

1994 Annual Report



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San Francisco Estuary Regional Monitoring Program for Trace Substances

A Cooperative Program Managed and Administered by the San Francisco Estuary Institute



Regional Monitoring Program Participants

Municipal Dischargers:

City of Benicia **Burlingame Waste Water Treatment Plant** City of Calistoga Contra Costa County Sanitation District Central Marin Sanitation Agency Delta Diablo Sanitation District East Bay Dischargers Authority East Bay Municipal Utility District Fairfield-Suisun Sewer District City of Hercules Las Gallinas Valley Sanitation District Millbrae Waste Water Treatment Plant Mountain View Sanitary District Napa Sanitation District Novato Sanitation District City of Palo Alto City of Petaluma City of Pinole Rodeo Sanitary District Program City of San Francisco City of San Jose/Santa Clara City of San Mateo Sausalito-Marin City Sanitation District Sewerage Agency of Southern Marin San Francisco International Airport Sonoma Valley County Sanitation District South Bayside System Authority City of South San Francisco/San Bruno City of St. Helena City of Sunnyvale Marin County Sanitary District #5, Tiburon Union Sanitary District Vallejo Sanitation and Flood Control West County Agency Town of Yountville

Industrial Dischargers:

C & H Sugar Chevron USA Dow Chemical Company EXXON Company, USA General Chemical Pacific Refining Company Rhone-Poulenc Shell Oil Company TOSCO Refining Company Union Oil Company USS-POSCO

Cooling Water:

Pacific Gas & Electric

Stormwater:

Alameda Countywide Clean Water Program CALTRANS Contra Costa Clean Water Program Fairfield-Suisun Sewer District Marin County Stormwater Pollution Prevention Program City and County of San Francisco San Mateo County Stormwater Pollution Prevention Program Santa Clara Valley Nonpoint Source Pollution Control Program Vallejo Sanitation and Flood Control

Dredgers:

Benicia Terminal Industries Port of Oakland Port of Redwood City Port of Richmond Port of San Francisco US Army Corps of Engineers US Navy, Western Division

EXECUTIVE SUMMARY =

his is the second Annual Report of the Regional Monitoring Program for Trace Substances (RMP). It describes concentrations of pollutants in water, sediment, and tissue samples of oysters, mussels, and clams at 15 to 24 sampling locations for three discrete sampling events - during the wet season in February, in April during a period of declining Delta outflows, and during the dry season in August. The sampling stations are located throughout the Estuary and at the major tributaries including the mouths of the Guadalupe River and Coyote Creek in the extreme southern portions of the Estuary to the confluence of the Sacramento and San Joaquin Rivers (Figure 1). In 1994, water samples were also taken at two upstream locations at Rio Vista (Sacramento River) and Manteca (San Joaquin River) to determine river contaminant concentrations during a six-week period in spring.

The RMP is one important component described in a document entitled "Regional Monitoring Strategy" (SFEP 1993). This document was prepared as part of the Comprehensive Conservation and Management Plan for the San Francisco Estuary and is centered around the five key management issues identified in the Plan: pollution prevention and reduction; dredging and waterway modification; biological resources; land use management; and water use. A large number of management actions in these five areas were identified that could contribute to the restoration of a "healthy" Estuary. For most of the five key management issues, some monitoring efforts are already in place so that the outcome of individual management actions taken can be evaluated. The RMP provides information on how contaminant concentrations in the Estuary are responding to pollution prevention and reduction steps and, ultimately, if financial resources spent on these efforts have the desired effects.

The RMP evolved out of a pilot program funded under the State's Bay Protection and Toxic Cleanup Program, after the Regional Water Quality Control Board had developed a funding and implementation structure. Sixty-three public and private entities that discharge treated waste water and cooling water or are involved in dredging activities contribute the financial resources necessary to conduct the RMP. Many of these program participants also contribute expertise or logistical support. The San Francisco Estuary Institute, as the entity designated to implement the Regional Monitoring Strategy, is administering the program.

The objectives of the Regional Monitoring Program for Trace Substances can be summarized as follows:

 to describe the condition of the Estuary with respect to toxic and potentially toxic trace elements and organic contaminants in the water, sediment, and the tissue of bivalve mollusks;

2) to develop a long-term data base on trends in trace contaminant concentrations in water and sediments;

3) to determine if water and sediment quality are in compliance with established regulatory objectives; and

 to provide a data base on trace contaminants which is compatible with data being developed in other ongoing studies.

The Program, as currently designed, does not include elements to determine contaminant sources, mechanisms of contaminant transport and fate, or ecological effects, but may include these additional objectives at some time in the future. The interpretation of RMP data and synthesis of results in the context of the already existing knowledge base is not an explicit objective, although this report is a first attempt at serving that purpose to the extent that available resources allow.

In 1994 more than 100 individual chemical parameters were analyzed in water, sediment and tissue between two and three times per year. Bioassays on water and sediment samples were also conducted to determine possible toxicity to selected organisms. 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. In 1994, two stations adjacent to the wastewater outfalls of the Cities of San Jose and Sunnyvale were added on a trial basis.

Unlike the first sampling year, 1994 was relatively dry and produced only about 40% of the peak runoff that occurred in 1993. As Delta outflow decreased, salinities generally increased with each sampling period. The five parts per thousand isohaline, which the Regional Board has proposed as the dividing line for application of fresh water and marine water quality objectives, moved progressively up the Estuary.

Water Monitoring

Trace contaminant concentrations in Estuary water were far from uniform among the 24 stations and among the three sampling periods in 1994. For example, dissolved and total concentrations of most contaminants typically differed by one to two orders of magnitude. However, dissolved lead differed 10,000-fold among the 22 stations, while dissolved selenium and total arsenic varied by a factor of 6.5 and 2.5, respectively.

Two general gradients in total trace metal concentrations were observed in 1994: one gradient, with the highest levels at the southern slough stations decreasing toward the Central Bay, and the other from elevated concentrations in San Pablo Bay to lower levels in the Sacramento and San Joaquin Rivers. Only selenium and mercury were exceptions to these patterns. Selenium exhibited only a slight gradient from the South Bay to the rivers, and mercury had elevated concentrations in the rivers in August. Dissolved copper, mercury, nickel, lead, selenium, and zinc, and total silver and selenium were always highest at the slough stations, located in the bayward ends of Coyote Creek and the Guadalupe River. These tributaries receive treated municipal and industrial effluent, as well as runoff from the Santa Clara Valley. It is not possible from current RMP data to determine which of those possible sources are contributing which contaminants. Dissolved and total (the sum of dissolved and particulate forms) concentrations of most trace elements were generally lowest in the Central Bay, reflecting the influence of oceanic flushing. At times, arsenic, selenium, silver, and zinc were lowest at the two Sacramento and San Joaquin River stations, located just above their confluence.

Organic contaminants were distinctly elevated in the Estuary compared to the reference station outside the Golden Gate. PAHs and PCBs had similar spatial distributions, with relatively high concentrations in the South Bay and the northern Estuary, lower concentrations in the Rivers, and lowest concentrations at the Golden Gate. Compared to the PAHs and PCBs, pesticides tended to have higher concentrations in the northern Estuary and high concentrations in the Rivers. Special sampling on the San Joaquin River at Manteca and the Sacramento River at Rio Vista vielded the highest concentrations of most pesticides in 1994, including DDTs, chlordanes, and dieldrin. The Manteca station had a median concentration of DDTs that was 22 times higher than the median for RMP base stations. Diazinon was found at a high concentration at Coyote Creek during the wet season, suggesting that runoff from the Santa Clara Valley is a source of this insecticide.

Trace elements in both dissolved and particulate phases usually occurred in the highest concentrations at the southern slough stations. Seasonal differences in trace contaminant concentrations may suggest different sources. For example, dissolved zinc, dissolved mercury, and total selenium were higher in February and April than during the dry-season sampling in August, pointing toward runoff as a likely source of these elements. Conversely, elements that are elevated during the dry season, with little surface runoff entering the Estuary, suggest continuous sources, such as waste water outfalls, atmospheric deposition, or mobilization from sediments.

For trace organic contaminants, a switch in contractors between the February and April cruises constrains interpretation of seasonal patterns in contamination. For example, measured diazinon concentrations were much higher in February samples. This pattern might be expected due to seasonal variation in the influence of urban runoff, but methodological differences provide an alternative explanation. Intercalibration exercises between the two contractors for water organics analysis are planned for 1996 to help determine the actual extent of seasonal variation.

The aquatic bioassays showed significant toxicity to the mysid *Mysidopsis* at the Napa River and Red Rock in February. Just which component(s) in the water at those stations caused the observed toxicity is not known. There were no obvious corresponding elevations in trace contaminants in the water in those samples.

Comparisons to Water Quality Standards

Concentrations of seven of the ten trace elements silver, cadmium, chromium, lead, selenium, silver, zinc - and total PAHs were below existing water quality criteria or objectives in 1994. However, concentrations for near-total and dissolved copper, total mercury and near-total nickel were often above U.S. EPA criteria. PCBs were well above the criteria at all saltwater stations sampled, similar to the situation reported in March 1993. Seven individual PAH compounds, heptachlor epoxide, dieldrin and p,p'-DDE were above water quality criteria. The insecticide diazinon was above the National Academy of Science guideline of 9,000 ppg at three freshwater stations in February. Despite the numerous exceedances of water quality guidlines throughout the Estuary, only two samples exhibited significant water toxicity.

Sediment Monitoring

The variability of contaminant concentrations in sediments in the San Francisco Estuary reflects the complexity of estuarine geochemical cycles and proximity to the varied sources of contamination. The adsorption of dissolved contaminants onto sediment particles, particle transport by rivers, streams, and storm drains into the Estuary, sediment mixing by currents, tides, and organisms that live in the sediment, and many other factors may affect what is measured by the RMP.

Similar to the spatial gradient observed for trace elements in water, the 1994 sediment samples exhibited the highest concentrations in the southern sloughs. Concentrations decreased into the Central Bay, then increased again in the northern Estuary (except at the coarse sediment stations), and decreased at the Rivers. Concentrations typically ranged over an order of magnitude except for silver and selenium which ranged over two orders of magnitude.

Concentrations of eight of the ten trace elements measured were highest at one or both southern slough stations (silver, cadmium, lead, chromium, copper, mercury, nickel, and zinc) for various sampling periods. Arsenic in sediments was highest at Pinole Point, and selenium was highest at the Napa River station. Excluding the southern slough stations, which are in close proximity to wastewater outfalls, the fine sediment stations in the northern Estuary had the highest average concentrations of arsenic, copper, chromium, mercury, nickel, selenium, and zinc during one or the other sampling periods. Honker Bay had the greatest number of incidents of elevated trace element concentrations in the northern Estuary reach.

Concentrations of all metals were almost always lowest at the coarse sediment stations. In particular, Red Rock, located just south of the San Rafael Bridge, most often had the lowest concentrations of trace elements in sediment. This probably reflects the sandy sediment there.

The elevated sediment concentrations observed in the southern sloughs parallel the patterns in water and reflect the proximity to large urban areas. Coyote Creek and Guadalupe Slough drain runoff, and receive treated industrial and municipal wastewater. The sediments in these sloughs probably function as geochemical sinks for dissolved and particulate contaminants coming into the Estuary.

Only a few of the trace elements were appreciably higher in one or the other sampling period. Silver, copper, and selenium were generally higher in February, and nickel, lead, and zinc were generally higher in August. Mercury concentrations showed no obvious seasonality.

For trace organic contaminants in sediments, the two most obvious patterns in the 1994 RMP data were 1) nearly all trace organic contaminants were highest in the South Bay, and lowest at the coarse sediment stations, and 2) concentrations were usually higher during wetseason sampling (February) than in the dry season (August).

Red Rock and the other coarse sediment stations generally had the lowest concentrations of trace organics. PAH and PCB concentrations at the northern Estuary fine-sediment stations were intermediate between the higher concentrations at stations to the south and the relatively low concentrations at the River stations. In contrast, DDT concentrations at the fine sediment stations in the northern Estuary were generally higher than those measured at the more southerly stations. The elevated p,p'-DDT sampled at Horseshoe Bay during both sampling periods is probably due to a nearby source of fresh DDT.

Total PAHs were comprised of a remarkably constant ratio of individual PAHs at nearly all stations and in both seasons. The homogeneous mixture of PAHs in sediment suggests that the sources also consist of homogeneous mixtures and that the rates of degradation of different PAHs are rather uniform throughout the Estuary. The profile of PAH compounds measured in sediment suggests that automobile exhaust is a primary source.

The most obvious seasonal pattern observed for trace organics was consistently higher PAH concentrations in February at 19 of 20 stations. No general seasonal pattern emerged for total PCBs. Total DDTs were higher in February than August at 13 of the 18 stations where it was measured. Alpha-HCH and dieldrin were also detected at most stations in February but were generally undetected in August.

The elevated trace organics concentrations in February 1994 samples, together with the observed seasonal trends during the previous year, suggest that trace organics contaminants concentrations in the Estuary are influenced by runoff or flows during wet weather. However, the mechanism behind the elevated concentrations is not clear.

Average trace element concentrations in each of the five Estuary reaches over the four RMP sampling periods in 1993 and 1994 were generally similar. There appeared to be very little variation in the South Bay and Rivers stations, with the most variation in the Central Bay and northern Estuary stations.

Sediment bioassays showed that nine of the 12 RMP stations tested indicated toxicity from one of the tests during one or the other of the sampling periods in 1994. The Alameda station was toxic to amphipods and mussel embryos during the February tests, but not in August. Napa River and Grizzly Bay were toxic to amphipods in February and to mussel embryos in August. The River stations were toxic to mussel embryos during both sampling periods. Stations in the northern Estuary (Napa River, Grizzly Bay), and the Rivers were the only stations to indicate toxicity during both sampling periods.

Comparison of the general patterns in sediment contamination with the sediment bioassay results show

that both elevated trace contaminant concentrations and significant toxicity were observed in the South Bay and northern Estuary. Sediment contamination was generally low in the Central Bay, and there was no sediment toxicity. More specifically, spikes in sediment PAHs at the Coyote Creek and Alameda stations in February corresponded to amphipod toxicity measured there. However, spikes in PCBs at Yerba Buena Island in February, and DDTs at Horseshoe Bay did not result in significant toxicity. Additionally, significant toxicity to bivalve larvae at the Rivers during both sampling periods did not correspond with any obviously elevated contaminant concentrations, although there were several ERL exceedances in the Rivers. It is not known which contaminants in sediments could have caused the apparent toxicity reported. Because sediment contains mixtures of numerous potential agents, it is difficult using the RMP data alone to determine which ones may have been responsible for the observed toxicity.

Comparisons to Sediment Quality Guidelines

Only two trace elements, cadmium and lead, were below both the "effects range low" (ERL) and "effects range median" (ERM) values at all stations during both sampling periods. ERL values were compiled from the literature as sediment concentrations at which effects on biota are "possible". ERM values are contaminant concentrations above which effects are "probable". As in 1993, nickel was the only trace metal that exceeded the ERM values for sediments, and it was above the ERM (51.6 ppm) at all but three stations in February. However, the ERM value for nickel has low confidence (Long and Morgan 1990), thus making evaluation difficult. Concentrations of silver and zinc were above the ERL at only one and three stations, respectively, but the remaining trace elements were above the ERL values at 11 to 22 stations in each sampling period.

Total PCBs were above the ERL in eight samples, six in February and two in August. Concentrations of total PAHs and many individual PAHs were above ERLs. Total PAHs exceeded the ERL in 10 samples, nine of which were collected in February. Two low-molecular weight PAHs, fluorene and acenaphthene, had the largest number of ERL exceedances. Total DDTs were above the ERL in 31 samples, but they were evenly divided between the two sampling periods. Nearly all of the instances where trace organics were above the ERLs occurred in February samples.

These results indicate that the background concentrations of the major classes of contaminants in sediments of the Estuary are generally within the range in which biological effects could be occurring. Further, additive effects of numerous contaminats may occur. None of the five trace organic compounds for which the EPA has proposed sediment quality objectives were above their guidelines.

Bivalve Monitoring

Monitoring the accumulation of trace substances in transplanted bivalves integrates water quality conditions over time because bivalves are exposed to ambient water continuously. This component of the RMP identifies compounds bioavailable that accumulate above levels found in the tissue of clams, oysters, and mussels from "clean" locations after transplanting them into the Estuary.

Tissue concentrations were higher for three trace metals - chromium, lead, and nickel - in all three species after transplanting them to the Estuary from presumably clean locations. Of these metals, only lead showed consistently high bioaccumulation factors throughout the Estuary. Chromium and nickel concentrations were considerably higher than pre-deployment levels at five of the 15 stations. Arsenic, cadmium, and selenium did not accumulate in any species above pre-deployment concentrations.

Interannual differences are apparent between 1994 and 1993 results. For those metals exceeding background concentrations by a great amount, dry-season levels were more likely to be higher than wet-season concentrations in the southern portion of the Estuary, while 1993 showed the opposite pattern. The observation made in 1993 that chromium, nickel, copper, lead, and zinc concentrations in bivalve tissue were much higher at various locations throughout the Estuary than they were at "reference" sites generally holds true for 1994.

Some spatial and temporal patterns were evident in trace organic concentrations in bivalves. In oysters, elevated wet-season concentrations of PAHs, PCBs, DDTs, chlordanes, and dieldrin, were observed at the Petaluma River and Napa River stations, suggesting that these tributaries were sources of these compounds in late winter and spring. These elevated concentrations corresponded with "spikes" in water at the Petaluma River during the corresponding sampling period. PAHs, PCBs, chlordane, and dieldrin in oysters were also relatively high in both May and September at the Coyote Creek station, another location under the influence of freshwater runoff to the Estuary. Temporal trends were not apparent in trace organics in oysters.

Broader spatial patterns in trace organic concentrations were observed in mussels. Concentrations of PCBs from Yerba Buena Island into the South Bay were uniformly higher than in the Central Bay or the northern Estuary. This difference was most apparent for a specific PCB congener (PCB180), which had average concentrations in the South Bay that were four times higher than in the Central Bay and the northern Estuary. The elevated PCB concentrations are consistent with water measurements. Concentrations within the South Bay were fairly uniform. The South Bay also had elevated concentrations of total chlordanes. Total chlordane concentrations were also relatively high in mussels at the Petaluma River station. In contrast to the high concentrations of DDTs in sediment at Horseshoe Bay, this station had the lowest concentrations of DDTs (and chlordanes) found in mussels, suggesting that the DDT is not entering the water column.

Clams at the River stations had considerably higher concentrations of PCBs, DDTs, chlordanes, and dieldrin than clams at another Estuary site, suggesting that the Rivers are measurable sources of these compounds to the Estuary. This observation is consistent with the striking concentration gradient of pesticides in water at the upstream river stations.

A few trace organics showed consistent seasonal variation across stations. Mussels had higher concentrations of carcinogenic PAHs in the wet season at all stations, similar to the seasonal contrast between wet- and dry-season sediment samples. Chlordanes and dieldrin concentrations in tissue were slightly higher in May at almost all stations.

These data on bioaccumulated trace organics support some hypotheses regarding sources. Elevated concentrations of all trace organics in tissue relative to other stations were observed at the Petaluma River, Napa River, and Coyote Creek stations, indicating either remobilization of these contaminants from the sediment or the presence of continuing sources of these compounds within the watersheds of these tributaries. Investigations as part of the 1996 RMP may further elucidate this question. Similarly, the Sacramento and San Joaquin Rivers appear to be sources of PCBs, DDTs, chlordanes, and dieldrin. Concentrations of PAHs, chlordanes, and dieldrin were higher in bivalves deployed during the wet season, suggesting that runoff is a source. Strong correlations among individual PAHs and individual pesticides are consistent with them having similar sources. Urban runoff is a likely source of the uniform PAH mixture that is distributed throughout the Estuary. Pesticide inputs from a multiplicity of sources in watersheds might be responsible for the consistent mixtures of chemicals found in RMP, as indicated by strong correlations among individual pesticides.

Comparisons to Tissue Quality Guidelines

Seven of the ten metals were accumulated above background concentrations by one or more bivalve species in 1994. Tissue concentrations were higher than Median International Standards (MIS) for one or more metals at all stations measured, including the three reference sites. Mercury, selenium, and arsenic had most of the incidences of being higher than the MIS, followed by cadmium, chromium, zinc, and copper. Lead was the only metal that was consistently lower than the MIS throughout the Estuary. Although none of the measurements of trace organic contaminants in tissue exceeded the Food and Drug Administration's action levels or National Academy of Sciences guidelines, tissue levels at all Estuary locations were higher than the Maximum Tissue Residue Levels (MTRLs) developed by the State Water Resources Control Board for most of the trace organics groups. PCB, PAH, and total chlordane concentrations were consistently higher than MTRLs. For a detailed description of guidelines used to compare RMP tissue concentrations, see Bivalve Bioaccumulation and Condition section in the report.

Trace Contaminant Patterns

For two years in a row, PCBs were identified as a group of contaminants that cause concern in the Estuary. Concentrations exceeded water quality guidelines at all stations during all three sampling periods each year. In both years, the South Bay exhibited the highest mean concentrations of total PCBs in water, although sediment and tissue concentrations did not reflect this pattern nearly as strongly. Bivalve tissue measurements corresponded much better with elevated dissolved PCBs at the Coyote Creek station. At the Petaluma River, wet-season spikes in near-total chromium, copper, nickel, silver, total PCBs, PAHs, and DDTs in water generally corresponded with elevated wet-season tissue concentrations. However, other stations did not necessarily reflect the same contaminant patterns across all three media.

Tissue concentration patterns corresponded better with total concentrations of metals in water, rather than with the dissolved fraction. Station comparisons with respect to bioaccumulation are difficult, because species differences frequently obscure station contamination characteristics.

RMP scientists have begun to work on developing a meaningful index that summarizes the contaminant information obtained from water, sediment, and tissue analyses in a concise way. An index is envisioned that would reflect which stations and Estuary reaches had the most exceedances of water quality standards, as well as sediment and tissue guidelines. Effects information, such as bioassay results, and benthic community data should also be included and perhaps even more heavily weighted, since they reflect actual biological responses to contaminant levels. This Estuary Contamination Index would serve to track progress toward environmental improvement goals and could be combined with other ecological measurements to evaluate overall Estuary health.

SFEI staff will work with risk assessment experts and others to refine these initial thoughts. Ultimately, the Estuary Contamination Index could become part of a set of "health indicators" for the San Francisco Estuary that cover all of the five key management areas outlined in the Comprehensive Conservation and Management Plan.

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Introduction



Introduction

The aim of environmental monitoring is to determine whether societal goals for environmental quality are being met. The goals of the Regional Monitoring Program (RMP) for Trace Substances address the amount of pollutants that exist in the water, sediment, and biota of the Estuary.¹ In the simplest of terms, the primary purpose for the RMP is to answer the question, is the Estuary as clean as it should be?

How clean should the Estuary be? The most clearly stated goals regarding pollutants in the Estuary are the numeric water quality objectives adopted by the California Water Quality Control Boards of Region 2 (San Francisco Bay) and Region 5 (Central Valley), and criteria promulgated by the U.S. EPA. These water quality standards state the exact concentration of a substance that is allowed to be in the waters of the Estuary. They are based upon laboratory research in which test organisms are subjected to varying concentrations of chemicals to determine the concentration that proves to be toxic or are back-calculated from human health risk assessments from eating contaminated seafood.

No similar numeric objectives currently govern the concentration of potentially toxic chemicals in the sediments in the Estuary, or in the tissue of aquatic organisms that live within it. These media, however, fall under the narrative requirement of the Basin Plans that toxic pollutants not be present in toxic amounts. Thus, to meet the goals for a clean Estuary, ecological effects of contamination must also be considered, and may be more important to concentrations alone. Water and sediments should not cause toxicity in animals exposed to them, and aquatic animals should not be adversely affected by eating other organisms that have accumulated pollutants in their tissues. Human health standards also come into play; seafood eaten by humans should not adversely affect our health.

A tremendous amount of effort is now being put into the task of making the Estuary cleaner. Treatment of sewage and industrial waste, stormwater programs to reduce the pollutant load of urban runoff, testing and limitations on dredging and disposal of dredged materials, and programs to reduce the amount of toxic chemicals used in the first place, should be having a significant effect on the condition of the Estuary.

Is the Estuary getting cleaner? Are current conditions a measure of the accumulation of contamination from the long-past practice of discharging untreated waste, or does it reflect current sources of chemicals (either human or natural)? In any event, what are the ecological effects of these contaminants? To answer these questions will take several years. The measurements we make vary within the year and between years based largely on natural variation in conditions, such as the amount of rainfall.

After a sufficient amount of baseline data concerning the condition of the Estuary has been accumulated, certain questions not directly addressed in the current program objectives might then be considered. The RMP does not currently attempt to identify, or to measure the importance of, the sources of pollutants entering the Estuary.

¹ A note on jargon: The term trace substance refers to a long list of metals and organic compounds that may be found in the Estuary; they are potentially toxic in small quantities. Many trace substances are naturally occurring, and their presence does not necessarily imply an environmental problem. Trace substances are distinguished from standard water quality parameters such as nutrients, temperature, pH, total suspended solids, and biological oxygen demand (BOD). The term contaminant refers to a substance—whether a trace substance or other water quality parameter that is of human origin or that is elevated in the natural environment through human activity over natural or "background" concentrations. The term pollutant refers to any contaminant that is having an adverse effect or that is present in concentrations that exceed regulatory standards. Measurement of sources is currently considered by Regional Board 2 to be a responsibility of the individual discharger. During 1994, an effort was begun to compare conditions around several major sewage outfalls (measured by individual program participants) with those in the main part of the Estuary. This cooperative effort will help both dischargers and regulators to understand the contributions and effects of these individual discharges. Questions about the relative importance of urban stormwater, of the Sacramento and other rivers that drain into the Estuary, and of in-place pollutants (sediments) as sources of water pollution would require either a significant change to the design of the baseline program, or a new level of effort (i.e. additional funding) on the part of participants.

The other question that becomes more important as the amount of information on baseline conditions increases, is: What are the ecological effects of this level of pollution? Is aquatic life being adversely effected? There is a general assumption that if water quality objectives are met, then aquatic life is not adversely affected, and if water quality objectives are not met, then aquatic life is being adversely affected. Both assumptions can be evaluated using RMP data. How well do water quality standards predict ecological effects? Pollutants probably behave differently in the natural environment than in the laboratory, and the background or "natural" concentrations of trace substances in a particular region are not taken into account. Further, the species that actually live in the Estuary may be either more or less sensitive than standard test species.

Some evidence suggests that adverse effects are taking place. Previous studies suggest that contaminant concentrations in the Estuary are high enough to be toxic at several trophic levels. Copper concentrations in the South Bay appear to be high enough to inhibit reproduction of dinoflagellates, a group of unicellular algae that are rare in South Bay. High concentrations of diazinon associated with stormwater runoff in both the Delta and the Bay probably cause acute and chronic toxicity in sensitive zooplankton species. PCB concentrations in fish in the Estuary have been associated with impaired reproduction in starry flounder, and are present in fish tissues in concentrations high enough to cause health warnings to be issued. PCB concentrations in some harbor seals from the Estuary are elevated above values associated with adverse effects on reproduction and immune function. Studies of contaminants in birds in the Estuary indicate that PCBs, DDTs, selenium, and mercury concentrations are at or above their thresholds for toxic effects, especially on reproduction. RMP data indicates sediment toxicity is widespread throughout the Estuary, although which contaminant(s) cause this toxicity have not been identified.

As the cost, both in dollars and in lifestyle changes, to produce a cleaner Estuary increases, our need to know with more certainty what the ecological effects of pollutants are will, no doubt, become more important. The RMP currently addresses effects in aquatic and sediment bioassays conducted in the laboratory. In 1994, RMP Pilot and Special Studies were begun to evaluate the use of benthic invertebrates as ecological indicators. Additional studies could address cause and effect relationships more directly. These efforts could become a proportionally more important part of the program in future years.

RMP Objectives

The formal program objectives listed below are those with which the RMP began in 1993. They were developed by staff at the Regional Board, representatives of the RMP participants, and SFEI staff.

• To obtain high quality baseline data describing the concentrations of toxic and potentially toxic trace element and organic contaminants in the water and sediment of the San Francisco Estuary;

• To determine seasonal and annual trends in chemical and biological water quality in the San Francisco Estuary;

• To 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;

• To determine whether water quality and sediment quality in the Estuary at large are in compliance with objectives established by the Basin Plan;

• To provide a data base 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 and model development, sediment quality objectives development, in-bay studies of dredged material disposal, IEP water quality studies, primary productivity studies, local effects biomonitoring programs, and state and federal mussel watch programs.

Who is involved in the Regional Monitoring Program

The RMP is funded by 63 federal, state, and local agencies, private companies and special districts that are permitted for discharge into the Estuary. These program participants are listed inside the front cover of this report. The Steering Committee (listed in Acknowledgements) is composed of management representatives of the major groups of RMP sponsors: small, medium, and large

| Prime Contractors | Dr. Bob Spies |
|-----------------------------------|---|
| | Dr. Andy Gunther |
| | Applied Marine Sciences, Livermore, CA |
| Trace Element Chemistry | Dr. Russ Flegal, UC Santa Cruz |
| , | Dr. Eric Prestbo, Brooks-Rand, Seattle, WA |
| | Dr. Allen Uhler, Battelle, Duxbury, MA |
| Trace Organic Chemistry | Dr. Bob Risebrough, Bodega Bay Institute |
| | Dr. Terry Wade, Texas A&M University |
| | Dr. Walter Jarman, UC Santa Cruz |
| Water Toxicity Testing | Dr. Stephen Hansen, S.R. Hansen and |
| | Associates, Concord, CA |
| Sediment Toxicity Testing | Mr. John Hunt and Mr. Brian Anderson |
| | Marine Pollution Lab, Granite Canyon, CA |
| Bagged Bivalve Sampling | Mr. Dane Hardin, Applied Marine Sciences. |
| Pilot Study on Water Quality | Dr. Jim Cloern, USGS, Menlo Park, CA |
| Thorstudy on Water Quality | Dr. Alan Jassby, UC Davis. |
| Pilot Study on Sediment Transport | Dr. David Schoellhamer, USGS. |
| y 1 | Sacramento, CA |
| Pilot Study on Benthic Macrofauna | Dr. Bruce Thompson, SFEI, Richmond, CA |
| - | Mr. Harlan Proctor, Dept. of Water Resources, |
| | Sacramento, CA |

Table 1. 1994 RMP Contractors and Principal Investigators.

municipal dischargers, industrial dischargers, cooling water dischargers, stormwater dischargers, dredged material dischargers, staff of the Regional Board, and SFEI. The Steering Committee provides a forum for discussions on regional environmental issues, provides policy and direction for the program, and guidance for interpretation of results.

The Technical Program Review Committee (listed in Acknowledgements) is composed of technical representatives of the major groups of participants listed above. Their responsibility is to develop annual work plans, review monitoring design, identify special studies consistent with the guidance of the Steering Committee and Regional Board, and to review data and reports produced by the RMP.

The RMP is carried out under the direction of the San Francisco Bay Regional Water Quality Control Board, which authorized the program in Resolution 92-043. All final decisions on the scope of the program, the program design laid out in the implementation plan, and budgets are made by the Board, or the Board's staff. This report, when reviewed and approved by program participants at their annual meeting, will be transmitted to the Regional Board in compliance with Resolution 92-043.

The San Francisco Estuary Institute is a private nonprofit organization with a mandate to provide scientific understanding of the Estuary. SFEI's role in the RMP is to administer and manage the RMP, provide technical direction, receive, maintain, and manage RMP data, and produce the Annual Report. SFEI's Committee of Science Advisors, composed of nine eminent scientists, provides scientific oversight and review for the RMP. SFEI and the San Francisco Bay Regional Water Quality Control Board have signed a Memorandum of Understanding outlining roles and responsibilities.

Readers interested in additional background and rationale for the RMP are referred to the Introduction of the 1993 Annual Report (SFEI 1993).

Sampling and analysis were conducted through a contract with Applied Marine Sciences in Livermore,

| Six new stations added | Coyote Creek San Bruno Shoal Alameda Red Rock Petaluma River Honker Bay | Better spatial coverage of the Estuary and major tributaries, and to provide better estimates of conditions in the reaches of the Estuary |
|---|---|---|
| Aquatic Bioassays changed | Three times per year to two times | Lack of "hits" last year led to conclusion fewer tests were needed |
| | Use of diatom <i>Thalassiosira</i> was discontinued. The mysid <i>Mysidopsis</i> was used instead | <i>Thalassiosira</i> found to be not very sensitive. |
| Additional trace substance included | Diazinon measured in 1994 | Diazinon found to be important in other studies |
| Minor changes in analysis and reporting | See methods section for details | |

Table 2.Changes to the RMP in 1994.

California. Principal Investigators for the main components of the RMP are listed on Table 1. Their technical staffs are listed in the Acknowledgements.

The 1994 Program

The 1994 Regional Monitoring Program (RMP) was generally similar to the 1993 program. The base program included measurements of water quality and chemistry, sediment quality and chemistry, bioaccumulation of contaminants by transplanted bivalves, and aquatic and sediment bioassays. Changes to the program are summarized in Table 2.

Since this is the second report of the RMP, it is possible to compare two years of data. Thus, plots of the 1993 and 1994 RMP data are presented to visually compare concentrations in each sampling period from the main Estuary reaches. However, two years of data are still insufficient to conduct time-series analyses of trends. Such trend analyses will be performed in future years.

Three Pilot Studies were conducted in 1994. Two of them are continuations from 1993: the pilot study of hydrography and water quality was conducted by scientists from the USGS in Menlo Park, and a pilot study of suspended sediments was conducted by scientists from the USGS in Sacramento. A new pilot study of benthic invertebrates in the Estuary was started in 1994. This study was begun because there is a need to develop other indicators of contaminant effects for use in the RMP. The results of these pilot studies are included in this report. Some of the results from the two USGS studies are also integrated into the base program results.

The RMP supported two Special Studies in 1994. Special studies are studies that will help interpret RMP data better, or that help make better RMP measurements. These studies were conducted because the program participants, Regional Board staff, and SFEI staff determined that they represented important issues that deserved more detailed study. A study of optimal sampling design was conducted in cooperation with the Bay Area Discharges Associations (BADA). It addresses the question of how to use RMP and Local Effects Monitoring studies near outfalls together to determine whether an outfall is having an effect (or not). Another special study was conducted on development of ecological indicators of contaminant effects. This study addresses the question of which ecological indicators the RMP should be using and will be published under separate cover.

How the Regional Monitoring Program for Trace Substances relates to other monitoring programs

The Regional Monitoring Program provides a comprehensive look at pollutant concentrations in the Estuary, but is not the only trace substance monitoring program that is operating in the San Francisco Estuary area. Related studies are conducted under the Bay Protection and Toxic Cleanup Program by the State Water Resources Control Board and Regional Water Quality Control Boards 2 and 5. The Regional Boards conduct special studies such as the recent Fish Contamination Study of Region 2 and work on the toxicity of agricultural drains and acid mine drainage conducted by Region 5. The U.S. Geological Survey has conducted long term studies of bioaccumulation of pollutants in the Estuary, has surveyed pesticide transport, is examining cores of sediment to determine the historical extent of pollution, and is conducting a National Water Quality Assessment in the Sacramento River. The City and County of Sacramento conduct a monitoring program to determine the trace metal concentrations in the lower Sacramento River. Some individual dischargers, including the cities San Jose and Sunnyvale, and some discharger groups, such as of Bay Area Dischargers Association and Western States Petroleum Association, conduct local effects monitoring.

SFEI staff makes a concerted effort to coordinate the RMP with all of these efforts, and is exploring ways to collaborate with each. Efforts are being undertaken to avoid duplication and to insure that data from different programs are compatible. Brief descriptions of these programs are included in the Appendix. It is a SFEI goal that future Annual Reports will involve a greater degree of integration of all of the information produced by pollutant monitoring programs to assess the overall condition of the Estuary and its resources with regard to trace substances.

Pollutants are of course only one of the many results of human habitation of the Bay and Delta area that have adverse effects upon environmental health. Participants in the RMP, as well as those involved in monitoring programs that address issues such as water management, need to know how a variety of factors affect the Estuary and its resources. Such activities include dredging and dredged material disposal, diversion of water for urban and agricultural use, harvest of seafood, diking and filling of wetlands, channelizing streams, and continuing urbanization. A variety of monitoring programs have been established to address these uses. Chief among them are the Interagency Ecological Program to assess impacts of water projects and the Long Term Management Strategy for Dredging and Dredged Material Disposal. The RMP is one component of a comprehensive and coordinated Regional Monitoring Strategy produced by the San Francisco Estuary Project (SFEP 1993). The Strategy ties all of these programs together-and identifies gaps in current effort, such as wetlands and watersheds-into an effort to monitor the overall health of the Estuary. SFEI is working to implement the Regional Monitoring Strategy through cooperative efforts with other programs and through initiating programs for resources not currently monitored. Eventually, the Regional Monitoring Program for Trace Substances will be part of a more comprehensive Regional Monitoring Program for Estuary Health.

In order to facilitate coordination and information exchange, summaries of some of the other monitoring activities in the Estuary are included in this report. These summaries were contributed by investigators from some of the other programs and are intended to provide the readers with some knowledge of the range of monitoring activities occurring in the Estuary.

Methods



Sampling Design

The RMP sampling design was based on the Bay Protection and Toxic Cleanup Program Pilot Studies developed by the San Francisco Bay Regional Water Quality Control Board. The reasoning behind the original design, with stations located along the "spine" of the Estuary, was to include stations that in a long-term monitoring program would indicate spatial and temporal trends in toxicity and chemistry, determine background concentrations for different reaches of the Estuary, and assess wether there were high levels of contaminants or toxicity (Taberski et al. 1992). The RMP sampling design is still evolving into an optimal design determined through iterative sampling, data analysis, and interpretation. An optimal design is one that samples an adequate number of stations and measures sufficient parameters to make reasonable statistical statements about the Estuary's condition within cost constraints. Consistent with the goal of design optimization, decisions about what is an adequate number of stations and what is reasonable statistical power are made annually by the Steering Committee based on recommendations from the Program Manager and Technical Program Review Committee.

The station locations were not randomly chosen, and therefore estimates of the areal extent of water quality changes cannot be made. It was decided instead to locate sites as far as possible from the influence of major contaminant sources in order to be able to interpret temporal and spatial variability in the data without the confounding variable of contaminant inputs from nearby sources. A randomized design, on the other hand, would allow estimates of the extent and distribution of altered environmental conditions throughout the Estuary. Both designs have advantages and disadvantages which could be evaluated as part of a major program review in 1997, after data from four years of sampling efforts are available.

The original 16 stations sampled in 1993 were augmented by six locations in 1994. These include stations in the Estuary Channel off San Bruno Shoal (BB15), Alameda (BB70), at Red Rock (BC60), Honker Bay (BF40), and at the mouths of the Petaluma River (BD15) and Coyote Creek (BA10). The addition of these six sites does not provide optimal coverage or statistical power, but considering sampling needs and fiscal constraints, the new stations represent progress towards optimal RMP design. The new locations were selected to fill large areas of the Estuary where no samples were taken, and to better monitor areas around major tributaries.

On a trial basis, upon request by the Regional Board, two local effects monitoring stations of the San Jose and Sunnyvale Water Pollution Control Plants were included into the RMP sampling regime and treated identically to regular RMP monitoring locations. These two stations are referred to as the "southern slough" stations, reflecting their locations in the lower channels of Coyote Creek and the Guadalupe River.

The locations of the 22 RMP and two southern slough stations are shown in Figure 1, and Table 3 lists the station names, codes, locations, and sampling dates for all 1994 stations. The coding system developed in the BPTCP Pilot program was adopted for use in the RMP. Water, bioaccumulation, or sediment sampling stations with the same station name (location) may have slightly different locations due to practical considerations such as sediment type or ability to deploy bivalves, and thus different station codes. For example, at the South Bay station, BA20 is the water station code and BA21 is the sediment station code.

Some complementary samples that were not part of the base program were collected in 1994 and are identified as such. For example comparisons of sediment chemistry were made using two different samplers - a modified Van Veen grab and a Ponar grab - to identify if the stainless steel Ponar grab introduces measurable amounts of contamination to sediment samples. Yet another complementary measurement that was not part of the base program is the analysis of aluminum in bivalve tissue. The rationale for this is described in Appendix 1 describing the detailed methods and quality assurance



Figure 1. Locations of 1994 Regional Monitoring Program stations

| Statian | Ctation. | | Maaaaaa | | | | | - 4:4 | 1. | Lanait | |
|---------------------|--------------|-----------------|------------------|----------------------------------|--------------------|------------------------|----------|--------------|----------|---------|--------------|
| Name | Code | Type of Sample | Made | Т | Dates Sampled | | dea | autuc min | sec | deg mi | uue n sec |
| T tunic | code | Type of Sumple | Wittee | 1 | Suites Sumpled | | | | 500 | acg inn | 1 500 |
| Coyote Creek | BA10 | water | Q,M,O,T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 28 | 11 | 122 3 | 50 |
| South Day | BA10 BA20 | bioaccumulation | M,O,C | Jan 18 - May 6 Jan 21 Eab 0 | Apr 10 27 | June 1 - Sep 14 | 37 | 28 | 11 | 122 3 | 20 |
| South Bay | ΒA20 ΒΔ21 | sediment | Q,M OMOT | Jan 31 - Feb 9 Feb 10-16 | Apr 19-27 | Aug 15-25 | 37 | 29 29 | 41 38 | 122 5 | 15 |
| Dumbarton Bridge | BA30 | water | Q,M,O,1 | Ian 31 - Feb 9 | Apr 19-27 | Aug 25-30 Aug 15-23 | 37 | 30 | 54 | 122 3 | 7 |
| Dumbarton Bridge | BA30 | sediment | 0 M 0 | Feb 10-16 | mpi 19-27 | Aug 25-30 | 37 | 30 | 54 | 122 8 | 7 |
| | BA30 | bioaccumulation | M.O.C | Jan 18 - May 6 | | June 1 - Sep 14 | 37 | 30 | 54 | 122 8 | 7 |
| Redwood Creek | BA40 | water | Q,M,O,T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 33 | 40 | 122 12 | 34 |
| | BA40 | bioaccumulation | M,O,C | Jan 18 - May 6 | | June 1 - Sep 14 | 37 | 32 | 49 | 122 11 | 42 |
| | BA41 | sediment | Q,M,O,T | Feb 10-16 | | Aug 25-30 | 37 | 33 | 40 | 122 12 | 37 |
| San Bruno Shoal | BB15 | water | Q,M | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 37 | 1 | 122 17 | 0 |
| | BB15 | sediment | Q,M,O,T | Feb 10-16 | | Aug 25-30 | 37 | 37 | 1 | 122 17 | 0 |
| Oyster Point | BB30 | water | Q,M | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 40 | 12 | 122 19 | 45 |
| | BB30 | sediment | Q,M,O | Feb 10-16 | | Aug 25-30 | 37 | 40 | 12 | 122 19 | 45 |
| Alameda | BB70 | water | Q,M,O,T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 44 | 50 | 122 19 | 24 |
| | BB/0 DD71 | sediment | Q,M,O,I M O C | Feb 10-16 | | Aug 25-30 | 37 | 44 | 50 | 122 19 | 24 |
| Varba Puona Island | | viotor | M,O,C | Jan 16 - May 0 | Apr 10 27 | Julie 1 - Sep 14 | 27 | 41 | 44 22 | 122 20 | 23 58 |
| I CIDa Ducha Island | BC10 | bioaccumulation | Q,M,O,I M O C | Jan 18 - May 6 | Арі 19-27 | Iune 1 - Sen 14 | 37 | 49 | 22 | 122 20 | 58 |
| | BC11 | sediment | O M O T | Feb 10-16 | | Aug 25-30 | 37 | 49 | 26 | 122 20 | 56 |
| Golden Gate | BC20* | water | Q,M,O | Jan 31 - Feb 9 | | 114g 20 00 | 37 | 45 | 49 | 122 32 | 9 |
| | | water | Q,M,O | | Apr 19-27 | | 37 | 46 | 12 | 122 32 | 24 |
| | | water | Q,M,O | | 1 | Aug 15-23 | 37 | 47 | 44 | 122 29 | 17 |
| Horseshoe Bay | BC21 | sediment | Q,M,O,T | Feb 10-16 | | Aug 25-30 | 37 | 49 | 59 | 122 28 | 26 |
| | BC21 | bioaccumulation | M,O,C | Jan 18 - May 6 | | June 1 - Sep 14 | 37 | 49 | 59 | 122 28 | 26 |
| Richardson Bay | BC30 | water | Q,M | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 51 | 49 | 122 28 | 40 |
| | BC32 | sediment | Q,M,O | Feb 10-16 | | Aug 25-30 | 37 | 51 | 49 | 122 28 | 43 |
| Point Isabel | BC41 | water | Q,M | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 53 | 2 | 122 20 | 33 |
| | BC41 | sediment | Q,M,O | Feb 10-16 | 10.27 | Aug 25-30 | 37 | 53 | 2 | 122 20 | 33 |
| Red Rock | BC60 | water | Q,M,O,T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 55 | 0 | 122 26 | 0 |
| | BC60 BC61 | bioaccumulation | Q,M,O,I M O C | Feb 10-10 | | Aug 25-30 | 37 | 55 55 | 42 | 122 20 | 0 e |
| Petaluma River | BD15 | water | M,O,C | Jan 31 - Feb 9 | Apr 19-27 | Δug 15-23 | 38 | 6 | 42 | 122 20 | 13 |
| i ctaranna Kryer | BD15 BD15 | bioaccumulation | MOC | Jan 18 - May 6 | mpi 19-27 | June 1 - Sep 14 | 38 | 6 | 37 | 122 29 | 13 |
| San Pablo Bav | BD20 | water | 0.M.O | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 38 | 2 | 55 | 122 25 | 11 |
| | BD20 | bioaccumulation | M,O,C | Jan 18 - May 6 | 1 | June 1 - Sep 14 | 38 | 2 | 55 | 122 25 | 43 |
| | BD22 | sediment | Q,M,O | Feb 10-16 | | Aug 25-30 | 38 | 2 | 52 | 122 25 | 14 |
| Pinole Point | BD30 | water | Q,M,O,T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 38 | 1 | 29 | 122 21 | 39 |
| | BD30 | bioaccumulation | M,O,C | Jan 18 - May 6 | | June 1 - Sep 14 | 38 | 1 | 0 | 122 22 | 3 |
| | BD31 | sediment | Q,M,O,T(4) | Feb 10-16 | | Aug 25-30 | 38 | 1 | 29 | 122 21 | 43 |
| Davis Point | BD40 | water | Q,M,O | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 38 | 3 | 7 | 122 16 | 37 |
| | BD40 | bioaccumulation | M,O,C | Jan 18 - May 6 | | June 1 - Sep 14 | 38 | 3 | 16 | 122 15 | 38 |
| Nana Diara | BD41 | sediment | Q,M,O,T(6) | Feb 10-16 | A 10, 27 | Aug 25-30 | 38 | 3 | 1 | 122 16 | 39 |
| INapa Kivei | BD50 | sodimont | Q,M,O,T | Jall 31 - Feb 9 | Apr 19-27 | Aug 15-25 | 20 | 5 | 47 | 122 15 | 27 |
| | BD50 BD50 | bioaccumulation | Q,M,O,I M O C | Ian 18 - May 6 | | June 1 - Sen 14 | 38 | 5 | 47 | 122 15 | 37 |
| Pacheco Creek | BE10 | water | 0 M | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 38 | 3 | 5 | 122 13 | 48 |
| r denievo creen | BF10 | sediment | 0.M.O | Feb 10-16 | | Aug 25-30 | 38 | 3 | 5 | 122 5 | 48 |
| Grizzly Bay | BF20 | water | Q.M.O.T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 38 | 6 | 58 | 122 2 | 19 |
| 5 5 | BF20 | bioaccumulation | M,O,C | Jan 18 - May 6 | 1 | June 1 - Sep 14 | 38 | 6 | 29 | 122 3 | 22 |
| | BF21 | sediment | Q,M,O,T | Feb 10-16 | | Aug 25-30 | 38 | 6 | 58 | 122 2 | 21 |
| Honker Bay | BF40 | water | Q,M | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 38 | 4 | 2 | 121 55 | 56 |
| | BF40 | sediment | Q,M,O | Feb 10-16 | | Aug 25-30 | 38 | 4 | 2 | 121 55 | 56 |
| Sacramento River | BG20 | water | Q,M,O,T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 38 | 3 | 34 | 121 48 | 35 |
| | BG20 | sediment | Q,M,O,T | Feb 10-16 | | Aug 25-30 | 38 | 3 | 34 | 121 48 | 35 |
| ст · р. | BG20 | bioaccumulation | M,O,C | Jan 18 - May 6 | 10.27 | June I - Sep 14 | 38 | 3 | 34 | 121 48 | 35 |
| San Joaquin River | BG30 BC20 | water | Q,M,O,T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 38 20 | 1 | 24 | 121 48 | 27 |
| | BC30 | bioaccumulation | Q, M, O, I | Teu 10-10 | | Aug 23-30 | 38 29 | 1 | ∠4 24 | 121 48 | 21 |
| San Jose | C-3-0 | water | OMT | Jan 10 - May 0 Jan 31 - Feb 0 | Apr 19_27 | Aug 15-23 | 30 | 27 | 24 43 | 121 40 | 32 |
| San Jose | C-3-0 | sediment | 0.M | Feb 10-16 | ripi 1 <i>7-21</i> | Aug 25-30 | 37 | 27 | 43 | 121 58 | 32 |
| Sunnyvale | C-1-3 | water | Q.M.T | Jan 31 - Feb 9 | Apr 19-27 | Aug 15-23 | 37 | 26 | 8 | 122 0 | 40 |
| - | C-1-3 | sediment | Q,M | Feb 10-16 | | Aug 25-30 | 37 | 26 | 8 | 122 0 | 40 |

Table 3. Summary of RMP 1994 sampling stations and activities.

* location dependent on salinity Q = water and/or sediment quality

O = trace organics C = bivalve condition index
$$\label{eq:main_state} \begin{split} M &= trace metals \\ T &= toxicity \\ T(4) &= only during sediment cruise #4 \\ T(6) &= only during sediment cruise #6 \end{split}$$

procedures. Results from these samples are included in Appendix 3.

Sampling was conducted three times in 1994: during the wet period (February), a period of declining Delta outflow (late April), and during the dry period (late August). Exact sampling dates are listed in Table 3. Logistic and scheduling constraints of this large, Estuarywide program precluded sampling at consistent monthly or daily tidal cycles.

As part of a RMP Special Study designed to determine optimal sampling design and replication, three stations were selected for triplicate samples for bioaccumulation, sediment chemistry, and benthos, with two of those stations also containing triplicates for trace contaminants in water (Table 3). The three RMP stations were sampled concurrently with stations around three outfall areas (funded by the Bay Area Dischargers Association) for comparison purposes. None of the samples at the other 19 stations were replicated. Consistent with the objectives of the RMP and available funding, within-station replication was traded off for samples in more Estuary locations. Replication at three

Table 4.Conventional water quality parameters
and sediment quality parameters mea-
sured during the 1994 RMP.

A. Conventional Water Quality Parameters

Conductivity Dissolved Organic Carbon Dissolved Oxygen (DO) Hardness pH (acidity) Phaeophytin (chlorophyll degradation product) Salinity Temperature Total Chlorophyll-a Total Suspended Solids Dissolved Phosphates Dissolved Silicates Dissolved Nitrate Dissolved Nitrate Dissolved Ammonia

B. Sediment Quality Parameters

% clay % sand % silt Eh (reduction-oxydation potential) @ 2.5 cm @ 5.0 cm pH Temperature Total Organic Carbon sites will, for the first time, provide an estimate of withinstation variability, which will help in refining sampling design in future years.

The five different types of samples that were collected in 1993 were continued in the 1994 base program:

- 1. Conventional water quality parameters and chemistry.
- 2. Aquatic bioassays.
- 3. Sediment quality characteristics and chemistry.
- 4. Sediment bioassays.

5. Transplanted, bagged bivalve bioaccumulation and condition.

Complete listings of all chemical parameters measured in 1994 are on Tables 4 to 6. Methods of collection and analysis are detailed in Appendix 1.

Not all parameters were measured at all RMP stations for each sampling period. Sampling activities at each station are listed on Table 4. Water samples were collected at all stations during all three sampling periods. However, trace organics contaminants in water were only measured at 14 of the 15 stations where bioaccumulation

| Table 5. | Trace elements analyzed in water sediment, and bivalve tissues in the |
|----------|---|
| | RMP Estuary sampling. |

| | Water | Sediment | Biota | |
|---------------|-------|----------|-------|--|
| Aluminum* | | • | • | |
| Arsenic | • | • | • | |
| Cadmium* | • | • | • | |
| Chromium | • | • | • | |
| Copper* | • | • | • | |
| Iron* | | • | | |
| Lead* | • | • | • | |
| Manganese* | | • | | |
| Mercury | • | • | • | |
| Nickel* | • | • | • | |
| Selenium | • | • | • | |
| Silver* | • | • | • | |
| Zinc* | • | • | • | |
| Tetrabutyltin | | | • | |
| Monobutyltin | | | • | |
| Dibutyltin | | | • | |
| Tributyltin | | | • | |
| | | | | |

*Near-total rather than total concentrations measured (see text).

Table 6. Trace organic compounds analyzed in water, sediment, and bivalve tissues

W = water, S = sediment, T = tissues

| | | W | S | Т | | | w | S | т |
|----|--------------------------|---|---|---|---|----------------------------|---|---|---|
| Α. | Petroleum Compounds | | | | | Endrin | | • | • |
| | Alkanes, n-C10 to n-C34 | • | • | • | | Chlordanes | | | |
| | Phytane | | • | • | | Alpha-Chlordane | • | • | • |
| | Pristane | | • | • | | Cis-Chlordane | • | | |
| | | | | | | Cis-Nonachlor | • | • | • |
| В. | Polynuclear Aromatic | | | | | Gamma-Chlordane | • | • | • |
| | Hydrocarbons (PAHs) | | | | | Heptachlor | • | • | • |
| | 2 Rings | | | | | Heptachlor Epoxide | • | • | • |
| | 1-Methylnaphthalene | • | • | • | | Oxychlordane | • | • | • |
| | 2,3,5-Trimethnaphthalene | | • | • | | Trans-Chlordane | | • | • |
| | 2,6-Dimethnaphthalene | | • | • | | Trans-Nonachlor | | • | |
| | 2-Methylnaphthalene | • | • | • | | | • | • | • |
| | Biphenyl | | • | • | | DDTe | | | |
| | Naphthalene | | • | • | | 2 /יםם מחמי | | • | |
| | 3 Rings | | | | | | • | • | • |
| | 1-Methylphenanthrene | • | • | • | | | • | • | • |
| | Acenaphthene | | • | • | | | • | • | • |
| | Acenaphthylene | | • | • | | | • | • | • |
| | Anthracene | • | • | | | | • | • | • |
| | Fluorene | • | | | | 4,4°DD1 | • | • | • |
| | Phenanthrene | • | | | | 4,4'DDMU | • | | |
| | 4 Rings | • | • | • | | HCHs | | | |
| | Benzo(A)Anthracene | | | | | Alpha-HCH | • | • | • |
| | Chrysene | | | | | Beta-HCH | • | • | • |
| | Eluoranthono | | | | | Delta-HCH | • | • | • |
| | Durono | • | | | | Gamma-HCH | • | • | • |
| | Fyrene 5 Dingo | • | • | • | | Other | | | |
| | 5 Kings | • | • | | | Mirex | • | • | • |
| | Benzo(R)Fluerenthene | • | • | • | | Chlorpyrifos | • | | |
| | Benzo(B)Fluoranthene | • | • | • | | Dacthal | • | | |
| | Benzo(E)Pyrene | • | • | • | | Diazinon | • | | |
| | Benzo(K)Fluorantnene | • | • | • | | Endosulfan | | | |
| | Dibenz(A,H)Anthracene | • | • | • | | | • | | |
| | Perylene | | • | • | | | • | | |
| | 6 Rings | | | | | Endosultan Sultate | • | | |
| | Indeno [1,2,3-CD] Pyrene | • | ٠ | • | | Methylchlorpyrifos | ٠ | | |
| | Benzo(GHI)Perylene | • | • | • | | Oxadiazon | • | | |
| | | | | | | Toxaphene | • | | |
| | Alkylated PAHs | | | | | Trifluralin | • | | |
| | C1-Chrysenes | | • | • | | | | | |
| | C1-Diben | | • | • | D | PCBs and Related Compounds | | | |
| | C1-Fluoran Pyr | | • | • | | Hexachlorobenzene | • | • | • |
| | C1-Fluorenes | | ٠ | • | | PCB 3/31 | | • | • |
| | C1-Naphthalenes | | ٠ | • | | PCB 7/9 | • | • | |
| | C1-Phen Anthr | | ۲ | • | | PCB 8 | • | • | • |
| | C2-Chrysenes | | ٠ | • | | PCB 8/5 | - | • | - |
| | C2-Diben | | ٠ | • | | PCB 15 | | | |
| | C2-Fluorenes | | ٠ | • | | DCB 16/32 | • | | |
| | C2-Naphthalenes | | • | • | | | • | | |
| | C2-Phen Anthr | | • | • | | PCB 10/16 | • | • | • |
| | C3-Chrysenes | | • | • | | PCD 10/10 DCB 22/51 | • | • | • |
| | C3-Diben | | ٠ | • | | PCB 22/31 | | • | • |
| | C3-Fluorenes | | ٠ | • | | PCB 24/27 | • | • | • |
| | C3-Naphthalenes | | • | • | | PCB 25 | | • | • |
| | C3-Phen Anthr | | ٠ | • | | PCB 26 | | • | • |
| | C4-Chrysenes | | • | • | | PUB 27 | ٠ | | |
| | C4-Naphthalenes | | ٠ | • | | PCB 28 | • | • | ٠ |
| | C4-Phen Anthr | | ٠ | • | | PCB 28/31 | • | | |
| | Dibenzothiophene | | ٠ | • | | PCB 29 | • | • | ٠ |
| | - | | | | | PCB 31 | • | • | ٠ |
| C. | Synthetic Biocides | | | | | PCB 33 | • | | |
| | Cyclopentadienes | | | | | PCB 33/53/20 | | • | ٠ |
| | Aldrin | | ٠ | • | | | | | |
| | Dieldrin | • | ٠ | • | | | | | |
| | | | | ' | • | | | | |

| Table 6. | (continued) Trace organic compounds analyzed in water, sediment, and |
|----------|--|
| | bivalve tissues |

| w = water, s = seument, r = ussut | W | = water, S | = sediment, | T = | tissues | 3 |
|-----------------------------------|---|------------|-------------|-----|---------|---|
|-----------------------------------|---|------------|-------------|-----|---------|---|

| <u>WST</u> | | <u>W</u> | S | <u> </u> |
|---------------------|----------------------------|----------|---|----------|
| PCB 37/42/59 • • | PCB138 | • | | - |
| | PCB 138/160 | • | • | • |
| | PCB 141/179 | | • | • |
| | PCB 146 | • | • | • |
| | PCB 149/123 | • | • | • |
| PCB 46 • • | PCB 151 | • | • | • |
| PCB 47/48/75 • • | PCB 151/82 | • | | |
| PCB 49 • • | PCB 153 | • | | |
| PCB 52 • • • | PCB 153/132 | • | • | ٠ |
| PCB 60 | PCB 156 | • | | |
| PCB 60/56 ● ● ● | PCB 156/171 | | • | • |
| PCB 66 • • • | PCB 156/171/202 | • | | |
| PCB 66/95 • | PCB 157 | • | | |
| PCB 70 • • • | PCB 157/201 | • | | |
| PCB 74 • • • | PCB 157/173/201 | • | | |
| PCB 82 • • | PCB 158 | • | • | ٠ |
| PCB 83 • • | PCB 167 | | • | ٠ |
| PCB 84 • • | PCB 170 | • | | |
| PCB 85 ● ● | PCB 170/190 | • | • | ٠ |
| PCB 87 • | PCB 172 | | • | ٠ |
| PCB 87/115 ● ● ● | PCB 174 | • | • | • |
| PCB 88 • • | PCB 177 | • | • | • |
| PCB 92 • • | PCB 178 | | • | • |
| PCB 95 • | PCB 180 | • | • | ٠ |
| PCB 97 • • • | PCB 183 | • | • | ٠ |
| PCB 99 ● ● | PCB 185 | • | • | ٠ |
| PCB 100 • • | PCB 187 | • | | |
| PCB 101 • | PCB 187/182/159 | | • | ٠ |
| PCB 101/90 ● ● ● | PCB 188 | | | • |
| PCB 103 • | PCB 189 | • | • | ٠ |
| PCB 105 ● ● ● | PCB 191 | • | • | ٠ |
| PCB 105/132 | PCB 194 | • | • | • |
| PCB 107/108/144 • • | PCB 195 | • | | |
| PCB 110 ● ● ● | PCB 195/208 | • | • | ٠ |
| PCB 110/177 • | PCB 196/203 | • | • | ٠ |
| PCB 114 • | PCB 196/204 | • | | |
| PCB 114/131/122 | PCB 198 | • | | |
| PCB 118 ● ● ● | PCB 199 | • | | |
| PCB 119 • | PCB 200 | | • | • |
| PCB 126 | PCB 201 | | • | • |
| PCB 128 ● ● ● | PCB 203 | • | | |
| PCB 129 • • | PCB 205 | • | • | • |
| PCB 129/178 | PCB 206 | • | • | • |
| PCB 132 | PCB 207 | • | - | - |
| PCB 136 ● ● | PCB 209 | | • | • |
| PCB 137 | Sum PCBs | • | - | 2 |
| PCB 137/176 ● ● ● | Polychlorinated Terphenyls | | • | ٠ |
| | | | | |

measurements were made. Aquatic bioassays were conducted at 11 stations during the wet- and dry-season sampling periods.

Sediment sampling was conducted during the wetand dry-season periods only. Sediment samples were collected from all RMP stations, and sediment toxicity was measured at 12 of those stations during the wet and dry-sampling periods. Bivalve bioaccumulation and condition were measured at 15 stations during the wet and dry-season sampling periods.

For an RMP Pilot Study, macrobenthic invertebrates were collected at eight Estuary stations during the wet and dry seasons as part of a cooperative effort with the California Department of Water Resources (DWR). DWR collected benthic invertebrates at six additional stations in the northern reaches of the Estuary and Delta. The goal of sampling invertebrates was to evaluate their effectiveness as bioindicators of environmental conditions in the Estuary.

In addition to the Estuary stations, water samples were collected from the Sacramento and San Joaquin Rivers at Rio Vista and Manteca, respectively. Samples were obtained six times over a two-month period from April 7 through May 25 and analyzed for water quality parameters and trace contaminants.

Parameters Sampled

Water, sediment, and benthic samples were collected from aboard the R/V DAVID JOHNSTON chartered through the University of California Santa Cruz. During each sampling period, water sampling was conducted first at all RMP stations. Sediment sampling followed, making a separate run though the Estuary. Each sampling run required 3-5 days for completion. Details of sample collection are included in Appendix 1.

The bivalve monitoring consisted of three parts: deployment of transplants from reference sites, maintenance, and retrieval. This work was conducted using the R/V RINCON POINT, owned by the City of San Francisco, in cooperation with the Bureau of water Pollution Control. Details of sample collection are included in Appendix 1.

Quality Assurance Improvements

In order to engage the collective expertise of RMP participants, participating laboratories, and interested individuals, a quality assurance (QA) work group was formed with the purpose of providing a mechanism for coordination and information exchange, to assist in efforts to achieve data comparability between various programs and laboratories, to participate in laboratory performance evaluations, and to assist in other program improvements. As its first task, the work group guided the first RMP Intercalibration Exercise to determine capabilities of participating laboratories and comparability of results. The outcome of this exercise has not yet been determined and will be published under separate cover. The work group also sponsors informal technical seminars with various experts in the field.

As part of the QA program, split samples are periodically analyzed by participating RMP laboratories and compared with results from highly respected labs. In 1994, selenium concentrations were measured in water, sediment, and tissue by Dr. Ivan Palmer's group at South Dakota State University and compared with those generated by the RMP laboratory, Brooks-Rand, Ltd., in Seattle. Results of this analysis are included in Appendix 2.

Another important component of the RMP quality assurance program is the storage and maintenance of archived samples which can be used in future years as analytical methodologies improve. This particularly applies to measurements of organic trace contaminants. Detection limits for some of these constituents are very close to, or above water quality criteria or guidelines, one example being the dioxin-like compounds. Analysis of archived samples in future years could serve to reconstruct trends for these compounds. The same is possible for samples taken prior to the initiation of the RMP to increase the sample size and therefore the statistical confidence in trend analyses.

Data Management and Analysis

Data generated by the RMP were first transmitted to AMS electronically in various spreadsheet formats for a primary scan for completeness. AMS then formatted the spreadsheets for submission to SFEI where the data are maintained in an Oracle data base. Data tables are included in the Appendices of this report, and data in electronic form are available from SFEI upon request.

Environmental concentrations of many organic contaminants are near or below the limits of detection of the analytical methods. Consequently, a large proportion of the results obtained for the organics are reported as below detection limits. In order to use these semiquantitative results in statistical analyses, they must be converted to quantitative results. Commonly used options for making this conversion include using zero, half the detection limit, the detection limit, or the uncensored result, even if it is below the detection limit.

For a number of reasons, censored or qualified data in the RMP dataset are treated as zeros in the analyses presented in this report. First, this option allows for the most meaningful calculations of totals for a contaminant class and the relative contribution of individual chemicals to that total. By using zeros, these calculations are not affected by the varying detection limits of the chemicals. Second, this option avoids complications posed by the different ways in which qualifiers were applied to the raw data by the three different laboratories that produced the organics data. Third, this option focuses attention on samples where large masses of contaminant were found instead of cases where large numbers of individual contaminants were analyzed. The first step in analysis of the organics data was to examine the frequency of detection for each chemical (Appendix 4). Detailed analysis was reserved for chemicals with high frequencies of detection. Where appropriate, a sensitivity analysis was performed to determine whether different methods of handling values below detection significantly affected the results.

Although concentrations at or below the MDL cannot be quantified, they do contain information that can be statistically evaluated in large data sets (Osborn and Rosecrans 1995). The RMP therefore strives to retain uncensored values in its data base whenever possible.

The analyses presented in this report were conducted using the PC version of SAS (1990). Several SAS procedures were used: CLUSTER, CORR, REG, TABULATE, and MEANS were used and will be referred to and explained throughout this report.

Statistical analysis of significant differences in contaminant concentrations in space (between stations or parts of the Estuary) and time (among the sampling periods) is not presented in this report. Even after two years of sample collection, the ability of RMP monitoring data to accurately determine such differences is limited. Statistical power (the ability to detect actual differences) of six sampling events is still low, although qualitative comparisons can be made. The Special Study on optimal sampling design evaluates statistical differences among stations and will serve as foundation for the analysis of long-term trends. Trends in contaminant concentrations over time are presented qualitatively for the six sampling events from March of 1993 until August of 1994. Several years of RMP data collection are needed before analyses of significant trends in space and time will be conducted.

The results of the aquatic and sediment bioassays were analyzed by statistical comparison of the ambient sample endpoints to laboratory control sample endpoints. These statistical tests (analysis of variance) are prescribed in the ASTM protocols used.

Interpretation of Monitoring Results

This report describes contaminant concentrations measured in the Estuary in 1994 and compares these results with those obtained during the previous year. The results presented should be interpreted considering the above discussion. Relationships between contaminant concentrations and other water or sediment variables are identified to show which factors may influence contaminant concentrations. As pointed out in Appendix 1, in many instances the RMP is at the cutting edge of analysis capabilities. Particularly with respect to organic trace contaminants, measured concentrations are often close to the detection limit. Uncertainties in the analyses may therefore be higher in some cases than in more conventional programs that do not attempt to measure analytically challenging compounds.

The water quality objectives currently in effect for the San Francisco Estuary are those adopted in the 1986 Basin Plan and standards promulgated by the U.S. EPA in the National Toxics Rule (February 1993). These objectives cover only a limited set of constituents. A process is currently underway at the statewide level to develop a more comprehensive set of objectives that reflects updated technical information and other factors. The U.S. EPA has developed criteria for almost all contaminants monitored in the RMP and is scheduled to propose standards for California based on these criteria. In some cases the measurements made by the RMP are different than those prescribed for regulatory purposes. Comparisons between existing or proposed standards and RMP results should be made for informational purposes only. Also, no regulatory standards exist for any contaminant in sediment or tissue. Any comparisons of RMP data to non-regulatory sediment or tissue guidelines should therefore be interpreted accordingly. The details and qualifications for the comparisons used in this report are included in the appropriate sections.

Water Monitoring



Water Monitoring

General Water Quality

The water quality characteristic component of the RMP has two purposes. The first is to provide adequate supporting data for geochemical interpretation of contaminant concentrations, which can be directly influenced by salinity, total suspended sediments (TSS), dissolved organic carbon (DOC), and other parameters. The second purpose is to assess overall water quality conditions of the Estuary by using conventional water quality parameters as indicators. Basic water quality parameters, such as pH or dissolved organic carbon can be difficult to interpret individually because they reflect the net effect of many different processes in the Estuary. For the same reason, they may be able to serve as good indicators of overall water quality, given adequate sampling to establish a baseline.

In 1994 water quality characteristics were measured in three ways. As in 1993, the water samples collected for determination of contaminant concentrations were analyzed for water quality parameters. The parameters measured are listed in Table 4, and data are included in Appendix Table 3.1. In addition, during both the water and sediment cruises, a conductivity, temperature, and depth (CTD) profiler was used to collect data over depth of these three parameters as well as dissolved oxygen and optical backscatterance (OBS) at all stations. Conductivity was used to determine salinity, and OBS was used to measure total suspended solids (TSS). The two USGS Pilot Studies provided a third source of water quality data. The Hydrography and Water Quality Pilot Study took vertical profiles of salinity, temperature, depth, suspended particulate matter (SPM = TSSmeasured by RMP), light penetration, dissolved oxygen, and chlorophyll a at 35 locations along a north to south transect of the Estuary on a monthly basis. In addition, horizontal profiles (typical resolution about 20m) of salinity, temperature, chlorophyll and SPM in near surface waters were collected using new MIDAS (Multiple-Interface Data Acquisition System) instrumentation. The Sediment Transport Pilot Study measured TSS, using in-situ OBS sensors, at 15 minute intervals near the surface and near the bottom at seven

stations in the Estuary. These various sources of information were measured at a variety of temporal and spatial scales, thus providing different perspectives on spatial and temporal trends in estuarine water quality in 1994.

In order to make comparisons of trace contaminant concentrations between different areas of the Estuary (e.g., South Bay and Central Bay), RMP stations were grouped into five Estuary reaches based on cluster analysis of water quality and contaminant concentrations, as well as geographical locations. The reaches are: southern sloughs (C-1-3, C-3-0), South Bay (7 stations: BA10 - BB70), Central Bay (5 stations: BC10 - BC60), northern Estuary (8 stations: BD15 - BF40), and Rivers (BG20, BG30). Although "South Bay" is usually considered to be south of the Dumbarton Bridge, the stations south of Alameda more often clustered together indicating that their water masses were similar. The use of Estuary reaches in this report are only intended to facilitate comparisons and does not imply knowledge of any consistent functionality. These reaches are based on water data; a separate analysis and groupings were used for sediment stations.

Fresh Water Flows and Salinity

RMP sampling was conducted in February, April, and August, in order to characterize water quality in the Estuary over a range of hydrologic conditions. Estimated Delta discharge and RMP sampling times are shown in Figure 2. Peak outflows in the winter and spring of 1994 occurred in late February, after the first RMP sampling, and their magnitude was only about one third of the peaks in 1993. The lower Delta outflows were reflected in higher salinities and a narrower range of salinities in the Estuary in 1994. Depth-averaged salinities from the RMP water cruises are shown in Figure 3. The lowest salinities were measured in April, as the influence of the peak Delta outflows reached the main Estuary. The lower salinities in February reflect sampling before peak Delta outflows reached the Estuary. However, this difference was not substantial. In general, salinities were similar during the first two cruises, and then increased, as expected, in August. There was little salinity gradient in the South Bay; except for the Coyote Creek (BA10), San Jose (C-1-3) and Sunnyvale (C-3-0) stations, salinities consistently exceeded 25 ppt. For comparison, in March



Figure 2. Estimated Delta outflow in 1994. Dots indicate RMP sampling periods for 1994. CMS = cubic meters per second. (courtesy of Department of Water Resources, Sacramento)

1993, salinities at RMP stations in the South Bay ranged from 8 to 18 ppt. The northern Estuary displayed a typical estuarine salinity gradient. The decrease in salinity between February and April was not as consistent, likely due to the influence of local freshwater inflows at the Petaluma and Napa Rivers. Salinities were always higher than during the comparable sampling periods in 1993 (SFEI, 1994).

Comparison with the horizontal salinity profile produced by the Hydrography and Water Quality Pilot Study (Figure 4) shows that salinities in the Estuary were lowest in March, between the winter and spring RMP sampling periods.

Other Water Quality Parameters

Water temperatures throughout the Estuary increased seasonally (February, April, August) as expected. In the Central Bay the range of temperatures was the least, due to the moderating influence of oceanic waters. At Golden Gate (BC20), temperatures ranged from 12° C in February to 15° C in August. Both in the extreme South Bay and in the rivers (BG20 and BG30) temperatures ranged from 10 to 11° C in February to $23-25^{\circ}$ C in August.

Suspended sediment is linked to a number of processes in the Estuary, including limitation of light penetration and primary productivity, erosion or accretion of wetlands, and transport of sorbed contaminants and nutrients. TSS directly influences the concentration of total (unfiltered) contaminants in the water column due to the presence of contaminants sorbed onto suspended particulate matter. TSS may potentially affect dissolved concentrations, as well, by serving either as a source or "scavenging" dissolved contaminants, if the rate of sorption or desorption is rapid compared to TSS dynamics. TSS concentrations reflect the net effect of sediment inflows, deposition, and resuspension. The Suspended Sediment Transport Processes Study is



Depth-Averaged Salinity

Figure 3. Salinity in parts per thousand (0/00) at each RMP water station during the three water sampling periods of 1994. Depth average salinity is the average of salinities measured over water depth using CTD (conductivity, temperature, depth) data. For station names and locations see Table 1. ○ indicates not analyzed.

collecting time series measurements of TSS at fixed stations to investigate the influence of tides, winds, and fresh water inflows on TSS. These processes vary on time scales that range from hours to months, resulting in a parallel range of time scales in TSS. However, the study has identified the spring-neap tidal cycle as a particularly important source of variability in TSS.

TSS concentrations were measured both in the water samples collected for contaminant analysis and in vertical transects using an optical backscatter sensor attached to the CTD. The two data sets show a high level of consistency at the one meter sampling depth, with TSS concentrations in the vertical transects increasing with depth. TSS concentrations measured in the water samples are shown in Figure 5. In general, TSS concentrations were higher in the northern Estuary than in South Bay. The TSS measurement of 350 mg/L at Petaluma River (BD15) was 150 mg/L higher than any other station in 1993 or 1994. A similar "spike" of TSS was also measured at San Pablo Bay station (BD20) in May of 1993. Based on information collected for the Sediment Transport Pilot Study, it is believed that this pattern represents a typical response to spring tides that occurs monthly throughout the Estuary. This phenomenon has only been coincidentally measured by the RMP base program in San Pablo Bay in the spring samples, but continued sampling should identify similar events throughout the Estuary.

Both the April and August cruises took place over periods of strong spring to neap tidal variations, which affected TSS concentrations throughout the Estuary. In particular, during the course of the April cruise, TSS



Figure 4. Horizontal salinity profile (Courtesy of USGS, Water Resources Division, Menlo Park and Alan Jassby, UC Davis).

increased significantly at the Pilot Study stations. Since the RMP cruises start in the South Bay and end up at the Delta, any perceived increase in TSS from south to north is at least in part due to temporal variability rather than spatial variability.

Dissolved organic carbon (DOC) provides a collective measurement of organic compounds from a wide range of sources, including primary and secondary production within the Estuary as well as point and nonpoint sources in the watershed (Jassby 1994). The presence of DOC causes metals, particularly copper, to form organic complexes which are more likely to stay in solution than inorganic copper complexes. Thus higher DOC concentrations can result in a higher ratio of dissolved to total copper in the water column.

