Effects Monitoring Program
ml	Milliliter
NAS	Naval Air Station
NBSP	National Benthic Surveillance Project
NMFS	National Marine Fisheries Service
NS&T	National Status and Trends Program
NSY	Naval Ship Yard
NOAA	National Oceanic and Atmospheric Administration
NWS	Naval Weapons Station
RI	Remedial Investigation
RI/FS	Remedial Investigation/Feasibility Study
SEM	Simultaneously Extracted Metals
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SFEI	San Francisco Estuary Institute
SWRCB	State Water Resources Control Board
TOC	Total Organic Carbon
TPH	Total Petroleum Hydrocarbons
USGS	United States Geological Survey

EXECUTIVE SUMMARY

For decades human activities have substantially influenced the physical, biological, and chemical character of the San Francisco Bay/Sacramento-San Joaquin Delta estuary. The rapid growth and development of the entire Bay-Delta watershed since the Gold Rush in the mid-1800s has significantly affected this estuary, the largest on the U.S. Pacific Coast. Effects include an increased loading of anthropogenic contaminants into the estuary from both point and non-point sources. Bay sediments serve as a major repository for these contaminants. Both in the Bay Area and nationally, concern about sediment contamination and how to assess sediment quality has risen as more information becomes available on the potential adverse effects of sediment contamination. These concerns include:

- Various toxic contaminants found only in barely detectable amounts in the water column can accumulate in sediments to much higher levels;
- Sediments serve as both a reservoir for contaminants and a source of contaminants to the water column and organisms;
- Sediments integrate contaminant concentrations over time, whereas water-column contaminant concentrations are much more variable and dynamic;
- Sediment contaminants (in addition to water column contaminants) affect bottom-dwelling organisms and other sediment-associated organisms, as well as both the organisms that feed on them and humans; and
- Sediments are an integral part of the aquatic environment that provide habitat, feeding, spawning, and rearing areas for many aquatic organisms (EPA 1996).

Because of these and other concerns, numerous studies have investigated sediment contamination in San Francisco Bay. These investigations each have had distinct objectives and geographic scopes and have employed a wide variety of sampling methodologies and analytical techniques. Very few studies have taken a comprehensive approach to evaluating contamination throughout the Bay. However, there have been several important surveys or compilations of contaminant data in the Bay published in recent years (Citizens for a Better Environment 1987; Phillips 1987; Long et al. 1988; Davis et al. 1991; Long and Markel 1992). Each of these reports commented on specific gaps in the available contaminant data (e.g., spatial, temporal, quality control, lack of information on specific contaminants), some arguing the need for a comprehensive contaminant database. In 1988, Long et al. reported that "No bay-wide survey and monitoring of contaminants or measures of effects have been conducted recently in the Bay with state-of-the-art methods." Phillips (1987) concluded that "the quality of the existing database which may be employed to elucidate the abundance of contaminants in the Bay-Delta ecosystem is poor." Citizens for a Better Environment concluded in a 1987 report on toxic hot spots in San Francisco Bay: "Many

data have been gathered, but no comprehensive, accurate data base on sediment accumulation and bioaccumulation of toxic pollutants has yet been assembled, nor have the potential effects of toxic hot spots been systematically assessed for the Bay-Delta estuary."

Since these summary reports were produced, many more studies have been completed (e.g., investigations for military base closures, hazardous waste site assessments, dredging projects) and several important monitoring programs have been developed and begun collecting data. This report summarizes the sources for sediment contaminant data for the San Francisco Bay since the mid-1980s, focusing on long-term Bay-wide monitoring programs. Some site-specific investigations covering single event sampling investigations, including six hazardous waste sites, are also summarized. Sediment source documents organized by embayment are listed in tables in Appendix A and provide information on the type of data in each document. Appendix B provides the reference list organized by embayment, documents are sorted alphabetically in Appendix C. Maps showing sampling station locations for eight of the bay-wide sediment investigations are in Appendix E. Documents that discuss or synthesize sediment studies in the Bay, but do not contain original data, are listed in Appendix D. The document is intended to serve as a quick reference for those seeking information on the current status and sources of sediment contaminant data for San Francisco Bay, providing a tool for understanding the health of this important natural resource.

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INTRODUCTION

The San Francisco Bay/Sacramento-San Joaquin Delta estuary is the largest estuary on the Pacific Coast of the United States, with a surface area of 1,240 square km (Figure 1). The estuary consists of two distinct regions: the Sacramento-San Joaquin Delta and San Francisco Bay. San Francisco Bay can be divided into two major circulatory systems: the southern reach, or South Bay, and the northern reach, or North Bay, which consists of Suisun Bay, San Pablo Bay, and the Central Bay. Suisun Bay is a shallow embayment between Chipps Island, at the western boundary of the Delta, and the Benicia-Martinez Bridge. San Pablo Bay is a large, open bay that extends from the Carquinez Strait to the San Pablo Strait near the Richmond-San Rafael Bridge. For purposes of this report, San Pablo Bay includes Carquinez Strait. Central Bay is typically considered the portion of the Bay bounded by the San Pablo Strait to the north, the Golden Gate Bridge to the west, and the Oakland-San Francisco Bay Bridge to the south. The South Bay is generally considered all the Bay south of the Oakland-San Francisco Bay bridge. The Delta is a vast interconnecting maze of channels where the Sacramento and San Joaquin rivers mix. These rivers drain more than 40 percent of the entire state of California. This report focuses on San Francisco Bay and does not address sampling and investigations carried out primarily in the Delta.

The major distinction between the North and South bays is that the North Bay receives considerable freshwater inflow from the Delta. The South Bay receives very little freshwater and functions more like a large lagoon. Freshwater inflow in the North Bay meets the bottom-flowing oceanic water in the region between Chipps Island in the western Delta and San Pablo Bay, depending upon the amount of inflow. This interface region is referred to as the null zone and supports a significant phytoplankton-zooplankton food web. Occasional freshwater cells move into the South Bay from the North Bay in the winter. In the summer, however, the major freshwater source for the South Bay is treated domestic effluent. The salinity of the North Bay varies considerably and increases along a gradient from the Delta to Central Bay, whereas salinities in the South Bay remain at near-ocean conditions much of the year. Much of the bottom of the South Bay is covered with soft mud, a mixture of material with more than 80 percent silt and clay. Coarse, sandy sediments predominate in the Central Bay. Most of the bottom of San Pablo Bay is covered by fine mud carried out of the Delta during high winter flows. The bottom of Suisun Bay is nearly all mud.

The estuary supports an extremely diverse and productive ecosystem, providing habitat for hundreds of species of phytoplankton, zooplankton, benthos, and fishes. The estuary also supports many important economic activities, including commercial and recreational fishing, shipping, industry, agriculture, recreation, and tourism. Since the discovery of gold in the Sierra Nevada in the mid-1800s, human activities have substantially changed the estuary. The enormous economic development and land use changes in the Bay Area and Delta since the Gold Rush has considerably degraded some habitat and destroyed others.

Additionally, an increased loading of anthropogenic contaminants is potentially harmful to the Bay's biota. These contaminants continue to enter the Bay from a variety of sources, including municipal and industrial effluent, urban runoff, non urban/agricultural runoff, major tributaries, dredging and disposal of dredged material, atmospheric deposition, spills, and discharge from boats. One major sink for these contaminants is the sediments at the bottom of the estuary's embayments and nearby sloughs, channels, and wetlands. Concerns over the potentially harmful effects of these contaminants on the estuary's biota and overall ecosystem have prompted investigations on the anthropogenic contaminant loading to the Bay.

Purpose

This report:

- Presents a compilation of sources for recent sediment chemistry data (1985-present) collected in San Francisco Bay, organized by responsible agency or organization;
- Summarizes the major sediment monitoring programs that are active in the Bay, including information on contacts and availability of electronic datasets. Along with this report, NOAA is developing an electronic database that includes data from several of the more comprehensive investigations. Tables in the report (Appendix A) that summarize the investigations also indicate whether the data are included in the NOAA database. NOAA expects to make the database available once quality control checks are complete;
- Provides as complete a list as possible, in bibliographic form, of references for sediment investigations in the Bay since the mid-1980s from a variety sources, ranging from individual studies with a narrow focus to large-scale studies, including remedial investigations at a selected number of hazardous waste sites;
- Provides summary information (e.g., geographic scope of investigation, sampling locations, analytes) in tables on as many of the investigations as were available for review;

- Provides maps of sampling locations for the major monitoring programs and selected investigations.

This report focuses on data collected since the mid-1980s. For analysis of long-term contaminant trends, historical data from numerous sediment investigations conducted in the Bay are available for review (Long et al. 1988). Comparing data collected at different times by different groups should be done carefully. Because studies were done for different purposes, comparisons between different investigations may be inappropriate if they used different sampling methodologies, analytical techniques, detection limits, and quality control or assessment procedures. Therefore, when comparing data from different investigations it is critical to review the original documents to determine what procedures were used, and whether the planned comparisons are appropriate.

Organization

This report is organized to provide the collected information on sediment contaminant data and sources in the Bay in a variety of ways to enhance the report's utility for a variety of users, though it is primarily intended for internal use by NOAA.

- Section 1 provides information on the major long-term bay-wide monitoring programs, organized by the responsible agency. Details are provided on overall design and objectives of the program, sampling and analysis methods used, key contacts, number of sampling locations, etc. Table 1 summarizes this information.

- Section 2 provides information on other major sources of sediment contaminant data from individual studies not part of a bay-wide monitoring program. For instance, this section includes information both on studies conducted by the U.S. Geological Survey and studies conducted at individual hazardous waste sites, such as some of the major Superfund sites in the Bay Area.

- Appendix A contains a table, organized by embayment, which summarizes (e.g., geographic scope, analytes) each of the investigations for which the documents were available for review.

- Appendix B contains the list of references organized by each of the four embayments.

- Appendix C consists of all the documents listed in Appendix A, presented in alphabetical order.

- Appendix D provides a list of documents that do not contain original sediment contaminant data collected in the Bay, but are useful as either compilations or discussions of such data. Many of these documents provide useful analyses of the data and background information on pollutant sources, historical trends, related issues, etc.

- Appendix E provides maps of the sampling locations for the major monitoring programs discussed in Section 1, as well as some other selected investigations.

Some users may be particularly interested in the details (e.g., geographic scope, analytes) for a few specific investigations. The table provided in Appendix A, summarizes all the references we were able to review. Other users may be interested in the recent comprehensive monitoring programs and/or agency involvement (e.g., the Regional Monitoring Program), so we provided additional details in Section 1 on these programs, including maps in Appendix E showing the sampling locations for many of these investigations.

Because we recognize that many users of this document may only be interested in a particular area of the Bay, we organized the document lists by the Bay's four embayments: Suisun Bay, San Pablo Bay, Central Bay, and South Bay. These lists (Appendix B) provide a chronological snapshot of post-1985 sediment contaminant investigations in each of these embayments; the user then can refer to the corresponding table in Appendix A for more information.

Appendix C, which contains an alphabetical list of all the references we could identify that contain recent sediment contaminant data, may be the first place to look for a particular study. (References are coded by geographic location, such as *SuB* for Suisun Bay). The summary documents listed in Appendix D discuss many of the investigations presented elsewhere in this document. These summary documents may be useful for providing an overview of sediment contaminant information in the Bay. These documents contain background information on pollutant sources, historical trends, specific contaminants, and related issues, including some analysis of the existing data.