Throughout the Estuary, DOC concentrations were lowest in February, highest in April, and intermediate in August (Figure 6). In 1993 DOC concentrations



Total Suspended Sediments

Figure 5. Total suspended sediments in milligrams per liter (mg/L at each RMP water station during the three sampling periods of 1994. For station names and locations refer to Figure 1.

decreased from the winter sampling to the fall sampling. The peak later in the year coincides with the later peak in fresh water inflows in 1994 compared to 1993, pointing to the importance of riverine sources of organic matter. The high DOC concentration at the river stations in March 1993 provides further indication that DOC concentrations in the Estuary are a function of fresh water inflows. The range of DOC concentrations was similar to 1993 (except at the two new South Bay stations): 68 to 300 µM, with the lowest concentrations at Golden Gate (BC20) and the highest in the South Bay stations. The Sunnyvale and San Jose stations (C-1-3, C-3-0) had the highest concentrations of DOC in the Estuary. DOC concentrations at the Sunnyvale station (C-1-3) in April (824 μ M) and August were almost twice as high as at any other station.

Nutrients

Concentrations of total ammonia, nitrite, nitrate, and phosphate during the three water cruises are reported in Appendix Table 3.1. Nutrient concentrations were generally highest in the South Bay with a steady gradient to the lowest concentrations in the Central Bay. As an example, phosphate concentrations are shown in Figure 7.

The two South Bay slough stations (C-1-3 and C-3-0) consistently had nutrient concentrations much higher than anywhere else in the Estuary, except for nitrate in February. In the rest of the Estuary, concentrations of phosphate ranged from 35 to 600 μ g/L (PO₄ -P), concentrations of nitrate ranged from 92 to 1,200 μ g/L (NO₃—N), nitrite ranged from 7 to 92 μ g/L (NO₂- -N), and total ammonia nitrogen ranged from 1.3 to 274 μ g/L. There was no clear temporal trend in nutrient concentrations.



Dissolved Organic Carbon

Figure 6. Dissolved organic carbon in micromoles (μM) at each RMP water station during the three sampling periods of 1994. For station names and locations refer to Table 1. 1 μM of dissolved organic carbon is equal to 12 μg/L.

Chlorophyll

Chlorophyll a is an indicator of phytoplankton or algal biomass, which forms the base of the food web. Typically, the spring bloom in South Bay and the summer maximum in Suisun Bay or upstream are the primary causes of variations in chlorophyll concentrations in the Estuary, although there was no summer maximum in 1994. Since phytoplankton dynamics can be relatively rapid (on the order of 1-2 weeks), they cannot be documented without frequent sampling.

Among the three RMP water cruises, chlorophyll concentrations were highest at almost every station in April, and the variations in chlorophyll concentrations between the three cruises were minor (Figure 8). Concentrations were highest in the extreme South Bay and in San Pablo Bay.

The monthly USGS transects confirm that, among the three RMP water cruises, chlorophyll concentrations throughout the Estuary were highest in April. The USGS monthly cruise measured maximum concentrations of chlorophyll of around 35 μ g/L in the South Bay in mid-March, between the February and April cruises (see Pilot Studies). In 1993, the bloom peak of chlorophyll *a* in the South Bay was about 70 μ g/L.
80 February 70 ■April August 60 50 Phosphate,µM 40 30 20 10 ▋▖▆▋▋▖▅▋ 0 C-3-0 BA10 BB15 BD15 **BA20 BA30** C-1-3 BA40 **BB30 BB70** BC60 BD20 **BD**30 **BF10** BG30 BC30 BD40 BD50 BF20 BC20 BC4 BF4(ШÖ Southern Northern Estuary Rivers South Bay Central Bay Slough

Phosphate

Figure 7. Phosphate concentrations in micromoles (μM) at each RMP water sampling station during the three sampling periods of 1994. For station names and locations refer to Table 1. 1 μM of phosphate is equal to 31 μg/L.



Figure 8. Concentrations of chlorophyll a in parts per million (mg/m³) at each RMP water sampling station during the three sampling periods of 1994. For station names and locations refer to Table 1.

Chlorophyll a

Contaminants in Water

Concentrations of ten trace elements were measured at all 22 RMP base program stations, and 135 trace organic compounds were measured at the 15 stations where the bioaccumulation samples were collected (Table 3). The contaminants measured are listed in Tables 5 and 6. Sampling was conducted during all three sampling periods in 1994.

In addition to the RMP base program sampling, two more stations were sampled in cooperation with the Regional Board and the Cities of San Jose and Sunnyvale. These stations are located upstream in Coyote Creek (C-3-0) and Guadalupe Slough (C-1-3), between the outfalls of those cities and the RMP Coyote Creek station (BA10) (Figure 1). The two additional stations are designated the San Jose and Sunnyvale stations, and collectively they are refered to as the southern slough stations.

One of the objectives of the RMP is "to determine whether water quality...in the Estuary at large is in compliance with objectives established by the Basin Plan". In this report, comparisons to water quality standards are made to generally evaluate the overall condition of the Estuary in terms of contamination, and not for any regulatory purpose. Water quality standards currently in effect for the San Francisco Estuary are those adopted in the 1986 Basin Plan for the San Francisco Bay Region and criteria promulgated by the U.S. EPA in the National Toxics Rule (1993). However, a process is currently underway at the statewide level to develop a more comprehensive set of objectives that reflect updated technical information, and other factors. The statewide process for adopting objectives will probably last for another 2-3 years. The U.S. EPA has proposed criteria for almost all contaminants monitored in the RMP and proposed standards for California based on those criteria (National Toxics Rule, expected in 1995). After federal standards are promulgated they will remain in effect until either state or site-specific objectives are adopted and approved by the EPA.

For this report, RMP data are compared to a conservative set of values composed of the lower values from: a) the existing 1986 Basin Plan objectives, b) U.S. EPA human health criteria (at a 10⁻⁶ risk level), or c) U.S. EPA acute or chronic aquatic life criteria. There is

a fair amount of certainty that there will be no adverse effects at concentrations below these values.

In some cases, measurements made by the RMP are above one of the criteria or differ from the way the criteria are expressed. The details and qualifications for comparisons used in this report are included with descriptions for each contaminant. Also, different standards exist for saltwater and freshwater (salinity below 5 ppt as defined in the Basin Plan). Eight RMP stations had salinities below 5 ppt in 1994: Honker Bay (BF40), and the Sacramento and San Joaquin River stations (BF20, BF30) in February and April, and the two River stations only in August. Water quality objectives for six of the ten metals measured at those stations are related to water hardness (expressed as mg/L calcium carbonate, 1995 Basin Plan Update). Since the RMP measured water hardness at those stations (see Appendix Table 3.1), the exact criteria values at each station were calculated.

Another objective of the RMP is to describe spatial and temporal trends in contaminant concentrations in the Estuary. In order to compare trace contaminant concentrations between different areas of the Estuary (e.g. South and Central Bays), the Estuary reaches described in the preceding section are used.

Since this is the second year of the RMP, contaminant concentrations measured in the six sampling periods over the past two years are compared. Rigorous statistical analysis of trends requires many more sampling periods, thus the data presented are interpreted qualitatively. It will require several more years of RMP data to accurately delineate seasonal or interannual patterns in trace contaminant trends.

Trace contaminant concentrations in the San Francisco Estuary are variable in space and time because of the influence of many different factors. Geochemical interactions with conventional water quality parameters (salinity, nutrients, suspended sediments), mixing with fresh or seawater, changes in sorption or desorption onto sediment particles, or inputs of contaminants can all affect trace contaminant concentration patterns in the Estuary (Flegal 1991, Kuwabara *et al.* 1989; Luoma and Phillips 1988).

The degree of mixing between fresh water, primarily from the Sacramento and San Joaquin Rivers, and seawater from the ocean has a large influence on dissolved trace element concentrations. In theory, in the absence of contaminant inputs or sinks plots of dissolved contaminants vs. salinity would demonstrate a simple linear relationship, or conservative mixing model, which can be considered as background concentrations for the Estuary along a salinity gradient. However, values at some stations fall either above or below this theoretical line, indicating higher or lower than expected values. Higher values may be due to proximity to natural or anthropogenic sources or geochemical or biological remobilization. Lower values may be due to "sinks" or losses due to geochemical and biological scavenging of contaminants, or may be due to artifacts of non-steady state conditions (Flegal 1991).

In this report, dissolved contaminant concentrations vs. salinity plots (mixing profiles) are shown to help evaluate how well the RMP stations conform to conservative mixing, and help understand variation in contaminant concentrations in space and time. Stations from the South Bay are distinguished from the other stations because they have been previously shown to exhibit deviations from conservative mixing, due to hydrologic factors influencing water quality in the South Bay compared to other areas of the region, and the large urban areas surrounding South Bay. Examination of these plots can be used to make inferences about where and when anthropogenic inputs of dissolved trace metals may be occurring. If elevated concentrations occur during periods of high runoff, but not during low flow periods, then a runoff source is implied. Conversely, if the points are elevated above the curve during the dry period, but not during the high flow periods, then more continuous sources, such as outfalls or atmospheric deposition are implied. Elevated concentrations occurring during both high flows and low flows may suggest many sources.

Dissolved trace contaminants may be chemically complexed with other organic material in water, such as dissolved organic carbon (DOC), producing complex organic-contaminant molecules. DOC in the Estuary has several sources including plankton and other algae, tidal marshes, and rivers (Jassby *et al.* 1993). The relationship between DOC and contaminant concentrations provides an evaluation of the affinity of dissolved contaminants and DOC. Similarly, contaminants associated with the organic or mineral particles in a water sample may also affect the contaminant concentrations. Geochemistry of adsorption of contaminants onto particles is complex and dynamic. Mineral particles, particularly clays, may adsorb contaminants onto their surfaces due to electrostatic forces or through interaction with other adsorbed organic molecules. Organisms may remove these adsorbed layers when ingested. The relationship between measurements of total suspended sediment (TSS) and contaminant concentrations are used to evaluate the affinity of contaminants for sorption onto sediment particles.

Trace Elements in Water

Dissolved (0.45 μ m filtered) and total (arsenic, chromium, mercury, selenuim) or near-total (cadmium, copper, lead, nickel, silver, zinc) concentrations are presented in graphic form in the following section. Data are listed in Appendix Tables 3.2 and 3.3. For continuity and ease of comparison to appropriate water quality objectives and criteria, all trace elements are expressed in parts per billion (ppb = μ g/L). Dissolved trace element concentrations were sometimes reported as higher than the total or near-total concentration. This occurs because of variability associated with collection and measurement of low levels of contamination. When this occurs, the data are interpreted as no difference between dissolved and total (near-total) values, or that the values consist entirely of dissolved fractions.

Arsenic (As)

Dissolved As concentrations ranged between 1.3 and 4.7 ppb (Figure 9). The highest concentration was at the Extreme South Bay (BA20) in August, and the lowest concentrations were at the Golden Gate (BC20). Average concentrations were highest at the South Bay reach in August, and were lowest at the Rivers reach. Dissolved As contributed averages of 86-93% to total As during the three sampling periods.

Total As concentrations ranged between 1.7 and 5.0 ppb (Figure 9). The highest concentration was at the Petaluma River (BD15) in April, and the lowest



Total Arsenic in Water 1994



Figure 9. Dissolved and total arsenic (As) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.

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Table 7.Correlation coefficients (r) for dissolved trace metals and several water quality
parameters. * means r is significant at $\alpha = 0.01$. n = 22 to 24, depending on missing values. See
Appendix Table 3.2.

| Trace Metal | | <u>Salinity</u> | | Water Q | uality Para DOC | ameters | TSS | | | |
|-------------|------|-----------------|------|---------|--------------------|---------|------|-----|------|--|
| | Feb | Apr | Aug | Feb | Apr | Aug | Feb | Apr | Aug | |
| Ag | .59* | 16 | .57* | 40 | .93* | 09 | .06 | .01 | 13 | |
| As | .46 | .10 | .12 | .15 | .51 | .60* | .50 | 15 | .44 | |
| Cd | .52* | .67* | .73* | .06 | 08 | 21 | .53* | .01 | .01 | |
| Cr | 83* | 43 | 46 | .23 | .92* | .54* | 18 | .01 | .56* | |
| Cu | 44 | 30 | 04 | .59* | .72* | .50 | .54* | .05 | .56* | |
| Hg | 41 | 17 | 13 | .69* | .70* | .54* | .25 | 06 | .69* | |
| Ni | 24 | 17 | 02 | .75* | .80* | .81* | .44 | .01 | .68* | |
| Pb | 58* | 29 | 21 | .92* | .92* | .97* | .24 | 04 | .31* | |
| Se | .00 | .06 | .09 | .45 | .69* | .66* | .31 | 30 | 09 | |
| Zn | 29 | 24 | 20 | .76* | .85* | .83* | .28 | 07 | .65* | |

| Table 8. | Correlation coefficients (r) for total or near-total (+) trace metals and several water |
|----------|--|
| | quality parameters. * means r is significant at $\alpha = 0.01$. n = 22 to 24, depending on missing |
| | values. See Appendix Table 3.3. |

| Trace Metal | Water Quality Parameters | | | | | | | | | | | | |
|-------------|--------------------------|------|----------|-----|-----|------|------|------|------|------|------|------|--|
| | Dissolved Element | | Salinity | | | TSS | | | DOC | | | | |
| | Feb | Apr | Aug | Feb | Apr | Aug | Feb | Apr | Aug | Feb | Apr | Aug | |
| +Ag | .05 | .59* | .15 | 07 | 26 | .01 | .81* | .80* | .84* | .63* | .59* | .46 | |
| As | .91* | .29 | .81* | 37 | 08 | .05 | .59* | .83* | .47 | .26 | .15 | .65* | |
| +Cd | .99* | .88* | .78* | .49 | .48 | .70* | .52* | .40 | .34 | .10 | 09 | 01 | |
| Cr | 25 | .03 | .57* | .06 | 27 | 23 | .84* | .99* | .94* | .26 | .09 | .42 | |
| +Cu | .76* | .30 | .74* | 32 | 33 | 26 | .77* | .95* | .91* | .61* | .15 | .44 | |
| Hg | .41 | 10 | .76* | 05 | 25 | 16 | .93* | .98* | .79* | .48 | .09 | .65* | |
| +Ni | .86* | .30 | .85* | 17 | 29 | 18 | .79* | .94* | .91* | .71* | .23 | .51 | |
| +Pb | .48 | .13 | .43 | 06 | 39 | 23 | .93* | .91* | .94* | .56* | .25 | .47 | |
| Se | .76* | .86* | .73* | .01 | .09 | .23 | .35 | 16 | .07 | .44 | .69* | .74 | |
| +Zn | .95* | .23 | .77* | 28 | 37 | 25 | .54* | .92* | .95* | .82* | .29 | .51 | |

concentration was at the Golden Gate (BC20) in August. Average concentrations were highest in different Estuary reaches during each sampling period. They were highest in February at the South Bay stations, in April at the northern Estuary stations, and in August at the southern slough stations. Concentrations were generally lowest at the Central Bay stations.

Both dissolved and total As were usually higher in the dry sampling period (August) and lowest in the wet period (February) samples.

Dissolved As was not significantly correlated with salinity in any sampling period, and was significantly correlated with DOC only in August (Table 7). Regression analysis showed that salinity and DOC together accounted for 60%, 40%, and 44% of the variation in dissolved As concentrations in the three sampling periods respectively.

Plots of dissolved As vs. salinity are shown on Figure 19. In February and April, at most stations, dissolved As concentrations remained rather constant regardless of salinity. Some of the South Bay stations had concentrations that were higher than expected based on conservative mixing alone. In August when flows were lowest, the South Bay stations, as well as several other Estuary stations were even more elevated. The lowest concentration in August was at the Golden Gate.

Dissolved and total As were significantly correlated in the February and August samples, but not in the April (Table 8). Total As was significantly correlated with TSS in the February and April samples. Regression analysis showed that dissolved As and TSS together accounted for 86%, 86% and 70% of the variation in total As during each sampling period respectively.

Average total As concentrations in each Estuary reach from the 1993 and 1994 RMP samples are shown on Figure 20. Ranges of concentrations were similar in both years. Average values in the dry season samples were slightly higher than those from the other sampling periods in most reaches, but there were no obvious increasing or decreasing trends.

The U.S. EPA water quality criterion is 36 ppb for both dissolved and total As, and none of the RMP stations were above that value. The freshwater objective for As is 190 ppb (not related to water hardness). None of the eight stations sampled with salinities below 5 ppt had As concentrations above that level.

Cadmium (Cd)

Dissolved Cd concentrations ranged between 0.014 and 0.217 ppb (Figure 10). The highest concentration was at the Dumbarton Bridge (BA30) in August, and the lowest concentration was at the Sacramento River (BG20) in February. On the average, dissolved Cd was highest at the South Bay reach and lowest at the Rivers reach during all sampling periods. Dissolved Cd contributed averages of 82-100% to near-total Cd. In February and August, dissolved concentrations often equaled or exceeded near-total concentrations (see Methods for interpretation).

Near-total Cd concentrations ranged between 0.018 and 0.179 ppb. Due to the large contribution of dissolved Cd to near-total Cd, patterns in their concentrations were nearly identical.

Both dissolved and near-total Cd were highest in August and lowest in February. Concentrations in August were nearly twice as high as during the other sampling periods. Reasons for these differences are not known.

Dissolved Cd was the only metal significantly correlated with salinity during all three sampling periods (Table 7), but Cd was not significantly correlated with DOC, and was significantly correlated with TSS only in the February samples. Together, salinity and DOC accounted for 60%, 52%, and 54% of the variation in dissolved Cd during each sampling period respectively.

Plots of dissolved Cd vs. salinity show that dissolved Cd concentrations increase as salinity increases (Figure 19), opposite of the relationship shown for most other metals. This is because background concentrations of Cd in ocean water are higher than in fresh water, particularly during upwelling. During the first two sampling periods, the South Bay stations, as well as some other Estuary stations were above the mixing curve. In August, all stations generally conformed to the linear mixing curve.

Near-total Cd was highly correlated to dissolved Cd during all sampling periods, mainly because most of the Cd in the Estuary was in the dissolved phase (Table 8). Near-total Cd was not significantly correlated with salinity and TSS in two of the three sampling periods, and was not significantly correlated with DOC in any of the sampling periods. Together, dissolved Cd and TSS



Dissolved Cadmium in Water 1994

Figure 10. Dissolved and near-total cadmium (Cd) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.

Central Bay

Rivers

Northern Estuary

Southern

Slough

South Bay

accounted for 99%, 93%, and 72% of the variation in near-total Cd during each sampling period, respectively. Most of that variation was attributable to dissolved Cd alone.

Comparison of the 1993 and 1994 RMP results indicates that average near-total Cd concentrations were quite variable in each Estuary reach except the Rivers (Figure 20). The dry period samples were higher than the other sampling periods in all reaches but the rivers, which remained comparatively consistent. The August 1994 samples were higher than all other samples.

The 1986 Basin Plan objective, as well as the current EPA criterion for dissolved and total Cd is 9.3 ppb. None of the stations sampled had dissolved or near-total Cd concentrations above that level. The freshwater objective for total Cd is related to water hardness and ranged between 1.1 and 4.2 ppb at the eight stations with salinities below 5 ppt. However, none of the near-total Cd concentrations were above those values.

Chromium (Cr)

Dissolved Cr concentrations ranged between 0.07 and 2.70 ppb (Figure 11). By far, the highest concentration was at the Sunnyvale station (C-1-3) and the lowest concentration was at Oyster Pt. (BB30) in April. Average dissolved Cr concentrations were highest at the southern sloughs reach in April and August, and at the Rivers reach in February. Average concentrations were lowest at the South Bay reach in February and the Central Bay reach in April and August. Dissolved Cr contributed an average of 10-11% to near-total Cr during the three sampling periods.

Total Cr ranged between 0.19 and 44.89 ppb. The highest concentration was measured at the Petaluma River (BD15) in April reflecting the elevated TSS measured there at the same time. The lowest concentration was measured at the Golden Gate (BC20) in April. Average concentrations were highest in the southern sloughs reach in February and August, and in the northern Estuary reach in April. The April measurement reflects the one high value at the Petaluma River. Average total Cr was lowest at the Central Bay stations during all three sampling periods. In general, dissolved Cr was higher in August, but not at the southern slough or River stations. Total Cr was higher in April at the northern Estuary and River reaches, but there was no clear seasonal difference at the other reaches.

Dissolved Cr was significantly correlated with salinity only in February (Table 7). Dissolved Cr was significantly correlated with DOC in April and August, and with TSS in August. Together, DOC and salinity accounted for 83%, 84%, and 42% of the variation in dissolved Cr in each sampling period respectively.

Plots of dissolved Cr and salinity show that dissolved Cr was well-mixed throughout the Estuary during all three sampling periods (Figure 19). In April, the Sunnyvale station (C-1-3) was much higher than expected.

Total Cr was significantly correlated with dissolved Cr only in August (Table 8), but total Cr was significantly correlated with TSS during all sampling cruises. Together dissolved Cr and TSS accounted for 73%, 98%, and 76% of the variability in near-total Cr during the three sampling periods respectively. However, most of that variation was attributable to TSS alone.

Compared to the 1993 RMP data, total Cr in 1994 had similar ranges of values (Figure 20). Concentrations in the northern Estuary reach in the spring samples were higher and more variable than those in other Estuary reaches. There were no obvious seasonal trends or increasing or decreasing trends.

The 1986 Basin Plan objective, as well as the U.S. EPA criterion is expressed in terms of one chemical form of chromium (Cr VI) at 50 ppb. RMP analysis did not distinguish between Cr VI and other forms of Cr. None of the RMP stations had dissolved or total Cr concentrations above the objective. The freshwater objective is 11 ppb (not related to water hardness), and none of the concentrations at the eight stations with salinities below 5 ppt were above that value.

Copper (Cu)

Dissolved Cu concentrations ranged between 0.3 and 5.9 ppb (Figure 12). The highest concentration was at the San Jose station (C-3-0) in April, and the lowest concentrations were at the Golden Gate (BC20). On the



Dissolved Chromium in Water 1994

Figure 11. Dissolved and total chromium (Cr) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.
♥ indicates not analyzed.

average, concentrations were highest at the southern sloughs reach, and lowest at the Central Bay reach in all sampling periods. Dissolved Cu contributed averages of 56-74% to near-total Cu during the three sampling periods.

Near-total Cu concentrations ranged between 0.5 and 20.7 ppb. By far, the highest concentration was measured at the Petaluma River (BD15) in April, reflecting the elevated TSS measured there. The lowest concentration was at the Golden Gate (BC20). Average near-total Cu was highest at the southern sloughs reach in February and August, but was highest at the northern Estuary stations in April due to the high concentration at the Petaluma River.

Both dissolved and near-total Cu were higher in April and August samples than in the February samples. Dissolved Cu was higher during April at the southern sloughs and some South Bay stations, but near-total Cu was higher in August at those stations.

Dissolved Cu was not significantly correlated with salinity during any of the sampling periods (Table 7). Dissolved Cu was significantly correlated with TSS in February and August, and with DOC in February and April. Together, salinity and DOC accounted for 31%, 52%, and 26% of the variability in dissolved Cu in each sampling period, respectively.

Plots of dissolved Cu and salinity (Figure 19) show that most of the Estuary stations conformed to conservative mixing in February. In April, most of the South Bay stations had elevated concentrations, while the remaining RMP stations exhibited a curvelinear relationship with salinity. The "hump" in the mixing curve at the freshwater end suggests riverine sources of dissolved Cu. In August, the relationship became even more non-linear as the "hump" moved further into the main Estuary.

Near-total Cu was significantly correlated with dissolved Cu in February and August (Table 8), and with TSS during all sampling periods. Together dissolved Cu and TSS accounted for 72%, 97%, and 91% of the variability in near-total Cu in each sampling period, respectively.

Comparisons of 1993 average near-total Cu with those reported in 1994 show rather consistent concentrations in all Estuary reaches (Figure 20). The northern Estuary sites had wider ranges of values than those in other reaches. There was no observable seasonality, or increasing or decreasing trends.

The U.S. EPA water quality criterion for total Cu is 2.9 ppb (National Toxics Rule, 1993). Forty of the RMP sites sampled in the three sampling periods had near-total Cu concentrations above that value (Table 16). The U.S. EPA also uses a criterion of 2.4 ppb for dissolved Cu, and 29 RMP stations had higher dissolved concentrations. Neither of these criteria were adjusted to account for local water effects. The freshwater objective for total Cu depends on water hardness. The range of objectives at the eight stations with salinities below 5 ppt was 11.4 to 49.2 ppb, and none of the near-total concentrations measured at those stations were above those objectives.

Lead (Pb)

Dissolved Pb concentrations ranged between 0.0003 and 1.249 ppb (Figure 13). By far, the highest concentration was at the Sunnyvale station (C-1-3) in April; the lowest concentration was at Pt. Isabel (BC41) in April. Average dissolved Pb concentrations were highest at the southern sloughs reach during all sampling periods, and were lowest in the northern Estuary reach in April and August.

Near-total Pb ranged between 0.045 and 7.730 ppb. The highest concentration was at the San Jose station (C-3-0) in August, but the concentration at the Petaluma River (BD15) in April was nearly as high. The lowest concentrations occurred at the Golden Gate (BC20). Average concentrations were highest at the southern sloughs reach in February and August and at the northern Estuary reach in April, reflecting the elevated measurement at the Petaluma River. Average near-total Pb was lowest at the Central Bay reach in all 3 sampling periods. Dissolved Pb contributed averages of only 3-7% to near-total Pb in the three sampling periods.

There was no clear seasonality in either dissolved or near-total Pb concentrations, but average dissolved Pb tended to be lower in August than the other sampling periods.

Dissolved Pb was significantly correlated with salinity only in February, but was significantly correlated



Figure 12. Dissolved and near-total copper (Cu) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.
♥ indicates not analyzed.

Dissolved Copper in Water 1994

with DOC in all sampling periods (Table 7). Together, DOC and salinity accounted for 84%, 88%, and 93% of the variation in dissolved Pb in each sampling period respectively.

Plots of dissolved Pb vs. salinity show that Pb was generally well mixed throughout the Estuary in February, but the southern slough stations had slightly elevated concentrations (Figure 19). In April, the southern slough stations had concentrations much higher than expected according to conservative mixing, and in August the pattern was again similar to that in February.

Near-total Pb was not significantly correlated with dissolved Pb in any of the sampling periods (Table 8), but was significantly correlated with TSS during all sampling periods and accounted for 87%, 83%, and 89% of the variability in near-total Pb in each sampling period, respectively.

Average near-total Pb concentrations had similar ranges of values in 1993 and 1994, except that ranges were greater at the South Bay stations in 1994 compared to 1993 (Figure 20). Concentrations in the northern Estuary were much more variable than those in other Estuary reaches, with average concentrations in the spring samples being higher than those in the other sampling periods. There was no indication of increasing or decreasing trends in concentrations.

The U.S. EPA criterion for total Pb is 8.5 ppb, and is 8.1 ppb for dissolved Pb. None of the RMP stations sampled in 1994 had concentrations above those values. The freshwater criteria are dependent on water hardness. The range of criteria for the eight stations with salinities below 5 ppt was 156 to 1177 ppb, and none of the neartotal Pb concentrations measured at those stations were above those values.

Mercury (Hg)

Dissolved Hg concentrations ranged between 0.0003 and 0.0432 ppb (Figure 14). The highest concentration was at the San Jose station (C-3-0) in August and the lowest was at the Golden Gate (BC20). Average dissolved Hg concentrations were highest at the southern sloughs reach, and the lowest concentrations were measured at the Central Bay reach during all sampling periods. Dissolved Hg contributed averages of 19-54% to total Hg in each sampling period.

Total Hg concentrations ranged between 0.001 and 0.110 ppb. By far, the highest concentration was measured at the Petaluma River (BD15) in April, reflecting the elevated TSS measured there. The lowest concentration was at the Golden Gate (BC20). Average total Hg was highest at the southern sloughs reach in February and August, but was highest at the northern Estuary reach in April, mainly due to the elevated concentration at the Petaluma River.

On the average, dissolved Hg was highest in the April samples and lowest in the February samples. However, there was no clear seasonality for total Hg. It was highest at the northern Estuary and River stations in April and lowest there in February. Concentrations were highest at the southern slough stations in August.

Dissolved Hg was not significantly correlated with salinity during any of the sampling periods (Table 7), but dissolved Hg was significantly correlated with DOC during all sampling periods. Together salinity and DOC accounted for 48%, 52%, and 29% of the variability in dissolved Hg in each sampling period, respectively.

Plots of dissolved Hg and salinity (Figure 19) also indicated that salinity had little influence on dissolved Hg concentrations. All stations appeared to be wellmixed in February. In April (highest flows) and August (dry period) the southern slough stations and Coyote Creek (BA10, in April) had higher than expected concentrations related to conservative mixing alone.

Total Hg was significantly correlated with dissolved Hg only in the August samples (Table 8), but was significantly correlated with TSS during all sampling periods. Together dissolved Hg and TSS accounted for 89%, 96%, and 66% of the variability in total Hg in each sampling period, respectively.

Comparisons of 1994 average total Hg with those reported in 1993 show that rather consistent concentrations were measured in all Estuary reaches (Figure 20). The northern Estuary sites had wider ranges of values than those in other reaches. There was no observable seasonality, or increasing or decreasing trends in any of the reaches.

The 1986 Basin Plan objective and U.S. EPA criterion for protection of aquatic life for total Hg is 0.025 ppb. Fourteen of the RMP stations sampled in 1994 had



Dissolved Lead in Water 1994

Figure 13. Dissolved and near-total lead (Pb) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.

concentrations above that level (Table 16). There is no U.S. EPA criterion for dissolved Hg. The U.S. EPA freshwater criterion for total Hg is 0.012 ppb (not related to water hardness). Of the eight stations sampled with salinities below 5 ppt, the three stations sampled in April (Honker Bay BF40, Sacramento River BG20, and San Joaquin River BG30) had total Hg values above the criterion.

Nickel (Ni)

Dissolved Ni concentrations ranged between 0.5 and 8.8 ppb (Figure 15). The highest concentration was at the San Jose station (C-3-0) in April. Dissolved Ni at the Petaluma River (BD15) was also elevated in February. The lowest concentrations were at the Golden Gate (BC20). Average concentrations were highest in the southern sloughs reach, and were lowest at the Central Bay reach during all sampling periods. Dissolved Ni contributed averages of 43-46% to near-total Ni during the three sampling periods.

Near-total Ni concentrations ranged between 0.6 and 36.0 ppb. The highest concentration was at the San Jose station (C-3-0) in August, and the lowest concentration was measured at the Golden Gate (BC20). On the average, concentrations were highest at the southern sloughs reach in February and August, and at the northern Estuary stations in April reflecting the elevated concentration at the Petaluma River (BD15). Concentrations were generally lowest at the Central Bay reach.

There was no clear seasonality in either dissolved or near-total Ni concentrations. However, concentrations were usually lower in February than the other sampling periods. Dissolved and near-total concentrations were higher in different Estuary reaches during each sampling period.

Dissolved Ni was not significantly correlated with salinity in any of the sampling periods, but was significantly correlated with DOC in all sampling periods (Table 7). Regression analysis showed that salinity and DOC accounted for 63%, 69%, and 68% of the variation in dissolved Ni concentrations in the three sampling periods respectively.

Plots of dissolved Ni vs. salinity are shown on Figure 19. These plots help explain why there was no significant linear correlation between dissolved Ni and salinity. Although most of the stations demonstrated linear conservative mixing, most of the South Bay stations, and the Petaluma River in February, had elevated concentrations in all sampling periods.

Near-total and dissolved Ni were significantly correlated in the February and August samples, but not in the April samples (Table 8). Near-total Ni was significantly correlated with TSS in all sampling periods. Regression analysis showed that dissolved Ni and TSS together accounted for 95%, 96% and 92% of the variation in near-total Ni during each sampling period, respectively.

Ranges of near-total Ni concentrations in each Estuary reach during 1993 and 1994 were similar (Figure 20). The northern Estuary stations were most variable with elevated average concentrations occurring each spring. There were no obvious increasing or decreasing trends.

The U.S. EPA criterion for protection of aquatic life for total Ni is 8.3 ppb. Eighteen RMP stations sampled in 1994 had concentrations above that value (Table 16). The U.S. EPA criterion for dissolved Ni is 8.2 ppb, and only one station (San Jose, C-3-0, in April) had concentrations above that value. The freshwater criteria for total Ni depends on water hardness. The criteria ranged between 14.8 and 63.0 ppb at the eight stations where salinity was below 5 ppt, and none of them had near-total Ni concentrations above those values.

Selenium (Se)

Dissolved Se concentrations ranged between 0.12 and 0.79 ppb (Figure 16). The highest concentration was at Sunnyvale (C-1-3) in August, and the lowest concentration was at the Sacramento River (BG20) in August. Average dissolved Se concentrations were highest at the southern slough reach, and the lowest at the Rivers reach during all sampling periods. Dissolved Se contributed averages of 93-100% to total Se in the three sampling periods.

Total Se concentrations ranged between 0.06 and 0.70 ppb. Due to the large contribution of dissolved Se to total Se, patterns in their concentrations were nearly identical.



Figure 14. Dissolved and total mercury (Hg) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.

Dissolved Mercury in Water 1994



Dissolved Nickel in Water 1994

Figure 15. Dissolved and near-total nickel (Ni) concentrations in water (parts per billion, ppb) at the 24 stations

for the three sampling periods in 1994. For station names and locations see Table 1.

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There were no obvious seasonal trends in dissolved Se. Total Se was usually higher in February and lower in August at most stations.

Dissolved Se was not significantly correlated with salinity during any of the sampling periods (Table 7), but was significantly correlated with DOC in April and August. Together salinity and DOC accounted for 32%, 66%, and 50% of the variability in dissolved Se in each sampling period, respectively.

Plots of dissolved Se vs. salinity show that salinity has little influence on dissolved Se concentrations (Figure 19). During February and April the southern sloughs stations and some South Bay stations had higher than expected values. In August, only Sunnyvale had higher values than expected.

Total Se was significantly correlated with dissolved Se in all sampling periods (Table 8), reflecting the large contribution of dissolved Se to total Se. Total Se was not significantly correlated with TSS during any of the sampling periods, but was significantly correlated with DOC in April and August. Dissolved Se alone accounted for 58%, 73%, and 53% of the variability in total Se in each sampling period, respectively.

Comparisons of 1994 average total Se concentrations in each Estuary reach with those reported in 1993 show similar ranges of values (Figure 20). However, the northern Estuary samples in August 1994 had a large range, and the Rivers stations had lower average values than previously reported. There was no obvious seasonality in total Se concentrations.

The U.S. EPA standard for total Se is 5 ppb for both salt- and freshwater. None of the RMP stations sampled in 1994 had total Se concentrations above that value. There is no dissolved Se standard.

Silver (Ag)

Dissolved Ag concentrations ranged between 0.0003 and 0.0341 ppb (Figure 17). By far, the highest concentration was at the Sunnyvale station (C-1-3) in April; the lowest concentration was at the Sacramento River (BD20) in August. Average dissolved Ag concentrations were highest at the South Bay Reach in February and August, and at the southern slough stations in April. The lowest concentrations were River stations. Dissolved Ag contributed averages of 18-32% to near-total Ag in the three sampling periods.

Near-total Ag ranged between 0.0024 and 0.1397 ppb. The highest concentration was at the Petaluma River (BD15) in April, but concentrations at the southern slough stations were also elevated. The lowest concentration occurred at the San Joaquin River (BG30) in August. Average concentrations were highest at the southern slough reach in all sampling periods, and the lowest at the Central Bay stations in February and April, and at the River stations in August.

There were no obvious seasonal differences in dissolved or near-total Ag. Dissolved Ag was higher in different Estuary reaches during different sampling periods. In February, the Rivers and Central Bay had the highest concentrations; in April, the southern sloughs were higher, and in August some South Bay and northern Estuary stations were higher. Near-total Ag was higher in April, in the northern Estuary and rivers, and lower there in February.

Dissolved Ag was significantly correlated with salinity in February and August, but was only significantly correlated with DOC in April (Table 2). Together, DOC and salinity accounted for 44%, 95%, and 33% of the variation in dissolved Ag in each sampling period respectively.

Plots of dissolved Ag and salinity show that Ag was well mixed throughout the Estuary in February (Figure 19). In April, the southern sloughs stations were higher than expected, but in August they were similar to the other stations and some other South Bay stations were elevated.

Near-total Ag was poorly correlated with dissolved Ag except in April (Table 8). However, near-total Ag was significantly correlated with TSS during all sampling cruises. Together, TSS and dissolved Ag accounted for 66%, 97%, and 77% of the variability in near-total Ag in each sampling period respectively.

Compared to the 1993 RMP data, average near-total Ag in 1994 was generally less variable, except at the northern Estuary stations (Figure 20). All samples collected in May 1993 were much higher than those collected in any of the other sampling periods. There was no obvious seasonality or increasing or decreasing trends in near-total Ag.



Figure 16. Dissolved and total selenium (Se) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.



Figure 17. Dissolved and near-total silver (Ag) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.
♥ indicates not analyzed.

Both the 1986 Basin Plan objective and the U.S. EPA criterion for the protection of aquatic life for total Ag is 2.3 ppb. None of the RMP stations sampled in 1994 had concentrations above that value. The EPA's criterion for dissolved Ag is 1.9 ppb, and no dissolved Ag concentrations were above that limit. The freshwater objective for total Ag depends on water hardness. The range of objectives at the eight stations where salinities were below 5 ppt was 0.5 to 9.7, and none of the near-total Ag concentrations were above those values.

Zinc (Zn)

Dissolved Zn concentrations ranged between 0.21 and 24.89 ppb (Figure 18). By far the highest concentration was at the San Jose station (C-3-0) in February. The lowest concentrations were at the Golden Gate (BC20). Average concentrations were always highest at the southern sloughs reach, and were lowest at the Central Bay reach, except in April where the lowest concentrations were measured at the Rivers reach. Dissolved Zn contributed averages between 19-26% to near-total Zn in the three sampling periods.

Near-total Zn concentrations ranged between 0.44 and 46.36 ppb. The highest concentration was measured at the Petaluma River (BD15) in April, reflecting the elevated TSS measured there. Concentrations were also elevated at the San Jose station (C-3-0). The lowest concentration was at the Golden Gate (BC20). Average near-total Zn was highest at the southern sloughs reach in February and August, but was highest at the northern Estuary reach in April due to the large spike at the Petaluma River. Average concentrations were lowest at Central Bay reach during all sampling periods.

Unlike most other trace elements, dissolved Zn exhibited rather clear seasonality. Concentrations were usually higher in February and lower in August. Neartotal Zn was usually higher in April at the northern Estuary and river stations, but higher in February at the other stations.

Dissolved Zn was not significantly correlated with salinity during any of the sampling periods (Table 8), but it was significantly correlated with DOC in all sampling periods. Together, salinity and DOC accounted for 63%, 74%, and 69% of the variability in dissolved Zn in each sampling period, respectively. Examination of plots of dissolved Zn and salinity (Figure 19) shows that some of the southern slough and South Bay stations contained higher than expected concentrations of dissolved Zn. Those concentrations became more similar to the other Estuary stations as the year progressed from wet to low flow to dry. This pattern suggests that runoff is an important source of dissolved Zn in the Estuary.

Near-total Zn was significantly correlated with dissolved Zn in February and August (Table 8), and with TSS during all sampling periods. Together dissolved Zn and TSS accounted for 98%, 93%, and 95% of the variability in near-total Zn in each sampling period, respectively, providing a high degree of predictability for near-total zinc.

Comparisons of 1994 average near-total Zn values with those reported in 1993 show rather consistent concentrations were measured in all Estuary reaches (Figure 20). The northern Estuary sites had a wider range of values than those in other reaches, with the spring samples being higher. There was no observable seasonality or overall increases or decreases over the 6 RMP sampling periods.

The U.S. EPA criterion for the protection of aquatic life for total Zn is 86 ppb. None of the RMP stations sampled in 1994 has near-total Zn concentrations above that value. The saltwater objective is 58 ppb, and no stations were above that level either. The U.S. EPA's dissolved Zn objective is 81 ppb, and none of the RMP stations were above that level either. The freshwater criterion for total Zn depends on water hardness. The range of criteria at the eight stations where salinity was below 5 ppt was 22.3 to 95.0 ppb, and none of the neartotal Zn concentrations were above the hardnessdependent criteria.



Dissolved Zinc in Water 1994

Near-Total Zinc in Water 1994



Figure 18. Dissolved and near-total zinc (Zn) concentrations in water (parts per billion, ppb) at the 24 stations for the three sampling periods in 1994. For station names and locations see Table 1.



Salinity, 0/00

- Southern Slough Stations
- South Bay Stations
- O Remaining Stations

Figure 19. Plots of dissolved trace element concentrations (parts per billion, ppb) versus salinity (parts per thousand, 0/00) for water samples collected in February, April, and August of 1994. The southern slough stations and South Bay stations (see text for listing of which stations they are) are indicated by different symbols than the stations in the other Estuary reaches (see legend).



Figure 19. (continued) Plots of dissolved trace element concentrations (parts per billion, ppb) versus salinity (parts per thousand, 0/00) for water samples collected in February, April, and August of 1994.



Salinity, 0/00

Figure 19. (continued) Plots of dissolved trace element concentrations (parts per billion, ppb) versus salinity (parts per thousand, 0/00) for water samples collected in February, April, and August of 1994.













RMP sampling periods.

Water Monitoring

Trace Organic Contaminants in Water

Three major groups of trace organic contaminants were measured in water from 15 RMP base program stations, during all three sampling periods. They were the PAHs, PCBs and pesticides. These contaminants, and some of the numerous individual compounds they each include, are generally described below.

Two different laboratories analyzed the trace organic compounds in water in 1994. The Bodega Bay Institute (BBI, Richmond Field Station) extracted all samples and analyzed the February samples, and UCSC analyzed the samples from April and August. Each laboratory analyzed a slightly different set of individual compounds, confounding comparisons of total PAHs or total PCBs between the three sampling periods. Therefore, information presented on total PCBs or PAHs, or comparisons among sampling periods should be interpreted carefully.

Since information on water trace organic contaminants was only reported from one sampling period (March) in the 1993 RMP Annual Report, graphs of mean concentrations in each Estuary reach are not presented in this section. Instead, ranges of values are tabulated for comparison (Table 15).

Descriptions of Trace Organic Contaminants

The term polychlorinated biphenyl (PCB) refers to a group of 209 individual chemicals ("congeners") based on substitution of the biphenyl molecule with varying numbers of chlorine atoms. Due to their resistance to electrical, thermal, and biochemical processes, PCBs were used in a wide variety of applications (e.g., in electrical transformers and capacitors, vacuum pumps, hydraulic fluids, lubricants, inks, and as a plasticizer) from the time of their initial commercial production in 1929. By the 1970s a growing appreciation of the toxicity of PCBs led to restrictions on their production and use. However, in 1981 it was estimated that 58% of the world inventory of PCBs was still in place in industrial equipment (Rice and O'Keefe 1995). Leakage from, or improper handling of such equipment has led to PCB contamination of runoff from industrial areas. Other major sources of PCBs to the Estuary are atmospheric deposition, effluents, and remobilization from sediment (Gunther *et al.* 1987).

In spite of the fact that their use has been restricted for almost two decades, PCBs remain among the environmental contaminants of greatest concern because many of the PCB congeners are potent toxicants that are resistant to degradation and have a strong tendency to accumulate in biota. Individual PCB congeners vary greatly in their resistance to metabolic breakdown and the type of toxicity they elicit. In general, PCBs are not very toxic in acute exposures, but certain congeners are extremely toxic in chronic exposures. The most toxic PCB congeners are those that closely mimic the potency and mechanism of toxicity of 2,3,7,8-tetrachlorodibenzop-dioxin ("dioxin", one of the most toxic compounds known). These PCB congeners can cause toxic symptoms similar to those caused by dioxin exposure, including developmental abnormalities, disruption of the endocrine system, impairment of immune function, and cancer promotion (Ahlborg et al. 1994).

Other biologically active PCB congeners and their metabolites exert their toxicities through different, less thoroughly characterized mechanisms than the dioxinlike congeners. In aquatic ecosystems many PCB congeners, including the dioxin-like PCBs, tend to biomagnify through the food web, leading to rising concentrations with increasing trophic level. Consequently, predatory fish, birds, and mammals (including humans that consume fish) at the top of the food web are particularly vulnerable to the effects of PCB contamination.

Two other types of chlorinated chemicals of industrial origin are measured in the Regional Monitoring Program. Polychlorinated terphenyls (PCTs), as the name suggests, consist of compounds with various arrangements of three benzene rings and varying degrees of chlorine substitution of the rings. The chemical and toxicological properties of PCTs are very to those of the PCBs, but PCTs have received far less scrutiny as environmental contaminants. Like PCBs, however, PCTs are ubiquitous in environmental samples and represent a potential hazard in aquatic food webs. Hexachlorobenzene (HCB) is another ubiquitous chemical that is a by-product of the manufacture of chlorinated industrial chemicals, incineration, and other processes. Like the PCBs, HCB is very persistent, very toxic, and carcinogenic. The Puget Sound standard for HCB in sediment is lower than that for any other organic contaminant.

Polycyclic aromatic hydrocarbons (PAHs) are a group of chemicals consisting of two or more fused benzene rings in various arrangements. They are present in crude and refined petroleum products and are also formed during the combustion of petroleum products and other organic material. The copious use of petroleum products in a diversity of applications in the Estuary's watershed leads to the presence of PAHs throughout the Estuary, especially near urban and industrial areas. The major sources of PAHs in the Estuary are urban runoff, atmospheric deposition, spills, and effluents (Gunther *et al.* 1987). Remobilization from sediment can also be important since PAHs can be persistent in sediment.

There are hundreds of different PAH compounds, each with varying numbers and arrangements of benzene rings and varying patterns of substitution on the rings. A subset of this class of compounds with two to six rings is typically measured in aquatic environments because of their abundance, mobility, and toxicity. The chemical and toxicological properties of these compounds vary greatly (Eisler 1987). Lower molecular weight PAHs (two and three ring compounds) tend to be more water soluble, more readily metabolized, and less persistent. Higher molecular weight PAHs (four to seven ring compounds) are less water soluble, less readily metabolized, and more persistent. In general, PAHs are metabolized and excreted by vertebrates and are not transferred through the vertebrate portion of the food web.

Many of the high molecular weight PAHs (HPAH) are carcinogenic (CPAHs), and some are among the most potent carcinogens known. Studies have shown that PAHs are associated with increased incidences of tumors in bottom fish and other species (Malins et al. 1987; Eisler 1987). Both the low molecular weight PAHs (LPAHs) and HPAHs include individual compounds that can cause significant acute toxicity to aquatic organisms (Long *et al.* 1995).

The pesticides measured in the RMP include cyclopentadienes (three compounds), chlordanes

DDTs (six compounds), (six isomers), hexachlorocyclohexanes (HCHs, four isomers), and other pesticides (including oganophosphates) (Table 6). These compounds have varying degrees and modes of toxicity. Recognition of the toxicological importance of metabolites (new compounds produced upon metabolism) of these compounds has expanded the list of analytes for these classes, especially the DDTs and chlordanes. The acute toxicity of most insecticides is due to their interference with signal transmission by neurons. These compounds also have sublethal effects, the most well-known of which is the effect of DDT and its metabolites on the thickness of avian eggshells. This sort of effect was evident in a study of black-crowned night herons in the Estuary (Ohlendorf and Marois 1990). Disruption of endocrine systems through interactions with hormone receptors is another possible chronic effect of exposure to organochlorine insecticides (Colborn et al. 1993). Furthermore, most of the organochlorine insecticides measured in the RMP are carcinogenic, which in combination with their endocrine disrupting effects is cause for concern over their possible impacts on humans that eat fish from the Estuary. In aquatic ecosystems many organochlorine pesticides, like many PCB congeners, tend to biomagnify through the food web, making predators at the top of the food web particularly vulnerable to their effects.

Most of the organochlorine insecticides have been banned for varying lengths of time. Like the PCBs, however, these compounds are very persistent in the environment. Since the Estuary is a sediment trap, residues of persistent compounds are lost very slowly from the ecosystem, making remobilization an important source of residues that enter the food web. Concentrations of pesticides are generally highest in portions of the Estuary closest to agricultural activity, where historic and current pesticide usage leads to elevated mass loadings. Other major sources of pesticides to the Estuary are nonurban and urban runoff, effluents, and atmospheric deposition. Also similar to the PCBs, these organochlorine insecticides are very lipophilic and have a strong tendency to accumulate in biota. As a consequence of their persistence and lipophilicity, these organochlorine insecticides continue to accumulate to significant concentrations in estuarine biota.

PAHs

RMP water samples were analyzed for a total of 16 individual PAHs in 1994, with a minor amount of variation in the particular compounds measured in each sampling period. Fifteen individual PAHs were measured in February, and 13 were measured in April and August. Eleven PAHs were common to all three sampling periods (Table 6). February data for many of the most abundant PAHs were approximately half the magnitude of those from April and August. It is not known whether this difference is due to actual variation in the Estuary or methodological differences between the two labs.

Frequencies of detection were comparable between the two laboratories and generally high, with most compounds detected in 93% or more of the samples (Appendix Table 4.1). The proportion of dissolved PAHs detected varied greatly among stations, with the highest proportion of dissolved PAHs observed at the Golden Gate BC20 (40%).

Most of the individual PAHs were highly correlated with total PAHs and with each other (r = 0.90 or greater; data from April and August only). LPAHs, HPAHs and CPAHs were very closely correlated with total PAHs (r = 0.96, 1.00, and 1.00, respectively). Since these different categories of PAHs were so highly correlated, their concentrations showed nearly identical patterns. Thus, the detailed discussion of total PAHs presented below gives a general representation of spatial and temporal patterns for this class of contaminants as a whole. Both total and dissolved PAHs are discussed since their distributions showed different patterns, as reflected in the low correlation of the two fractions (r = 0.04).

The HPAHs contributed an average of 90% to PAHs in both the total and dissolved phases. LPAHs and CPAHs comprised averages of 10 and 42% of total PAHs, respectively. However, the percentage of LPAHs was somewhat variable among stations. Samples from the Golden Gate (BC20) had the highest average percentage of LPAHs (25%). The next highest averages were 14% at both Red Rock (BC60) and the San Joaquin River (BG30). The lowest percentages of LPAHs (6%) were found at Coyote Creek (BA10), Dumbarton Bridge (BA30), Redwood Creek (BA40), and Petaluma River (BC15). The higher values for percent LPAHs were found



Dissolved PAHs in Water 1994

Figure 21. Dissolved and total PAH concentrations in rivers (parts per quadrillion, pg/L at the fifteen stations for the three sampling periods in 1994. For station names and locations see Table 1. Generation indicates not analyzed.

Northern Estuary

Rivers

Central Bay

South Bay

at stations with low concentrations of suspended sediment, consistent with the tendency of the hydrophobic HPAHs to be more strongly sorbed to sediment particles. As might be expected due to their greater solubility in water, LPAHs comprised a larger proportion (an average of 25%) of dissolved PAHs, up to a maximum of 43% at the Golden Gate.

Dissolved PAH concentrations ranged between 17,300 parts per quadrillion (ppq) at Alameda (BB70) in April to "not detected" at Redwood Creek (BA40) and Red Rock (BC70) (Figure 21). The Napa River (BD50) also had comparatively high dissolved PAH concentrations. Average concentrations were highest in the South Bay largely because of the high concentration at Alameda. The River stations had the lowest average concentrations. Average dissolved PAHs from Yerba Buena Island (BC10) south were 3.5-fold higher than at the Golden Gate (BC20), and average concentrations in the northern Estuary were 2.8-fold higher than at the Golden Gate.

Dissolved PAHs contributed averages of 15 to 19% to total PAHs each sampling period, demonstrating that most of the mass of PAHs is partitioned onto sediment particles.

Total PAHs ranged between 1,500 and 258,700 ppq. By far, the highest concentration was at Alameda (BB70) in February, but concentrations were also elevated at the Petaluma River (BD15) in April (Figure 21). The lowest concentrations were at the Golden Gate (BC20). Average concentrations were highest in the South Bay in February and August, and in the northern Estuary in April. The Rivers had the lowest concentrations, but concentrations were also quite low in the Central Bay.

There were no consistent seasonal differences in either dissolved or total PAH concentrations between the three sampling periods.

Dissolved PAHs were not significantly correlated with other water quality parameters (salinity, DOC, TSS) except for TSS in August (Table 9). Salinity and TSS together accounted for 8%, 14%, and 58% of the variation in dissolved PAHs in the three sampling periods respectively.

Total PAHs were significantly correlated with DOC in August, and with TSS in April and August (Table 9). The spatial gradients in total PAHs observed in the RMP samples are quite similar to corresponding gradients in TSS concentrations (Figure 5), at least for the April and August samples. Additionally, most stations with low TSS had high percentages of dissolved PAHs. The higher proportions of dissolved PAHs at these stations is due mainly to the absence of suspended sediment, which carries most of the mass of hydrophobic organic contaminants. Low proportions of dissolved PAHs were found at stations with higher TSS concentrations, such as the Petaluma River (4% dissolved) and Coyote Creek (5%). Together, salinity, DOC and TSS provided the best predictors of total PAHs, accounting for 21%, 97%, and 87% of the variation in total PAHs in each sampling period respectively.

Fluoranthene and pyrene were typically the PAH compounds with the highest concentrations in both the dissolved and total phases. Total fluoranthene ranged between 570 and 51,000 ppq, and was detected at all RMP stations with the highest concentration at Alameda (BB70). Pyrene concentrations ranged between "not detected" and 43,149 ppq. Pyrene was detected at 96% of the RMP stations with the highest concentrations also measured at Alameda.

The water quality objective for total PAHs from the 1986 Basin Plan is 15 parts per billion (15 million ppq). All RMP measurements were well below that value. U.S. EPA criteria for concentrations of several individual PAHs also apply (National Toxics Rule 1993). Concentrations of carcinogenic PAHs were frequently greater than the criteria of 2,800 ppq for each compound. Benzo(b)fluoranthene concentrations were above the criterion in 68% of the saltwater samples. Indeno(1,2,3cd)pyrene concentrations were higher in 61% of the samples. Other PAHs with concentrations above EPA criteria were chrysene (14 of 38 samples), benz(a)anthracene (10 of 38 samples), benzo(a)pyrene (5 of 25 samples), dibenz(a,h)anthracene (3 of 28 samples), and benzo(g,h,i)perylene (2 of 25 samples) (Table 16). There are no freshwater water quality guidelines for PAHs.

PCBs

A total of 75 PCB congeners, 41 of which were in 19 coeluting domains (groups of congeners that were not separated by gas chromatography), were quantified by



Dissolved PCBs in Water 1994

Figure 22. Dissolved and total PCB concentrations in rivers (parts per quadrillion, pg/L at the fifteen stations for the three sampling periods in 1994. For station names and locations see Table 1. ★ indicates not detected.

BD15

BD30

BD20

BD40

Northern Estuary

BD50

BF20

BG20

L

BG30

Rivers

2000

1000

0

BA10

BA30

South Bay

BA40

BB70

BC10

BC20

Central Bay

BC60

BBI in February, and 48 congeners (with no coelution reported) were quantified by UCSC in April and August. Although there was a great deal of overlap in the congeners analyzed by each lab, the sums of all congeners (SPCBs) generated by the two labs are not strictly comparable because of the different suites of congeners analyzed and possible methodological differences. Median total PCB concentrations in February were about 40% lower than the median for April and August. Intercalibration between BBI and UCSC in 1996 will help clarify whether these differences in concentrations

Frequencies of detection were high for both labs. UCSC detected 26 congeners in all samples, and 42 of 48 congeners in more than 50% of samples. Bodega Bay Institute had similar frequencies of detection. Ten congeners individually contributed at least 4% of the average mass of total PCBs in each sample (UCSC data). Collectively these ten congeners accounted for 58% of total PCBs. The largest individual contributions were from PCB 153 (9.3%) and PCB 138 (8.5%).

are related to differences in analytical methods.

A few dioxin-like congeners (see description above) were analyzed and contributed substantially to total PCBs. These included PCB 118 (5%, TEF = 0.0001),

PCB 180 (4%, TEF = 0.00001), PCB 170 (2%, TEF = 0.0001), and PCB 105 (1%, TEF = 0.0001). None of the highly toxic coplanar PCBs were analyzed.

Water samples were split into two fractions using a 1 µm filter. The fraction that passed through the filter is referred to as "dissolved" in this report, even though it likely includes the influence of small particles that could pass through a 1 µm filter. The material that collected on the filter is referred to as the "particulate" fraction. The proportion of dissolved PCBs varied greatly among stations. The highest proportion of dissolved PCBs was observed at the Golden Gate (56%). Other low TSS stations also had high percentages, such as Yerba Buena Island (37%), Alameda (37%), and Red Rock (34%). The higher proportions of dissolved PCBs at these stations is due mainly to the absence of suspended sediment, which carries most of the mass of hydrophobic organic contaminants. Low proportions of dissolved PCBs were found at stations with higher TSS concentrations, such as the Petaluma River (9% dissolved) and Coyote Creek (8%).

The sum of PCB congeners (SPCBs) was very closely correlated with concentrations of most individual congeners. Because of these high correlations, detailed

Table 9. Correlation coefficients (r) between some organic compound totals and several water quality parameters. n = 14 or 15 depending on missing samples (see Appendix Tables 3.4 - 3.9). * $\alpha = 0.05$, ** $\alpha = 0.01$.

| | | | | | Dissolv | ed | | | | | |
|------|----------|---------|--------|----------------|---------|-------|----------|--------------|----------|-------|--------|
| | Salinity | | | DOC | | | - | TSS | | | |
| | February | April | August | Fe | ebruary | April | August | | February | April | August |
| PAHs | 0.24 | 0.34 | 0.07 | | -0.14 | -0.14 | 0.36 | | 0.17 | -0.18 | 0.74** |
| PCBs | 0.37 | 0.26 | 0.37 | | 0 | 0.21 | 0.61* | | 0.27 | -0.16 | 0.23 |
| DDTs | -0.41 | -0.67** | -0.37 | | 0.56* | 0.35 | 0.34 | | 0.57* | 0.26 | 0.81** |
| | | | | | Total | | | | | | |
| | | Dissol | ved | Salini | | | DOC | | TSS | | |
| | February | Anril | August | February April | August | | February | April August | February | Anril | August |

discussion of SPCBs provides a good representation of the spatial and temporal patterns for this class of contaminants as a whole.

Dissolved SPCB concentrations ranged between 67 and 588 ppq (Figure 22). The highest concentrations were measured at Redwood Creek (BA40) in April and Davis Point (BD40) in April. The lowest concentration was measured at Red Rock (BC60) in February. Average dissolved PCBs were highest in the South Bay. The clearest features of the dissolved PCB profile are the elevated concentrations from Yerba Buena Island south and the high concentrations in April in the northern Estuary. Dissolved PCBs had a slightly different spatial distribution in the Estuary than total PCBs, as reflected in the low correlation of these two parameters in February and April (Table 9). In August, however, this correlation was significant. Dissolved SPCBs contributed averages of 22 to 27% of total SPCBs during the three sampling periods.

Total SPCBs ranged between 181 and 9233 ppq. The highest concentration by far was at Coyote Creek (BA10) in February. Another high concentration was measured at Petaluma River (BD15) in April when TSS was also elevated. Average total PCB concentrations were highest in the South Bay and the northern Estuary. The Golden Gate (BC20) had the lowest average concentrations.

Like dissolved PCBs, total PCBs were usually highest in the April samples, especially in the northern Estuary.

Dissolved PCBs were significantly correlated with DOC in August, but not with DOC, TSS, salinity, or temperature in any other sampling period (Table 9). Total PCBs were significantly correlated with TSS in February and April and DOC in August. The spatial pattern of total PCB concentrations closely paralleled the pattern of TSS in the Estuary. The correlations between total PCBs and TSS reflect the tendency of these hydrophobic chemicals to adsorb to and be transported with sediment particles.

The USEPA water quality criteria for total PCBs are 44 ppq for saltwater and 14,000 ppq in for freshwater. However, these criteria apply to PCBs measured as Aroclor (formerly commercially available mixtures of congeners) equivalents and not the sum of individual congeners as used in this report. Since there are no water quality guidelines for PCB congeners, the EPA criteria only provide an approximate frame of reference for concentrations measured in the RMP. All RMP water samples from saltwater stations were well above the criterion. Even the minimum concentration measured as saltwater stations (181 ppq) was well above the saltwater criterion. The highest concentration measured (9233 ppq) exceeded this criterion by over 200-fold. All of the freshwater samples were well below the freshwater criterion of 14,000 ppq.

Pesticides

A total of 28 pesticide compounds were measured in February samples by Bodega Bay Institute (BBI) and 27 were measured in April and August by U.C. Santa Cruz (UCSC). Median concentrations of the major groups of organochlorines (chlordanes, DDTs, and HCHs) were comparable between the two laboratories. However, large differences in median concentrations were obtained for several other pesticides, such as dacthal, diazinon, dieldrin, and oxadiazon. Intercalibration between BBI and UCSC in 1996 will help clarify whether these differences in concentrations are related to differences in analytical methods. Frequencies of detection were high for both labs. UCSC and BBI both detected 16 compounds in at least 90% of samples.

Information is presented for chlordanes, DDTs, diazinon, dieldrin, and HCHs. Raw data for all analytes are listed in Appendix Tables 3.8 and 3.9.

Chlordanes

Dissolved chlordanes ranged between 3 and 254 ppq (Figure 23). The highest concentration was at Coyote Creek (BA10) in April. A relatively high concentration was also measured at the adjacent Dumbarton Bridge (BA30) station in April. The lowest concentration was at the Golden Gate (BC20) in April. Concentrations in all portions of the Estuary were fairly uniformly elevated over the low concentrations measured at the Golden Gate.

Total chlordanes concentrations were between 9 and 410 ppq. As with dissolved chlordanes, the highest concentration was at Coyote Creek (BA10) in April and the next highest concentration was at Dumbarton Bridge



Dissolved Chlordanes in Water 1994

Figure 23. Dissolved and total chlordanes concentrations in water (parts per quadrillion, pg/L) at the fifteen stations for Febuary and April sampling periods in 1994. For station names and locations see Table 1.


Dissolved DDTs in Water 1994

Figure 24. Dissolved and total DDTs concentrations in water (parts per quadrillion, pg/L) at the fifteen stations for Febuary and April sampling periods in 1994. For station names and locations see Table1.

(BA30) in April. The dissolved fraction contributed a median of 65% of total. At least partially as a consequence of this large dissolved contribution, the spatial distribution of dissolved and total chlordanes were similar and these parameters were significantly correlated with each other in all three sampling periods. Total chlordanes were also significantly correlated with DOC in all three sampling periods, with TSS in February and August, and with temperature in April and August. a-Chlordane, g-chlordane, and *trans*-nonachlor contributed most of the mass of total chlordanes.

USEPA water quality criteria exist for two chlordane compounds: heptachlor and heptachlor epoxide. Heptachlor epoxide in the samples from Coyote Creek (BA10) and Dumbarton Bridge (BA30) in April exceeded the saltwater criterion of 100 ppq. None of the samples exceeded the criteria for heptachlor.

DDTs

Dissolved DDTs ranged between 8 and 409 ppq (Figure 24). The highest concentrations was at Grizzly Bay (BF20) in August, and the lowest was at the Golden Gate (BC20) in August. Average concentrations were highest in the northern Estuary. Concentrations in the rivers and South Bay were also elevated above the low values seen at the Golden Gate.

Total DDTs ranged between 62 and 1598 ppq. Coyote Creek (BA10) in February yielded the highest concentration. The lowest concentration was at the Golden Gate in February. The dissolved fraction contributed a median of 32% of total DDTs. The spatial distributions of dissolved and total DDTs were similar, with the highest average concentrations in the northern Estuary, lower concentrations in the Rivers and South Bay, and lowest concentrations at the Golden Gate. Reflecting this similar spatial distribution, dissolved and total DDTS were significantly correlated with each other in all three sampling periods (Table 9). Total DDTs were also significantly correlated with TSS in all three sampling periods. Total DDTs were principally comprised of approximately equal amounts of p,p'-DDD (an average of 43% of total) and p,p'-DDE (42% of total).

Water quality criteria exist for p,p'-DDD (830 ppq), p,p'-DDE (590 ppq), and p,p'-DDT (590 ppq).

Concentrations of p,p'-DDE exceeded the criterion at Coyote Creek (BA10) in February and at Petaluma River (BD15) in April (Table 16). Freshwater criteria only exist for p,p'-DDT (1000 ppq), and none of the eight stations with salinities below 5 parts per thousand had concentrations above the criterion.

Diazinon

Diazinon was found essentially entirely in the dissolved phase, thus only total diazinon data are presented. Diazinon concentrations ranged between "not detected" and 98000 ppq (Figure 25). The highest concentration was at Coyote Creek (BA10) in February. The Golden Gate (BC20) had the lowest average concentrations.

Concentrations in the February samples were generally an order of magnitude higher than in the April and August samples. This may reflect actual seasonal variation in the Estuary or may be due to methodological differences since BBI analyzed the February samples and UCSC analyzed the April and August samples. Intercalibration between BBI and UCSC in 1996 will help clarify whether these apparent differences in concentrations are related to differences in analytical methods.

Total diazinon concentrations were significantly correlated with DOC in all three sampling periods.

Although there are no U.S. EPA water quality criteria for diazinon, the National Academy of Sciences (NAS 1973) recommended a guideline of 9,000 ppq for the protection of aquatic life in freshwater. The three freshwater stations sampled in February (Grizzly Bay BF20, Sacramento River BG20, and San Joaquin River BG30) were above the NAS guideline.

Dieldrin

Dissolved dieldrin comprised a median of 86% of total, thus only total dieldrin data are presented. Total dieldrin concentrations ranged from "not detected" to 257 ppq (Figure 26). The highest concentration was from Dumbarton Bridge (BA30) in April. Concentrations in February and April were generally comparable, while concentrations in August were markedly lower.



Total Diazinon in Water 1994

Figure 25. Total Diazinon concentrations in rivers (parts per quadrillion, pg/L at the fifteen stations for the three sampling periods in 1994. For station names and locations see Table 1.
☺ indicates not analyzed and ★ indicates not detected.

Dieldrin was above the U.S. EPA saltwater criterion of 140 ppq in 4 instances, including 2 at Dumbarton Bridge (BA30) and 1 each at Coyote Creek (BA10) and Yerba Buena Island (BC10). No stations approached the freshwater criterion of 1,900 ppq.

Hexachlorocyclohexanes (HCHs)

Total HCHs were the organochlorine pesticides measured in the highest concentrations in 1994 (Appendix Table 3.8). Nearly all of the total HCHs were in the dissolved fraction, thus only total HCHs concentrations are summarized. Total HCHs concentrations were between 142 and 7509 ppq. The highest concentration was at Coyote Creek (BA10) in February and the lowest was at Red Rock (BC60) in April. g-HCH or a-HCH were usually the most abundant HCH isomer. U.S. EPA saltwater criteria exist for a-HCH (3900 ppq) and b-HCH (14,000 ppq), and both salt- and freshwater criteria exist for g-HCH (19,000 and 80,000 ppq, respectively). None of the HCH concentrations were above these criteria.

Aquatic Bioassays

Toxicity of water collected at 13 RMP stations (listed on Table 3) was tested during two sampling periods in February and September and at two river stations, Rio Vista and Manteca in May. Three different laboratory toxicity tests were conducted. Bivalve larvae, and the mysid *Mysidopsis bahia* were used to test Estuary water, and striped bass larvae (*Morone saxatilis*) were used to test river water. Detailed methods are included in Appendix 1. The striped bass bioassay was not part of the RMP base program and was included in 1994 to test



Total Dieldrin in Water 1994

Figure 26. Total Dieldrin concentrations in rivers (parts per quadrillion, pg/L at the fifteen stations for the three sampling periods in 1994. For station names and locations see Table 1.
 ★ indicates not detected.

its usefulness. This bioassay, conducted with water collected from the May cruise, was somewhat experimental in nature, since the methods outlined in a State Water Resources Control Board toxicity guideline report were adjusted to accommodate the RMP sampling design. For the 48-hour bivalve larvae development test, larval mussels (*Mytilus edulis*) were used in February, and larval oysters (*Crassostrea gigas*) were used in August, due to differences in seasonal availability of the larvae. The 96-hour growth test with the unicellular alga *Thalassiosira pseudonana* that was used in 1993 was discontinued primarily because of its low precision and replaced with a seven-day growth and survival test using the mysid *Mysidopsis bahia*.

Reference toxicant tests using copper and chromium were conducted concurrently with the bivalve larvae and *Mysidopsis* tests, respectively. Control limits (mean effects concentration plus or minus 2 standard deviations) provide a means of determining the acceptability of individual tests. Reference toxicity test results that fall outside the control limits usually invalidate the results of the ambient toxicity tests.

As in 1993, the bivalve tests showed that no toxicity was apparent in ambient water samples collected from any of the RMP stations during the two sampling periods (Figure 27). Three bivalve tests with ambient water from the Alameda (BB70), Yerba Buena (BC10), and Red Rock (BC60) stations failed during the August sampling period The target concentration of fertilized embryos that should be added to each test vial is between 75 and 150. During the August survey, the average innoculation count was only 18 embryos per test chamber and impaired the power of the test.

In 1994, *Mysidopsis* bioassays exhibited toxicity with water collected from two stations in February. *Mysidopsis* survival was significantly lower compared



Figure 27. Chart showing results of water bioassay testing at selected RMP stations.

to controls when exposed to water collected at the Napa River station (BD50) in February. *Mysidopsis* tested at Red Rock (BC60) in February also exhibited significantly lower survival and growth rates than the control. No toxicity in *Mysidopsis* was observed in ambient water collected from any of the RMP stations in August.

Coefficients of variation (CV) provide a measure of the precision of toxicity tests, with values less than 0.5 indicating acceptable test precision. Separate CVs were calculated for EC50 and EC25 values for each species tested (Appendix Table 2.8). Both bioassays indicate acceptable test precision.

The striped bass toxicity tests on Sacramento and San Joaquin River water failed because minimum acceptable survival requirements of 60% in the control treatments were not met. Survival in the 100% and 50% Sacramento River water concentrations were 89% and 79%, respectively, and bass larvae almost doubled their initial weight after 10 days. Survival rates in 100% and 50% San Joaquin River water were 83% and 91%, respectively. Larvae more than doubled their dry weight in San Joaquin River water. Whether this is acceptable growth could not be determined because the guidelines do not state a 10-day minimum growth criterion, and therefore there is no basis for comparison.

Because of the poor larval survival in different control waters, the use of striped bass as an indicator species is not feasible until a standard laboratory control water has been found that meets the minimum 60% survival requirement.

The RMP has been assessing contaminant concentrations and potential toxic effects on selected organisms at discrete sampling events two to three times annually, although it is known that variations occur on smaller time scales (pesticide pulses, runoff events, accidental spills, and toxic flushes during high flow, for example). Sensitive life stages of various organisms are present in the Estuary at certain times which may be particularly susceptible to episodic events on time scales that the RMP would not detect. The results of the RMP aquatic bioassays should therefore be interpreted accordingly. They indicate that, despite concentrations of trace contaminants that are higher in certain Estuary locations than existing or proposed regulatory standards, effects on test organisms are generally not discernible. However, determination of chronic long-term declines in species of concern, either through direct toxicity or through food web impacts, would require a sampling approach that would require high-frequency observations of water chemistry and aquatic toxicity at a few Estuary sites that appear likely to be impacted by episodic events of toxicity.

River Monitoring

The 1994 RMP included water sampling performed at two locations in the Delta: Manteca on the San Joaquin River and Rio Vista on the Sacramento River (Figure 28). The river sampling stations were chosen to provide data on metal and organic contaminant concentrations in the two largest tributaries to the Estuary during a period of declining flows. Since the sampling period was only 1.5 months, these samples were not representative of conditions found throughout the rest of the year but permitted evaluation of relations between trace contaminants in the rivers during declining flow and conditions in the Estuary.

Six samples were taken at each location approximately weekly between April 6 and May 24, 1994. The samples were analyzed for conventional water quality parameters, such as nutrients, TSS, DOC, dissolved oxygen, and chlorophyll, as well as for the dissolved and total (or near-total) components of selected trace elements, PAHs, PCBs, and pesticides. Data are compiled in Appendix Tables 3.11-3.19.

River flows throughout the year, including the sampling period, were substantially lower in 1994 than in 1993. Comparison of the Delta outflow between years shows that peak flows during April and May 1994 were less than half of the flows in April and May during the previous year. Flows during April and May 1994 were 40% of those recorded during the high-flow periods of February 1994. Sacramento River flow oscillated around 8500 cfs, whereas San Joaquin River flows oscillated around 2000 cfs (Figure 29).

The Rio Vista sampling location was not far enough upstream to escape the tidal influence of the Estuary. Tidal flows there are at least an order of magnitude larger than river flows. Although Manteca is beyond tidal influence, measurable salinity was recorded at Manteca on May 11 and on May 17, demonstrating that saline water had moved that far upstream into the San Joaquin River. San Joaquin River flow was not substantially weaker on these days compared to others during the study period, so tides are probably an important factor at Manteca also.

Data for conventional water quality parameters, such as salinity, dissolved oxygen, total suspended solids (TSS), dissolved organic carbon (DOC), nutrients, and chlorophyll, are tabulated in Appendix Table 3.11. During the study period, TSS concentrations in the San Joaquin River decreased from 77 to 55 mg/L, while TSS concentrations in the Sacramento River increased from 11 to 29 mg/L. These values are within the range of values measured in the Estuary. DOC was also higher in the San Joaquin River than in the Sacramento, as were most



Figure 28. Locations of the RMP river sampling stations.



Flows for the Sacramento and San Joaquin Rivers

Figure 29. Flows (cubic feet per second) in the Sacramento and San Joaquin Rivers on the days when RMP river sampling was conducted. (Flow data courtesy of Department of Water Resources).

nutrients, chlorophyll a, and phaeophytin (a chlorophyll break-down product).

Trace Elements

Concentrations of the 10 dissolved and total (or neartotal) trace elements measured during 1994 are plotted against time in Figure 30. For each of the two river sampling stations, concentration ranges for almost all metals, (near-)total or dissolved, showed relatively little variability over time. In most cases, the differences between the rivers were much greater than temporal variations in each river. This contrasts with results from 1993, which described greater temporal variability relative to spatial variability. This difference could be the result of lower river flow in 1994, or the changes in sampling locations that occurred in 1993.

The dissolved fraction contributed only a small percentage to the total concentrations for chromium, copper, lead, mercury, nickel, silver, and zinc. In contrast, differences between total and dissolved cadmium and selenium concentrations were small. However, differences between concentrations measured in each river were relatively large. For most dissolved metals, concentrations in the Sacramento were higher than or about equal to concentrations in the San Joaquin. The exceptions were chromium and selenium. Except for arsenic and cadmium, total metal concentrations were higher in the San Joaquin River than the Sacramento.

Correlations between metal concentrations and some water quality parameters are described using Pearson correlations coefficients (Tables 10 and 11). Sacramento River flow was correlated at the 95% level of confidence with total silver and selenium, while San Joaquin River flow was negatively correlated with total arsenic and dissolved nickel.

TSS was significantly correlated with total concentrations of many of the metals sampled. TSS in the San Joaquin River was correlated with total copper, lead, nickel and zinc. In the Sacramento River, TSS was correlated with these metals and also with total cadmium and chromium.



Figure 30. Dissolved and total (or near-total) concentrations of ten trace elements in the Sacramento and San Joaquin Rivers over the period of April 7 to May 25, 1994. Concentrations in parts per billion (μg/L).



Figure 30. (continued) Dissolved and total (or near-total) concentrations of ten trace elements in the Sacramento and San Joaquin Rivers over the period of April 7 to May 25, 1994.



Figure 30. (continued) Dissolved and total (or near-total) concentrations of ten trace elements in the Sacramento and San Joaquin Rivers over the period of April 7 to May 25, 1994.

DOC was correlated at the 95% level of confidence with relatively fewer dissolved metal concentrations. Dissolved selenium was correlated with DOC in both the Sacramento and San Joaquin Rivers. DOC in the San Joaquin was also correlated with dissolved copper concentrations.

Dissolved and total metal concentrations were not well correlated with each other. In the San Joaquin River, dissolved and total concentrations of mercury and selenium only were correlated with each other, and no pairs were correlated in the Sacramento River.