One of the most important sources of recent sediment contaminant data in the Bay comes from site-specific investigations of hazardous waste sites (often Superfund sites) that have received Federal or state regulatory attention in the form of remedial investigations, ecological risk assessments, etc. To address this source of contaminant information in the Bay, we focused on six of the many sites around the Bay of particular interest to NOAA. Investigations of some of these other sites are included in this document, though a complete list of all of these site-specific investigations was outside the scope of this report. The information provided in Section 2 for the six priority sites investigated (i.e., Hunters Point

Naval Shipyard, Naval Air Station Alameda, Naval Weapons Station Concord, Mare Island Naval Shipyard, Hamilton Army Airfield, and United Heckathorn) could serve as a template for future documentation on other sites.

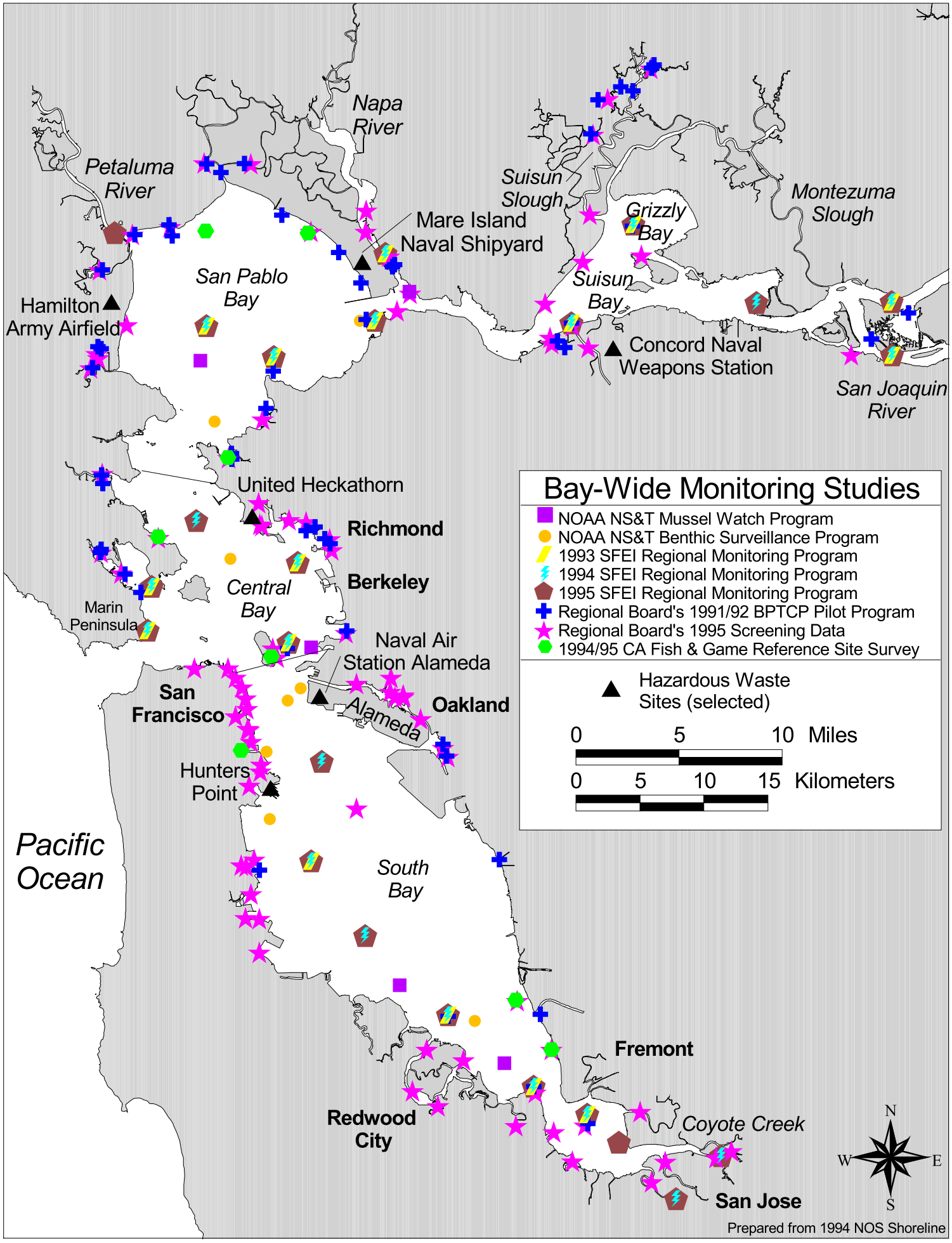

Figure 1. Bay-wide monitoring studies

1 BAY-WIDE SEDIMENT MONITORING PROGRAMS

This section of the report summarizes the contaminant monitoring programs active or recently active in San Francisco Bay that include or included sediment chemistry monitoring as part of the program. These monitoring programs are differentiated from other sources of sediment data in this report because these programs generally sampled throughout the Bay and/or were conducted as part of a long-term, multi-year study of contaminants. Many of these programs involve the participation of several agencies or organizations. This section is organized by the agency primarily responsible for the program. All the programs described in this section are summarized in Table 1.

State Water Resources Control Board (SWRCB) and San Francisco Bay Regional Water Quality Control Board (SFBRWQCB)

In 1989 the California Water Code was amended to create the statewide Bay Protection and Toxic Cleanup Program (BPTCP). The four primary goals of the program are to 1) protect existing and future beneficial uses of bay and estuarine waters; 2) identify and characterize toxic hot spots; 3) plan for the prevention and control of further pollution at toxic hot spots; and 4) develop plans for remedial actions of existing toxic hot spots and prevent new hot spots (SWRCB 1995). Overall management of the BPTCP monitoring activities is provided by the Bays and Estuaries Unit of the State Water Resources Control Board (SWRCB). Expertise in specific analytical techniques and field collection of samples is provided by the California Department of Fish and Game (DFG) and their contracted organizations.

The BPTCP is a comprehensive effort by the SWRCB and the Regional Water Quality Control Boards to link standards development, environmental monitoring, water quality control planning, and site cleanup planning. The program includes seven primary activities:

1 Development and amendment of the California Enclosed Bays and Estuaries Plan. This plan will contain the State's water quality objectives for enclosed bays and estuaries and the implementation measures to attain the objectives.

2 Development and implementation of regional monitoring programs designed to identify toxic hot spots. These monitoring programs include analysis for a variety of chemicals, the completion of a variety of toxicity tests, measurements of biological communities, and various special studies to support the program.

3 Development of a consolidated database that contains information pertinent to describing and managing toxic hot spots.

4 Development of a narrative and numeric sediment quality objectives for the protection of California enclosed bays and estuaries.

5 Preparation of criteria to rank toxic hot spots that are based on the severity of water and sediment quality impacts.

6 Development of regional and statewide toxic hot spot cleanup plans that include identifying and priority ranking of toxic hot spots, identification of pollutant sources, identification of actions already initiated, strategies for preventing formation of new toxic hot spots, and cost estimates for remedial action recommendations.

7 Implementation of a fee system to support all BPTCP activities (SWRCB 1995).

The following information focuses on the sediment monitoring and database development programs associated with the objectives listed above. Two major sampling efforts initiated by the BPTCP in the San Francisco Bay Region will be briefly summarized: the San Francisco Estuary Pilot Regional Monitoring Program, which included sediment sampling in the Bay in 1991 and 1992; and the Bay Protection and Toxic Cleanup Program, which was partly based on the pilot program. Screening sampling for this program began in 1995 and included confirmation sampling in 1996.

Table 1. Summary of recent comprehensive sediment monitoring efforts in San Francisco Bay.

Program	Source/Major Sponsor	Contact(s)	Database Format
S.F. Estuary Pilot Regional Monitoring Program (1991-1992)	State Water Resources Control Board and S.F. Bay Regional Water Quality Control Board	Craig Wilson, SWRCB: 916/657-1108 Karen Taberski, SFBRWQCB 510/286-1346	Oracle at SWRCB Environmental Database; SAS at EcoAnalysis, Inc.
Bay Protection and Toxic Cleanup Program (BPTCP) 1995-97	State Water Resources Control Board and S.F. Bay Regional Water Quality Control Board	Craig Wilson, SWRCB: 916/657-1108 Karen Taberski, SFBRWQCB: 510/286-1346 Rusty Fairey, CDFG: 408/633-6035	dBase at California Department of Fish and Game (CDFG) - Moss Landing
Regional Monitoring Program (RMP) 1993-1995	San Francisco Estuary Institute (SFEI)	Dr. Bruce Thompson 510/231- 9539 Jung Yoon, 510/231-9539	Available from SFEI's World Wide Web page
Bay Area Dischargers Association - Local Effects Monitoring Program	Bay Area Dischargers Association/SFEI	Dr. Bruce Thompson 510/231- 9539 Jung Yoon , 510/231-9539 Jim Salerno, City and County of S.F., 415/648-6882	Excel files, converting to Oracle at SFEI
South Bay Dischargers Association-Local Effects Monitoring Program	South Bay Dischargers Association/SFEI	Dr. Bruce Thompson 510/231- 9539 Jung Yoon, 510/231-9539 Dave Tucker, City of San Jose 408/945-5300.	Excel files, converting to Oracle at SFEI
1994/1995 Reference Site Survey	California Department of Fish and Game/SFBRWQCB	Rusty Fairey, CDFG: 408/633-6035 Karen Taberski 510/286-1346	dBase at CDFG-Moss Landing
National Benthic Surveillance Project (NBSP) of National Status and Trends Program (NS&T)	NOAA/National Marine Fisheries Service	Bruce McCain, NMFS 541/867-0346 Sue Pierce, NMFS 206/860-3304	Available from NOAA's ORCA World Wide Web page; Bruce McCain, NMFS
Mussel Watch of National Status and Trends Program	NOAA/National Marine Fisheries Service	Gunnar Lauenstein, NOAA 301/713-3028 ext. 152	Available from NOAA's ORCA World Wide Web page

San Francisco Estuary Pilot Regional Monitoring Program (1991/92)

Design and Objectives

The primary objective of the study was to develop a pilot project that would serve as a model for future regional monitoring and surveillance programs in the San Francisco Bay estuary and in other bays and estuaries throughout California. Secondary objectives of the study were to obtain data for the development of a list of toxic hot spots for sediments in the San Francisco Bay estuary, sediment quality criteria for the estuary, and baseline concentrations of contaminants in the estuary (SFBRWQCB 1994).

The project consisted of three different sampling efforts designed to identify bay-wide trends for contaminant distributions and toxicity, detect contaminants and toxic effects in marshes that border the bay, and evaluate sediment toxicity methodology along a gradient in Castro Cove. These efforts included chemical analyses of the sediments and pore waters, benthic community analyses, toxicity studies with amphipods, bivalves, larval fish, and studies of genotoxicity and developmental responses with invertebrate and bacterial test organisms. This report focuses on the sediment chemistry studies.

Methods and Sampling Program

The sediment study consisted of three different sampling efforts: bay studies, marsh studies; and gradient studies at Castro Cove near Richmond.

Bay Studies

The sampling locations for the bay studies were located just off the main channel of the bay and were geographically distributed based upon historical data between the extreme south bay and the extreme north bay station in the Sacramento River (Figure 1 in Appendix E). Stations were selected to reflect ambient conditions in the Bay. Stations were sampled in August 1991 (Bay Run #1) and March-April 1992 (Bay Run #2) to determine temporal trends during dry and wet periods of the year, respectively. All stations were sampled using a modified Gray-Ohare box core to collect the depositional layer, described as the top layer of sediment that lacks the smell of hydrogen sulfide and black anoxic color. A total of 15 stations in San Francisco Bay were sampled. Reference stations were collected at Tomales Bay (marine reference) and Lake Mendocino (freshwater reference).