Mean concentrations for each river were compared to concentrations measured in April at the two downstream river stations that are part of the Estuarywide sampling program (BG20 in the Sacramento River and BG30 in the San Joaquin, Table 12). In the Sacramento River, metal concentrations measured at Rio Vista were lower than those at BG20, except for dissolved zinc, which was lower at BG20, and dissolved and total arsenic, total selenium and dissolved silver, which were within the 95% confidence interval. In the San Joaquin River, concentrations were greater at BG30 than at Manteca for total and dissolved arsenic, cadmium, copper, and mercury, and for total silver and dissolved zinc. Concentrations were greater at Manteca for total and dissolved chromium, lead, and selenium and for total nickel and zinc. The greatest difference was in selenium concentrations, which were seven times larger at Manteca than at BG30.

Comparison of total, or near-total, metal concentrations from the rivers and the other Estuary stations shows that arsenic, chromium, mercury, lead, and zinc were roughly comparable between the two. Total silver, cadmium, and copper were higher in the Estuary. Only selenium at Manteca was noticeably higher than Estuary concentrations. Dissolved metal concentrations showed similar patterns.

Metal concentrations were compared to EPA's freshwater criteria. None of the metal samples taken in either river exceeded the water quality criteria.

Trace Organic Contaminants

PAHs

Sixteen individual PAH compounds were analyzed in river water (Appendix Tables 3.14 and 3.15). Most of

| | | Sacramento F | River | San Joaquin River | | | | |
|------|----------|--------------|-------------|-------------------|-----------|-------------|--|--|
| | TSS | flow | diss. metal | TSS | flow | diss. metal | | |
| Ag | 0.217 | 0.877 * | 0.635 | 0.628 | 0.324 | 0.798 | | |
| As + | 0.573 | -0.805 | 0.252 | 0.357 | -0.963 ** | 0.450 | | |
| Cd | 0.868 * | 0.063 | 0.807 | 0.575 | -0.272 | -0.248 | | |
| Cr + | 0.914 * | 0.049 | 0.686 | 0.127 | -0.159 | 0.475 | | |
| Cu | 0.888 * | 0.069 | 0.746 | 0.916 * | -0.270 | 0.626 | | |
| Hg + | 0.809 | 0.114 | 0.114 | 0.683 | 0.376 | 0.814 * | | |
| Ni | 0.926 ** | 0.039 | 0.744 | 0.884 * | -0.323 | 0.402 | | |
| Pb | 0.886 * | 0.061 | 0.777 | 0.872 * | -0.083 | 0.461 | | |
| Se + | -0.150 | 0.930 ** | 0.750 | 0.500 | -0.436 | 0.950 ** | | |
| Zn | 0.911 * | 0.154 | 0.511 | 0.828 * | -0.009 | 0.245 | | |

Table 10. Pearson correlation coefficients of total (+) or near total metal concentrations with river flow, TSS, and dissolved metal concentrations. n = 6. * means significant at a = 0.05. ** means significant at a = 0.01.

| Table 11. | Pearson correlation coefficie | ents of dissolved m | etal concentra | tions with |
|-----------|-------------------------------|---------------------|--------------------|------------|
| | river flow and DOC. $n = 6$. | * means significar | it at $a = 0.05$. | ** means |
| | significant at $a = 0.01$. | | | |

| | Sacrame | ento River | San Joa | quin River |
|----|---------|------------|----------|------------|
| | DOC | flow | DOC | flow |
| Ag | 0.429 | 0.795 | 0.176 | 0.585 |
| As | -0.036 | 0.000 | 0.632 | -0.605 |
| Cd | 0.062 | 0.278 | -0.024 | -0.724 |
| Cr | -0.007 | 0.021 | -0.381 | -0.530 |
| Cu | 0.034 | 0.169 | 0.960 ** | -0.425 |
| Hg | 0.006 | 0.578 | 0.374 | 0.115 |
| Ni | 0.041 | 0.250 | 0.613 | -0.969 ** |
| Pb | 0.107 | 0.456 | 0.557 | 0.315 |
| Se | 0.872 * | 0.594 | 0.842 * | -0.607 |
| Zn | 0.355 | 0.609 | 0.710 | -0.238 |
| | | | | |

these chemicals were detected in at least 80% of the samples analyzed. Dissolved anthracene, benz(a)anthracene, chrysene, fluoranthene, phenanthrene and pyrene were detected in 100% of the samples taken, along with total 2-methyl-phenanthrene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(e)pyrene and benzo(k)fluoranthene.

The chemicals with the highest median concentrations in both rivers were fluoranthene, phenanthrene and pyrene. Total chrysene was also relatively high in the San Joaquin River. Fluoranthene and pyrene were also PAH compounds with the highest concentrations in both the dissolved and particulate phase in the Estuary. PAH compounds with 100% detection frequencies showed statistically significant correlations between many compound pairs. Unlike PAH compounds found in the Estuary, however, only dissolved fluoranthene, phenanthrene, and pyrene were highly correlated with dissolved PAHs (correlation coefficients of 0.90 or greater).

The dissolved portion of LPAHs was more predominant than the dissolved portion of HPAHs, consistent with the tendency of the hydrophobic HPAHs to be more strongly sorbed to sediment particles. The dissolved portion of LPAHs typically made up about 68% of the total LPAHs, while the dissolved portion of HPAHs only made up about 36% of the total HPAHs. The Sacramento River had a higher proportion of LPAHs

Table 12. Comparison of mean concentrations of metals in Sacramento and San Joaquin samples to concentra-
tion at river stations (BG20 and BG30) of Estuary-wide sampling in April, 1994. D is dissolved. T is
total (particulate plus dissolved). Units in μg/l (ppb). </> means the concentration at BG20 or BG30 is less/
greater than the mean -/+ the 95% confidence interval (CI).

| | | Sacramento River | | | | San Joaquin River | |
|-----|--------|------------------|----------|--|--------|-------------------|----------|
| | mean | CI | BG20 | | mean | CI | BG30 |
| AgD | 0.0012 | 0.0005 | 0.0010 | | 0.0005 | 0.0002 | 0.0004 |
| AgT | 0.0035 | 0.0015 | 0.0155 > | | 0.0069 | 0.0024 | 0.0105 > |
| AsD | 1.91 | 0.09 | 1.92 | | 1.51 | 0.13 | 1.79 > |
| AsT | 1.99 | 0.21 | 2.18 | | 1.96 | 0.12 | 2.15 > |
| CdD | 0.0177 | 0.0010 | 0.0223 > | | 0.0036 | 0.0005 | 0.0164 > |
| CdT | 0.0266 | 0.0028 | 0.0442 > | | 0.0095 | 0.0013 | 0.0266 > |
| CrD | 0.30 | 0.03 | 0.77 > | | 0.25 | 0.02 | 0.14 < |
| CrT | 2.57 | 0.53 | 7.01 > | | 5.76 | 0.61 | 3.69 < |
| CuD | 1.65 | 0.08 | 2.30 > | | 0.98 | 0.11 | 2.24 > |
| CuT | 2.98 | 0.30 | 5.82 > | | 3.50 | 0.29 | 3.82 > |
| HgD | 0.0011 | 0.0003 | 0.0022 > | | 0.0011 | 0.0002 | 0.0015 > |
| HgT | 0.0034 | 0.0009 | 0.0126 > | | 0.0081 | 0.0015 | 0.0146 > |
| NiD | 0.98 | 0.06 | 1.26 > | | 1.02 | 0.12 | 0.99 |
| NiT | 2.95 | 0.47 | 5.75 > | | 5.27 | 0.41 | 3.82 < |
| PbD | 0.050 | 0.007 | 0.070 > | | 0.025 | 0.009 | 0.006 < |
| PbT | 0.337 | 0.074 | 1.508 > | | 0.964 | 0.099 | 0.814 < |
| SeD | 0.18 | 0.03 | 0.22 > | | 1.52 | 0.64 | 0.20 < |
| SeT | 0.38 | 0.34 | 0.25 | | 1.47 | 0.55 | 0.22 < |
| ZnD | 0.95 | 0.14 | 0.80 < | | 0.28 | 0.04 | 0.36 > |
| ZnT | 4.51 | 0.70 | 11.49 > | | 7.32 | 0.70 | 4.04 < |

relative to HPAHs, and also higher dissolved to total ratios for PAHs.

The time series of PAHs (Figure 31) was clearly dominated by variations in HPAHs, especially the total concentrations. PAHs were not significantly correlated with TSS, DOC or river flow, but there was significant correlation between the dissolved and total components of PAHs in the Sacramento (Table 13). Correlation coefficients computed for LPAHs or HPAHs with water quality parameters were low.

Dissolved PAHs ranged from a low of 1,435 ppq at Manteca on April 13, to a high of 10,167 ppq at Rio Vista on April 7. Concentrations of dissolved PAHs were consistently higher in the Sacramento River approximately six times higher on April 7 - than concentrations in the San Joaquin. Total PAHs (particulate and dissolved) ranged from 5,299 ppq at Manteca on May 25 to 13,879 ppq at Rio Vista on April 7. Particularly interesting are the peak values for HPAHs which occurred in the San Joaquin on May 11, when salinity was relatively high. Comparisons between the median concentrations of PAHs at Rio Vista and Manteca and the concentrations measured further downstream near the confluence of the two rivers (BG20 and BG30, Table 14) should only be made with the caveat that individual PAH compounds analyzed in the rivers did not completely match those measured in the Estuary. Generally, however, the median concentrations of PAHs measured in the river sampling were much larger than those measured at either BG20 or BG30.

The river sampling stations at Rio Vista and Manteca fall under the regulatory jurisdiction of the Inland Surface Water Plan, as opposed to the Basin Plan of the San Francisco Bay Regional Water Quality Control Board. Since the Inland Surface Water Plan is currently not in effect, comparisons between contaminant concentrations in river water and water quality guidelines listed in the plan should be interpreted accordingly. For total PAHs, the guideline for potential sources of drinking water is 2,800 ppq and for other waters 31,000 ppq. All samples taken at both river stations were higher than the drinking

| | | Sacram | ento River | | | San Joaquin River | | | | |
|-----------------|-------------------|--------------|--------------------------|------------------------|-------|-------------------|---------------------------|------------------------|--|--|
| | DOC | TSS | Sacramento River flow | Total vs. Dissolved | DOC | TSS | San Joaquin River flow | Total vs. Dissolved | | |
| D: 1 10 | | | | | | | | | | |
| Dissolved Con | <u>istituents</u> | 0.00 | 0.00 | | | | 0.01 | | | |
| PAHs | -0.30 | -0.36 | 0.08 | | -0.70 | -0.77 | -0.01 | | | |
| LPAHs | -0.29 | -0.30 | -0.05 | | -0.30 | -0.20 | 0.15 | | | |
| HPAHs | -0.27 | -0.44 | 0.36 | | -0.77 | -0.93 * | -0.13 | | | |
| PCBs | 0.02 | -0.56 | 0.02 | | -0.51 | -0.60 | -0.59 | | | |
| DDTs | 0.09 | 0.04 | 0.40 | | 0.40 | 0.39 | -0.86 * | | | |
| Chlordanes | 0.13 | -0.07 | 0.33 | | -0.53 | -0.21 | 0.58 | | | |
| Dieldrin | -0.07 | 0.09 | 0.54 | | 0.37 | 0.34 | -0.89 * | | | |
| Chlorpyrifos | 0.44 | -0.27 | 0.20 | | 0.60 | 0.52 | -0.10 | | | |
| Diazinon | -0.07 | 0.04 | 0.94 * | | -0.16 | -0.69 | -0.17 | | | |
| Total (dissolve | ed plus partici | ilate) Const | ituents | | | | | | | |
| PAHs | -0.65 | 0.02 | -0.05 | 0.88 * | -0.06 | 0.36 | 0.57 | -0.47 | | |
| LPAHs | -0.34 | -0.26 | -0.06 | 1.00 * | -0.17 | 0.21 | 0.82 * | 0.48 | | |
| HPAHs | -0.84 * | 0.36 | -0.03 | 0.50 | -0.05 | 0.36 | 0.53 | -0.44 | | |
| PCBs | -0.03 | -0.50 | -0.12 | 0.99 * | -0.28 | -0.05 | -0.64 | 0.79 | | |
| DDTs | -0.36 | 0.75 | 0.08 | 0.66 | 0.43 | 0.43 | -0.83 * | 0.98 * | | |
| Chlordanes | 0.15 | 0.00 | 0.48 | 0.98 * | -0.07 | -0.01 | -0.24 | 0.60 | | |
| Dieldrin | -0.36 | -0.38 | 0.21 | -0.06 | 0.23 | 0.26 | -0.86 * | 0.99 * | | |
| Chlorpyrifos | 0.43 | -0.25 | 0.21 | 1.00 * | 0.60 | 0.54 | -0.09 | 1.00 * | | |
| Diazinon | -0.07 | 0.04 | 0.94 * | 1.00 * | -0.16 | -0.69 | -0.17 | 1.00 * | | |

| l'able 13. | Correlation coefficients of concentrations of PAHs, PCBs, and various pesticides in the Sacramento |
|------------|--|
| | and San Joaquin Rivers with selected water quality parameters. n = 6, * indicates a significant |
| | correlation (p<.05). |

water guideline but lower than the 31,000 ppq listed for "other waters".

PCBs

Seventy-two PCB congeners present in 54 domains were measured in the river samples and are listed in Appendix Tables 3.16 and 3.17. Eleven domains were detected in the dissolved fraction in 100% of the samples. Twenty-six domains expressed as totals (dissolved plus particulate) had a frequency of detection of 100%. Total concentrations of 15 domains were detected in less than 50% of the samples.

Qualifiers indicating the presence of non-PCB compounds that interfered with quantification of PCBs (i.e., "M" or "Q" in Appendix Tables 3.16 and 3.17) were prevalent for the river samples. These qualifiers mean that PCB residues were detected, but could not be

quantified due to the presence of an unknown interferent. These qualifiers were completely absent for only nine domains. The presence of scattered M and Q qualifiers throughout the dataset is an impediment to calculation of sums of congeners. In this report values with these qualifiers were set to zero for calculating sums of congeners, a procedure that underestimates the true mass of PCB in the sample. In spite of these problems, however, the patterns observed for the sums of congeners matched those for PCB 153, an abundant congener that was measured without interferences and that is generally a good indicator of PCB residues as a whole.

Concentrations of dissolved PCBs ranged between 155 and 685 ppq (Figure 31). The highest concentration (685 ppq) was measured at Rio Vista on April 7. The highest concentration at Manteca (384 ppq) was obtained on May 18. Variability was greater in the Sacramento River, with a four-fold difference between the highest



Figure 31. Dissolved and total concentrations for trace organic contaminants in the Sacramento and San Joaquin Rivers over the period of April 7 to May 25, 1994. Concentrations in parts per quadrillion (pg/L). LPAHs = low molecular weight PAHs, HPAHs = high molecular weight PAHs.



Figure 31. (continued) Dissolved and total concentrations for trace organic contaminants in the Sacramento and San Joaquin Rivers over the period of April 7 to May 25, 1994.



Figure 31. (continued) Dissolved and total concentrations for trace organic contaminants in the Sacramento and San Joaquin Rivers over the period of April 7 to May 25, 1994.

and lowest concentrations compared to a two-fold difference in the San Joaquin.

Concentrations of total PCBs ranged between 253 ppq on May 11 at Rio Vista and 1056 ppq on May 6 at Manteca (Figure 31). The highest concentration at Rio Vista was 838 ppq on April 7. As with dissolved PCBs, variability was greater at Rio Vista. The relative contribution of the dissolved fraction varied in the two rivers. In the San Joaquin River dissolved PCBs comprised 35% of total PCBs, while in the Sacramento River dissolved PCBs were 70% of total PCBs.

Neither dissolved nor total PCBs were significantly correlated with DOC, TSS, or river flow at Manteca or Rio Vista (Table 13). Dissolved and total PCBs were closely correlated at Rio Vista (r=.99, p=.0001) and somewhat less closely at Manteca (r=.79, p=.06).

Concentrations of PCB 153 can be used to provide an index of total PCBs that is minimally affected by interferences or interlaboratory variation. Median PCB 153 concentrations in the San Joaquin River (51 ppq) and in the Sacramento River (22 ppq) were similar to those measured at the RMP base stations in the San Joaquin (BG30) and Sacramento (BG20) rivers.

As for the freshwater RMP base stations, an EPA criterion based on Aroclor equivalents (14,000 ppq)

provides one frame of reference for PCB concentrations at Manteca and Rio Vista. All of the samples, which had a maximum total PCB concentration of 1056 ppq, were well below the criterion. Another relevant criterion (70 ppq) appears in the Inland Surface Water Plan. Total PCBs measured at Manteca and Rio Vista were between 3 and 15 times higher than this guideline.

Pesticides

DDTs

Seven DDT compounds were measured in the river samples (Appendix Tables 3.18 and 3.19). All except o,p'-DDT were consistently detected. Concentrations of all metabolites and were approximately an order of magnitude higher in the San Joaquin than the Sacramento.

The sum of measured total DDTs ranged between 316 ppq at Rio Vista on April 7 to 10,041 ppq at Manteca on April 13. The highest concentration at Rio Vista was 598 ppq on May 25. Concentrations were fairly uniform at both stations over time. The dissolved component of DDTs comprised 22% of total in the San Joaquin and 55% in the Sacramento.

Table 14.Comparison of median concentrations of PAHs, PCBs, and various pesticides in the Sacramento
and San Joaquin Rivers to concentrations at river stations (BG20 and BG30) of Estuary-wide sam
pling in April, 1994. nm means not measured in April. na means cannot compare because sums include
different compounds. Units in pg/l (ppq). </>> means the concentration at BG20 or BG30 is less/greater
than the mean -/+ the 95% confidence interval (CI).

| | | Sacramento | River | | | | San Joaquin | River | | |
|----------------------------|---------------------------|------------|-------|-------|----|---------------------------|-------------|-------|------|----|
| | frequency of detection | median | CI | BG20 | _ | frequency of detection | median | CI | BG30 | _ |
| Dissolved Constituents | | | | | | | | | | |
| PAHs | 100 | 5448 | 1706 | 860 | na | 100 | 1842 | 222 | 911 | na |
| PCBs | 100 | 262 | 152 | 241 | na | 100 | 265 | 67 | 312 | na |
| DDTs | 100 | 237 | 47 | 222 | | 100 | 1845 | 314 | 190 | < |
| HCHs | 17 | 0 | 4 | 384 | > | 83 | 235 | 429 | 706 | > |
| Chlordanes | 100 | 177 | 35 | 92 | na | 100 | 323 | 86 | 84 | < |
| Dieldrin | 100 | 153 | 50 | 170 | | 100 | 435 | 57 | 170 | < |
| Chlorpyrifos | 100 | 1408 | 400 | nm | | 100 | 12805 | 3057 | nm | |
| Diazinon | 100 | 6422 | 3538 | 2500 | < | 100 | 7233 | 6962 | ND | < |
| Trifluralin | 83 | 239 | 123 | nm | | 100 | 4963 | 1395 | nm | |
| Dacthal | 100 | 1797 | 594 | 600 | < | 100 | 2890 | 674 | 730 | < |
| Oxadiazon | 100 | 1140 | 849 | 140 | < | 100 | 533 | 271 | 17 | < |
| Total (dissolved plus part | ticulate) Constitu | uents | | | | | | | | |
| PAHs | 100 | 9839 | 1787 | 12037 | na | 100 | 6879 | 1407 | 5549 | na |
| PCBs | 100 | 374 | 171 | 850 | na | 100 | 749 | 139 | 762 | na |
| DDTs | 100 | 468 | 80 | 592 | > | 100 | 8207 | 1446 | 430 | < |
| HCHs | 17 | 0 | 4 | 387 | > | 83 | 235 | 429 | 709 | > |
| Chlordanes | 100 | 209 | 35 | 128 | na | 100 | 706 | 124 | 107 | na |
| Dieldrin | 100 | 190 | 64 | 179 | | 100 | 510 | 72 | 179 | < |
| Chlorpyrifos | 100 | 1431 | 400 | nm | | 100 | 13307 | 3198 | nm | |
| Diazinon | 100 | 6453 | 3534 | 2500 | < | 100 | 7356 | 6969 | ND | < |
| Trifluralin | 83 | 239 | 122 | nm | | 100 | 5230 | 1472 | nm | |
| Dacthal | 100 | 1797 | 592 | 631 | < | 100 | 2945 | 682 | 771 | < |
| Oxadiazon | 100 | 1140 | 844 | 157 | < | 100 | 1249 | 1019 | 17 | < |

DOC and TSS were not significantly correlated with dissolved or total DDTs at either station (Table 13). Dissolved and total DDTs at Manteca, however, were negatively correlated with river flow (r = -.86 and -.83, p = .03 and .04, respectively). Dissolved and total DDTs were significantly correlated at Manteca (r = .98, p = .0004), but not at Rio Vista.

Dissolved DDTs at Manteca were approximately ten-fold higher at Manteca than at the RMP base station further downstream (BG30) and total DDTs were approximately 20-fold higher.

A freshwater criterion exists for p,p'-DDT (1000 ppq) but no other DDT compounds. Only one river sample (from Manteca on April 13: 1028 ppq) had a p,p'-DDT concentration higher than the criterion.

Chlordanes

Of the total and dissolved chlordane compounds measured, half were detected 100% of the time: gamma-

chlordane, trans-nonachlor and total alpha-chlordane. The sum of all measured total chlordanes (dissolved plus particulate) at Manteca ranged from 465 ppq to 841 ppq, while Rio Vista samples showed concentrations between 155 and 253 ppq.

Dissolved and total chlordanes were significantly correlated with the individual chlordane compounds that were most frequently detected, except alpha-chlordane, which was not significantly correlated with any other pesticide. Other pesticides that were correlated with chlordanes include DDTs, chlorpyrifos, trifluralin and dacthal. Chlordanes were not correlated with TSS, DOC, or riverflow, and total chlordanes were correlated with dissolved chlordanes only in the Sacramento.

Median concentrations of chlordane should be compared with chlordanes from BG20 and BG30 with caution, because the individual chlordane compounds measured by the two sampling programs were slightly different. Overall, concentrations were considerably higher at Manteca and Rio Vista than stations BG20 and BG30, but did not exceed any water quality guideline.

Other Pesticides

The most important other pesticides in terms of frequency of detection were chlorpyrifos, diazinon, dieldrin, trifluralin, dacthal and oxadiazon. The HCHs, methylchlorpyrifos, and endosulfan I and II were not detected often enough to allow meaningful analysis. Diazinon and chlorpyrifos consistently had the highest concentrations, which were generally an order of magnitude higher than those of any other single pesticide. Dacthal also had high concentrations in the Sacramento River. Most concentrations, other than dacthal, were higher in the San Joaquin River than in the Sacramento. The ratio of dissolved to total concentrations for all these pesticides was > 0.8, and it was most often > 0.95. Dissolved diazinon concentrations at Manteca ranged from 1,539 ppq to 26,354 ppq, with a median value of 7233 ppq. Dissolved concentrations at Rio Vista were between 5,090 and 15,556 ppq, with a median value of 6422 ppq.

Neither diazinon nor oxadiazon were correlated with any other pesticide, dissolved or total. In contrast, chlorpyrifos and dacthal were correlated with most other pesticides. No significant correlation coefficients were calculated between TSS and DOC and any of these pesticides. Total and dissolved diazinon were both correlated with Sacramento riverflow, and total and dissolved dieldrin were negatively correlated with San Joaquin riverflow.

Diazinon was the only pesticide that showed higher concentrations at the downstream stations at BG20 and BG30 than the upstream Delta sites. The National Academy of Sciences (NAS 1973) recommended a guideline of 9,000 ppq for the protection of aquatic life in freshwater, and diazinon levels were measured above that guideline at both Manteca and Rio Vista on two dates each.

Dieldrin at BG20 was within the 95% confidence interval for data collected at Rio Vista. In the San Joaquin River, dieldrin was lower at BG30 than further upstream at Manteca. Compared to the Inland Surface Water Plan guideline of 140 ppq for both drinking water and other waters, all but one sample, taken at Rio Vista on April 13, 1994, had concentrations higher than 140 ppq.

Summary

The six sampling events during a period of high flows between April 7 and May 25 showed that the rivers were not contributing particularly elevated levels of any metal to the Estuary, and that for some metals, notably silver, but also to a much lesser degree cadmium and copper, Estuary water concentrations were consistently higher. Because of the substantial tidal influence at Rio Vista, samples at that location were not particularly good indicators of contaminant levels coming into the Estuary from the Sacramento River. Yet, despite this Estuary influence, a declining spatial concentration trend from the Estuary proper to the lower river stations to Rio Vista and Manteca could be observed for some metals.

The San Joaquin River at Manteca yielded the highest concentrations of DDTs, chlordanes, and dieldrin measured in the entire Estuary. Concentrations of DDTs were particularly high, approximately 10-fold higher at this station than at other Estuary stations. The Sacramento River had dissolved concentrations of PAHs, DDTs, chlordanes, and dieldrin and total concentrations of dieldrin that were among the highest measured in the RMP. Therefore, both rivers appear to be sources of pesticides to the Estuary, and the Sacramento River appears to be a source of PAHs. Diazinon was an exception to this pattern. Concentrations of diazinon in the rivers were low relative to other RMP stations. Local sources of diazinon in this sampling period appeared to be more important than inputs from the rivers. It should be noted, however, that large pulses of diazinon and other dormant spray pesticides occur in the rivers in January and February when the pesticides are applied in stonefruit orchards (Kuivila and Foe, 1995), and the April-May sampling events may have only detected "background" concentrations.

PCB profiles in the rivers were distinctly different for both dissolved and total phases from the general profile in the lower Estuary. The PCB profile in the San Joaquin River was dominated by PCB 149 and PCB 118, not by PCB 153 and PCB 138, which were most abundant in the lower Estuary. In Sacramento River samples the most abundant congeners were PCB 105/ 132 and PCB 5/8.

The dynamics of organic contaminant concentrations in the two Rivers appear to have one major difference. In the Sacramento River residues of DDTs and diazinon were positively correlated with flow. In the San Joaquin River, on the other hand, concentrations of several contaminants (DDTs, dieldrin, and PCBs) were negatively correlated with flow.

Discussion of Water Monitoring Results

Spatial Patterns in Trace Contaminant Concentrations

Trace contaminant concentrations in the San Francisco Estuary were variable among the RMP stations, and among the three sampling periods in 1994 (February, April, August). Dissolved and total (near-total) contaminant concentrations typically ranged between one and two orders of magnitude. However, dissolved Pb ranged over 4 orders of magnitude, and dissolved Se and total As concentrations varied by a factor of 6.5 and 2.5, respectively.

There were two general gradients in total (near-total) trace metal concentrations in the Estuary. One, from elevated concentrations in the South Bay to lower concentrations in the Central Bay, then again to elevated concentrations in San Pablo Bay decreasing to lower concentrations in the Rivers. These gradients are obvious from visual observation of the plots of trace element concentrations (Figures 9-18). Total Se and Hg were the exceptions: Se exhibited only a slight gradient from elevated concentrations in the Rivers, and Hg had elevated concentrations in the Rivers in August. The gradients of dissolved As, Cu, Ni, and Ag were similar to those for total (near-totals), but the remaining dissolved metals did not exhibit such clear gradients.

Dissolved and total (near-total) trace elements usually occurred in highest concentrations at the southern slough stations (San Jose, C-3-0 and Sunnyvale, C-1-3). Dissolved Cu, Hg, Ni, Pb, Se, and Zn, and total (neartotal) Ag and Se were always highest at those stations. On the average, all dissolved and total (near-total) trace elements were measured in highest concentrations at one time or the other at the southern slough reach. Those stations are not located in the main Estuary, but in the bayward ends of Coyote Creek and Guadalupe Slough. These tributaries receive municipal effluent, urban runoff, and a wide range of other treated effluents from the Santa Clara Valley. The elevated contaminant levels measured there reflect these sources. However, it is not possible to determine from the RMP data which of those possible sources are contributing which contaminants.

Total (near-total) concentrations of As, Cd, Cr, Ag, and Zn were highest at the Petaluma River (BD15) in the April samples. The elevated total (near-total) concentrations measured there reflect the very high TSS levels measured at the same time (Figure 5). That sample was collected during a spring tide when resuspended sediments were at their maximum concentrations.

Dissolved and total (near-total) concentrations of most trace elements were generally lowest in the Central Bay, reflecting the influence of oceanic flushing. However, dissolved As, Se, Ag, and Zn were occasionally lowest in the Rivers suggesting that they were not important sources of these elements during the RMP sampling.

Trace organic contaminant concentrations were distinctly higher in the Estuary relative to waters at the Golden Gate (BC20). However, each major class of organic contaminant exhibited a different distribution of dissolved concentrations within the Estuary. Dissolved PAH concentrations were elevated in the southern part of the Estuary (from Yerba Buena Island south) and the northern Estuary, and low in the Rivers. Dissolved PCB concentrations showed a slightly different pattern, with a somewhat higher degree of contamination in the southern part of the Estuary. Dissolved DDTs, representative of the organochlorine pesticides, displayed a third pattern, with greater contamination in the northern Estuary and significant concentrations at the River stations. These divergent patterns probably reflect differences in either current or historical loadings to the different segments of the Estuary. The northern Estuary, for example, has received relatively large loadings of DDTs from the extensive agricultural regions in its drainage basin. The southern portion of the Estuary appears to have received relatively large loadings of PCBs.

Diazinon has received considerable attention over the past year. Major sources of diazinon have been identified from agricultural runoff in the Central Valley (Kuivila and Foe 1995), and in urban runoff in several Bay Area Counties. Diazinon has been measured in concentrations that are lethal to bioassay organisms in the Delta and in Alameda County. The high concentration of diazinon measured at the Extreme South Bay (BA10) during wet season sampling suggests that runoff from the Santa Clara Valley is a source of diazinon to the Estuary. The Central Valley Regional Board is currently conducting a study of diazinon sources (see summary in Other Monitoring Activities).

Like the trace elements, total PCBs, PAHs, and to a lesser extent DDTs, also exhibited two concentration gradients in the Estuary: one from elevated values in the South Bay to lower values in the Central Bay, then to elevated concentrations in San Pablo Bay decreasing to lower concentrations in the Rivers. However, spikes were observed at some stations. Total PAHs were highest at Alameda (BB60) where dissolved PAHs were also highest, and total PCBs and total Chlordanes were greatly elevated at Coyote Creek (BA10). Total PAHs, and PCBs, were elevated at Petaluma River in April, and total chlordanes were elevated at Yerba Buena Island (BC10). The spikes of total PAHs, and PCBs at the Petaluma River in April reflected the high TSS measured there. It is believed that this pattern represents a typical response to spring-neap tides that occurs monthly throughout the Estuary that was coincidentally measured only in the northern Estuary in the Spring. More sampling should identify similar events throughout the Estuary.

Both total and dissolved trace organic contaminants were usually lowest in the Central Bay. Trace organics at the River stations were generally intermediate between the low concentrations at the Golden Gate and other RMP stations.

Spikes in total concentrations should be interpreted differently than spikes for dissolved contaminants. Total contaminant concentrations include sediment particles (organic and mineral) which may be resuspended, transported, and deposited. The contaminants associated with them may be dynamically sorbed and desorbed depending on salinity, DOC, TSS, or other factors. Therefore, spikes in total trace contaminant concentrations reflect dissolved and particulate fractions subjected to the factors just listed, and may not reflect proximity to contaminant sources.

The river sampling at Rio Vista and Manteca showed that the rivers contained elevated levels of dissolved lead, selenium, DDTs, total selenium and total DDTs compared to the Estuary stations. Estuary water concentrations were consistently higher for most other contaminants. Because of the substantial tidal influence, particularly at Rio Vista, samples at that location where not particularly good indicators of contaminant levels coming into the Estuary from the Sacramento River. Yet, despite this Estuary influence, a declining spatial concentration trend from the Estuary proper to the lower river stations to Rio Vista and Manteca could be observed for some metals.

The San Joaquin River at Manteca yielded the highest concentrations of DDTs, chlordanes, and dieldrin measured in the entire Estuary. Concentrations of DDTs were particularly high, approximately ten-fold higher at Manteca than at the Estuary stations. The Sacramento River had dissolved concentrations of PAHs, DDTs, chlordanes, and dieldrin, and total concentrations of dieldrin that were among the highest measured in the RMP. Therefore, both Rivers appear to be sources of pesticides to the Estuary, and the Sacramento River appears to be a source of PAHs. Diazinon was an exception to this pattern. Concentrations of diazinon in the Rivers were low relative to other RMP stations. Local sources of diazinon in the lower Estuary appeared to be more important than inputs from the Rivers during this sampling period. It should be noted, however, that large pulses of diazinon and other dormant spray pesticides occur in the Rivers in January and February when the pesticides are applied in stone-fruit orchards (Kuivila and Foe, 1995).

Temporal Patterns in Trace Contaminant Concentrations

There were few obvious seasonal trends (among the three sampling periods) for trace elements. In general, both dissolved and total (near-total) concentrations were lowest in February during the wet sampling period when flows were highest, generally causing dilutions of concentrations. However, Zn was usually higher in February. Hg was higher in April, but Se was usually lower then. Dissolved As and Cd were highest in August, but Pb and Zn were lower then. For total (near-total) metals, Se was usually higher in February, and As, Cu, and Cd were lower in February. Near-total As and Cd were highest in August.

High flows and runoff tend to dilute concentrations and mobilize contaminants reducing residence times. Dissolved Zn, Hg, and total Se were higher at Estuary stations in February and April suggesting that stormwater runoff may be sources of these metals. Conversely, elements that are elevated during the dry periods (dissolved and total or near-total As, Cd) suggest continuous sources, such as outfalls or atmospheric deposition, that become more obvious in the absence of runoff.

The observation of any seasonal trends in trace organic contaminants was confounded by possible differences between the two laboratories that measured them. Both dissolved and total PCBs were distinctly higher in April at northern Estuary stations. Diazinon and dieldrin exhibited large apparent seasonal variation. Intercalibration exercises in 1996 will aid in interpretation of these data.

Annual differences between 1993 and 1994 showed that most trace metals occurred within similar ranges of values. Only a few samples showed large increases during any sampling period, such as Ag in the South Bay in May 1993. However, there were no obvious increasing or decreasing trends in any of the trace metal concentrations.

Variation was usually lowest in the Central Bay and Rivers. There was more variability in the South Bay samples in 1994 than in 1993. Se had the most variability overall.

The only suggestion of seasonality was for As and Cd. Although the pattern of some elevated contaminants at northern Estuary stations in the spring samples appears to be seasonal, those samples were elevated because of single samples in each sampling period that contained very high TSS concentrations (Petaluma River in 1994, San Pablo Bay in 1993) which resulted in elevated contaminant concentrations.

As trace organic contaminants were reported from only one sampling period in 1993, no "trends" plots were constructed. However, ranges of values for total PAHs, PCBs, and DDTs in water measured in each RMP sampling period, as well as reported from previous surveys, are listed on Table 15. The highest concentration of total PCBs measured was in February 1994 at Coyote Creek. There was a large amount of variation in the highest values measured among the years. Usually the highest value in each sampling period was a "spike" as observed at Coyote Creek (BA10) in April 1994. Similarly, the highest value measured in 1993 was a spike at the Golden Gate. These spikes suggest that PCBs are intermittently released into the Estuary when a "slug" of buried or otherwise confined PCBs are uncovered by sediment scour or some other mechanism.

Total PAH concentrations were much higher in 1994 than in 1993. Reasons for these large differences are not known.

With only two years (six sampling periods) of RMP data it is not yet possible to conduct rigorous time-series analysis of contaminant trends. As a RMP Special Study in 1995, Bay Protection Toxic Clean-up Program pilot study data collected in 1991-1992, as well as some earlier data, will be combined with the RMP data to provide five-six years of trace element data, but somewhat less for trace organics data. That analysis may provide more detail about long term trends in trace metal contamination in the Estuary.

Relationships Between Trace Contaminants and Water Quality Parameters

The relationships shown among trace contaminants and other water quality parameters demonstrate the complexity of the geochemical cycles for these elements. The dissolved fraction is related to salinity through mixing, but may be affected locally by runoff, or other inputs, geochemical scavenging such as sorption and desorption onto particles, or complexing with DOC. The total (near-total) fraction includes the dissolved fraction and the fraction sorbed onto the particulate phase, thus is strongly related to TSS. Similarly, suspended sediments and DOC are affected by flows, tides, wind, or other factors. Therefore, in order to understand the variation of trace contaminants in space and time in the Estuary, it is necessary to understand these mechanisms and processes.

The relationship between dissolved trace contaminants and salinity from each sampling period reflects fundamental processes of mixing, inputs, and geochemistry. Linear correlations do not adequately describe the nature of this relationship, mainly due to variations in linear conservative mixing in each Estuary reach.

The plots of dissolved contaminants vs. salinity showed two general patterns. Concentrations above the mixing curve during February and April when runoff was highest and dilution of continuous sources was greatest indicate that runoff was a primary source of all dissolved trace metals and PCBs and PAHs measured, particularly Cd, Pb, Se, and Zn. Elevated concentrations in August suggest that in the absence of runoff and dilution from flows, continuous inputs are a primary source of all dissolved contaminants except Cr. None of the contaminants had elevated concentrations only in August. Instead, values were elevated in both high flow periods and dry periods suggesting that both runoff and continuous sources contributed to all trace element concentrations, except Cr. Information about rainfall patterns and flows in Coyote Creek and other large tributaries would also facilitate these interpretations.

Similar patterns were observed in the 1993 RMP data, but there were some notable differences. Probably due to differences in runoff and freshwater flow in 1993 and 1994, Pb Se, and Zn were elevated in the dry sampling period in 1994 but not in 1993. The higher flows and greater dilution with fresh water in 1993 produced steeper mixing gradients. Lower flows in 1994 through April accentuated the runoff sources. Additionally, the inclusion of the southern slough stations showed the contributions from the South Bay more clearly.

Only dissolved Ag and Cd were significantly correlated with salinity throughout the Estuary during two or three sampling periods. There does not appear to be any affect of salinity on dissolved metal concentrations for As, Ag, Hg, Se, and Zn. The generally poor correlations reflect the non-linear nature of the dissolved metal vs. salinity plots which is largely due to differences in the nature of mixing in the different Estuary reaches, and the influence of elevated samples due to local inputs within each reach.

Dissolved Hg, Ni, Pb, and Zn were significantly correlated to DOC in all sampling periods. Concentrations of these metals were all directly related to DOC concentrations, suggesting that organic-metal complexes are formed. How these large molecules are used by plankton or whether they are absorbed by contact to gill or other tissues is poorly understood.

There were generally strong relationships between total (near-total) metals and TSS. Concentrations of Ag, Cr, Cu, Hg, Ni, Pb, and Zn were always significantly correlated to TSS, reflecting their strong affinity for sorption onto particles. All trace elements measured, except Se, were significantly correlated with TSS at least during one sampling period.

Dissolved PAHs, PCBs, and DDTs were generally not very well correlated with water quality parameters. only dissolved DDTs were significantly correlated with salinity. Dissolved DDTs had the strongest relationships with water quality parameters, particularly with TSS in February and August.

Total PAHs, PCBs, and DDTs were also poorly correlated with salinity and DOC, except in August with DOC. These contaminants were all significantly correlated with TSS (except PAHs in February and PCBs in August), demonstrating the affinity of these contaminants for partitioning onto the particulate phase.

Comparison to Water Quality Standards

Concentrations of As, Cd, Cr, Pb, Se, Ag, Zn, and total PAHs were all below existing water quality criteria for total and dissolved concentrations in 1994. However, total (near-total) Cu, Hg, and Ni concentrations were often above U.S. EPA criteria. Near-total Cu had widespread elevations and was also often above the dissolved standards. PCBs were well above the criteria at all saltwater stations sampled, similar to the situation reported in March 1993. Seven individual PAHs, heptachlor epoxide, dieldrn and p,p'-DDE were above water quality criteria (Table 16). Diazinon was above the NAS standard of 9,000 ppq at three freshwater stations in February.

Compared to the 1993 RMP results, there were some important differences in the number of stations with concentrations above the guidelines. Total Hg and neartotal Ni were above existing guidelines in two to three times as many samples as in 1993. Near-total Pb and Cr were above standards at two stations in 1993, but none in 1994. Total (near-total) As, Cd, Se, Ag, and Zn were not above EPA criteria either year.

| Table 15. | Summary of ranges for total organic concentrations for RMP water samples in 1993 and 1994. |
|-----------|--|
| | Units are parts per quadrillion (pg/l). |

| | Other S | Studies | March | February | April | August |
|-------------------|---------------|--------------------------|--------------|---------------|---------------|---------------|
| | 1975 | 1994 | 1993 | 1994 | 1994 | 1994 |
| Total PCBs | 400 - 6600 1) | 621 - 2139 ²⁾ | 239 - 847 | 181 - 9233 | 230 - 5916 | 249 - 3054 |
| Total PAHs | | - | 4350 - 27780 | 3875 - 258691 | 1539 - 212627 | 3433 - 105677 |
| Total DDTs | | • | 0 - 769 | 62 - 1598 | 63 - 1167 | 70 - 925 |

Anderlini *et al.* 1975.
 Risebrough 1994.

| Table 16. | Summary of compounds that were above water quality guidelines at each 1994 RMP water |
|-----------|--|
| | sampling location. Numbers indicate which sampling period, February, April or August (cruise 4, 5 or 6 |
| | respectively) was above guidelines. Compounds listed are only those that contained samples above |
| | guidelines Indicates that no samples were above guidelines. * Compound not sampled for at this |
| | station. |

| | WATER | | | | | | | | | | | | | | | |
|--------------|-------------------------------|--------|---------|--------|----------|----------|----------|--------------------|--------------------|-----------------|-----------------------|---------------------|----------|------------------------|--------------------------|------------|
| Code | Station Name | ſ | Vetal | s | | | | | | Or | ganics | | | | | |
| | | Copper | Mercury | Nickel | p,p'-DDE | Diazinon | Dieldrin | Heptachlor epoxide | Benz(A)-Anthracene | Benzo(A)-Pyrene | Benzo(B)-Fluoranthene | Benzo(GHI)-Perylene | Chrysene | Dibenz(A,H)-Anthracene | Indeno(1,2,3,-CD) Pyrene | Total PCBs |
| C-3-0 | San Jose | 4,5,6 | 6 | 4,5,6 | * | * | * | * | * | * | * | * | * | * | * | * |
| C-1-3 | Sunnyvale | 4,5,6 | 6 | 4,5,6 | * | * | * | * | * | * | * | * | * | * | * | * |
| BA10 | Coyote Creek | 4,5,6 | 4,6 | 4,5,6 | 4 | - | 4 | 5 | 4,6 | 4,5 | 4,5,6 | 4 | 4,5,6 | 6 | 4,5,6 | 4,5,6 |
| BA20 | South Bay | 4,5,6 | - | - | * | - | - | - | * | * | * | * | * | * | * | * |
| BA30 | Dumbarton Bridge | 4,5,6 | 6 | - | - | - | 4,5 | 5 | 6 | - | 5,6 | - | 5,6 | 6 | 5,6 | 4,5,6 |
| BA40 | Redwood Creek | 5,6 | - | - | - | - | - | - | - | - | 5,6 | - | 5 | - | 5,6 | 4,5,6 |
| BB15 | San Bruno Snoal | 4,5,6 | - | - | * | | * | - | * | | | * | | * | * | * |
| BB30 | Oyster Point | 5,6 | - | - | | | | - | | | 4 5 6 | | | | 4 5 6 | |
| BB/U BC10 | Alameda Verbe Buene Jelend | 0 | - | - | - | - | - | - | 4 | - | 4,5,6 | - | 4 | - | 4,5,6 | 4,5,6 |
| BC10 | Yerba Buena Island | - | - | - | - | - | 4 | - | - | - | Э | - | - | - | 5 | 4,5,6 |
| BC20 | Biobardoon Boy | - | - | - | * | * | * | - | * | * | - * | - * | - * | - * | - * | 4,5,0 |
| BC30 BC41 | Richardson Day | - | - | - | * | * | * | - | * | * | * | * | * | * | * | * |
| BC60 | Red Rock | - | - | - | _ | _ | _ | - | _ | _ | _ | _ | _ | _ | _ | 156 |
| BD15 | Petaluma River | 5.6 | 5 | 5.6 | 5 | _ | _ | _ | 5 | 5 | 456 | _ | 5 | 5 | 5.6 | 4,5,6 |
| BD20 | San Pablo Bay | 5,6 | 56 | 5.6 | - | - | _ | - | 56 | 5 | 5.6 | _ | 5 | - | 5.6 | 4 5 6 |
| BD30 | Pinole Point | 4.5.6 | 5.6 | 5 | - | - | - | - | 4.5 | 4 | 4.5.6 | 4 | 4.5 | - | 4.5.6 | 4.5.6 |
| BD40 | Davis Point | 5.6 | - | - | - | - | - | - | - | - | 5.6 | _ | - | - | 5 | 4.5.6 |
| BD50 | Napa River | 5.6 | 5 | 5 | - | - | - | - | - | - | 5.6 | - | 6 | - | 5.6 | 4.5.6 |
| BF10 | Pacheco Creek | 5,6 | 5 | 5 | * | * | * | - | * | * | * | * | * | * | * | * |
| BF20 | Grizzly Bay | 4,5,6 | 5,6 | 5,6 | - | 4 | - | - | 5 | - | 4,5,6 | - | 5,6 | - | 5,6 | 4,5,6 |
| BF40 | Honker Bay | 6 | 5 | - | * | * | * | - | * | * | * | * | * | * | * | * |
| BG20 | Sacramento River | - | 5 | - | - | 4 | - | - | - | - | - | - | - | - | - | - |
| BG30 | San Joaquin River | - | 5 | - | - | 4 | - | - | - | - | - | - | - | - | - | - |

The relationship between dissolved and total (neartotal) concentration is of interest because the U.S. EPA has modified its aquatic life criteria for metals from total to dissolved concentrations, and because the partitioning between dissolved and suspended particulates forms the basis for any calculations used to modify the criteria to reflect local conditions better (water effect ratios). For most trace elements, total or near-total concentrations were variously related to dissolved concentrations in space and time. Only dissolved and total (near-total) Se and Cd were always significantly correlated. Dissolved and total (near-total) As, Cu, Ni, and Zn were significantly correlated in February and August, and the other metals were correlated only once, except Pb, which was not significantly correlated at all (Table 8). Total (near-total) concentrations were composed of above 90% dissolved metal for Se during all cruises, and for Cd and As in February and August (they were above 82% in April). Cu was always more than 50% dissolved, and Cr, Ni, Pb, Ag and Zn were always below 50% dissolved; Pb only ranged between 4-7% dissolved.

These results reflect the varying contribution of dissolved metals to total (near-total) metals. These results show that the relationship between dissolved and total (near-total) concentrations vary both spatially and temporally. Predicting dissolved concentrations from total concentrations will be difficult and subject to considerable error. However, for As, Cd, and Se, predictions would be less variable.

It must be emphasized that the objectives and criteria used as guidelines in this report use total extractable concentrations where many of the RMP values are expressed as "near-total" concentrations, thus underestimating total extractable values. Additionally, Cr VI is specified in the EPA criterion, whereas the RMP measures near-total Cr. For trace organic contaminants there are also many differences. PCB criteria are based on Aroclor compounds, whereas RMP uses sums of congeners. These differences should be considered in comparing RMP measurements to the water quality objectives and criteria.

Effects of Water Contamination

Contaminants in water can potentially cause ecological effects in several ways. Dissolved

contaminants can be absorbed directly into animal and plant tissues. Contaminants associated with the particles in water may also be biologically important since particles may be utilized as food by filter feeders or other organisms, providing an entrance into the food web. Length of exposure and concentration of the contaminant determine whether an effect will occur.

Little is known about ecological effects of contaminants in water in the Estuary. The aquatic bioassays showed significant toxicity to the mysid Mysidopsis at the Napa River (BD50) and Red Rock (BC60) in February. Just which component(s) in the water at those stations caused the observed toxicity is not known. There were no corresponding elevations in trace contaminants in the water in those samples. Although both stations exceeded the water quality standard for PCBs, there were no other water quality standard exceptions. Although some water quality guidelines were exceeded at every station, each sampling period, significant toxicity was observed at only two stations in February. No toxicity was associated with any of the 25 near-total Cu measurements that exceeded the EPA criterion. Similarly, diazinon and total PCBs concentrations measured at Coyote Creek (BA10) were well above water quality guidelines, but resulted in no toxicity.

Toxicity due to diazinon in the Sacramento and San Joaquin rivers (Kuivila and Foe 1995) as well as in several other Estuary watersheds (Alameda Co., Santa Clara Co.) has also been reported. Diazinon toxicity was shown to be episodic, occurring following rains that wash the insecticide into runoff. There may be other toxic episodes occurring that are being missed using the current RMP sampling design of sampling only two times per year. Perhaps the RMP should consider conducting aquatic toxicity testing on different time scales.

Finally, many water quality standards are based on back-calculation of water concentrations based on risks to human health from eating contaminated seafood. For example, the U.S. EPA's PCB criteria are so calculated. Therefore, it is not surprising that PCB levels in sport fish in the Estuary have been recently determined to be generally above acceptable levels for consumption (SFBRWQCB, 1995). A discussion of how ppq can become ppm in fish is included in the final Discussion.

Sediment Monitoring



Sediment Monitoring

Sediment quality, trace elements, and trace organic contaminants were measured at 20 RMP base program stations in 1994, and sediment bioassays were conducted at 12 of those stations (Table 3). Additionally, sediment samples were collected at two stations in the southern end of the Estuary in cooperation with the Regional Board and the Cities of San Jose and Sunnyvale. Those stations are located in the bayward ends of Coyote Creek and Guadalupe Slough between their respective outfalls and the RMP Coyote Creek station (BA10) (Figure 1).

Measurements made on sediment samples included sediment grain-size, organic content, reduction-oxidation potential (Eh), pH, trace metals, and trace organic contaminants (Tables 4 to 6). Sediment monitoring was conducted during the wet (February) and dry (August) sampling periods.

As part of the RMP Special Study on Optimal Sampling Design, triplicate samples were collected at three stations in 1994: Alameda (BB70), Horseshoe Bay (BC21), and Davis Pt. (BD41). For the following section, the triplicate measurements are presented as average values at those three stations.

Concentrations of sediment contaminants measured in the 1994 samples are compared to those collected in 1993 using line charts. However, statistical analysis of trends in contaminant concentrations in the Estuary will require many years of data and are not attempted at this stage in the RMP.

There are currently no Basin Plan objectives or other regulatory criteria for sediment contaminant concentrations in the Estuary. However, EPA has suggested draft objectives for 5 trace contaminants: three PAHs, acenapthene, fluoranthere, phenanthrene and two pesticides, dieldrin and endrin. (EPA 1991). As a guide to interpretation of sediment contaminant concentrations measured in the RMP, Effects Range-Median (ERM) and Effects Range-Low (ERL) values are used (Long and Morgan 1990; Long *et al.* 1993). These values are based on data compiled in numerous studies in the U.S. that included sediment contaminant and biological effects information. The guidelines were developed to identify concentrations of contaminants that were associated with biological effects in laboratory, field, or modeling studies. The 10th percentile of the effects concentration range is the ERM, and the 50th percentile is the ERL. These values are intended to be used as informal screening tools and hold no regulatory status. Incidences of effects were often greater than 75%, and occasionally 100%, at concentrations above the ERM values. However relatively weak relationships between concentrations and effects were identified for mercury, nickel, PCBs and DDTs. Concentrations between the ERL and ERM are interpreted to indicate a "possible effects range" within which effects would occasionally occur. Concentrations above the ERM are interpreted to indicate a "probable effects range" within which effects frequently occur (Long et al. 1993).

In order to compare results among the major areas, or reaches of the Estuary, the RMP stations are separated into six groups of stations based on geography, similarities in sediment types, and patterns of trace contaminant concentrations. Classification based on any one of these three considerations produced slightly different groupings. Therefore, the groupings used in this section of the report are rather subjective.

The six Estuary reaches are: the southern sloughs (C-1-3 and C-3-0), South Bay (six stations, BA21 through BB70), Central Bay (four stations, BC11 through BC41), northern Estuary fine sediment stations (five stations, BD22, through BF40) coarse sediment stations (three stations, BC60, BD41, BF10), and Rivers (BD20 and BD30).

Sediment Quality

In order to understand trace contaminant concentrations in sediments, it is necessary to understand

| Station | Station | Water | Percen | t Sand | Percent | t Fines | T(% dev |)C | E | h Nolte |
|---------|--------------------|-----------------|---------|--------|---------|---------|--------------------|-----------|-------|------------|
| Number | Name | Deptn meters | Mean | CV | Mean | CV | Mean | CV | Mean | CV |
| BA21 | Extreme South Bay | 4.0 | 7 | 33 | 87 | 9 | 1.05 | 28.3 | -33.0 | 132.9 |
| BA30 | Dumbarton Bridge | 8.0 | , 16 | 115 | 81 | 29 | 0.76 | 16.7 | -44.0 | 80.4 |
| BA41 | Redwood Creek | 3.5 | 10 | 24 | 83 | 9 | 0.69 | 22.5 | -34.5 | 84.0 |
| BB15 | San Bruno Shoal | 12.0 | 34 | 27 | 63 | 13 | 0.48 | 43.2 | -27.5 | 110.6 |
| BB30 | Ovster Point | 8.5 | 45 | 27 | 52 | 24 | 0.95 | 33.7 | -26.0 | 114.2 |
| BB70 | Alameda | 10.0 | 24 | 35 | 76 | 12 | 1.01 | 8.0 | -31.0 | 22.8 |
| BC11 | Yerba Buena Island | 6.5 | 38 | 13 | 54 | 29 | 0.83 | 11.1 | -35.5 | 89.6 |
| BC21 | Horseshoe Bay | 12.0 | 40 | 19 | 60 | 12 | 0.94 | 15.5 | -18.0 | 196.4 |
| BC32 | Richardson Bay | 3.0 | 25 | 3 | 75 | 0 | 0.81 | 11.1 | -17.5 | 141.4 |
| BC41 | Point Isabel | 2.5 | 15 | 15 | 86 | 2 | 0.97 | 5.0 | -19.5 | 112.4 |
| BC60 | Red Rock | 10.5 | 87 | 3 | 4 | 61 | 0.19 | 590.0 | -48.0 | 67.8 |
| BD22 | San Pablo Bay | 4.0 | 10 | 28 | 89 | 3 | 1.14 | 11.2 | -30.5 | 85.8 |
| BD31 | Pinole Point | 7.0 | 15 | 0 | 85 | 1 | 1.32 | 0.5 | -11.5 | 412.0 |
| BD41 | Davis Point | 7.3 | 77 | 7 | 21 | 31 | 0.18 | 26.1 | -44.5 | 30.2 |
| BD50 | Napa River | 3.3 | 3 | 28 | 90 | 2 | 1.47 | 13.3 | -17.5 | 125.3 |
| BF10 | Pacheco Creek | 6.0 | 78 | 5 | 23 | 9 | 0.36 | 42.2 | -16.0 | |
| BF21 | Grizzly Bay | 2.5 | 2 | 47 | 99 | 1 | 1.47 | 0.3 | -27.5 | 84.9 |
| BF40 | Honker Bay | 3.0 | 2 | 71 | 99 | 2 | 1.64 | 0.9 | -7.0 | 868.7 |
| BG20 | Sacramento River | 8.5 | 60 | 23 | 41 | 33 | 0.71 | 36.1 | -29.0 | 78.0 |
| BG30 | San Joaquin River | 6.5 | 61 | 13 | 40 | 20 | 0.51 | 7.9 | -19.5 | 264.7 |

Table 17. Means and coefficients of variation (CV) for several sediment parameters. n=2 sampling periods. Data is the mean of three replicates at Alameda, Horseshoe Bay and Davis Point. Percent sand is >63μm dia.

Estuary sediment types. Sediment type is a general term for descriptions of sediment grain-size (mineral particles composed of sand, silt, or clay) and organic content (usually the particulate remains of biogenic origin, although some organic material may be flocculated onto the surfaces of mineral particles from dissolved material). Most contaminants have an affinity for sediments through adsorption and binding with the organic components. Fine sediments generally have greater proportions of organic material. This is because of the increased surface to volume ratio of smaller sediment particles and their geochemistry. Stations with coarser sediments (more sand) are characteristic of areas with dynamic currents that keep the fine sediment suspended in water. Fine sediments (clay and silt) are resuspended at moderate current velocities. Thus, stations with large proportions of fine sediments are characteristic of more quiescent water where those sediments may be deposited.

Based on the August samples, the sediments at the RMP stations ranged from silty clay (99% fine at BF21, Grizzly Bay) to silty sand (85% sand at BC60, Red Rock) (Table 17). Additionally, sediment at Davis Point (BD41), Pacheco Creek (BF10), the southern slough stations, and the River stations were predominantly coarse sediment (more than 50% sand).

Eh is a measure of the reduction-oxidation potential of sediments. It is related to the breakdown of organic material in the absence of oxygen which creates hydrogen sulfide. It has long been understood that some trace metals form insoluble complexes with sulfides. These metalsulfide complexes bind the metals in a form that is not bioavailable. Measurement of these complexes are not currently conducted by the RMP.

Eh values ranged between -76 and 36 millivolts (Appendix Table 3.20). However, there was a large amount of seasonal variability at each station in these measurements (Table 17). These values generally indicate aerobic to slightly reducing conditions (very low oxygen and sulfide concentrations) at the RMP sediment stations. Eh values below approximately -100 millivolts would indicate biologically important sulfide concentrations.

Total organic carbon in sediments ranged between <0.01% at Red Rock (BC60) in February to 1.65% at Honker Bay (BF40) in February (Table 17). In general, higher TOC values are associated with finer sediments.



Arsenic in Sediment 1994

Figure 32. Arsenic (As) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

Trace Elements in Sediment

Thirteen trace elements were quantified at each RMP station. However, the status and trends of only ten of them are described below. The other three, aluminum, manganese, and iron, are reported in Appendix Table 3.21, as they are not considered to be contaminants, but are naturally occurring metals. Data for all information presented below are included in Appendix Table 3. 21.

Arsenic (As)

Arsenic concentrations in sediments ranged between 5.2 and 20.2 ppm (Figure 32). The highest concentration was measured at Pinole Pt. (BD31) in August and the lowest concentrations were at the Sacramento River (BG20) in February. On the average, arsenic concentrations were highest at the northern estuary fine sediment stations and lowest at the coarse sediment stations. Concentrations were higher in August at most northern Estuary stations, but were higher in February at the South and southern Central Bay stations.

Plots of average As concentrations in the 1993 and 1994 RMP samples in each Estuary reach are shown on Figure 42. Average concentrations in 1994 were within the range of concentrations measured in 1993. In the northern Estuary, the dry sampling periods had higher concentrations than those in the wet season in both years, suggesting possible seasonality.

Arsenic concentrations were not significantly correlated to TOC or Eh in sediments during either sampling period, but were significantly corrected with % fines in August (Table 18).

None of the stations had As concentrations above the ERM value of 70 ppm, but 15 stations were above the ERL value of 8.2 ppm in February, and 16 stations were above that value in August.

Table 18. Pearson product moment correlation coefficients (r) between sediment quality parameters and trace metal concentrations. n=20-22 except for TOC and Eh in August where n=19. *=significant at α =.05. **= significant at α = 0.01. Missing values in Febuary for % Fine due to QA problems.

| Trace | <u>% Fine</u> | | TOC | | | <u></u> <u></u> <u></u> | | |
|-------|---------------|-----------|-------|-------|-----|-------------------------|-------|--|
| Metal | Feb | Aug | Feb | Aug | | Feb | Aug | |
| Ag | | 0.31 | 0.05 | -0.03 | - (| 0.34 | 50* | |
| As | | . 6 0 * * | -0.09 | 0.06 | - | 0.2 | -0.12 | |
| Cd | | 0.21 | 0 | 0.03 | - (| 0.36 | -0.22 | |
| Cr | | .60** | 0.33 | 0.16 | (| 0.11 | -0.31 | |
| Cu | | .76** | 0.16 | 0.03 | - (| 0.27 | -0.33 | |
| Hg | | .68** | 0.09 | -0.02 | - (| 0.27 | -0.37 | |
| Ni | | . 5 8 * * | 0.21 | 0.14 | (| 0.26 | -0.26 | |
| Pb | | 0.29 | 0.27 | -0.15 | - | 0.1 | -0.28 | |
| Se | | .56** | 0.13 | 0.03 | - (| 0.14 | 0.03 | |
| Zn | | . 7 0 * * | 0.22 | 0.12 | - | 0.2 | -0.4 | |

Cadmium (Cd)

Cadmium concentrations in sediment at the RMP stations ranged between 0.03 and 0.68 ppm (Figure 33). The highest concentration was measured at San Jose (C-3-0) in August and the lowest concentrations were at Red Rock (BC60). Average concentrations were highest at the southern slough stations, and the lowest concentrations were at the coarse sediment stations.

Cadmium concentrations in the northern Estuary stations were usually highest in August, but some Southand Central Bay stations were highest in February.

Average Cd concentrations in the South- and Central Bays and Rivers appeared to increase each sampling period in 1993 and 1994 (Figure 42), and the range of concentrations was greater in 1994 than in 1993. There was no obvious seasonality in Cd measurements.

There were no significant correlations between Cd and % fines, TOC, or Eh in either sampling period (Table 18).

None of the sediment Cd concentrations were above the ERM value of 9.6 ppm, or above the ERL value of 1.2 ppm.

Chromium (Cr)

Chromium concentrations in sediments ranged from 49.7 to 170.5 ppm (Figure 34). The highest concentration was at Sunnyvale (C-1-3) in August, and the lowest was at Red Rock (BC60). On the average, concentrations were highest in the southern sloughs in February and in the northern Estuary in August. Concentrations were lowest at the coarse sediment stations in both sampling periods.

Chromium concentrations were highest in February at most South- and Central Bay stations and highest at the northern Estuary stations in August.

Average concentrations measured in 1993 and 1994 were generally similar (Figure 42). However, mean concentrations at the Central Bay and River stations were higher in 1994 than in 1993. There was no apparent seasonality in Cr concentrations.

There were no significant correlations between sediment Cr and TOC or Eh in either sampling period, but Cr was significantly correlated with % fines in August (Table 18).

None of the Cr concentrations were above the ERM of 370 ppm. However, 14 stations were above the ERL



Cadmium in Sediment 1994

Figure 33. Cadmium (Cd) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

value of 81 ppm in February and 11 stations were above that value in August.

Copper (Cu)

Copper in sediments ranged between 8.0 and 94.6 ppm (Figure 35). The highest concentration was at Sunnyvale (C-1-3) in February, and the lowest concentration was at Red Rock (BC60) in August. Average concentrations were highest at the northern Estuary stations and were lowest at the coarse sediment stations during both sampling periods.

Most stations had higher concentrations in February than in August, but there was no strong trend.

The range of concentrations was wider in 1994 than in 1993. Mean concentrations in the South- and Central Bays in 1994 were generally comparable to those measured in 1993 (Figure 42). However, average concentrations at the northern Estuary and River stations were slightly higher in 1994 than 1993. Wet season samples in the South Bay were always higher than those in the dry season suggesting possible seasonality in the South Bay.

Copper was not significantly correlated with TOC or Eh in either sampling period, but Cu was significantly correlated with % fines in August (Table 18).

None of the Cu measurements were higher than the ERM of 270 ppm. However, concentrations at 15 stations in February were above the ERL value of 34 ppm, and concentrations at 15 stations were above that value in August.

Lead (Pb)

Lead concentrations in sediments ranged between 8.0 and 45.4 ppm (Figure 36). The highest concentration was measured at Sunnvyale (C-1-3) in February, and the lowest concentration was at Pacheco Creek (BF10) in February.



Chromium in Sediment 1994

Figure 34. Chromium (Cr) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

On the average, the highest concentrations were at southern slough stations and the lowest concentrations were at the coarse sediment stations in both sampling periods.

Concentrations were usually higher in August than in February, but not at all stations. The difference between the two sampling periods was most pronounced at the San Jose station (C-3-0), and at the River stations.

The range of concentrations was higher in 1994 than in 1993, mainly due to the inclusion of the southern slough stations. Otherwise, most of the 1994 measurements were within the range of values reported in 1993 (Figure 42). Average Pb concentrations were highest in the South Bay in March 1993, and in the Rivers in August 1994. There was no apparent seasonality in Pb concentrations.

There were no significant correlations between Pb and % fines, TOC, or Eh during either sampling period (Table 18).

None of the lead concentrations measured were above the ERM of 223 ppm, or the ERL of 46.7 ppm.

Mercury (Hg)

Mercury concentrations in sediment ranged between 0.015 and 0.543 ppm (Figure 37). The highest concentration was at San Jose (C-3-0) in August, and the lowest was at Red Rock (BC60). Average concentrations in the northern Estuary were highest in February, but were highest in the southern sloughs in August. The lowest concentrations were at the coarse sediment stations in both sampling periods.

Concentrations were not obviously higher in one sampling period than the other at the RMP stations.

Comparisons between average 1993 and 1994 Hg concentrations are shown on Figure 42. In general, the range of concentrations was wider in 1994 than in 1993. Average concentrations in the South Bay in September 1993 were higher than the other samples. The dry season



Copper in Sediment 1994

Figure 35. Copper (Cu) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

samples there were higher than the wet season samples suggesting seasonality in Hg concentrations in the South Bay.

There were no significant correlations between Hg and TOC or Eh in either sampling period, but Hg was significantly corrected with % fines in August (Table 18).

None of the samples were above the ERM of 0.71 ppm. However, 17 stations were above the ERL value of 0.15 ppm in February, and 19 stations were above that value in August.

Nickel (Ni)

Nickel concentrations in sediment ranged between 45.1 and 130.8 ppm (Figure 38). The highest concentration was at Sunnyvale (C-1-3) in February, and the lowest concentration was at San Bruno Shoal (BB15) in February. Average concentrations were highest at the southern slough stations in February, but were highest at

the northern Estuary fine sediment stations, especially Suisun Bay, in August. The lowest concentrations were in the South Bay in February and at the coarse sediment stations in August.

Most stations had higher Ni concentrations in August than in February, suggesting an inverse relationship with runoff and flows.

The range of Ni values was wider in 1994 than in 1993. Average Ni concentrations were similar in both years, except for low values sampled in the South Bay in February 1994 (Figure 42).

There were no significant correlations between Ni and TOC or Eh during any of the sampling periods, but Ni was significantly correlated with % fines in August (Table 18).

Nickel was the only metal measured with concentrations above the ERM of 51.6 at all but three stations in the South and Central Bays in February. Concentrations were above the ERL value of 20.9 ppm



Lead in Sediment 1994

Figure 36. Lead (Pb) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

at all stations. Nickel is believed to be elevated in the Estuary due to natural geologic sources, probably serpentine soils, that exist in the region.

Selenium (Se)

Selenium concentrations in sediments ranged between 0.02 and 1.03 ppm (Figure 39). The highest concentration was measured at the Napa River (BD50) in February, and the lowest concentration was measured at Red Rock (BC60) in August. The highest average concentrations occurred at the northern Estuary fine sediment stations in February, and at the southern slough stations in August. The lowest concentrations were measured at the coarse sediment stations in August.

Selenium concentrations exhibited greater differences between the 2 sampling periods in 1994 than the other trace elements. Concentrations at all stations were much higher in February than in August. The reasons for these differences are not understood.

The range of concentrations had lower values in 1994 than in 1993, but generally overlapped (Figure 42). Average Se concentrations were generally consistent among the sampling periods in 1993 and 1994, except for elevated values measured at the northern Estuary stations in September 1993.

There were no significant correlations between Se in sediments and TOC or Eh in either sampling period , but Se was significantly correlated with % fines in August (Table 18).

There are no ERL or ERM values for Se in sediments.

Silver (Ag)

Silver concentrations in sediments ranged between 0.01 and 1.11 ppm (Figure 40). The highest concentration



Mercury in Sediment 1994

Figure 37. Mercury (Hg) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.



Nickel in Sediment 1994

Figure 38. Nickel (Ni) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

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Selenium in Sediment 1994

Figure 39. Selenium (Se) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.



Figure 40. Silver (Ag) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.


Zinc in Sediment 1994

Figure 41. Zinc (Zn) concentrations in sediments (parts per million, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

was measured at Sunnyvale (C-1-3) in February and the lowest was measured at Red Rock (BC60). Average concentrations were highest at the southern slough stations, and were lowest at the coarse sediment stations in both sampling periods. Concentrations at the River stations were nearly as low as at the coarse sediment stations.

Silver concentrations were usually higher in February than in August, but not at all stations. The difference between Ag concentrations in February and August was greatest at the southern slough stations, but the highest concentrations occurred in different sampling periods at each station.

Silver concentrations in 1994 were generally within the range of the 1993 values. Average silver concentrations were quite consistent in the Estuary reaches in 1993 and 1994 (Figure 42). Concentrations in the Central Bay in February 1993 were much more variable than in the other Estuary reaches.

Silver was the only trace metal that exhibited a significant correlation with Eh in 1994. Ag was also significantly correlated with % fines in August (Table 18).

None of the Ag concentrations were above the ERM of 3.7 ppm. Sunnyvale (C-1-3) was above the ERL value of 1.0 ppm in February.

Zinc (Zn)

Zinc concentrations in sediments ranged between 50.4 and 221.8 ppm (Figure 41). The highest concentration was at Sunnyvale (C-1-3) in February, and the lowest was at Red Rock (BC60) in August. On the average, Zn concentrations were highest at the southern slough stations in February and at the northern Estuary fine sediment stations in August. They were lowest at the coarse sediment stations, but the River stations also had low Zn concentrations in the sediments.

Concentrations measured in August were usually higher than those measured in February. However, concentrations at Sunnyvale (C-1-3) were about twice as high in February than in August.

Zinc concentrations in 1994 encompassed a wider range of values than in 1993. Average Zn concentrations were very similar in each Estuary reach in 1994 as in



Figure 42. Plots of average trace element concentrations (parts per million, ppm) in sediments in each Estuary reach (see text for descriptions) in 1993 and 1994. The vertical bars are ranges of values. Sample sizes: South Bay, 1993 n=4, 1994 n=6; Central Bay, n=4; Northern Estuary, 1993

n=4, 1994 n=5; coarse sediment stations, 1993 n=2, 1994 n=3; Rivers, n=2. The southern slough stations were not sampled in 1993.

Figure 42. descriptions) in 1993 and 1994. (continued) Plots of average trace element concentrations (parts per million, ppm) in sediments in each Estuary reach (see text for





Figure 42. (continued) Plots of average trace element concentrations (parts per million, ppm) in sediments in each Estuary reach (see text for descriptions) in 1993 and 1994.



1993 (Figure 42). There was no apparent seasonality, and no obvious increases or decreases in concentrations.

There were no significant correlations between Zn and TOC or Eh in sediment in either sampling period, but Zn was significantly correlated with % fines in August (Table 18).

None of the RMP stations had Zn concentrations above the ERM of 410 ppm. One station (C-1-3) had Zn concentrations above the ERL value of 150 ppm in February, and two stations (C-3-0, BF40) had concentrations above that value in August.

Trace Organic Contaminants in Sediment

A total of 137 trace organic contaminants were measured at the RMP sediment stations in 1994. They included three major classes of compounds, the polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and related compounds, and pesticides. Within each of those classes, numerous individual compounds were measured. General descriptions of these compounds are included in the Water Trace Organics section. Methods of summing the individual compounds to obtain total PAHs, PCBs, etc. are described in the Methods Section. Raw data are listed in Appendix Tables 3.22 to 3.24.

In addition to NOAA's ERL and ERM values, the U.S. EPA has proposed sediment quality objectives for five trace organic compounds (EPA 1991). These objectives are proposed to provide protection to benthic organisms and are the EPA's best recommendation of concentrations of a substance in sediment that will not unacceptably affect benthic organisms. They are based on the biologically available concentration of the substance in sediments, thus are expressed on an organic carbon basis rather than a dry weight basis. These values are used as additional guidelines for evaluation of sediment quality.

PAHs

Sediment samples were analyzed for 25 individual PAHs (Table 6). All of these chemicals were detected in a large percentage of the samples (Appendix Table 4.7).

Pyrene and fluoranthene were detected in every sample, and many other PAHs were detected in 39 of 40 samples.

The relative contributions of individual PAH compounds to total PAH in each sample was remarkably consistent. As a result, the subgroupings used to summarize the PAHs were very highly correlated with each other and with individual PAHs. Due to these strong correlations, the geographic patterns observed for most individual PAHs and sub-groupings of PAHs were virtually identical. Therefore, total PAHs are discussed below as a general index of all of the PAHs and their subgroupings. On average, the low molecular weight PAHs (LPAHs) comprised 14% of total PAHs and the high molecular weight PAHs (HPAHs) comprised 86%. The carcinogenic PAHs.

Two PAH compounds, acenaphthene and fluorene, had spatial patterns that were distinct from the other PAHs, as reflected in their relatively low correlation coefficients with total PAHs (r=0.69 and 0.74, respectively). These two PAHs were highly correlated with each other (r=0.94) due to the strong similarities in their spatial distribution. Therefore, concentrations of fluorene are discussed as representative of these two important, anomalous PAHs.

Total PAHs ranged from 3 to 7632 ppb (Figure 43). The highest concentration was at the Extreme South Bay station (BA21) in February, but San Pablo Bay (BD22) had concentrations nearly as high, and the highest concentration in August. The lowest concentration was at Red Rock (BC60). Low concentrations were also observed at the other two coarse sediment stations. On the average, the South Bay and Central Bay stations had the highest concentrations, and the coarse sediment stations and the River stations had the lowest concentrations.

There were obvious differences in concentrations between the two sampling periods. Total PAH concentrations were more than twice as high in February as in August. February concentrations were higher at every station except the Sacramento River (BG20). The station with the highest concentration shifted from South Bay in February to San Pablo Bay in August.

Total PAHs were not significantly correlated with TOC in sediments at the RMP stations in either sampling period

(r=0.36 and 0.13 respectively, α =0.05). However total PAHs were significantly correlated with percent fines in both sampling periods (r=0.61 and 0.48 respectively).

Comparisons of average total PAH concentrations in sediments during each sampling period in 1993 and 1994 show that PAHs were quite variable in most Estuary reaches (Figure 48). The highest concentrations were measured in February 1994 in all reaches but the Rivers, often 2-3 times higher than measurements from the other sampling periods. Wet season averages were usually higher than dry season averages, suggesting possible seasonal variation in PAH concentrations. There were no obvious increasing or decreasing trends.

Fluorene, a three ring PAH compound, is one of EPA's priority pollutants. Concentrations ranged between <1 to 43 ppb (Figure 44). Unlike the other PAHs, fluorene concentrations were highest at Alameda (BB70) in February. Pacheco Creek (BF10) also had elevated concentrations. Fluorene was not detected in samples from Red Rock (BC60) and the San Joaquin River (BG30). As with total PAHs, average concentrations were highest in the South and Central Bays. Because of the elevated concentrations at Pacheco Creek, the lowest concentrations were at the River stations instead of at the coarse sediment stations.

As with total PAHs, fluorene concentrations were approximately twice as high in February as in August. The highest August concentration was at Horseshoe Bay (BC21), which had a similar concentration in February.

In 1993 fluorene was only analyzed in the September samples. The Estuary-wide average concentration in these samples was 9 ppb, equal to the average for the August 1994 samples.

The ERL for total PAHs is 4,022 ppb. Nine stations were above that value in February, and one was above it in August (Table 19), reflecting the seasonal differences described above. None of the RMP stations had total PAH concentrations above the ERM of 44,790 ppb. Concentrations of ten individual PAH compounds were above ERL values, but none were above ERM values. Twelve stations had fluorene concentrations above the ERL of 19 ppb, the most ERL exceedances of any PAH compound. Eleven of these were collected in February. Only the Horseshoe Bay (BC21) sample exceeded the ERL in August. No samples had fluorene concentrations



Total PAHs in Sediment 1994

Figure 43. Total PAHs concentrations in sediments (parts per billion, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

above the ERM of 540 ppb. The other compounds above ERL values are summarized on Table 19.

PCBs and Related Compounds

Sediment samples were analyzed for 102 PCB congeners in 73 domains (groups of one or more congeners that coelute from the gas chromatograph) (Table 6). Only 11 domains were detected in 50% or more of the samples (Appendix Table 4.8). Most congeners were detected in fewer than 15% of samples. PCB 138/ 160 had the highest frequency of detection (88%) and the second highest median concentration (1.3 ppb). PCB 153/132 had the second highest frequency of detection (83%) and the highest median concentration (1.4 ppb). PCB 110/77, PCB 180, and PCB 60/56 were also detected with relatively high frequency. The remainder of this section will focus on total PCBs (the sum of all 102 congeners) and the eleven individual domains detected in more than 50% of samples.