Sediment was homogenized and analyzed for concentrations of trace elements and organic compounds and for toxicity. For the toxicity testing, sediment salinities dictated whether the test organism would be *Daphnia magna* (salinities <3 ppt), *Eohaustorius estuarius* (salinities 4-33 ppt), or *Rhepoxinius abronius* (>25 ppt). Sediments from freshwater sites were tested using the chronic seven-day test for *Daphnia magna* described by Nebeker et. al (1984). The ASTM standard guide for conducting ten-day static sediment toxicity tests with marine and estuarine amphipods (ASTM 1991 E1367-90) provided the protocol for the acute tests using *Eohaustorius* and *Rhepoxinius*. Sediment elutriates from the Bay Studies sites were used for toxicity tests using bivalve embryos (*Crassotrea gigas*) and fish larvae (*Menidia beryllina*). The tests with bivalve embryos were conducted following ASTM guidelines (ASTM 1992), with adaptations for elutriate testing given in the Puget Sound Protocols (Tetra Tech 1986). The tests with fish larvae followed EPA protocol for inland silversides *Menidia beryllina* (Weber et al. 1988).

Marsh Study

The marsh studies were designed to detect contaminants and their toxic effects in "critical habitats" (marshes, mudflats, and creeks) that border San Francisco Bay. Each station was sampled once between July 1991 and February 1992. The collection methods were by diver-operated cores and, in very shallow areas, diver-operated scrapes or non-diver operated scrapes. Cores were taken to at least six inches deep. Diver-operated scrapes were taken using a polyethylene-gloved hand and non-diver-operated scrapes were taken using a Teflon scoop dragged across the sediment, scooping up a few millimeters at a time. Sediments were assessed to assure that the sulfide-rich layer was not sampled. Composite samples of the depositional layer were collected at each station. The sediment was analyzed for trace elements and organic compounds and tested for toxicity using the same tests used for the Bay Studies samples. Thirty-five stations were sampled (Figure 1 in Appendix E).

Gradient Study

The gradient study was conducted at Castro Cove near Richmond in an area that historically has received discharges from a nearby oil refinery. The purpose of the study was primarily to evaluate sediment toxicity methodology by simultaneously evaluating several sediment toxicity tests at a gradient of stations that previous studies had shown to vary from relatively uncontaminated (Point Pinole Pilings) to highly contaminated (inner Castro Cove Stations). Two sediment layers were sampled: a surface depositional layer (one centimeter to a few centimeters in depth) and a layer under the shallow layer that was generally more

compacted, black in color, and smelled of petroleum products. All sediments were collected by cores. Seven stations were sampled (Figure 1 in Appendix E).

Data Management

More information on quality assurance, sampling protocols, analytical procedures, and results for these studies are contained in San Francisco Estuary Pilot Regional Monitoring Program: Sediment Studies (SFBRWQCB 1994).

The State Water Resource Control Board's environmental database at the Teale Data Center in Sacramento compiles data from this study. Data from this study is also collected in a database at the California Department of Fish and Game, at EcoAnalysis Inc., and at the San Francisco Bay Regional Water Quality Control Board.

Bay Protection and Toxic Cleanup Program: Screening in San Francisco Bay (1995-1997)

Design and Objectives

The four statewide objectives of the BPTCP regional monitoring program are to:

1 Identify locations in enclosed bays, estuaries, or the ocean that are toxic hot spots;

2 Determine the extent of biological impacts in portions of enclosed bays and estuaries not sampled (areas of unknown condition);

3 Confirm the extent of biological impacts in enclosed bays and estuaries that have been sampled; and

4 Assess the relationship between toxic pollutants and biological effects.

The study used a two-tier process to identify known toxic hot spots. The first tier was a screening step where at least two toxicity tests (e.g., a ten-day solid phase amphipod test and an urchin development test using pore water) were used at each site. Organisms used were *Eohaustorius estuarius* or *Rhepoxinius abronius* for the amphipod tests and *Stronglyocentrotus* for the urchin test. Sediment grain size, total organic carbon (TOC), and hydrogen sulfide concentration were measured to differentiate pollutant effects found in

screening tests from natural factors. Chemical analyses (trace elements and organic compounds) were performed on samples where tests showed toxic effects. If effects were found, some sites were retested to confirm the effects.

Four different categories of sites were identified for sampling in the BPTCP screening: 1) potential toxic hot spots based on existing information; 2) high-risk sites based on existing information; 3) stratified random sites; and 4) reference sites. For the San Francisco Bay area, the BPTCP began screening sampling in 1995. About 100 stations were sampled in 1995 (Figure 2 in Appendix E). Ten stations were sampled in 1996 and 28 stations were sampled in 1997.

Methods and Sampling Program

The cruise reports indicate that six liters of sediment were collected at each station for use in toxicity testing and analyses of trace elements, organic compounds, TOC, and grain size. Samples were collected from the top five centimeters of sediment. Chemistry analyses were performed on samples where toxicity tests showed toxic effects, and some additional stations.

The State Water Resources Control Board has published a Quality Assurance Project Plan that details quality assurance procedures for field, laboratory, and analytical components of the screening program (Stephenson et al. 1994). The SFBRWQCB plans to publish a report summarizing the results of the San Francisco Bay screening program in 1998.

Data Management

The California Department of Fish and Game maintains the data from the BPTCP screening in dBase files at the Moss Landing Marine Laboratory facilities. The data are available in electronic format upon request. Data from the San Francisco Bay screening will also eventually reside in the SWRCB's environmental database in Sacramento and at the San Francisco Bay Regional Water Quality Control Board in Oakland.

References

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SAN FRANCISCO ESTUARY INSTITUTE

The San Francisco Estuary Institute (SFEI; formerly Aquatic Habitat Institute) administers and manages the Regional Monitoring Program (RMP) with the San Francisco Bay Regional Water Quality Control Board. The RMP is the result of Resolution 92-043 of the SFBRWQCB, which initiated the RMP for San Francisco Bay. In 1995, 63 Federal, state, and local agencies and companies participated in the RMP. The objectives of the RMP are to:

- Obtain high-quality baseline data describing the concentration of toxic and potentially toxic trace elements and organic contaminants in the water and sediment of the San Francisco Estuary;
- Determine seasonal and annual trends in chemical and biological water quality in the San Francisco Estuary;
- Continue to develop a data set that can be used to determine long-term trends in the concentrations of toxic and potentially toxic trace elements and organic contaminants in the water and sediments of the San Francisco Estuary;
- Determine whether water quality and sediment quality in the Estuary at large are in compliance with objectives established by the Basin Plan; and
- Provide a database on water quality and sediment quality in the Estuary which is compatible with data being developed in other ongoing studies in the system, including, but not limited to, wasteload allocation studies, model development, sediment quality objectives development, in-bay studies of dredged material disposal, Interagency Ecological Program water quality studies, primary productivity studies, local effects biomonitoring programs, and state and Federal mussel watch programs.

The following sections provide more detailed descriptions of each year of the program, focusing on sediment contaminant characterization and monitoring. Results from sampling conducted in 1996 should be available in early 1998.

San Francisco Estuary Regional Monitoring Program for Trace Substances: 1993

Design and Objectives

The RMP 1993 sampling design was based in part on the BPTCP Pilot Regional Monitoring Program conducted by the SFBRWQCB in 1991 and 1992 and summarized previously in this report. The station locations for the RMP, which were selected based on information

from the Pilot Program as well as other studies, were not selected randomly and may not represent the areas from which they were collected. Most of the station locations were chosen so they would be as far as possible from the influence of major contaminant sources and to be as representative as possible of "background" contaminant concentrations. Sampling locations are presented in Figure 3 in Appendix E.

Sampling was conducted at 16 stations throughout the estuary three times during 1993: the wet period (March), during declining Delta outflow (May), and during the dry period (September). Five different types of samples were collected in 1993: conventional water quality parameters and chemistry; water toxicity; sediment quality characteristics and chemistry; sediment toxicity; and transplanted, bagged bivalve bioaccumulation and condition. Water sampling was conducted during all three sampling periods. Water-column toxicity was evaluated from samples collected at eight stations using a 48-hour mollusk embryo development test and a 96-hour algal growth test. Transplanted, bagged bivalve bioaccumulation and condition was measured at eleven stations during the wet and dry sampling periods. Sediment sampling was conducted only during the wet and dry sampling periods.

Methods and Sampling Program

Sediment sampling was conducted using a modified Van Veen grab with a surface area of 0.1 m^2. When the sampler was on deck, a sub-core was removed for measurement of the Eh (oxidation-reduction potential) at 2.5 cm and 5.0 cm using a temperature compensated Eh meter. The top 5 cm of sediment was then scooped from each of two replicate grabs and mixed in a bucket to provide a single composite sample for each station. Aliquots were split on board for each analytical laboratory and for sediment toxicity tests. Duplicate samples for archiving were collected from a composite of two additional grabs. Parameters measured at all 16 stations included sediment quality characteristics (grain size, total organic carbon, Eh, and pH) and chemistry (trace elements and organic contaminants). Sediment toxicity was measured at eight stations. Two sediment toxicity tests were used: a ten-day acute mortality test using *Eohaustorius estuarius* exposed to whole sediment using ASTM method E 1367 (ASTM 1992), and a sediment elutriate test where larval bivalves were exposed to the material dissolved from whole sediment in a water extract using ASTM method E 724-89 (ASTM 1991). Sampling locations are presented in Figure 3 in Appendix E.

More information on sampling results, quality assurance, sampling and analytical protocols, etc. are contained in the 1993 Annual Report (SFEI 1994).

Data Management

Sampling and data analysis for the 1993, 1994, and 1995 RMP are complete. SFEI currently has all the RMP data available electronically through its home page on the World Wide Web (http://www.sfei.org/index.html). The sampling results and analyses are also contained in Annual Reports produced by SFEI (SFEI 1994; SFEI 1995; SFEI 1996). The RMP data are also stored at SFEI in an Oracle database or in SAS data tables.

San Francisco Estuary Regional Monitoring Program for Trace Substances: 1994

Design and Objectives

The 1994 RMP was generally similar to the 1993 program. Six new stations were added from 1993: Coyote Creek (no sediment sampling), San Bruno Shoal, Alameda, Red Rock, Petaluma River (no sediment sampling), and Honker Bay (Figure 4 in Appendix E). Two stations were added on a trial basis in the southern end of the estuary adjacent to the wastewater outfalls of the Cities of San Jose (station C-3-0) and Sunnyvale (station C-1-3). Monitoring at these stations was conducted in cooperation with the SFBRWQCB and the two cities. These stations are located in the bayward ends of Coyote Creek and Guadeloupe Slough between the two outfalls and the RMP Coyote Creek station (BA10).

Aquatic bioassays were changed from three times a year to two times and the mysid *Mysidopsis* was used instead of the diatom *Thalassiosira* because *Thalassiosira* was found to be not very sensitive. Also, diazinon was added as an analyte. Three pilot studies were conducted in 1994. Two studies were continuations from 1993: the pilot study of hydrography and water quality and pilot study of suspended sediments, both conducted by USGS scientists. A new pilot study was started in 1994 in which macrobenthic invertebrates were collected at eight stations.

Methods and Sampling Program

Sediment quality, trace elements, and organic contaminants were measured at 20 RMP base program stations in 1994 and two additional stations near the Sunnyvale and San Jose wastewater outfalls. Sediment monitoring was conducted during the wet (February) and dry (August) seasons. Sediment bioassays were conducted at 12 stations in 1994.

Sediment sampling and analysis methods in 1994 were basically the same as those used in 1993. More information on data results, quality assurance, sampling protocols, analytical procedures etc. are contained in the 1994 Annual Report (SFEI 1995).