All eleven domains detected in more than 50% of samples were significantly correlated with total PCBs (α =.05). The domains with the strongest correlations with total PCBs were PCB 153/132 and PCB 138/160 (r = .96 and p=.0001 for both).

Total PCBs in sediments ranged between 0.3 and 41.2 ppb (Figure 45). The highest concentration was at Alameda (BB70) in August and the lowest was at Red Rock (BC60) in August. Excluding coarse sediment stations, average total PCB concentrations were higher in the South Bay (21 ppb) than in the Central Bay (14 ppb) and Northern Estuary (13 ppb) reaches. The River and coarse sediment stations had the lowest concentrations.

Total PCB concentrations were higher in February at 13 of 20 stations, but concentrations were substantially higher in August at several stations. Individual domains showed distinct differences in seasonal patterns. Median concentrations of PCB 138/160 and PCB 153/132 were higher in February, while concentrations of PCB 110/77



Fluorene in Sediment 1994

Figure 44. Fluorene concentrations in sediments (parts per billion, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations. ★ indicates not detected.

were higher in August. Concentrations of PCB 110/77 were higher in August at all stations where it was detected.

Total PCBs were significantly correlated with percent fines in February (r=0.46, p=.04) and a similar relationship was observed in August (r=0.43, p=.06). A weaker relationship was observed between total PCBs and TOC (r=0.40 and 0.28 in February and August, respectively).

Plots of concentrations of the sum of selected PCB congeners in sediments during 1993 and 1994 suggest different patterns in different reaches of the Estuary (Figure 48). Concentrations were quite variable within sampling periods in the South and Central Bays. In the Northern Estuary concentrations were more consistent within each period. In the South Bay and Northern Estuary mean wet season concentrations were higher than dry season concentrations, but this pattern did not hold in Central Bay.

Eight samples had total PCB concentrations above the ERL of 22.7 ppb (Table 19). Six of these samples were collected in February and two were collected in August. Sediments from Alameda (BB70) exceeded the ERL in both February and August. No stations were above the ERM of 180 ppb. There are no ERL or ERM values for individual congeners.

Pesticides

Sediment samples were analyzed for 21 chlorinated pesticides and pesticide derivatives (Table 6). Only three of these were detected in 50% or more of the samples: p,p'-DDD (95%), p,p'-DDE (93%), and dieldrin (53%) (Appendix Table 4.9). Only data for the DDTs are discussed in detail, but summaries of the distribution and concentrations of some of the other detected pesticide compounds are also presented.



Total PCBs in Sediment 1994

Figure 45. Total PCBs concentrations in sediments (parts per billion, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations.

DDTs

Total DDTs were calculated as the sum of 6 DDT isomers (Table 6). Total DDT concentrations in sediments ranged from "not detected" to 33.9 ppb (Figure 47). The highest concentration was at Horseshoe Bay (BC21) in August. A high concentration was also measured at Horseshoe Bay in February. Most of the DDT sampled there, during both sampling periods, was p,p'-DDT, the undegraded parent compound. Those samples contained the highest sediment concentrations of any pesticide sampled in 1994. Despite its being banned in 1972, the occurrence of these high concentrations suggests fresh sources of DDTs in the sediments at Horseshoe Bay. Also unusual at Horseshoe Bay was the detection of o,p'-DDT in both February and August, since this compound was only detected in one other sample in all of 1994.

Except for Horseshoe Bay, and the low or undetectable concentrations at the coarse sediment and river stations, total DDT concentrations were relatively uniform at the other RMP stations (Figure 47). In general, total DDTs at most stations were primarily composed of roughly equal amounts of p,p'-DDD and p,p'-DDE.

Concentrations of total DDTs at most stations were higher in February than August, but the pattern was not consistent.

Total DDTs were significantly correlated with TOC in sediments at the RMP stations in February (r=0.46, a=0.05), but not in August (r=0.05). Total DDTs were not significantly correlated with % fines in either sampling period.

Average total DDT concentrations in sediment had different patterns in each Estuary reach in 1993 and 1994 (Figure 48). Concentrations were most variable among the four sampling periods at the South Bay stations. Variability was highest within sampling periods at the Central Bay stations, but average values were quite consistent. Concentrations at the coarse sediment and River stations were also quite consistent over the four sampling periods. Average wet season samples were



Total DDTs in Sediment 1994

Figure 47. Total DDTs concentrations in sediments (parts per billion, dry wt.) at 20 RMP stations sampled in February and August, 1994. * indicates coarse sediment stations. ★ indicates not detected.

always higher than the dry season samples in the Southand Central Bays and northern Estuary, suggesting seasonal differences in concentrations. There were no obvious increasing or decreasing trends.

The ERL for total DDTs in sediments is 1.58 ppb. Fourteen stations had concentrations above that value in February, and 17 were above it in August (Table 19). None of the RMP stations had concentrations above the ERM of 46.1 ppb. The ERL for p,p'-DDE is 2.2 ppb. That value was exceeded at 3 RMP stations in 1994, but none of the stations had concentrations above the ERM of 27 ppb.

Other Pesticides

 α -hexachlorocyclohexane (HCH) was detected in 40% of the samples. All of these were collected in February, with the highest concentrations occurring at Grizzly Bay (BF21, 1.56 ppb) and the Napa River (BD50, 1.05 ppb).

Data for dieldrin were very similar to those for α -HCH, with uniformly detectable concentrations in February (16 of 20 stations) but only five detectable concentrations in August. The highest dieldrin concentration was from the South Bay (BA21, 0.88 ppb). The only other sample having a pesticide concentration greater than 1 ppb was from South Bay, with 1.28 ppb of endrin in February. The South Bay and Dumbarton Bridge (BA30) stations both had detectable concentrations of all of the aldrin analogs (aldrin, dieldrin, and endrin) in February. Concentrations of other pesticides were low or not detectable and showed no consistent patterns (Appendix Table 3.24).

There are no current ERL or ERM values for pesticides other than DDTs.

Figure 48. Plots of average Total PAHs, PCBs, and DDTs concentrations (parts per billion, dry wt.) in sediments in each Estuary reach (see text for Only compounds analyzed both by Bodega Bay Institute and GERG were used to create the sums presented in these figures. Estuary, 1993 n=4, 1994 n=5; coarse sediment stations, 1993 n=2, 1994 n=3; Rivers, n=2. The southern slough stations were not sampled in 1993 descriptions) in 1993 and 1994. The vertical bars are ranges of values. Sample sizes: South Bay, 1993 n=4, 1994 n=6; Central Bay, n=4; Northern



Sediment Bioassays

Laboratory bioassays are commonly used to indicate possible toxicity to invertebrates associated with contaminants in sediments (Swartz 1987; DeWitt *et al.* 1989). Sediment bioassays were conducted using sediment collected from 12 RMP stations (Figure 49). Two tests were conducted on samples collected during February and August: the first was a 10 day survival test using the estuarine amphipod *Eohaustorius estuarius* exposed to homogenized sediment, with percent survival as the endpoint. The other test was a 48 hour test using mussel embryos (*Mytilus edulis*) exposed to water extracts of the sediment (elutriates), with percent normal development as the endpoint. If the test result is significantly different from "controls" (analysis of variance), then toxicity is indicated.

The details of these tests are included in the Methods Appendix 1 and in the test protocols referenced. Salinities of the overlaying water in the amphipod tests were adjusted to 12-18 parts per thousand in February and 26-30 in August using Granite Canyon seawater mixed with distilled water. Different salinities were used in each sampling periods to adequately reflect differences in ambient salinities in the wet and dry periods. Salinities for the mussel tests were similarly adjusted to 27-30 parts per thousand, per the ASTM protocol. This procedure raised the salinity of the water in the sample, particularly those collected from the northern Estuary and river stations.

The control used in the amphipod test was clean home sediment from Yaquina Bay, Oregon where the amphipods were collected. That sediment is composed of 99% sand with 0.25% total organic carbon (TOC), while the RMP stations ranged between 1-85% sand with 0.19 - 1.64 % TOC (Table 17). Thus, the home sediments used for controls are of much different sediment quality than those sampled by the RMP in the Estuary. However, *Eohaustorius* is not particularly sensitive to differences in sediment type (DeWitt *et al.* 1989; EPA 1994). The control for the mussel tests was clean Granite Canyon seawater.

The San Francisco Bay Regional Water Quality Control Board has been investigating possible local "reference" or control sites for sediment bioassays for the past year through the State's Bay Protection and Toxic Clean-up Program (BPTCP). They have identified three areas in the Estuary where sediments contain reduced levels of contaminants and have not exhibited toxicity in fine-grained sediment bioassays. One station is located in Paradise Cove (off Tiburon), and two stations are located in northern San Pablo Bay, one off Tolay Creek, and one off Island #1 adjacent to Mare Island. Those sediments were sampled in April and September 1994, and tested using *Eohaustorius* with the same protocols, and in the same laboratory as the RMP samples.

The results of those tests are used to provide local sediment control values for comparison to the RMP *Eohaustorius* tests results. However, since the tests were not conducted concurrently with the RMP samples, as required by the protocols, no statistical comparisons were made. Instead, the local controls provide an informal additional comparison that facilitates interpretation of the RMP results.

The local sediment control tests were used to calculate a local "reference envelope" (Smith, 1995). The Regional Board has calculated the mean percent survival from 33 tests conducted at the reference stations. For comparison to the 1994 RMP samples, any stations with mean percent survival below 68% would indicate possible toxicity.

Quality assurance information for the sediment bioassays is summarized in Appendix Table 2.9. There were no quality assurance exceptions for most of the tests. However, the August amphipod tests had two exceptions. Therefore, the results from those samples should be interpreted cautiously. First, amphipod survival in the home sediment controls was 86% in August, below that specified for control survival in the test protocol (which is 90% mean survival, with survival in all replicates above 80%). One of five home sediment control replicates was below 80%. The tests were not repeated because of extended sample storage beyond protocol guidelines. Despite this exception, the test data are considered acceptable, mainly because all of the test sediments had high survival. Second, the organisms were also exposed to a reference toxicant, cadmium chloride, to determine that they were healthy (e.g. their EC_{50} and LC_{50} were within standard limits). The cadmium chloride EC₅₀ for the amphipod test was approximately

30 mg/L, well above LC_{50} values previously measured at the testing laboratory. However, that value was within control chart limits. These results suggest that the amphipods used in this test were more tolerant to contaminants than usual, which could explain the lack of toxicity observed in the August samples.

The bioassay results for 1994 indicated that sediment from three stations in the Central Bay were not toxic at all in 1994 (Figure 49). Four other stations indicated toxicity only from the amphipod test in February.

The February amphipod bioassays indicated that seven of the 12 stations tested had possibly toxic sediments (Figure 49). Mean survival at those seven stations was 65% compared to 97% in the home sediment control. The August amphipod tests did not indicate any significant differences from the home sediment controls. Survival ranged between 75-87%, compared to 86% in the home sediment control. As noted above, these results could be due to a batch of tolerant animals, although the survival rates are only slightly elevated from previous results at those stations. Using the local reference comparison three of the seven stations that indicated toxicity compared to "home" sediment were not toxic: the February samples from San Bruno Shoal (BB15), Pinole Point (BD31) and Grizzly Bay (BF21).

The February mussel development test indicated possible toxicity at three stations: Alameda (BB70), and the Sacramento and San Joaquin River stations (BG20, BG30). Percent normal development for all stations ranged from 0 to 99% compared to 98% in the control. The August mussel development test indicated that four stations were possibly toxic. All four stations were at the eastern side of the Estuary and included the Napa River (BD50), Grizzly Bay (BF20), and the Sacramento and San Joaquin Rivers (BG20, BG30). Percent normal development for all stations ranged between 1 - 72% compared to 76% in the controls.

Correspondence between the amphipod and mussel tests was low; only one (BB70) of 24 tests conducted indicated toxicity in both tests at the same time. These results may be due to different responses to different contaminants by the different organisms used.

There are several factors that should be considered in interpretation of the 1994 sediment bioassay results. Salt water elutriates or replacement of fresh water with saltwater in tests at the River stations produce results that are difficult to interpret. Mussels can tolerate the increased salinities, and salinity itself is probably not a factor affecting their toxicity. However it has not been determined whether such substitution affects the sorption or desorption of contamination in the sample rendering them more or less toxic. Similarly, in the amphipod test, the effect of overlaying seawater onto freshwater sediments in not known. Thus, it is possible that the sediment toxicity reported at Grizzly Bay (BF21) and at the River stations is an artifact of the test procedures. Further investigations should be conducted by RMP in future years.

Limitations to interpreting the results of the August amphipod tests with low home sediment control survival and a high EC_{50} were discussed above.

Using the three proposed San Francisco Estuary reference station results as local sediment controls for the amphipod test changed the number of stations with sediment toxicity from seven to four. Further testing and evaluation of the local reference stations should be conducted and incorporated into the RMP sampling design. Although the mean percent survival on the local sediments is lower than that on the home sediment, it provides a more reasonable control. Reference envelope confidence intervals should become smaller as more samples are used in the reference envelope calculations. However, home sediment controls will also continue to be used for quality assurance.

The use of the Regional Board's BPTCP studies has enhanced the ability to interpret the RMP results, and demonstrates how coordination among those programs can be beneficial.

Compared to the 1993 RMP sediment bioassay results, there was considerably less sediment toxicity indicated in 1994. In 1993, toxicity was reported from all eight RMP stations tested during one or the other sampling periods using one or the other of the tests. Yerba Buena Island (BC11), and the Sacramento and San Joaquin Rivers (BG20, BG30) were toxic to the amphipods in 1993 but not in 1994. For the bivalve embryos, Redwood Creek (BA41) and Pinole Pt. (BD30) were toxic in 1993 but not in 1994. The Sacramento and



Figure 49. Chart showing results of sediment bioassays at selected RMP stations.

San Joaquin River stations were toxic in all 1993 and 1994 samples.

Discussion of Sediment Monitoring

The variability of contaminant concentrations in sediments in the San Francisco Estuary observed in the past two years of RMP sampling reflect the complexity of estuarine geochemical cycles and the varied sources of contamination. Sediment mineral particles may adsorb dissolved contaminants onto their surfaces, and particulate organic material may absorb contaminants into the organic matrix. As runoff from local rivers and streams bring new mineral particles into the Estuary, they undergo chemical changes that facilitate adsorption of dissolved contaminants (Stumm and Morgan 1991). If runoff also contains dissolved contaminants, they may be readily adsorbed into the suspended sediment phase. These particles may then be deposited in the sediment. This mechanism may explain the generally higher trace contaminant concentrations observed at the southern slough stations and near the turbidity maximum (Entrapment Zone) in the northern Estuary. However, few studies have been conducted to demonstrate this phenomenon.

Once in the Estuary, sediments are transported by currents and tides, deposited, and resuspended (see Sediment Transport Pilot Study). Organisms that live in the sediments may mix the deeper layers with the newly deposited material. Animals that ingest particles remove some of that material, then deposit the sediment where it may then adsorb more contaminants. The time scales of these mechanisms are variable and mostly unpredictable.

All of the mechanisms described above may affect what is measured by the RMP. Monitoring measurements alone can only provide information on the status of sediments at the time collected. Understanding the variability among the stations, Estuary reaches, and between the sampling periods or over the long-term will require understanding more of the details of the mechanisms summarized above.

It is difficult to attribute elevated sediment contamination to a particular source. Concentrations of contaminants measured in sediments reflect areas where contaminants associated with particulate material are deposited. Sediment deposition and resuspension is known to be very dynamic in San Francisco Estuary (Krone 1992), often removing or depositing large volumes of sediment within short time-periods. Such dynamic resuspension, transport, and deposition in sediments may result in sediment measurements that do not necessarily reflect proximity to the contaminant sources.

Spatial Patterns in Trace Contaminants

The general pattern in trace element concentrations in sediments from the 1994 RMP samples was elevated concentrations in the southern sloughs decreasing into the Central Bay, then increasing again in the northern Estuary (except at the coarse sediment stations), and decreasing at the Rivers. Concentrations typically ranged an order of magnitude except for Ag and Se which ranged two orders of magnitude.

Concentrations of Ag, Cd, and Pb were always highest at the southern slough stations. Additionally, either Sunnyvale (C-1-3) or San Jose (C-3-0) was highest in Cr, Cu, Hg, Ni, or Zn during one or the other sampling period. Arsenic in sediments was highest at Pinole Pt. (BD31), and Se was highest at the Napa River (BD50). Excluding the southern slough stations, the northern Estuary fine sediment stations had the highest average concentrations of As, Cu, Cr, Hg, Ni, Se, and Zn during one or the other sampling periods; most often, Honker Bay (BF40) had elevated concentrations.

Concentrations of all metals were lowest at the coarse sediment stations, except Ni in August and Cr in February at the South Bay stations. In particular, Red Rock (BC60) most often had the lowest concentrations of trace elements in sediment.

The elevated concentrations observed in the southern sloughs reflects the proximity to large urban areas. Coyote Creek and Guadalupe Slough drain wet weather runoff, and industrial and sewage effluent into the South Bay. Measurements of contaminants in water were also generally elevated in the southern sloughs. As described above, the sediments in these sloughs may function as geochemical sinks for dissolved and particulate contaminants coming into the Estuary. The two most obvious patterns in trace organic contaminants in sediments observed in the 1994 RMP data were 1) nearly all trace organic contaminants were highest in the South Bay, and lowest at the coarse sediment stations, and 2) concentrations were usually higher in the wet sampling season (February) than in the dry sampling season (August).

Red Rock (BC60) and the other coarse sediment stations generally had the lowest concentrations of trace organics. PAH and PCB concentrations at the northern Estuary fine sediment stations were intermediate between the higher concentrations at stations to the south and the very low concentrations at the River stations. In contrast, DDT concentrations at the fine sediment stations were generally higher than those measured at the more southerly stations. The elevated p,p'-DDT sampled at Horseshoe Bay (BC21) during both sampling periods strongly suggests a nearby source of fresh DDT.

Total PAHs were comprised of a remarkably constant ratio of individual PAHs at nearly all stations and in both seasons. The homogeneous mixture of PAHs in sediment suggests that the sources also consist of homogeneous mixtures and that the rates of degradation of different PAHs are rather uniform throughout the Estuary. The profile of PAH compounds measured in the sediments is characteristic of street runoff (McDonald, gerg, pers. comm.).

Temporal Patterns in Trace Contaminants

Only a few of the trace elements were obviously higher in one or the other sampling period. Ag, Cu, and Se were generally higher in February, and Ni, Pb, and Zn were generally higher in August. Often these differences occurred only in one or the other Estuary reaches. For example, As, Cd and Cr were higher in February in the South Bay, but were higher in August in the northern Estuary. Such apparent seasonality could be related to the sources of these elements (e.g. runoff) but the partitioning of dissolved elements in water onto sediment, sediment resuspension, and hydrodynamics probably all play a role in the spatial and temporal variability observed in trace metals in sediments. Mercury concentrations showed no obvious seasonality. Plots of average 1993 and 1994 RMP trace element concentrations also showed what appeared to be seasonality in some sediment concentrations. Mean concentrations of As in the northern Estuary and South Bay, Ag and Cu in the South- and Central Bays, and Hg in South Bay had consistently higher concentrations in one sampling period or the other. It is not possible yet to ascertain whether these patterns are indeed seasonal differences in sediment trace element concentrations. Several more years of information should clarify those patterns.

The most obvious seasonal pattern observed for trace organics was consistently high PAH concentrations in February at 19 of 20 stations. No general seasonal pattern emerged for total PCBs. Total DDTs were higher in February than August at 13 of the 18 stations where it was measured. Concentrations of å-HCH and dieldrin were also detected at most stations in February and were generally undetected in August.

The elevated trace organics concentrations in February 1994 samples together with the observed seasonal trends in plots of the 1993 and 1994 data (Figure 48) suggest that trace organic contaminant concentrations in sediments are generally influenced by runoff or flows during wet weather. However, as discussed above, the mechanism behind the elevated concentrations occur in sediments is not clear.

Comparisons of 1993 and 1994 RMP sediment trace element results showed that the ranges of values measured for each trace element in 1994 overlapped with those in 1993. Average trace element concentrations in each of the five Estuary reaches over the four RMP sampling periods in 1993 and 1994 were generally similar (Figure 42). Except for an occasional high or low measurement, each trace element exhibited a slightly different "trend". There appeared to be very little variation in the South Bay and Rivers stations, with the most variation in the Central Bay and northern Estuary stations. Only a few suggestions of increases in concentrations were observed. Mean concentrations of Cd, Cr, and Cu at the River stations increased over time, but mean concentrations of Cu at the coarse sediment stations decreased over time. The two years of RMP data did not indicate any evidence of increasing or decreasing trends in trace organic contamination in the Estuary.

Interpretation of apparent trends in sediment contamination should be made considering sevearl factors. The top 5 cm of sediment sampled may represent the result of varying rates of deposition and erosion at the various stations sampled. Some stations may be depositional (e.g. Grizzly Bay, BF21), and some may be erosional (e.g. Davis Point, BD41). Other causes of differences may be local patchiness of sediment contamination or bioturbation of sediments.

There is currently insufficient information to ascertain the presence of definite long-term trends. Several more years of data will be needed to establish trends.

Comparisons to Sediment Quality Guidelines

Only two trace elements, Cd and Pb were below both ERL and ERM values at all stations during both sampling periods. As in 1993, Ni was the only trace metal that exceeded the ERM values for sediments, and it was above the ERM (51.6 ppm) at all but three stations in February. Concentrations of Ag and Zn were above the ERL at only one and three stations respectively, but the remaining trace elements were above the ERL values at 11 to 22 stations in each sampling period (Table 19).

Total PCBs were above the ERL in eight samples, six in February and two in August (Table 19). Concentrations of total PAHs and many individual PAHs were above ERLs. Nearly all of the instances where trace organics were above the ERLs occurred in February samples. Total PAHs exceeded the ERL in ten samples, nine of which were collected in February. Two LPAHs, fluorene and acenaphthene, had the largest number of ERL exceedances. Total DDTs were above the ERL in 31 samples, but they were evenly divided between the two sampling periods.

These comparisons indicate that the background concentrations of individual contaminants in the Estuary are within the range that biological effects "possibly" occur. However, cumulative effects of multiple contaminants must also be considered. Research conducted to date suggests that these effects are generally additive (Swartz *et al.* 1988; 1995). Therefore, the potential for biological effects may be much greater than suggested by individual ERL values.

None of the five trace organic compounds for which the EPA has proposed sediment quality objectives were above their guidelines.

Concentrations above ERM values "probably" cause biological effects (Long *et al.* 1995). However, the ERM values for Ni have low confidence, thus making evaluation difficult. It is possible that organisms sensitive to Ni may be excluded from inhabiting the Estuary, although no specific studies have been conducted. Concentrations between the ERL and ERM values may "possibly" cause biological effects. Therefore, biological effects due to exposure to all of the trace contaminants listed on Table 19 cannot be ruled out.

Effects of Sediment Contamination

The sediment bioassays showed that nine of the 12 RMP stations tested indicated toxicity from one of the tests during one or the other of the sampling periods in 1994. The Alameda station (BB70) was toxic to amphipods and mussel embryos during the February tests, but not in August. Napa River and Grizzly Bay were toxic to amphipods in February and to mussel embryos in August. The River stations were toxic to mussel embryos during both sampling periods. Stations in the northern Estuary (Napa River, Grizzly Bay), and the Rivers were the only stations to indicate toxicity during both sampling periods.

It is not known which component of sediments could be causing the apparent toxicity reported. However, toxicity caused by ammonia, sulfide or sediment grainsize was ruled, out since those parameters were all within the range of tolerance of this species (EPA 1995; DeWitt *et al.* 1989). As discussed above, contaminants in sediments above the ERL, or possibly some unmeasured factor, could have caused the sediment toxicity observed. However, because the sediments measured contain mixtures of numerous potential effectors, it will be difficult using this data alone, to determine which one(s) may have caused the observed toxicity.

Comparison of the general patterns in sediment contamination with the sediment bioassay results show that elevated trace contaminant concentrations and significant toxicity both were observed in the South Bay and northern Estuary. Sediment contamination was generally low in the Central Bay and there was no

Numbers indicate which sampling period, February or August (cruise 4 or 6 respectively) was above guidelines. Compounds listed are only those that contained Table 19. Summary of compounds that were above ERL and ERM guidelines for sediment, at each 1994 RMP sediment sampling location. samples above guidelines. - Indicates that no samples were above guidelines. * Compound not sampled for at this station.

| | | | | | | | | SE | DIMEN | F | | | | | | | | | | | | |
|--------------|---------------------------------|--------|----------|----------|------------|-------------|------------|------|------------|------------|---------------------|----------|------------|------------|------------|-------------------|---|------------|---------|----------------|-----------------|------------|
| Code | Station Name | | | | Σ | etals | | | | | | | | | ľ | Drgani | cs | | | | | |
| | | | | | ERL | | | ┢ | ERM | | | | | | | ERL | | | | | | |
| | | | | | | | | | | əua | əuəl | | əu | | וה | ุ คุณควุณาที่ไ | 111111 | Arene | | 5 | | 5 |
| | | Silver | oinostA | Chromium | Copper | Mercury | Nickel | oniS | Nickel | odtdganaoA | anaphth Manaphth | Fluorene | Phenanthre | Anthracene | Dinorantic | uv-(v)∠uð8 | Chrvsene | A-(A)ozn98 | t't.DDE | eTOU IstoT | PCBs Total PCBs | eHA9 letoT |
| C-3-0 | San Jose | | 1 | 4,6 | 6 | 4 | 4,6 | 6 | 4,6 | * | * | * | * | * | * | * | * | * | * | * | * | * |
| C-1-3 | Sunnyvale | 4 | ı | 4 | 4,6 | 4,6 | 4,6 | 4 | 4,6 | * | * | * | * | * | * | * | * | * | * | * | * | * |
| BA21 | South Bay | · | 4,6 | 4,6 | 4,6 | 4,6 | 4,6 | 1 | 4,6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4,6 | ,4, | 4 | 4 |
| BA30 | Dumbarton Bridge | • | 4,6 | 9 | 4,6 | 4,6 | 4,6 | | 9 | 4 | | 4 | | ı | 1 | 4 | • | 4 | ' | 4, | 4 | 4 |
| BA41 | Redwood Creek | ı | 4 | 4 | 4,6 | 4,6 | 4,6 | ı | 4,6 | 4 | 9 | 4 | 4 | , | 4 | 4 | ' | 4 | ' | 4,(| 4 | 4 |
| BB15 | San Bruno Shoal | · | ı | 4 | ı | 4,6 | 4,6 | | 9 | ı | ı | 4 | ı | ı | | | | ı | · | 9 | ı | I |
| BB30 | Oyster Point | ı | 4,6 | 4,6 | 4 | 4,6 | 4,6 | ı | 4,6 | 4 | | ı | | ı | ч 1 | 4 | • | ' | ' | 4,(| 4 | 4 |
| BB70 | Alameda | • | 4,6 | 4,6 | 4,6 | 4,6 | 4,6 | ı | 4,6 | 4 | ı | 4 | 4 | 4 | 4 | 4 | ، ــــــــــــــــــــــــــــــــــــ | 4 | ' | 4, | 4,6 | 4 |
| BC11 | Yerba Buena Island | • | 4,6 | ı · | 9 . | 4,6 | 4,6 | 1 | 9 | · . | | · . | | | | | | 1 | | 4. | 4 | 1 . |
| BC21 BC33 | Horseshoe Bay | ı | 4,6 | 4 - | 4 | 4,6 7 6 | 4,6 | ı | 4,6 | 4,6 | ı | 4,6 | 4,6 ^ | 4 - | 4 - | 4 - | • • | 4 - | 4 | 4, 4 | | 4 - |
| BC32 RC41 | Nicharusoli Day Point Isahal | | ې c t | t 4 | 4,0 4 9 | 4,0 7 6 | 4,0 4 6 | | 4,0 4 6 | 1 4 | | t 4 | t 4 | t 4 | t 4 | - | • • | t 4 | 4 2 | 5, 4 7 7 | | 4 4 |
| BC60 | Red Rock | ı | 4,6 | | · · | , , , | 4,6 | 1 | 4,6 | | | | | | | | | | I | | 1 | |
| BD22 | San Pablo Bay | ı | 4,6 | ı | 4,6 | 4,6 | 4,6 | ı | 4,6 | 4 | ı | 4 | 4 | ı | 4 | 4 | 4 | 4,6 | 1 | 4,6 | 1 | 4,6 |
| BD31 | Pinole Point | ı | 4,6 | 4,6 | 4,6 | 4,6 | 4,6 | ı | 4,6 | ı | ı | ı | ı | ı | ı | 1 | | ı | ı | 4,6 | 9 | I |
| BD41 | Davis Point | • | · | · | ı | ı | 4,6 | | 4,6 | ı | ı | ı | ı | ı | | • | | ' | ' | ' | ' | ı |
| BD50 | Napa River | ı | 4,6 | 4,6 | 4,6 | 4,6 | 4,6 | ı | 4,6 | · | | | | ı | | | • | ' | ' | 4,(| 1 | ' |
| BF10 | Pacheco Creek | ı | ı | ı | ı | ı | 4,6 | ı | 4,6 | 4 | ı | 4 | ı | ı | , | 1 | ı | ' | ' | 9 | ' | ' |
| BF21 | Grizzly Bay | ı | 4,6 | 9 | 4,6 | 4,6 | 4,6 | ı | 4,6 | ı | · | 4 | ı | , | , | 1 | ' | ' | ' | 4,(| 1 | ' |
| BF40 | Honker Bay | ı | 4,6 | 4,6 | 4,6 | 4,6 | 4,6 | 9 | 4,6 | · | | | | ı | | | | ' | ' | 4, | 1 | ' |
| BG20 | Sacramento River | ı | 9 | 4,6 | 9 | 9 | 4,6 | ı | 4,6 | ı | ı | ı | ı | ı | , | | ' | ' | ' | 9 | ' | ' |
| BG30 | San Joaquin River | ' | 4,6 | 4,6 | 4 | 4,6 | 4,6 | - | 4,6 | ı | ŗ | 1 | ı | 1 | , | | ' | ' | ' | ' | ' | ' |

sediment toxicity. More specifically, spikes in sediment PAHs at Extreme South Bay and Alameda in February corresponded to amphipod toxicity measured there. However, spikes in DDTs at Horseshoe Bay did not result in significant toxicity. Additionally, significant toxicity to bivalve larvae at the Rivers during both sampling periods did not correspond with any obviously elevated contaminant concentrations, although there were several ERL exceedances in the Rivers.

Several previous studies have addressed sediment toxicity in the Estuary (Chapman *et al.* 1987; Swartz *et al.* 1994; Hoffman *et al.* 1994). SFEI is currently participating in an evaluation of existing BPTCP and RMP data to determine associations between sediment contamination and sediment toxicity. Additionally, BPTCP is investigating the causes of sediment toxicity using toxicity identification evaluations (TIEs). However, determination of cause-and-effect will require additional manipulative field and laboratory experiments.

Bivalve Bioaccumulation and Condition



Bivalve Bioaccumulation and Condition

Monitoring the accumulation of trace substances in transplanted bivalves integrates water quality conditions over time. In addition to estimating the bioavailable portion of contaminants in the Estuary, this component of the Regional Monitoring Program, together with survival and growth measurements, attempts to relate the accumulation of trace substances and their concentrations in water to biological effects. However, the RMP bivalve condition measurements, discussed later in this section, only allow for indirect statements about possible contaminant impacts and are unable to assign specific causes to any observed changes in condition.

Bivalve Bioaccumulation

It has long been known that bivalves will accumulate contaminants in concentrations much greater than those found in ambient water (Vinogradov 1959). This phenomenon results from the difference between the contaminant-specific kinetics of uptake and depuration associated with the inability of bivalves to regulate the concentrations of most contaminants in their tissues. This method of active bio-monitoring has been widely applied by the California State Mussel Watch Program (Phillips 1988, Rasmussen 1994) and others (Young et al. 1976; Wu and Levings 1980; Hummel et al. 1990; Martinic et al. 1992). Bioaccumulation of contaminants, however, does not necessarily imply that toxic effects exist. The combined measurements of trace contaminants in Estuary water and tissue allow for investigation of quantitative relationships between the chemistry of the environment and the chemistry of the organism. As the RMP data base increases over the years, patterns in these relationships may become apparent.

Almost two decades of measurements taken by the State Mussel Watch Program, with a number of stations that overlap with those of the RMP, provide a long-term data base that does not exist for chemical parameters in water. The Mussel Watch data base, provides a large amount of information for comparisons with RMP and Local Effects Monitoring data. Given the substantial improvements in wastewater treatment efforts that have been made over this time period, comparisons between RMP data and the long-term bioaccumulation record may be used to provide some insight into how these improvements in wastewater treatment are reflected in the natural environment, if the steps taken so far were effective, and where additional pollution management steps may be needed.

As in 1993, this section compares bivalve tissue concentrations of various trace contaminants to a variety of guidelines and ranks measurements of tissue contaminant concentrations in the Estuary among numerous sites along the State's coastline, bays, and harbors. These guidelines are the same as those used to evaluate data from the California State Mussel Watch Program (Rasmussen 1994). Since no regulatory tissue standards for trace metal and organic contaminants exist in the United States, comparisons to these guidelines and other measurement sites only serve as a relative yard stick. These comparisons are useful, as the data base grows, in evaluating if there are improvements in Estuary conditions relative to other sites throughout the State or relative to various guidelines.

The U.S. Food and Drug Administration (FDA) has issued action levels for trace organic contaminants and a tolerance for harmful substances at or above which it will take legal action to remove contaminated fish or shellfish from the market. The National Academy of Sciences (NAS) developed recommendations for maximum concentrations of toxic organic substances in freshwater animal tissue to protect both the animals containing the toxic substance and any animals that prey on the contaminated organisms. Concentrations of RMP samples were never higher than either of these two guidelines. In addition, Maximum Tissue Residue Levels (MTRLs) and Median International Standards (MIS) are included in this report. MTRLs were developed by the State Water Resources Control Board and are used as alert levels indicating water bodies with potential human health concerns. MTRLs are only an assessment tool and not used as compliance or enforcement criteria. Median International Standards are not enforceable in the United States, but they give an estimate of what other countries have decided are undesirable concentrations of trace elements in shellfish (Nauen 1983).

Tissue guidelines are expressed in ppm wet weight, while the RMP tissue data are presented as ppm dry weight. A wet-to-dry weight conversion factor of 7, based on an average of 85% moisture content in bivalves, was applied for comparisons (G.Ichikawa, personal communication).

Results from the two 1994 deployment periods were compared to statewide compilations of bioaccumulation data to provide the reader with a measure of contamination in San Francisco Bay relative to other sites throughout the State. The recently released six-year data review of the State Mussel Watch Program (Rasmussen 1994) outlines how cumulative frequency distributions and percentile rankings for all measurements were obtained. RMP measurements were ranked in relation to the state-wide measurements for the same bivalve species. It should be noted that the State Mussel Watch Program predominantly monitors "locations where higher than expected concentrations of pollutants exist...", i.e. it is not a probability-based sampling design. Concentrations are therefore likely to be biased toward the higher end, and comparisons with RMP data should be interpreted accordingly.

The Regional Monitoring Program Pilot Studies used 30, 60, 90, and 120-day deployments to evaluate differences in bioaccumulation for different deployment periods (Stephenson 1992). Based on the Pilot Study findings, an optimal deployment period of 90-100 days was chosen for the RMP. In addition to the State Mussel Watch Program, the NOAA Status and Trends Program measured contaminant concentrations in resident mussels and oysters (O'Connor 1992). Using resident mussels introduces many confounding factors, one of which is the uncertain exposure period. RMP results are therefore primarily compared to Pilot Program data and those generated with transplanted bivalves from the State Mussel Watch Program (Phillips 1988, Rasmussen 1994).

Bivalves were collected at three presumably uncontaminated 'reference sites' (clams at Lake Isabella, mussels at Bodega Head, and oysters at Tomales Bay) in the middle of the wet season (February 1994) and the beginning of the dry season (May 1994) and transplanted to 15 stations in the Estuary. An important consideration in interpreting bioaccumulation in transplanted bivalves is whether or not the transplants accumulate appreciably greater masses of contaminants than are present in their tissues prior to placing the animals in the Estuary. Tissue concentrations were therefore measured at the beginning of the deployment period, delineated by "T0" or timezero concentrations, and at the end of the deployment period in transplanted bivalves.

Dividing the concentrations measured in transplants by the concentrations in time-zero controls provides an index of the amount of accumulation that occurred. In this report this ratio is referred to as an "accumulation factor (AF)". For organic contaminants, these accumulation factors were calculated as the average of two seasonal medians to avoid the influence of extreme values. Contaminants with high accumulation factors lend themselves to more rigorous interpretation, since most of the contaminant mass in the bivalve tissue is known to have been accumulated from the Estuary's water column. Conversely, data for contaminants with low accumulation factors are difficult to interpret because it is not clear whether the residues were accumulated from the Estuary or at the control site.

There are some drawbacks associated with using transplanted bivalves. The most significant limitation of this technique is the salinity tolerances of each species, which restrict the spatial distribution of stations where each species may be deployed. Although use of more than one species affords greater geographic coverage, significant differences in contaminant accumulation among bivalve species prevents comparison of data from different species. Oysters, for example, accumulate higher concentrations of some trace metals and organics than do mussels and clams. For this reason, data for each species are considered separately in discussion of spatial or temporal patterns in the bivalve data. Since only one round of samples is available for trace organics in bivalves for 1993, longer-term temporal trends are only discussed for trace metals.

Bivalve condition was determined at both times at the reference locations (T0 - at deployment and T1 control site bivalve condition at transplant retrieval), as well as on animals after retrieval from their respective Estuary locations (for a more detailed description of field procedures and analysis methods, please refer to



Appendix 1). Bioaccumulation data generated for this component of the RMP are listed in Appendix Tables 3.26 to 3.29.

Bioaccumulation of Trace Elements

Arsenic (As)

Arsenic did not accumulate appreciably above initial "time zero" (T0) concentrations at any station in either the wet season or the dry season (Figure 50). Freshwater clams exhibited the highest arsenic concentrations of 33.4 ppm at the Sacramento River station (BG20) in the dry season with an accumulation factor of 1.4. Oysters ranged from a low of 8.1 ppm at Davis Point (BD40) to a high of 13.0 ppm in San Pablo Bay (BD20), while tissue concentrations in mussels ranged from 10.1 ppm to14.8 ppm at Redwood Creek (BA40) and Yerba Buena Island (BC10), respectively. AFs for oysters ranged from 0.7 to 1.1 and for mussels from 0.6 to 0.9.

Wet and dry season values did not show pronounced differences. With the exception of *Corbicula*, tissue concentrations of arsenic were very similar between 1993 and 1994. Tissue concentration differences in clams compared to mussels and oysters were more pronounced in 1994 than the previous year.

Table 20 summarizes concentration ranges of trace metals obtained during the Pilot Program, two years of RMP results at corresponding stations, and the 1987-93 State Mussel Watch data summaries (Rasmussen 1994). Comparisons to the Pilot Program revealed similar tissue levels in oysters and mussels. Relative to other locations along the State's coast, bays, and harbors, arsenic concentrations in *Mytilus californianus* were low at all Estuary stations.

However, all stations except Davis Point (BD40) were higher than the Median International Standard (MIS) of 9.8 ppm dry weight during the wet season, including the three "reference" locations. During the dry season, only the Coyote Creek (BA10), Redwood Creek (BA40), Petaluma River (BD15), San Pablo Bay (BD20), Pinole Point (BD30), Davis Point (BD 40), Napa River (BD50), and Grizzly Bay (BF20) stations were lower than the MIS. A review of State Mussel Watch data indicates that arsenic concentrations in bivalves even at uncontaminated sites are frequently as high or higher than the Median International Standard.

Cadmium (Cd)

Mussels exhibited no bioaccumulation of cadmium at any of the stations where they were deployed either during the wet or the dry season. Oysters showed a similar pattern and even lost cadmium during the dry-season deployment, relative to initial tissue concentrations of oysters taken from Tomales Bay. Cadmium concentrations ranged from a high of almost 50 ppm in oysters at the Tomales Bay reference station and 20.5 ppm at the Napa River station (BD50) to a low of 0.2 ppm in clams in the San Joaquin River (BG30). Mussels exhibited intermediate tissue concentrations between 6.1 and 9.9 ppm (Figure 51). *Corbicula* were deployed with very low tissue concentrations and remained low upon retrieval.

Tissue levels were not appreciably different between seasons or years and were also comparable to historic values. Only mussels deployed in the southern Estuary reach showed somewhat lower dry-season concentrations in 1994 than during the previous year.

Compared to state-wide cadmium concentrations in transplanted *Mytilus californianus*, no Estuary station fell into the top 15%, and neither did clam tissue levels.

Tissue concentrations at Coyote Creek (BA10), Red Rock (BC60) during the wet season, all northern Estuary stations (with the exception of Grizzly Bay-BF20) and the reference location at Tomales Bay were higher than the MIS of 7 ppm dry weight.

Chromium (Cr)

Chromium bioaccumulation was variable throughout the Estuary with respect to seasonality and magnitude (Figure 52). Oysters did not accumulate chromium during the wet season at any of the stations where they were deployed. However, oysters did exhibit accumulation factors between 2 and 108 during the dry season. Oysters, unlike mussels, did not bioaccumulate chromium at the Petaluma River station (BD15) where they were transplanted side-by-side with mussels during both deployment periods. The difference in tissue concentrations between these two species there was dramatic and suggests that chromium was in a form more

| | | pili (µg/g), | u y weigin. | | oer or sampre | ůs. | | | | 2 | |
|------------------|-----------------|------------------|-------------|-----------------|-----------------------|--------------|-----------------|-----------------------|--------------|------------------|------|
| | R | MP Pilot 19 | 91 | | RMP 1993 | | | RMP 1994 | | State | e Mu |
| | <u>C</u> 0 | rbicula flumi | nea | <u>C</u> 0 | <u>rbicula flumin</u> | <u>ea</u> | <u>C</u> 0 | <u>rbicula flumin</u> | lea | | Cor |
| Metal | Average | Min. | Max. | Average | Min. | Max. | Average | Min. | Max. | Averag | œ |
| Ag | 0.4 | 0.2 | 0.6 | 0.1 | 0.1 | 0.3 | 0.2 | 0.1 | 0.4 | 0.2 | |
| ≥ ° | 3920.0 | 790.0 | 7050.0 | • | • | | 422.9 | 62.3 | 615.9 | 1423.5 | |
| As | 9.0 | 6.0 | 12.0 | 15.6 | 10.6 | 18.6 | 23.4 | 6.8 | 33.4 | 8.6 | |
| Cd | 2.7 | 2.4 | 2.9 | 0.6 | 0.1 | 1.0 | 0.8 | 0.2 | 1.9 | 6.4 | |
| Ç | 19.6 | 8.2 | 31.0 | 5.7 | 1.4 | 10.2 | 5.8 | 1.7 | 11.5 | 12.5 | |
| Cu | 65.0 | 45.0 | 85.0 | 39.0 | 29.1 | 55.5 | 42.8 | 27.8 | 58.1 | 78.0 | |
| Hg | 0.3 | 0.2 | 0.4 | 0.2 | 0.2 | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | |
| Ni | 68.5 | 41.0 | 96.0 | 5.2 | 2.3 | 7.8 | 5.2 | 1.3 | 11.1 | 8.7 | |
| Pb | 1.5 | 0.7 | 2.4 | 0.7 | 0.4 | 1.1 | 0.7 | 0.2 | 1.2 | 1.2 | |
| Se | 3.1 | 3.0 | 3.1 | 3.0 | 1.7 | 4.2 | 2.2 | 1.4 | 3.0 | 4.3 | |
| Zn | 160.0 | 120.0 | 200.0 | 101.2 | 62.0 | 126.6 | 84.5 | 56.7 | 114.6 | 160.0 | |
| | R | MP Pilot 19 | 91 | | RMP 1993 | | | RMP 1994 | | | |
| | C | rassostrea gig | as | <u>c</u> | rassostrea giga | 150 | <u>c</u> | rassostrea giga | S | | |
| Metal | Average | Min. | Max. | Average | Min. | Max. | Average | Min. | Max. | | |
| Ag | 6.8 | 4.3 | 8.3 | 1.8 | 0.7 | 3.0 | 5.0 | 0.7 | 9.1 | | |
| A . | 635.0 | 390.0 | 950.0 | • | • | • | 239.4 | 129.3 | 311.3 | | |
| As | 6.8 | 5.5 | 9.0 | 8.1 | 6.2 | 10.7 | 8.9 | 5.0 | 13.0 | | |
| Cd | 8.0 | 6.1 | 9.8 | 14.0 | 5.1 | 25.3 | 12.6 | 7.9 | 20.5 | | |
| ρÇ | 3.6 | 1.1 | 6.0 | 3.8 | 1.2 | 6.4 | 32.9 | 1.7 | 154.8 | | |
| | 286.6 | 180.0 | 420.0 | 339.7 | 154.9 | 034.2 | 417.4 | 188.1 | 083.0 | | |
| Nig | 0.2 71.4 | 49.0 | 95.0 | 2.9 | 0.2 | 4 C 5 C | 23.9 | 1.3 | 0.0 | | |
| Pb | 0.8 | 0.5 | 1.6 | 0.8 | 0.2 | 1.5 | 0.6 | 0.2 | 1.0 | | |
| Se | 3.5 | 2.7 | 4.3 | 4.7 | 2.0 | 8.3 | 3.4 | 1.9 | 5.2 | | |
| Zn | 3687.8 | 900.0 | 21002.0 | 1268.4 | 554.6 | 2646.5 | 1582.3 | 763.9 | 3268.4 | | |
| | R | MP Pilot 19 | 91 | | RMP 1993 | | | RMP 1994 | | State Mi | |
| | Myt | tilus california | anus | Myt | ilus california | nus | Myt | ilus california | nus | <u>Myti</u> | |
| Metal | Average n=30 | Min. | Max. | Average n=39 | Min. | Max. | Average n=48 | Min. | Max. | Average n=432 | |
| $^{\mathrm{Ag}}$ | 0.2 | 0.1 | 0.5 | 0.5 | 0.0 | 1.1 | 0.4 | 0.2 | 0.7 | 0.3 | I |
| AI | 1530.6 | 640.0 | 2000.0 | | | • | 393.3 | 74.7 | 651.0 | 611.2 | |
| As | 8.5 | 7.7 | 10.0 | 12.6 | 7.2 | 18.6 | 12.1 | 7.9 | 15.2 | 9.5 | |
| Cd | 9.1 | 7.0 | 12.0 | 9.7 | 1.4 | 19.5 | 5.9 | 1.8 | 9.9 | 7.6 | |
| Q. | 8.0 | 2.2 | 19.0 | 9.8 | 2.6 | 40.9 | 14.7 | 2.1 | 80.9 | 4.3 | |
| Cu | 10.7 | 7.0 | 13.0 | 5.6 | 2.7 | 8.6 | 7.5 | 3.4 | 22.0 | 26.1 | |
| Hg | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 | 0.5 | 0.4 | 0.2 | 1.9 | 0.2 | |
| I. | 29.7 | 20.0 | 54.0 | 8.6 | 3.0 | 28.9 | 11.4 | 1.3 | 64.4 | 2.4 | |
| Pb | 2.6 | 1.8 | 3.9 | 2.3 | 0.0 | 4.2 | 1.8 | 0.6 | . 03 1 53 | 5.0 | |
| 7 X | 2.4 | 1.2 | 3.4 | 2.1 | 0.8 | 4.2 ≠00 1 | 3.3 | 1.6 | 4.7 260 5 | 4.0 | |
| Zn | 220.0 | 170.0 | 260.0 | 327.2 | 135.8 | 588.1 | 234.6 | 122.3 | 369.5 | 261.4 | 1 |

Table 20. Average trace element concentrations in bivalve tissue statewide and in the Estuary, 1991 - 1993. State Mussel Watch data is the average of all samples, state-wide. Units are num (110/0) dry weight n = number of samples.



Cadmium, mg/kg dry weight

(June-Sept.) sampling periods. T0 (time zero) are concentrations measured on a subsample of animals prior to deployment in the Estuary.





* logarithmic scale

available to mussels. The highest chromium concentrations in oysters were found in Grizzly Bay (BF20) at 155 ppm. The only two stations where mussel concentrations exceeded pre-deployment concentrations appreciably during the wet season, were the Alameda station (BB70) at three times background levels and the Petaluma River station (BD15) at 13.5 times background levels. At Dumbarton Bridge (BA30), Redwood Creek (BA40), and Petaluma River (BD15), mussels accumulated chromium during the dry-season deployment to levels between 12.9 and 45.8 ppm, with accumulation factors of 1.9, 2.1, and 6.9, respectively. During the wet season, concentrations in clams were two and five times higher than prior to deployment at Grizzly Bay and the Sacramento River Station, respectively, while tissue concentrations in clams at the San Joaquin River station only increased 1.5 times. During the dry season, clams exhibited accumulation factors between 3.4 and 21.1 Clams in Grizzly Bay (BF20), deployed side-byside with oysters during the dry season, exhibited tissue concentrations of 9.7 ppm, 21 times higher than background and consistent with the pattern observed in oysters at that station. Chromium bioaccumulated in all three species in 1994, but showed remarkable accumulation differences among species and stations.

Bioaccumulation differed markedly between years. In 1993, almost all stations exhibited higher chromium tissue concentrations during the wet than the dry season, while this pattern was reversed in 1994, except at the Sacramento, San Joaquin, and Petaluma River stations (BG20, BG30, BD15) and at Alameda (BB70).

Historic values of chromium concentrations in oyster and mussel tissue were generally in the same range for the same stations, with the exception of Grizzly Bay (BF20) in fall of 1994 which showed extremely high concentrations in oysters and clams. While Pilot Study data suggest almost equal concentration ratios between mussels and oysters, 1994 data show that the chromium bioaccumulation potential in mussels is orders of magnitude higher than in oysters where the two species were deployed side by side. Chromium concentrations in mussels at several Estuary stations, notably Alameda (BB70), Pinole Point (BD30), and Petaluma River (BD15) ranked among the highest 5% of measurements in the State, and the mussel tissue concentration of 81 ppm at the Petaluma River station was among the highest measured since the inception of the State Mussel Watch Program.

None of the reference station bivalves exceeded the MIS for chromium, but five and ten stations during the wet and dry season, respectively, showed higher levels than the MIS of 7 ppm dry weight (Alameda-BB70, Red Rock - BC60, Petaluma River-BD15, Pinole Point-BD30, and Sacramento River-BG20 during the wet season; and Coyote Creek-BA10, Dumbarton Bridge-BA30, Redwood Creek-BA40, Yerba Buena Island - BC10, Petaluma River-BD15, San Pablo Bay-BD20, Pinole Point-BD30, Napa River-BD50, and Grizzly Bay-BF20, during the dry season).

Copper (Cu)

Bioaccumulation of copper showed pronounced differences among the three species used (Figure 53). No bioaccumulation of copper was observed for mussels or clams at any of the stations where they were deployed either during the wet or dry season. Bioaccumulation occurred in oysters at levels 2 and 2.5 times T0 concentrations during the wet season deployment at all sites, while dry-season concentrations only increased appreciably (2.5 times over background levels) at the Coyote Creek station (BA10).

Wet-season concentrations in clams were almost twice as high as dry-season tissue levels, but the same was true for reference stations, which were only marginally lower than the three Estuary stations (BF20, BG20, BG30). Data from 1993 and 1994 showed almost identical station characteristics for all three species. For example, copper concentrations in mussels ranged from 3.9 ppm to 8.6 ppm in the wet season of 1993, versus 3.4 ppm to 6.8 ppm during the corresponding deployment period of 1994. Wet-season tissue concentrations were consistently higher in 1994 than dry-season levels, whereas no consistent seasonal patterns could be observed in 1993.

The concentrations of copper were generally within the historic ranges for mussels transplanted to the San Francisco Estuary (Phillips 1988; Stephenson 1992; Rasmussen 1994). Unlike the somewhat anomalous 1993 dry-season concentrations in oysters at the Napa River station (BD50), which exceeded those reported for the Pilot Program by Stephenson (1992), the 1994 values are very similar to the Pilot Program data. In 1994, differences between oyster and mussel tissue concentrations (average factor of 28:1) were also more consistent with historical data than 1993 results. Only the Petaluma River station (BD15) exhibited copper tissue concentrations in *Mytilus californianus* that ranked in the highest 15% of state-wide measurements.

Bivalve tissue concentrations at the Tomales Bay reference station, as well as at Coyote Creek (BA10), Petaluma River (BD15), San Pablo Bay (BD20), Davis Point (BD40), and the Napa River (BD50) during both wet and dry season deployments were higher than the MIS of 140 ppm dry weight.

Lead (Pb)

Bioaccumulation of lead occurred throughout the Estuary in all three species (Figure 5.). Oysters consistently exhibited tissue concentrations during the wet season that were between three and eight times higher than T0 levels. During the wet season, mussels accumulated lead to levels between two and four times background concentrations at four of the eight stations where they were deployed - Alameda (BB70), Red Rock (BC60), Petaluma River (BD15), and Pinole Point (BD30). Clams were approximately six times higher than background at all stations during the wet season. During the dry season, mussels accumulated less lead than during the wet season, and tissue concentrations were approximately the same before and after the deployment period at almost all stations. Only two South Bay stations were exceptional in this regard, with higher tissue concentrations in the dry than the wet season. Concentrations were 3.3 and 2.9 ppm at Dumbarton Bridge (BA30) and Redwood Creek (BA40), respectively. Oysters exhibited lower dry-season concentrations, with accumulation at roughly six times pre-deployment concentrations occurring only at the Coyote Creek station (BA10). All other stations where oysters were deployed were very similar to T0 levels. Clams also exhibited lower dry-season concentrations, although tissue levels were still between two and three times background concentrations.

Comparisons between years point out that seasonal differences were reversed, with dry-season concentrations being generally higher in 1993 and higher wet-season concentrations in 1994 (except two South Bay stations). Lead concentrations in tissue were quite comparable between years for all species at all stations and with Pilot Study data. It is noteworthy that, unlike some other metals, lead levels in neither mussels nor clams transplanted to the Estuary seem to be appreciably elevated compared to State Mussel Watch concentrations compiled between 1977 and 1993. No measurements taken from bivalves in the Estuary were higher than the MIS of 14 ppm dry weight.

Mercury (Hg)

With the exception of two stations - Redwood Creek (BA40) and Pinole Point (BD30), mercury did not accumulate appreciably above T0 concentrations in any of the three bivalve species (Figure 55). The two stations mentioned above are exceptional not only with respect to bioaccumulation characteristics but also with respect to their seasonal differences. Wet season concentrations showed no appreciable difference between Estuary sites and control areas for any species, while dry season concentrations in mussels at Redwood Creek (0.87 ppm) and Pinole Point (1.9 ppm) were three and almost seven times higher than pre-deployment concentrations.

For oysters and mussels, mercury concentrations at both the control sites from where bivalves were obtained and deployment sites in the Estuary were slightly higher in 1994 than in 1993, but similar species differences in concentrations were observed, consistent with those reported by Stephenson (1992). Clams exhibited no noticeable differences in mercury concentrations between the two years. Mercury concentrations in tissues of transplanted *Mytilis californianus* at Redwood Creek (BA40) and Pinole Point (BD30) ranked among the highest 5% in the State.

Because mercury bioaccumulates by a factor of up to 107, top-level predators have been shown to contain high body burdens (Regional Water Quality Control Board, 1995). Through a variety of pathways, this mercury may find its way back into the water column. High mercury concentrations in bivalves are therefore not necessarily indicative of nearby anthropogenic sources, as evidenced by the highest concentrations recorded in the State Mussel Watch Program at stations



Copper, mg/kg dry weight



with high seal or sea lion densities (e.g., Año Nuevo, Pup Rock, San Miguel Island).

Tissue concentrations at all Estuary locations were considerably lower than the MIS of 3.5 ppm. The Maximum Tissue Residue Level of 7 ppm dry weight was also not exceeded anywhere in the Estuary.

Nickel (Ni)

Nickel and chromium showed nearly identical bioaccumulation patterns. (Figure 56) shows concentrations in all three bivalve species. During the wet season, only mussels and clams accumulated nickel to levels between three and ten times pre-deployment concentrations at Alameda (BB70), Petaluma River (BD15), Grizzly Bay (BF20), and the Sacramento River (BG20). Mussel concentrations during the wet season ranged from a low of 4 ppm at Yerba Buena Island (BC10) to a high of 64.4 ppm at Petaluma River (BD15). Clams ranged from 2.5 to 11.1 ppm during the same deployment period. Dry-season patterns were dramatically different, with only one station (Petaluma River) where mussels were deployed showing appreciably elevated nickel levels over pre-deployment concentrations (three times higher). Oysters, on the other hand, which did not show any elevated levels during the wet season, exhibited concentrations three, four, 15, and 60 times higher than pre-deployment levels at the Coyote Creek (BA10), San Pablo Bay (BD20), Napa River (BD50) and Grizzly Bay (BF20) stations, respectively. Clams showed concentrations between 2.5 and 15 times higher than predeployment levels at all stations where they were deployed.

With the exception of the Petaluma and Napa River stations (BD15; BD50), nickel concentrations were within the same range as in 1993 for both seasons. It should be noted, though, that the Petaluma River station was added in 1994 and therefore cannot be compared between years. The ratios for differences between the three bivalve species were also very similar to 1993, although this was not the case when comparing the ratios to other studies (O'Connor 1992; Stephenson 1992). Nickel concentrations in mussels at several Estuary stations, notably Alameda (BB70), Pinole Point (BD30), and Petaluma River (BD15) during both deployment periods, and Dumbarton Bridge (BA30) and Redwood Creek (BA40) during the dry season, ranked among the highest 5% of measurements in the State. Clam tissue concentrations at the Sacramento River station (BG20) fell within the top 15% of state-wide measurements.

No tissue standards exist for nickel in any country that could be compared with San Francisco Estuary concentrations, but Maximum Tissue Residue Levels of 1540 ppm dry weight were not exceeded anywhere.

Selenium (Se)

No appreciable accumulation of selenium was observed at any station (Figure 57). The greatest differences between pre- and post-deployment concentrations could be observed in Grizzly Bay (BF20) and the two river stations (BG20, BG30) during the wet season. There, clams accumulated selenium to levels 1.3 to 1.6 times the concentrations measured prior to deployment. Concentration ranges during the wet season in transplanted mussels were between 1.58 and 4.48 ppm, in oysters between 3.56 and 5.19 ppm, and in clams 2.47 and 2.99 ppm. For most stations, no appreciable differences between wet- and dry-season values could be observed in any bivalve species, with the exception of the Petaluma River (BD15), San Pablo Bay (BD20), Davis Point (BD40), and Grizzly Bay (BF20) stations, where wet-season concentrations were higher than those in the dry season.

Average concentrations were comparable to 1993 results, although station variability was higher in 1993. RMP results from that year did show appreciable bioaccumulation at a few stations. The 1994 values were roughly in the same range as historical values reported for the Estuary by Phillips (1988), Rasmussen (1994), and Stephenson (1992). Compared to state-wide measurements, values obtained by the RMP for either mussels or clams were not not particularly elevated and did not fall among the highest 15%. However, measurements from all stations during the wet season, except the Petaluma River station (BD15) and the Lake Isabella reference station, were higher than the MIS of 2.1 ppm. Dry-season RMP measurements were below the MIS for the Lake Isabella reference station, as well as for the Petaluma River (BD15), Grizzly Bay (BF20), and the San Joaquin River stations (BG30) only.



Mercury in Bivalve Tissues



Nickel in Bivalve Tissues

(June-Sept.) sampling periods. T0 (time zero) are concentrations measured on a subsample of animals prior to deployment in the Estuary.



Selenium in Bivalve Tissues

Silver (Ag)

Accumulation above T0 levels occurred at almost all stations in mussels and clams during the wet season where these two species displayed levels two to almost four times pre-deployment concentrations. Mussel concentrations ranged between 0.25 ppm dry weight at Coyote Creek (BA10) and 0.67 ppm at the Petaluma River station (BD15) during the wet season. Clams exhibited tissue levels during the same deployment period between 0.18 ppm at the San Joaquin River station (BG30) and 0.37 ppm at Grizzly Bay (BF20). Wet-season concentrations were almost always higher than dryseason levels in all three species. The exception to this, as with a number of other metals, was the Coyote Creek station (BA10), as Figure 58 points out.

Species differences between mussels and clams on one hand and oysters on the other, were remarkable and much more pronounced in 1994 than in 1993. Oysters had high silver concentrations before deployment in the Estuary (8.4 ppm in the wet season and 5.2 ppm in the dry season) and roughly maintained those levels at all stations where they were deployed during the wet season. Oyster tissue concentrations were lower in the dry season compared to pre-deployment levels, with the exception of Coyote Creek (BA10) where they increased by 3 ppm.

Tissue levels in both mussels and clams were similar to those observed in 1993 and also in the same range as historically reported values for both deployment periods. Oysters, however, showed concentrations up to three times higher in 1994 than in the previous year. These levels were consistent with Pilot Study results. Only one of 15 RMP stations (Grizzly Bay, BF20) in 1994 ranked among the 5% with the highest silver concentrations in the State, while mussel tissue concentrations were comparable to other urbanized sites. There are no international standards for silver to which RMP concentrations could be compared.

Tributyltin (TBT)

Tributyltin is an organometallic antifouling compound used primarily on ship hulls to inhibit attachment of marine organisms. This toxicant enters the water column, and a significant portion is adsorbed by sediment (Salazar and Salazar 1985). Laboratory and field studies have shown that TBT is highly toxic to mollusks and that filter-feeding bivalves readily accumulate TBT (Stephenson *et al.* 1986; Salazar and Salazar 1992).

Accumulation above reference site concentrations occurred in all three species at almost all sites (Figure 59). During the wet season, mussel concentrations ranged from 0.10 to 0.41 ppm at Horseshoe Bay (BC21) and Yerba Buena Island (BC10), respectively. Dry season concentrations in mussels were lowest at the Petaluma River (BD15) at 0.09 ppm and highest at Yerba Buena Island (BC10) at 0.23 ppm. Oysters exhibited very similar TBT concentrations from 0.17 ppm at Coyote Creek (BA10) to 0.42 at Petaluma River (BD15) during the wet season and from 0.13 ppm at Petaluma River (BD15) to 0.67 ppm at Napa River (BD50) during the dry season. Tissue levels in clams ranged from 0.17 to 0.34 ppm during the wet season and 0.29 to 0.44 ppm during the dry season. Accumulation factors ranged from 1.2 to 4.9 in mussels, 1.6 to 4.6 in oysters, and 3.4 to 486 in clams.

The highest TBT concentrations in bivalves were found in the northern Estuary reaches and at Yerba Buena Island (BC10). As with other contaminants, the Petaluma River station (BD15), where mussels and oysters were deployed side-by-side during the wet season, showed much higher concentrations and a greater accumulation factor in oysters than in mussels. It is important to note, however, that TBT tissue levels at all Estuary stations were quite low, compared to the State Mussel Watch data base. Probable toxic effects in bivalves occur above tissue concentrations of 7.5 ppm (Salazar and Salazar 1994) more than an order of magnitude higher than even the highest levels measured in the Estuary.

Zinc (Zn)

Zinc did not appreciably accumulate in tissues of clams or mussels at any station during either deployment period and exhibited no consistent seasonal patterns. Oysters, however, did appear to accumulate zinc above pre-deployment levels of 745 ppm primarily during the wet season (Figure 60). Concentrations ranged from 1253 to 1809 ppm. Tissue concentrations in mussels were




133

indicates not detected.



between 124 and 315 ppm. Clams ranged from 95 to 115 ppm. Bioaccumulation in oysters during the dry season occurred only at the Grizzly Bay station (BF20), where concentrations reached 3268 ppm. The oyster concentration and accumulation at 2.7 times background level was in distinct contrast to clams deployed at the same site. Tissue concentrations in clams were only slightly elevated over background levels and were 25 times lower than in oysters.

Zinc concentrations were remarkably similar, both among stations and species between 1993 and 1994, although seasonal differences were much more variable among stations in 1994 than the previous year. Compared to State Mussel Watch data, mussel concentrations in the Estuary were somewhat elevated, although no station fell into the top 15% state-wide.

Bivalve tissue concentrations in the Estuary were above the MIS of 490 ppm dry weight at Coyote Creek (BA10), Petaluma River (BD15), Davis Point (BD40), and Napa River (BD50) during both dry and wet seasons, at the San Pablo Bay station (BD20) during the wet season only, and at Grizzly Bay (BF20), as well as the Tomales Bay reference station during the dry season only.

Aluminum (Al)

Aluminum concentrations in all three bivalve species were measured as an analog for sediment in the bivalves' digestive tracts. Since bivalves are not depurated prior to analysis of trace contaminants, sediment that remains in their guts may introduce potentially serious errors, especially for those contaminants that are associated with the particulate fractions of water samples. Lobel et al. (1992) found that aluminum was detected in digestive glands and guts of undepurated Mytilus edulis but was not detected in the feet, kidneys, or gills of this species, indicating that it is not readily accumulated in tissue. Aluminum concentrations in at least two species of bivalves are strongly correlated with acid-insoluble residue (Lobel et al. 1991, 1992), suggesting that the concentrations of aluminum in whole organisms may be used to correct for contaminants that are bound to undepurated sediments in the gut. A detailed analysis of which contaminant concentrations are affected by sediment artifacts will be conducted for the 1995 Annual Report. As Appendix Table 3.26 shows, aluminum concentrations in bivalves were higher during the wet season, except for the southern-most Estuary stations. Aluminum concentrations in bivalves in the northern Estuary and river stations were approximately one order of magnitude higher during the wet than the dry season, reflecting the larger suspended sediment load in those locations. Seasonal bivalve concentration differences for those metals that are associated with suspended particles may therefore be heavily influenced by the sediment content in the bivalve gut.

Bioaccumulation of Trace Organic Contaminants

General characteristics of trace organic contaminants and technical terms were described in the Water Monitoring, Trace Organic Contaminants section. An important point to mention in the context of bioaccumulation characteristics of many of the most persistent and toxic trace organic contaminants is that they are highly lipophilic. In aquatic ecosystems, these chemicals tend to accumulate in the lipid (fat) of organisms to concentrations that are far greater than those in the water column. The total mass of these highly lipophilic contaminants that is accumulated by an individual organism is proportional to the amount of fat tissue available for storage of contaminant residues. With comparable levels of contaminant exposure, an individual with a large amount of fat tissue will accumulate larger masses of lipophilic contaminants than an individual with a low amount of fat. Lipid content of the bivalves collected in 1994 sampling for the RMP varied from 4 to 37% (dry weight basis). In order to prevent this variation in lipid content from masking real differences in accumulation among species, locations, or sampling periods, data for trace organics in bivalves are expressed on a lipid weight basis unless otherwise noted. Raw data are included in Appendix Tables 3.26-3.29. Appendix Tables 4.7-4.9 list summaries of trace contaminant concentrations.

Polynuclear Aromatic Hydrocarbons (PAHs)

Bivalves were analyzed for 25 individual PAHs (Appendix Tables 3.27 and 4.7). Fourteen of these were

detected in 31 or more of 33 samples analyzed (94% or greater frequency of detection). These generally high frequencies of detection provide a firm basis for quantitative analysis of these data.

The composition of the mixtures of PAHs present varied among species and between controls and transplants. Time zero control clams collected from Lake Isabella had a high average proportion (71%) of low molecular weight PAHs (LPAHs). In contrast, transplanted clams had only 18% LPAHs. This shift toward predominance of high molecular weight PAHs (HPAHs) in transplants is an indication of the generally elevated concentrations of HPAHs in the Estuary relative to Lake Isabella. Similarly, control mussels collected from Bodega Head had a high average proportion (89%) of LPAHs, while transplanted mussels had only 44% LPAHs. Like the other two species, transplanted oysters had a low LPAH fraction (14%), but unlike the other controls the control oysters collected at Tomales Bay did not have a high proportion of LPAHs (27%). The high proportions of LPAHs at the control sites for clams and mussels suggests that LPAH concentrations are elevated at those locations.

Net accumulation of LPAHs in transplanted mussels was low (average AF = 1.3), while in transplanted clams a net loss of LPAHs appears to have occurred (AF = (AF)0.6). Since total PAHs includes the LPAH fraction, this lack of accumulation of LPAHs lowers the AFs calculated for total PAHs in these species. HPAHs, on the other hand, had relatively high AFs for all species (8, 14, and 7 for clams, mussels, and oysters, respectively). Carcinogenic PAHs (CPAHs), a subset of the HPAHs, also had high AFs. Therefore, of the various subsets of PAHs, the HPAHs and CPAHs showed the strongest accumulation, and their concentrations were most indicative of water quality in the Estuary. Overall AFs for total PAHs were moderate (2.6, 2.7, and 5.7 for clams, mussels, and oysters, respectively), and were dampened due to the lack of accumulation of LPAHs.

Percent lipid was significantly correlated with dry weight concentrations of total PAHs, HPAHs, and CPAHs in mussels and oysters, with correlation coefficients between 0.85 and 0.92 and p values between 0.002 and 0.0001. Correlations for clams are not presented because of the small sample size (n=6).

LPAHs were significantly correlated with percent lipid in mussels (r=0.87, p=0.0001), but not in oysters (r=0.42, p=0.23). Total PAHs, HPAHs, and CPAHs were highly correlated with each other in both oysters and mussels. LPAHs were significantly correlated with the other groups in mussels, but not in oysters. Data for total PAHs and CPAHs are described in detail below. Total PAH concentrations are presented as a concise summary of this class of compounds and to allow comparison with guidelines. CPAH data are presented as representative of the HPAHs that show distinct accumulation in transplanted bivalves.

Total PAHs

Total PAHs generally showed some accumulation above concentrations measured in time-zero controls (Figure 61). Oysters showed the highest increase (average AF = 5.7), while accumulation in mussels (average AF =2.7) and clams (average AF = 2.6) was dampened by the lack of increase in LPAH concentrations, as discussed above. Total PAH concentrations in all oyster samples were higher than any concentrations measured in mussels or clams. Oysters appear to either accumulate PAHs at a higher rate or have a lower capacity for metabolism and/ or excretion of these compounds.

Exceptionally high total PAH concentrations were measured in oysters at the Petaluma River (BD15) in May (79,000 ppb). These oysters also contained extremely high concentrations of PCBs and pesticides. Since mussels deployed at this station on the same mooring did not show a comparable elevation in trace organic concentrations, it is not clear whether these high values are representative of water quality at this location. As indicated above, aluminum concentrations in bivalves can be employed as an index of the presence of undigested sediment in bivalve guts. However, aluminum concentrations in these oysters were not unusually high. Quality assurance data do not indicate problems for this sample. In summary, the very high concentrations of trace organics at the Petaluma River in May are difficult to explain. The second highest total PAH concentration was measured at the Napa River (BD50) in May (17,000 ppb). The Napa River also had the highest concentration in September (12,700 ppb). The lowest concentration in



Total PAHs, µg/kg Lipid weight

Total PAHs in Bivalve Tissues Lipid Weight*

* logarithmic scale

oysters was 5,295 ppb at the Grizzly Bay station (BF20). Concentrations at Coyote Creek (BA10) (average = 9,981 ppb) were intermediate.

Total PAH concentrations in mussels were rather uniform. The highest concentration was from the Petaluma River (BD15) in May (4,156 ppb), but the difference between this maximum and the other concentrations in mussels was not nearly as large as for oysters. The lowest concentration in mussels was from the Petaluma River in September (689 ppb).

Total PAH concentrations in clams were similar to those in mussels. Concentrations in Grizzly Bay (BF20) (average = 3,275 ppb) were higher than those in the Sacramento (average = 2611) and San Joaquin Rivers (average = 2,267 ppb).

The only guideline available for comparison of total PAHs in bivalves is the MTRL of 6.51 ppb dry weight. The lowest total PAH concentration measured in the RMP was approximately 42 ppb dry weight in control mussels from Bodega Head in May, and even this value was much higher than the MTRL.

Carcinogenic PAHs

Transplanted bivalves accumulated much higher concentrations of CPAHs than were found in the timezero controls (Figure 62). AFs for all three species were substantial (10, 6, and > 11 for oysters, mussels, and clams, respectively). Thus, while AFs for total PAHs are unimpressive, AFs for the CPAHs indicate that substantial accumulation of these PAHs, which are of great concern because of their mutagenic potency, does actually occur in transplanted bivalves. As with total PAHs, CPAH concentrations in oysters were uniformly higher than in the other species.

The highest CPAH concentration was in oysters from the Petaluma River (BD15) in May (26,027 ppb), followed by the Napa River (BD50) in May (5,335 ppb) and the Napa River in September (3,577 ppb). The lowest CPAH concentration in oysters was measured at Grizzly Bay (BF20) (1,975 ppb). Concentrations at Coyote Creek (BA10) (average = 3,383 ppb) were nearly as high as those at the Napa River. In mussels CPAH concentrations displayed a seasonal pattern, with higher concentrations during the wet season at all stations. The Petaluma River station (BD15) yielded both the highest CPAH concentration (in May: 1,230 ppb) and the lowest (in September: 58 ppb). No distinct spatial pattern in mussel CPAHs was apparent. CPAH concentrations in clams were similar to those in mussels. No patterns were evident at the three stations where clams were deployed.

No guidelines are available for CPAHs in bivalve tissue.

PCBs

Bivalves were analyzed for 101 PCB congeners/73 domains. (Appendix Tables 3.28 and 4.8). Seventeen domains were detected in 31 or more of the 33 samples collected (94% or greater frequency of detection). Twenty-six congeners individually contributed at least 1% of the average mass of PCBs in each sample. Collectively these 27 domains accounted for 95% of the average mass of PCBs in each sample. Detection frequencies for these congeners were generally high, providing a firm basis for quantitative analysis. PCB 180 has weak dioxin-like activity (TEF = 0.00001) and was one of the most abundant congeners, contributing an average of 6.4% of the total mass of PCBs. PCB 153/ 132 and PCB 138/160 contributed the greatest masses of any individual congeners (16.3% and 11.4%, respectively).

Total PCBs (dry weight) were significantly correlated with percent lipid in mussels (r=0.52, p=.04)and oysters (r=0.83, p=.006, Petaluma River outlier excluded). Correlations for clams are not presented because of the small sample size (n=6). The most abundant domains, PCB 153/132 and PCB 138/160, had the strongest correlations with lipid (r=0.75 and 0.81 for mussels, and r=0.89 and 0.91 for oysters, respectively). Most of the major domains, including PCB 153/132 and PCB 138/160, were highly correlated with total PCBs.

Data for total PCBs, PCB 138/160, and PCB 180 are described in detail below. Total PCB concentrations are presented as a concise summary of this entire class of compounds and for comparison with available guidelines. PCB 138/160 is discussed as a respresentative of the highly intercorrelated subset of congeners that is most strongly associated with bivalve lipids. PCB 180 is



Carcinognic PAHs, µg/kg lipid weight

Figure 62. Carcinogenic PAH concentrations (ppb lipid weight) in three species of transplanted bivalves at 15 RMP stations during the wet (Jan-May) and dry (June-Sept.) sampling periods. T0 (time zero) are concentration measured on a subsample of animals prior to deployment in the Estuary. * logarithmic scale. ★ Indicates not detected.





discussed because it is relatively toxic and because this congener had very high AFs for all three species.

Total PCBs

Transplanted bivalves accumulated substantial masses of total PCBs (Figure 63). Mussels had the highest average AF (18), followed by oysters (14), and clams (4.7). Unlike the PAHs, absolute concentrations were not markedly higher in oysters than in the other species. AFs in May samples were approximately double those of September samples, largely due to increased concentration in controls for all species in September.

As seen for PAHs, unusually high total PCB concentrations (data for trace organics in bivalves are expressed on a lipid weight basis unless otherwise noted) were found in oysters from the Petaluma River (BD15) in May (26,311 ppb) (see PAH section for discussion). Oysters from the Napa River (BD50) in May had the next highest concentration, followed closely by Coyote Creek (BA10) oysters in September. At each of these stations concentrations differed greatly among the two sampling rounds, with the lower concentrations in the range of other oyster stations. The lowest concentrations of total PCBs in oysters were measured at San Pablo Bay.

Total PCBs in mussels showed a distinct spatial pattern, with relatively high concentrations in the South Bay. Concentrations were high in both periods at the Redwood Creek (BA40) and Alameda (BB70) stations. High concentrations were also detected at Dumbarton Bridge (BA30) in September (5,286 ppb, the highest concentration in mussels) and Yerba Buena Island (BC10) in September, but May concentrations at these two stations were markedly lower. Total PCBs in mussels from Horseshoe Bay (BC21) north were much lower and very consistent, averaging between 2,000 and 2,500 ppb. At 5 of 7 mussel stations concentrations were higher in September, but the differences from the May values were generally not great.

Clams accumulated total PCB concentrations comparable to the low end of the range seen in mussels. Average concentrations in clams were highest at the San Joaquin River station (BG30) (2,756 ppb) and lowest at Grizzly Bay (BF20) (2,151 ppb). Clams had higher concentrations in May at all three stations. Total PCB concentrations were well below FDA action levels for freshwater and marine shellfish (14,000 ppb dry weight) and NAS guidelines for freshwater shellfish (3,500 ppb dry weight). However, the MTRL for total PCBs for enclosed bays and estuaries is much lower (15.4 ppb dry weight), and every total PCB measurement in bivalves, except for one control sample, exceeded this value.

PCB 138/160

Data for PCB 138/160 are representative of many PCB domains that were strongly associated with percent lipid in bivalves. Accumulation factors for PCB 138/160 in oysters (average = 14) and mussels (average > 18) were higher than those for total PCBs. The average AF for PCB 138/160 in clams (4.1) was slightly lower than that for total PCBs. The low AFs observed in clams may be due to the location of the clam deployments rather than intrinsically low capacities for PCB accumulation.

The spatial pattern of PCB 138/160 concentrations in bivalves (Figure 64) closely resembles that for total PCBs (Figure 63). However, one important difference is that the seasonal variance observed for total PCBs is greatly diminished, leaving an even clearer picture of spatial trends. A sharp contrast is apparent between concentrations in South Bay mussels and mussels from Horseshoe Bay north. The four South Bay stations averaged 536 ppb in 1994 while the four stations in Central Bay and San Pablo Bay averaged 321 ppb, and the ranges associated with these averages were narrow.

The low seasonal variance observed for PCB 138/ 160 demonstrates that transplanted bivalves are capable of yielding consistent, reproducible measures of concentrations of persistent, lipid-associated contaminants in the water column. The generally low within-station variance suggests that the bivalves are indeed providing integration of trace organic concentrations over time. Combined with the high AFs for compounds like PCB 138/160, transplanted bivalves provide a very useful measure of concentrations of these chemicals in the water column.

No guidelines are available for PCB 138 or PCB 160 in bivalve tissue.





PCB 138/160 in Bivalve Tissues, Lipid Weight*

PCB 180

PCB 180 was the third most abundant congener, was associated with bivalve lipid, and has weak dioxin-like activity (TEF = 0.00001). AFs for PCB 180 were among the highest for any congener. While substantial concentrations were present in transplants of all species, PCB 180 residues were not detected in controls of oysters and mussels. PCB 180 was detected at low concentrations in control clams making it possible to calculate the very high AF of 25. The presence of this congener seems to be characteristic of PCB contamination in the Estuary in comparison to the control sites, relating perhaps to a greater concentration of Aroclor 1260 to the PCB mixture found in the Estuary.

The spatial pattern of PCB 180 contamination was generally similar to that for PCB 138/160 and total PCBs (Figure 65). The contrast between concentrations in South Bay mussels and mussels from Horseshoe Bay north was even sharper for PCB 180 than for PCB 138/ 160. The average concentration at the four South Bay mussel stations (263 ppb) was over 4-fold higher than the average concentration at the four Central and North Bay mussel stations (63 ppb). One qualitative difference for PCB 180 relative to PCB 138/160 and total PCBs was the presence of elevated concentrations in clams at the Sacramento (BG20 - average = 317 ppb) and San Joaquin River (BG30) (average = 318 ppb) compared to clams at Grizzly Bay (BF20) (average = 137 ppb), suggesting that the Rivers are a source of this congener. Concentrations of PCB 180 in clams in the Rivers were even higher than in South Bay mussels. A seasonal pattern is also indicated for PCB 180, with higher concentrations in May at all stations from Horseshoe Bay north.

No guidelines are available for PCB 180 in bivalve tissue.

Pesticides

Bivalves were analyzed for 21 pesticides and pesticide derivatives. Ten pesticides were detected in 31 or more of 33 samples (94% or greater frequencies of detection). Only four pesticides had frequencies of detection less than 50% (Appendix tables 3.29 and 4.9).

The most abundant pesticides by far were p,p'-DDE and p,p'-DDD, with median concentrations of 584 ppb and 471 ppb, respectively (data for trace organics in bivalves are expressed on a lipid weight basis unless otherwise noted). Residues of dieldrin were the next most abundant (median = 122 ppb), followed by four chlordane derivatives with median concentrations ranging from 68 to 91 ppb. Concentrations of HCHs were comparatively low (medians ranging from "not detected" to 19 ppb).

Percent lipid was significantly correlated with all of the major categories of organochlorine pesticides (total DDTs, total chlordanes, total HCHs, and dieldrin) in both mussels and oysters. Correlation coefficients for these pesticides ranged between 0.78 and 0.95, with p values between 0.007 and 0.0001. Correlations for clams are not discussed because of the small sample size (n=6). In general, correlations among individual pesticide compounds were also highly significant.

DDTs

Oysters had the highest AF for total DDTs (12), with much lower AFs for mussels (3.5) and clams (2.3). The strong tendency of DDTs to accumulate in transplanted mussels and clams was obscured by the high total DDT concentrations in controls, most of which was comprised of p,p'-DDE. High concentrations of p,p'-DDE at the Lake Isabella (average = 553 ppb) and Bodega Head (average = 188 ppb) are a large part of the explanation for the low overall AFs for total DDTs in mussels and clams. In the controls p,p'-DDE was much more abundant than p,p'-DDD, with DDE/DDD ratios of 5.6, 5.3, and 2.8 in mussels, clams, and oysters, respectively. This ratio shifted greatly in transplants (1.1, 2.0, and 1.1 in mussels, clams, and oysters, respectively). The increase in the relative abundance of p,p'-DDD in transplants is reflected in high AFs for this isomer (23, 10, and 4.7 for oysters, mussels, and clams, respectively). Increased proportions of p,p'-DDD seem to be characteristic of DDT contamination in the Estuary.

Total DDT concentrations in oysters were high relative to mussels, but overlapped the range of concentrations in clams (Figure 66). The highest concentration in oysters was at the Petaluma River (BD15) in May (16,868 ppb), followed by the Napa River (BD50) in May (3,490 ppb). A relatively high value was also obtained at the Petaluma River in September (1,935



PCB 180 in Bivalve Tissues, Lipid Weight*

10000



Total DDT in Bivalve Tissues, Lipid Weight*

Figure 66. Total DDT concentrations (ppb lipid weight) in three species of transplanted bivalves at 15 RMP stations during the wet (Jan-May) and dry (June-Sept.) sampling periods. T0 (time zero) are concentrations measured on a subsample of animals prior to deployment in the Estuary. * logarithmic scale. ppb). San Pablo Bay oysters (BD20) had the lowest concentrations.

The highest total DDT concentration in mussels was obtained for the Petaluma River (BD15) in September (1,577 ppb). The lowest concentrations were at Horseshoe Bay (BC21) (average of 268 ppb). Concentrations at other stations were somewhat variable with no discernible pattern.

Clams exhibited high concentrations of total DDT both before and after deployment in the Estuary. Clams appear to be relatively strong accumulators of total DDT, and their low AF for total DDT is principally due to the high concentrations in the Lake Isabella controls (553 ppb). The highest total DDT concentration in clams was at the Sacramento River (BG20) in May (2,375 ppb) and the lowest was at Grizzly Bay (BF20) in September (1,154 ppb). Concentrations in the Rivers were elevated compared to Grizzly Bay.

Total DDT concentrations were lower than NAS guidelines for shellfish (3,500 ppb dry weight). The MTRL for total DDT in enclosed bays and estuaries (224 ppb dry weight) is much lower, and nine stations (and no controls) had concentrations greater than this value. Seven of the nine instances occurred in May. Clams at the Sacramento River (BG20) station had more than 224 ppb dry weight in both sampling rounds.

Total Chlordanes

As seen for total DDT, oysters had the highest AF for total chlordanes (7.2), with much lower AFs for mussels (1.9) and clams (2.0). One reason for the lower AFs for mussels and clams was the higher concentrations at the Lake Isabella and Bodega Head control locations compared to Tomales Bay. Total chlordane concentrations in oysters were not uniformly higher than in the other species (Figure 67). The highest concentration in oysters was at the Petaluma River (BD15) in May (3,782 ppb), followed by the Napa River (BD50) in May (900 ppb). Concentrations were moderately high at the Coyote Creek station (BA10) in both periods (586 ppb in May and 574 ppb in September). Aside from the extremely high May values at the Petaluma and Napa Rivers, concentrations were lower at the oyster stations in the northern Estuary. The lowest total chlordane concentration was in oysters at the San Pablo Bay station (BD20) in September (233 ppb). Concentrations at all oyster stations, and indeed for all bivalve stations, were higher in May than in September, though the magnitude of the seasonal difference varied greatly among stations.

Redwood Creek (BA40) in May yielded the highest concentrations of total chlordanes in mussels (416 ppb), followed closely by the Petaluma River (BD15) in May (411 ppb) and Yerba Buena Island (BC21) in May (395 ppb). There was some indication of a spatial gradient in the South Bay mussel stations, with concentration gradually declining with distance from the Dumbarton Bridge and Redwook Creek stations. Concentrations were higher in May than in September at all mussel stations.

Total chlordane concentrations in clams were highest at the Sacramento River station (BG20) in May (600 ppb). Average concentrations at the Sacramento River (average = 466 ppb) and San Joaquin River (average = 471 ppb) were greater than at Grizzly Bay (average = 302 ppb). Concentrations in May exceeded those in September at all three stations.

FDA action levels exist for two chlordane compounds, heptachlor and heptachlor epoxide (2,100 ppb dry weight for both), but values obtained in the RMP did not approach this level. The MTRL for total chlordane in enclosed bays and estuaries is 8.4 ppb dry weight, and every sample analyzed except for one time zero control oyster from Tomales Bay exceeded this level.

Dieldrin

Dieldrin accounted for nearly all of the mass of the aldrin analogues present in bivalve samples. Clams had the highest AF for dieldrin (14) followed by oysters (5.6) and mussels (1.4). Consistently high concentrations at Bodega Head underly the low AF for dieldrin in mussels (Figure 68).

Both the highest and lowest concentrations of dieldrin in bivalves occurred in oysters. The highest concentration was measured at the Petaluma River (BD15) in May (576 ppb). The Napa River (BD50) in May had the next highest value (128 ppb). Concentrations at Coyote Creek (BA10) were relatively



Total Chlordanes in Bivalve Tissues, Lipid Weight*

Bivalve Bioaccumulation

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* logarithmic scale.



high in both May (92 ppb) and September (80 ppb). The lowest concentration in any transplanted bivalve was found in oysters at the San Pablo Bay station (BD20), which had low values in both rounds (average = 43 ppb). Dieldrin concentrations were higher in May at 4 of 5 oyster stations. The low AF for mussels constrains interpretation of patterns in dieldrin concentrations, but mussels appeared to show a seasonal pattern similar to oysters, with 7 of 8 stations having higher concentrations in May. Dieldrin in clams had a pattern similar to that seen for the other pesticides, with higher concentrations at the River stations than in Grizzly Bay. All three clam stations had higher concentrations in May.

None of the bivalve samples had dieldrin concentrations approaching the FDA action level of 2,100 ppb dry weight. The MTRL for dieldrin in enclosed bays and estuaries is 4.9 ppb dry weight, and every station but one (Petaluma River in September) and three of six control samples had greater concentrations. The May Petaluma River mussel sample had a dieldrin concentration (49 ppb dry weight) placing it in the top 15% for all SMW data. The MTRL for aldrin is 2.31 ppb dry weight, and nine transplants and 2 of 6 controls had greater concentrations.

HCHs

Hexachlorocyclohexanes (HCHs) had low frequencies of detection and were present in relatively small quantities in bivalve samples. Furthermore, AFs for HCHs were low in oysters (average = 1.0) and mussels (average = 0.7), and inconsistent in clams (8.6 in May and 0.3 in September). Nevertheless, concentrations of two HCH isomers, alpha-HCH and gamma-HCH were comparable to the upper percentiles of the SMW database. Alpha-HCH concentrations approached but did not exceed the MTRL of 11.9 ppb dry weight. One mussel sample from the Petaluma River station (BD15) in May had an alpha-HCH concentration that scored within the highest 5% of SMW observations (7.7 ppb dry weight). Two other RMP values, from Red Rock (BC60) in May and Bodega Head in May, had concentrations higher than 85% of SMW observations (4.2 ppb wet weight). For gamma-HCH, concentrations did not approach the MTRL of 56.7 ppb dry weight. One mussel sample from the Dumbarton Bridge (BA30) ranked among the highest 5% of SMW measurements, and four other mussel samples were among the highest 15% of measurements state-wide.

Bivalve Condition and Survival

The biological condition and survival rates of transplanted bivalves following exposure to Estuary water is evidence that the animals were healthy and capable of bioaccumulation. Because of improvements in the 1994 design of the bivalve monitoring component, the condition index can be looked at as a long-term *in-situ* aquatic bioassay that integrates natural phenomena and exposure to contaminants in the Estuary over a 90-to 100-day period during the wet and dry seasons. The condition index was calculated based on measurements of dry tissue weight and shell cavity volume. The pertinent section in Appendix 1 describes in detail how the index is derived.

Condition measurements were made not only prior to the deployment period at the "control" sites from which the organisms were transplanted to various locations in the Estuary (i.e., the 'T0' condition), but also at the end of the deployment period (i.e., the 'T1' condition), in order to account for some natural variables affecting condition measurements, such as weight loss due to reproduction.

Bivalves can be regarded as a bioindicator system that reflects biological effects of contamination in responses related to growth, physiology, and reproduction (Salazar and Salazar 1995). Both natural and pollutionrelated stress can reduce mussel growth rates (Bayne et al. 1985), and it is important to quantify the most important factors contributing to biological responses before natural stressors can be separated from contaminant effects. At this stage in the RMP, the bivalve condition index represents a tool among the suite of other measurements to help evaluate bioaccumulation results, in refining the program, or initiating follow-up studies. Decreases in the bivalve condition index and survival were not statistically evaluated relative to trace contaminant concentrations in water or tissue because of the limited data base.

Figure 69 shows survival rates of the three species at their respective deployment locations. Survival of



Figure 69. Percent survival in three species of transplanted bivalves following exposure to Estuary water during the wet (Jan.-May) and dry-season (June-Sept.) deployment periods.

Mytilus edulis during both deployment periods was consistently above 90% at all high-salinity stations from the Dumbarton Bridge (BA30) into San Pablo Bay. Survival rates at the Petaluma River (BD15) were 32.5% and 80% during the wet and dry season, respectively. Oysters were deployed at the Petaluma River station side-by-side with mussels and had higher survival rates (96%) during the wet season than mussels. The dry season survival rate for oysters at the Petaluma River station was 75%.

Survival of oysters at the other stations was above 90% during both wet and dry seasons, except at Coyote Creek (BA10) where survival was 73% during the wet season and 69% during the dry season, and at Grizzly Bay (BF20) where only 23% survived during the dry season. Clams had survival rates of 86% and 93% at the two river stations and 72% at Grizzly Bay (BF20) during the wet season. Dry-season survival was 94%, 95%, and 45% at the Sacramento River (BG20), San Joaquin River (BG30), and Grizzly Bay stations, respectively. Oysters and clams were deployed side-by-side at Grizzly Bay during the dry season, but apparently the salinity regime caused high mortalities in both species. Overall survival was much higher in 1994 than during the previous year. Unlike 1993, survival at the Napa River stations was consistently high.

Although tissue samples were analyzed at all stations regardless of survival rates, condition measurements were only taken if sufficient numbers of animals had been deployed to provide enough tissue for chemical analyses. This explains the lack of condition



Figure 70. Condition indices of three species of bivalves at reference locations prior to deployment (TO), at the end of the deployment period (T1), and at their deployment locations after exposure to Estuary water during the wet (Jan-May) and dry-season (June-Sept.) deployment periods.



concentrations are subtracted from time zero (T=0) concentrations to give actual bioaccumulation. Range of values of all stations where species were deployed. * Designates different scale.







measurements for the Petaluma River station (BD15). Figure 70 shows condition indices for the three species at the Estuary locations and the respective reference sites (Bodega Head, Tomales Bay, Lake Isabella). Comparisons between condition indices prior to the animals' deployment in the Estuary (T0) and the reference site condition indices at retrieval time (T1) were also made in order to relate the magnitude of changes at the three reference sites with those encountered in the Estuary. Oysters, for example, grew significantly at Tomales Bay between February and May, but so did oysters at all but one Estuary station, although at much lesser rates. During the dry season, oysters did not appear to change condition in Tomales Bay; however, their condition index decreased significantly at all Estuary locations.

During the wet season, clams gained weight relative to their shell volume at Lake Isabella, but remained roughly in their pre-deployment condition at their Estuary stations. Dry season patterns were the exact opposite. The clam condition index increased at all Estuary stations relative to the reference site condition at retrieval. However, this has to be related to large decreases of "control" clams at Lake Isabella during the time animals were transplanted to the Estuary and retrieved for analysis.

The condition index of transplanted mussels during the wet season was higher than T1 condition at all sites where they were deployed except at Red Rock and Pinole Point. During the dry season, the condition index at Treasure Island (BC10) and Horseshoe Bay (BC21) increased relative to the reference site, but decreased everywhere else.

Discussion of Bivalve Bioaccumulation

Trace Elements

Although bioaccumulation data from four deployment periods in two years are still too limited to arrive at any definitive trends, even in combination with Pilot Study (Stephenson, 1992) and Local Effects Monitoring Program results, some preliminary patterns in bioaccumulation among trace contaminants, species, or Estuary reaches are apparent. Figure 71 depicts



Figure 71. (continued) Trace element accumulation (ppm, dry weight) in three species of transplanted bivalves for four sampling periods in 1993-

preliminary Estuary-wide concentration means from four sampling periods for all trace metals analyzed as part of the base program. "Error bars" represent the minimum and maximum concentrations encountered at all sampling stations combined. Detailed statistical analyses for those stations where triplicate measurements were taken as part of the Optimal Sampling Design Special Study (Chapter 6), are reported in the Special Study chapter.

Tissue concentrations in the Estuary as a whole were generally comparable between 1993, 1994, and historical values, but no consistent patterns are recognizable for stations or seasons. For those metals that did show elevated concentrations in bivalve tissues over predeployment levels, only lead exhibited similar concentrations at each station between the two years. When looking for metals with very similar bioaccumulation patterns throughout the Estuary, chromium and nickel appear to have almost identical dynamics. This suggests that the same common factor governs the uptake dynamics for these two metals.

Tissue concentrations were higher for three trace metals - chromium, lead, and nickel - in all three species after transplanting them to the Estuary from presumably clean locations. Of these metals, only lead showed consistently elevated concentrations throughout the Estuary. Chromium and nickel concentrations were considerably higher than pre-deployment levels at five of the 15 stations. Arsenic, cadmium, and selenium did not accumulate in any species above pre-deployment concentrations. Copper and zinc accumulated during the wet season in oysters but not in mussels or clams. Silver accumulated during the wet season in mussels and clams, but not in oysters. Mercury concentrations were appreciably higher than background in mussels at only two stations during the dry season. As the different bioaccumulation characteristics for different metals and bivalve species point out, the species variable needs to be tightly controlled if the goal of generating a longterm concentration trend among different stations and seasons is to be met. Regardless of hydrologic conditions, the same species will need to be deployed at the same stations to make trend analyses possible.

Interannual differences are apparent between 1994 and 1993 results. For those metals exceeding background concentrations by a great amount, dry-season levels were more likely to be higher than wet-season concentrations in the southern portion of the Estuary, while 1993 showed the opposite pattern. Wet-season concentrations of chromium and nickel in 1994 were lower than in 1993, invalidating some preliminary indication of possible wetseason concentration increases over time using historical data. The observation made in 1993 that chromium, nickel, copper, lead, and zinc concentrations in bivalve tissue were much higher at various locations throughout the Estuary than they were at reference sites holds true for 1994, although much less pervasively for zinc than for the other metals.

The fact that silver concentrations in mussel tissue were not exceptionally elevated in the Estuary in 1994, relative to other sites throughout the State, indicates that this trace metal may occur in a form that is not particularly available to *Mytilus californianus*, given that water concentrations (dissolved and particulate) were as high as 0.14 ppb and Estuary sediments are among the most grossly enriched in the world (Smith and Flegal 1993). Differences in food particles between stations throughout the State would provide an alternative explanation.

Two other metals that deserve special mention are lead and copper for which long-term databases exist for mussel tissue (Stephenson and Leonard 1994). Among 20 sites analyzed along the California coast, 40% showed significant decreases in lead. Declines appear to be related to decreased mass emission rates by wastewater treatment facilities and the phase-out of lead as a gasoline additive. It is interesting to note, however, that the three San Francisco Bay stations included in the analysis were not among those for which decreasing trends were observed. The hypothesis of Flegal and Sañudo-Wilhelmy (1993) that sediments may represent a large reservoir of contaminants in San Francisco Bay may explain those observations. In contrast, lead levels in sediment and the water column at other heavily contaminated sites near ocean outfalls along the open coast may have decreased not only because of reduced mass emissions but also due to dispersion of the historically contaminated sediment layers. Ritson and Flegal (in preparation) took measurements of variations of the stable lead isotopic composition of dated sediment cores and 14 surface sediments from around the Estuary. They showed that surface sediments in the San Francisco Estuary exhibit a homogeneous isotopic lead signal distinct from that derived from atmospheric deposition. No point source associated with wastewater could be identified by a distinct isotopic composition of the surface sediments of the water of the South Bay either. This indicates that the major source of lead in the Estuary appears to be from remobilization from historically contaminated sediment, and lead concentrations in bivalve tissue would reflect this to a large degree.

Copper showed steadily increasing trends at five of the 20 stations Stephenson and Leonard (1994) analyzed throughout California. The authors attributed this to increased copper use in co-polymer boat paints which consist of up to 30% copper. However, none of the five stations with increasing trends were within the Estuary.

The potential use of aluminum for correcting contaminant values in whole, undepurated bivalves deserves further experimental exploration. One of the reasons that bivalves are not depurated in most large-scale monitoring programs is the increased cost for this additional step. If corrections of metal values based on aluminum as a sediment analog provide similar results as values obtained from depurated mussels, the application of correction factors for sediment in bivalve guts based on aluminum measurements may prove to be a reasonable and more costeffective method than the additional step of depuration to control for minimizing measurement artifacts.

Although only seven of the ten metals were accumulated above background concentrations by one or more bivalve species in 1994, tissue concentrations were higher than Median International Standards for one or more metals at all stations measured, including the three reference sites. Mercury, selenium, and arsenic were most often higher than the MIS, followed by cadmium, chromium, zinc, and copper. Lead was the only metal that was consistently lower than the MIS throughout the Estuary (Table 21).

Trace Organic Contaminants

Transplanted bivalves are a valuable tool for monitoring concentrations of trace organic contaminants in the water column of the Estuary. The high concentrations of trace organics accumulated by bivalves are easily detected analytically, leading to high frequencies of detection and straightforward quantitative interpretation. Accumulation factors (increase over time zero concentrations) for trace organics in bivalves were high, leaving no doubt that the residues measured were accumulated from the water column of the Estuary. Furthermore, data for some trace organics (e.g., PCB 138/ 160) displayed low variability at each station. Integration of varying concentrations over time, one of the theoretical benefits of using transplanted bivalves, is probably contributing to the consistent concentrations observed at RMP stations.

The significant differences in contaminant accumulation among bivalve species prevents data comparisons among different species. Oysters, for example, accumulated much higher concentrations of PAHs than mussels and clams. Although species differences in accumulation were not obvious for other trace organics, it is likely that other differences do exist. Consequently, interpretation of spatial trends in bioaccumulation is best limited to consideration of single species. Mussels were deployed at the broadest ranges of stations and consequently yielded the best information on spatial gradients in trace organic contaminants.

Some spatial and temporal trends were evident in trace organic concentrations in bivalves. For PAHs, DDTs, chlordanes, and dieldrin, elevated wet-season concentrations were observed in oysters at the Petaluma River and Napa River stations, suggesting that these tributaries were sources of these compounds in the spring. PAHs, PCBs, chlordane, and dieldrin in oysters were also relatively high in both May and September at the Coyote Creek station, another location under the influence of freshwater runoff to the Estuary. Temporal trends were not apparent in trace organics in oysters.

Broader spatial patterns in trace organic concentrations were observed in mussels. Concentrations of PCBs from Yerba Buena Island into the South Bay reach were uniformly higher than in the Central Bay or San Pablo Bay reach. This difference was most apparent for PCB 180, which had average concentrations in the South Bay that were four times higher than in Central Bay and San Pablo Bay. Concentrations within the South Bay were fairly uniform. The South Bay also had elevated concentrations of total chlordanes, with a suggestion of a gradient of increasing concentrations toward the

| | | | | | | | | Mytilus californianus | | | | | | | Crassostrea gigas | | | | Corbicula fluminea | | | Species | |
|-------------------------|---------------------|-------------------|-----------------------|---------------|---------------------|---------------------|-------------------|-------------------------|---------------------------|------------------------|-------------------------|-------------------------|-------------------------|-----------------------|-------------------------|---------------|-------------------|---------------------|---------------------------|---|-----|--------------|--------|
| T-0 | BD30 | BD15 | BC60 | BC21 | BC10 | BB71 | BA40 | BA30 | T-0 | BF20 | BD50 | BD40 | BD20 | BD15 | BA10 | T-0 | BG30 | BG20 | BF20 | | | Code | |
| Bodega Bay | Pinole Point | Petaluma River | Red Rock | Horseshoe Bay | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Tomales Bay | Grizzly Bay (dry only) | Napa River | Davis Point | San Pablo Bay | Petaluma River | Coyote Creek | Lake Isabella | San Joaquin River | Sacramento River | Grizzly Bay | | | Station Name | |
| w,d w,d - w,d w,d w,d - | w w w,d - w,d w,d - | w w w,d - w,d d - | w,d w,d w - w,d w,d - | w,d w,d w,d - | w,d - d - w,d w,d - | w,d - w - w,d w,d - | w - d - w,d w,d - | w,d - d - w,dw,dw | w,d w,d - w,d w,d w,d w,d | - d d d d - d | w w,d d w,d w,d w,d w,d | - w,d - w,d w,d w,d w,d | w w,d d w,d w,d w,d w,d | w w,d - w,d w,d w w,d | w w,d d w,d w,d w,d w,d | w,d w,d | w,d w,d w - | w,d - w - w,d w,d - | w - d - w,d w - | Arsenic Cadmium Chromium Copper Mercury Selenium Zinc | MIS | Metals | TISSUE |
| | | | | | | | | | | | | _ | _ | - | v | | p | W | V | | | | |

southern limit of mussel deployments (Dumbarton Bridge). Total chlordane concentrations were also relatively high in mussels at the Petaluma River. In contrast to the high concentrations of DDTs in sediment at Horseshoe Bay, this station had the lowest concentrations of DDTs (and chlordanes) found in mussels. Clams at the River stations had higher concentrations of PCBs, DDTs, chlordanes, and dieldrin, suggesting that the Rivers are sources of these compounds to the Estuary.

A few trace organics showed consistent seasonal variation across stations. Mussels had higher concentrations of CPAHs in the wet season at all stations, similar to the seasonal contrast between wet- and dryseason sediment samples. Chlordanes and dieldrin were slightly higher in May at all stations.

These data on bioaccumulated trace organics support some hypotheses regarding sources. Elevated concentrations of all trace organics were observed at the Petaluma River, Napa River, and Coyote Creek stations, indicating the presence of continuing sources of these compounds within the watersheds of these tributaries. Similarly, the Sacramento and San Joaquin Rivers appear to be sources of PCBs, DDTs, chlordanes, and dieldrin. Concentrations of PAHs, chlordanes, and dieldrin were higher in May, implicating runoff in the wet season as a source. Strong correlations between individual PAHs and pesticides are consistent with them having similar sources. As discussed in the sediment organics section, urban runoff is a likely source of the uniform PAH mixture that is distributed throughout the Estuary. Pesticide inputs from a multiplicity of sources in watersheds might be responsible for the consistent mixtures of chemicals, as indicated by strong correlations among pesticides, within this class.

Although none of the measurements of organic contaminants in tissue exceeded the FDA action levels or NAS guidelines, tissue levels at all Estuary locations were higher than the Maximum Tissue Residue Levels for most of the trace organics groups. PCB, PAH, and total chlordane concentrations were consistently higher than MTRLs, followed by the aldrin analogues and DDTs (Table 21).

Bivalve Condition and Survival

The primary objective of survival and condition measurements was to determine if the transplanted animals were capable of contaminant uptake. Survival, in particular, seemed to have been influenced by salinity, with those stations that were at the empirically determined tolerance margins for the three bivalve species exhibiting the lowest survival rates. Since hydrologic conditions in the Estuary cannot be predicted with any certainty prior to bivalve deployment, especially during the wet season, a combination of species is deployed at the stations with highly variable salinities. No relationship between condition and survival could be discerned. In fact, at the station with the lowest clam survival (Grizzly Bay, BF20), the condition index increased relative to the reference station.

It is interesting to note that some of the stations with the lowest ratios of dry weight to shell volume coincided with the stations with high concentrations of many trace contaminants. A number of trace contaminants were high at the Petaluma and Napa River stations (BD15 and BD50) and in the South Bay reach, particularly trace organics. The lowest oyster condition indices coincided with these high tissue concentrations. Mussels and clams, however, did not show any staightforward relationships between tissue concentrations and condition.

Despite improvements in the monitoring design, many factors may affect bivalve condition that RMP measurements do not take into account. For example, in order to compare bivalve condition at control sites to condition at Estuary deployment sites appropriately, control site animals would have to be suspended in nylon mesh bags above the bottom, similar to the treatment the transplanted animals receive. This modification to the monitoring design was initiated in 1995. In addition, natural variables that may affect bivalve growth at control sites may be very different than in the Estuary, such as food availability, salinity, and temperature. Aside from being modified by natural factors, the way experimental animals are handled, and the contaminants they are exposed to, bivalve biology is also affected by internal biochemical and physiological cycles. All of these factors influence growth, survival, and bioaccumulation. Therefore, the bivalve condition index should only be used together with the complete suite of RMP measurements and not interpreted as directly related to trace contaminant concentrations until their responses are calibrated by separating natural and biological factors from the effects of contaminants. These variables are not completely addressed when comparing control sites with Estuary sites, and results should be interpreted in that context.

Salazar and Salazar (1995) have developed a mussel bioindicator model based on field studies in San Diego Bay and existing knowledge of mussels and their response to tributyl tin (TBT). Since natural factors, contaminants, and biological responses are cyclical and variable and difficult to separate, the authors combined real-time chemistry and the use of transplanted bivalve indicators to measure the relative importance of natural factors and contaminants on biological responses. If refinement of bivalve condition as bioindicator for contaminants is desired, this model could be explored in more detail in the Estuary.

Pilot Studies



"Sieving benthic macroinvertebrates from sediment"

Pilot Studies

Benthic Macrofaunal Assemblages in the San Francisco Estuary: 1994

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Introduction

Benthic macrofauna are invertebrates, usually larger than 0.5 mm, that inhabit the sediments of the Estuary. They may be free living, burrow, construct a tube, or attach to shell or rock fragments.

Analyses of macrobenthic species composition, abundances, and biomass are used in the major national monitoring programs such as EPA's EMAP and NOAA's National Status and Trends Program. Benthos are also monitored in all other large regional monitoring programs in the U.S., including those in other complex estuaries such as Chesapeake Bay and Puget Sound. Benthos are monitored because they inhabit sediments where they may be exposed to elevated contaminant concentrations compared to water. Since they are generally not very motile, they can provide reliable indicators of sediment conditions within a local area. Additionally, benthos may accumulate contaminants from sediments into the estuarine food web as benthos may provide food for bottom feeding fish and birds. They also facilitate other important sediment functions such as nutrient and carbon flux by their burrowing and feeding activities.

This Pilot Study was begun because it is important for the RMP to include measurements of the condition of resident biota in order to evaluate whether or not ecological effects from contamination actually occur in the Estuary. The objective of this Pilot Study is to evaluate the use of benthic information for determining environmental conditions in the Estuary. This implies knowledge of what a "normal" benthic assemblage is, or should be. While there is a need to understand benthic communities in general, a more specific objective for the RMP is their use in determining adverse affects from exposure to contaminants.

This summary reports progress after the first year of the Pilot Study. It includes a general description of the benthic assemblages (= communities) in the Estuary in 1994. Through coordination with a RMP Special Study on optimal sampling design (see next chapter), and the Regional Board's Reference Site Project, additional samples near major sewage outfalls and at possible "reference sites" were also collected. Therefore, comparisons between near-outfall and reference sites are made. However, relationships to environmental variables such as sediment type, salinity, and contaminants are not rigorously analyzed since some of the data is incomplete. Instead, only general relationships are discussed based on measurements made previously at many of the same stations.

In order to provide an Estuary-wide evaluation, benthic data from the RMP and the California Department of Water Resources (DWR) monitoring programs were combined.

Benthos have been well studied in the San Francisco Estuary (reviewed by Nichols and Pamatmat 1988). They concluded that it was not possible to distinguish effects of pollutants from natural variability. However, they also



Figure 1. Sampling locations in the San Francisco Estuary and Delta. Stations with similar shading are classification analysis site groupings (see Figure 2).

concluded that long term sampling studies were needed to adequately address the problem. Other studies have shown changes in species composition and abundances in contaminated areas. Studies in the 1950s showed reduced diversity and high abundances of the polychaete *Capitella capitata* near sewage outfalls (Filice 1959). More recently, benthos in the Islais Creek Channel was also characterized by reduced diversity, few amphipods, and by a preponderance of *Capitella capitata* (Chapman *et al.* 1987).

Methods

Twenty nine stations were sampled during several sampling periods in 1994 (Figure 1, Table 1). Eight RMP stations were sampled during February and August in 1994. Nine stations near three sewage outfalls were sampled in August (LEM outfall), and three possible reference stations being investigated by the San Francisco Bay Regional Water Quality Control Board were sampled in early September 1994. DWR sampled nine stations at six locations between San Pablo Bay and the Delta. These stations were sampled monthly, but no March data are included in this analysis. Samples from the center (C), left (L), or right (R) sides of the channel were collected at some stations (DWR 1994). Replicate samples were collected at the DWR stations, three of the RMP stations, and all LEM outfall stations. Those replicates were averaged for the analysis in this report. A total of 127 samples were included in the analysis.

A 0.05 m² Ponar Grab was used to collect most of the samples. However, the CCCSD samples were collected with a 0.1 m² Smith-McIntyre grab which was split in half to equal the grab area of the other samples. All samples were sieved through 0.5 mm screens. The animals were preserved and identified to the lowest practical taxon. Each program used different taxonomists (persons who name organisms, see Acknowledgments in this section). In order to analyze all of the data together, it was necessary to standardize the species names reported by each program. This required an assessment of taxonomic differences, then resolution through discussions by the taxonomists to produce a standardized species list.

The determination of which stations had similar species composition and abundances was made using classification analysis (Smith *et al.*1988). Briefly, this analysis included data transformation and standardization, and calculation of a Bray-Curtis similarity matrix that uses abundances of all species to summarize the patterns of overall community composition and abundances. The result of this analysis is a dendrogram showing the degree of difference (ecological distance) in the biota among the stations sampled (Figure 2). Numbers of species and individuals at each station are used to express species diversity rather than formal diversity indices.

 Table 1. Summary of the benthic samples analyzed in this report. Outfall stations sampled included City and County of San Francisco (CCSF) outfall near Islais Creek, the East Bay Municipal Utility District (EBMUD) outfall near Treasure Island, and the Central Contra Costa Sanitation District (CCCSD) outfall near Pacheco Creek (see Fig. 1).

| Program | Number of Stations | Sampling Dates | Total Number of Samples |
|-------------|-----------------------|-------------------|----------------------------|
| RMP | 8 | Feb., Aug. | 16 |
| LEM Outfall | 9 | Aug. | 9 |
| RWQCB | 3 | Sep. | 3 |
| DWR | 9 | Monthly | 99 |



Figure 2. Dendrogram showing the results of classification analysis of 127 benthic samples collected from the region in 1994. Numbers designate site groupings with similar species composition and abundances.

Results

Community Composition and Abundances. Nine groups of stations were identified by classification analysis (Figures 1, 2). The stations in each group generally had similar species composition and abundances. These groupings are interpreted as the various benthic communities, or assemblages of the San Francisco Estuary and Delta.

These groupings generally reflected spatial differences among stations rather than temporal differences, although some seasonal differences were observed (see below). The main division of the dendrogram was between the Delta, River and northern Estuary stations, and the Central and South Bay stations.

Stations at Old River (D28A), Frank's Tract (D19), and Sherman Lake (D11) formed Group 1, which had two sub-groups. Group 1a included samples from all months sampled, whereas most of the stations classified in Group 1b were sampled in the dry season. The subgroups had very similar species composition, but differed in which species were dominant and total abundances (Table 2). These stations were dominated by freshwater species, e.g. the amphipods *Gammarus daiberi* and *Corophium stimsoni*, the polychaete *Manayunkia speciosa* and the clam *Corbicula fluminea*.

Group 2 included all 11 monthly stations sampled at the Sacramento River central channel station (D4C) in 1994. These stations are characterized by very coarse sediments typical of river flows, and had greatly reduced abundances and numbers of species (Table 2).

Group 3 included almost all of the Sacramento River (D4) left and right channel stations, and the wet season samples from Sherman Lake (D11C). These stations were composed of fine-grained sediments and were dominated by two species of amphipods (Table 2).

The three stations near the CCCSD outfall at Pacheco Creek formed Group 4. The benthic assemblages there included both brackish water and estuarine species (Table 2). The dominant species were the polychaete *Marenzelleria viridis* and the clam *Potamocorbula amurensis*.

Group 5 included all 11 monthly samples from Grizzly Bay (D7). The benthos was dominated by the amphipod *Corophium alienense* and *P. amurensis*, and, as at the CCCSD stations, included species characteristic of both brackish water. Thus, these stations may be considered transitional stations between freshwater and estuarine conditions.

Groups 6 included all 11 monthly samples from off Pinole Point in San Pablo Bay (D41A). The samples were dominated by the amphipod *Ampelisca abdita* and *P. amurensis*.

Group 7 included samples from Red Rock (BC60) and from the Regional Board's two San Pablo Bay reference stations (SF02 and SF03). The Red Rock station is located in an area of strong currents, thus the bottom sediment is very sandy. That station was inhabited by four to six species with very low abundances. However, the Regional Board reference stations had very fine sediments and higher densities. The presence of *P. amurensis* and tubificid oligochaetes at all of these otherwise quite different stations appears to have caused them to classify together. Therefore, this group is not considered to be a discrete assemblage.

Group 8 included four stations from two different Estuary reaches, approximately equidistant from the Golden Gate. Two stations from Davis Point (BD41) in San Pablo Bay, and two stations from South Bay (BA21) were classified together because of their similar species composition and abundances. The clam *P. amurensis* was by far the most abundant species at these stations.

Group 9 included 17 samples from the Central Bay (Figure 1). Stations near the CCSF and EBMUD outfalls were classified together with five non-outfall RMP stations, and the Regional Board's reference station at Paradise Cove (SF01). This suggests that all of these stations had similar species composition and abundances. This assemblage was characterized by the presence of numerous marine species, such as brittle stars. On the average, the most abundant species at these stations were *A. abdita* and the polychaete *Euchone limicola*, but the dominant species at each station was often different.

Seasonal variation in benthic species composition and abundances was only observed at some of the Delta and River stations. Group 1b appears to represent dry season assemblages at those stations. Twelve of thirteen stations in Group 1b represented dry season samples. Samples from two of the stations, D28A (L) in Old River, and D11 in Sherman Lake collected during the wet season were classified with other groups. Wet season samples from station D28A (L) were classified in Group 1a with

| SPECIES NAME | TAXON | FREQUENCY | 1A | 18 | 2 | 3 | 4 | 2 | 9 | 7 | 8 | 6 |
|------------------------------------|-------|-----------|-------|-----|-----|-----|------|-----|------|------|-------|-------|
| | | | n= 28 | 13 | 5 | 25 | 3 | 4 | 4 | 4 | 4 | 17 |
| Manavunkia speciosa | Po | 0.27 | 14.5 | - | | | | | | | | |
| Aulodrilus limnobius | 0 | 0.26 | 6.0 | 0.1 | | | | | | | | |
| Quistadrilus multisetosus | 0 | 0.24 | 1.8 | | | | | | | | | |
| Dorylaimus species a | z | 0.28 | 2.3 | 0.1 | | | | | | | | |
| Corophium spinicorne | A | 0.39 | 4.7 | 0.7 | | 0.1 | | | | | | |
| Corbicula fluminea | Pe | 0.57 | 2.9 | 3.7 | | 0.6 | | | | | | |
| Potamilla species a | Po | 0.43 | 0.5 | 1.2 | | 0.3 | | | | | | |
| Corophium stimpsoni | A | 0.44 | 4.8 | 5.5 | | 4.3 | | | | | | |
| Bothrioneurum vejdovskyanum | 0 | 0.47 | 0.6 | 0.2 | | 0.4 | | | | | | |
| Gammarus daiberi | A | 09.0 | 4.7 | 1.1 | 0.1 | 2.4 | | | | | | |
| Varichaetadrilus angustipenis | 0 | 0.56 | 1.2 | 0.3 | | 2.1 | | | | | | |
| Limnodrilus hoffmeisteri | 0 | 0.50 | 2.1 | 0.3 | | 2.2 | | 0.4 | | | | |
| Marenzelleria viridis | Po | 0.39 | | | 0.1 | 1.4 | 21.2 | 0.1 | | | | |
| Neomysis mercedis | Ø | 0.13 | | | | 0.1 | | | | | | |
| Corophium alienense | A | 0.13 | | | | | | 8.5 | | | | |
| Tubificoides heterochaetus | 0 | 0.09 | | | | | | 0.1 | | | | |
| Hemileucon hinumensis | A | 0.44 | | 0.1 | | 0.3 | | 1.6 | 0.2 | 0.3 | 0.1 | 1.9 |
| Grandidierella japonica | A | 0.15 | | | | | 0.8 | - | | | 0.1 | 0.2 |
| Synidotea laevidorsalis | _ | 0.20 | | | | | 0.1 | | | 4.8 | 1.5 | 0.7 |
| Potamocorbula amurensis | Pe | 0.57 | | | 0.1 | 1.6 | 6.6 | 5.6 | 1.8 | 7.3 | 835.9 | 1.2 |
| Neanthes succinea | Ро | 0.16 | | | | | | | 0.1 | 2 | 0.4 | 0.2 |
| Heteromastus filiformis | Po | 0.11 | | | | | | | 0.1 | | 6.1 | |
| Heteropodarke heteromorpha | Po | 0.01 | | | | | | | | 5.5 | | |
| Gemma gemma | Pe | 0.04 | | | | | | | | 8 | | |
| Glycera americana | Po | 0.05 | | | | | | | | 0.8 | | 0.3 |
| Balanus spp. | в | 0.03 | | | | | - | | | | 0.2 | 0.4 |
| Eusarsiella zostericola | Po | 0.21 | | | | | 0.1 | | 0.2 | | 3.5 | 1.2 |
| Aphelochaeta spp. | Po | 0.06 | | | | | | | | | 1.1 | 0.4 |
| Heteromastus spp. | Po | 0.11 | | | | | 0.1 | | | 15.3 | 8.2 | - |
| Tapes japonica | Pe | 0.17 | | | | | | | | | 6.3 | 2.7 |
| Ampelisca abdita | A | 0.31 | | | | | 0.6 | 0.1 | 26.5 | 2.5 | 1.7 | 613 |
| Musculista senhousia | Pe | 0.20 | | | | | | | 0.4 | | 0.2 | 5.3 |
| Corophium heteroceratum | A | 0.22 | | | | | | 0.1 | 1.2 | | 0.8 | 113.8 |
| Glycinde polygnatha | Po | 0.14 | | | | | 0.1 | | | - | 0.4 | 4.5 |
| Mediomastus spp. | Po | 0.13 | | | | | 0.2 | | | | | 64.1 |
| Dorvillea rudolphi | Po | 0.11 | | | | | | | | | | 2.3 |
| Euchone limnicola | Po | 0.11 | | | | | | | | 0.3 | | 127.2 |
| Leptochelia dubia | Tn | 0.09 | | | | | | | | | | 26 |
| MEAN NO. OF SPECIES PER SAMPLE | | | 23 | 16 | 4 | 14 | 80 | 6 | 16 | 80 | 19 | 55 |
| MEAN NO. OF INDIVIDUALS PER SAMPLE | | | 861 | 275 | 8 | 308 | 33 | 337 | 591 | 53 | 903 | 1171 |
| | | | | | | | | | | | | |






Figure 3. Plots of numbers of species, numbers of individuals, and biomass per sample at each station sampled during the wet (February) and dry (August/September) sampling periods in 1994. Biomass was not measured at the DWR stations. The stations are arranged with the South Bay stations at the left, through the Estuary to the Delta stations at the right.

Table 3. Percentages of total biomass (wet grams) contributed by major taxa at each station. Biomass was not measured at the DWR stations.

| Station name | Station code | n code Crustacea | | Mol | Mollusca | | Polychaeta | | Others | |
|--------------------|--------------|------------------|---------|------|----------|------|------------|----------|---------------------|--|
| | _ | Feb | Aug/Sep | Feb | Aug/Sep | Feb | Aug/Sep | Feb | Aug/Sep | |
| South Bay | BA21 | 0.2 | 0.7 | 99.6 | 98.9 | 0.2 | 0.4 | | 0.0 | |
| Redwood Creek | BA41 | 0.1 | 4.0 | 33.7 | 43.7 | 62.1 | 33.8 | 4.1 | 18.5 | |
| San Bruno Shoal | BB15 | 0.7 | 0.9 | 91.8 | 24.2 | 6.0 | 20.7 | 1.4 | 54.2 ⁽¹⁾ | |
| Alameda | BB70 | 37.5 | 61.2 | 21.4 | 5.6 | 25.8 | 23.5 | 15.2 | 9.8 | |
| Yerba Buena Island | BC11 | 21.7 | 6.1 | 21.5 | 10.8 | 29.8 | 40.8 | 27.0 | 42.3 | |
| Horshoe Bay | BC21 | 5.4 | 6.3 | 3.4 | 7.8 | 37.2 | 81.2 | 54.0 (2) | 4.7 | |
| Red Rock | BC60 | 4.8 | 0.0 | 81.0 | | 9.5 | 94.7 | 4.8 | 5.3 | |
| Davis Point | BD41 | 0.2 | 0.6 | 99.7 | 31.0 | 0.0 | 0.0 | 0.0 | 68.4 ⁽¹⁾ | |
| CCCSD01 | CCCSD01 | | 38.5 | | 59.7 | | 1.8 | | - | |
| CCCSD02 | CCCSD02 | | 1.3 | | 98.0 | | 0.7 | | - | |
| CCCSD03 | CCCSD03 | | 77.8 | | 11.1 | | 11.1 | | - | |
| CCSF01 | CCSF01 | | 58.7 | | 18.5 | | 13.1 | | 9.7 | |
| CCSF02 | CCSF02 | | 72.1 | | 5.4 | | 10.2 | | 12.4 | |
| CCSF03 | CCSF03 | | 78.2 | | 10.7 | | 3.8 | | 7.3 | |
| EBMUD01 | EBMUD01 | | 25.5 | | 10.1 | | 55.6 | | 8.8 | |
| EBMUD02 | EBMUD02 | | 20.5 | | 1.1 | | 44.5 | | 33.9 | |
| EBMUD03 | EBMUD03 | | 32.1 | | 8.0 | | 57.8 | | 2.1 | |
| Paradise Cove | SF01 | | 52.2 | | 0.0 | | 28.2 | | 19.6 | |
| San Pablo Island | SF02 | | 0.4 | | 98.2 | | 1.4 | | - | |
| Tubbs Island | SF03 | | 0.0 | | 80.0 | | 20.0 | | 0.0 | |

other Delta stations sampled in all months. Wet season samples from D11 were classified in Group 3 with the Sacramento River samples from all months. There were no other obvious seasonal differences in species composition among the stations within each Group. Significant monthly or seasonal changes in species composition or abundances at a station would have resulted in separate classification groupings such as observed in Group 1b.

Diversity and Biomass. Over 309 species representing mainly mollusks, annelids, and crustaceans composed most of the macrobenthos in the San Francisco Estuary and Delta in 1994. The average number of species and individuals per sample was highest at the Group 9 stations in Central Bay (Table 2). The numbers of species and individuals at the CCSF and EBMUD outfall stations were among the highest in the Estuary (Figure 3). Those parameters decreased at stations to the south and to the

north into Suisun Bay. Stations with the sandiest sediments (Red Rock, BC60; Sacramento River central channel, D4C) generally had the fewest species and individuals, reflecting the dynamic, non-depositional nature of coarse sediment habitats. However, most of the other stations in San Pablo and Suisun Bays also had low diversity. The CCCSD outfall station had reduced abundances compared to the Grizzly Bay station (D7). Numbers of species and individuals at the fine sediment Delta and River confluence stations (Groups 1, 3) were slightly greater than those at the Suisun Bay stations.

Total biomass was highest at the South Bay (BA21) and Davis Point (BC41) stations (Group 8) due to the large numbers of *P. amurensis* collected at those stations (Figure 3). Biomass at the remaining stations was mostly below 5 wet grams per sample. Biomass was not measured at the DWR stations. Biomass was dominated by different kinds of animals at the stations sampled







Figure 4. Plots of numbers of amphipod species and individuals, and abundances of *Ampelisca abdita* per sample during the wet (February) and dry (August/September) sampling periods in **1994.** The stations are arranged with the South Bay stations at the left, through the Estuary to the Delta stations at the right.

(Table 3). Mollusks (usually *P. amurensis*) dominated biomass at South Bay, and at one sampling period or the other at most other RMP stations. Crustacea dominated the biomass at Alameda (BC60), CCSF, and Paradise Cove (SF01). Polychaetes dominated at Yerba Buena Island (BC11) and EBMUD. Tunicates dominated at San Bruno Shoal (BB15) and Davis Pt. in August, and Bryozoa dominated at Horseshoe Bay (BC21)in February.

Seasonal differences in numbers of species, individuals, and biomass were obvious at many of the stations sampled in both the wet sampling period (February) and the dry sampling period (August / September). Numbers of individuals and biomass generally had greater seasonal differences than numbers of species. There was no consistent trend whether one season was higher than the other. For example, seasonal differences in abundances of *P. amurensis* at BA21 and BD41 occurred in opposite sampling periods.

Indicator Species. Several benthic taxa or species may be considered "indicators" of contaminated sediments because of their decreased abundances near contaminant sources, or known sensitivity to contaminated sediments.

Amphipod crustaceans have been used as indicators of sediment contamination in several previous studies (Sanders *et al.*1980; Long and Chapman 1985). They are commonly used in laboratory sediment bioassays. However, *Eohaustorius estuarius* used in the RMP sediment bioassays was not collected in any of the 1994 samples.

Amphipods usually inhabit a small tube in, or on the sediment. Some species may emerge into the water column related to light or salinity and are a favorite food of most estuarine fish. Amphipods were among the most abundant species in all of the benthic assemblages described, except at Red Rock (BC60). However, different amphipod species occurred in each assemblage. Numbers of amphipod species and abundances at each station appeared to reflect salinity and sediment type. There were more amphipod species and higher abundances at the Central Bay stations (Group 9) including the CCSF and EBMUD outfall stations than at the other stations sampled (Figure 4). Numbers of amphipod species and abundances were lowest at the coarse sediment stations (BC60), and were generally lower at the northern Estuary, river confluence, and Delta stations than in the Central Bay. In a previous study, amphipod abundances were reduced at contaminated sites in the Lauritzen Canal in Richmond Harbor, and their abundances were correlated with elevated sediment toxicity (Swartz *et al.*1994).

The amphipod *Ampelisca abdita* was the most abundant species collected in the saline reaches of the Estuary in 1994. Their abundances decreased with salinity, and they were not collected in samples from the Delta or River confluence. They occurred in 80% of the samples in Groups 4 - 9. However, none were collected from the sandy sediment at Red Rock (BC60). They were the most abundant species, dominating samples from San Pablo Bay (D41A), CCSF, EBMUD, Alameda (BB70), and Yerba Buena Island (BC11). Densities up to 64,360 m⁻² were reported at the EBMUD outfall stations. Their abundances were quite variable at the Central Bay stations and seasonal at Alameda (BB70).

Abundances of *A. abdita* near the Central Bay outfall stations were much higher than at the Central Bay nonoutfall stations sampled at the same time. Densities at CCSF averaged 15,600 m⁻² and at EBMUD averaged 39,347 m⁻², compared to average densities of 4,901 m⁻² at the Group 9 non-outfall stations sampled at the same time. Densities near the CCCSD outfall averaged 11.3 m⁻² compared to 19 m⁻² at station D7.

Ampelisca abdita is widely used in laboratory sediment bioassays, with well developed protocols. The RMP began development of a sublethal bioassays protocol for this species (see Sediment Toxicity Special Study). Information about its growth, mortality, and reproduction from both laboratory and field studies should provide a powerful tool in attempting to understand this species responses to contaminated sediments

The small polychaete *Capitella "capitata"* (possibly a suite of closely related species) is a cosmopolitan indicator of contamination and organic enrichment (e.g. Reish 1957). Off southern California they are always most abundant in a "contaminated" zone around sewage outfalls (B. Thompson 1982). However, in the San Francisco Estuary, they appear to have a wider distribution occurring at many apparently uncontaminated sites, often in densities exceeding 10,000 m^{-2} (Hopkins 1986). In 1994, they were collected at Red Rock (BC60) and at several non-outfall Central Bay stations.

Densities near the Central Bay outfall stations were higher than at the non-outfall stations. At EBMUD densities averaged 155.3 m⁻², and at CCSF they averaged 11.3 m⁻². Densities at the Group 9 non-outfall sites sampled at the same time averaged 7.8 m⁻². None were collected at CCCSD in Suisun Bay probably because of the reduced salinities there.

The Asian clam Potamocorbula amurensis has received considerable attention since its introduction to the Estuary in 1986 (Carlton et al. 1990). They were collected at 57% of the stations sampled in 1994 and were components of all of the benthic assemblages described except for the Group 1 stations in the Delta (Table 2). They were most abundant at the Group 8 stations with the highest abundances collected at the South Bay (BA21) in February, where 29,880 m⁻² were collected. The DWR has conducted intensive studies of the distribution and abundances of this clam between San Pablo Bay and the Delta; their reports are in preparation. This species was collected from stations near all three of the outfalls sampled. Densities at EBMUD averaged 4.7 m⁻² and densities at CCSF averaged 31 m⁻² compared to an average of 18.9 m⁻² at the other Group 9 non-outfall stations sampled at the same time. In Suisun Bay, densities at CCCSD averaged 131 m⁻², while none were collected at the Grizzly Bay station (D7) sampled in August.

Potamocorbula amurensis accumulated PAHs to concentrations one-to-two orders of magnitude higher than in their surrounding sediments (Pereira *et al.* 1992). These clams are currently the focus of intensive research by the USGS in Menlo Park, to determine whether exposure to contamination causes biological effects. Their results will facilitate decisions about their future use as an indicator of contaminant effects in the Estuary.

The freshwater clam *Corbicula fluminea* is resident in the fresh- and brackish water habitats of the region. They were most abundant at the Delta (Group 1) stations averaging around 55 m⁻². They also occurred at the Sacramento River and Sherman Is. stations, but were not collected at the saline Estuary stations. Clams transplanted from Lake Isabella are currently used by RMP in bioaccumulation testing. However, as a resident of the region, their use as an indicator could be broadened to include use as an ecological indicator of a variety of effects, including contamination and reductions in flow, etc. A considerable amount is already known about their ecology, including how and where to collect them (e.g. Foe and Knight 1986).

Discussion and Conclusions

This report has described macrobenthic species composition, abundances, and biomass of nine assemblages from the Delta and Estuary in 1994. These assemblages probably represent samples from dynamically changing groups of species in space and time, rather than discrete animal communities. Additionally, other assemblages probably exist that were not sampled.

The Regional Board's proposed reference station at Paradise Cove (SF01) clustered with other RMP Central Bay stations, indicating similar macrobenthic species composition and abundances. However, the San Pablo Bay reference stations (SF02, SF03) clustered with Red Rock, a unique station. Therefore, they may not represent common, or large-scale assemblages.

The benthic assemblages described in this report represent post-P. amurensis assemblages. Prior to the invasion of P. amurensis, there was no evidence of long term changes in species composition in the benthos of San Francisco Estuary (Nichols 1979). However, two years after P. amurensis was found in Grizzly Bay, decreases in numbers of species and individuals, particularly resident bivalves were reported there, along with large increases in P. amurensis abundances (Nichols et al. 1990). Changes in species composition in other Estuary benthic assemblages following the invasion of P. amurensis have not been well studied. Except for the dominance of P. amurensis at many stations, the general patterns of species composition, diversity, and biomass reported in this paper are similar to the pre-P. amurensis patterns described by Nichols and Pamatmat (1988). Further study is needed to determine exactly how the benthos of the Estuary have responded to the invasion of P. amurensis nine years ago.

Previous analyses showed that many benthic populations exhibit fluctuations in abundances over various time scales (Nichols and J. Thompson 1985; Hymanson *et al.* 1993). Seasonal differences in 1994 were observed in abundances and biomass at most stations, while numbers of species did not change appreciably among the months or seasons sampled. Seasonal changes in species composition was only observed at some of the Delta and River stations.

The species that compose macrobenthic assemblages may respond to a variety of environmental factors including salinity, sediment type, and contaminant concentrations. Previous analyses concluded that the strongest environmental factor affecting the benthos in the Estuary is temporal variation in salinity (Nichols and J. Thompson 1988; Hymanson *et al.* 1993). The assemblages identified in this report appear to change along a salinity gradient extending from the Delta and Rivers through the northern Estuary into Central Bay. A shorter gradient exists from South Bay to the Golden Gate. Group 8 contained stations approximately equidistant to the north and south of the Golden Gate. Presumably these stations had similar sediment and salinity regimes, thus supporting similar assemblages.

In terms of responses to sediment contamination, there was no apparent difference in benthic assemblage species composition near the CCSF and EBMUD sewage outfalls and other non-outfall stations in the Central Bay. This conclusion is supported by the presence of taxa known to be sensitive to contaminated sediments, such as amphipods and ophiuroids, at all Central Bay stations including the CCSF and EBMUD stations. However, Capitella "capitata", a well known indicator of contaminated sediments was present at the outfall stations in elevated concentrations compared to non-outfall stations. Mean densities, numbers of amphipod species and amphipod densities at the EBMUD stations, were significantly higher than at non-outfall stations in the same classification group (see LEM / RMP Pilot Study). Elevated numbers of species and individuals often occur at moderately contaminated sites, probably due to the increased organic material in sediment. However, these increases are usually accompanied by changes in species composition (Pearson and Rosenberg 1978; Smith et al. 1985).

The CCCSD outfall stations formed a separate grouping (Group 4) suggesting the benthos at those stations form a distinct assemblage. However, those stations generally had species composition similar to station D7 in Grizzly Bay, but densities at CCCSD were about an order-of- magnitude lower than at D7. No indicator species commonly associated with degraded conditions were collected near CCCSD.

The stations sampled near the three outfalls ranged between 15 and 30 m from the outfall at CCCSD and CCSF, and between 100 and 270 m at EBMUD. Based on the data summarized in this report, the benthic assemblages near the outfalls did not appear to be impacted by sediment contamination. This conclusion is supported by similarities in sediment contamination data (see LEM / RMP Pilot Study) and by sediment bioassays using *A. abdita* (see Sediment Toxicity Special Study).

Benthic assemblages from impacted areas in the Estuary were sampled by Chapman *et al.* (1987). Their stations were located within the Islais Creek Channel and contained elevated contaminants, as well as sulfide and TOC, from several possible sources. The benthos there was dominated by *C. capitata*, with very low abundances of *A. abdita*. There were low numbers of species and individuals. These patterns are typical of contaminant impacted locations throughout the world. Other contaminant impacted stations in the Estuary would be expected to have similar benthic assemblage structure.

The two stations sampled in Suisun Bay (D7, CCCSD) include species characteristic of both freshwater and estuarine assemblages. These assemblages also had low diversity (numbers of species and individuals) compared to the other assemblages, except for the coarse sediment stations. Suisun Bay encompasses the entrapment zone which is characterized by changes in salinity related to Delta outflow and tidal action, as well as elevated turbidity. It is not known whether these factors limit the diversity of these assemblages or whether other factors may be responsible. As shown in the Sediment Monitoring section of this report, contaminant concentrations were often elevated in this portion of the Estuary. However, the relationships between the benthos and environmental parameters have not been rigorously analyzed.

The Sacramento River and Suisun Bay are subjected to pulses of pesticides from agricultural applications in

the Central Valley (Kuivila and Foe 1995). Concentrations of diazinon in these pulses ranged up to 122 ng l⁻¹ in Suisun Bay, exceeding some of the known lethal concentrations (e.g. 96 hour LC_{50} for crustaceans range between 30 and 210 ng l⁻¹) for up to 4 days. The benthos of these areas are inhabited by up to ten species of crustaceans susceptible to these pesticides. The data presented in Figure 4 showed that the number of amphipod species and abundances at the Sacramento River (D4) and Suisun Bay (D7, CCCSD) were among the lowest in the Estuary. Further study is necessary to determine whether the pesticide pulses and reduced benthic diversity in Suisun Bay are related.

The assemblage patterns reported in this summary should be considered preliminary as they are based on only one year of data. If the assemblages described in this report prove to be persistent and typical of the habitats from which they were collected (e.g. estuarine coarse, and fine sediments, reflective of salinity gradients) then they may be used as "baseline" assemblages for comparison to future measurements, or for determining similarity to assemblages at suspected impacted stations.

Currently, the RMP, DWR and USGS sample benthos in various parts of the Estuary, but no regular Estuary-wide benthic monitoring is conducted. The establishment of a collaborative Estuary-wide benthic sampling program will provide the ability to track these assemblages over time, to observe how, or if they change in species composition or abundances, correlated with environmental stressors, such as fresh water flow or contamination. Such a program will provide much of the data necessary to understand the sources of variability in the benthos and how they may be used as indicators of the Estuary's condition.

Acknowledgments

Mr. Harlan Proctor (Environmental Services, DWR), and Ms. Arleen Navarret (Biology Laboratory, City and County of San Francisco) coordinated their respective agency's participation in this study. The taxonomists who identified the specimens were Mr. Wayne Fields (Hydrozoology, Sacramento) for the DWR material, and Michael Kellogg, Kathy Langan-Cranford, Patricia McGregor, and Brian Sak (City and County of San Francisco) for the remaining samples. Dr. Bob Smith and Ms. Laura Riege (EcoAnalysis, Inc., Ojai) conducted the classification and ordination analysis and provided discussions on interpretation. Ms. Sarah Lowe and Mr. John Haskins (SFEI) assisted with data and reporting.

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Statistical Comparison of Data from the Local Effects Monitoring Program and the RMP

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Introduction

The Bay Area Dischargers Association (BADA), which represents a group of municipal wastewater treatment facilities that discharge to San Francisco Bay, has monitored bioaccumulation of contaminants near selected BADA outfalls since 1991 (SFEI, 1995). This work has been conducted under the Local Effects Monitoring Program (LEMP). The objective of the LEMP has been to determine if the BADA outfalls are point sources of bioaccumulative pollutants.

In 1994, as a RMP Pilot Study, monitoring near the outfalls was expanded to include sediment chemistry and benthic community composition. The objective of this study is to determine whether locations near selected BADA outfalls exhibit adversely impacted benthic communities or high contaminant concentrations in transplanted bivalves or sediment relative to data from RMP stations. This study demonstrates how RMP data can be employed as a frame of reference for LEMP data.

In studies comparing impacted locations with one or more reference locations one-way ANOVA (or a ttest, the equivalent of one-way ANOVA comparing two means) is often employed to compare outfall and reference locations. In this approach, replicates (referred to as "sites" in this study) at the outfall and reference locations are used to characterize the variance and distribution of values at each location. The mean and variance of the outfall location is then compared to the mean and variance of the reference location or locations to determine statistical significance.

A recent review concluded that application of the ANOVA approach to compare an outfall location with a reference location or locations is inappropriate because the ANOVA model ignores broader-scale variation in space and time among the reference locations (Smith 1995). Application of ANOVA to this problem is an example of "pseudoreplication". In the context of ANOVA, pseudoreplication is formally defined as the testing for treatment effects with an error term inappropriate to the hypothesis being considered (Hurlbert 1984). In the ANOVA model the error term of the test is based on variance among replicates over small spatial scales. Since the outfall location and reference locations are separated by much larger distances, this test would be likely to detect apparent impacts that are actually due to variation over broader spatial scales. The error term in the ANOVA model contains no information

| EBMUD and | Mussels | BA30, BA40, BB71, BC10, BC21, | 5/94, 9/94 |
|-----------|----------|------------------------------------|------------------------|
| CCSF | | BC60, BD15, BD30 | |
| | Sediment | BB70, BC21, BC31, BC41, SF01 | 2/94, 8/94 |
| | Benthos | BB70, BC21, SF01 | 2/94, 8/94 |
| CCCSD | Oysters | BA10, BD15, BD20, BD40, BD50, BF20 | 5/94, 9/94 |
| | Sediment | BD41, BF10 | 3/93, 9/93, 2/94, 8/94 |
| | Benthos | BD41, D07 | 2/94, 8/94, 9/94 |

Table 1. Stations included in the development of reference distributions for the various indicators.

on the background variability over the broader spatial scale. One of the properties of a pseudoreplicated statistical test comparing two locations is that differences will be detected, regardless of the presence of outfall influence, if the number of replicates is increased sufficiently. This is because the variance of the means being compared (S^2/n) will approach zero as n increases. As the variance of the means approaches zero, smaller and smaller differences among means will be detected, whether or not the differences are large enough to have any ecological significance.

Smith (1995) describes alternative approaches to this problem that avoid pseudoreplication by including broader scale spatial and temporal variance components in the model. These alternative techniques are based upon comparison of impacted locations with multiple reference locations instead of single reference locations. In the San Francisco Estuary, the RMP provides a body of high quality data on background conditions in the Estuary that makes it possible to apply Smith's approach to the LEMP data. This section presents a screening-level application of one of the tests described by Smith to compare the outfall location observations with percentiles of reference station distributions obtained from RMP data.

Methods

Sampling of bioaccumulation in transplanted bivalves, sediment chemistry, and benthic community structure was performed near three outfalls for comparison with results from RMP stations (Figure 1). Methods used to generate RMP data are described elsewhere in this report under "Methods of Sampling and Analysis".

Methods used to deploy transplanted bivalves and collect sediments for chemical and biological analysis were similar to methods used in the RMP (see "Methods of Sampling and Analysis"). Mussels were deployed near the East Bay Municipal Utility District (EBMUD) and City and County of San Francisco (CCSF) outfalls and oysters near the Central Contra Costa Sanitation District (CCCSD) outfall. Trace organics and trace elements in sediments and bivalves were analyzed by EBMUD, CCSF, and California Department of Fish and Game laboratories. Benthic organisms were processed in the



Figure 1. Locations of LEMP outfalls.

same manner described for the RMP (see Benthic Pilot Study).

The statistical method employed for comparison of outfall stations with RMP stations was described by Smith (1995). A "tolerance interval" method was employed to establish a statistical interval which would be expected to include the values obtained from locations near the outfalls if the near-outfall locations were not significantly different from the RMP stations. The width of the interval is dependent on the variance of the reference location means, a (=0.05 in this study), and the percentile (e.g., 90th or 95th) chosen for the boundary of the interval. The statistical intervals derived in this manner are also known as "reference envelopes".

This section presents a screening level application of a tolerance interval approach. Application of this approach is valid if several conditions are met. Among these conditions are normal distributions, effectively random sampling of reference stations, and equal replication and replicate variance at all stations. Since demonstration that these conditions have been satisfied would require a level of effort beyond the scope of this study, a screening-level analysis is presented based on the assumption that they are met.

Different subsets of RMP stations and stations from other Bay programs were used to develop reference envelopes for different parameters. For bivalves, all RMP stations with the same species deployed were used. For sediment and benthos, stations with similar grain size within the same reach of the Estuary were used. Since mussels were used at both CCSF and EBMUD and sediment characteristics were similar at these outfalls, the same reference envelopes applied to both.

While the multiple sites sampled at each outfall were intended to be replicates of a single location, the large ranges observed among them (Figures 2-5) indicate that they were not truly replicates. If they are not true replicates, then it is inappropriate to compare the mean of these observations to the RMP reference envelope; it is more appropriate to compare them individually to the RMP reference envelope. For this reason, each outfall site was compared individually with its respective RMP reference envelopes.

For comparison of LEMP and RMP data for total PAHs and total PCBs only those chemicals that were common to both datasets were used to calculate totals.

Results

Transplanted Bivalves

Of the three techniques employed to measure the influence of outfalls, contaminant accumulation in transplanted bivalves provided the most sensitive and consistent index. Concentrations of many contaminants in bivalves exceeded or approached the upper boundary of the reference envelope, including both trace elements and trace organics. Variation among replicates at each outfall was low relative to the variation observed in the sediment chemistry and benthic community data at the outfall locations.

In general, the same contaminants were found at high concentrations in bivalves at both the EBMUD and CCSF locations. PAHs were the only exception, which were elevated at CCSF but not at EBMUD. A similar suite of contaminants was found in high concentrations at the CCCSD outfall.

Figure 2 illustrates findings for eight contaminants with high concentrations in mussels deployed near the EBMUD and CCSF outfalls. For three contaminants (Ag, Hg, and o,p'-DDE), comparison of LEM data with RMP data is constrained by the high limits of detection (LOD) in the LEM relative to the LOD attained by the RMP contractors. Results for the other five contaminants (As, Cd, Cu, Se, and total PAHs) were all above the LOD. In some cases (Cu, Hg, and total PAHs) the presence of an outlier in the RMP data had a significant effect on the magnitude of the upper boundary of the reference envelope. For the screening-level analysis presented here these values were excluded from the reference distribution. Pb concentrations at EBMUD and CCSF also approached, but did not exceed, the upper boundary of the reference envelope. Concentrations of Ag, Hg, Se, total PAHs, and o,p'-DDE exceeded the 95th percentile of their respective reference distribution at one or more sites. As, Cd, and Cu concentrations exceeded the 90th percentile of the reference distribution at one or more sites.

The presence of high concentrations of the six trace elements found near the treatment plant outfalls is consistent with previous studies that have shown EBMUD and CCSF to be sources of these elements to the Estuary (Davis *et al.* 1991). Prior studies have also documented PAH contamination at Islais Creek, near the CCSF outfall (reviewed by Phillips 1987). The presence of a formerly heavily used container shipping port and creosote coated pilings near the outfall provide possible explanations for the source of PAHs near the CCSF outfall. Multivariate analysis of the PAH profiles at LEMP and RMP sites, which will be conducted in 1996, may help establish the source of this PAH contamination.

The detection of elevated concentrations of o,p'-DDE near both outfalls is interesting. o,p'-DDE is a relative of p,p'-DDT that is usually a minor component of DDT mixtures in environmental samples. o,p'-DDE was also relatively abundant in oysters near the CCCSD outfall (see below). It is not clear why the relative abundance of o,p'-DDE might be greater in treatment plant effluents. Concentrations of this compound were near the limits of detection for the LEM samples, suggesting that methodological differences may have a role in explaining these observations.



Figure 2. Comparison of LEMP outfall mussel bioaccumulation data with distributions of RMP data. Results for each individual site indicated as follows: E=EBMUD, S=CCSF. Six sites were sampled at each outfall (three each in January and June). Boxplots show median (vertical line in box), 25th/75th percentiles (sides of box), and 10th/90th percentiles (bars) of the RMP reference distribution. RE90 and RE95 are the reference envelope boundaries for the 90th and 95th percentiles, respectively, of the reference distribution.

Figure 3 illustrates findings for the eight contaminants with high concentrations in oysters deployed near the CCCSD outfall. Pb concentrations were near the LOD and could not be precisely compared to the RMP reference distribution. All results for the seven other contaminants (Ag, As, Cd, Cu, Hg, Zn, and o,p'-DDE) were above the LOD. For both Zn and o,p'-DDE one outlier in the RMP data was excluded from the reference distribution. Se concentrations at CCCSD also approached, but did not exceed, the upper boundary of the reference envelope. Concentrations of Ag, Cu, Pb, Hg, Zn, and o,p'-DDE exceeded the 95th percentile of their respective reference distribution at one or more sites. As and Cd concentrations exceeded the 90th percentile at one site each.

In addition to the elements associated with the EBMUD and CCSF outfalls, high concentrations of Pb and Zn were observed at the CCCSD outfall. These



Figure 3. Comparison of LEM outfall oyster bioaccumulation data with distributions of RMP data. Results for each individual site indicated as with "C" symbol. Six sites were sampled (three each in January and June). Boxplots show median (vertical line in box), 25th/75th percentiles (sides of box), and 10th/90th percentiles (bars) of the RMP reference distribution. RE90 and RE95 are the reference envelope boundaries for the 90th and 95th percentiles, respectively, of the reference distribution.

elements are also commonly found in Bay Area municipal effluents (Davis *et al.* 1991). The presence of o,p'-DDE at all three outfalls included in this study was discussed previously.

In addition to exceeding reference envelope boundaries, which indicates that concentrations near outfalls are high in relation to RMP stations, concentrations of As, Cd, Cu, Se, Zn, and total PAHs also exceeded median international standards (MISs) or Maximum Tissue Residue Levels (MTRLs) (MISs and MTRLs are described in the Bivalve Bioaccumulation and Condition section) in at least one bivalve sample (Figures 2 and 3). As is apparent in Figures 2 and 3, RMP observations were also frequently higher than their relevant MISs and MTRLs.



Figure 4. Comparison of LEM outfall sediment contamination data with distributions of RMP data. Results for each individual site indicated as follows: E=EBMUD, S=CCSF. Three sites were sampled at each outfall in September. Boxplots show median (vertical line in box), 25th/75th percentiles (sides of box), and 10th/90th percentiles (bars) of the RMP reference distribution. RE90 and RE95 are the reference envelope boundaries for the 90th and 95th percentiles, respectively, of the reference distribution.

Sediment

Fewer contaminants were found outside their respective reference envelopes in sediment. In addition, variation among replicate samples for the organics was extreme. In spite of these shortcomings, the sediment data do provide additional support for some of the findings with transplanted bivalves. Several contaminants identified at high concentrations in bivalves were also elevated in sediment. Various trace elements were abundant at each outfall, and PAHs were high near CCSF. In addition, one site near EBMUD had significantly elevated concentrations of PCBs relative to the RMP reference envelope. In contrast to the bivalve data, the contaminants present in high concentrations in sediment differed between the two outfalls.

Figure 4 illustrates findings for the four contaminants in sediment at EBMUD and CCSF with individual observations exceeding the reference envelope. Hg and total PAH values were outside the reference envelope at the CCSF outfall. Pb and total PCB values were elevated at the EBMUD outfall. Ag



Figure 5. Comparison of LEM outfall sediment contamination data with distributions of RMP data. Individual sites at CCCSD outfall indicated with "C" symbol. Two sites were sampled in September. Boxplots show median (vertical line in box), 25th/75th percentiles (sides of box), and 10th/90th percentiles (bars) of the RMP reference distribution. RE90 and RE95 are the reference envelope boundaries for the 90th and 95th percentiles, respectively, of the reference distribution.

and Cd were close to the upper boundary of the reference envelope at the CCSF outfall. Proximity of the LEM data to the LOD posed a problem for Ag, Cd, and PCBs. All results for Hg, Pb, and total PAH were above the LOD. Concentrations of Hg, Pb, total PAHs, and total PCBs were higher than the 95th percentile of their respective reference distribution at one or more sites.

Elevated PAH concentrations in sediment at CCSF were consistent with the high concentrations in mussels. Relative to the typical RMP PAH profile, phenanthrene and fluoranthene were greatly elevated in the most highly contaminated sediment. Sediment PAH data will be included in the multivariate analysis to be conducted in 1996, as mentioned above, that may shed light on the source of PAH contamination near the CCSF outfall.