San Francisco Estuary Regional Monitoring Program for Trace Substances: 1995

Design and Objectives

The 1995 RMP was generally similar to the 1993 and 1994 programs. Sulfides and ammonia measurements in sediment were added in 1995. The 1995 Benthic Pilot Study continued in 1995 with only a few changes from the 1994 study. A Tidal Wetlands Pilot Study was started in 1995 with two major objectives: 1) develop equipment and train personnel to sample tidal marsh sediments for contaminant analysis and produce a methodology that yields results that are comparable to other RMP results as well as other scientific efforts to understand tidal marshes; and 2) gain insight about the usefulness of natural tidal marsh physiography as a spatial template for sampling sediment contaminants within and among tidal marshes. Sampling was conducted at China Camp State Park in Marin County and Petaluma Marsh in Sonoma County.

Methods and Sampling Program

Sediment quality, trace elements, and organic contaminants were measured at 22 RMP base program stations in 1995 and the two additional stations near the Sunnyvale and San Jose wastewater outfalls (Figure 5 in Appendix E). Sediment monitoring was added at the Coyote Creek and Petaluma River base program stations in 1995. Sediment monitoring was conducted during the wet (February) and dry (August) seasons. Sediment bioassays were conducted at twelve stations in 1995. The designation of "toxic" used in the 1995 RMP sediment bioassays was different than that used in previous Annual Reports. A second criterion was added to eliminate the problem of designating toxicity based only on comparison to controls with low replicate variance. The second criterion that must be met is that mean organism response in the bioassay test was less than 80 percent of the laboratory control value.

Sediment sampling and analysis methods in 1995 were basically the same as those used in 1993 and 1994. More information on data results, quality assurance, sampling protocols, analytical procedures etc. are contained in the 1995 Annual Report (SFEI 1996).

Bay Area Dischargers Association: Local Effects Monitoring Program

The Bay Area Dischargers Association (BADA) is an organization of the five largest municipal wastewater dischargers in the San Francisco Bay Area including: the Central Contra Costa Sanitary District; East Bay Dischargers Authority; East Bay Municipal Utility District; City and County of San Francisco; and the City of San Jose. In addition, BADA has several associate member agencies, including Fairfield Suisun Sewer District, City of Palo Alto, City of San Mateo, and South Bayside System Authority.

Design and Objectives

Growing out of a transplanted bivalve monitoring program that began in 1989, BADA started a sediment chemistry and benthic infauna monitoring program in 1994 to help determine and assess environmental impacts at the association's outfalls. In coordination with SFEI, sediment and benthic infauna samples were collected and analyzed in 1994, 1995, 1996, and 1997 from locations near the three municipal sewage outfalls for the City and County of San Francisco, Central Contra Costa Sanitary District, and East Bay Municipal Utility District (EBMUD).

Methods and Sampling Program

Three sites at each of the three outfalls have been sampled twice a year since 1995. Samples were collected once in 1994. Samples are collected and analyzed for sediment chemistry and benthic infauna using methods and techniques similar to the RMP.

Data Management

The main contacts for the program are Jim Salerno (415) 648-6882 and Michael Kellogg at the City and County of San Francisco. Data generated by the BADA LEMP are maintained electronically at SFEI.

South Bay Local Effects Monitoring Program

Objectives

In conjunction with the RMP sampling conducted near the outfalls for San Jose and Sunnyvale water pollution control plants, the South Bay Dischargers Authority (cities of San Jose, Santa Clara, Palo Alto, and Sunnyvale) samples annually at two additional stations in the South Bay for regulatory purposes as part of a Local Effects Monitoring Program (LEMP): 1) San Jose/Sunnyvale (C-1-7), located in Coyote Creek midway between Alviso

Slough and Guadeloupe Slough and; 2) Palo Alto, located downstream from the Palo Alto Regional Water Quality Control Plant. Since 1996, two additional stations have been added in Coyote Creek and Guadeloupe Slough as pilot stations for the LEMP.

Methods and Sampling Program

The LEMP stations are collected and analyzed by USGS using similar methods and techniques as the RMP, which is described above.

Data Management

The main contact for the program is Dave Tucker at the City of San Jose (408) 945-3711. The data are included in SFEI's annual reports and are maintained electronically at SFEI.

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California Department of Fish and Game

The California Department of Fish and Game (DFG) is responsible for the field and laboratory work for the Bay Protection and Toxic Cleanup Program, described earlier. In addition to the BPTCP screening, the California DFG has conducted a Reference Site Survey in San Francisco Bay in cooperation with the SFBRWQCB.

1994/1995 Reference Site Survey

Objectives

The main purposes of this study were to:

- identify sediment reference sites in San Francisco Bay to use in toxicity tests;
- recommend sediment toxicity test protocols to use in monitoring sediment toxicity in San Francisco Bay;
- develop Sediment Toxicity Identification (TIE) protocols for use in San Francisco Bay; and
- identify the cause of toxicity at previously identified reference sites.

Methods and Sampling Program

The study selected five sites in San Francisco Bay as potential reference sites for future toxicity assessments in the Bay (Figure 6 in Appendix E). Sites were selected using criteria established in previous studies, including low concentrations of anthropogenic chemicals, distance from known major sources of pollution, and natural features such as grain size and total organic carbon (TOC) that are similar to test sediments. Sites with fine-grained sediment were selected because most heavily contaminated test sites have been found in depositional areas with fine sediments. Sites in Tomales Bay and Bolinas Lagoon were also investigated because they had been previously considered as reference sites and found to show toxicity, although concentrations of anthropogenic contaminants were low. Three other sites were also sampled (Islais Creek, Castro Cove, and Clipper Cove) where previous studies had shown either high toxicity or high concentrations of toxic chemicals. Data from these sites were compared to reference sites.

Chemical analyses, total organic carbon, and grain-size analyses were conducted at all potential reference sites. Up to nine toxicity tests were conducted on each sample from all sites. The tests were:

1 the ten-day solid-phase amphipod test using *Eohaustorius* in undisturbed cores;
2 the ten-day solid phase amphipod test using *Ampelisca*;
3 the ten-day amphipod test using *Eohaustorius* in pore water;
4 the ten-day amphipod testing using *Eohaustorius* in intact cores;
5 a bivalve larvae development test in pore water;
6 an urchin larvae development test in pore water;
7 an urchin larvae development test using a sediment/water interface exposure;
8 the *Neanthes* growth and survival test; and
9 a ten-day solid phase test using *Nubelia*.

Not all of these toxicity tests were conducted at each site. Tests were evaluated for control response acceptability, laboratory replicate variability, and sensitivity. TIE protocols were developed for *Eohaustorius*, and the mussel and urchin larval development tests in sediment pore water. TIEs were conducted on four sediment samples that exhibited toxicity.

Data Management

The California Department of Fish and Game maintains the data for the Reference Site Survey, as well as the Bay Protection and Toxic Cleanup Program data, in dBase files at the Moss Landing Marine Laboratory facilities. The data are available in electronic format upon request. EcoAnalysis, Inc. also maintains Reference Site Survey data in a database format.

National Oceanic and Atmospheric Administration (NOAA): Long-term Monitoring

National Status and Trends Program

The National Status and Trends (NS&T) Program for Marine Environmental Quality was formed to monitor spatial distributions and temporal trends of contaminant concentrations in U.S. coastal and estuarine regions, and biological responses to that contamination. Samples for chemical analysis are collected through two projects: the National Benthic Surveillance Project (NBSP) and the Mussel Watch Project. Since 1984, the NBSP has annually collected benthic fish and sediments at about 60 sites in embayments along the Atlantic, Gulf, and Pacific coasts of the United States. The NBSP determines the concentrations of contaminant chemicals and prevalence of pathological lesions in bottom fish and relates them to contaminant concentrations in associated sediment. The NBSP is a cooperative effort between the National Marine Fisheries Service (NMFS) and the Coastal Monitoring and Bioeffects Assessment Division (CMBAD) of NOAA's National Ocean Service. Since 1986, the Mussel Watch Project has annually collected and chemically analyzed mussels and oysters and sediments from more than 150 sites around the coastal and estuarine United States. The following is a brief summary of the sediment monitoring activities of these two NOAA programs in San Francisco Bay.

National Benthic Surveillance Project (NBSP)

Objectives

The specific objectives of the NBSP are:

- Measurement of concentrations of chemical contaminants in sediment and in species of bottom-dwelling fish at selected sites in urban and non-urban embayments.
- Determination of the prevalence of diseases in these same fish species.
- Exploration of associations between contaminant concentrations in tissue and sediment and among tissue, sediment, and fish disease.
- Evaluation of spatial and temporal trends of contaminant concentrations and fish diseases.

Methods and Sampling Program

Sediment sampling for the NBSP in San Francisco Bay began in 1984. Sampling sites were chosen based on the following characteristics:

1 availability of bottom-feeding fish;
2 subtidal, sedimentary-depositional zone;
3 away from point sources or authorized dumpsites; and
4 not subject to dredging, scouring, or slumping.

Surface sediments (top 2-3 cm) were collected and analyzed at eight stations in the Bay from 1984 through 1995 (Figure 7 in Appendix E). Each sampling site was not sampled each year. At each sampling site, three grabs were taken at each of three stations and three cores were taken from each grab (total of 27 core tubes per site). PAHs, PCBs, chlorinated pesticides, and trace elements were analyzed. Fish liver tissue and, at some sites, stomach contents, were collected and analyzed for trace elements, PCBs, and pesticides.

Data Management

Some of the NBSP data are available on the World Wide Web at http:\\www-orca.nos.noaa.gov. Data from the Pacific Coast sites are maintained in a database at the Northwest Marine Fisheries Center in Seattle. Results and analyses of the data are provided in several NOAA publications, including Meador et al. 1994 and Varanasi et al. 1989. These publications also provide details on study design, objectives, methods, and analysis.

Mussel Watch

Objectives

Since 1986, the NS&T Program has included a component called the Mussel Watch Project that has annually collected and chemically analyzed mussels, oysters, and sediments, from more than 200 sites around the coastal and estuarine U.S. (NOAA 1989). Measurements are made at sites designed to be representative of large areas rather than small-scale patches of contamination. The results help describe the spatial distribution of contamination and temporal trends, and to help differentiate between the effects of human activity and those of natural influences. Sessile mollusks were chosen as test organisms because they are permanent residents of geographically fixed sites and because contaminant concentrations in mollusk tissue change fairly rapidly in response to the surroundings.

Methods and Sampling Program

The Mussel Watch Project monitors five sites in San Francisco Bay for sediment chemistry and three sites for mussel (*Mytilus edulis*) tissue. Three grabs or cores are obtained at each of three stations at each sampling site. A station can be anywhere within 500 m of the center of the site where mollusks were collected. Composite samples are made from surface sediment in those three grabs or cores. Three separate composites are made per station: one for organic chemical analysis, one for inorganic analysis, and one for other sediment characteristics such as grain size and TOC. For the mussel tissue analysis, composite samples are made by homogenizing the soft parts of 30 mussels. Six composites are used for chemical analysis: three for replicate organic contaminant analysis, three for trace elements. Sediments and mussel tissue are analyzed for trace elements, PCBs, pesticides, and PAHs. Mussels are collected and analyzed approximately every other year. Sediment chemistry is analyzed periodically, though less frequently than the mussel tissue. In addition to the Federal program, since the late 1970s the California State Mussel Watch Program has monitored contaminants in the tissue of resident and transplanted mussels and clams at more than 40 stations in the state, including stations in San Francisco Bay. The California Department of Fish and Game carries out the program for the State Water Resources Control Board.