PCB residues in sediment near the EBMUD outfall were extremely heterogeneous. One of the outfall sites had 96 ppb total PCB (calculated using an abbreviated list of congeners analyzed in both the LEM and RMP), a concentration higher than any sediment sample measured in the RMP in 1994. In contrast, no PCBs were detected in sediment from the two other outfall sites. A relatively large proportion of PCB 180 in this sample (29 ppb) was probably partially due to an unknown interference. Other congeners in this sample, however, showed a consistent pattern of contamination. PCB 153, for example, which has appeared to be free of interferences in RMP data, was measured at 11 ppb, a concentration that greatly exceeds the 95th percentile of the PCB 153 reference distribution (4.3 ppb).

Individual concentrations of three contaminants (Ag, As, and Cd) in sediment at CCCSD exceeded the upper boundary of the reference envelope (Figure 5). Ag and Cd were higher than the 95th percentile of the reference distribution at one site each. Arsenic was higher than the 90th percentile at one site. All results for each of these elements were above the LOD. These three elements were also above or near the 90th percentile of their reference distributions in oysters at CCCSD.

In addition to exceeding reference envelope boundaries, which indicates that concentrations near outfalls are high in relation to RMP stations, sediment concentrations of As, Hg, Pb, total PAHs, and total PCBs were also above ERLs (described in the Sediment Monitoring section) in at least one sediment sample (Figures 4 and 5). ERLs are concentrations at which biological effects due to sediment contamination are possible. In one sample (at CCSF) Hg exceeded the ERM, indicating that biological effects are probable at this site.

Benthos

Comparison of several selected benthic community parameters measured near the outfalls did not reveal any adverse impacts related to proximity to the outfalls. In

| Site | Number of Species | Average Number of Individuals | Average Biomass | Number of Amphipod Species | Average Number of Amphipod Individuals | Average Number of <i>Ampelisca</i> |
|---------|-------------------------|-------------------------------------|--------------------|----------------------------------|---|--|
| CCSF01 | 62 | 844 | 1.8 | 7 | 622 | 148 |
| CCSE02 | 80 | 2443 | 3.3 | 11 | 2131 | 1892 |
| CCSE03 | 66 | 1082 | 23 | 8 | 897 | 300 |
| | 100 | 1002 | 2.0 | 10 | 007 | 0040 |
| EBMODU | 100 | 4866 | 5.0 | 16 | 3402 | 3218 |
| EBMUD02 | 78 | 2448 | 3.7 | 13 | 1651 | 1524 |
| EBMUD03 | 91 | 2574 | 3.7 | 21 | 1781 | 1160 |

| Table 2. | Benthic community data in each sample from EBMUD and CCSF outfall sites. | Samples |
|----------|--|---------|
| | were collected in September 1994. | |

fact, at EBMUD and CCSF conditions appeared to be enhanced relative to comparable RMP stations. Since it is inappropriate to apply the one-tailed tolerance interval employed in this study to both the upper and lower boundary of a reference envelope, these high values were not compared statistically to their RMP reference distributions.

In general, reference distributions for the benthic community parameters were poorly characterized. One reason for this is that there are few RMP stations with similar habitat characteristics that are suitable for comparison to the outfall stations. A second reason is that variability of the benthic community parameters is high even among stations with similar habitat characteristics.

At EBMUD, all three locations had high individual values of two or more community parameters (Table 2). At CCSF, one location had high values of three parameters. None of the parameters at CCCSD were unusually high. The cause of the enhanced conditions near EBMUD and CCSF is not clear (see discussion in Benthic Pilot Study).

Conclusions

This analysis demonstrates that the comparison of outfall locations with RMP locations using the reference envelope approach is sensitive enough to detect the influence of the outfalls. The relatively high precision of the RMP data is essential to making this approach viable. Transplanted bivalves at each outfall accumulated high concentrations of many contaminants. Fewer contaminants were identified at high concentrations in sediment. Adverse effects of the outfalls on benthos were not detected; instead, communities near the outfalls were found to be unusually diverse and abundant.

The main problem encountered in this analysis was the substantially greater variance observed in LEMP data relative to RMP data. To a certain extent higher variance would be anticipated at outfalls due to the relatively steep gradients in concentrations that would be expected to occur there. However, another factor contributing to the high LEMP variance in many cases were relatively high LODs which resulted in data that were either censored or imprecise relative to RMP data. In several cases data from the small number of samples near outfalls had a broader range than the entire RMP reference distribution. Application of methods with lower LODs at the outfalls would allow a much clearer assessment of outfall influence.

The existence of considerable heterogeneity over the spatial scales sampled near outfalls probably also contributed to the large variances of the outfall data. This observation indicates that near-outfall sites must be carefully selected if they are to be considered true replicates. Finer scale sampling of gradients near outfalls may be helpful in establishing whether some of the observed patterns are actually due to the influence of wastewater. An additional problem encountered was a shortage of suitable reference locations for comparison of sediment and benthic community parameters at CCCSD.

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Choosing Optimum Station Configurations for Summarizing Water Quality Characteristics

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Introduction

One of the central problems in regional monitoring is choosing a station array that accurately reflects the distribution of values for the entire region of interest. For time-consuming or expensive measurements, an additional goal is to make the number of sampling locations and times as small as possible. These problems are probably most difficult in estuaries because of the relatively large variability on many different spatial and temporal scales. This high variability often means that comprehensive historical data are not available for accurately assessing sparser sampling efforts. It also implies that a higher frequency of sampling in space and time is required compared to other water bodies.

In this report, we focus on selection of an "optimum" station configuration for the channel of San Francisco Bay for vertical profiling of water quality. Our analysis is based on the monthly cruises conducted by the USGS under the auspices of the Regional Monitoring Program for Trace Substances (Caffrey et al. 1994; SFEI 1994). The underlying rationale for undertaking the analysis is that the distribution of trace substances is structured, at least in part, by the same forces acting on water quality parameters. This must be true to some extent, as trace substance concentrations are partially dependent on water quality characteristics such as salinity. On the other hand, the quantitative importance of these parameters in accounting for overall variability in individual trace substances is unknown. Furthermore, trace substances have their own unique sources, and these sources may dominate their distribution.

Methods

Measurement techniques

Here, we take water quality to mean explicitly salinity, suspended particulate matter (SPM), and chlorophyll a, each of which is measured by electronic instrumentation (conductivity meter, optical backscattering sensor and fluorometer, respectively). The instruments, along with sensors for temperature, depth, dissolved oxygen and photosynthetically active radiation, are mounted on a frame and lowered at constant velocity from surface to bottom at each station. Average values were calculated for 1-m vertical intervals centered at 1m increments from the surface. The vertical sampling interval is about 2 cm, so each average was calculated from about 50 measurements. Sampling stations coincided with the "traditional" USGS channel stations (Figure 1). Although the original justification for these stations is somewhat obscure, we decided to maintain continuity with the historical sampling until the evidence suggested we do otherwise. Caffrey et al. (1994) describe

the techniques, sampling times, and stations in detail. Measurements from 1993 transects are analyzed here.

Semidiurnal tidal distortion is an ongoing problem with transect data. In principle, the channel (but not shoal) chlorophyll *a* data can be corrected, as the tidal currents result simply in advection of isopleths (Cloern et al. 1987). In practice, however, too many assumptions are involved. Moreover, other water quality variables such as SPM cannot be corrected, even in the channel, as sources and sinks are strongly affected by tides. When possible, monthly cruises are scheduled to coincide approximately with neap tide, when the semidiurnal effects are at a minimum.

Station subsampling

We concentrated on finding the best size for a systematic sample, i.e., for stations spaced at equal intervals. On the basis of theoretical considerations, it can be shown that a systematic sample is superior to uniform random samples and stratified random samples for estimating the mean (Ripley 1981). Stratified samples can be the best of all, provided that the strata can be identified accurately and are stable in time; if not, they can be distinctly inferior to systematic samples. At this early stage of the program, we therefore thought it prudent to emphasize systematic samples.

How can we choose a systematic sample from the existing station network? We cannot, strictly speaking,



Figure 1. Map of San Francisco Bay Showing location of CTD stations.

but we can choose a pseudo-random stratified sample that is close to a systematic sample: Let the distance between the first and last station be d. Let the number of stations be N. Ideally, we want to put N stations at 0, d/(N-1),...,d. Form equal strata centered on each of these positions, each with width of d/(N-1). Choose one station from each stratum by eliminating, if possible, stations that have lots of missing data and selecting from the remainder the one that results in the most even (most systematic) distribution of positions overall. Note that we must decrement the number of stations until we find a number with at least one station in every stratum. North Bay (NB) (stations 15-657) and South Bay (SB) (stations 21-36) are considered separately for two reasons: (1) their hydrodynamics and probably spatial correlation structure are different, and (2) the large gap in Central Bay (CB) might force an overly large stratum size.

Selection criteria

Three different sets of criteria were used to compare sample sizes, each one taking into account more complex features of the data. We arrived at these criteria by considering what sorts of data would be useful for a status and trends program that also involved regulatory compliance:

(1) The first criterion was the estimated spatial mean, standard deviation, and skewness, i.e., the first three moments of the data. The mean is perhaps the most basic summary that one can make of a spatial variable; the standard deviation is essential when comparing two means; and the skewness is a guide to the normality of the data and therefore the appropriateness of tests used to compare two means.

(2) The second criterion was the quintiles of the data, which is an approximation of the empirical cumulative distribution function (ECDF). The ECDF enables statements about the frequency with which a variable exceeded some threshold and is therefore well-suited for embodying regulatory standards.

(3) The third criterion was an actual spatial map of the data. We constructed maps from data by using a bivariate interpolation scheme based on the Delaunay triangulation (Akima 1978). We could not use kriging to obtain an "optimally" interpolated map because of the small number of stations in the smallest sample sizes.

Because stations are not exactly equally spaced, it is necessary to adjust the calculations to avoid bias. We used the method of polygonal declustering to assign appropriate declustering weights to each measurement (Isaaks and Srivastava 1989). A given sampling location (i.e., a given depth at a given station) is joined to its neighbors by straight lines. The perpendicular bisectors of these lines form a polygon (the "polygon of influence"), the area of which is used to weight the importance of the given location. Thus, clustered measurements are downweighted compared to relatively sparser measurements.

Results

"Systematic" subsamples

For North Bay, d=77.3 km and the largest N=14, implying a mean interstation distance of 5.9 km. For South Bay, d=46.5 and the largest N=15, implying a mean interstation difference of 3.3 km. Note that both of these are within the tidal excursion and therefore could be giving adequate coverage. However, we will use the full set of stations (17 from North Bay and 18 from South Bay) for our reference statistics to compare with these "systematic" subsamples, as well as those for N=10 and 5. The specific station selections for each sample are listed in Table 1. For all subsamples except South Bay with N=10, the coefficient of variation (CV) of interstation differences is improved over the collection of all stations. Note how North Bay achieves closest to a systematic sample (Table 2).

Criterion 1: Moments

We examined the effects of the different station configurations on distributions of data for 1993. We present the results only for chlorophyll *a* here, but note that the same conclusions can be drawn from similar analyses of the other variables. Only the first six cruises were used: the in situ fluorometer frequently malfunctioned during the last half of 1993 and only nearsurface discrete measurements are available for that

| Embayment | Ν | Stations |
|-----------|----|---|
| | | |
| South Bay | 18 | 21,22,23,24,25,26,27,28,28.5,29,29.5,30,31,32,33,34,35,36 |
| | 15 | 21,22,23,24,25,26,27,28,29,29.5,30,31,32,34,36 |
| | 10 | 21,22,24,26,27,29,30,32,34,36 |
| | 5 | 21,24,27,31,35 |
| | | |
| North Bay | 17 | 657,655,653,649,2,3,4,5,6,7,8,9,10,11,12,13,14,15 |
| | 14 | 657,653,649,3,4,5,6,7,8,10,11,12,14,15 |
| | 10 | 657,653,649,3,5,7,9,11,13,15 |
| | 5 | 653,2,6,10,14 |
| | | |

| Table 1. | "Systematic" subsamples of USGS stations used to compare station arrays of different size. |
|----------|---|
| | N, number of stations in subsample. The largest N in each case is the full set of stations. |

period. The first three moments are listed in Table 3. Perhaps the most important generalization from these results is that N=10 usually preserves the essential features of the data, but N=5 usually does not. Essentially the same results were obtained for salinity and SPM.

Criterion 2: Quintiles

The data set was also used to examine the effect of decreasing sample size on the quintiles (Table 4). The same conclusions can be drawn, namely that N=10, but not N=5, appears to preserve most of the features in the original data set. This becomes especially clear during bloom periods, namely March in South Bay and June in North Bay (the North Bay increase is not really a bloom, but the beginning of a summer increase in chlorophyll near the turbidity maximum).

Similarly, the empirical cumulative distribution functions for N=10 are virtually indistinguishable from the corresponding functions for all stations. Figure 2 illustrates these functions for the first six cruises combined.

Table 2. Coefficients of variation (CV) of
interstation distances for the subsamples
described in Table 1.

| Embayment | Ν | CV | |
|-----------|----|------|--|
| | 40 | 0.00 | |
| South Bay | 18 | 0.36 | |
| | 15 | 0.24 | |
| | 10 | 0.37 | |
| | 5 | 0.25 | |
| North Bay | 17 | 0.29 | |
| | 14 | 0.27 | |
| | 10 | 0.15 | |
| | 5 | 0.18 | |



Figure 2. Empirical cumulative distribution functions for the January-June 1993 chlorophyll data combined.

Criterion 3: Spatial Maps

The preservation of spatial information is the most demanding test when assessing the effect of decreasing sample size. We constructed two-dimensional maps (depth and distance along the channel) for each subsample of stations by interpolating to every meter in depth and kilometer along the channel using a bivariate interpolation scheme (Akima 1978). We used data for the March cruise in South Bay and the June cruise in North Bay, which were the times of highest chlorophyll concentrations in each case. Maps of the different subsamples show that the picture degenerates significantly only when the number of stations drops below 10 (Figure 3 and Figure 4).

For N=5, the areas of highest chlorophyll accumulation are distorted both in their location and their magnitudes. So once again, N=10 appears to be a sample size that retains the essential features of the data.

Discussion

Station number

A careful examination of the data in Table 3 and Figures 3 and 4 reveal that the estimates do not always deteriorate monotonically as the sample size decreases. For example, N=10 gives an estimate of the June mean for North Bay that is closer to the "correct" one (N=17) than is the estimate for N=15. Similarly, the map for N=10 appears to be slightly closer to the one for N=17 than the intervening N=15. Why does this happen?

Because of the relatively small number of stations in this study, we were not able to select large numbers of samples for each N; in fact, we could not find even a single sample for N=15 in North Bay that satisfied our criteria for a "pseudo-systematic" sample and were forced to use N=14. Our assessment for each N is therefore based on a single sample. If we had sufficient stations to select many samples for each N, we would find that the mean estimates deteriorated monotonically as N decreased. We would probably also find, however, that the distributions of estimates overlapped as N decreased, so that some samples for a given N gave better results than some samples for a higher N. In this study, the value corresponding to a given N is not necessarily near the mean value for that *N*, and so estimates do not necessarily deteriorate with smaller *N*.

How can we arrive at a more reliable estimate of the appropriate N? The most accessible way to address this issue is through the use of the MIDAS (Multiple-Interface Data Acquisition System) instrumentation now installed on the Polaris. This system collects data at high spatial resolution (typically ca. 20 m) from near-surface waters, including measurements of salinity, temperature, chlorophyll, and turbidity. A single transect along the Bay's mainstem therefore provides data for over 5000 positions. With this amount of data, multiple subsamples can be chosen for each N, enabling comparison of mean estimates for different N. Salinity and temperature measurements are available from January 1994, chlorophyll and turbidity since November 1994. Analysis of these data for minimum station configuration is now underway.

The use of the MIDAS data for this purpose assumes that near-surface horizontal spatial structure is a guide to two-dimensional structure. This is true qualitatively for the major features in the Bay — the South Bay spring bloom and North Bay summer estuarine turbidity maximum. There seem to be no important features in the channel that do not express themselves significantly near the surface.

An analysis could be conducted of cruise number, similar to that of station number. However, we have at most 12 full transects per year, which is unlikely to increase due to economic reasons and probably should not decrease except for economic reasons.

Station location

Where should the N stations be located? Station location, even for a systematic sample, is an issue apart from the number of stations. Although a given set of locations may be optimal for a specific transect, a universally optimal set does not exist. The main water quality features are not stationary in space, not simply waxing and waning while maintaining their position. This is especially so in the North Bay where turbidity and chlorophyll maxima may undergo an upstream migration as river flows diminish. As a result, it is probably best to determine an optimal value for N, but not to try to



Figure 3. Chlorophyll distributions in South Bay during March 1993 reconstructed from data for different subsamples of stations. Distances are measured from the Golden Gate along the axis of the estuary, negative to the south. Rav, Ravenswood Pt.; SFO, San Francisco Airport; Ang, Pt. Blunt on Angel I.



Figure 4. Chlorophyll distributions in North Bay during June 1993 reconstructed from data for different subsamples of stations. Distances are measured from the Golden Gate along the axis of the estuary, positive to the north. Rio, Rio Vista; Roe, Roe I.; Pin, Pinole Pt.; Ang, Pt. Blunt on Angel I.

determine the exact locations for these *N* equally-spaced stations. In the South Bay, a stronger argument can be made for choosing exact locations as the spring bloom, which is by far the main biological event, is usually found within specific boundaries. The bloom is a relatively extensive feature, however, and any systematic configuration of 10 stations for South Bay will result in several stations within the spatial extent of the bloom.

A further issue is whether or not to augment a baseline array during specific events such as a turbidity maximum or a bloom. For pollutant concentrations modeled as bivariate Gaussian density functions, stratified systematic sampling outperforms most alternatives, with higher allocation in strata with higher concentrations (McArthur 1987). In the case of South Bay, such augmentation can be planned in advance to

 Table 3. Effect of sample size on chlorophyll a data distribution for the first 6 cruises of 1993. Column headings give the embayment and number of stations. The four rows for each cruise give the number of samples, mean, standard deviation and skewness. Three digits are significant.

| Jan | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
|------|---------|---------|---------|--------|---------|---------|---------|---------|
| num | 234.000 | 212.000 | 139.000 | 70.000 | 207.000 | 140.000 | 125.000 | 42.0000 |
| mean | 1.220 | 1.220 | 1.220 | 1.210 | 1.300 | 1.300 | 1.300 | 1.3600 |
| sd | 0.298 | 0.314 | 0.324 | 0.297 | 0.143 | 0.148 | 0.141 | 0.0589 |
| skew | 1.090 | 1.420 | 1.330 | 1.010 | -0.978 | -0.933 | -0.919 | -1.0500 |
| Feb | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 225.000 | 206.000 | 129.000 | 64.000 | 196.000 | 133.000 | 124.000 | 43.000 |
| mean | 1.960 | 1.970 | 1.980 | 1.880 | 1.740 | 1.760 | 1.730 | 1.900 |
| sd | 0.581 | 0.624 | 0.644 | 0.548 | 0.320 | 0.309 | 0.314 | 0.246 |
| skew | 0.898 | 1.180 | 1.120 | 0.384 | -0.239 | -0.121 | -0.115 | -0.405 |
| Mar | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 214.000 | 193.000 | 126.000 | 62.000 | 189.000 | 126.000 | 117.000 | 43.000 |
| mean | 23.400 | 23.200 | 23.000 | 21.600 | 1.660 | 1.670 | 1.630 | 1.690 |
| sd | 14.000 | 13.900 | 14.300 | 12.900 | 0.290 | 0.299 | 0.293 | 0.256 |
| skew | 0.264 | 0.295 | 0.382 | 0.405 | 1.230 | 1.180 | 1.360 | 0.649 |
| Apr | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 232.000 | 192.000 | 136.000 | 67.000 | 204.000 | 143.000 | 113.000 | 53.0000 |
| mean | 7.560 | 7.620 | 7.610 | 7.280 | 2.460 | 2.380 | 2.540 | 2.3700 |
| sd | 2.300 | 2.350 | 2.390 | 1.990 | 0.543 | 0.441 | 0.626 | 0.3820 |
| skew | -0.481 | -0.490 | -0.458 | -0.668 | 1.780 | 0.847 | 1.900 | -0.0933 |
| May | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 218.000 | 196.000 | 128.000 | 63.000 | 213.000 | 142.000 | 122.000 | 52.000 |
| mean | 1.640 | 1.650 | 1.680 | 1.570 | 3.090 | 2.940 | 2.960 | 3.150 |
| sd | 0.357 | 0.383 | 0.396 | 0.348 | 1.040 | 0.790 | 0.736 | 1.260 |
| skew | 1.380 | 1.400 | 1.150 | 2.070 | 1.110 | 0.540 | 0.613 | 0.979 |
| Jun | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 223.000 | 200.000 | 128.000 | 66.000 | 205.000 | 144.000 | 124.000 | 55.000 |
| mean | 2.360 | 2.330 | 2.350 | 2.310 | 4.950 | 5.120 | 5.110 | 4.700 |
| sd | 1.120 | 1.110 | 1.050 | 1.180 | 2.510 | 2.640 | 2.590 | 2.500 |
| skew | 1.080 | 1.150 | 1.080 | 1.470 | 0.634 | 0.266 | 0.602 | 0.478 |

| Table 4. Effect of sample size on chlorophyll data distribution | n for the first 6 cruises of 1993. Column headings give the |
|---|---|
| embayment and number of stations. The six rows | s for each cruise give the number of samples and the five |
| quintiles. Two or three digits are significant. | |

| Jan | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
|------------|------------------|------------------|------------------|----------------|------------------|------------------|------------------|-------------------|
| num min | 234.000 0.800 | 212.000 0.800 | 139.000 0.800 | 70.000 | 207.000 1.000 | 140.000 1.000 | 125.000 1.000 | 42.0000 1.2000 |
| 1p | 1.000 | 1.000 | 1.000 | 1.000 | 1.200 | 1.200 | 1.200 | 1.3000 |
| mea | 1.100 | 1.100 | 1.100 | 1.100 | 1.400 | 1.400 | 1.400 | 1.4000 |
| q3 | 1.400 | 1.400 | 1.400 | 1.400 | 1.400 | 1.400 | 1.400 | 1.4000 |
| Шах | 2.000 | 2.000 | 2.000 | 2.000 | 1.500 | 1.500 | 1.500 | 1.4000 |
| Feb | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 225.000 | 206.000 | 129.000 | 64.000 | 196.000 | 133.000 | 124.000 | 43.000 |
| min | 1.000 | 1.000 | 1.000 | 1.000 | 1.100 | 1.200 | 1.100 | 1.500 |
| q1 | 1.500 | 1.500 | 1.500 | 1.300 | 1.500 | 1.500 | 1.500 | 1.600 |
| med | 1.900 | 1.900 | 1.900 | 1.800 | 1.700 | 1.700 | 1.700 | 1.900 |
| q3 | 2.300 | 2.300 | 2.300 | 2.300 | 2.000 | 2.000 | 2.000 | 2.100 |
| max | 4.600 | 4.600 | 4.600 | 3.200 | 2.300 | 2.300 | 2.300 | 2.200 |
| Mar | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 214.000 | 193.000 | 126.000 | 62.000 | 189.000 | 126.000 | 117.000 | 43.000 |
| min | 4.200 | 4.200 | 4.200 | 4.300 | 1.300 | 1.300 | 1.300 | 1.400 |
| q1 | 9.700 | 9.700 | 9.300 | 8.300 | 1.500 | 1.500 | 1.400 | 1.500 |
| med | 24.200 | 24.200 | 20.000 | 20.700 | 1.600 | 1.600 | 1.500 | 1.500 |
| q3 | 35.200 | 34.200 | 36.800 | 27.700 | 1.800 | 1.800 | 1.700 | 2.000 |
| max | 54.700 | 54.700 | 54.700 | 46.900 | 2.800 | 2.800 | 2.800 | 2.100 |
| Apr | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 232.000 | 192.000 | 136.000 | 67.000 | 204.000 | 143.000 | 113.000 | 53.0000 |
| min | 3.400 | 3.400 | 3.400 | 3.400 | 1.600 | 1.600 | 1.600 | 1.6000 |
| q1 | 5.400 | 5.200 | 5.200 | 6.100 | 2.100 | 2.000 | 2.100 | 2.0000 |
| med | 8.300 | 8.500 | 8.400 | 8.200 | 2.500 | 2.400 | 2.600 | 2.3000 |
| q3 | 9.200 | 9.300 | 9.400 | 8.900 | 2.700 | 2.700 | 2.800 | 2.7000 |
| max | 12.000 | 12.000 | 11.200 | 9.900 | 5.200 | 4.600 | 5.200 | 2.9000 |
| May | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| num | 218.000 | 196.000 | 128.000 | 63.000 | 213.000 | 142.000 | 122.000 | 52.000 |
| min | 1.200 | 1.200 | 1.200 | 1.200 | 1.800 | 1.800 | 1.900 | 1.800 |
| a1 | 1.400 | 1.400 | 1.400 | 1.300 | 2.300 | 2.300 | 2.300 | 2.200 |
| med | 1.600 | 1.600 | 1.600 | 1.400 | 2.800 | 2.800 | 2.800 | 2.800 |
| a3 | 1.800 | 1.800 | 1.800 | 1.700 | 3.500 | 3.500 | 3.400 | 3.500 |
| max | 3.000 | 3.000 | 3.000 | 3.000 | 6.000 | 4.600 | 4.600 | 6.000 |
| Jun | SB18 | SB15 | SB10 | SB5 | NB17 | NB14 | NB10 | NB5 |
| | 222.000 | 200.000 | 128.000 | 66.000 | 205 000 | 144.000 | 124.000 | 55 000 |
| min | 223.000 | 200.000 | 128.000 | 1 100 | 203.000 | 144.000 | 124.000 | 55.000 1.700 |
| 1111N | 0.700 | 0.700 | 1.000 | 1.100 | 1.700 | 1.700 | 1.700 | 1.700 |
| q1 | 1.500 | 1.500 | 1.500 | 1.500 | 2.800 | 2.700 | 2.800 | 2.300 |
| med | 0 100 | A 000 | 0 100 | 1 000 | 1 200 | 1 000 | 1 1/11 | 7 D/M |
| | 2.100 | 2.000 | 2.100 | 1.900 | 4.300 | 4.200 | 4.400 | 3.800 |
| q3 | 2.100 3.000 | 2.000 2.900 | 2.100 2.900 | 1.900 2.400 | 4.300 6.400 | 4.200 7.800 | 4.400 7.700 | 3.800 6.300 |

bracket the expected appearance of the spring bloom. In fact, a stratified sampling regime is already in place in South Bay with many supplementary cruises scheduled in the spring (Figure 5).

Augmentation of a baseline configuration in Central and North bays must involve adaptive sampling. For example, a transect in one direction gathering only MIDAS data can yield information about appropriate strata and variability within strata. This information can then be used to select station locations for CTD profiles during the return transect. Usually one allocates a number of stations proportional to both stratum size (length in this case) and within-stratum variability. The very large areas with essentially no activity combined with spatially and temporally localized "hot spots" (Figure 5) suggest that there are large gains to be made from adaptive sampling methods.

Shoal stations

Although the MIDAS data should resolve the issue of station configuration for the channels, the problem will remain unsolved for the shoals. Even if the Polaris could handle the shallower water, the time and labor required to survey the shoals on a regular basis are impractical. In the long term, we have to turn to remote sensing data for a solution. Several sources of data are available, but they differ radically in temporal and spatial resolution, cost, accessibility, and precision for estimating chlorophyll, turbidity and temperature. Most have been used in estuaries, but they have not yet achieved the needed reliability and ease. New and improved sensors should be orbiting in the near future. When a suitable source of remote sensing data becomes available, the MIDAS transects will provide an excellent means of calibrating and validating these measurements.

Conclusions

1. The evidence that N=10 is an adequate number of stations is quite consistent, whether we consider the first three moments of the data, the empirical cumulative distribution functions or the spatial maps; and whether we consider chlorophyll, salinity or SPM. Because of this consistency, and despite the caveats regarding conclusions from single subsamples, we believe that as

an interim measure the number of channel stations could be reduced to 10 in both South and North bays to form a baseline systematic station array.

2. The MIDAS dataset allows multiple subsamples of the data for a given N and will therefore be a more reliable guide to a minimum station number.

3. Any slack resulting from decreasing the baseline effort in South and North bays should be devoted to closing the big gap in Central Bay by increasing the number of baseline stations there.

4. The exact siting of a baseline systematic station array probably does not matter in North Bay, because of large spatial and temporal variability in its main water quality features, nor in South Bay, because of the large spatial extent of the spring bloom.

5. A baseline systematic station array should be augmented into a stratified systematic array in response to local water quality events. Augmentation already exists in the South Bay in response to the spring bloom. In the North Bay, adaptive sampling using MIDAS transects to locate CTD stations is probably needed for a better and more efficient characterization of water quality.

6. Remote sensing data need to be incorporated into the program to properly assess sampling needs in the shoals.



Figure 5. Near-surface (1 m) chlorophyll a concentrations during 1994. Dots represent the time and location of sampling. Distances are measured from the Golden Gate along the axis of the estuary, positive to the north and negative to the south.

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Central San Francisco Bay Suspended-Sediment Transport Processes and Comparison of Continuous and Discrete Measurements of Suspended-Solids Concentrations

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Sediments are an important component of the San Francisco Bay estuarine system. Potentially toxic substances, such as metals and pesticides, adsorb to sediment particles (Kuwabara and others, 1989; Domagalski and Kuivila, 1993). Sediments on the bottom of the bay provide the habitat for benthic communities that can ingest these substances and introduce them into the food web (Luoma and others, 1985). Nutrients, metals, and other substances are stored in bottom sediments and pore water in which chemical reactions occur and which provide an important source and/or sink to the water column (Hammond and others, 1985; Flegal and others, 1991). The transport and fate of suspended sediment is an important factor in determining the transport and fate of the constituents adsorbed on the sediment. Seasonal changes in sediment erosion and deposition patterns contribute to seasonal changes in the abundance of benthic macroinvertebrates (Nichols and Thompson, 1985). Tidal marshes are an ecologically important habitat that were created and are maintained by sedimentation processes (Atwater and others, 1979). In Suisun Bay, the maximum suspended-sediment concentration marks the position of the turbidity maximum, which is a crucial ecological region in which suspended sediment, nutrients, phytoplankton, zooplankton, larvae, and juvenile fish accumulate (Peterson and others, 1975; Arthur and Ball, 1979; Kimmerer, 1992; Jassby and Powell, 1994). Suspended sediments confine the photic zone to the upper part of the water column, and this limitation on light availability is a major control on phytoplankton production in San Francisco Bay (Cloern, 1987; Cole and Cloern, 1987). Suspended sediments also deposit in ports and shipping channels, which must be dredged to maintain navigation (U.S. Environmental Protection Agency, 1992).

The objectives of the Central San Francisco Bay suspended-sediment transport processes study are to estimate which factors determine suspended-solids concentrations (SSC) in Central Bay and to collect time series of SSC data that are appropriate for (1) continuous monitoring of SSC and (2) calibration and validation of numerical models. Potentially important factors include semidiurnal and diurnal tides, the spring/neap cycle, delta discharge, dredging and dredged material disposal, and wind waves.

SSC monitoring sites were established at Point San Pablo in December 1992 and at San Francisco Pier 24 in May 1993 (Figure 1) (Buchanan and Schoellhamer, 1995). At each site, optical backscatterance (OBS) sensors are positioned at mid-depth and near the bottom. The OBS sensors optically measure the amount of material in the water every 15 minutes, and the output of the sensors is converted to SSC with calibration curves developed from analysis of water samples. The sites are serviced every 1 to 5 weeks to clean the sensors, which are susceptible to biological fouling, and to collect water samples for sensor calibration. About half the data collected is invalid, primarily because of sensor fouling. SSC monitoring sites also are located in South San Francisco Bay and Suisun Bay (Figure 1). The sites are operated in cooperation with the U.S. Army Corps of Engineers (Central Bay); the California Regional Water Quality Control Board, San Francisco Bay Region, as part of the Bay Protection and Toxic Cleanup Program (South Bay); and the Interagency Ecological Program (Suisun Bay).

Continuous SSC data can be used to help place the discrete water-quality data collected as part of the Regional Monitoring Program (RMP) into a proper context. Vertical profiles of SSC were collected with an

OBS sensor at 22 sites in the bay three times in 1994 as part of the RMP--February, April, and August. The OBS sensor was calibrated using water samples collected 1 meter below the water surface. Continuous USGS SSC data collected at mid-depth at Point San Pablo during the three RMP water-quality sampling periods are shown in Figure 2.

Delta discharge, the spring/neap tidal cycle, and wind may affect SSC in the estuary. Sediments from the Delta account for 86 percent of the fluvial sediment supply to San Francisco Bay, with the remainder from other smaller watersheds and local runoff (Porterfield, 1980). Because 1994 was a dry year, Delta discharge was low $_{\rm hrms}$, but varied during and between sampling trips (Figure 3). The fortnightly spring/neap tidal cycle can be represented by the root-mean-squared water-surface elevation (hrms), which is determined by squaring the water level measured at Point San Pablo, low-pass filtering with an 11th order Butterworth filter with a cutoff frequency of 0.0271 hr-1, and taking the square root. Larger values of hrms



Figure 1. Continuous SSC (suspended-solids concentration) monitoring sites in San Francisco Bay.



Figure 2. Mid-depth SSC (suspended-solids concentration) at Point San Pablo and wind speed at San Francisco International Airport during the 1994 RMP (Regional Monitoring Program) water-quality sampling trips.

indicate more energetic spring tides, and smaller values indicate weaker neap tides (Figure 4). Wind speed measured at San Francisco International Airport during the three RMP water quality sampling periods are shown in Figure 2. The wind field varies over San Francisco Bay, so these wind data are used as a general indicator of the wind state.

The spring/reap cycle is an important factor affecting SSC at Point San Pablo corresponds with the spring/neap cycle. Approximately 50 percent of the variance of SSC in San Francisco Bay is attributable to the spring/neap cycle, and SSC typically lags the spring/neap cycle by about 2 days (Schoellhamer, 1994; Schoellhamer, in press). The February RMP water-quality data collection

started before a strong neap tide and concluded after a spring tide (Figure 4). SSC decreased slightly during the first half of the sampling period and increased slightly afterward (Figure 2). During the April sampling period, tidal energy increased greatly (Figure 3) and SSC at Point San Pablo also increased. The August data-collection period was centered on a weak spring tide, and maximum SSC occurred about one day after the spring tide.Stronger winds in April and August probably increased wind-wave resuspension in shallow water and account for the greater SSC compared to February.

The spring/neap variation in SSC is reflected in the discrete RMP sampling data. The sampling trips started in South and Central Bays, paused for 3 or 4 days, and



Figure 3. Estimated delta discharge and times of discrete sampling trips in 1994. Duration of RMP (Regional Monitoring Program) sampling trips are indicated by vertical bars.

then concluded in San Pablo and Suisun Bays. The ratio of SSC in San Pablo and Suisun Bays to SSC in Central and South Bays for the discrete data and for the continuous data collected in water year 1994 are given in Table 1. Spring/neap variations are removed from the continuous data by taking the mean of a year-long time series. The greatest ratio (5.6) is for the April discrete data, which is much greater than the ratio from the continuous data collected in water year 1994 (0.7). The spring tide at the end of the sampling period, when San Pablo and Suisun Bays were sampled, increased SSC and the ratio. For the August sampling trip, SSC at Point San Pablo was greater at the end of the sampling period, and the ratio (2.0) was also greater than the continuous data ratio. The SSC spring/neap variation was relatively small during the February sampling trip, and the ratio (0.8) is in good agreement with the continuous data ratio.

Interpretation of the discrete water-quality data is complicated by the spring/neap variation in SSC. For example, the conclusion that SSC in San Pablo and Suisun Bays was greater than in Central and South Bays in 1994 could incorrectly be made from the discrete data because of the relation between sample timing and the spring/ neap cycle. A similar conclusion from a spatial comparison of total constituent concentrations may also be incorrect.



Figure 4. Root-mean-squared (RMS) water-surface elevation (h_{rms}) at Point San Pablo and times of discrete sample trips in 1994. Larger values of h_{rms} indicate spring tides, and smaller values indicate neap tides. Duration of RMP (Regional Monitoring Program) sampling trips are indicated by vertical bars.

Delta discharge was small during 1994 and did not appreciably influence SSC. The maximum discharge was twice as large in 1993 than in 1994. Discharge peaks in February did not noticeably affect SSC at Mallard Island or Martinez. The first increase in delta discharge in February coincided with the collection of discrete samples, but the samples show no obvious influence from the increased discharge. Delta discharge variations had no effect on suspended-solids flux measured at Mallard Island from April 14 to June 20 (Tobin and others, 1995). Thus, Delta discharge is not responsible for the large ratio of SSC in San Pablo and Suisun Bays to SSC in Central and South Bays for the April data set.

Wind and dredged-material disposal did not cause significant variations in SSC at Point San Pablo during the RMP water-quality sampling trips. Wind speed in February was relatively small, and the wind speed in August contains a stronger diurnal (afternoon sea breeze) signal than in April (Figure 2). Winds can generate waves that can resuspend bottom sediments, especially in shallow waters with a large fetch. The seasonal increase in wind speed during the summer increases SSC in South Bay (Schoellhamer, in press). A dredged-material disposal site is located in San Pablo Bay about 3 miles north of point San Pablo. The amounts of disposed material during the February, April, and August. RMP water-quality

Table 1. Ratio of SSC in San Pablo and Suisun Bays to SSC in Central and South Bays

[For continuous data, Point San Pablo, Martinez, and Mallard data collected in water year 1994 are considered to be from San Pablo and Suisun Bays, and mid-depth or near-surface SSC were used. Large ratios for the April and August discrete data are caused by spring tides and large SSC at the end of the sampling period when San Pablo and Suisun Bays samples were collected]

| Data set | Ratio |
|------------|-------|
| | |
| February | 0.8 |
| April | 5.6 |
| August | 2.0 |
| Continuous | 0.7 |
| | |



Figure 5. Predicted ebb current speed and measured SSC (suspended-solids concentration) 1 meter above the bed at the Dumbarton Bridge on January 31, 1994. The break in the continuous measurement near 0900 hours is due to temporary fouling of the optical sensor.
sampling trips were 0, 4,750, and 5,000 yd^{3,} which are relatively small quantities for the site (Tom Gandesbery, California Regional Water Quality Control Board, oral commun., 1995) and did not noticably affect SSC at Point San Pablo.

In addition to the SSC variation associated with the spring/neap cycle, SSC varies with the diurnal and semidiurnal tides. The site with the best data to demonstrate this is the Dumbarton Bridge site because the sampling locations for discrete and continuous data are the closest of any sites in the bay. Figure 5 shows continuous and discrete SSC 1 meter above the bed. These concentrations were measured at the Dumbarton Bridge on January 31, 1994. The discrete measurement was

collected at 1300 hours during a floodtide when SSC was relatively low. Two SSC maxima, about two to three times larger than the 1300-hour concentration, occurred at 0900 and 2100 hours, concurrent with slack water after ebb. SSC in South Bay channel typically is greatest at slack after ebb; this indicates a landward gradient of SSC with larger values to the south and in shallower water (Schoellhamer, in press).

SSC can vary greatly during a day, so samples collected only a few hours apart are not a true synoptic sample. For example, if the discrete measurement had been taken 3 hours earlier at 1000 hours, the SSC would have been about double the 1300-hour value.

Table 2. Statistical summary of suspended solids concentration data, San Francisco Bay, water year 1994

| [All measurements are given in milligrams | per liter | From | P.A. | Buchanan | and | others, | U.S. | Geological |
|---|-----------|------|------|----------|-----|---------|------|------------|
| Survey, written commun., 1995] | | | | | | | | |

| Site | Depth | Mean | Median | Lower quartile | Upper quartile |
|-------------------|--------------|------|--------|-------------------|-------------------|
| Channel marker 17 | Mid-depth | 166 | 135 | 76.1 | 222 |
| | Near-bottom | 204 | 145 | 82.9 | 256 |
| Dumbarton Bridge | Mid-depth | 96.9 | 85.7 | 63.0 | 118 |
| C | Near-bottom | 133 | 112 | 68.0 | 173 |
| San Mateo Bridge | Mid-depth | 62.6 | 51.7 | 38.3 | 73.0 |
| 2 | Near-bottom | 95.6 | 75.7 | 53.1 | 118 |
| Pier 24 | Mid-depth | 42.7 | 38.4 | 25.8 | 54.6 |
| | Near-bottom | 45.4 | 40.0 | 26.2 | 60.2 |
| Point San Pablo | Mid-depth | 98 5 | 78.8 | 45.2 | 128 |
| | Near-bottom | 96.3 | 77.2 | 45.4 | 126 |
| Martinez | Near-surface | 56.9 | 52.4 | 41.9 | 66.4 |
| Mallard Island | Near-surface | 44.5 | 42.1 | 34.0 | 52.4 |
| | Near-bottom | 54.3 | 51.8 | 38.9 | 65.6 |

In addition to temporal variations of SSC at a site, there are long-term spatial variations in the bay. The mean and median SSC are greatest at channel marker 17, decrease at Dumbarton Bridge and San Mateo Bridge, and are smallest at San Francisco Pier 24 (Table 2) (P.A. Buchanan and others, U.S. Geological Survey, written commun., 1995). Thus, average SSC from continuous data provides further evidence of a landward gradient of increasing suspended solids from Central to South Bays.

In 1995, the Central Bay suspended-sediment transport processes study will continue operation of the existing continuous sites, install an additional site at the Golden Gage Bridge, monitor suspended-sediment transport processes in shallow water, prepare a report summarizing data collected during water year 1994, and continue to analyze the data.

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Special Studies



Special Studies ———

Development of a Chronic Ampelisca abdita Bioassay as an Indicator of Sediment Toxicity

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Introduction

Sediment toxicity tests are a critical component in many programs to assess environmental quality. The San Francisco Estuary Regional Monitoring Program (RMP), for example, regularly monitors the toxicity of Bay sediments to the benthic amphipod Eohaustorius estuarius using acute mortality as the measurement endpoint. Recently there has been interest expressed in using growth rate of the amphipod Ampelisca abdita as another potential measure of sediment toxicity (Scott and Redmond, 1989; Redmond et al., 1994). The use of an A. abdita growth toxicity test offers several attractive features. First, the species has been often used for a 10day mortality test (ASTM,1993; DiToro et al., 1990), but a chronic growth rate test is likely to be a more sensitive indicator of pollution than acute mortality, and thus the use of a growth test would provide a greater degree of environmental protection. Secondly, standardized procedures for collection and laboratory maintenance of the species, at least on a short-term basis, are already established (ASTM 1993). Thirdly, some information already exists on sensitivity to toxicants. Exposure to contaminated harbor sediments has caused a reduction in growth rate and a reduced egg production by the smaller females (Scott and Redmond, 1989), demonstrating that an impaired individual growth rate can have negative consequences at the population level. This linkage between smaller females and reduced egg production has also been demonstrated specifically in San Francisco Bay populations (KLI, 1983).

A. abdita is widespread in San Francisco Bay, living in subtidal muds and muddy sands. In some areas its

membranous tubes carpet the sediment surface, with animal densities exceeding 80,000 individuals m⁻² (KLI, 1983). As a dominant organism in the Bay, it is a particularly attractive species for sediment toxicity testing because of the direct and immediate relevance of results to the Bay ecosystem. Moreover, if growth rate can be shown to be a sensitive indicator of sediment toxicity, then it may be possible to acquire similar data from sizefrequency analysis of field populations. The use of the same endpoint for both laboratory toxicity tests and monitoring of field populations is an attractive unifying concept that has been largely unexplored.

The present study is part of an effort funded by the RMP to develop environmental quality indicators suitable for use in San Francisco Bay. The project has two principal components. The first consists of collection of sediments from numerous sites throughout San Francisco Bay, and testing them by both acute mortality and chronic growth tests using A. abdita. The purpose of this component is to: 1) develop procedures for growth rate testing: 2) establish the sensitivity of the growth endpoint to Bay sediments; and 3) allow comparisons with other toxicity test data (e.g. E. estuarius, mussel larvae) collected concurrently under the RMP. The second component will directly compare the sensitivity of acute mortality and chronic growth endpoints in laboratoryspiked sediments (i.e. cadmium and crude oil) in order to determine if a concentration threshold for growth impairment is less than the threshold for acute toxicity. This second component is in progress and results are not presented in this report.



Figure 1. Location from which sediments were collected for toxicity testing. The Tomales Bay station at 38°08.35'N 122°52.47'W is not shown.

METHODS

Test sediments were collected at nine sites in San Francisco Bay (Figure 1). Three of these sites (Horseshoe Bay, Davis Point and Alameda) are standard RMP sites. Three additional Bay sites (Paradise Cove, Tubbs Island, and San Pablo Island #1), as well as a station in Tomales Bay, were sampled as part of the Regional Water Quality Control Board's efforts to locate a fine-grained reference site for Bay monitoring. They were deliberately located far from known contaminant point sources. Three other sites were located in the vicinity of municipal wastewater outfalls from the East Bay Municipal Utility District (EBMUD-01), Central Costa Costa Sanitary District (CCCSD-03) and the City and County of San Francisco (CCSF-01). These stations were all within 25 m of the submerged outfalls. These stations were selected, since sediment chemistry and benthic infauna sampling was already planned through another project (BADA/LEMP), and because of an a priori assumption that toxic sediments might be found near these municipal wastewater discharges. Sediment from all sites was collected in late August or early September of 1994 using a 0.05 m² Ponar grab. In order to remove large debris and indigenous A. abdita that were present at many of these sites, the sediment was wet sieved through a 0.5 mm screen. The material passing through the screen was allowed to settle overnight, the overlying water was decanted, and the sediment thoroughly homogenized. The sediment was then stored at 4°C for 5 to 15 days prior to initiating the toxicity tests.

A. abdita were collected in the northern San Pablo Bay area of San Francisco Bay using a 0.025 m² Ponar grab. The material in the grab was sieved on stacked 2.0, 1.0 and 0.5 mm screens. The material on the 2.0mm screen (mostly tubes from *A. abdita* and other macrofauna) was discarded. About one half the *A. abdita* were retained on the 1.0mm screen, and these too were discarded. Since it was our intent to measure growth, we did not use the larger, fully-grown individuals that would be retained by the 1.0mm sieve. In addition, males die shortly after mating (ASTM, 1993), and elimination of this group from the test would likely increase our overall measures of survival. The amphipods and other material retained on the 0.5 mm screen were gently lowered into a pan of seawater, and the amphipods trapped by the surface tension were skimmed off with a dip net. They were placed in plastic dishes with seawater, and kept cool until arrival at the lab later that same day. The amphipods were then transferred to sediment-filled plastic trays and allowed to rebuild tubes. For most toxicity tests the amphipods were held in the laboratory for 2-11 days prior to use in the toxicity tests, and fed the diatom Phaeodactylum tricornutum daily during this period. For four test sediments (Paradise Bay, Tubbs Island, San Pablo Island #1, and Tomales Bay), no acclimation period was used, and the animals were placed in the test containers the same day they were collected from the field. No acclimation period was considered necessary, since temperature at the amphipod collection site was identical to toxicity test temperatures (20°C) and seawater from the amphipod collection site was used for all toxicity tests (i.e. constant salinity of 28 ppt). Sediment from the San Pablo Bay site was also collected and handled in the same way as the test sediments for purposes of establishing a home sediment control.

One quart canning jars were used as the test containers for toxicity testing. A layer of sediment 3-4 cm deep was placed in the jar, and 500 ml seawater slowly added so as to minimize sediment disturbance. The jars were allowed to sit undisturbed for 8-24 hours before adding amphipods. Aeration was provided through a pipette with the tip a few cm above the sediment-water interface.

Twenty amphipods were added to each test container. The test was conducted under 24-hr light, since preliminary data (ASTM 1993; pers. observ.) suggested this was more effective in insuring the amphipods did not emerge from their tubes and become trapped in the surface tension at the air-water interface. Water quality conditions (temperature, salinity, pH, dissolved oxygen) were monitored in five randomly selected containers every 2-3 days. The exposures continued for ten days (acute mortality) or 30 days (chronic growth). Each container holding amphipods to be used in the chronic tests were supplied approximately 15 ml of Phaeodactylum tricornutum culture each day (approx. 107 cells ml-1 in culture, thus providing about 7x10⁶ cells amphipod⁻¹ day⁻¹). The amphipods for the acute tests were not fed. Seawater in the acute tests was not replaced except for a small amount of distilled water (<20 ml) added once or twice during the experiment to compensate for evaporation. The daily addition of algal culture to the chronic test containers resulted in an increase in volume that was periodically removed, with a total of about one water renewal over the 30-d test period.

After completion of the exposures, the sediment was sieved on a 355 μ m screen to recover the amphipods. Surviving amphipods were preserved in 10% buffered formalin for later enumeration and measurment. Body length was measured along the dorsum from the insertion point of the first antennae to the base of the telson, using an image analysis system incorporating a video camera and digitizing pad.

A positive control treatment was established using cadmium chloride as a toxicant. This test was done as a 96-hr, water-only exposure without aeration.

Data were collected on survivorship, number of F1 amphipods appearing in the treatments, and body length. Data were analyzed for normality by Shapiro-Wilks tests and were found to be normally distributed in the vast majority of cases. Subsequent analyses were done on both untransformed and \log_{10} transformed data with identical results. Comparions of survival, recruitment and mean body length between the home sediment control and all other test sediments were done by a one-tailed Dunnett's test. Size frequency histograms were compared by a one-tailed Kolmogorov-Smirnov test. The LC₅₀ from the positive control was calculated by the probit method (Finney, 1971).

RESULTS

Site Conditions

Sediments at the San Pablo Bay home site of *Ampelisca abdita* consisted of 88% silt and clay (Table 1). The grain size distribution in the test sediments varied widely. Those sites near the municipal outfalls were the sandiest, with as little as 11% silt and clay (CCCSD). Other sites, such as Tubbs Island, Island #1, and Tomales Bay had as much as 99% silt and clay.

Data on sediment contaminant concentrations are available from other investigations conducted at the same sampling sites (Table 2). Because these data were collected as part of other studies, they were not all collected concurrently with the sediments used for toxicity testing. It is recognized that this compromises strong quantitative linkages between concentration and toxicity, but the data are useful in providing a more general indication of the degree of contamination at each site. None of the sites consistently ranked highest across a broad range of organic and heavy metal toxicants. CCSF, near San Francisco's municipal wastewater outfall, tended to have comparatively high levels of PAH and mercury, but was comparable to the other sites for all other contaminants. Two RMP stations, Alameda and Horseshoe Bay, had concentrations of PCB considerably higher than all other sites, and Horseshoe Bay also had an order-of-magnitude higher DDT concentrations. One consistent pattern observed across all contaminants was the comparatively low level of contamination at the Davis Point site. Davis Point sediments had among the lowest reported concentrations of all organics and metals listed in Table 2.

The present toxicity study did not incorporate infaunal community sampling, but data are available from other projects which sampled the same sites, often concurrently with the collection of sediments for *A*. *abdita* toxicity testing. *A. abdita* is a common resident species in San Francisco Bay, and populations were found at all of the sites, although varying substantially in density (Table 3). The densest populations were found at two Central Bay sites, Alameda and EBMUD-01. *A. abdita* tubes formed a continuous mat over the sediment surface at these sites, with amphipod densities ranging from 26,000 to 64,000 individuals m⁻². Davis Point and CCCSD-03 populations were very sparse, with an average of one or fewer individuals collected at each site.

Toxicity Testing Conditions

Water quality conditions in the test containers never deviated far from initial conditions nor reached levels that would be considered stressful. Average and range of conditions over both the acute and chronic exposures were as follows: temperature = 20° C (19.5-21.0), salinity = 29 ppt (26-30), pH = 7.6 (7.1-8.3), and dissolved oxygen = 8.7 mg l⁻¹ (8.1-9.1). **Table 1. Grain size distribution and total organic carbon content at all sampling sites.** Home sediment and CCCSD grain size data determined by wet sieving by the author. Other data found in RMP (1995) or provided by M. Kellogg or R. Fairey (pers. comm.). Paradise Cove, Tubbs Island, Island #1, and Tomales Bay grain size data from a sampling event four months prior to collecting sediments for toxicity testing.

| | Percentage of sediment by weight | | | | | |
|-------------------------|----------------------------------|---------------|---------|--|--|--|
| Site | Sand | Silt and Clay | тос | | | |
| Home sediment | 11 | 88 | no data | | | |
| (San Pablo Bay) | | | | | | |
| Horseshoe Bay | 45 | 55 | 0.94 | | | |
| Davis Point | 81 | 16 | 0.18 | | | |
| Alameda | 30 | 70 | 1.01 | | | |
| Paradise Cove | 8 | 92 | 1.13 | | | |
| Tubbs Island | 1 | 99 | 1.43 | | | |
| San Pablo Bay Island #1 | 1 | 99 | 0.86 | | | |
| Tomales Bay | 1 | 99 | 2.39 | | | |
| EBMUD-01 | 49 | 51 | 0.55 | | | |
| CCCSD-03 | 89 | 11 | no data | | | |
| CCSF-01 | 45 | 55 | 0.69 | | | |

Reference Toxicant

A 96-hr exposure to cadmium chloride in water-only systems was used as a positive control to determine the sensitivity of the test *A. abdita* in comparison to cadmium sensitivity of the species as reported in the literature. A 96-hr LC_{50} of 0.35 mg l⁻¹ cadmium was measured, with a 95% confidence interval of 0.30-0.41. This estimate is consistent with literature values ranging from 0.28-0.58 mg l⁻¹ (Di Toro et al., 1990; ASTM, 1993; Redmond et al., 1994).

Cohort Differentiation

In order to determine survivorship, growth, and recruitment success, it was necessary to distinguish the initial cohort of amphipods from the F1 recruits. Partitioning the individuals into initial and F1 cohorts was done on the basis of body size. This was readily done after the 10-day exposure by considering any individual less than 1.8 mm in length to be a member of the F1 cohort. In the initial population only one individual out of 250 amphipods was less than 1.8 mm in length. With 700 individuals used in the 10-day tests, it would be expected that only about 3 of these amphipods would be less than 1.8 mm assuming no F1 recruitment and no growth during the 10 days. However, 78 amphipods less than 1.8 mm were found after 10 days. Thus, it is likely that the vast majority of these represent F1 recruits and not misclassification of small representatives of the initial cohort. The use of a 1.8 mm threshold consistently gave good separation of cohorts, with home sediment data provided as an example in Figure 2.

Distinguishing cohorts after 30 days was more problematic since the fastest-growing F1 amphipods sometimes had body lengths comparable to slow-growing representatives of the initial cohort. It was also not possible to use a single universal size threshold as for Table 2. Concentration of selected contaminants in surficial sediments at all sampling sites. Organics and mercury concentrations in μ g kg⁻¹; other metal concentrations in mg kg⁻¹. Unless noted, data were collected at the same time but in separate grabs from toxicity testing sediment. CCSF was reoccupied for chemistry sampling later the same day; EBMUD was reoccupied several weeks later. Paradise Cove, Tubbs Island, Island #1, and Tomales Bay data from a sampling event four months prior to collecting sediments for toxicity testing. Data found in RMP (1995) or provided by M. Kellogg and R. Fairey (pers. comm.).

| | Total | Total | Total | | | | | | |
|--------------------|-------|-------|-------|----|-------|----|-----|--|--|
| Site | PAH | РСВ | DDT | Cu | Hg | Pb | Zn | | |
| Horseshoe Bay | 2,648 | 22 | 34 | 28 | 216 | 23 | 88 | | |
| Davis Point | 114 | 3 | 1 | 18 | 76 | 13 | 75 | | |
| Alameda | 2,328 | 50 | 4 | 39 | 332 | 25 | 117 | | |
| Paradise Cove | 2,391 | 12 | 5 | 51 | 351 | 25 | 154 | | |
| Tubbs Island | 1,382 | 6 | 4 | 66 | 319 | 29 | 180 | | |
| SPB Island #1 | 1,001 | 4 | 4 | 50 | 258 | 22 | 142 | | |
| Tomales Bay (no d | lata) | | | | | | | | |
| EBMUD-01 | 728 | 1 | 8 | 21 | 180 | 31 | 71 | | |
| CCCSD-03 (no data) | | | | | | | | | |
| CCSF-01 | 7,127 | 2 | nd | 25 | 1,080 | 19 | 66 | | |
| | | | | | | | | | |

Table 3. Abundance of resident *Ampelisca abdita* at the sampling sites in August or September, 1994. An abundance of 20 individuals m⁻² would represent a single individual collected in a 0.05 m² grab. Data were generally collected at the same time but in separate grabs from toxicity testing sediment. CCSF was reoccupied for infaunal sampling later the same day; EBMUD was reoccupied several weeks later. Data found in RMP (1995) or provided by M. Kellogg (pers. comm.).

| A. abdita r | retained on 0.5 mm sieve |
|---------------------|---------------------------|
| Site | (indiv. m ⁻²) |
| Horseshoe Bay | 107 |
| Davis Point | 13 |
| Alameda | 26,640 |
| Paradise Cove | 140 |
| Tubbs Island | 60 |
| San Pablo Island #1 | 140 |
| Tomales Bay | (no data) |
| EBMUD-01 | 64,353 |
| CCCSD-03 | 20 |
| CCSF-01 | 2,960 |



Figure 2. Number of *A. abdita* within specified size classes after a 10-day exposure in home sediments. Each panel represents a replicate with 20 initial amphipods. The vertical line represents the threshold of distinction between F1 and initial individuals, with the number in each group shown on either side of the line.

the 10-day tests, since there was an expectation that growth rates may differ among the treatments (i.e. the body sizes of the initial cohort may be smaller in a toxic sediment than in a non-toxic one). Therefore, it was necessary to assess the size distribution from each 30day test container individually and assign amphipods to initial and F1 cohorts. Several guidelines were used in making these judgements:

• The number of amphipods assigned to the initial cohort could not exceed 20, the number of individuals placed in each container at the start of the experiment.

• The threshold size differentiating the cohorts is likely to be similar, though not necessarily exactly the same, among all replicates of a given sediment.

• The size-frequency distribution of a cohort tends to approximate a bell-shaped curve.

Using this approach, the F1 cohort after 30 days was considered to be <3.4 to <4.0 mm in body length depending on the particular sample. As an example, home sediment data are shown in Figure 3. Distinguishing cohorts is most difficult in replicate 1, and it is possible that a couple individuals in the 3.40-3.79 size classes could be misclassified. (Note that not all individuals greater than 3.2 mm can be the initial cohort as this would exceed 20.) There is only one questionable individual in replicate 2, and distinction of the cohorts in replicates 3-5 is clear-cut. This approach was necessary because of the overlapping body sizes of the cohorts after 30 days, and it is recognized that it introduces some uncertainty in estimates of 30-day survivorship and F1 recruitment. This uncertainty is not believed to be great enough to materially affect the conclusions. This uncertainty has no affect on 10-day survivorship or recruitment estimates or estimates of growth rate differences among the treatments for reasons discussed in that section.

Survivorship

An average of $91\%(\pm 13.5\% \text{ s.d})$ of the amphipods survived a standard 10-day test in the San Pablo Bay home sediment (Figure 4). This value is somewhat depressed by a single replicate with 70% survival. In three out of the five replicates using home sediment, 100% survival was obtained after 10 days. Even after 30 days in home sediment, good survival was obtained with two replicates having 100% survival, and all five replicates averaging 93% (\pm 7.5%).

Survival was high in most test sediments collected throughout the Bay. The lowest ten-day survival was observed in sediments from CCSF in which an average of 78% (\pm 14%) of the amphipods survived the exposure. In all other test sediments, ten-day survival ranged from 86-93%. After 30 days exposure survival rates ranged from 89-99%, with no increased mortality at CCSF. None of the test sediments demonstrated mortality rates significantly different from that of the home sediment, in both the ten and 30-day tests (one-tailed Dunnett's test, p>0.05).

F1 Recruitment

At the completion of the tests it was common to find more than the 20 amphipods that were initially added to the test sediment. For reasons provided in the discussion section, these additional amphipods were considered to represent an F1 generation that had hatched during the tests. After ten days an average of 2.2 additional amphipods were found in each test container. Ten of the 35 ten-day test containers contained no F1 amphipods; the others contained up to eight F1 amphipods.

After the 30-day test there were an average of nine F1 amphipods in all test containers. In the home sediment there were an average of 4.6 (\pm 3.6) F1 amphipods (Figure 5). Most test sediments had recruitment rates that exceeded that of the home sediment, with a maximum of 16.8 (\pm 6.8) F1 amphipods averaged over the Tubbs Island replicates. Since it would be expected that sediment toxicity would reduce, rather than enhance, the recruitment rate, these data were tested with a one-tailed Dunnett's test. None of the test sediments had recruitment significantly less than that of the home sediment (p>0.05).

Growth

At the beginning of the exposures, the amphipods used had a size distribution as shown in Figure 6. It should be recognized that this distribution represents that of the test population and not that of the *in situ* field population.



Figure 3. Number of *A. abdita* within specified size classes after a 30-day exposure in home sediments. Each panel represents a replicate with 20 initial amphipods. The vertical line represents the threshold of distinction between F1 and initial individuals, with the number in each group shown on either side of the line.



Figure 4. Number of surviving amphipods and percentage survival after exposure to test sediments for 10 days (upper panel) and 30 days (lower panel). Mean and standard deviation of five replicates shown for each station.



Figure 5. Number of F1 amphipods found after 30-day exposure to test sediments. Mean and standard deviation of five replicates shown for each station.

Since large amphipods retained on a 1.0 sieve were removed prior to toxicity testing, the size distribution shown would be shifted towards smaller body sizes than those found *in situ*. The modal body length of the test population was approximately 3.8 mm (mean = 3.5), with a minimum of 1.6 mm and a maximum of 5.6mm.

A comparison of the initial size-frequency distribution with that observed after the ten-day exposure to home sediment (Figure 7) showed no obvious increase in body size. Growth of the initial amphipods was negligible, although the appearance of the F1 generation is apparent in the approximately 6% of the population less than 1.8 mm in length.

After 30 days the modal body size of the initial amphipods had increased to about 4.7 mm (mean = 4.5),

an increase of about 0.9 mm (24%) relative to the initial conditions (Figure 7).

Differences in growth rates among the sediments was done by using length data from the 15 largest amphipods in each replicate of each test sediment. This approach was used in order to avoid the problems of distinguishing small amphipods from the initial cohort with large F1 amphipods. In all replicates in which cohorts were easily distinguishable after 30 days, there were at least 15 amphipods from the initial cohort, and in some samples up to 20 individuals. However, by using size data only from the largest 15 individuals in all samples, growth comparisons among treatments could be made without any question of which cohort was represented.

The mean body size of the largest 15 amphipods exposed to home sediment for 30 days, averaged over

Size class (body length in mm) Figure 6. Percentage of A. abdita individuals (n=250) within specified size classes at initiation of the experiments.

3.60-3.79 3.80-3.99 4.00-4.19 4.20-4.39 4.40-4.59 4.60-4.79

2.60-2.79

2.00-2.19 2.20-2.39 2.40-2.59 3.00-3.19 3.20-3.39 3.40-3.59

2.80-2.99

the five replicates, was 4.6 mm (± 0.2) versus 3.9 mm (± 0.3) at the start of the experiment (Figure 8). Among the test sediments throughout San Francisco Bay, mean body size after 30 days ranged from 4.4 mm (± 0.2) in Davis Point sediment to 5.0 mm (±0.2) in Tubbs Island sediment. None of the test sediments had mean amphipod body sizes significantly less than the home sediment (onetailed Dunnett's test, p>0.05) indicating no depression of growth in any sediments tested. Growth was also elevated by comparing the size-frequency distribution of animals in the test sediments to that of the home sediment treatment after a 30-day exposure. This aproach, using the Kolmogorov-Smirov stastic, appeared more sensitive than mean length comparisons. Of all sediments tested, only the Davis Point treatment had a size-frequency distribution significantly different (p < 0.05) from the

20

18

16

14

12

10

8

6

4

2

0

.00-1.19 .20-1.39 .40-1.59 .60-1.79 .80-1.99

Percentage of amphipods within class

home sediment control (based on data from largest amphipods per replicate).

5.00-5.19

5.20-5.39 5.40-5.59 5.60-5.79 5.80-5.99

4.80-4.99

DISCUSSION

With the exception of growth rate in Davis Point sediments, none of the sediments tested showed a significant reduction relative to the home sediment in ten-day survival, 30-day survival, 30-day F1 recruitment, or growth. This result is not suprising given the sediment chemistry data. There was no strong gradient of contamination among the stations, even when including those sites in close proximity to the municipal wastewater outfalls. In addition, two of these outfall sites (EBMUD and CCSF) had numerous resident *A. abdita*, with thousands of individuals m⁻². Moreover, *Eohaustorius*



Size class (body length in mm)

Figure 7. Percentage of *A. abdita* individuals (n=125) within specified size classes after exposure to home sediment for 10 days (upper panel) and 30 days (lower panel).



Figure 8. Mean body length of the largest 15 amphipods in each test container. Mean and standard deviation of five replicates shown for each test sediment.

estuarius tests from the three outfall sites conducted with splits from our samples also showed survival rates comparable to the home sediment control (home = 95 ± 3.5 ; EBMUD = 76 ± 22.2 ; CCSF = 82 ± 9.1 ; CCCSD = 93 ± 4.5 — J. Hunt and B. Anderson, unpub. data). The growth inhibition observed in Davis Point sediments may be related to the coarse nature of the substrate (81% sand), although no growth rate depression was observed at another equally sandy site (CCCSD-03). The next obvious step in development of this test is demonstration of sensitivity to contaminated sediments, and these tests are in progress.

This work has shown that good survivorship can be attained with *A. abdita* when used for toxicity testing of San Francisco Bay sediments. Survival generally exceeded 85% for the 10-day tests and 90% over 30 days.

The higher survival rates for the 30-day test may be the result of providing food to the animals on a daily basis. Feeding is not included in the standard 10-day test protocol for marine amphipods.= 93 ± 4.5 — J. Hunt and B. Anderson, unpub. data). The consistently high survival, recruitment and growth is thus an encouraging result, demonstrating the rigor of the *A. abdita* toxicity test over a variety of sediment types (11-99% silt and clay) collected throughout San Francisco Bay. The next obvious step in development of this test is demonstration of sensitivity to contaminated sediments, and these tests are in progress.

Our survival rates are comparable to those reported by Long et al. (1990). Excluding the contaminated sediments of Oakland Harbor, tests with sediments from throughout San Francisco Bay demonstrated 84-92%



Figure 9. Mean length and standard deviation of A. abdita as a function of age. Animals were reared in the laboratory at 25°C. Figure modified from Redmond et al. 1994).

survival of *A. abdita*. Long et al. (1990) also reported 84-95% survival in Tomales Bay sediments; a result consistent with our Tomales Bay sediment collected 3 km from Long's site.

This high survival represents an advantage over the mortality rates often observed in the RMP using *E. estuarius*. February 1995 samples, averaged over all RMP stations, showed a mean survival of 74% (range 53-96%). August 1994 samples averaged 83% (range 75-87%) (RMP, 1995). *E. estuarius* has tended to show erratic survival rates, with apparent "toxicity" in sediments distant from known point sources of contamination.

Four of the stations (Paradise Cove, Tubbs Island, Island #1 and Tomales Bay) were not tested in a 10-day exposure but only by the 30 d test. Sample splits from these same sites were, however, tested by a standard *A*. *abdita* 10-d toxicity test at the California Department of Fish and Game laboratory in Granite Canyon. This lab reported mean (\pm s.d.) survival values of 69 (\pm 10), 79 (\pm 6), 74 (\pm 4), and 79(\pm 7) for the stations as listed above (J. Hunt and B. Anderson, unpub. data). We found 89-99% survival at these sites in the 30-d test, and 10-d survival is likely to be similar or only slightly less. The lower survival reported by the Granite Canyon lab is likely to be attributable to interlaboratory differences arising from two factors. First, the Granite Canyon lab did not remove large amphipods using a 1.0 sieve, and thus may have experienced greater mortality simply due to senescence (ASTM, 1993). Secondly, the Granite Canyon lab purchased *A. abdita* from commercial sources rather than collecting them locally, and handling and shipping stress may have contributed to greater mortality.

A. *abdita* is apparently able to brood eggs and successfully release young amphipods while held under laboratory conditions. We found F1 amphipods in 25 of the 35 10-day test containers and 50 of the 55 30-day test containers. (Note: in two 17-day tests conducted after the ezperiments reported here, no recruitment was observed). We are confident that these "new" amphipods are indeed a new cohort because of both their small size and their greater numbers in the 30-day test. It is unlikely that these individuals were resident amphipods retained in the sediment despite 0.5 mm sieving, for one would expect to see their density reflect that of the original population where the sediment was collected. In fact,

EBMUD and Alameda stations had very dense populations of *A. abdita*, but the number of "new" amphipods in test containers from these sites was no greater than in other stations having no resident *A. abdita*.

We did not deliberately include ovigerous females among the amphipods used in the toxicity tests. It is possible that they occasionally were included unknowingly or that some females became ovigerous after initiation of the tests. It is not known how long it takes for the eggs to move from the oviducts to between the brood plates and ultimately hatch. Based on very limited observations, Redmond et al. (1994) reported a period of about 10 days between appearance of egg-brooding females and release of young at a temperature of 25°C.

Recruitment success was not a good endpoint in these tests because of the very high coefficient of variation. The standard deviation among the five replicates for each sediment was often equal to or greater than the mean number of F1 amphipods. This is probably due to the fact that a single ovigerous female in San Francisco Bay typically bears 3-16 eggs (KLI, 1983). One ovigerous female in a test container could thus produce many young, whereas no F1 individuals would be found in the absence of that single female. If recruitment success were to be a viable endpoint, greater control would have to be exercised over the sex and reproductive state of the initial amphipods used in the tests.

Impairment of growth, reflected in these tests by a reduction in mean body size at the completion of the test, remains a potentially valuable endpoint worthy of further exploration. The 30-day test period utilized here was, in retrospect, too long, for it allowed the sizefrequency distributions of the two cohorts to partially overlap, complicating differentiation between initial amphipods and F1 animals. Further tests are now underway using a 17-day test period, and initial results are promising.

It would be very desirable if the standard ten-day toxicity test could be used to derive a growth endpoint in addition to the survival endpoint normally obtained. This, however, does not appear possible. No growth was seen in the ten-day tests, probably because food was not provided. A ten-day test might be able to provide both survival and growth data, but only if standard protocols are modified to allow feeding during the test.

The amphipods used in these tests grew from an initial mean length of 3.5 mm to a mean length of 4.5 mm after 30 days (home sediment data). From Figure 9, taken from Redmond et al. (1994), it is likely that these individuals initially averaged about 25 days old, and were held to about 55 days of age. Free-swimming juveniles are first observed with a body length of 1.5 mm (pers. observ.) The most rapid growth occurs in the first few weeks of life, and a substantial number of the individuals used in our tests were beyond this period of most rapid increase. While growth was still measurable, it would have been greater and stations discriminated perhaps more readily if smaller individuals had been used. The use of smaller sieve sizes than those used in this study may allow recovery of these smaller individuals, but it is also likely to complicate separation of A. abdita from sediments retained in the sieves and increase the effort needed to collect the organisms. A preferable long-term solution may be to maintain A. abdita in culture, thus providing a consistent supply of juveniles. Efforts to maintain cultures over several generations have generally been unsuccessful for reasons unknown (Redmond et al., 1994).

This work and that of others (Scott and Redmond, 1989; Redmond et al., 1994) have demonstrated the feasibility of measuring growth of *A. abdita* as an endpoint in toxicity tests. A reduction in growth rate is associated with exposure to contaminated sediments (Scott and Redmond, 1989) and our on-going research will demonstrate the relative sensitivity of this endpoint. The fact that reduced growth has population level consequences due to reduced fecundity (KLI, 1983; Scott and Redmond, 1989) makes it an attractive chronic measure. While these preliminary tests are promising, several issues need to be addressed before the test can be generally adopted. Among these issues are:

• Can the test be done with smaller individuals, approximately 5-15 days of age, by using smaller sieve sizes for collection?

• Since the test is currently dependent upon the collection of animals from wild populations, are small individuals available at all times or only during seasonal periods of recruitiment? Past work with San Francisco Bay populations suggest recruitment occurs April through October, and juveniles are found in sufficient abundance

in most months with the possible exception of March (KLI, 1983). We have successfully collected animals in September, May and June.

• Can size-frequency data from wild populations be used to derive growth rates and these data used as a measure of anthropogenic effect? *A. abdita* is widespread in San Francisco Bay as evidenced by its presence at every station sampled for this study. If cohorts could be identified and growth rates determined, we may be in the unique position of using growth rate as an indicator of chronic toxicity both in laboratory tests and field surveys.

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Other Monitoring Activities



Other Monitoring Activities

CONTAMINANT LEVELS IN FISH TISSUE FROM SAN FRANCISCO BAY

Karen Taberski, San Francisco Bay Regional Water Quality Control Board

Introduction

The main purpose of this study was to measure levels of contaminants in edible fish tissue from species caught by anglers in San Francisco Bay. The study was designed in a cooperative effort between state agencies, environmental groups and anglers. This study was managed by the San Francisco Bay Regional Water Quality Control Board, funded by the Bay Protection and Toxic Cleanup Program and conducted by the California Department of Fish and Game. The study was designed as a pilot study. The main objective of the study was to identify, to the maximum extent possible, chemicals, fish species and geographic areas of concern in San Francisco Bay. The EPA guidance document, Guidance For Assessing Chemical Contaminant Data For Use In Fish Advisories- Volume 1-Fish Sampling And Analysis (EPA 823-R-93-002, 1993), was used as a model for designing the study and determining potential chemicals of concern. As the design developed, the study was expanded to provide enough information to perform a limited health risk assessment on consuming certain fish species caught in San Francisco Bay. The Office of Environmental Health Hazard Assessment is currently using these data to conduct a human health risk assessment to determine if health advisories should be issued. An interim health advisory on consuming fish from San Francisco Bay was issued as a result of a preliminary analysis of the data from this study in December 1994. The purpose of this report is to provide information on concentrations of contaminants in certain species and at certain geographic areas in the Bay, and to identify potential chemicals of concern in the Bay as a whole.

Study Design

A total of 16 geographic areas throughout the Bay were sampled in this study: thirteen geographically discrete "stations", and three geographically non-discreet "regions" of the Bay (for the collection of sharks). Criteria used to select discrete sampling stations were: 1) good geographic representation of all areas of the Bay, 2) proximity to commonly fished shorelines or piers, 3) stations that were near contaminated areas in order to evaluate worst case conditions, and 4) stations that were distant from chemically contaminated areas and, therefore, more likely to be chemically uncontaminated reference sites.

The thirteen geographically discrete "stations" which were sampled were:

- 1. San Mateo Bridge
- 2. Dumbarton Bridge
- 3. Fremont Forebay
- 4. Richmond Inner Harbor (Friendship Shamada Park)
- 5. Berkeley Pier
- 6. Oakland Inner Harbor (Fruitvale)
- 7. Oakland Middle Harbor Pier
- 8. Double Rock (Candlestick)
- 9. Islais Creek
- 10. Point Molate
- 11. Rodeo Pier
- 12. San Francisco Pier #7
- 13. Vallejo Pier- Mare Island Strait

The two stations thought to be least contaminated were Berkeley Pier and San Francisco Pier #7. Although these were chosen originally as reference sites, results showed that these stations were not the least contaminated for all chemicals. These two stations were chosen also because of the large amount of fishing done from these piers. Three geographically non-discrete "regions" were sampled for sharks. These were the North Bay (north of the Richmond-San Rafael Bridge), Central Bay (between the Richmond-San Rafael Bridge and the San Mateo Bridge) and South Bay, (south of the San Mateo Bridge). In addition, one composite sample of sturgeon was collected from Grizzly Bay, and one composite sample of striped bass was collected from the Sacramento River.

Fish species were selected and prioritized by two criteria: 1) likelihood of catch and consumption by Bay area anglers, and 2) likelihood of contaminant accumulation based on tissue lipid content or feeding behavior. White croaker was the highest priority species at all 13 stations. Other fish species collected included: shiner surfperch, walleye surfperch, leopard sharks, brown smoothhound sharks, striped bass and halibut.

Fish Sample Collection

At each of the 13 discrete stations, enough fish to prepare four composites of fillets were collected. At each station, three composites of the highest prioritized fish with sufficient numbers, and one composite of the second most abundant fish, in order of priority, were collected. Three composites of shark were collected in each region. When three composites of any fish were collected, they were size-classed. Composites were comprised of fillets from a standard number of fish for each particular species. The number of fish per composite depended on fish species size, and ranged from three for sharks, sturgeon, striped bass and halibut to 20 for shiner surfperch. In total, 66 composite fish samples were prepared from 494 individual fish that were collected.

Fish were collected between May 2nd and June 10th, 1994, by several standard collection methods such as seines, gill nets, and hook and line.

Laboratory Analysis

All sample composites were analyzed for trace metals, PAHs, PCB congeners and pesticides. The largest size-class composite at each station was analyzed for dioxins, furans and coplanar PCB congeners, in additition to standard analysis previously listed. For all chemical analyses, small fish (white croaker and surfperch) were analyzed with skin intact, and larger fish (shark, striped bass, sturgeon and halibut) were analyzed with skin removed. Although the skin generally contains higher lipid levels than muscle tissue, this approach was chosen to better represent the manner in which anglers most often cook and consume particular fish species.

Data Analysis

The EPA approach to assessing chemical contaminants in fish tissue, contained in the EPA guidance document, has been used in this report. This approach allows pilot study screening values (PS-SVs) to be calculated for identification of potential chemicals of concern. PS-SVs are more conservative (i.e. protective with respect to human consumption) than EPA screening values because they include calculations based on a tissue consumption rate of 30 grams/day (one meal week) rather than the 6.5 grams/day rate (one meal per month) used by the EPA. The 30 grams/day rate was chosen, because it better represents recreational anglers, the target group addressed by the study. Comparisons of sample tissue levels with PS-SVs are meant to assist in guiding further investigations and focusing activities at the Regional Board. They should not be construed as regulatory action levels or be used as definitive answers to questions concerning the safety of fish consumption.

Results

Six chemicals or chemical groups exceeded their respective pilot study screening values. Therefore, for the purposes of this study, these chemicals appear to be the main chemicals of concern for consumption of fish from San Francisco Bay. These chemicals were PCBs (Aroclors), mercury, dieldrin, total chlordanes, total DDTs, and total dioxin/furans (TEQ).

The PS-SV of 3 ppb for total PCBs, based on the sum of Aroclors, was exceeded in all 66 tissue composite samples analyzed in this study. Levels were highest (638 ppb) at stations nearest San Francisco and Vallejo-Mare Island, particularly in fish with higher tissue lipid contents, such as white croaker. PCBs, which were banned from production in the U.S. by the EPA in 1979, have been one of many chemicals monitored by the California Mussel Watch Program. Long-term monitoring of this suite of contaminants in tissues of filter feeding mussels revealed that PCB concentrations have decreased dramatically since 1979. However, despite these encouraging declines, PCBs should be one of the primary chemicals of concern in the Bay, due to the high levels of PCBs and large number of screening value exceedences found in this study.

Mercury exceeded the PS-SV of 0.14 ppm in 40 of 66 composite samples. Mercury levels were highest in composites from large leopard sharks (1.26 ppm) and brown smoothhound sharks, regardless of where they were collected in the Bay. Mercury was also elevated in other species, with larger fish exhibiting higher levels of mercury contamination, especially in the North Bay. Mercury is a naturally-occurring element that is assimilated by fish in its organic form, methylmercury. The major sources of mercury in the Bay are naturallyoccurring mercury deposits, many of which were historically mined. Other mining activities, urban runoff, an industrial and agricultural processes are also mercury sources (Phillips 1987). Most of the fish advisories issued in the U.S. are in response to elevated methylmercury levels. The Food and Drug Administration currently recommends that shark and swordfish be consumed no more than once a week (7 ounces) for the general population and no more than once a month for pregnant women and women of childbearing age who might become pregnant (FDA, 1994). The California Mussel Watch Program has found that mercury concentrations in mussels have stayed fairly constant over the past 15 years.

Thirty-five of 66 tissue composite samples analyzed for dieldrin exceeded the PS-SV of 1.5 ppb. Concentrations of this pesticide were highest in white croaker composites (4.2 ppb), and screening value exceedences were found at stations throughout Bay. Striped bass and shiner surfperch composites also exceeded screening values throughout the Bay. As with PCB's, dieldrin exhibits a strong tendency to accumulate in fatty tissue and is found in highest concentrations in fish with high lipid content. Total chlordanes exceeded the PS-SV of 18 ppb in seven of 66 composite samples analyzed. Of the seven, the three highest levels occurred at the Vallejo-Mare Island station, with a maximum concentration (36 ppb) found in the largest size class of white croaker. The use of chlordane was phased out beginning in 1975. Longterm data from the Mussel Watch program indicate declining concentrations of this pesticide in mussel tissues over the past 15 years.

Total DDT exceeded the PS-SV of 69 ppb for nine of 66 tissue composite samples analyzed. Concentrations of this pesticide were found to be highest (155 ppb) in composites prepared from white croakers caught near the north end of the Bay. DDT was banned from use in 1972. Long-term data from the Mussel Watch program indicate declining concentrations of this pesticide in mussel tissues over the past 15 years.

Due to the high cost of dioxin analysis, only 19 of 66 tissue composite samples were analyzed. Sixteen of the 19 samples exceeded the dioxin-TEQ PS-SV of 0.15 parts per trillion. The highest levels (1.3 to 1.75 parts per trillion) were found in composites from white croaker caught at stations near the San Mateo and Dumbarton Bridges. Although dioxin values from the Bay exceed the screening value, they fall well within the range of background dioxin values reported by the EPA for 60 fish samples collected from relatively clean areas across North America. However, in a draft document, EPA stated that these background levels are of health concern (EPA, 600/6-88/005Ca, 1994).

A number of chemicals measured in this study fell below the pilot study screening values. Based on the results of this report, these chemicals are not considered chemicals of concern for consuming fish from the Bay, at this time. These chemicals are cadmium, selenium, endosulfan, endrin, heptachlor epoxide, hexachlorobenzene, mirex, toxaphene and chlorpyrifos. Many chemicals measured in this study have no EPA screening values and therefore pilot study screening values could not be calculated. However, some generalizations can be made about these chemicals. The PAH analysis in this study indicated that levels were near or to method detection limits in all samples measured. Levels of other analytes measured in this study appeared to be at low levels which are not cause for concern. One exception to this may be arsenic levels in sharks which deserve further evaluation.

Additional evaluation of study results and statistical analysis of data are included in the report. The main conclusions of the study are:

1) The EPA guidance document, *Guidance For Assessing Chemical Contaminant Data For Use In Fish Advisories Volume 1- Fish Sampling And Analysis* (EPA 823-R-93-002, 1993), was an effective tool for designing the pilot study and analyzing data collected from San Francisco Bay.

2) Based on calculated pilot study screening values (PS-SVs), six chemicals or chemical groups are identified as potential chemicals of concern in San Francisco Bay. They are PCBs, mercury, dieldrin, total DDT, total chlordane and the dioxin/furans.

3) High levels of the pesticides dieldrin, total DDT and total chlordane were most often found in fish from the North Bay.

4) Levels of PCBs, mercury and the dioxin/furans were found at concentrations exceeding the pilot study screening values throughout the Bay.

5) Fish with high lipid content (croaker and shiner surfperch) in their tissue samples generally exhibited higher organic contaminant levels, with the exception of methyl mercury. Fish with low lipid levels (halibut and shark) generally exhibited lower organic contaminant levels. It should be noted though that skin on/skin off sampling differences may have magnified lipid differences between species in this study.

6) Of Bay fish collected, white croaker consistently exhibited the highest tissue lipid concentrations. Lipophilic PCBs and pesticides concentrated to the highest levels in the tissue of this fish.

7) Mercury levels were found to be highest in the two shark species collected; leopard shark and brown smoothhound shark. Leopard sharks and white croaker exhibited increasing mercury concentration with increasing fish size, suggesting bioaccumulation of this metal in Bay area fish. 8) Vallejo-Mare Island is the sampling location from which fish most often exhibited high levels of chemical contaminants. Oakland Inner Harbor also exhibited a high incidence of tissue contamination.

9) A comprehensive study of potential chemicals of concern, and accumulation of these chemicals in fish and invertebrate tissues, is recommended for the San Francisco Bay area and its tributaries.

The final report was issued in June 1995. For copies of the final report or for more information about the study please contact Karen Taberski at (510) 286-1346.

SACRAMENTO COORDINATED WATER QUALITY = MONITORING PROGRAM

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INTRODUCTION

The Sacramento Coordinated Water Quality Monitoring Program (CMP) is a cooperative program initiated and implemented by the Sacramento Regional County Sanitation District (SRCSD), the City of Sacramento (City) and the Sacramento County Water Agency (SCWA). These three public entities are responsible for the management of all municipal wastewater and stormwater in the vicinity of Sacramento within Sacramento County. The CMP was established in July, 1991 through a Memorandum of Understanding between these entities.

The purpose of the CMP is to develop a scientifically defensible database of water quality information on the Sacramento River and American River in the Sacramento metropolitan area. Key features of the CMP include:

1. The Ambient Water Quality Monitoring Program (Ambient Program) for the Sacramento River and American River.

2. The coordination of ongoing surface water quality monitoring programs within the Sacramento area.

3. A water quality database management system for the water quality data on the Sacramento and American Rivers.

4. Special studies to address specific monitoring needs and to address new regulatory initiatives.

5. An annual technical report summarizing the data collected under the Ambient Program, results of special studies and proposed changes in the CMP for the upcoming year.

The Ambient Program is the primary water quality data collection element of the CMP. Sampling under the Ambient Program began in December, 1992. The 1994 Annual Report for the Sacramento CMP assesses the results of Ambient Program monitoring completed through June, 1994. The monitoring program features, monitoring results from the first year and one half of Ambient Program sampling (December, 1992 through June, 1994 covering 37 sampling events), and future direction of the program are summarized below.

Ambient Monitoring Program

Six river sites are monitored under the Ambient Program, three on the Sacramento River (Alamar Marina, Freeport and River Mile 44) and three on the American River (Folsom, Nimbus, Discovery Park) (See Figure 1). The monitoring sites have been selected to provide water quality data upstream and downstream of the influence of discharges from the Sacramento community.

Sampling is performed using peristaltic pumps. Methods for sample collection have varied by site, ranging from midstream, middepth shore samples at Nimbus, to dock-mounted 24-hour composite samplers at Alamar and Freeport, to cross-sectional spatial composite samples taken by boat at Folsom, Discovery and River Mile 44.

Samples are taken twice per month at each site at two week intervals.

Parameters monitored include trace elements (total and dissolved), cyanide, and conventional parameters (pH, TSS, TDS, hardness, TOC, temperature). Sampling frequency has varied by constituent, with sampling frequency either twice monthly, monthly, or quarterly.



Figure 1. Ambient program monitoring sites.

Clean sampling and analytical methods are employed to produce contaminant-free samples with low detection limits. Sample containers, equipment cleaning, field quality control and laboratory QA/QC procedures are described below.

Sample containers and preservatives. High density polyethylene containers are used for all samples except mercury. Teflon bottles are used for mercury samples. Trace element samples are acidified with ultrapure reagent grade nitric acid (ULTREX II). Cyanide samples are preserved with NaOH. Total organic carbon and hardness samples are preserved with sulfuric acid. Dissolved samples are filtered in the laboratory within 72 hours of collection.

Equipment cleaning. All sample tubing and sample containers are acid rinsed and soaked in

concentrated nitric acid before use. After washing, tubing ends are covered and tubing is placed in acid rinsed plastic bags for transport to the field.

Field quality control. Field quality control includes sampling procedures to avoid contamination and use of field control samples. Field control samples include field blanks, bottle blanks, and Milli-Q water blanks.

Laboratory QA/QC procedures. Both external and internal laboratory QA/QC procedures are employed. External laboratory quality control samples include blind field duplicates, blind spike samples and blind duplicate spikes. Internal laboratory quality control samples include laboratory duplicates, matrix spikes, matrix spike duplicates, method blanks and filter blanks. One set of internal QC samples is run with each batch of field samples.



Figure 2. Time series plots for dissolved and total recoverable copper in the Sacramento River mile 44, December 1992 to July 1994.

Monitoring Results

Data collected over the first year and one half of the Ambient Program have indicated the following:

1. Total recoverable levels of most trace metals exhibit a seasonal pattern in the Sacramento River, with higher concentrations occurring during the wet season (November through April) when river flows and suspended solids levels are highest (Figures 2 and 3). The pattern of correlations between river flows and total recoverable metals concentrations is consistent with an hypothesis that episodic high river flows are a primary mechanism of both sediment and trace element transport in the Sacramento River system.

2. Levels of trace elements in the American River generally do not exhibit significant correlation with river flow (for river flow see Figure 4). Median values of suspended solids, temperature, hardness, organic carbon and trace metals were typically lower in the American River than in the Sacramento River (for total suspended solids see Figure 5).

3. For most parameters tested, significant differences (p=0.05) were not observed between spatially integrated cross sectional samples and 24-hour composite samples taken at middepth from docks at Alamar Marina and Freeport. As a result of this finding, the decision was reached in September, 1994 to switch from 24-hour composite to cross sectional samples at these two locations.

4. For compliance evaluation purposes, it is assumed that EPA criteria will be interpreted as dissolved (as recommended by EPA) for all trace elements except mercury and selenium. A compliance problem exists with EPA human health criteria for total mercury in the Sacramento River (Figure 3). For all other trace elements, no compliance problems have been observed. If EPA



Figure 3. Time series plots for dissolved mercury in the Sacramento River mile 44, December 1992 to July 1994.

criteria were interpreted as total concentrations, a different compliance picture would result. In the Sacramento River, total copper and lead and potentially total cadmium and zinc would pose infrequent compliance problems. In the American River, total cadmium, lead and zinc would pose infrequent compliance problems.

5. In an analysis of trace element concentration changes in the Sacramento River, slight increases in dissolved copper and total recoverable zinc were observed downstream of the Sacramento metropolitan area. In the American River, slight downstream increases were observed for total recoverable copper and lead and total mercury.

Future Direction

The Ambient Program is generating scientifically defensible data and is fulfilling the monitoring objectives of the CMP. The CMP Steering Committee has initiated a review of the program in 1995 to reconfirm program goals and to adjust the program accordingly. Changes to be considered include a reduction in sampling frequency, the addition or subtraction of parameters to be monitored, and a reduction in the number of monitoring sites. These adjustments will be made documented in the 1995 annual report and will be made in the 1996 monitoring year. As in past years, an ongoing effort will be made to update sampling and analytical methods to maintain a high level of scientific support for the data collected under this program.



Figure 4. Time series plots for mean daily flow of the Sacramento River mile 44, December 1992 to July 1994.



Figure 5. Time series plots for total suspended solids in the Sacramento River mile 44, December 1992 to July 1994.

A South Bay POTW Local Effects Monitoring Program Comparison with Southern Slough RMP Stations

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This report is a compilation of data from two reports: 1) the "Near field receiving water monitoring of trace metals in clams (*Macoma balthica*) and sediments near the Palo Alto and San Jose/Sunnyvale Water Quality Control Plants in South San Francisco Bay: June 1993 through October 1994" completed by USGS and; 2) comparable data collected for the 1994 Annual Regional Monitoring Program report. These two reports are part of two separate monitoring programs, the Local Effects Monitoring Program (LEMP) for South Bay Dischargers, and the Regional Monitoring Program (RMP).

The stations included in this report are defined as follows: 1) San Jose (RMP) is located in Coyote Creek, midway between Artesian Slough and Mud Slough; 2) Sunnyvale (RMP) is located in Guadalupe Slough approximately one kilometer downstream from the Sunnyvale Water Pollution Control Plant; 3) SJ/ SU(LEMP) is located in Coyote Creek midway between Alviso Slough and Guadalupe Slough and; 4) Palo Alto (LEMP) is located downstream from the Palo Alto Regional Water Quality Control Plant. The LEMP data collection and analysis was performed by methods and techniques comparable to the RMP. A copy of the LEMP report has been filed with the Regional Water Quality Control Board.

The sediment analysis demonstrates a relationship between percent TOC and concentration of trace metals in the sediment samples (Tables 1A & 1B, 2A & 2B). As the percent TOC increases, so does the concentration of metals. Manganese is the only metal that does not follow this trend directly. The concentration of this metal decreased from the wet to dry season at the San Jose and SJ/SV sites independent of the percent TOC (Tables 1A & 2A).

The San Jose and SJ/SV sites increased in percent TOC and decreased in percent sand from the wet to dry season (Figures 1 & 2). In contrast, the Sunnyvale and Palo Alto sites demonstrated a different trend, where percent TOC decreased in both sites, but percent sand increased in Sunnyvale and decreased in Palo Alto from wet to dry seasons.

The San Jose site demonstrated a large increase in percent TOC whereas both the Sunnyvale and Palo Alto sites decreased from February to August (Figure 3). The change in percent sand from February to August exhibited a wide variation from substantial decreases at San Jose and SJ/SU to large increases at Sunnyvale (Figure 4).

Tissue burden in the bivalve *Macoma balthica* was examined during February, April, June, and September illustrating variations in tissue burden from the wet to dry seasons (Table 3). Concentrations of silver, copper and lead decreased from February to June, then began to rise again slightly in September. In contrast, Zinc decreased consistently from February to September. The data for cadmium is incomplete, and therefore no trends are identifiable. The data for chromium, nickel and vanadium all follow similar trends where the concentrations increased from February to April, decreased from April to June, and again increased from June to September.

The salinity measurements for the San Jose and Sunnyvale sites (RMP) were taken from the water and the salinity for the SJ/SU and Palo Alto sites (LEMP) were taken from the sediment samples (Tables 1A & 2B). The SJ/SU sample showed a significant increase in salinity where the value was doubled from the wet to the dry seasons.

Comparisons between these four stations was made possible by the efforts of personnel to coordinate

sampling design, analytical methods and collection techniques. The limitation on comparison between these sites is only one site has been sampled for more than 1 year (Palo Alto). In the future, more in-depth analysis can be performed with this collaborative effort.

| Sediment | | | | | | |
|-----------|-------|----------|-----------|---------|-----------|--|
| Metals | | RMP | | LEM | | |
| Parameter | Units | San Jose | Sunnyvale | SJ/SV | Palo Alto | |
| | | (C-3-0) | (C-1-3) | (C-1-7) | (No ID) | |
| | | | | | | |
| Ag | ppm | 0.13 | 1.11 | 0.51 | 1.0 | |
| Al | ppm | 14891 | 46785 | 38200 | 42300 | |
| As | ppm | 6.97 | 7.89 | N/A | N/A | |
| Cd | ppm | 0.18 | 0.48 | 0.20 | 0.19 | |
| Cr | ppm | 81.0 | 170.5 | 101.0 | 120.0 | |
| Cu | ppm | 21.99 | 94.59 | 45.0 | 52.0 | |
| Fe | ppm | 29996 | 82760 | 39000 | 47700 | |
| Hg | ppm | 0.072 | 0.413 | 0.37 | 0.34 | |
| Mn | ppm | 2817 | 1250 | 1229 | 1202 | |
| Ni | ppm | 68.56 | 130.82 | 92.0 | 107.0 | |
| Pb | ppm | 10.64 | 45.4 | 38.0 | 49.0 | |
| Se | ppm | 0.3 | 0.87 | 0.30 | 0.3 | |
| Zn | ppm | 60.77 | 221.84 | 136.0 | 156.0 | |
| | | | | | | |

Sediment Analysis, February 1994

Table 1A: Sediment Metal Concentrations (dry wt.)

| Sediment Quality | | | | | | |
|---------------------|-------|----------|-----------|------------|-------|-----------|
| Parameter | Units | San Jose | Sunnyvale | | SJ/SV | Palo Alto |
| % Sand | % | 93.0 | 1.0 | | 41.0 | 52.0 |
| % TOC | % | 0.33 | 1.63 | | 1.24 | 1.39 |
| Carbon | | | | | | |
| Salinity | 0/00 | 8.0 | 10.5 | Salinity | 15 | 25 |
| (Water) | | | | (Sediment) | | |

Table 1B : Sediment Quality

| Sediment | | | | | |
|-----------|-------|----------|-----------|---------|-----------|
| Metals | | RMP | | LEM | |
| Parameter | Units | San Jose | Sunnyvale | SJ/SV | Palo Alto |
| | | (C-3-0) | (C-1-3) | (C-1-7) | (No ID) |
| | | | | | |
| Ag | ppm | 0.98 | 0.28 | 0.58 | 0.7 |
| AI | ppm | 27009 | 18749 | 45100 | 31200 |
| As | ppm | 8.02 | 7.51 | N/A | N/A |
| Cd | ppm | 0.68 | 0.3 | 0.26 | 0.24 |
| Cr | ppm | 107.7 | 75.1 | 112.0 | 85.0 |
| Cu | ppm | 57.81 | 34.79 | 47.0 | 33.0 |
| Fe | ppm | 38405 | 26248 | 44000 | 33800 |
| Hg | ppm | 0.543 | 0.236 | 0.41 | 0.33 |
| Mn | ppm | 559 | 467 | 542 | 863 |
| Ni | ppm | 118.59 | 81.13 | 104.0 | 78.0 |
| Pb | ppm | 41.22 | 27.98 | 39.0 | 31.0 |
| Se | ppm | 0.42 | 0.54 | 0.30 | 0.23 |
| Zn | ppm | 162.92 | 112.49 | 140.0 | 106 |

Sediment Analysis, August 1994

Table 2A: Sediment Metal Concentrations (dry wt.)

| Sediment Quality | | | | | | |
|---------------------|-------|----------|-----------|------------------------|-------|-----------|
| Parameter | Units | San Jose | Sunnyvale | | SJ/SV | Palo Alto |
| % Sand | % | 4.0 | 38.0 | | 10.0 | 40.0 |
| % TOC | % | 1.39 | 1.06 | | 1.33 | 0.98 |
| Salinity (Water) | 0/00 | 16.5 | 13.6 | Salinity (Sediment) | 30 | 27 |

 Table 2B: Sediment Quality

| FEBRUAR | Y Ag | Cd | Cr | Cu | Ni | Pb | V | Zn |
|--------------------|-------|-----|------|------|------|------|------|-------|
| Mean (μg/g) | 12.19 | * | 3.93 | 126 | 6.54 | 4.8 | 2.44 | 423 |
| STD | 2.73 | * | 1.27 | 22 | 1.51 | 1.31 | 0.81 | 94 |
| APRIL | | | | | | | | |
| Mean (μg/g) | 1.8 | 0.1 | 5.9 | 30.5 | 7.8 | 4.1 | 4.6 | 231 |
| STD | 0.3 | * | 2 | 3.9 | 1.9 | 1 | 1.5 | 21 |
| JUNE | | | | | | | | |
| Mean (μg/g) | 1.3 | 0.3 | 1.6 | 29.6 | 4.3 | 1.7 | 1.2 | 229.0 |
| STD | 0.4 | 0.2 | 0.6 | 10.4 | 1.2 | 0.5 | 0.5 | 26.7 |
| SEPTEMBER | | | | | | | | |
| Mean (μg/g) | 1.6 | 0.3 | 4.8 | 33.8 | 7.6 | 4.4 | 3.9 | 163.0 |
| STD | 0.3 | * | 1.6 | 5.8 | 1.6 | 0.8 | 1.3 | 24 |

Macoma balthica

* incomplete data sets

 Table 3: Mean trace metal concentrations in bivalve tissue of Macoma balthica collected at SJ/SV LEM site



Figure 1: Percent TOC and Sand in sediment samples during the month of Feburary



Figure 2: Percent TOC and Sand in sediment samples during the month August.



Figure 3: Percent TOC in sediment sample during the wet and dry seasons.


Figure 4: Percent Sand sediment sample during the wet and dry seasons.

Summary of Central Valley Ambient Monitoring Program 1994-95 Central Valley Regional Water Quality Control Board

Valerie Connor, Central Valley Regional Water Quality Control Board, Sacramento

Physical Features

The Sacramento-San Joaquin Delta estuary is of ecological, aesthetic, and economic significance to California. The total area of the Delta encompasses 4,950 square miles, including 90 square miles of water area. Within the Delta lies 70 levied islands and 550,000 acres of agriculture. The Delta provides drainage for one fourth of the total area of California. Major estuarine and tidallyinfluenced rivers of the Delta include the Sacramento River, Mokelumne River, Consumnes River, Old River, Middle River and the San Joaquin River. The Delta contains major State and federal water project facilities including the Clifton Court Forebay, and the Delta-Mendota and California Aquaducts. Delta facilities provide approximately 40 percent of California's drinking water while two thirds of the water consumed in California comes from the Delta. One half of California's anadromous fish migrate through or live in the Delta and estuary. The Port of Sacramento and the Port of Stockton are on the north and south ends of the Delta, respectively.

Goals and Objectives

As part of the Bay Protection Toxic Cleanup Program, Regional Board staff have established a monitoring program in the Delta to determine if Delta waters exceed either numerical water quality criteria for metals or the narrative toxicity objective. When exceedances of the narrative objective are detected, follow-up work includes Toxicity Identification Evaluations (TIEs) to determine the chemical responsible for the toxicity and more focused monitoring to define the temporal and spatial extent of the toxicity. Results will be used to assess and rank toxic" hot spots" for cleanup and to formulate clean-up plans.

Summary of Delta Monitoring

Delta Toxicity Monitoring During the 1993-94 monitoring season the Central Valley Regional Monitoring Plan included 24 fixed station water column sites located throughout the Delta. Sites included the major riverine inputs as they entered and moved across the Delta, peripheral inputs, back sloughs and agricultural drains. Sites were sampled monthly for toxicity using the EPA three species bioassay protocols. During the 1994-95 monitoring year, monitoring funds were reduced significantly, thus requiring a scaled-back regional program. Fish testing has been essentially eliminated and sampling site locations have been reduced with attention shifted to areas of the Delta that have shown toxicity or potential problems in the past. The results of two years of monitoring will be summarized briefly below.

During the 1993-94 monitoring program, fathead minnow toxicity was detected in Sacramento River water as it entered and flowed across the Delta. This fish toxicity in Sacramento River water has been detected in prior Regional Board and Sacramento monitoring programs. Toxicity is detected about 20 percent of the time. No toxicants have been identified. Fish testing was not included in the 1994-95 program because of insufficient funds.

Acute *Ceriodaphnia dubia* mortality has been observed in water samples collected from the San Joaquin River, upland agriculturally dominated creeks, back sloughs and constructed drains discharging to the Delta. Diazinon, chlorpyrifos and carbofuran were identified as the toxicants during the TIEs and were detected in the samples at levels known to cause *Ceriodaphnia* mortality.

Periodic toxicity to the algal test species, *Selenastrum capricornutum*, has been detected in water samples collected from the San Joaquin River, upland agriculturally dominated creeks, peripheral Delta inputs and agricultural drains. Toxicity appears to occur during both wet and dry weather. TIEs have identified the herbicide, diuron, as a toxicant, but additional toxicants still remain unidentified. In particular, the chemical(s) responsible for algal toxicity in the south Delta during the summer has yet to be identified.

Delta Metals Monitoring One component of the ongoing Bay Protection Toxic Cleanup Program is a metal monitoring program with three objectives: (1) To define the extent of metal objective exceedances throughout the Delta; (2) to define the extent of metal associated toxicity throughout the Delta; and (3) to determine the metal loading patterns to the Delta, with an emphasis on storm events.

Two patterns have emerged after almost two years of study. First, no incidents of toxicity to bioassay test species have been linked to metals. Second, exceedances of water quality objectives appear to be generally limited to storm events.

Past riverine monitoring has indicated that the major loading of metals to the Delta is associated with the high flows of sediment-laden water caused by storm runoff. Therefore, characterizing metal loads during extreme flow events is essential for understanding Delta metal dynamics. The winter of 1995 was very wet. Beginning in January, metal samples were collected from the Sacramento River at Greene's Landing and from the bottom of the Yolo Bypass at Prospect Slough. Samples were collected daily during peak flows and twice weekly following peak flows. Samples are currently being analyzed for copper, cadmium, zinc, nickel, lead, chromium, silver and mercury. Results currently are available only for mercury. The water quality criterion for mercury is 12 ng/l. For several months the mercury concentrations in the Sacramento River and Prospect Slough ranged between 10-85 and 15 -700 ng/l, respectively. For comparison, dry weather mercury concentrations in the Sacramento River average 2-4 ng/l. The high mercury levels detected in Prospect Slough suggest a potentially significant source of mercury into the Delta from waters in the Bypass. Followup studies of the major inputs to the Bypass suggest that the Cache Creek watershed is the probable source. In Cache Creek the mercury levels ranged from 400- 2200 ng/l. Preliminary load estimates suggest that Cache Creek may be a major source of estuarine mercury, as Creek flows are estimated to have been in excess of a million acrefeet during the winter and spring of 1995.

Urban Runoff Monitoring Last year, in addition to the Bay Protection Program, Regional Board staff began a multi-year study to identify the constituents in urban storm runoff responsible for toxicity to each of the three EPA freshwater bioassay species. Toxicity to all three species is common. The most significant finding is the ubiquitous lethality of storm runoff to the invertebrate test species, Ceriodaphnia dubia. Toxic storm runoff is detected from many Bay area and Central Valley cities including Stockton whose runoff drains into the back sloughs of the eastern Delta. Toxicity Identification Evaluations (TIEs) have identified the insecticides, diazinon and chlorpyrifos, as the major toxicants. The widespread occurrence of these insecticides in urban creeks prompted a follow-up study to determine the sources. Both diazinon and chlorpyrifos were detected simultaneously in city creeks and in composite rainfall samples in a pattern that suggests that the pesticides are coming from both urban and agricultural sources. Diazinon is found in urban creeks throughout the year, but concentrations peak in January and February during the orchard dormant spray period. At this time high levels of diazinon are detected in rain samples collected as far apart as the cities of Patterson and Red Bluff. The highest concentrations in rain samples are measured near orchards. This year diazinon levels in some rain samples exceeded the Department of Fish and Games draft Water Quality Criteria by two orders of magnitude. A similar picture is emerging for the insecticide chlorpyrifos. Chlorpyrifos is detected in rain and urban creeks during the dormant spray period, however it also is detected in rain during the period when chlorpyrifos is applied to alfalfa (March).

Additional constituents of concern for *Ceriodaphia* identified in urban storm runoff include malathion, copper, zinc and nickel. TIEs with *Selenastrum*, the algal component of the EPA three species bioassay, have identified the herbicide, diuron, and copper and zinc as causing toxicity. Finally, runoff from the first major storm of the year in Stockton appears to annually produce an oxygen deficit causing fish kills in adjacent Delta back sloughs. The cause of the deficit has not yet been determined.

For more information on the Central Valley Regional Monitoring Program, contact Chris Foe at (916) 255-3113.

STORM WATER MONITORING PROTOCOL STANDARDIZATION PROJECT

Rainer Hoenicke, San Francisco Estuary Institute and Terry Cooke, Woodward Clyde Consultants, Inc., Oakland

Alameda, Contra Costa, and Santa Clara Counties each conduct monitoring at two stations in their respective watersheds as a condition of their NPDES discharge permits - a total of six stations. Sample collection and analysis are conducted independently by each county and their contractors. In the interest of producing more comparable information on regional storm water monitoring and to relate the storm water database to the information generated from the Estuary, the Monitoring Committee of the Bay Area Stormwater Management Agencies Association (BASMAA) determined that standardized methods of collection and analysis should be established. Additionally, they requested that data collected at those six stations should be included as part of the Regional Monitoring Program (RMP) database maintained at the San Francisco Estuary Institute (SFEI).

The existing monitoring programs were designed to provide general characterization of the chemical composition of storm water. This has been accomplished for trace metals of potential or real concern and for a limited number of biocides (generic term for pesticides and herbicides) and other trace organic contaminants with adverse or potentially adverse effects on biota or human health. Tests conducted to determine the potential toxicity of storm water on selected test species during the sampling periods also produced some useful information, although the current sampling protocols are unable to account for episodic events that discrete sampling may not be able to detect, such as accidental spills or mobilization of biocides during unsampled rainfall events. Summaries of the 1994 monitoring programs are listed in Table 1.

During this characterization phase, management goals were fairly general, such as to "help identify sources of storm water pollution, evaluate effectiveness of controls..., and evaluate effectiveness of the overall Program on improving water quality." (Alameda County Storm Water Management Plan). These general goals are reflected in monitoring plans. However, the more specific management goals are, the better directed monitoring programs can be, and the less ambiguous is the information generated. Based on this first phase of the storm water monitoring programs, more specific management questions can now be formulated. After more rigorous measurement and data quality objectives are established, sampling programs can be designed appropriately and balanced with fiscal constraints. However, careful attention should be given to analyzing and integrating the accumulated data base on a regular basis to continuously refine and increase the specificity of management objectives and goal statements, which will then serve to adjust monitoring program design.

The first step in making separate monitoring efforts compatible consists of setting field and laboratory performance standards. Field sampling and laboratory performance are evaluated based on a set of measurements that provide a specified degree of certainty regarding the validity of results. These measurements are generally part of the quality assurance and control component of a monitoring program. Quality assurance and control procedures need to maximize the probability that environmental data collected will meet or exceed the objectives for data quality. Appropriate measurements for determining if data are comparable and if the monitoring system is "under control" serve to evaluate the required performance of each sampling and analytical process. Even though sampling techniques and laboratory procedures may not be completely identical among individual storm water monitoring programs, if the monitoring system meets the necessary performance standards, the confidence in the data generated will generally be high.

As monitoring and special study needs for storm water evolve, it is important to keep in mind that even the most rigorous data sets are of little use to

| Issue | Current Status | Goal | Next Step |
|---|--|--|--|
| Uniform QA/QC requirements for contamination control. (pre-equipment check- out or field blanks). | Some programs conduct pre-deployment QA/QC others collect field blanks others do neither. | All programs should collect field blanks at a minimum. Pre- deployment QA/QC is advised. | Develop method for field blank collection using autosamplers. |
| Uniform Laboratory Performance Goals | ACCWP, SCVNPS, and CCCWP have similar laboratory performance goals. Others differ. | Laboratory minimum level should be 1/5th of WQO | Determine PQL for labs (Survey reported Detection limits and/or practical quantitation limits). |
| Uniform field and laboratory QA/QC requirements (field and laboratory duplicates, spikes, and reference materials) | Differences in laboratory and field QA/QC between programs | Set frequency goals for analysis of field and laboratory dups, spikes, and reference material analysis. | Determine reasonable frequency for QA/QC. |
| Standardized QA terms | Differences in QA term definition | Standardize QA nomenclature | Adopt definitions listed in report |
| Uniform Parameter List | Differences in parameter list between programs. | Baseline parameter list for all programs. Additional watershed - specific parameters would be added as necessary. | Conduct analysis of existing monitoring data to determine data needs (Currently being conducted by WCC for BASMAA). |
| Uniform reporting of data and hydrologic parameters | Hydrologic data reporting varies with each county. | Collect all data necessary to perform routine data analysis/reporting. | Agree on what hydrologic data should be reported. |
| Is the Current Monitoring Network Able to Adequately Detect Trends In Pollutants ? | Unknown (six stations are monitored 5x/year) | Detect 40% change In Concentrations | Conduct power analysis using data collected by existing monitoring network |
| Should Monitoring Protocols be changed to better measure dissolved metals? | Samples are collected in the field as composites and filtered in the laboratory. | Use clean techniques to clean equipment and collect samples. EPA guidance should be followed. | Determine if field filtration is necessary and/or feasible. ACCWP is conducting pilot study in FY 95-96. |
| Uniform Toxicity Monitoring Protocols | Alameda and Contra Costa using flexible bioassay design and calculating LT50 and reproductive survival. Santa Clara measuring % mortality. | Report data and calculate % survival, LT50 and reproductive survival per day and per female. | Evaluate in detail the analysis of existing toxicity data to determine data needs. (Analysis currently being conducted by WCC for BASMAA). |
| Data Formats | Formats are variable. | Standardized formats whenever possible. | Evaluate suggested data formats and agree on |

implementation.

Summary Table: Recommended modifications to "monitoring system", leading to standardized protocols and procedures

environmental decision-makers if they cannot easily be retrieved, manipulated, integrated with other relevant data, and presented in contexts that will make observable patterns more obvious. Currently, the wealth and complexity of information that has been collected over the past years as part of storm water management programs make it difficult for decision-makers to glean the pertinent highlights out of any data set without a substantial involvement of staff resources. Therefore, new ways of organizing and managing data are in order.

At this stage, SFEI has proposed a data and information management system and protocols for entering (or transferring) data into the system that are flexible and can be readily adjusted to evolving monitoring needs. "System" is very loosely defined as being comprised of the individual agency's data repository (computer) and SFEI's data base and associated tools expected to be connected to it, such as GIS or the World-wide Web.

A review of the existing monitoring activities revealed key areas, outlined in the following summary table, where standardization can be accomplished and modifications are recommended. A comprehensive review of management objectives and related monitoring efforts has not yet been undertaken. Therefore, the protocol modifications are based on the existing system, and should be continuously refined as management and monitoring goals become more specific.

Making monitoring programs compatible will eventually lead to a meaningful evaluation of storm runoff contributions to contaminant patterns observed in various segments of the Estuary and lead to better prioritization and better targeted application of management practices.

Developing Partnerships in Watershed Assessment and Monitoring

Gwen Starrett, State Water Resources Control Board, Mike Rigney and Rainer Hoenicke, San Francisco Estuary Institute

The Regional Monitoring Program for Trace Substances is currently designed to provide baseline data on the status and trends of trace contaminants in the Estuary. Invariably, questions arise about the sources and controllability of some contaminants occurring at levels of concern. Particularly with respect to nonpoint sources of contaminants, large information gaps still exist about the efficacy of prevention and control measures and relative benefits of a variety of management approaches.

Managing nonpoint source pollution on a watershed basis is a central theme of the State Water Board's efforts. Emphasis is placed on solutions drawn from the community's expertise and experience, as well as from the unique characteristics of each individual watershed. In order to sustain improvements in a watershed, the community must be aware of the value of the natural resources, including water quality, and how actions undertaken protect and enhance those resources. Actively involving the public in monitoring, restoring, and enhancing watersheds is an effective means of fostering a sense of stewardship that will enhance and complement government programs.

In keeping with the State Water Board's desire to play an active role in promoting community-based watershed monitoring and in recognition of the increasingly complex information needs, the State Board called for a meeting of agency representatives and volunteer organizations in November 1994. The purpose of the first meeting was to explore how non-governmental organizations and individuals with the desire to increase environmental stewardship or to become involved in environmental assessment and monitoring activities could obtain the necessary scientific and logistical tools to actively participate in protecting water quality and other watershed resources. A Volunteer Monitoring Steering Committee was subsequently formed with the mission to provide a link between citizen monitoring groups, community-based watershed awareness programs, and agencies in the Bay Area with the purpose of coordinating collection and use of volunteer monitoring data designed to improve natural resources management and planning. The committee has the following objectives:

- Establish the appropriate uses for data collected by volunteers, depending on program design and levels of training for participants. Uses of volunteer monitoring data may range from assessments, to management decisions, to enforcement actions.
- Use volunteer monitoring to activate citizen involvement and promote watershed stewardship.
- Use volunteer monitoring for education.
- Promote cooperative relationships between volunteer monitoring groups and federal, state, and local governmental agencies.
- Promote cost-effective monitoring.
- Provide a mechanism for quality control and quality assurance through training and technical assistance to volunteer monitoring groups.
- Generate information that is compatible and useable on a regional basis.
- Act as a clearinghouse for volunteers and organizations that need volunteers.

The Steering Committee developed a workplan that addresses the above objectives. At the same time, the State Board made available funding to SFEI to implement a number of workplan tasks, among them development of a "How-to-Guide" for establishing Riparian Stations, development of a model grant proposal directed at potential funding sources willing to support additional Riparian Stations, identification of monitoring objectives and parameters, development of new and/or modification of existing monitoring protocols, including quality assurance and data management requirements, and workshops to disseminate the products.

The concept of "Riparian Stations" combines grassroots involvement in local assessment and awareness activities under the motto of "get government off your back - shoulder a little more responsibility" (Dennis Bowker, Napa Co. Resource Conservation District) with regional networking that will eventually produce an integrated picture of the status of the 'Golden Gate Ecosystem'. Interested in following the successful model of the Coyote Creek Riparian Station, ten volunteer groups around the Bay Area asked for and will receive technical and logistical assistance from SFEI in becoming full-fledged riparian stations from Pacifica to Walnut Creek and from Sonoma to San Jose. Two of these organizations, the Lindsay Museum in Walnut Creek and the Sonoma Ecology Center were selected to receive assistance at a level intense enough to maximize their potential in becoming local "hubs" for community education and involvement in watershed assessment and monitoring activities.

The Alexander Lindsay Museum, a regional hub for environmental education in Contra Costa County, possesses unique capabilities and place in the community. In 1992, the Museum began its successful Watershed Watchers program with funds from the City of Walnut Creek and the U.S. Environmental Protection Agency. This program, involving the efforts of people from all walks and age groups, began by conducting temperature measurements on Walnut Creek and its tributaries. The program has evolved to include monitoring biological and chemical indicators along six creeks which drain into San Pablo Bay, Carquinez Straits, and Suisun Bay. Their role as an environmental education center for regional school districts solidifies their position as a regional hub for watershed data gathering activities.

The Sonoma Ecology Center represents the opposite end of the spectrum from the Lindsay Museum. This small organization has focused on issues related to growth in this still primarily rural area. Understanding the need to communicate often complex developmental issues, the Sonoma Ecology Center began several years ago to establish technical capabilities in the arena of Geographic Information Systems (GIS). Funded initially by donations from the community, Sonoma volunteers have compiled an impressive array of data layers, maps, and models, which they are providing for local government officials and community groups to help focus efforts on watershed planning. They also have received funding from the State's Department of Water Resources, Urban Stream Restoration Grant Program, to involve the community in eliminating noxious and invasive nonnative plants. This group will test monitoring programs in rural areas where the pool of potential volunteers may be smaller.

Eventually, Riparian Stations will not only contribute to more effective and successful pollution prevention programs and help integrate complex environmental issues, but also inform the environmental management process through watershed inventories and monitoring efforts by volunteers. It is our hope that data from the RMP can be placed in context with data generated upstream for better determination of how the Estuary is responding to actions taken in the surrounding watersheds. Riparian Stations may become one of the upland information sources to what we see in the Estuary. By becoming more directly involved in their watersheds, volunteers may also became leaders in Estuary protection with a better understanding of results generated by the RMP.

Discussion and Conclusions



Discussion and Conclusions

The 1994 RMP has produced a tremendous amount of information on contaminant concentrations and their possible effects in the San Francisco Estuary. This report has been largely descriptive, although some interpretation and synthesis has been presented (also see below). However, much more could be done with this information. For example, relationships between water quality parameters (salinity, DOC, nutrients) and contamination, or between sediment contamination and toxicity results, or between water contamination and bioaccumulation and condition have not been rigorously analyzed. These topics could be addressed in future Annual Reports, special studies, or by other researchers.

Consistent with the RMP objectives (listed on page 2), this report provides information on the status and trends (although only based on two years) of contaminants in the Estuary, and the data have been evaluated in terms of applicable standards and guidelines. RMP data are available to other researchers, modelers, or students by request from SFEI.

Conditions reported at RMP stations or for Estuary reaches may not be representative of conditions within the reach at other locations. RMP station locations were not randomly selected and are located primarily in main channels, although a few stations are located in shallower areas. Conditions at other locations in any Estuary reach may be different than those at the RMP stations, thus contaminant conditions or possible effects may also be different.

Inferences about Sources of Contamination

The RMP is designed to provide information on "background" contaminant concentrations of trace contaminants and trends over time throughout the Estuary. RMP data, together with information generated from other studies, can also be used to draw some general inferences regarding sources of contaminants, such as, the relative importance of contaminant contributions from the Sacramento and San Joaquin Rivers, local surface runoff, resuspension of historically contaminated sediment, or contributions from treated wastewater discharges. Seasonal differences observed in some trace contaminant concentrations suggested runoff as a source. In general, elevated concentrations during the wet season coincident with high volumes of surface runoff entering the Estuary suggest that runoff is a predominant source, while higher levels during the dry season with little local runoff indicate that other, more constant sources contribute a larger proportion of the overall contaminant load.

Near-total zinc concentrations in water were consistently higher during the wet season at all stations, indicating that runoff may have been the predominant source. Zinc is used in tire production, and small particles deposited on roadways from tire wear may easily be scoured during rainfall events and carried into storm drains and creeks and eventually deposited in the Estuary. Zinc accumulation factors of oysters, deployed at the southern and northern reaches, showed the same pattern: greater tissue levels compared to control sites during the wet season, and lower zinc levels during the dry-season deployment. Selenium is another trace element with pronounced and consistent seasonal differences that may be attributable to a preponderance of nonpoint source loading during the wet season.

In the northern Estuary, total or near-total metal concentrations were consistently higher for all trace elements with strong affinity to suspended particulates during the April sampling period when sediment resuspension may have dominated the observed signal. Other indications for sediments re-introducing historically deposited contaminants come from previous studies using stable lead isotopes for comparisons between atmospheric, runoff, point-source, or historic sources. The ratio of PCB congeners and PAH compounds can also provide clues as to sources, and more detailed investigations are planned for 1996. The PAH profile in sediment appears to be derived from automobile exhaust (Tom McDonald, pers. comm.), suggesting urban runoff and atmospheric deposition as a major source of this contaminant group. However, more specific analyses need to be conducted to verify that suggestion.

Many of the pesticides, and particularly DDT and its break-down products, showed a strong gradient in water from the upstream river stations at Rio Vista and Manteca toward the lower Delta near the confluence of the Sacramento and San Joaquin and the northern Estuary, indicating that for many pesticide groups the largely agricultural watersheds of the big rivers are a major source. It is our hope that the evolving cooperation between the Comprehensive Sacramento Monitoring Program and the RMP will shed additional light on these preliminary findings.

The LEM and Benthic Pilot Studies focused on possible biological effects near three large sewage outfalls in the Estuary. These studies showed that only a few contaminants were elevated in sediments near the outfalls compared to the RMP stations: Hg and PAHs at CCSF, PCBs and Pb at EBMUD, and Ag, As, and Cd at CCSF. Despite these elevated concentrations, there was little indication of effects on benthic macrofauna at those sites. Further, sediment toxicity tests using both the Eohaustorius test (Hunt and Anderson, unpublished) and Ampelisca test (see Special Studies) did not indicate any sediment toxicity near the outfalls. However, many trace metal and organic contaminants were accumulated in bivalves near the outfalls to levels significantly higher than in bivalves deployed at other RMP stations. These results demonstrated that transplanted bivalves provided more sensitive indicators of contamination than sediment chemistry, toxicity, or benthic measurements, and that contaminants near outfalls were generally more bioavailable than at the RMP locations.

Synthesis of Contamination in Water, Sediment, and Tissues

Contaminant concentrations in water, sediment, and transplanted bivalves in the Estuary were reported in

separate sections of this report. Only a few obvious patterns were consistently observed in all three media (Table 22). Both water (dissolved and total / near total) and sediment concentrations generally showed similar patterns of elevated concentrations in the southern Estuary decreasing into the Central Bay, increasing again into San Pablo Bay, then decreasing into the River stations. This pattern was most pronounced in total (neartotal) water concentrations, and was only slightly obvious in the sediment data. The southern sloughs had elevated concentrations of Ag, Zn, Pb, Hg, Ni, and Cd in both water and sediment. Comparisons of patterns in water and sediments with tissue concentration patterns was confounded by differences among the three species used. However, there was general correspondence between the spikes in near-total Cr, Cu, Ni, Ag, total PCBs, PAHs, and DDTs in water, and elevated concentrations of those contaminants in tissues at the Petaluma River station (BD15) in the wet weather sampling. Further, dissolved PCBs in water and PCBs in bivalve tissues were both elevated in the South Bay. Temporally, As and Ni in water and sediment were usually higher in August than in February, and Se in water and sediment were usually higher in February.

A considerable amount of information exists for most of the contaminants measured by the RMP. In particular, good summaries and bibliographies are included in Phillips 1987; Long *et al.* 1988 ; Davis *et al.* 1991. In order to facilitate interpretation of the RMP data, summaries of the fate, transport, and effects of Cu, Se, PCBs, and diazinon are included below, because they have been widely discussed recently.

Copper

Copper has been a trace metal of concern in the Estuary for several years, largely because concentrations of copper in Estuary water are often above water quality standards. RMP data from 1993 and 1994 showed that the U.S. EPA criterion of 2.9 ppb was exceeded at over 60% of the stations sampled both years.

Along with mercury and silver, copper is one of the most toxic trace metals. However, it is also an essential trace element at low concentrations. Thus, the "window" between essential and toxic concentrations is small.

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| | | Water (E | stuary) | Water (| River) | Sediment | Tissue |
|-----------|-------|-------------------|-----------------|-----------------|-----------------|--------------|---------------|
| Parameter | Units | Dissolved | Total | Dissolved | Total | Dry Weight | Dry Weight |
| Arsenic | mg/kg | 0.001 - 0.005 | 0.002 - 0.005 | 0.001 - 0.002 | 0.002 - 0.002 | 5 - 20 | 5 - 33 |
| Cadmium | ug/kg | 0.014 - 0.217 | 0.018 - 0.179 | 0.003 - 0.019 | 0.007 - 0.032 | 30 - 680 | 180 - 20460 |
| Chromium | mg/kg | ND - 0.0027 | 0.0002 - 0.0449 | 0.0002 - 0.0003 | 0.0018 - 0.0072 | 50 - 171 | 2 - 155 |
| Copper | mg/kg | 0.0003 - 0.0059 | ND - 0.0207 | 0.0009 - 0.0017 | 0.0025 - 0.004 | 8 - 95 | 3 - 684 |
| Lead | µg/kg | 0.0003 - 1.249 | 0.05 - 7.73 | 0.0153 - 0.0605 | 0.212 - 1.116 | 8010 - 45400 | 180 - 3310 |
| Mercury | hg/kg | 0.0003 - 0.0432 | 0.0012 - 0.11 | 0.0006 - 0.0014 | 0.0023 - 0.011 | 15 - 543 | 138 - 1936 |
| Nickel | mg/kg | 0.0005 - 0.0088 | 0.0006 - 0.036 | 0.0008 - 0.0012 | 0.0023 - 0.006 | 45 - 131 | 1 - 113 |
| Selenium | ug/kg | 0.12 - 0.79 | 0.056 - 0.7 | 0.122 - 2.51 | 0.154 - 2.54 | 20 - 1030 | 1360 - 5190 |
| Silver | ug/kg | 0.0003 - 0.0341 | ND - 0.1397 | 0.0002 - 0.0021 | 0.0023 - 0.0112 | 10 - 1110 | 130 - 9130 |
| Zinc | mg/kg | 0.0002 - 0.0249 | 0.0004 - 0.0464 | 0.0002 - 0.0012 | 0.0036 - 0.0086 | 50 - 222 | 57 - 3268 |
| PCBs | hg/kg | 0.00007 - 0.00059 | 0.0002 - 0.0092 | 0.0002 - 0.0007 | 0.0003 - 0.0011 | 0.33 - 41 | 170 - 2289 |
| PAHs | hg/kg | ND - 0.017 | 0.002 - 0.259 | 0.001 - 0.01 | 0.005 - 0.014 | 3 - 7632 | 70 - 6899 |
| Diazinon | ng/kg | ND - 97.63 | ND - 98 | 1.54 - 26.35 | 1.6 - 26.49 | | , |
| Dieldrin | ng/kg | ND - 0.23 | ND - 0.26 | 0.083 - 0.513 | 0.139 - 0.636 | ND - 880 | 2800-54100 |
| P,P'-DDE | ng/kg | 0.008 - 0.425 | 0.06 -1.60 | 0.2 - 2.3 | 0.4 -10.3 | ND - 33880 | 41000-1467000 |
| | | | | | | | |

Information compiled by Phillips (1987) indicated that 0.01 ppm is an approximate toxic threshold for some organisms. However, 5.8 to 600 ppm is the range of acute sensitivity for Cu in seawater. Mysid life cycle effects become evident at around 77 ppm. In freshwater, around 16 ppm is an estimated effects threshold (EPA 1986). In sediments, copper may cause toxicity between 17.8 and 2,820 ppm depending on organism sensitivity and the geochemical state of the copper (Long and Morgan 1990). Sediment Cu concentrations around 20 ppm can inhibit clam burrowing responses if the metal is not chelated or bound in the sediment (Phelps *et al.* 1983). The currently used effects range (ERL) and 270 ppm for a median effects range (ERM) (Long *et al.* 1995).

The Sacramento and San Joaquin Rivers are believed to be the largest sources of Cu to the Estuary with the greatest contribution from river particulate load, and secondarily from the dissolved fraction in rivers (Eaton 1979). However, where the copper is derived from is not known. The RMP data showed that both dissolved and near-total Cu concentrations were lower at Rio Vista and Manteca than at the Sacramento and San Joaquin River confluence stations. However, plots of dissolved Cu vs. salinity (Fig. 19) shows higher Cu concentrations at the freshwater end of the plot than at the ocean end, suggesting that Cu concentrations in general are higher in rivers, in agreement with similar analyses by Eaton (1979). Sewage effluent is also considered to be an important source of Cu (Luoma and Cloern 1982). Other sources that are currently being evaluated include Cu from automobile brake pads, roofing material, and garden fertilizers and pesticides.

The geochemistry of Cu in estuarine water is similar to that of many other trace metals. It may exist simultaneously in ionic form, several oxidation states, as organic complexes, or chelated with other molecules. These different forms of Cu are generally controlled by pH, and the presence of other organic and inorganic molecules (Stumm and Morgan 1981). Up to 60% of total Cu may occur in the dissolved phase (Girvin *et al.* 1978). Similar information was obtained in the RMP where 56 - 74% was dissolved, and concentrations varied by an order of magnitude between 0.3 to 5.9 ppb (Table 22).

In sediment, Cu may bind with particles through sorption or chemical complexation resulting in much higher concentrations in sediments than in water. RMP measurements of sediment Cu concentrations were usually two to three orders of magnitude greater than water concentrations (Table 22). However, changes in the chemical environment may alter the equilibria and cause desorption, where Cu again enters the dissolved phase. In particular, Cu may bond with sulfides, theoretically rendering it unavailable for uptake by organisms, but the experimental evidence for that is still somewhat controversial.

Many studies have suggested that Cu is not accumulated in aquatic food chains (Kay 1994). However, RMP data showed that tissue concentrations were usually an order-of-magnitude greater than sediment and up to six orders-of -magnitude greater than the dissolved fraction in water. RMP bivalve tissues contained between 3-684 ppm Cu (dry weight) in their tissues, but they did not appreciably accumulate Cu in the Estuary.

Birds generally contain less Cu than bivalves. Greater scaup ducks from the South Bay had 97 ppm dry weight in livers, and surf scoters had 49.8 ppm dry, probably obtained through their diet of algae and bivalves. It is not known if these concentrations caused any biological problems (Ohlendorf *et al.* 1986). Copper in livers of starry flounder ranged between 76 to 118 ppm dry weight in the 1984 NOAA National Status and Trends Program (Long *et al.* 1988). However, most recently, fish tissue only ranged up to 0.690 ppm wet weight in shiner surf perch from Oakland Inner Harbor, out of 66 samples of various species sampled by the Regional Board and DFG (SFBRWQB *et al.* 1995). All fish were below human health tissue screening levels.

The 1994 RMP data showed that Cu in water and sediments had similar patterns. Both were elevated in the southern sloughs and South Bay. The southern slough stations were highest in both dissolved Cu and sediment concentrations. Water and sediment Cu decreased into the Central Bay, then increased again into the northern Estuary and decreased into the Rivers. Spatial concentrations in bivalve tissues were obscured by species differences. Oysters accumulated much greater concentrations of Cu than mussels. Mussel Cu concentrations were similar in the South Bay and Central Bay.

Selenium

Selenium has received considerable attention over the past several years because of its effects on birds and the elevated concentrations measured in refinery effluent in the northern Estuary and in sewage effluent in the South Bay. The SFBRWQCB proposed ecological assessment guidelines for Se in water, sediment and tissues based on the assumption that adverse effects to upper trophic level organisms are generally caused by selenium in food. For dissolved Se in water the guideline is 0.4 to 7 ppb, depending on Se oxidation states. For Se in sediment the guideline is 1.5 ppm dry weight. For tissue, the guideline is 3.0 ppm dry weight. The tissue guideline is based on knowledge that tissue levels higher than 4 ppm are cause for concern because they would exceed the best estimate of a "no adverse effects level" for wildlife prey (Taylor et al. 1992).

Using these guidelines, a few of the 1994 RMP dissolved Se concentrations were above the minimum water guideline of 0.4 ppb (the southern slough stations, Coyote Creek BA10, and Red Rock (BC60). However, none of the stations were above the U.S. EPA criterion of 5 ppb. All RMP sediment concentrations were below 1.5 ppm, providing an estimate of sediment quality in the absence of ERL or ERM values for Se. However, most of the bivalve tissue concentrations, including some of the samples from the "clean" source sites, were above 3 ppm.

The main sources of Se to the Estuary are the Sacramento and San Joaquin Rivers. The Se they carry is largely derived from natural soil deposits. Concentrations of total Se measured at Rio Vista and both dissolved and total Se at Manteca were higher than concentrations measured at the San Joaquin and Sacramento River stations at their confluence (Table 30). Other sources include the sewage treatment plants in the South Bay, refinery effluent in the northern Estuary, and geochemical transformations of Se adsorbed onto particulates (Cutter 1989). The 1994 RMP data indicated that the highest concentrations occurred at the southern slough stations. The source of this Se is presumably from sewage outfalls, but where the Se coming into the treatment plants comes from is not known. It may be derived from water piped to the Santa Clara Valley from the Central Valley.

The geochemistry of Se in the Estuary was described by Cutter (1989). Se may occur in one of several oxidation states. Most Se in Estuary water is in the form of dissolved selenate. It also exists in inorganic forms bound to particles or adsorbed to organic material. Each form has different biogeochemistry and toxicities. Complicating the ability to interpret the RMP data is the fact that only total Se is measured. The 1994 RMP data showed that Se in water is mostly in the dissolved form (>93% of total Se). Dissolved concentrations in water vary by an order of magnitude in space and time (Table 22).

Sediment (mineral and organic material) provides numerous binding sites for Se, thus the concentrations in sediments are higher than those in the water column. Se in sediment at the RMP stations was 2-4 orders of magnitude higher than in Estuary waters (Table 22). It occurs in sediments from direct adsorption of dissolved-phase Se to particles, in organic material excreted by organisms, or detritus. Se in sediments may undergo further geochemical transformations. It may be reduced back to elemental selenium under anoxic conditions by microbial reduction of selenate, or change oxidation states in oxic sediments. Benthic organisms accumulate Se from sediment as elemental Se or organic forms. It is estimated that about 20% of the Se in sediment is available for accumulation by benthos (Luoma *et al.* 1992).

Se enters the food chain primarily by algal uptake where it may be bioconcentrated three to four orders of magnitude. Algae convert inorganic Se to organic forms which may be excreted, or become incorporated into the organism and transferred to other organisms feeding on algae. Se does not appear to biomagnify much more than two to six times once incorporated into algae. The 1994 RMP data showed that Se in bivalve tissues was an order of magnitude higher than in sediments and three to four orders of magnitude greater than in Estuary water (Table 22). Bioaccumulation factors derived for the northern Estuary in the late 1980s indicated that sediment accumulated up to three orders of magnitude more Se than is in the water, and that bivalves accumulated three to four orders of magnitude more than in water (DFG, 1989), similar to the RMP results. Further, ducks accumulated five to six times more than in water.

Ecological effects appear to be primarily caused by selenium obtained in the food of higher trophic level

organisms such as birds and fish. Liver tissues of adversely affected bird populations at the Kesterson Wildlife Refuge, in the San Joaquin Valley, ranged between 46 to 82 ppm (SWRCB 1990). Selenium levels above about 40 ppm caused reproductive failure in some birds. The teratogenic effects (deformities) threshold in bird embryos is between 13 and 24 ppm (Skorupa and Ohlendorf 1991). More recently, black-necked stilt eggs at the Chevron Refinery's water enhancement wetland in the northern Estuary, contained Se concentrations averaging 25.8 ppm; mallard and coot eggs contained up to 57 ppm and some embryos had developmental abnormalities (Chevron 1994).

Fish also contain elevated Se concentrations. Levels in striped bass from the Sacramento and San Joaquin River ranged between 0.28 and 0.48 ppm wet weight, and white sturgeon contained 0.51 to 3.3 ppm (DFG 1989). Neither of these levels prompted health advisories. More recently, the Regional Board reported a maximum in white sturgeon from Grizzly Bay of 1.04 ppm wet weight. Shark tissue contained a maximum of 0.289 ppm wet weight (SFBRWQCB *et al.* 1995). These values are below the estimate of 12 ppm dry weight as a threshold for adverse effects (Lemly and Smith 1987).

The Regional Board summarized the available information of Se in the Estuary: "The available data indicate that selenium levels in the food chain of several segments of the ...Estuary are significantly above background levels and are approaching or exceed those known to cause adverse effects in organisms elsewhere" (Taylor *et al.* 1992).

PCBs

The PCBs are a large class of compounds with widely varying biogeochemical and toxicological properties. A description of some of the important uses and properties of PCBs was provided in the Water Organics section.

An inventory of the sources of PCBs to the San Francisco Estuary has not been compiled. In general, major sources of PCBs to the environment have included industrial sites that employed them, direct emissions in periods with less stringent emission guidelines than are currently in place, and landfills which improperly received PCB-contaminated waste. Currently a major source of PCBs to surface waters is remobilization or redeposition of residues in soil, sediment, or the atmosphere. Due to the extreme persistence of PCBs, this mobile environmental reservoir will only diminish slowly. Potential sources of "fresh" PCBs still exist. According to a 1981 estimate, 58% of the total quantity of PCBs manufactured were either still in use or not yet disposed of (Rice and O'Keefe 1995).

A recent incident at Dunsmuir Reservoir in Alameda County demonstrates how accidental releases of PCBs can occur in local watersheds, leading eventually to PCB loading to the Estuary. Joint caulking used in the basins of this reservoir contained 15-20% PCBs. Replacement of this caulking, which began in 1992, led to release of PCBs to San Leandro Creek, where concentrations as high as 500 ppm were measured in sediment. Remediation of this contamination is being performed.

The analyses presented in this report indicate that PCB concentrations are elevated in the South Bay (from Yerba Buena Island south) and somewhat elevated in the northern Estuary, but does not provide any strong indication of sources of PCBs. Detailed analysis of the profile, or mixture, of congeners present in RMP samples may provide information on sources of PCB contamination in the Estuary. Such an analysis, however, is beyond the scope of this report.

The physical and chemical properties of PCBs determine their fate in waters of the Estuary. PCBs are generally much more soluble in organic material (primarily fats) than in water. Solubility varies with the chlorination of the biphenyl molecule, with lower chlorinated congeners having relatively greater aqueous solubility. PCB congeners with 5 chlorines, as a representative example, have a maximum aqueous solubility on the order of only 10 μ g/l and are 10 million times more soluble in octanol (a solvent with properties similar to lipid) than in water. PCBs, therefore, are generally very hydrophobic and have a strong tendency to partition out of the water column and into organic material.

PCBs, especially the higher chlorinated congeners, are resistant to abiotic and biotic chemical transformations in the environment. Microbial degradation of PCBs, although slow, is probably the ultimate degradation process for PCBs in sediment (Rice and O'Keefe 1995). Although some congeners are also metabolized by higher organisms, many congeners, including many of the highly toxic dioxin-like congeners, pass largely unmetabolized through the food web. Due to their resistance to metabolism and high affinity for lipid, in aquatic environments PCBs reach higher concentrations with increasing trophic level; this process is known as "biomagnification".

Data from the Estuary illustrate the processes of partitioning and biomagnification (Table 22) The median concentration of dissolved PCBs in water in 1994 was 198 pg/l (0.000198 ppb). The median concentration in the particulate fraction of water samples was 3.5-fold greater (0.000749 ppb), demonstrating the tendency of PCBs to associate with particles. Median concentrations in sediment (6 ppb wet weight) were 18,000 times higher than concentrations dissolved in water. Bivalve tissue had still higher concentrations (56 ppb wet weight), 179,000 times higher than dissolved in water. PCB concentrations in fish muscle tissue from the Bay were determined in a recent study (SFBRWQCB 1995). Although whole body concentrations would be most appropriate for illustrating biomagnification, typical concentrations in muscle were on the order of 100 ppb wet weight, 293,000 times higher than dissolved in water. Appropriate PCB data on fish predators in the Estuary for comparison with these data are not available. Data from elsewhere suggest, however, that concentrations in top predators would be much greater still. Herring gulls on Lake Ontario, for example, accumulate whole body PCB concentrations (on the order of 100,000 ppb wet weight) that are 100-200 times the concentration in Lake Ontario fish and 100 million times the concentration in water (Clark et al. 1988). Clark et al. demonstrated that PCB concentrations at the top of the Lake Ontario food web are a result of biomagnification, since equilibrium partitioning (fugacity) models would predict much lower concentrations in herring gulls.

PCBs are not exceptionally toxic in acute exposures. Most studies of acute PCB toxicity have used Aroclor mixtures and are not directly comparable with RMP data, but they do provide an order of magnitude approximation of concentrations that might be acutely toxic in waters of the Estuary. The most sensitive species of fresh- and saltwater fish and invertebrates exhibit acute toxicity at concentrations as low as 1 ppb (Eisler 1986a). Threshold concentrations for sublethal effects on aquatic species are indicated by "maximum acceptable toxicant concentrations" developed by EPA, which were as low as 0.16 ppb for Aroclor 1254 in an early life stage test with sheepshead minnows (Eisler 1986a). The highest total PCB concentration measured in the 1994 RMP was 0.009 ppb, well below concentrations known to result in direct acute toxicity to aquatic organisms.

On the other hand, certain PCB congeners are extremely toxic in chronic exposures. The most toxic PCB congeners are those that closely mimic the potency and mechanism of toxicity of 2,3,7,8-tetrachlorodibenzop-dioxin ("dioxin", one of the most toxic compounds known). These PCB congeners can cause toxic symptoms similar to those caused by dioxin exposure, including developmental abnormalities, disruption of the endocrine system, impairment of immune function, and cancer promotion (Ahlborg *et al.* 1994).

In sediments, PCBs are mostly partitioned onto surfaces of mineral particles or into particulate organic material. However, low concentrations may exist in pore water between the particles. Biological effects may begin in association with PCB concentrations above about 3 ppb (Long and Morgan 1990). In San Francisco Estuary, previous studies (largely laboratory bioassays) have determined average effective concentrations to range between 26 and 216 ppb (Long and Morgan 1990). The current Effects Range-Low (above which biological effects "possibly" occur) is 22.7 ppb (Long *et al.* 1995). Eight sediment samples from RMP stations were above that value (Table 19)

In aquatic ecosystems many PCB congeners, including the dioxin-like PCBs, tend to biomagnify through the food web, leading to rising concentrations with increasing trophic level. Consequently, predatory fish, birds, and mammals (including humans that consume fish) at the top of the food web are particularly vulnerable to the effects of PCB contamination. Several studies have indicated that PCB contamination of the food web may be severe enough to adversely affect either humans or wildlife species that consume fish caught in the Estuary. The Regional Board's fish contamination study (SFBRWQCB 1995) found that PCB concentrations in samples collected throughout the Bay exceeded screening values based on protection of human health and resulted in the issuance of an advisory for consumption of Bay fish. RMP findings that PCB concentrations in waters of the Estuary are uniformly greater than EPA's human health-based water quality criterion are consistent with the high concentrations found in Bay fish and the resultant advisory.

PCB concentrations at the top of the food web may also be high enough to elicit effects on sensitive life stages of Bay biota (Phillips and Spies 1988). Evidence suggesting adverse effects of PCBs on reproduction exists for starry flounder (Spies et al. 1988; Spies and Rice 1988) and black-crowned night herons (Hoffman et al. 1986). In more recent research, some harbor seals in 1991 and 1992 were found to have whole blood PCB concentrations that were more than double the concentrations associated with reproductive effects and immune dysfunction in harbor seals in the Netherlands (Kopec and Harvey, in preparation). Another study by researchers at U.C. Davis has employed a biomarker (cytochrome P450) that is responsive to the dioxin-like compounds, including the dioxin-like PCB congeners, to assess pollutant accumulation and effects in doublecrested cormorant embryos on the Bay. Data from 1993 and 1994 indicate that median concentrations of dioxinlike compounds in Bay embryos are at the threshold for toxic effects in this species. The pollutant profile in Bay fish (SFBRWQCB 1995) implicate PCBs as the primary compounds likely to be inducing cytochrome P450 in cormorant embryos.

Diazinon

Diazinon is classified as an organophosphate insecticide. Organophosphates owe their toxicity primarily to their inhibition of acetylcholinesterase, an enzyme that degrades the neurotransmitter molecule acetylcholine. Animals exposed to toxic quantities of organophosphates suffer from excessive stimulation of their nerve cells due to the lack of acetylcholine degradation.

Diazinon is a very effective pesticide that is used in agricultural, commercial, and residential applications to control a variety of insect and nematode species. Diazinon is heavily used in California. In 1990, 665,000 pounds of diazinon active ingredient were applied on over 32 crops in Central Valley counties (CVRWQCB 1993). One locally important use of diazinon is on stone fruit orchards (especially almonds) in the dormant season; this use alone accounted for over 250,000 pounds in 1990. Agricultural use of diazinon has probably increased since 1990 due to the restriction of the use of parathion, another organophosphate that had been a prevalent dormant spray. The combination of pesticide application and rainfall events in January and February lead to large fluxes of diazinon and other pesticides into the Delta from Central Valley runoff. In February 1993 a pulse of diazinon derived from orchard runoff was tracked from Sacramento all the way to Martinez, where 122 ng/l (parts per trillion, ppt) were measured (Kuivila and Foe 1995). Diazinon is also used extensively for pest control in and around homes, leading to significant mass loading in runoff from urbanized watersheds of the Estuary.

The limited diazinon data from the RMP base stations do support one interesting conclusion: significant diazinon inputs are possible in urbanized portions of the Estuary, as indicated by the high concentration (98 ppt) measured at Coyote Creek (BA10). Concentrations in the Rivers as Rio Vista and Manteca in April were lower (approximately 7 ppt), but due to the episodic nature of pesticide transport it would be inappropriate to generalize based on those observations. Concentrations in the February samples were generally an order of magnitude higher than in the April and August samples. This may reflect actual seasonal variation in the Estuary or may be due to methodological differences since BBI analyzed the February samples and UCSC analyzed the April and August samples. Intercalibration between BBI and UCSC in 1996 will help clarify whether these apparent differences in concentrations are related to differences in analytical methods.

The physical and chemical properties of diazinon are representative of the pesticides currently in wide usage, and are much different from the extremely persistent and lipophilic organochlorine pesticides and PCBs. Diazinon is somewhat lipophilic (1000 times more soluble in octanol than in water). The aqueous solubility of diazinon (40 mg/l) is 4000 times higher than pentachlorobiphenyl (discussed above). Nearly 100% of diazinon in RMP water samples was in dissolved form. These data emphasize the aqueous solubility of diazinon, but are somewhat surprising considering diazinon's octanol/water partition coefficient.

In further contrast to the organochlorines, diazinon is readily broken down in the environment by either abiotic or biotic processes, as reviewed by Eisler (1986b). Diazinon degrades rapidly in plants, with a half life usually less than 14 days. In water, diazinon is converted to comparatively nontoxic breakdown products. The rate of this conversion is highly dependent on pH, with a half life of several months at pH 7.4 and decreasing to days or hours at acid (3) or alkaline (10) pH in freshwater. Diazinon is also readily metabolized, eliminating the possibility of transfer through more than one trophic level, although consumption of exposed prey could conceivably lead to acute exposures in predators.

Diazinon toxicity varies widely among species. Currently there is no EPA criterion for protection of aquatic life due to diazinon toxicity. The National Academy of Sciences in 1973 established a guideline of 9 ppt as a maximum concentration for protection of aquatic life.

Kuivila and Foe (1995) found that water samples from the Rivers causing mortality in the small aquatic crustacean Ceriodaphnia dubia had concentrations of 100-200 ppt diazinon. Water samples from the Sacramento River at Rio Vista were acutely toxic to C. dubia for 3 consecutive days and from the San Joaquin River at Vernalis for 12 consecutive days in February 1993. Although C. dubia is relatively sensitive to diazinon toxicity, other freshwater invertebrates appear to be even more sensitive (Kuivila and Foe 1995), and sublethal effects occur at even lower concentrations than those causing mortality. Saltwater invertebrates tested to date have not been as sensitive as C. dubia, but the database is small. The more sensitive fresh- and saltwater fish species tested to date show effects at concentrations near 1000 ppt. Diazinon concentrations measured in RMP water samples are generally above the NAS guideline and appear to be in the range where effects on sensitive invertebrate species are possible. It is likely that diazinon pulses due to episodic runoff events in both agricultural and urban portions of the Estuary are toxic to sensitive species. It is possible that these concentrations are sufficient to have significant population-level impacts on sensitive zooplankton species.

Assessment of Estuary Condition in Terms of Contamination

All RMP results for 1994 were compared to applicable water quality standards, sediment and tissue guidelines in the discussions of the water, sediment, and bioaccumulation monitoring sections (Tables 16, 19, and 21). There were numerous instances where water, sediment, and tissue concentrations were above the respective criteria, objectives, guidelines, or standards. Additionally, indications of significant aquatic and sediment toxicity, and reduced bivalve survival and condition were shown at several RMP stations (Figures 27, 49, 69, and 70). While each of these pieces of information were used to evaluate Estuary quality in terms of contamination, it is desirable to integrate all of the RMP information into an "index" of the degree of contamination and possible effects at each station so that the RMP stations and Estuary reaches can be compared and improvement can be tracked over time. Additionally, an index for each contaminant integrating information in water, sediment, and tissues would help determine which contaminants were the biggest problems in the region.

An index is envisioned that would reflect which stations and Estuary reaches had the most exceedances of water quality standards, sediment and tissue guidelines. While this may seem like an inordinate amount of "bean counting", existing standards are the only yardsticks currently available, and provide a way to use RMP information to evaluate general Estuary condition. Ecological effects information, such as bioassay results, bivalve condition and survival, and benthic community data should also be included in an index, and perhaps even more heavily weighted since they reflect actual ecological condition.

Another approch might be to use techniques developed for ecological risk assessment, a relatively new field of environmental science devoted to such tasks.

One problem in evaluating all of the RMP data together is that not all parameters or tests are conducted at all RMP stations. For example, water and tissue are measured at Coyote Creek (BA10), but sediment is not, whereas water, sediment, and tissue measurements, as well as bioassays are measured at Redwood Creek (BA40). Index values at each station would depend on what is actually measured, and could be different depending on what was measured. Synoptic measurement of all RMP parameters at all stations would remedy this problem. Over the next year, SFEI staff will work with risk assessment experts, and others to develop an Estuary contamination index that expresses Estuary condition in terms of contamination.

Meanwhile, the tables presented in each of the water, sediment, and bioaccumulation discussion sections summarize the exceedances measured at each station. About 12% of the water measurements exceeded applicable water quality standards. About 19% of the sediment measurements exceeded ERL values, and about 40% of the bivalve tissue measurements exceeded MIS (metals) or MTRL (organics) values. Overall, an average of about 20% of the 1994 RMP measurements exceeded applicable standards and guidelines throughout the Estuary. However, these values are averages and are variable among stations and each sampling period. There were generally more exceedances at the northern Estuary stations than at the other RMP stations.

Another way to summarize the RMP findings is on a contaminant basis. Combining exceedances in water, sediment and tissues, copper, mercury, nickel, and total PCBs exceeded standards and guidelines in more than half the samples, suggesting that these are the main contaminants of concern. Ag, Zn, and Cd exceeded standards and guidelines in less than 10% of the measurements. Whether or not exceedances actually indicate ecological effects in the Estuary has not been well studied.

Improved source control, watershed awareness and stewardship programs, and pollution prevention efforts are all designed to improve Estuary condition in terms of contamination. Significant resources are spent on these programs, while few effective measurements are in place to find out if these resources were allocated and spent in the most effective way. The role of the RMP is to provide feedback to regulators, dischargers, and citizens about how their management programs, individual actions, and life style changes are reflected in the condition of the Estuary.