Data Management

The mussel watch data are available on the World Wide Web at http:\\www-orca.nos.noaa.gov. Requests for data can also be made to Gunnar Lauenstein of NOAA's Coastal Monitoring and Bioeffects Assessment Division, Coastal Monitoring Branch in Silver Spring, Maryland. NOAA has also produced several reports that provide information on the project, including analysis and results (NOAA 1987; NOAA 1989; NOAA 1991).

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2 Site-Specific and/or Single-Event Studies

This section focuses on sediment contaminant investigations in San Francisco Bay that are not part of a comprehensive monitoring program. These investigations include individual studies conducted by the U.S. Geological Survey and NOAA, site-specific studies on selected hazardous waste sites, and studies conducted at dredged areas, particularly in the Port of Oakland. More information on the studies mentioned in this section and on other individual studies can be found in the table in Appendix A.

National Oceanic and Atmospheric Administration Single Investigations

Sediment Quality Triad

Objectives

This study assessed the utility of the Sediment Quality Triad approach in augmenting the field measurements of NOAA's NS&T Program (Chapman et al. 1986). The Triad consists of coincident measurements of sediment contamination by chemical analyses, sediment toxicity through performance of laboratory sediment bioassays, and infaunal community structure by collection of benthic macroinfauna data. The hypothesis underlying the Triad is that no individual component of the Triad can be used to predict the results of the measurement of the other components. The hypothesis was tested in the study with synoptic measurements of the Triad components at three sites in San Francisco Bay.

Methods and Sampling Program

Ten stations were sampled at each of three sites in the Bay (Islais Waterway, near Oakland, and San Pablo Bay) for sediment bioassay testing, benthic infaunal analyses, and sediment chemistry determinations. Amphipod (*Rhepoxynius abronius*) sediment bioassays were performed on sediment samples from all thirty stations. Sediments from only three stations at each site were analyzed with the full complement of Triad measures. Sediments and benthos from the other seven stations at each site were archived after collection. Sediments from nine stations (three from each site) were fully analyzed with the following:

- Detailed chemical analyses on composited surface sediments, aliquots from which were also used for bioassay testing. Chemical analytes specified by NOAA for the NS&T

Program: conventionals, trace elements, polycyclic aromatic hydrocarbons, and chlorinated hydrocarbons.

- Four separate types of sediment bioassays were conducted on the composited surface sediment:

1 The *Rhepoxynius abronius* ten-day test developed by Swartz et al. (1982, 1985) was used to measure acute lethality;

2 The 48-hour mussel (*Mytilus edulis*) larvae test described by Mitchell et al. (1985) for use in solid-waste testing was used to measure sublethal effects;

3 Behavioral effects were measured by determining the rate of reburial of the clam *Macoma balthica* using techniques developed by McGreer (1979); and

4 Reproductive impairment was measured by determining copepodite production by the harpacticoid copepod, *Tigriopus californicus.*

- Benthic infauna were identified and enumerated for each of five grab samples from each of these stations. The benthos grabs were collected independently from those grabs composited and used for sediment chemistry and bioassay.

The results of the analyses were used to classify the expected degree of degradation of each station at each site, based on both individual and combined measures. Specific recommendations were then made regarding the application of the Sediment Quality Triad to NOAA's National Status and Trends Program.

Data Management

Data are maintained at NOAA in Seattle.

Evaluation of candidate measures of biological effects: 1987

Objectives

In addition to the studies conducted in San Francisco Bay under the Mussel Watch Project and the National Benthic Surveillance Program (discussed earlier in this report), NOAA conducted a study in 1987 in the Bay. This study evaluated the response and sensitivity of candidate measures of biological effects for the NS&T program (Long and Buchman 1989). The overall approach for the evaluation involved analyses of samples collected in the field at sites that were presumed to represent a range in chemical contamination. Biological tests were performed with subsamples of samples that were also analyzed for chemical concentrations. Data from the biological tests were then compared with each other and with the chemical data in various statistical procedures. It was presumed and hypothesized

before the evaluation began that biological tests most applicable to the NS&T program would be those that were able to indicate differences among sampling locations over a range in chemical contamination and/or between sampling locations and laboratory controls, had relatively large ranges in response among mean values for the sampling locations, had relatively small analytical errors, and indicated patterns in biological response that generally paralleled the pattern in chemical contamination.

Methods and Sampling Program

Sediments were sampled at a total of five sites, four of which were from the NS&T program: Yerba Buena Island, San Pablo Bay, Vallejo, and Tomales Bay (Figure 7 in Appendix E). Sediments were also sampled at a site in Oakland Inner Harbor. Three sites in the Bay were sampled for fish tissue analysis.

The field collection and analysis consisted of the following:

- Collection and chemical analyses of surficial sediments at 15 sampling stations (three stations at each of the five sites) in San Francisco Bay and Tomales Bay.
- Solid-phase sediment toxicity test with the amphipod *Rhepoxynius abronius*.
- Solid-phase sediment toxicity test with the amphipod *Ampelisca abdita*..
- Sediment elutriate toxicity test with the larvae of the mussel *Mytilus edulis*.
- Sediment elutriate toxicity test with the larvae of three sea urchin species.
- Sediment pore water toxicity test with the polychaete *Dinophilus gyrociliatus*.
- Taxonomic analyses of benthic community structure.
- Analyses of sedimentological and biological characteristics with sediment profiling photography.
- Fish collection, tissue chemical analyses, aryl hydrocarbon hydroxylase analyses, and plasma steroid hormone analyses.
- Fish blood micronucleated erythrocyte analyses; and
- Fish liver cytochome P-450 and ethoyresorufinn-O-deethylase enzyme analyses.

Sediments were sampled using the NS&T protocol: three stations at each site. Multiple grab samples were taken at each station and the upper one cm of sediment was removed and collected until about seven liters of sediment had been accumulated and composited from each station. All sediment samples were analyzed for PAHs, trace elements, PCBs, and pesticides. All toxicity tests were performed with five laboratory replicates or aliquots of the composited sediments per station.

Data Management

Long and Buchman (1989) produced a report summarizing the approach, methods, and results of this investigation. The data are maintained at NOAA in Seattle.

1990 Synoptic Sediment Survey

Objectives

The sampling plan was designed to determine spatial patterns and extent in sediment toxicity in San Francisco Bay (Long and Markel 1992). The sampling effort was focused on areas in the Bay where the highest concentrations of most toxicants were found through evaluating historical data. Patterns in toxicity were determined using a variety of arithmetical, statistical, and graphical methods.

Methods and Sampling Program

Sediment samples were collected in 1990 at 45 sites in the Bay and tested with a battery of bioassays. Three separate samples, one at each station, were collected at 30 of the 45 sites. The contents of the three samples were tested separately. At the remaining fifteen sites, three individual samples were collected at one of the stations, while the other two stations were sampled once as per the protocol in the first 30 sites. The toxicity tests chosen for the survey were those performed with bivalve embryos, bioluminescent bacteria, and sea urchin embryos.

In addition to subsampling for the toxicity testing, 400-ml aliquots were frozen and eventually transferred to the San Francisco Bay Regional Water Quality Control Board for chemical analysis, though no chemistry results were reported in Long and Markel's (1992) report.

Data Management

Results of the toxicity testing were reported by Long and Markel (1992). Data are maintained at NOAA in Seattle.

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U.S. Geological Survey (USGS)

For more than twenty years USGS researchers have investigated the transport and fate of anthropogenic contaminants in the San Francisco Bay estuary. Funded by the USGS Toxic Substances Hydrology Program and several other sources, USGS research in the Bay has included studies on (1) the fate of pesticides discharged into the San Francisco Bay's river-estuary system, (2) the fate and distribution of organic contaminants in Bay sediments, (3) the history of organic, as well as inorganic, contaminants in the Bay, and (4) the adverse effects of trace elements on benthic aquatic organisms. One of USGS's major long-term investigations in the Bay has been its studies of trace element concentrations in sediments and clams collected from two mudflats near the discharge points of two sewage treatment plants in the South Bay. Another large effort over the years has focused on the distribution and fate of trace elements and pesticides in the North Bay, including long-term surface sediment, water, and bioaccumulation studies at six stations: one each at Rio Vista, Carquinez Strait, Honker Bay, and San Pablo Bay, and two in Suisun Bay. A recent study examined the historic profile of both organic and inorganic contaminants in Bay sediments using two cores collected with unbroken sedimentary records, one from Richardson Bay and one from San Pablo Bay.

USGS researchers from multiple disciplines have conducted research in the Bay to understand the biological, chemical, and physical processes at work in this complex ecosystem. These scientists have published hundreds of articles on their research both in technical journals and USGS reports. Many of these publications are not specifically relevant to the purposes of this document, though they provide invaluable information on the processes that determine the behavior and effects of contaminants in Bay sediments. For this report, we attempted to identify the majority of USGS reports that contain original sediment chemistry data collected in the Bay since the mid-1980s. These documents are listed below and summarized in the table in Appendix A, based on the geographic scope of the investigation. For instance, Sam Luoma's investigations in the Palo Alto mudflats are summarized in the South Bay table.

Data Management

USGS does not maintain a database containing the results of the agency's many contaminant investigations in San Francisco Bay, although individual investigators at USGS can be contacted about specific studies and the possibility of receiving data in electronic format if available. There are a number of World Wide Web sites related to the USGS work

in the Bay, including the Estuary Toxic Contaminants Project page at http://water.wr.usgs.gov/toxics/index.html. A good contact at USGS regarding the sediment investigations is Sam Luoma at the Menlo Park office.

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Dredging and Dredged Material Disposal Data

More than six million cubic yards of sediments enter the estuary each year, mostly from the Sacramento and San Joaquin rivers, and as many as 286 million cubic yards of existing sediments are resuspended by currents and wind-driven waves (SFEP 1992). Between seven and eight million cubic yards of sediment are dredged and disposed of each year. Most of the dredging in the estuary is conducted by the Army Corps of Engineers. Since 1824, the Corps has planned, built, and maintained Federal navigation and flood control projects. In 1987, the Corps was responsible for 14 major and several minor navigation projects in the estuary, including projects at Oakland Harbor, Richmond Harbor, Mare Island Strait, Petaluma River, Pinole Shoal, and Suisun Bay Channel. The U.S. Navy also conducts extensive dredging at its facilities in the estuary. The bulk of the Navy's dredging activities are conducted at Mare Island and Alameda Naval Air Station. Public and private marine operators, ports, refineries, and flood control and reclamation districts also dredge for a variety of purposes. During the past 120 years, dredged material has been disposed of at more than three dozen locations in and around the estuary at aquatic sites in the Bay and Delta, on uplands, and in the ocean. Since 1975, the Corps has limited nearly all aquatic disposal of dredged material in the Bay to just three sites. These sites are next to Alcatraz

Island, in San Pablo Bay, and in Carquinez Strait. The disposal of dredged material may serve as a source of pollutants previously bound in the dredged sediments.

Physical, biological, and chemical testing of sediments is required for many dredging projects to obtain Army Corps permits and ensure that dredged material disposal does not chemically or biologically degrade the disposal area. The Corps and various other Federal and state agencies review sampling results to determine potential environmental impact, compliance with testing guidelines (i.e., ASACE Public Notice 93-2), and proper handling and disposal of the dredged material. Hard-copy reports containing these results are stored at the SFBRWQCB in Oakland, and at EPA and the Army Corps of Engineers in San Francisco, but no comprehensive electronic database has been developed for this data. An interagency effort is underway to develop such a database. Many of these dredging studies are too small or too old or of insufficient quality to be of much use for a baywide perspective on sediment contamination. However, several recent, relatively large studies are likely of sufficient size and quality to be helpful in determining the nature and extent of sediment contamination in the Bay.

The Lawrence Berkeley Laboratory published data compiled by Battelle/Marine Sciences Laboratory from five pre-dredging studies performed on sediments from the Ports of Oakland and Richmond between 1990-1991 (Hoffman 1994). These data sets were selected both to assess the frequency and magnitude of toxicity in the San Francisco data set and to determine the extent to which toxicity patterns are predicated on the influences of contaminant sources at different sites. Refer to the study for more information on its methodology and results. Because the Port of Oakland is one of the most active dredging sites in the Bay and has generated numerous sediment characterization investigations, this report has attempted to summarize most of these studies since the mid-1980s (Appendix A). Other selected sediment investigations related to dredging projects in the Bay are summarized in the tables in Appendix A, organized by embayment. However, it was beyond the scope of this report to list comprehensively all recent dredging investigations in the Bay that included sediment chemistry data.

Data Management

Dredging contaminant data are not yet collected in a centralized location in electronic format. Three good contacts for information on specific projects or dredging areas are David Dwinell at the Army Corps in San Francisco (415/977-8471), Tom Gandesbury at the

Regional Water Quality Control Board in Oakland (510/286-0841), and Erika Hoffman at EPA in San Francisco (415/744-1986).

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Hazardous Waste Site Facilities

This section contains information on six hazardous waste site facilities in the San Francisco Bay area that have been, and/or continue to be, potential sources of contaminants to the Bay. We focused on the sites that were of particular concern to NOAA and also had environmental investigations that include or will include sediment chemistry. Numerous other National Priorities List (NPL) and non-NPL sites affect the Bay, but are not addressed in this report. The facilities discussed here include four closed military bases (Alameda NAS, Mare Island Naval Shipyard, Hunters Point Naval Shipyard, and Hamilton Army Airfield) that are being investigated for reuse options, one operating naval base (NWS Concord), and one non-Federal site (United Heckathorn) that has ceased operation and is in the process of remediation.

This report provides brief background information on each site facility, a description of the aquatic habitats of interest to NOAA at each site, and a summary of recent (post-1985) and planned environmental investigations at each of the sites that included or will include sediment contamination information. Most, but not all, of the investigations summarized in this section were conducted as part of the site investigation process for NPL sites (e.g., site investigation, remedial investigation, ecological risk assessment, etc.) and/or as part of the remediation/reuse investigations at Naval facilities. Other investigations (e.g., a pre-dredging study) were included for each site because they included the collection and analysis of sediments in aquatic habitats of concern to NOAA at or adjacent to the site (i.e., San Francisco Bay and adjacent wetlands). The level of detail provided for each of the investigations summarized varies in this report depending on whether the relevant documents were available for review.

Hunters Point Naval Shipyard

Location/Background

Hunters Point Shipyard is in southeast San Francisco, just north of Candlestick Park and about eight miles north of the San Francisco airport. The facility lies on the southern tip of the Hunters Point Peninsula, which extends eastward into San Francisco Bay. The facility is bordered on the north, east, and south by the Bay, and to the west by the Hunters Point district of San Francisco, which consists of public and private housing and commercial and industrial buildings.

Hunters Point Shipyard was operated as a commercial dry-dock from 1869 until December 19, 1939, when the property was purchased by the U.S. Navy. The Navy leased the facility to Bethlehem Steel Company until December 18, 1941, when the Navy took possession and began operating the shipyard to produce ships during World War II. Navy ships were also modified, maintained, and repaired there. In 1989, the shipyard was placed on the National Priorities List. In 1990, the Department of Defense placed the shipyard on the base closure list, mandating that it be remediated and made available for non-defense use. The base ceased operations in 1994**.** The base was divided into five Operable Units (OU) for the Remedial Investigation/Feasibility Study (RI/FS). The OU-based investigation was recently reorganized into a parcel-based investigation to accelerate the RI/FS, provide a framework for interim actions, and accelerate cleanup of contiguous sites for reuse. Five onshore parcels (A through E) and one offshore parcel (Parcel F) have thus far been formally defined.

Offshore/Wetland Areas of Concern

The shipyard property covers about 955 acres with 522 acres on land, and 433 acres under water (below the high-tide line). About 400 acres of the underwater property are subtidal (below the low tide mark); the remaining 33 acres are intertidal mudflats (between the low and high tide mark; PRC 1996). The northern and eastern shores of the shipyard are developed with dry-dock and berthing facilities for ship repair. The southern shore is undeveloped and consists mainly of fill. The offshore property surrounding the shipyard can be divided into three geographic areas described below:

- *India Basin*: The north area consists of a small portion of India Basin bordered to the west by shipyard property, to the south by the submarine base area, and to the east by inactive submarine berthing slips. Information indicates that this area has not been dredged.

- *South Basin*: This is a moderate-sized, shallow inlet lying between the southern shore of Parcel E and northern shore of Candlestick Park. The South Basin receives freshwater inflow from Yosemite Creek. Information indicates that this area has not been dredged.

- *Berthing slips*: This area is the east-northeastern flank of the facility, extending from the inactive submarine berthing slips of Parcel B eastward and then southward to the slips and drydocks of Parcels C and D, terminating at the mouth of South Basin. Water in this area is relatively deep because the dry-docking and berthing facilities were periodically dredged between 1942 to 1986 to support various shipyard activities.

The aquatic habitats of India Basin and South Basin include (1) intertidal zones, which frequently contain man-made materials such as building debris, pier pilings, dock

embankments, and rip-rap; and (2) subtidal areas composed of unconsolidated mud substrates. India Basin is marginally isolated from the open waters of San Francisco Bay, while South Basin is substantially isolated from the open waters of the Bay. Aquatic habitats near the berthing slips next to the dry-dock and berthing facilities primarily consist of open-water areas influenced by San Francisco Bay.

Previous Environmental Investigations: Sediment Chemistry and Toxicity

ESA 1987: Homeporting Study

Environmental Science Associates prepared an Environmental Impact Statement (EIS) to assess the potential effects of home porting two ships of a battleship battle group, the *U.S.S. Missouri* and an escort cruiser, and a nine-ship cruiser destroyer group in San Francisco Bay. The main focus of this study addressed the potential environmental effects of the removal and disposal of dredge sediments from areas of proposed use. The EIS examined site selection at Naval Air Station Alameda, Naval Station Treasure Island, and Hunters Point Naval Shipyard. The homeporting study included ten testing sites, three of which were located at the shipyard. The selection of the shipyard as the preferred alternative homeporting site resulted in extensive environmental analyses at North Pier, South Pier, and Dry Dock 4 (ESA 1987a). Environmental analyses included testing dredge sediments to verify and expand existing chemical toxicity information. Each sampling location was divided into five replicate sublocations where sediment was collected with a coring device. Each core from the five sublocations was composited and tested for trace elements, cyanide, pesticides, PCBs, PAHs, phenolic compounds, total phthalates, and VOCs. Sediment from two of the sample locations was used in suspended particulate and solid phase bioassays.

EMCON 1987

In 1987, EMCON performed chemical and bioassay tests on dredge sediments in support of a maintenance dredging permit application for Dry Dock 4 at Hunters Point (EMCON 1987; ATT 1991). Three replicate surficial sediment samples were collected from each of five sampling sites near Dry Dock 4. Sediment samples were analyzed for sulfides, cyanides, trace elements, VOCs, SVOCs, pesticides, PCBs, and radioactivity. Both suspended particulate and solid-phase bioassays were performed on sediment samples collected from the Dry Dock 4 area.

Intertidal Sediment Study

During 1991 and 1992, Harding, Lawson and Associates collected sediment samples in the intertidal zone of the Hunters Point Naval Shipyard perimeter in India Basin and South

Basin. Most samples were collected along the Bay edge of Parcel E to determine whether landfill contaminants had leaked from that parcel. The sediment samples were tested for a full suite of contaminants. No document for this study was found, but the raw data are presented in Appendix C of Volume II of the ERA for Hunters Point (PRC 1996).

ATT 1991: Environmental Analysis and Sampling Plan

The ESAP, implemented in 1991, assessed the presence of chemicals in sediments and water of the nearshore areas of the shipyard (ATT 1991). The ESAP program measured concentrations of chemicals in sediments and water within the boundaries of the shipyard and used these same sediments for toxicological testing.

Seventeen sediment collection stations were located in the intertidal and offshore around the perimeter of the shipyard. Three offshore reference stations were also identified: south of Candlestick Park, north of Sierra Point, and in the middle of San Pablo Bay. These stations were chosen to assess potential contamination from onshore sources. Ten grab samples of surficial sediments were collected randomly within the sediment stations.

PRC 1996: ERA

The Phase 1B Ecological Risk Assessment (ERA) for the Hunters Point Shipyard collected data to: (1) obtain a general view of the nature and extent of the offshore contamination; (2) determine the risk to aquatic receptors posed by offshore contamination using quantitative or qualitative measurements; and (3) further define the risk posed to terrestrial receptors from onshore contamination. Sampling locations included (1) storm water outfall discharge zones, (2) areas offshore from the IR sites, (3) offshore areas where spills or discharges have been observed or documented, and (4) two sampling sites not previously sampled (Sites S01 and S02) but added at the request of California Regional Water Quality Control Board (PRC 1996).

Samples were collected from 28 transects leading from onshore sources to offshore sediments, as well as from two individual sampling locations not associated with a transect (S01 and S02). Surface sediment samples were collected at 105 stations. The vertical extent of contamination was assessed by collecting three-foot cores at eight stations and six-foot cores at eleven stations. All surface sediments and associated sediment pore water were analyzed for total trace elements, SVOCs, pesticides, PCBs, organotins, and total petroleum hydrocarbons (TPH). VOCs were analyzed at a limited number of stations. Sediments were also analyzed for pH, ammonia, total organic carbon (TOC), grain size, acid volatile sulfide and simultaneously extracted metals (AVS/SEM), and sediment biochemical oxygen demand

(BOD). Sediment pore water was analyzed for ammonia, dissolved organic carbon (DOC), pH, salinity, and sulfides.

An amphipod whole sediment test was used to test sediment, and an echinoderm abnormal development test was used to test sediment pore water. Samples were collected at 37 surface sampling locations to determine sediment toxicity. The MICROTOX bioassay was performed at 35 additional sampling locations, in addition to the amphipod and echinoderm sampling locations. Invertebrate species, such as polychaetes and clams, were collected by sieving sediments obtained in grab samples from ten selected intertidal areas where shorebirds have been observed feeding or are expected to feed. The tissue was analyzed for metals, PAHs, pesticides, PCBs, and organotins.

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Naval Air Station Alameda

Location/Background

Naval Air Station (NAS) Alameda is on Alameda Island, at the western end of Alameda, California. Alameda Island lies along the eastern side of San Francisco Bay next to the City of Oakland. The base, which occupies 2,634 acres, is about two miles long and one mile wide. The property includes 1,526 acres of land and 1,108 underwater acres. The base is bordered to the north by the Oakland Inner Harbor, and to the west and south by San Francisco Bay. To the east is a mixture of industrial, residential, and public land uses including shipyards, naval supply centers, single-family homes, apartments, restaurants, retail stores, schools, and a state beach. The majority of the base was created by filling tidelands, marshlands, and sloughs.

Before the U.S. Army acquired the NAS site from the city of Alameda in 1930, at least two large industrial sites, a borax processing plant and an oil refinery, were located on Alameda Island. In 1936, the U.S. Navy acquired title to the land and began building the air station. Following the end of World War II, NAS Alameda returned to its primary mission of providing facilities and support for fleet aviation activities. The eastern portion of NAS is developed with offices, residences, and industrial facilities. The western portion is primarily developed with runways and support facilities. The Air Station is being investigated for reuse options following its closure in 1997.

Offshore/Wetland Areas of Concern

Two major wetland areas have been identified at NAS Alameda: the West Beach Landfill Wetland and the Runway Wetland. The subtidal habitat at NAS Alameda comprises the open-water area on the north, west, and south sides of Alameda Island. This area has been divided into six areas, known as the Oakland Inner Harbor, Western Bayside, Skeet Range, Seaplane Lagoon, South Shore, and Breakwater Beach areas. The two wetland areas and three of the subtidal areas (Oakland Inner Harbor, Western Bayside, and Seaplane Lagoon) are the five areas at NAS Alameda that have been investigated as part of the Ecological Assessment (EA).

Previous Environmental Investigations: Sediment Chemistry and Toxicity

This section describes major studies that have included field investigation of contamination at or near Alameda Naval Air Station, focusing on studies that have collected data on sediment chemistry or toxicity. The large number of dredging and pre-dredging studies conducted in Inner Oakland Harbor are not summarized here.

ESA 1987: Homeporting Study

Environmental Science Associates (ESA 1987) prepared an EIS to assess the potential effects of homeporting two ships of a battleship battle group, the *U.S.S. Missouri* and an escort cruiser, and a nine-ship cruiser destroyer group in San Francisco Bay. The EIS examined site selection at Naval Air Station Alameda, Naval Station Treasure Island, and Hunters Point Naval Shipyard. The homeporting study included sediment sampling near Alameda.

E&E 1983

In 1983, Ecology and Environment conducted an initial assessment at NAS Alameda, which included sediment sampling in the Seaplane Lagoon.

Whaler Associates 1985

In 1985, Whaler Associates collected eight sediment samples from the bottom of the Seaplane Lagoon and two sediment samples from the channel outside the lagoon. The samples were analyzed for trace elements, PCBs, and pesticides.

Various Studies (1987, 1988, 1991)

Several groups conducted sediment sampling in 1987, 1988, and 1991 to characterize maintenance dredging materials in the outer breakwater area of Piers 1, 2, and 3 next to the Seaplane Lagoon (HLA 1988). Bioassays were conducted using mussel (*Mytilus edulis*) larvae as the test organism.

In 1991, PRC collected 151 surface soil samples, twelve wetland sediment samples, 23 wetland surface water samples, and subsurface soil samples from the West Beach Landfill for chemical analysis (PRC 1991). Sediment samples were analyzed for SVOCs, organochlorine pesticides, PCBs, total recoverable petroleum hydrocarbons, and trace elements.

PRC 1994: Environmental Assessment

In 1993, PRC conducted an environmental assessment that included sampling and analysis of surface water, storm water, and sediments at each of the five study areas; sediment and

storm water bioassays; bioaccumulation studies using a clam; and benthic infauna analyses (MEC 1994; PRC 1994). Wetlands were also delineated and evaluated using the Wetland Evaluation Technique.

Following are further details about the sediment and toxicity testing performed at each of the study areas:

Surficial sediments were collected and analyzed at seven locations in the West Beach Landfill Wetland, four stations in the Runway Wetland, ten stations in the Oakland Inner Harbor, 14 stations in the Western Bayside area, and seven stations in the Seaplane Lagoon. Sediment cores were collected and analyzed at a subset of the surficial sampling stations at each of the subtidal study areas: three stations in the Seaplane Lagoon, six stations in the Western Bayside area, and two stations in the Oakland Inner Harbor.

Sediment bioassay testing included a ten-day solid phase test with *Eohaustorius estuarius* and a 28-day chronic toxicity test with *Neanthes arenaceodentata* at each of the sediment sampling stations at the West Beach Landfill Wetland and the Runway Wetland

At the three subtidal areas, the same bioassay tests as at the wetland sites were performed at each of the sediment sampling locations, as well as a liquid-phase normal/abnormal development assay using *Mytilus edulis*..

At each of the study areas, bioaccumulation studies using a clam (*Macoma nasuta*) and analyses of benthic populations for species diversity were performed for only those samples that exhibited significant effects in the bioassay testing.

Planned Environmental Investigations: Sediment Chemistry and Toxicity

In 1996, the U.S. Navy updated the draft 1994 EA, revising the ecological risk assessment approach and identifying data gaps and further sampling to address these gaps (PRC 1996a). No new data were generated in this document. A field sampling plan was developed to address these data gaps in 1996 and sampling occurred in 1997 (PRC 1996b). Following is a brief summary of the sediment sampling and toxicity testing conducted as part of the follow-on ecological assessment at Alameda, based on the 1996 workplan:

West Beach Landfill Wetland

Six surface sediment sampling locations were selected in this area to address data gaps and supplement data collected during the draft EA.

Runway Wetland

Three surface sediment sampling locations were selected in this area to address data gaps and supplement data collected during the draft EA.

Western Bayside

Three surface sediment locations near three outfalls were selected in this area to address data gaps and supplement data collected during the draft EA.

Skeet Range

Twelve locations will be sampled at two depth intervals; from 0 to 1.5 feet below the surface of the sediment, and from 1.5 to 3.0 feet below the surface. Echinoderm larval development bioassays will be conducted using pore water from four randomly selected locations in this area.

Breakwater Beach

Twenty-one locations will be sampled at two depth intervals; one interval from 0 to 3.0 feet below the surface of the sediment, and one interval from 3.0 to 6.0 feet below the surface. The locations are based upon transects from each of seven outfalls along the southern shore of NAS Alameda in the Breakwater Beach area. Seven locations will be sampled for pore water and invertebrate bioassays.

South Shore

Surface sediment grab sample locations in the South Shore area were selected near five outfalls not previously sampled during the draft EA.

Seaplane Lagoon

Additional characterization of Seaplane Lagoon including sediment sampling has been conducted, but more specific information on the sampling program was not available.

BERC

Under separate contract with the U.S. Navy, the Berkeley Environmental Restoration Center (BERC) is developing and demonstrating new approaches to site assessment and remediation at NAS Alameda. BERC has been conducting additional ecological work in the wetlands at NAS Alameda and is coordinating with PRC to evaluate the results.

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Naval Weapons Station (NWS) Concord

Location/Background

Naval Weapons Station (NWS) Concord is in the north-central portion of Contra Costa County, California, approximately 30 miles northeast of San Francisco. The 13,000-acre facility is bounded by Suisun Bay to the north and by the city of Concord to the south and west. NWS Concord is the major naval explosive ordnance transshipment facility on the West Coast. The facility provides storage, maintenance, and technical support for ordnance operations. Homeported ships also unload fuel waste to a truck for disposal at a Class I permitted facility. The facility contains three main separate land holdings: the Tidal Area, the Inland Area, and a radiography facility in Pittsburg, California. The town of Clyde and the Los Medano Hills separate the 6,200-acre Inland Area from the Tidal Area. Seal Creek (also know as Mt. Diablo Creek) flows through the Inland Area into Hastings Slough, which drains into Suisun Bay. The Tidal Area is divided between mainland (6,077 acres) and islands (1,571 acres). Most of the facilities located in the Tidal Area are designated for ordnance operations. Almost all these Tidal Area facilities were built in areas that were constructed by adding large amounts of fill material in wetland areas. NWS Concord was placed on the National Priorities List in 1994.

Offshore/Wetland Areas of Concern

NWS Concord has been divided into two major areas of investigation: the Inland Area and Tidal Area. Three natural surface water bodies are located within or next to the Tidal Area at NWS Concord: Suisun Bay, Hastings Slough, and Belloma Slough. Otter's Sluice is an artificial channel running along the western and southern sides of the Tidal Area.

Previous Environmental Investigations: Sediment Chemistry and Toxicity

Lee et al. 1988: Initial Assessment Study

An initial assessment study (IAS) at NWS Concord identified and ranked sites and determined whether they posed a potential danger to human health or the environment. The IAS identified 14 Tidal Area sites and 12 Inland Area sites. No sediment sampling was conducted during the IAS. Ten of the 14 Tidal Area sites were evaluated as areas of potential contamination and recommended for further study. Six of these (Kiln Site, Allied Sites A and B, Coke Pile Site, K-2 Area, and G-1 Area), collectively known as the Litigation Area sites, were studied by the U.S. Army Corps of Engineers Waterways Experiment Station (Lee et al. 1988). Field investigation of these sites for the 1986 study did not include

sediment sampling, focusing instead on contamination in soils and vegetation. Clam and earthworm tissue were also collected and analyzed. The four remaining Tidal Area sites of concern include Tidal Area Landfill (Site 1), R Area Disposal Site (Site 2), Froid and Taylor Roads Site (Site 9), and Wood Hogger Site (Site 11).

IT 1992: Site Investigation

International Technology Corporation prepared a site investigation report on these four Tidal Area sites (IT Corp. 1992). Activities for this investigation included sampling and chemical analyses of surface water, sediments, soils, and groundwater at the Tidal Area sites. In addition, a caged clam study was conducted at the surface water/sediment sampling stations to evaluate potential bioaccumulation of contaminants. No toxicity testing was performed in this study. In terms of sediment sampling, two stations were sampled at the Tidal Area Landfill Site: six stations at the R Area Disposal Site, two at the Froid and Taylor Roads Site, and four Wood Hogger Site. At each sediment station, two sediment samples were obtained and analyzed: one from the sediment surface to an approximate 0.5-foot depth and the second from a depth of approximately 1.0 to 1.5 feet below the surface.

Confirmation Sampling

In 1993, a confirmation sampling study performed by PRC and Montgomery Watson consisted of limited sampling of surface soil, groundwater, surface water, and sediments. The samples were collected from some of the same sampling locations as reported in the site investigation. The sampling strategy was intended to (1) confirm the presence of chemicals detected during the site investigation and (2) to evaluate the practical quantitation limits obtainable from the samples. One sediment sample was collected southwest of the Tidal Area Landfill, and two sediment samples were collected along the eastern site boundary of the R Area Disposal Site. No sediment sampling was conducted in the confirmation sampling at either the Wood Hogger Site or the Froid and Taylor Roads Site, according to a summary of the confirmation sampling in the Interim Draft RI Report (PRC 1996a).

PRC 1996a: Phase 1A RI

In 1995 and 1996, a field investigation was conducted at the four Tidal Area sites as part of the Phase IA Remedial Investigation. Activities for this investigation included sampling and chemical analyses of surface and subsurface soils, sediments, and surface water at the four sites. In addition, groundwater elevation and tidal influence data were collected. No toxicity testing was performed. According to PRC, much of the data obtained in the site investigation by IT Corporation was of limited use because data validation was not performed according to EPA guidelines and IT Corporation "did not evaluate whether the

chemicals detected were actually present in the samples or resulted from laboratory or sampling contamination" (PRC 1996a). The Phase IA remedial investigation "obtain[ed] data of known quality using both unbiased and purposive sampling approaches" in part (it is assumed) to correct for the data validation problems of the site investigation. Two sediment samples were collected in Otter Sluice near the R Disposal Site (one near the tidal gates near Suisun Bay, one on the southwest corner of the site), and three samples in Otter Sluice near the Wood Hogger Site. No other sediment sampling was conducted.

PRC 1996b: Draft Qualitative Ecological Assessment

In 1996, PRC investigated the Litigation Area of Concord NWS to identify sources of risk to ecological receptors and to assess whether the parameters now being monitored are adequate and appropriate for the long-term evaluation of the success of the remedial and restoration activities. As part of this investigation, surface sediments at 77 locations in the ditches, sloughs, ponds, and wetlands of the Litigation Area were sampled and analyzed for chemistry. Fifty-four subsurface sediment locations were sampled. In addition, surface and subsurface sediments were sampled and analyzed at nine confirmation sampling locations. No sediments in Suisun Bay offshore from Concord NWS were sampled for this investigation.

Planned Investigations: Sediment Chemistry and Toxicity

In the Interim Draft Remedial Investigation Report, PRC states that RI field investigation Phase 1A results indicated that Phases 1B and II of the RI will not be necessary (PRC 1996). Phases 1B and II were to be conducted if the results of Phase 1A indicated the need to evaluate the groundwater pathway or to further define the extent of contamination identified during Phase 1A. The Draft RI recommends that feasibility studies be prepared to evaluate potential remedies at the R Area Disposal Site, the Froid and Taylor Roads Site, and the Wood Hogger Site. Additional evaluation under a quantitative ecological risk assessment at any of the Tidal Area sites was not recommended.

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Mare Island Naval Shipyard

Location/Background

Mare Island Naval Shipyard is northeast of San Francisco in San Pablo Bay. The City of Vallejo is directly east from the shipyard across Mare Island Strait. Since its establishment in 1854, Mare Island Naval Shipyard's primary mission has been fleet maintenance, overhaul, construction, and refueling. Ship building and ship maintenance activities have included operating machine shops and fueling activities. In the recent past, the primary mission was submarine overhaul and repair, including handling and storage of radioactive materials. The southern portion of Mare Island, known as the Concord Annex, has been used for munitions storage, ordnance production, and disposal operations since 1857. Since ordnance-related activities ceased in 1973, the area has been primarily used for storing inert materials and supplies. Mare Island Naval Shipyard was closed in April 1996 and is now being investigated for remediation and reuse options.

Offshore/Wetland Areas of Concern

The 5,460-acre Mare Island is bounded on the south by Carquinez Strait, on the west by San Pablo Bay, on the east by Mare Island Strait (the Napa River), and on the north by the Napa Marsh and historic diked marshlands. The site contains about 1,450 acres of tidal and non-tidal wetlands and 2,360 acres of submerged lands.

The western portion of the island next to San Pablo Bay is largely undeveloped open space and low-lying wetlands. The shipyard's main activities and waterfront are located on the eastern side of the island next to Mare Island Strait. Extensive dredging and maintenance operations have been conducted within the Strait to berth fleets and provide safe navigation for naval vessels. The U.S. Army Corps of Engineers dredges the channel in the Strait and disposes of the spoils in Carquinez Strait. Mare Island and its contractors dredge the berthing, dock, finger pier, and Fleet Reserve Pier areas, and pump the spoils to several

upland disposal ponds, most of which are on the west side of the island. Ten active dredge ponds cover about 500 acres, though a number of inactive ponds have been closed over the years. Dredge material from the ponds has been used (1) to widen and raise existing dredge pond berms, (2) to create pistol and rifle range berms, (3) as fill material for various locations on the island, and (4) as surface cover material for the facility landfill. The preliminary assessment of the ordnance sites conducted by PRC Environmental Management contains more information on dredging operations and the dredge ponds (PRC 1995).

Previous Environmental Investigations: Sediment Chemistry and Toxicity

900 Area investigations

IT Corporation conducted a study in 1988 to determine the nature and extent of contamination caused by sandblasting operations in the 900 Area near Building 900 and Pier 24 at the southern end of the industrial area at the Mare Island Naval Shipyard (IT 1992). The area has been used for abrasive blasting of a wide variety of submarine parts since 1952. Field investigations for this study focused in two areas: (1) chemical analysis of soils, sediments, and groundwater; and (2) distribution of spent and virgin greensand, local watershed delineation, and topographic surveying of the site. Soil and sediment samples were collected in a grid pattern comprised of 63 sampling locations: 24 in the tidally influenced sediments next to the Strait, three in the Strait; and the rest in soils next to the primary sandblasting area. All samples were analyzed for chromium, copper, lead, nickel, and zinc. Fifty samples were analyzed for tributyl tin.

A large portion of the blasting sand described in the Initial Assessment Study (IAS; Ecology and Environment, Inc. 1983) was removed between the time of that study and the sampling for the IT study in 1988. Following the IAS, sampling by Richesin & Associates in 1986 in the 900 Area included four soil borings onshore and one boring in tidally influenced sediment.

Power and Chapman 1989

This study collected and analyzed sediment and water samples and performed bivalve larvae bioassays on sediments to be dredged from Mare Island. Sediment samples for bulk chemical testing and bivalve larvae bioassays were collected in 1988 from six dredging areas within Mare Island Strait. Four sediment cores from separate locations within each sampling area were collected. Reference sediments were collected from the Carquinez disposal site.

Planned Environmental Investigations: Sediment Chemistry and Toxicity

Phase I ERA

Five offshore areas at Mare Island are proposed for study during the Phase I ERA, all of which are in Mare Island Strait (PRC 1997). These offshore areas were divided into two study areas for the investigation based upon whether unexploded ordnance was suspected in the area. The primary objective of the sampling at the three sites (Fleet Reserve Piers, Berths 1 and 2, and South Mare Island Strait) suspected of containing unexploded ordnance was to collect data to support the removal action planned for the ordnance (i.e., dredging and disposal). The primary objective of the sediment sampling in the other two areas (North Building Ways and North Mare Island) was to collect data to perform an ERA. Field sampling began in June 1997.

For the three areas potentially containing unexploded ordnance, a total of 31 sampling cells was selected. Sampling cells will be characterized by compositing sediment core samples collected in five randomly selected boring locations. The core will be divided into two sections (0- to 5-, and 5- to 10-feet below ground surface). The shallow section of the core will be analyzed for bulk sediment chemistry and whole-sediment and elutriate bioassays, and bioaccumulation. The deeper sections will be analyzed for bulk sediment chemistry only.

For the two areas without unexploded ordnance, 19 sampling cells in the North Mare Island Strait area and six sampling cells in the North Building Ways area were selected. One grab sample will be collected in each cell and analyzed for bulk sediment and pore water chemistry and bioassays. An additional grab sample will be collected in cells that contain an outfall. Additional grab samples will be taken under two piers, near the quay wall, and in selected intertidal areas. Also, two ten-foot cores will be taken in both areas to provide information on the vertical nature and extent of contamination.

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Hamilton Army Airfield

Location/Background

Hamilton Army Airfield is in Novato in Marin County, about 22 miles north of San Francisco. The base is bounded on the east by San Pablo Bay, on the west by U.S. Highway 101, and on the north and south mostly by agricultural land. The base served as a training field and staging area for Pacific operations during World War II. Declared surplus in 1974, the base is being investigated for remediation and reuse options following its closure in 1994.

Offshore/wetlands of concern

The base includes 88 acres of coastal salt marsh beyond the southeast end of the runway between the perimeter levee and San Pablo Bay and seven acres of seasonal wetlands, primarily near the northwest end of the runway. Much of the coastal salt marsh is inundated during high tides; at low tides, the wetland is almost completely drained except for perched ponds and deep channel segments. High marsh areas are dominated by pickleweed while low marsh areas are dominated by California cordgrass. The mudflats extend from the bayward edge of the emergent coastal salt marsh to the line of annual low water.

Previous environmental investigations: Sediment Chemistry and Toxicity

ESI 1993/USACE 1994

Engineering-Science, Inc. (ESI) conducted an environmental investigation for the Base Realignment and Closure (BRAC) Property at the airfield in 1993. The investigation defined the distribution, types, and concentrations of contaminants at the base, and provided a risk assessment of those contaminants. The U.S. Army Corps of Engineers provided additional information in preparation for remedial activities at the airfield. The scope of the investigation included collecting and analyzing soil, sediment, and groundwater samples from six areas within the BRAC Property that required additional investigation. These two investigations included sediment sampling in the coastal salt marsh and in the bay near the three pump station discharge points. Nineteen locations at two depths were sampled and analyzed for sediment chemistry.

USACE 1996

The Army Corps of Engineers provided additional information from investigations at six specific Operable Unit 2 sites of the BRAC property. The Accelerated Environmental Cleanup

Work Plan for the BRAC parcel at the airfield recommended additional investigation at this property, including sediment sampling in the coastal salt marsh. Twenty-five locations in the marsh within the BRAC property were sampled along with eight locations north and south of the BRAC property that were used as reference areas. Samples were collected at depths ranging from 0 to 36 inches and analyzed for sediment chemistry.

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United Heckathorn

Location/background

United Heckathorn is on the eastern shoreline of San Francisco Bay in the city of Richmond. The site includes the land portions of the Levin-Richmond Terminal on South Fourth Street and Wright Avenue, and a portion of the submerged areas in the nearby Lauritzen Channel, Santa Fe Channel, Parr Canal, and Richmond Inner Harbor. United Heckathorn operated as a chlorinated pesticide formulator from 1947 to 1966 in a facility located along the shoreline of the Lauritzen Channel. The chemical manufacturer sent technical grade pesticides to United Heckathorn. Once on site, the pesticides were ground in air mills, mixed with clays and other ingredients, and packaged for shipment off-site. Equipment wash water containing DDT and other pesticides was discharged directly into the Lauritzen Channel through drains or by runoff from spillage to the ground surface.

Offshore/wetlands of concern

The aquatic habitats of concern at the site are the Lauritzen Channel, Parr Canal, the Santa Fe Channel, Richmond Inner Harbor, and the adjacent areas of San Francisco Bay. These waterways are highly industrialized with an armored shoreline consisting of concrete, riprap,

rubble, and piers. The water in the area is between 15 and 35 feet deep and the substrate is soft bottom.

Previous Environmental Investigations

HLA 1986

Harding, Lawson and Associates collected 19 sediment cores in Lauritzen Channel, from which 33 samples were analyzed for DDT. Two composite samples were analyzed for trace elements, PCBs, pesticides, and other organic compounds.

Levine-Fricke 1990

Levine-Fricke collected sediment cores from the Lauritzen Channel and surface sediments from the Santa Fe Channel and analyzed the samples for pesticides, PCBs, and other organic compounds.

Battelle 1990,1992

Battelle collected sediment cores from the Santa Fe and Inner Richmond Harbor channels in two studies and analyzed the samples for trace elements, organotins, pesticides, and other organic compounds.

Battelle 1994

Sediment cores were collected from 53 stations in the Lauritzen Canal, Santa Fe Channel, Inner Harbor Channel, and Parr Canal. Vertical subsamples from each sediment core were analyzed for chlorinated pesticides. Sediment from selected cores was also analyzed for other contaminants. Younger Bay Mud sediment from multiple stations was mixed to form composite samples representing various segments. These composites were used for solid-phase toxicity (*Rhepoxynius abronius*) and bioaccumulation tests (*Macoma nasuta*). The probable quality of effluent produced by dewatering sediment was evaluated by chemical and toxicological testing (*Holmesimysis costata* and *Mytilus galloprovincialis*) of suspended-particulate phase and elutriate samples.

EPA 1994: ERA

Field studies for this investigation included bulk sediment toxicity testing, benthic community analyses, bioaccumulation testing, and chemical analyses in sediments, surface waters, and tissues of benthic organisms and fish and shellfish collected in trawls. Sampling was conducted in Lauritzen, Santa Fe, and Richmond Inner Harbor channels. Sediment samples were collected at nine primary stations—four in Lauritzen Channel, two in Santa Fe Channel, and three in Richmond Harbor Channel. Five replicate sediment grabs were taken

at each of the primary stations for chemical analysis and biological testing. In addition, a single sediment grab was taken at eleven other stations located between primary stations in the inner area and extending into San Francisco Bay.

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