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Acknowledgments

This report is the product of a tremendous amount of work by many people. Their contributions are gratefully acknowledged: Steve Ritchie, the Executive Officer of the San Francisco Regional Board, Michael Carlin and the staff of the Planning Division, and the report authors from the Regional Board listed below were instrumental in planning and implementing the RMP. The RMP was sponsored by 63 agencies in the region (listed inside the front cover). Their support and participation is appreciated. Numerous comments and suggestions were recieved from many reviewers. We greatly appreciate their input.

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In addition to the Principal Investigators listed on Table 1, their technical staffs are gratefully acknowledged.

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Appendices



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APPENDIX 1

Detailed Description of Methods

Water Sampling

One of the objectives of the RMP is to evaluate if water quality objectives at the stations sampled are met. Therefore, the sampling and analysis methods have to be able to meet quantification levels below the water quality objectives. In order to attain the low detection levels used in the RMP (Appendix Table 2.1), ultra-clean sampling methods were used in all sampling procedures (Flegal and Stukas 1987).

Water samples were collected approximately one meter below the water surface using pumps. The sampling ports for both the organic chemistry and trace element samplers were attached to aluminum poles that were oriented up-current from the vessel and upwind from equipment and personnel. The vessel was anchored and the engines turned off.

Total and dissolved fractions of Estuary water were collected. The evolution of the trace organic sampling system has been described in a series of papers (Risebrough et al. 1976; de Lappe et al. 1980; 1983). Water was pumped by a Teflon impeller pump with 3/4" Teflon tubing through a glass fiber filter $(1 \,\mu m)$ providing a sample of particulate-associated contaminants. The water was then passed through four exhaustively cleaned polyurethane foam plugs mounted in series which adsorbed the dissolved material. The entire sampling system was thoroughly rinsed with methanol prior to sampling, and an all-Teflon-stainless steel system further minimized potential contamination. During sampling, the system was closed to outside sources of contamination, and extreme precaution is taken at other times to minimize, if not eliminate, the introduction of contaminants. Total organics were calculated by adding particulate and dissolved fractions.

For trace metals, water samples were collected using a peristaltic pump system equipped with C-Flex tubing in the pump head. Sample aliquoting was conducted on deck on the windward side of the ship to minimize contamination from shipboard sources. The applicability of this sampling procedure has been demonstrated previously with intercalibrated analyses of water collected with the California Institute of Technology Deep Water Sampler and General Oceanics, Inc. trace metal clean Go-Flos (Flegal and Stukas 1987). Filtered water was obtained by placing an acid-cleaned polypropylene filter cartridge (Micron Separations, Inc., $0.45 \mu m$ pore size) on the outlet of the pumping system. Unfiltered water was pumped directly into sample containers. Prior to collecting water, several liters of water was pumped through the system, and bottles were rinsed three times before filling. Samples were acidified on board the vessel at the end of each second day except for chromium, which was acidified and extracted within an hour of collection.

Samples for conventional water quality parameters were collected using the same apparatus as for trace metals. Water samples were collected for bioassays using the same pumping apparatus as for the collection of the trace organics sample, but were not filtered. Five gallons of water were collected, and placed in ice chests for transfer at the end of each cruise day to the testing laboratory. Two field blanks were collected each cruise consisting of water known to be non-toxic from the Bodega Marine Laboratory and then filtered (0.45µm).

Sediment Sampling

Sediment sampling was conducted using a modified Van Veen grab with a surface area of 0.1 m². The grab is made of stainless steel, and the jaws and doors are coated with dykon (formerly known as kynar) to achieve chemical inertness. All scoops, buckets, and stirrers used to collect and composite sediments were also constructed of Teflon or stainless steel coated with dykon. Sediment sampling equipment was thoroughly cleaned prior to each sampling event. When the sampler was on deck, a sub-core was removed for measurement of the oxidation-reduction potential (Eh) at 2.5 cm and 5.0 cm using a temperaturecompensated Eh meter (Corning Model 240). Then, the top 5 cm of sediment was 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. The quality of grab samples was ensured by requiring each sample to satisfy a set of criteria concerning depth of penetration and disturbance of the sediment within the grab.

Benthos Sampling

Benthic invertebrates were collected with a 0.05m² Ponar grab sampler, with assistance from staff of the City and County of San Francisco. Samples were screened through 1.0mm and 0.5mm mesh screens and fixed in 10% borax-buffered formalin. In the laboratory, the samples were transferred to 70% ethanol, sorted to major taxa, and identified to the lowest practical taxon, usually species.

Bivalve Bioaccumulation Sampling

Bivalves were collected from uncontaminated sites and transplanted to 15 stations in the Estuary during the wet season (February through May) and the dry season (June through September). Contaminant concentrations in the animals' tissues, and the animals' biological condition (expressed as the ratio of dry weight and shell cavity volume) were measured before deployment (referred to as 'time zero' or 'background') and at the end of the 90-100 day deployment period. Survival during deployment was also measured. Composites of tissue were made from 40-60 individual bivalves from each site before and after deployment for analyses of trace contaminants.

As an improvement to the 1993 protocol, the condition of animals at "control" sites at Lake Isabella (*Corbicula fluminea*), Bodega Head (*Mytilus californianus*) and Tomales Bay (*Crassostrea gigas*) was also determined at the end of each deployment period in order to sort out Estuary effects from natural factors affecting bivalve condition.

Since the RMP sites encompass a range of salinities, three species of bivalves were used, according to the expected salinities in each area and the known tolerances of the organisms. The mussel Mytilus californianus was collected from Bodega Head and stored in running seawater at the Bodega Marine Laboratory until deployment at the stations expected to have the highest salinities, west of Carquinez Strait. Mytilus californianus will survive exposure to salinities as low as 5 ppt (Bayne 1976). The oyster Crassostrea gigas was obtained from Tomales Bay Oyster Company (Marshall, CA) and deployed at the three moderate-salinity sites closest to Carquinez Strait. Crassostrea gigas tolerates salinities as low as 2 ppt. The freshwater clam Corbicula fluminea was collected from Lake Isabella and deployed at the three most eastern sites with the lowest salinities. Corbicula fluminea tolerates salinities from 0 ppt to perhaps 10 ppt (Foe and Knight 1986). The effects of high short-term flows of freshwater on the transplanted bivalves west of Carquinez Strait were minimized by deploying the bivalves near the bottom where density gradients tend to maintain higher salinities. All bivalves were kept on ice after collection and deployed within 24-48 hours.

Within each species, animals of approximately the same size were used. Mussels were between 49-81 mm shell length, oysters were between 71-149 mm, and clams were 25-36 mm. One-hundred-fifty oysters and 160 mussels and clams were randomly allocated for deployment at the appropriate sites, with the same number being used as a 'travel blank' (time zero) sample for analysis of tissue and condition before deployment. At each site, oysters were divided among five nylon mesh bags, and mussels and clams were divided among four nylon mesh bags.

Moorings were associated with pilings or other permanent structures. Mooring installation, bivalve deployment, maintenance, and retrieval were all accomplished by SCUBA divers. The deployed samples were checked approximately half-way through the 90day deployment period to ensure consistent exposure. Moorings and nylon bags were checked for damage and repaired, and fouling organisms were removed.

Upon retrieval, the bags of bivalves were placed into polyethylene bags and taken to the surface. On the vessel, the number of dead organisms was noted, with 20 percent of the live organisms being allocated for condition measurement, and the remainder being equally split for analyses of trace metals and organic compounds. Based on findings by Stephenson (1992) during the RMP Pilot Program, bivalve guts were not depurated before homogenization for tissues analyses, although gonads were removed from organisms for trace metal analyses. Stephenson (1992) found that, with the exception of lead and selenium, no significant differences were found in trace metal concentrations between mussels held for 48 hours in "clean" Granite Canyon seawater before homogenization and undepurated mussels. However, sediment in bivalve guts may contribute to the total "tissue" contaminant concentration and introduce an unspecified amount of error into the measurement process. In order to obtain an estimate of that error, aluminum concentrations in bivalves were measured in 1994. Aluminum is a conservative element that generally is not taken up and incorporated into bivalve tissue. It can serve as an indicator of what proportion of sediment in bivalve guts contributes to the "tissue" metal values and as a quality assurance check.

Analytical Methods

Conventional Water Quality Parameters

Samples for dissolved phosphates, silicates, nitrate, nitrite, and ammonia were analyzed following the procedures described by Parsons et al. (1984). Total chlorophyll was measured using a fluorometric technique with filtered material from 200 ml samples (Parsons et al. 1984). Shipboard measurements for temperature and salinity were obtained using a portable conductivity/ salinity meter (YSI model 33), pH was measured with a portable pH meter (Orion SA250), and dissolved oxygen content was measured using a portable dissolved oxygen meter (YSI model 58). Dissolved organic carbon (DOC) was measured using high-temperature catalytic oxidation with a platinum catalyst (Fitzwater and Martin 1993). Total Suspended Solids (TSS) were determined using method 2540D in Standard Methods for the Examination of Water and Wastewater (Greenberg et al. 1992)

A Sea-Bird SBE19 Conductivity, Temperature and Depth probe (CTD) was used to measure water quality parameters at depths throughout the water column. CTD casts were taken at each site during water and sediment sampling. At each site, the CTD was lowered to approximately one meter below the water surface and allowed to equilibrate to ambient temperature for 3 minutes. The CTD was then lowered to the bottom at approximately 0.15 meters per second, and raised. Only data from the down cast were kept. Data were downloaded onboard the ship, and processed in the lab using software supplied by Sea-Bird.

The CTD measures temperature, conductivity, pressure, dissolved oxygen, and backscatter at a sampling rate of two scans per second. These data were edited and averaged into 0.25 m depth bins during processing. Also during processing, salinity (based on conductivity measurements), oxygen, time, and depth (based on pressure) were calculated. Later, SFEI calculated density and total suspended solids (TSS), which were compared with measurements obtained using the standard methods described above. Although the CTD data are not detailed in this report, SFEI maintains the data points in its data base. However, during the three water cruises, CTD measurements for temperature, salinity and dissolved oxygen were used to compare with those obtained via grab sample at 1 m when water was sampled for trace metal analysis. Results from the two methods were compared by calculating correlation coefficients for each parameter using data at 1 m (Appendix Table 1.1). Also compared are the values for TSS measured using the first method, and TSS computed from the CTD's measurement of backscatter. Only half of the CTD data used in the calculations are of the highest quality, though none are considered 'bad' data. Excluding the values of lesser quality does not change the correlation coefficients significantly.

Trace Elements

Total and dissolved (0.45 µm filtered) concentrations of arsenic, chromium, mercury, and selenium in water were measured, and near-total and dissolved concentrations of cadmium, copper, nickel, lead, silver, and zinc in water were measured. Appendix Table 1.2 summarizes individual methods and associated references. Near-total concentrations were used in the RMP for consistency with the BPTCP pilot studies results. Total metals in water are usually extracted with
| Parameter | February | April | August |
|------------------|----------|--------|--------|
| Salinity | 0.999* | 0.996* | 0.982* |
| Temperature | 0.837* | 0.952* | 0.827* |
| Dissolved Oxygen | 0.271 | 0.738* | 0.922* |
| TSS | 0.802* | 0.966* | 0.902* |

Table 1.1. Correlation coefficients between data collected by UCSC and by the CTD sensors.

* indicates correlation above the 95% level of confidence.

boiling aqua regia (a mixture of three parts concentrated hydrochloric acid and one part concentrated nitric acid) which extracts virtually all metals from the sample. Neartotal metals are extracted with a weak acid (pH < 2) for a minimum of one month, resulting in measurements that approximate bioavailability of some metals to Estuary organisms (Smith and Flegal 1993). Near-total concentrations underestimate total metals concentrations by an unknown amount. Therefore, comparisons to water quality objectives tend to be rather conservative.

To determine total chromium concentrations, the particulate matter in the sample was extracted and analyzed, rather than analyzing unfiltered samples. Total mercury samples were photo-oxidized with the addition of bromium chloride and quantified using a cold vapor atomic fluorescence technique. Trace metals (except for arsenic, mercury, and selenium) in water were measured using graphite furnace atomic absorption spectrometry preceded by sample preconcentration using the APDC/DDC organic extraction method (Bruland *et al.* 1985; Flegal *et al.* 1991).

Results for cadmium, copper, nickel, lead, silver, and zinc were reported by the laboratory in units of $\mu g/kg$. For use in this report, those values are reported as $\mu g/L$, without taking account of the difference in density between Estuary water and distilled water. This difference was not taken into account because it was much less than the precision of the data, which was on the order of 10% (see QA information in Appendix Tables 2.5, 2.8). In some instances, dissolved metals concentrations are reported as higher than total (dissolved+particulate) metals concentrations. This is due to expected analytical variation in the methods of analysis, particularly at concentrations near the detection limits. Such results should be interpreted as no difference between dissolved and total concentrations or that the total fraction of metals is in the dissolved phase.

Metals in sediments were extracted with aqua regia and analyzed as described in the standard methods developed for measuring trace element concentrations in marine sediments and wastewater sludge for the California State Water Resources Control Board (Flegal et al. 1981). This report compares several extraction procedures. The method chosen for RMP sediment analysis is comparable to standard EPA procedures (Tetra Tech 1986) but does not decompose the silicate matrix of the sediment. Because of this, any element tightly bound as a naturally occurring silicate may not be fully recovered, as is the case with hydrofluoric acid digestion. In order to eliminate possible confusion between the terms "near-total" concentrations of metals in water and sediment, the term near-total extraction in sediment based on the aqua regia digestion is therefore avoided.

Bivalve tissue samples were analyzed with techniques used in the California State Mussel Watch (e.g., Flegal *et al.* 1981; Smith *et al.* 1986) and consistent with the Pilot Program (Stephenson 1992). Hydride generation coupled with atomic absorption spectroscopy was used to quantify arsenic. Mercury was quantified using a cold-vapor atomic fluorescence technique, and selenium was quantified using the methods of Cutter (1986). Tributyltin was measured following NOAA Status and Trends Mussel Watch Project methods described in NOAA Technical Memorandum NOS/ORCA/CMBAD71 vol. IV. This technique involves extracting the sample with hexane and the chelating agent tropolone and measuring the butyltin residues by capillary

| Table 1.2. Summ: | ary of analyt | ical methods. | |
|---------------------------------------|-----------------|---|--|
| Parameter | Matrix | Method | Reference |
| Ag, Cd, Cu, Ni, Pb, Zn | WCT/WCD | Atomic absorption spectrometry (AAS) preceded by sample pre-concentration using APDC/DDC organic extraction method | 1 Bruland et al. (1985) |
| Ag, Cd, Cu, Pb, Ni, Zn. Fe. Al. Mn | SED / TISS | Inductively coupled plasma atomic emission spectroscopy after aqua regia digestion | Flegal et al. (1981) |
| Dissolved Cr | WCD | Ferrous hydroxide co-precipitation followed by GFAAS | Cranston & Murray (1978) |
| Fariculate Cr Hg | WCT/WCD | oratile turnace AAS preceded by six step actu digestion Oxidation, reduction, gold amalgamation, and CVAFS detection | Lormg (1979) Gill & Fitzgerald (1985): Liang & Bloom (1993) |
| As | WCT/WCD | Hydride generation, cryogenic pre-concentration, GC separation, and AAS detection | Crecelius et al. (1986); Braman et al. (1977) |
| Se | WCT/WCD | Hydride generation, cryogenic pre-concentration, GC separation, and AAS detection | Liang et al. (1994) |
| TBT in tissue Organic chemicals in | TISS WCT/WCD | Tissue extracted and analyzed by flame photometric detection Sovhelet extraction flourisit clean_un_GC/MS | Peven & Uhler (1993) After de Lanne et al. (1983) |
| water | | | truct de tappe et al. (1702) |
| Organic chemicals in | SED | Soxhelet extraction, purification with silica/alumina column chromatography, analysis by capilary gas | |
| sediment | TICC | chromatography with various detectors | |
| Organic cnemicals in fissue | CC11 | Extraction with NaZ>O4 and memylene chloride, purification with sinca/atumina column chromatography, analysi by canilary oss chromatography with various detectors | 20 |
| Dissolved PO4 | WCD | PO4 reduction using ascorbic acid containing Mo and measured spectrophotometrically | Parsons et al. (1984) |
| Dissolved silicate | WCD | Reaction with molybdate, reduction with metol-sulfite and measured spectrophotometrically | Parsons et al. (984) |
| Dissolved NH3 | WCD | Treatment with sodium hypochlorite and phenol in the presence of sodium nitroferricyanide and measured | Parsons et al. (1984) |
| Dissolved NO3, NO2 | WCD | secucions account and measured spectronhotometrically | Parsons et al. (1984) |
| Chlorophyll-a | WCD | Flourometric measurement of filtered particulates | Parsons et al. (1984) |
| Hardness | WCT | Titration and spectrophotometric measurement | EPA standard method 314B (1985) |
| Hd | WCD | Shipboard measurement using an Orion model SA250 pH meter | NA |
| Salinity | WCT | Shipboard measurement using a YSI model 33 conductivity/salinity meter; in lab with calibrated inductive salinometer | NA |
| CTD: sal., temp., cond., TSS, D.O. | WCT | Shipboard measurement using Seabird Model 19 CTD | NA |
| TSS | WCT | Dry weight measurement after filteration through 0.45 micron filter | Greenburg et al. (1992) |
| Dissolved Organic Carbon | WCD | High temperature catalytic oxidation with platinum catalyst | Fitzwater & Martin (1993) |
| Bivalve condition index | TISS | Liquid displacement and gravimentric determination | Pridmore et al. (1990) |
| Grain Size | SED | Hydrogen peroxide digestion, sieving for gravel $\&$ sand fractions, and sedigraph for silt and clay. | Flegal & Hibdon(in preparation) |
| Total Organic Carbon | SED | Coulometrics | MISO Carbon Analyser Manual |
| Eh in sediment | SED | Measured on ship with a Corning model 240 pH meter | NA |
| Aquatic Toxicity | WCT | 48-hr bivalve larval development test, 7-day Mysid growth and fecundity test | ASTM method E 724-89 |
| Benthic Infauna | SED | Shipboard sampling, identification and counting in laboratory | NA |
| | | | |

gas chromatography. TBT concentrations are expressed in Sn molecular weight.

Trace Organics

For water samples, plugs and filters were extracted in custom-built soxhlet extraction units. Extracts were reduced to 1-2 ml in hexane for cleanup with florisilcolumn chromatography. Chlorinated hydrocarbons (CH) in each of the three analytical fractions (F1, F2, F3) were analyzed on a Hewlett Packard 5890 Series II capillary gas chromatograph utilizing electron capture detectors (GC/ECD). A single 2µL splitless injection was directed onto two 60 m x 0.25 mm. columns of different polarity (DB-17 and DB-5) using a y-splitter to provide twodimensional confirmation of each analyte. The quantitation internal standard utilized for the CH analysis was dibromo-octafluorobiphenyl (DOB). Decachlorobiphenyl (PCB 209) was introduced to each sample prior to fractionation. This compound was treated as a surrogate standard, and analyte concentrations were corrected for PCB 209 losses prior to reporting.

PAHs were quantified in the F-2 fraction by analysis on a Hewlett-Packard 5890 Series II capillary gas chromatograph equipped with a 5971A mass spectral detector (GC/MS). A 2µL splitless injection was chromatographed on a DB-5 column and analyzed in a single ion monitoring (SIM) mode. The quantitation internal standard utilized for the PAH analysis when samples were at 100µL was hexamethyl benzene (HMB). Samples quantitated at a final volume of 1mL utilized deuterated fluoranthene. Deuterated phenanthrene and deuterated chrysene were spiked into each sample prior to fractionation. All PAH concentrations were corrected for deuterated phenanthrene recoveries prior to reporting. Sediment samples were freeze-dried, mixed with kilnfired sodium sulfate, and soxhlet-extracted with methylene chloride. The extract was concentrated and purified using EPA Method 3611 alumina column purification to remove matrix interferences. Tissue samples were homogenized and macerated, and the eluate was dried with sodium sulfate, concentrated, and purified using a combination of EPA Method 3611 alumina column purification and EPA Method 3630 silica gel purification to remove matrix interferences. Appendix Table 4.1-4.9 outline the frequency of detection for trace organic contaminants in all three media.

Aquatic Bioassays

Water column toxicity was evaluated using a 48-hour mollusk embryo development test and a seven-day growth test using the estuarine mysid Mysidopsis bahia. The bivalve embryo development test was performed according to ASTM standard method E 724-89 (ASTM 1991). The mysid test was based on EPA test method 1007. Larval Mytilus edulis were used in the February samples, and larval Crassostrea gigas were used in the August samples. Different species were used due to seasonal differences in larval availability. The mysid growth and survival test consisted of an exposure of 7day old Mysidopsis bahia juveniles to different concentrations of Estuary water in a static system during the period of egg development and was used during both sampling periods. Appropriate salinity adjustments were made for Estuary water from sampling stations with salinities below the test species' optimal ranges.Reference toxicant tests with copper chloride and potassium dichromate were performed for the bivalve and mysid tests, respectively. These tests were used to determine if the responses of the test organisms were relatively consistant over time.

The striped bass test was conducted by taking grab samples from the Sacramento River at Rio Vista and the San Joaquin River at Manteca on May 11, 1994. The test procedures were based upon methods outlined in the "Development of Aquatic Toxicity Testing Guidelines for Resident Aquatic Species of the Sacramento-San Joaquin Delta/Estuary" (SWRCB) with the following modifications:

1. The age of the test organisms was 12-13 days old, rather than 24 hour post-hatch larvae.

2. The test duration was 10 days rather than 28 days.

3. The test was conducted as a static daily renewal rather than a flow-through bioassay.

4. The test chambers used were opaque, 2-L highdensity polyethylene beakers rather than glass aquaria. 5. The test volume was 1 L per replicate (days 1-5) and 2 L per replicate (days 6-10) to accommodate for the growth of the larvae, not 3 L per replicate.

The salinities of the ambient samples and the control/ diluent (Evian spring water) were adjusted to 5 ppt using artificial sea-salts (Tropic Marin). The test concentrations were 100%, 50%, and control, each with four replicates, and with 20 larvae per replicate. Wastes, dead larvae, excess food, and 80% of the test water were siphoned from the test chambers daily, and general water chemistry paramters of dissolved oxygen, pH, and salinity were recorded before and after each water change.

Sediment Quality Characteristics

Eh was measured on board using a temperaturecompensated Eh meter (Corning 240). Sediment size fractions were determined with a grain-size analyzer based on x-ray transmission (Sedigraph 5100). Total organic carbon was analyzed according to the standard method for the Coulometrics CM 150 Analyzer made by UIC, Inc. This method involves measurements of transmitted light through a cell. The amount of transmitted light is related to the amount of carbon dioxide evolved from a combusted sample.

Sediment Bioassays

Two sediment bioassays were used: a ten-day acute mortality test using the estuarine amphipod *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). Elutriate solutions were prepared by adding 100 g of sediment to 400 ml of Granite Canyon sea water, shaken for 10 seconds, allowed to settle for 24 hours, and carefully decanted (USEPA/ACOE 1977; Tetra Tech 1986). Larval mussels (*Mytilus edulis*) were used in both sampling periods, where percent normally developed larvae was the endpoint measured.

Bivalve Condition and Survival

The condition of bivalves is a measure of their general health following exposure to Estuary water for 90-100 days. Measurements such as length, weight, volume, or ratios of those measurements have been used as indicators of integrated physiological response to contaminants in water (Pridmore et al. 1990; KLI 1984). Measurements were made on subsamples of specimens before deployment and on the deployed specimens following exposure. Dry weight (without the shell) and the volume of the shell cavity of each bivalve was measured. Bivalve tissue was removed from the specimens and dried at 60° C in an oven for 48 hours before weighing. Shell cavity volume was calculated by subtracting shell volume of water displaced by a whole live bivalve less the volume of water displaced by the shell alone. The condition index is calculated by taking the ratio of tissue dry weight and the shell cavity volume.

As in 1993, several Pilot and Special Studies were conducted as part of the RMP. The rationale, methods, and results of each of these studies are detailed in separate sections.

APPENDIX 2

Quality Assurance

During the start-up phases of the Regional Monitoring Program for Trace Substances, emphasis was placed on building on the efforts of the RMP pilot studies that were part of the State's Bay Protection and Toxic Cleanup Program (BPTCP). The guiding principle behind the RMP data collection and analysis efforts has been to use state-of-the-art field and laboratory techniques that were best able to meet the overall objectives of the program.

Data quality objectives are closely tied to the questions the RMP is designed to answer, and typically these questions are specified by the potential users of the data. Since the RMP is a new program that currently is primarily collecting baseline data, the only specific data quality objective for estimating the status of trace substance concentrations is: " To determine whether water quality and sediment quality in the Estuary at large are in compliance with objectives established by the Basin Plan." Other objectives of the RMP, such as obtaining baseline data, and determining trends in water quality parameters, are as of yet too general to develop the necessary decision and uncertainty criteria which are basic to the establishment of data quality objectives. For example, in order to estimate trends in water quality parameters, data users would have to decide what kind of change in water or sediment quality parameters, or bioaccumulation they would like to distinguish with a known level of certainty, such as a 25% change over a five-year period, at a minimum significance level of 0.1 and a minimum power level of 0.8. These decisions have not yet been made, but preparatory steps are underway as part of the Special Study on optimal sampling design and replication.

Participating laboratories were chosen on the basis of their capability to meet the data quality objective of comparing water quality parameters with corresponding Basin Plan standards and by evaluating their performance record. Quality assurance and control procedures were largely adapted from the pilot studies and are being updated on a regular basis. All participating laboratories are required to maintain detailed records of laboratory procedures and do not submit data whose integrity appears compromised without proper qualifications.

Since the RMP is *not* a regulatory program, but collects information designed to guide management decisions by a wide variety of data users, emphasis was placed on employing the most advanced measurement systems, although this choice compromised the ability to compare RMP data to regulatory standards to some extent, as described in the Methods section. RMP laboratories and field crews control measurement error to the greatest extent possible, which is reflected in the chosen field sampling protocols and laboratory analysis procedures. Quality objectives for the various measurements being made in the RMP are expressed in terms of accuracy, precision, and completeness requirements. These objectives were established based on instrument manufacturers' specifications, scientific experience, and historical data, particularly those obtained during the RMP Pilot Project. Appendix Tables 2.1-2.3 provide summaries of data quality objectives for water, sediment, and tissue analyses. Because the RMP was built on the Regional Board's Pilot Studies using essentially the same laboratories of high reputation that had already undergone a very strict evaluation process with respect to field and laboratory quality control measures, the individual QA components for a comprehensive Quality Assurance Report that includes explicit evaluations of individual data sets are only now being compiled in preparation for the 1997 Program Review. Ideally, demonstration of field sampling and analytical capabilities takes place annually for all parameters being measured, and as the RMP matures, formal guidance for consistent performance demonstrations will be implemented.

Representativeness

The data quality attribute of "representativeness" applies not only to the overall sampling design, but also to individual measurements and samples obtained as part of the RMP monitoring efforts. Holding time requirements for different types of samples ensure that analytical results are representative of conditions at the time of sampling. In addition, use of quality control samples which are similar in composition to samples being measured provides estimates of precision and bias that are representative of sample measurements. Therefore, as a general program objective, the types of QA documentation samples (i.e. performance evaluation material) used to assess the quality of analytical data are as representative as possible of the natural samples collected during the project with respect to both composition and concentration.

Completeness

Completeness is defined as "a measure of the amount of data collected from a measurement process compared to the amount that was expected to be obtained under the conditions of measurement" (Stanley and Verner 1985). The RMP established completeness goals between 90% and 98% for the various parameters being measured. These completeness goals were established in an attempt to provide a comprehensive set of data for each sampling location. Failure to achieve these goals usually results from lost or destroyed samples. Therefore, established protocols for tracking samples during shipment and laboratory processing are followed to minimize data loss following successful sample collection.

Comparability

Comparability is defined as "the confidence with which one data set can be compared to another" (Stanley and Verner 1985). One goal of the RMP is to generate a high level of documentation for reporting units and calculations, data base management processes, and interpretative procedures to ensure that future RMP efforts and those of other monitoring programs can be made comparable. To insure that comparisons with other monitoring programs are possible and meaningful, intercalibration efforts are currently underway (see 1995 Implementation Plan; SFEI 1994). Periodically, samples also are split among RMP and outside laboratories.

In 1994, split sample analyses were conducted on selenium by two separate laboratories on triplicate samples of tissue, sediment, and water taken from the RMP's Davis Point site (BD40), in August of 1994. The laboratories involved were: Brooks Rand Laboratories (BRL) of Seattle, Washington, and Olson Biochemistry Laboratories of South Dakota State University (SDSU). Dr. Ivan Palmer and his staff graciously donated their services to the RMP. BRL used an oxidation, reduction, cryogenic trap preconcentration and hydride generation atomic absorption method for all three sample types. SDSU used a hydride generation atomic absorption method for sediment analyses, but used a fluorometric method for tissue and water analyses. This method had a higher detection limit.

The analytical results are presented in Appendix Table 2.4 along with the results of a t-test. Sediment results were not statistically different between BRL and SDSU, while water and tissue results were significantly different. All three sample matrices met precision and accuracy criteria at both labs.

SDSU's MDLs were barely above the selenium levels found in water at the Davis Point (BD40) station, although results for all three matrices showed high precision. Recovery of matrix spikes was well within acceptable range, as well as analysis of NIST1643c standard reference material. It needs to be stressed, though, that the reference material was more than 20 times above concentrations found in sample water, and conclusions about the accuracy of SDSU water measurements cannot easily be drawn.

The split sample comparison for water and tissue was inconclusive, possibly due to low confidence in the SDSU results for water that were very close to the detection limit. The discrepancies in tissue results are probably based on inhomogeneous split samples, since both labs used suitable reference material and met QA criteria for accuracy. The much greater variability in the BRL replicates supports this hypothesis.

This example points out the benefits of split sample analysis. It indicated that improvements in the tissue sample preparation and homogenization are in order to reduce variability in RMP samples.

Within the RMP, certain data points are collected with two different methods to check the reliability of data, as was the case with salinity and oxygen measurements taken with the CTD and via grab sample. The two methods are significantly correlated at the 99% level for almost every parameter (see Appendix Table 1.1). The exception is dissolved oxygen during the February water cruise, which has a correlation coefficient of only 0.271. However, exclusion of a single oxygen data point (BG20) raises the correlation for oxygen above the 99% level.

Accuracy, Precision, and Total Error

The term "accuracy", which is used synonymously with the term bias, is defined as the difference between a measured value and the true or expected value, and represents an estimate of systematic error or net bias. Precision is defined as the degree of mutual agreement among individual measurements, and represents an estimate of random error. Collectively, accuracy and precision can provide an estimate of the total error or uncertainty associated with an individual measured value (Kirchner 1983; Hunt and Wilson 1986; Taylor 1987). Measurement quality objectives for the various indicators are expressed separately as accuracy (i.e. bias) and precision requirements. Accuracy and precision requirements may not be definable for all parameters due to the nature of the measurement type. For example, accuracy measurements are not possible for toxicity testing because "true" or expected values do not exist for these measurement parameters. In addition, no certified reference material exists for trace organic contaminants in water, and accuracy estimates are difficult to obtain. Summaries of QA results are presented in Appendix Tables 2.5-2.10.

A few elements fell outside accuracy acceptance criteria. Difficulty meeting QA target values were due primarily to incomplete matrix digestion with the aqua regia method. The elements which typically give low recoveries are aluminum, chromium, iron, manganese, and nickel. Three of these (Al, Fe, Mn) are metals that are major components of the earth's crustal matrix. The other two (Cr and Ni) are refractory elements that are not easily mobilized from the matrix. Only multi-step hydrofluoric (HF) microwave bomb digestion is able to completely digest and liquefy crustal matrix elements and kinetically inert elements. Historically, San Francisco Bay sediments analyzed using EPA methods have yielded chromium and nickel concentrations similar to those measured by the RMP. During the Pilot Program, it was decided not to use the HF bomb digestion. Typically, the aqua regia method will effectively extract silver, cadmium, copper, lead, and zinc.Occasionally low or high recoveries are due to instrumental variation. In particular, lead often gives low recoveries due to matrix interferences.

The evolution of the QA Program will continue. In 1995, the Quality Assurance Project Plan recieved major revisions. Because of emerging information needs by participating agencies, and in preparation for the Program Review, new QA components are being added and will be reported in the 1995 Annual Report.

| Analytical Measurement | Precision | Accuracy | Complete- | Detection Limit | QC Samples at frequency | Acceptance | Corrective |
|--|-----------|----------|-----------|--------------------|---|--|--|
| Wedstrement | (±%) | (± %) | (%) | Linit | (#s = number of samples) | chichu | nouon |
| Biocides, PCBs | 20 | t | 95 | 50 pg/L | LB at 10s, R at 3/cruise | LB < MDL; | LB: reanalyze 10 samples; |
| | | | | | | RPD of R \pm 20% | R:recalibrate and /or reanalyze |
| PAHs, alkanes, and other HCs | 20 | ţ | 95 | 50 pg/L | ¥ | ¥ | ₩ |
| Hg | 20 | 25 | 90 | 0.1 ng/L | LB & T at 10 s, SP at 20 s | LB < MDL; Recovery of SP or $R \pm$ accuracy DQO; | LB: reanalyze all 10 samples; FB: reanalyze/qualify data; |
| As | 25 | 25 | 90 | 2 ng/L | | RSD of T \pm precision DQO | T, SP, R: recalibrate and/or reanalyze |
| Se | 35 | 35 | 90 | 5 ng/L | ¥ | ¥. | ¥ |
| Cd, total* | 15 | 25 or † | 95 | <0.38 ng/kg | ED at ≈10s; R at once/cruise;. A all s; IB at 30s; EB at 2/cruise | IB,EB < MDL; Recovery of R± accuracy DQO; | ED: rextract/reanalyze sample; |
| Cr, total* | 15 | 25 or † | 95 | <353 ng/kg | | RPD of ED <15%; RPD of A <15% | R: recalibrate/re-extract/reanalyze sample set; |
| Cu, total* | 15 | 25 or † | 95 | <6.58 ng/kg | | I | A: recalibrate/reanalyze; |
| Pb, total* | 15 | 25 or † | 95 | <4.97 ng/kg | | | IB: check instrument, reanalyze; |
| Ni, total* | 15 | 25 or † | 95 | <9.50 ng/kg | | | EB: re-extract sample set |
| Ag, total* | 15 | 25 or † | 95 | <1.16 ng/kg | | | I I |
| Zn, total* | 15 | 25 or † | 95 | <7.38 ng/kg | | | |
| Cd, dissolved* | 15 | 25 or † | 95 | <0.34 ng/kg | | | |
| Cr, dissolved* | 15 | 25 or † | 95 | <25 ng/kg | | | |
| Cu, dissolved* | 15 | 25 or † | 95 | <5.81 ng/kg | | | |
| Pb, dissolved* | 15 | 25 or † | 95 | <2.79 ng/kg | | | |
| Ni, dissolved* | 15 | 25 or † | 95 | <5.44 ng/kg | | | |
| Ag, dissolved* | 15 | 25 or † | 95 | <0.25 ng/kg | | | |
| Zn, dissolved* | 15 | 25 or † | 95 | <0.82 ng/kg | ¥ | ¥ | ¥ |
| Mytilus & Mysid toxicity test | n/a | n/a | 95 | | R Toxicant@ one/set of organisms; FB@2/cruise | R within 2 std. dev. ; FB = no apparent toxoicity | R: evaluate organism health, culturing procedures, consider data interpretation; FB: evaluate problem, change procedures |
| Striped bass toxicity test (pilot) | n/a | n/a | 95 | | R Toxicant for organism | R within 2 std. dev. ; FB = no apparent toxoicity | ¥ |
| Ammonia | 15 | 25 or † | 95 | 0.45 µM | R, D,IB at once/sample set, A all s | RPD of D <15%; RPD of A <10% | D: re-extract/reanalyze; |
| Nitrate | 15 | 25 or † | 95 | 0.20 µM | | IB < MDL | A: recalibrate/reanalyze; |
| Nitrite | 15 | n/a | 95 | 0.10 µM | | Recovery of R ± accuracy DQO | IB: check instrument, reanalyze |
| Phosphate | 15 | 25 or † | 95 | 0.10 µM | | | |
| Silicate | 15 | n/a | 95 | 0.36 µM | * | V | V |
| Chl-a | 15 | n/a | 95 | 0.2 mg/m3 | D,IB at once/sample set | RPD of A <10%, RPD of D <15% | D: re-extract/reanalyze, A: recalibrate/reanalyze, B: check instrument, reanalyze |
| DOC | 5 | 10 | 95 | 5 μΜ | LB at 10s, SP at monthly, R at once/sample set | LB< MDL, RPD of R <5%, recovery of SP ± 10% | LB,R: recalibrate/reanalyze; SP: check instrument/reanalyze |
| Salinity | 15 | n/a | 95 | n/a | A all s, IB at once/sample set | IB < MDL, RPD of A <15% | IB: reanalyze set, A: check instrument/reanalyze |
| TSS | 25 | n/a | 95 | < 2 mg/L | LB at 10s, D at 10s | LB < MDL, RPD < 25% | LB, D: reanalyze sample |

Table 2.1. Summary of data quality objectives and quality control samples for laboratory analysis of water.

LB = lab blank A=analytical replicate, IB= instrument blank SP=spike, R=reference material, T=triplicate, D=duplicate, EB=extraction blank, ED=extraction duplicate, s=samples, († use value from certified R if applicable), (*actual MDL calculated for each set of samples) (RPD = relative percent difference)

LB = lab blank A=an/alytical replicate, IB= instrument blank SP=spike, R=reference material, T=triplicate, D=duplicate, EB=extraction blank, ED=extraction duplicate, s=samples, († use value from certified R if applicable), (*actual MDL calculated with each set of samples) (RPD = relative percent difference) (^a on a dry weight basis)

| Analytical Analytical Measurement Biocides, PCBs PAHs, alkanes, other hydrocarbons Hg | y of data Precision (±%) 20 20 35 35 | quality of Accuracy (± %) 20 20 20 20 20 20 20 20 20 20 20 20 20 25 25 | Complete- ness (%) 98 98 98 90 90 | nd quality cor Detection Limit ^a 1 ng/g 5 ng/g 0.005 mg/kg 1.6 mg/kg | QC Samples for laborat QC Samples @ frequency (#s = no. of samples) LB@10s, R@3/cruise ↓ LB & T@10s, R@20s; LB & T@ 10s, R@ 20s | Acceptance Acceptance Criteria LB < MDL; RPD of R ±20% ↓ LB < MDL; Recovery of R ± accuracy DQO; RPD of T \$± precision DQO |
|---|---|--|--|---|---|---|
| As Se | 25 35 | 25 35 | 90 90 | 1.6 mg/kg 2.2 mg/kg | - | |
| Cd* | 15 | 25 or † | 95 | <0.02 µg/kg | ED@≈10s, R@once/cruise, A all s; IB @ 30s; EB@2/cruise | EB, I of] |
| Cr* | 15 | 25 or † | 95 | <9.44 mg/kg | | RPI |
| Cu* | 15 | 25 or † | 95 ?- | <4.57 mg/kg | | |
| AI* | 15 | 25 or † | 56 C6 | 0 mg/kg</td <td></td> <td></td> | | |
| Fe* | 15 | 25 or † | 95 | <140 mg/kg | | |
| Pb* | 15 | 25 or † | 95 | <0.1 mg/kg | | |
| Ni* | 15 | 25 or † | 95 | <4.26 mg/kg | | |
| Ag* Zn* | 15 15 | 25 or † 25 or † | 95 95 | <1.2 µg/kg <18.9 mg/kg | 4- | |
| Grain Size (% sand) | 20 | na | 95 | 63 µ | D@10s | |
| Eh | S | 5 | 95 | 10 µMho | R@1/cruise day | |
| TOC | S | S | 95 | 1 μg C/mg | LB@15s, R@15s, T all s | |

| Analytical Measurement | Precision | Accuracy | Complete- | Detection Limit ^a | QC Samples @ frequency | Acceptance Criteria | Corrective Action |
|---------------------------|-----------|----------|-----------|---------------------------------|----------------------------------|---------------------------------|--|
| | ((干)) | (千 %) | (%) | | (#s = no. of samples) | | |
| Biocides, PCBs | 20 | 20 | 98 | 1 ng/g | LB@10s, R@3/cruise | LB < MDL; | LB: reanalyze all 10 samples; |
| PAHs, alkanes, | 20 | 20 | 98 | 5 ng/g | - | RSD of $R \pm 20\%$ | R: recalibrate/reanalyze |
| other hydrocarbons | | | | | | | |
| Hg | 35 | 25 | 90 | 0.001 mg/kg | LB & T@10s, R@20s | LB< MDL; | LB: reanalyze all 10 samples; |
| As | 25 | 25 | 06 | 1.6 mg/kg | LB & T@10s, R@20s | Recovery of R±accuracy DQO; | T & R: recalibrate/reanalyze |
| Se | 35 | 35 | 90 | 2.2 mg/kg | LB & T@10s, R@20s | RSD of $T \pm precision DQO$ | |
| | | | | | | | |
| Cd | 15 | 25 or † | 95 | <0.02 µg/kg | ED@≈10s, R@once/cruise, A all s, | EB, $IB < MDL;$ | ED: rextract/reanalyze sample; |
| Cr | 15 | 25 or † | 95 | <9.44 mg/kg | IB@30s, EB@twice/cruise; | Recovery of R± accuracy DQO; | R: recalibrate/re-extract/reanalyze sample set; |
| Cu | 15 | 25 or † | 95 | <4.57 mg/kg | SP@10s | RPD of SP, ED <15%; | A: recalibrate/reanalyze s; |
| Ag | 15 | 25 or † | 95 | <1.2 µg/kg | | RPD of A $<10\%$ | SP, EB: re-extract sample set; |
| Pb | 15 | 25 or † | 95 | <0.1 mg/kg | | | IB: check instrument, renanlyze |
| Ni | 15 | 25 or † | 95 | <4.26 mg/kg | | | |
| Zn | 15 | 25 or † | 95 | <18.9 mg/kg | | | |
| TBT | 15 | 25 or † | 95 | 0.1 mg/kg | | | |
| Condition | 10 | 10 or † | 95 | n/a | R@ 10 / species | $R \pm 5\%$ accuracy DQO | R: reanalyze sample weights or volumes |
| | | | | | | | |

LB = lab blank A=analytical replicate, IB= instrument blank SP=spike, R=reference material, T=triplicate, D=duplicate, EB=extraction blank, ED=extraction duplicate, s=samples, († use value from certified R if applicable), (*actual MDL calculated with each set of samples) (RPD = relative percent difference) (^a on a dry weight basis)

Table 2.4.Laboratory results and t-test results for selenium analyses of split samples from Brooks Rand Laboratories
(BRL) and Olson Biochemistry Laboratories (SDSU). MDLs for both laboratories were calculated as three times
the standard deviation of the blanks.

| TISSUE:(Crasso | ostrea gigas) | | | | | |
|----------------|---------------|--------|-------|------|---------|---------------|
| LABORATORY | NREPS | RESULT | UNITS | MDL | t-test: | |
| BRL | 1 | 3.54 | ppm | 0.38 | 0.03 | Statistically |
| BRL | 2 | 2.53 | ppm | 0.38 | | different |
| BRL | 3 | 5.46 | ppm | 0.38 | | |
| SDSU | 1 | 1.27 | ppm | 0.01 | | |
| SDSU | 2 | 1.88 | ppm | 0.01 | | |
| SDSU | 3 | 1.46 | ppm | 0.01 | | |
| SEDIMENT: | | | | | | |
| LABORATORY | NREPS | RESULT | UNITS | MDL | t-test: | |
| BRL | 1 | 0.12 | ppm | 0.05 | 0.46 | Statistically |
| BRL | 2 | 0.07 | ppm | 0.05 | | not different |
| BRL | 3 | 0.18 | ppm | 0.05 | | |
| SDSU | 1 | 0.14 | ppm | 0.02 | | |
| SDSU | 2 | 0.09 | ppm | 0.02 | | |
| SDSU | 3 | 0.14 | ppm | 0.02 | | |

WATER: (Water Column Dissolved (WCD) & Water Column Total (WCT)

| LABOR | ATORY | NREPS | RESULT | UNITS | MDL | t-test: | |
|------------|------------|--------|--------------|------------|--------------|---------|-------------------------|
| BRL BRL | WCD WCD | 1 2 | 0.31 0.30 | ppb ppb | 0.05 0.05 | 0.003 | Statistically different |
| BRL | WCD | 3 | 0.18 | ppb | 0.05 | | |
| SDSU | WCD | 1 | 0.66 | ppb | 0.45 | | |
| SDSU | WCD | 2 | 0.60 | ppb | 0.45 | | |
| SDSU | WCD | 3 | 0.76 | ppb | 0.45 | | |
| BRL | WCT | 1 | 0.13 | ppb | 0.05 | 9.5E-05 | Statistically |
| BRL | WCT | 2 | 0.24 | ppb | 0.05 | | different |
| BRL | WCT | 3 | 0.22 | ppb | 0.05 | | |
| SDSU | WCT | 1 | 0.65 | ppb | 0.45 | | |
| SDSU | WCT | 2 | 0.65 | ppb | 0.45 | | |
| SDSU | WCT | 3 | 0.63 | ppb | 0.45 | | |

¹ water column, dissolved

NREPS = replicate number

² water column, total

MDL = method detection limit

| Analysis T | ype: Water M | etals, Dissolv | ed | | | | | | |
|------------|--------------|----------------|---------------|-----------------|--------------------------------|---|-------------------------------|---------------------------------|------------------|
| Cruise # | Parameter | Units | MDL Target | MDL Measured | Precision Target (+/- %) | Precision Measured (% rpd/rsd) ¹ | Accuracy Target (+/- %) | Accuracy Measured (+/- %) | No. Blanks/Batch |
| 4 | Ag | ng/L | 0.25 | 0.16 | 15 | 5 | 25 | NA ² | 12/24 |
| 4 | As | μg/L | 0.002 | 0.051 | 25 | 5 | 25 | 4 | 2/20 |
| 4 | Cd | ng/L | 0.34 | 0.06 | 15 | 5 | 25 | 24 | 12/24 |
| 4 | Cr | ng/L | 25 | 5 | 15 | 7 | 25 | 4 | 6/24 |
| 4 | Cu | ng/L | 5.81 | 0.8 | 15 | 4 | 25 | 7 | 12/24 |
| 4 | Hg | ng/L | 0.1 | 0.2 | 25 | 4 | 25 | 5 | 2/20 |
| 4 | Ni | ng/L | 5.44 | 4 | 15 | 2 | 25 | 13 | 12/24 |
| 4 | Pb | ng/L | 2.79 | 0.4 | 15 | 3 | 25 | 5 | 12/24 |
| 4 | Se | μg/L | 0.005 | 0.036 | 35 | 7 | 35 | 7 | 2/20 |
| 4 | Zn | ng/L | 0.82 | 4 | 15 | 6 | 25 | 8 | 12/24 |
| 5 | Ag | ng/L | 0.25 | 0.145 | 15 | 15 | 25 | NA ² | 12/24 |
| 5 | As | μg/L | 0.002 | 0.068 | 25 | 7 | 25 | 3 | 2/20 |
| 5 | Cd | ng/L | 0.34 | 0.0579 | 15 | 5 | 25 | 1 | 12/24 |
| 5 | Cr | ng/L | 25 | 0.012 | 15 | 13 | 25 | 5 | 7/24 |
| 5 | Cu | ng/L | 0.006 | 0.005 | 15 | 6 | 25 | 2 | 12/24 |
| 5 | Hg | ng/L | 0.1 | 0.14 | 25 | 3 | 25 | 3 | 2/20 |
| 5 | Ni | ng/L | 0.005 | 0.008 | 15 | 5 | 25 | 6 | 12/24 |
| 5 | Pb | ng/L | 2.79 | 0.534 | 15 | 7 | 25 | 1 | 12/24 |
| 5 | Se | μg/L | 0.005 | 0.018 | 35 | 11 | 35 | 7 | 2/20 |
| 5 | Zn | ng/L | 0.0008 | 0.005 | 15 | 2 | 25 | 9 | 12/24 |
| 6 | Ag | ng/L | 0.25 | 0.129 | 15 | 3 | 25 | NA ² | 15/24 |
| 6 | As | μg/L | 0.002 | 0.09 | 25 | 10 | 25 | 10 | 2/20 |
| 6 | Cd | μg/L | 0.34 | 0.00005 | 15 | 3 | 25 | NA ³ | 15/24 |
| 6 | Cr | ng/L | 25 | 12.8 | 15 | 6 | 25 | NA^4 | |
| 6 | Cu | μg/L | 5.81 | 0.003 | 15 | 3 | 25 | 9 | 15/24 |
| 6 | Hg | ng/L | 0.1 | 0.44 | 25 | 10 | 25 | 4 | 2/20 |
| 6 | Ni | μg/L | 5.44 | 0.004 | 15 | 7 | 25 | 12 | 15/24 |
| 6 | Pb | µg/L | 2.79 | 0.752 | 15 | 5 | 25 | 18 | |
| 6 | Se | µg/L | 0.005 | 0.051 | 35 | 12 | 35 | 7 | 2/20 |
| 6 | Zn | $\mu g/L$ | 0.82 | 0.001 | 15 | 2 | 25 | 4 | 15/24 |

Table 2.5. Quality Assurance and Control Summary for Laboratory Analyses of WaterCruise 4: February 94, Cruise 5: April 94, and Cruise 6: August 94

| Analysis T | ype: Water M | etals, Total | | | | | | | |
|------------|--------------|--------------|---------------|-----------------|--------------------------------|---|-------------------------------|---------------------------------|------------------|
| Cruise # | Parameter | Units | MDL Target | MDL Measured | Precision Target (+/- %) | Precision Measured (% rpd/rsd) ¹ | Accuracy Target (+/- %) | Accuracy Measured (+/- %) | No. Blanks/Batch |
| 4 | Ag | ng/L | 1.16 | 1.01 | 15 | 6 | 25 | NA ² | 12/24 |
| 4 | As | μg/L | 0.002 | 0.051 | 25 | 5 | 25 | 4 | 2/20 |
| 4 | Cd | ng/L | 0.38 | 0.3 | 15 | 3 | 25 | 21 | 12/24 |
| 4 | Cr | ng/L | 353 | 9180 | 15 | 8 | 40 | 27 | 6/24 |
| 4 | Cu | ng/L | 6.58 | 5 | 15 | 6 | 25 | 4 | 12/24 |
| 4 | Hg | ng/L | 0.1 | 0.22 | 25 | 4 | 25 | 5 | 2/20 |
| 4 | Ni | ng/L | 9.5 | 12 | 15 | 8 | 25 | 20 | 12/24 |
| 4 | Pb | ng/L | 4.97 | 4 | 15 | 2 | 25 | 16 | 12/24 |
| 4 | Se | μg/L | 0.005 | 0.036 | 35 | 7 | 35 | 7 | 2/20 |
| 4 | Zn | ng/L | 7.38 | 4 | 15 | 3 | 25 | 12 | 12/24 |
| 5 | Ag | ng/L | 1.16 | 1.1 | 15 | 5 | 25 | NA ² | 8/24 |
| 5 | As | μg/L | 0.002 | 0.068 | 25 | 7 | 25 | 3 | 2/20 |
| 5 | Cd | ng/L | 0.38 | 0.429 | 15 | 1 | 25 | 19 | 8/24 |
| 5 | Cr | ng/L | 42 | 0.088 | 15 | 9 | 40 | 35 | 5/24 |
| 5 | Cu | μg/L | 0.007 | 0.018 | 15 | 4 | 25 | 15 | 8/24 |
| 5 | Hg | ng/L | 0.1 | 0.14 | 25 | 3 | 25 | 3 | 2/20 |
| 5 | Ni | μg/L | 0.009 | 0.026 | 15 | 3 | 25 | 23 | 8/24 |
| 5 | Pb | μg/L | 0.003 | 0.002 | 15 | 7 | 25 | 25 | 8/24 |
| 5 | Se | μg/L | 0.005 | 0.018 | 35 | 11 | 35 | 7 | 2/20 |
| 5 | Zn | μg/L | 0.005 | 0.021 | 15 | 4 | 25 | 6 | 8/24 |
| 6 | Ag | ng/L | 1.16 | 0.664 | 15 | 5 | 25 | NA^2 | 12/24 |
| 6 | As | μg/L | 0.002 | 0.09 | 25 | 10 | 25 | 10 | 2/20 |
| 6 | Cd | μg/L | 0.38 | 0.0004 | 15 | 5 | 25 | NA ³ | 12/24 |
| 6 | Cr | ng/L | 353 | 337 | 15 | 13 | 40 | 28 | |
| 6 | Cu | μg/L | 6.58 | 0.018 | 15 | 4 | 25 | 23 | 12/24 |
| 6 | Hg | ng/L | 0.1 | 0.44 | 25 | 10 | 25 | 4 | 2/20 |
| 6 | Ni | μg/L | 9.5 | 8 | 15 | 7 | 25 | 15 | |
| 6 | Pb | μg/L | 4.97 | 7 | 15 | 7 | 25 | 5 | |
| 6 | Se | μg/L | 0.005 | 0.051 | 35 | 12 | 35 | 7 | 2/20 |
| 6 | Zn | μg/L | 7.38 | 0.004 | 15 | 4 | 25 | 5 | 11/24 |

¹ relative percent difference or relative standard deviation

Table 2.5. (continued) Quality Assurance and Control Summary for Laboratory Analyses of Water

| Analysis Ty | nalysis Type: Water Organics, Dissolved & Particulate * (Total values are calculated as the sum of dissolved and particulate data.) | | | | | | | |
|-------------|--|-------|---------------|------------------------------|--------------------------------|--------------------------------|---|--|
| Cruise #** | Parameter | Units | MDL Target | MDL Measured Dissolved | MDL Measured Particulate | Precision Target (+/- %) | Precision Measured (% rpd/rsd) ¹ | |
| 5 | Aliphatics | pg/L | 50 | 3.9 - 39.2 | 3.9 - 39.2 | 20 | < 20 | |
| 5 | PAHs | pg/L | 50 | 5.1 - 6.6 | 5.1 - 6.6 | 20 | < 20 | |
| 5 | PCBs | pg/L | 50 | 0.51 | 0.51 - 4.1 | 20 | < 20 | |
| 5 | Pesticides | pg/L | 50 | .5 - 2.1 | 0.5 - 2.1 | 20 | < 20 | |
| 6 | Aliphatics | pg/L | 50 | 3.9 - 39.2 | 3.9 - 39.2 | 20 | < 20 | |
| 6 | PAHs | pg/L | 50 | 51 - 66 | 51 - 66 | 20 | < 20 | |
| 6 | PCBs | pg/L | 50 | .51 - 4.3 | .51 - 4.3 | 20 | < 20 | |
| 6 | Pesticides | pg/L | 50 | 0.8 - 3.3 | 0.8 - 3.3 | 20 | < 20 | |

¹ relative percent difference or relative standard deviation

Note: Certified reference Materials for trace organic contaminanats in water are not available.

Accuracy was measured using continuing calibration check solutions. Recoveries of these solutions were consistently 95 +/- 15% ** QA documentation for cruise 4 is being compiled in a comprehensive report at the time of this printing.

| 1994) |
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| (April-May |
| er Samples |
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| Analyses |
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| Summary |
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| Table 2.6. |

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| Diss |
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| Analysis Type | :: River Metal | s, Dissolved | | | | | | |
|-----------------|----------------|--------------|--------------|-----------------------------|--|-------------------------------|---------------------------------|----------------------|
| Parameter | Units | MDL Target | MDL Measured | Precision Target (+/- %) | Precision Measured (% rpd/rsd) ¹ | Accuracy Target (+/- %) | Accuracy Measured (+/- %) | No. Blanks/ Batch |
| Ag | ng/kg | 0.25 | 0.074 | 15 | 10 | 25 | NA | 6/batch ² |
| \overline{As} | ug/L | 0.002 | 0.107 | 25 | 7 | 25 | ŝ | 2/20 |
| Cd | ng/kg | 0.34 | 0.066 | 15 | 1 | 25 | NA | 6/batch |
| Cr | ng/kg | 25 | 11 | 15 | 6 | 40 | NA | 5/batch |
| Cu | ng/kg | 5.81 | 9 | 15 | L | 25 | 5 | 6/batch |
| Hg | ng/L | 0.1 | 0.067 | 25 | 8 | 25 | 5 | 2/20 |
| iN | ng/kg | 5.44 | ŝ | 15 | 6 | 25 | 12 | 6/batch |
| \mathbf{Pb} | ng/kg | 2.79 | 1.103 | 15 | 10 | 25 | 4 | 6/batch |
| Se | ug/L | 0.005 | 0.02 | 35 | 8 | 35 | 5 | 2/20 |
| Zn | ng/kg | 0.82 | 1 | 15 | 4 | 25 | 26 | 6/batch |
| Analysis Type | :: River Metal | s, Total | | | | Accuracy | Accuracy | |
| Parameter | Units | MDL Target | MDL Measured | Precision Target (+/- %) | Precision Measured (% rpd/rsd) ¹ | Target (+/- %) | Measured (+/- %) | No. Blanks/ Batch |
| Ag | ng/kg | 1.16 | 0.267 | 15 | 14 | 25 | NA | 5/batch |
| \mathbf{As} | ug/L | 0.002 | 0.107 | 25 | L | 25 | ŝ | 2/20 |
| Cd | ng/kg | 0.38 | 0.205 | 15 | 1 | 25 | NA | 5/batch |
| Ç | ng/kg | 353 | 337 | 15 | 11 | 40 | 28 | 5/batch |
| Cu | ng/kg | 6.58 | 12 | 15 | 4 | 25 | 25 | 5/batch |
| Hg | ng/L | 0.1 | 0.067 | 25 | 8 | 25 | 5 | 2/20 |
| Ņ | ng/kg | 9.5 | 4 | 15 | 9 | 25 | 9 | 5/batch |
| Pb | ng/kg | 4.97 | 9 | 15 | 9 | 25 | 5 | 5/batch |
| Se | ug/L | 0.005 | 0.02 | 35 | 8 | 35 | 5 | 2/20 |
| Zn | ng/kg | 7.38 | 3 | 15 | 2 | 25 | 5 | 5/batch |

Quality assurance and control summary for laboratory analyses of river organics are not available at printing time. ¹ relative percent difference or relative standard deviation

² batch size not to exceed 25.

| Analysis Typ | e: Sediment Me | etals | | | | | | | |
|--------------|----------------|-------|------------|--------------|--------------------------------|---------------------------------------|----------------------------|---------------------------------|---------------------|
| Cruise # | Parameter | Units | MDL Target | MDL Measured | Precision Target (+/- %) | Precision Measured (% rpd/rsd)* | Accuracy Target (+/- %) | Accuracy Measured (+/- %) | No. Blanks/Batch |
| 4 | Ag | μg/g | 0.0012 | 0.000058 | 15 | 6 | 25 | NA | 3/24 |
| 4 | Al | μg/g | 70 | 14.52 | 25 | 6 | 25 | 58 | 3/24 |
| 4 | As | ug/g | 1.6 | 0.001 | 25 | 2 | 25 | 2 | 2/20 |
| 4 | Cd | μg/g | 0.00002 | 0.000013 | 15 | 4 | 25 | 9 | 3/24 |
| 4 | Cr | μg/g | 9.44 | 27 | 15 | 12 | 60 | 14 | 3/24 |
| 4 | Cu | µg/g | 4.57 | 10.4 | 15 | 1 | 25 | 1 | 3/24 |
| 4 | Fe | µg/g | 140 | 3700 | 15 | 2 | 25 | 65 | 3/24 |
| 4 | Hg | ng/g | 5 | 0.85 | 35 | 4 | 25 | 4 | 2/20 |
| 4 | Mn | µg/g | 27 | 8.8 | 25 | 5 | 25 | 17 | 3/24 |
| 4 | Ni | µg/g | 4.28 | 18.6 | 15 | 15 | 25 | 55 | 3/24 |
| 4 | Pb | µg/g | 0.1 | 0.001 | 15 | 8 | 25 | 9 | 3/24 |
| 4 | Se | ug/g | 2.2 | 0.0009 | 35 | 5 | 35 | 8 | 2/20 |
| 4 | Zn | µg/g | 18.8 | 2.1 | 15 | 3 | 25 | 8 | 3/24 |
| 6 | Ag | µg/g | 0.0012 | 0.0001 | 25 | 5 | 25 | NA | 3/24 |
| 6 | Al | μg/g | 70 | 177 | 25 | 4 | 25 | 76 | 3/24 |
| 6 | As | ug/g | 1.6 | 0.0016 | 25 | 7 | 25 | 19 | 2/20 |
| 6 | Cd | µg/g | 0.00002 | 5.30E-05 | 25 | 3 | 25 | 5 | 3/24 |
| 6 | Cr | µg/g | 9.4 | 1 | 25 | 1 | 60 | 60 | 3/24 |
| 6 | Cu | µg/g | 4.57 | 0.13 | 25 | 2 | 25 | 21 | 3/24 |
| 6 | Fe | µg/g | 140 | 177 | 25 | 4 | 25 | 17 | 3/24 |
| 6 | Hg | ng/g | 5 | 0.36 | 35 | 4 | 25 | 8 | 2/20 |
| 6 | Mn | µg/g | 27 | 7.3 | 25 | 6 | 25 | 28 | 3/24 |
| 6 | Ni | µg/g | 4.26 | 1.7 | 25 | 2 | 25 | 6 | 3/24 |
| 6 | Pb | μg/g | 0.01 | 0.0005 | 25 | 1 | 25 | 26 | 3/24 |
| 6 | Se | ug/g | 2.2 | 0.048 | 35 | 7 | 35 | 11 | 2/20 |
| 6 | Zn | μg/g | 18.9 | 1.1 | 25 | 1 | 25 | 11 | 3/24 |

Table 2.7.Quality Assurance and Control Summary for Laboratory Analyses of SedimentCruise 4: February 94, and Cruise 6: August 94

Analysis Type: Sediment Organics

| Cruise # | Parameter | Units | MDL Target | MDL Measured | Precision Target (+/- %) | Precision Measured (% rpd/rsd)* | Accuracy Target (+/- %) | Accuracy Measured (+/- %) | Blank Frequency ⁷ |
|----------|-------------------------|-------|------------|--------------|--------------------------------|---------------------------------------|----------------------------|---------------------------------|---------------------------------|
| 4 | Aliphatics ¹ | ng/g | 5 | 1-27 | ± 20 | 24 | ± 20 | 88 | 5% min. |
| 4 | Aliphatics ² | ng/g | 5 | 1-27 | ± 20 | 33 | ± 20 | 98 | 5% min. |
| 4 | PAHs ¹ | ng/g | 5 | 0.3-4 | ± 20 | 28 | ± 20 | 78 | 5% min. |
| 4 | PAHs ² | ng/g | 5 | 0.3-4 | ± 20 | 12 | ± 20 | 93 | 5% min. |
| 4 | PCBs ³ | ng/g | 1 | 0.1 | ± 20 | 26 | ± 20 | SRM report | 5% min. |
| 4 | $PCBs^4$ | ng/g | 1 | 0.1 | ± 20 | 2 | ± 20 | SRM report | 5% min. |
| 4 | Pesticides ³ | ng/g | 1 | 0.2 | ± 20 | 46 | ± 20 | SRM report | 5% min. |
| 4 | Pesticides ⁴ | ng/g | 1 | 0.2 | ± 20 | 19 | ± 20 | SRM report | 5% min. |
| 6 | Aliphatics | ng/g | 5 | 1-27 | ± 20 | 4 | ± 20 | 75 | 5% min. |
| 6 | PAHs | ng/g | 5 | 1-5 | ± 20 | 12 | ± 20 | 84 | 5% min. |
| 6 | PCBs ⁵ | ng/g | 1 | 0.2 | ± 20 | 3 | ± 20 | 91 | 5% min. |
| 6 | PCBs ⁶ | ng/g | 1 | 0.2 | ± 20 | 3 | ± 20 | 109 | 5% min. |
| 6 | Pesticides ⁵ | ng/g | 1 | 0.1 | ± 20 | 4 | ± 20 | 86 | 5% min. |
| 6 | Pesticides ⁶ | ng/g | 1 | 0.1 | ± 20 | 3 | ± 20 | 95 | 5% min. |

* relative percent difference or relative standard deviation

¹ Batch M2032, ² Batch M2033, ³ Batch M2034, ⁴ Batch M2035, ⁵ Batch M2218, ⁶ Batch M2183

⁷ Maximum Batch size is 20 samples.

| Analysis Ty | pe: Tissue Me | etals | MDI | MDI | D | р ^{с с} | | | |
|-------------|---------------|-------|---------------|-----------------|-------------------|--------------------------|-------------------------------|---------------------------------|------------------|
| Cruise # | Parameter | Units | MDL Target | MDL Measured | Target (+/- %) | Measured (% rpd/rsd)* | Accuracy Target (+/- %) | Accuracy Measured (+/- %) | No. Blanks/Batch |
| 4 | Ag | µg/g | 0.0012 | 0.0000765 | 30 | 4 | 35 | 0 | 3/24 |
| 4 | As | μg/g | 1.6 | 0.005 | 25 | 3 | 25 | 1 | 2/20 |
| 4 | Cd | μg/g | 0.00002 | 0.0002 | 30 | 4 | 25 | 12 | 3/24 |
| 4 | Cr | µg/g | 9.44 | 0.22 | 30 | 3 | 25 | 25 | 3/24 |
| 4 | Cu | µg/g | 4.57 | 1.91 | 30 | 3 | 25 | 7 | 3/24 |
| 4 | Hg | ng/g | 1 | 0.16 | 35 | 3 | 25 | 0 | 2/20 |
| 4 | Ni | µg∕g | 4.26 | 1.04 | 30 | 9 | 25 | 25 | 3/24 |
| 4 | Pb | μg/g | 0.1 | 0.0001 | 30 | 23 | 25 | 1 | 3/24 |
| 4 | Se | μg/g | 2.2 | 0.003 | 35 | 5 | 35 | 1 | 2/20 |
| 4 | Zn | µg/g | 18.9 | 0.29 | 30 | 5 | 25 | 1 | 3/24 |
| 6 | Ag | µg/g | 0.0012 | 0.000027 | 25 | 7 | 30 | 22 | 3/24 |
| 6 | As | µg/g | 1.6 | 0.0079 | 25 | 17 | 25 | 7 | 2/20 |
| 6 | Cd | µg/g | 0.00002 | 0.00003 | 25 | 3 | 30 | 3 | 3/24 |
| 6 | Cr | µg/g | 9.4 | 0.55 | 25 | 17 | 60 | 63 | 3/24 |
| 6 | Cu | µg/g | 4.57 | 0.76 | 25 | 2 | 30 | 2 | 3/24 |
| 6 | Hg | ng/g | 1 | 1.8 | 35 | 17 | 25 | 8 | 2/20 |
| 6 | Ni | µg∕g | 4.26 | 0.57 | 25 | 22 | 30 | 14 | 3/24 |
| 6 | Pb | µg/g | 0.01 | 0.00066 | 25 | 6 | 30 | 12 | 3/24 |
| 6 | Se | µg∕g | 2.2 | 0.38 | 35 | 7 | 35 | 3 | 2/20 |
| 6 | Zn | µg/g | 18.9 | 40 | 25 | 1 | 30 | 13 | 3/24 |

Table 2.8. Quality Assurance and Control Summary for Laboratory Analyses of Bivalve Tissue Cruise 4: February 94, and Cruise 6: August 94

Analysis Type: Tisssue Organics

| Cruise # | Parameter | Units | MDL Target | MDL Measured | Precision Target (+/- %) | Precision Measured (% rpd/rsd)* | Accuracy Target (+/- %) | Accuracy Measured (+/- %) | Blank Frequency ⁵ |
|----------|-------------------------|-------|---------------|-----------------|--------------------------------|---------------------------------------|-------------------------------|---------------------------------|------------------------------|
| 4 | Aliphatics ¹ | ng/g | 5 | 1-20 | ± 20 | 25 | ± 20 | 11 | 5% min. |
| 4 | Aliphatics ² | ng/g | 5 | 1-20 | ± 20 | 2 | ± 20 | 1 | 5% min. |
| 4 | PAHs ¹ | ng/g | 5 | 0.1-1 | ± 20 | 10 | ± 20 | 5 | 5% min. |
| 4 | PAHs ² | ng/g | 5 | 0.1-1 | ± 20 | 5 | ± 20 | 5 | 5% min. |
| 4 | $PCBs^1$ | ng/g | 1 | 0.1 | ± 20 | 4 | ± 20 | 26 ^M | 5% min. |
| 4 | PCBs ² | ng/g | 1 | 0.1 | ± 20 | 7 | ± 20 | 22 ^M | 5% min. |
| 4 | Pesticides ¹ | ng/g | 1 | 0.1 | ± 20 | 7 | ± 20 | 16 | 5% min. |
| 4 | Pesticides ² | ng/g | 1 | 0.1 | ± 20 | 16 | ± 20 | 15 | 5% min. |
| 6 | Aliphatics ³ | ng/g | 5 | 3-50 | ± 20 | 3 | ± 20 | 21 | 5% min. |
| 6 | Aliphatics ⁴ | ng/g | 5 | 3-50 | ± 20 | 2 | ± 20 | 21 | 5% min. |
| 6 | PAHs ³ | ng/g | 5 | 0.2-3 | ± 20 | 6 | ± 20 | 24 | 5% min. |
| 6 | PAHs ⁴ | ng/g | 5 | 0.2-3 | ± 20 | 10 | ± 20 | 15 | 5% min. |
| 6 | PCBs ³ | ng/g | 1 | 0.2 | ± 20 | 5 | ± 20 | 9 | 5% min. |
| 6 | $PCBs^4$ | ng/g | 1 | 0.2 | ± 20 | 8 | ± 20 | 3 | 5% min. |
| 6 | Pesticides ³ | ng/g | 1 | 0.1 | ± 20 | 3 | ± 20 | 10 | 5% min. |
| 6 | Pesticides ⁴ | ng/g | 1 | 0.1 | ± 20 | 9 | ± 20 | 5 | 5% min. |

* relative percent difference or relative standard deviation
 ¹ Batch M797, ² Batch M981, ³ Batch M1395, ⁴ Batch M1396, ^M interference
 ⁵ Maximum Batch size is 20 samples.

| | Salinity (0/00) | EC50* | EC25** | QA Notes: |
|---------------------------|-----------------|-------|--------|-----------------------|
| February | | | | |
| Mytilus edulis | 27 | 11 | 9 | insufficient embyo #s |
| coefficient of variation: | | 0.44 | 0.45 | |
| Mysidopsis bahia | 26 | 6 | 4 | no exceptions |
| coefficient of variation: | | 0.18 | 0.23 | - |
| August | | | | |
| Mysidopsis bahia | 27 | 7 | 5 | no exceptions |
| coefficient of variation: | | 0.15 | 0.09 | |
| Crassostrea gigas | 29 | 12 | 9 | no exceptions |
| coefficient of variation: | | 0.23 | 0.33 | |

Table 2.9 Reference toxicant and QA information for the aquatic bioassays.

* Concentration of reference toxicant at which 50% of the organisms show effects.

** Concentration of reference toxicant at which 25% of the organisms show effects.

| Table 2.10 | Reference toxicant and (|)A information for | the sediment bioassays |
|------------|---------------------------------|---------------------------|------------------------|
| | | | |

| | EC50 ¹ /LC50 ² (Cd Cl) | Salinity °/ | Total Ammonia | Total Sulfide | QA Notes |
|-----------------|---|----------------|--------------------------|-----------------------------------|-----------------------------------|
| | ilig/L | 100 | mg/L | ilig/L | |
| February | | | | | |
| Eohaustorius | 2.64-4.41 | 12-18 | 0.11-1.90 | <.01 | no exceptions |
| Mytilus embryos | 4.8-5.8 | 27-30 | 0.48-1.50 | <.01 | no exceptions |
| August | | | | | |
| Eohaustorius | 30* | 26-30 | 0.004-0.011 ^u | 0-0.005 ^H | low control survival**/high EC50* |
| Mytilus embryos | 1.4-3.6 | 26-29 | 0.001-0.033 ^u | $0.007 \text{-} 0.017^{\text{H}}$ | no exceptions |

¹ Effects concentration of reference toxicant at which 50% of the organisms exhibit effects.

² Effects concentration of reference toxicant at which 50% of the organisms die.

* Within Granite Canyon Control Chart limits, see text.

** See Text

^u Unionized Ammonia

^H Hydrogen Sulfide

APPENDIX 3

Data Tables

Table 3.1. Conventional water quality parameters, 1994.

For conversion of μ M to μ g/L, use the following atomic weight multipliers: P = 31; C = 12; N = 14; Si = 28. . = Not Analyzed, ND = data not guantifiable

Chlorophyll-a Phaeophytin Temperature Conductivity Phosphate Ammonia Silicates Hardness Salinity Vitrate Nitrite Date **SS** Station g F Station Name Code μM μΜ °C mg/m³ mho μΜ μΜ pН mg/m³ μΜ ‰ μM mg/L μΜ **BA10** Covote Creek 1/31/94 18.5 2.2 24500 195 144.4 6.0 7.7 3.6 15.7 21.4 138.6 10.4 119.6 BA20 1/30/94 1.5 29800 137 30.6 3.0 7.9 1.5 8.5 South Bay 8.4 26.8 93.9 11.0 29.8 **BA30** Dumbarton Bridge 1/30/94 4.5 1.5 30200 127 59.9 2.4 7.9 1.4 8.4 27.3 45 8 11.0 48 5 **BA40** 29500 7.8 Redwood Creek 1/31/94 79 14 122 53.3 20 12 8 1 27 6 78 1 11 0 14 8 **BB15** 29200 1/30/94 6.0 2.3 1.6 28.3 48.3 34.7 San Bruno Shoal 113 41.9 2.0 7.7 6.7 11.2 **BB30** Oyster Point 1/30/94 7.3 1.8 29000 124 44.1 2.4 7.7 1.6 6.9 28.3 81.0 11.0 27.4 **BB70** Alameda 2/2/94 3.7 2.0 30000 131 45.8 1.8 8.1 1.1 6.8 27.8 71.3 12.0 12.0 BC10 Yerba Buena Island 2/2/94 9.3 18.5 34500 117 0.9 8.0 0.2 3.0 28.0 26.2 13.8 11.5 7.7 BC20 Golden Gate 2/2/94 12 1.1 34000 68 66 0.5 8.0 0.6 1.1 31.9 17 2 12.0 ND BC30 Richardson Bay 2/1/94 4 2 1.1 31000 77 14 5 0.6 8.0 0.8 14 28 7 45 0 12.0 12.2 81 30000 BC41 2/1/94 1.3 0.7 0.7 2.2 28.1 46.8 12.0 14.4 Point Isabel 3.9 16.1 8.0 BC60 Red Rock 2/6/94 3.6 1.0 32000 80 0.7 8.0 1.7 29.8 35.5 12.0 9.7 11.4 1.3 BD15 Petaluma River 2/6/94 8.0 4.2 18500 193 31.4 0.7 7.7 1.3 3.3 16.4 118.7 11.5 32.0 BD20 San Pablo Bay 2/6/94 0.6 22000 122 23.8 7.8 2.6 20.0 7.4 0.8 0.3 107.2 11.5 23.3 BD30 Pinole Point 2/6/94 6.3 1.2 23500 103 20.3 0.8 7.9 0.7 2.5 23.2 85.6 12.0 27.1 **BD40** Davis Point 2/7/94 8 2 1.0 20000 125 22.9 1.0 7.9 0.4 2.6 18.5 85 5 11 0 10.3 BD50 0.8 16000 126 2.8 138.7 Napa River 2/7/94 11.4 27.5 1.1 7.7 1.0 14.7 10.0 29.2 7.9 BF10 2/7/94 10.2 0.3 16000 153 27.0 0.2 2.6 12.6 99.8 11.5 Pacheco Creek 1.1 8.0 BF20 Grizzly Bay 2/7/94 8.9 9000 138 29.0 7.8 0.9 2.5 50.1 1.1 1.1 8.0 11.0 30.1 BF40 Honker Bay 2/8/94 9.5 0.9 3250 175 28.2 1.0 7.5 0.8 1.9 2.9 125.3 10.5 16.8 200 BG20 Sacramento River 2/8/94 13.7 1.0 254 181 26.3 0.8 7.5 0.9 2.3 0.0 103.3 10.1 10.2 96 **BG30** San Joaquin River 2/8/94 97 1.3 950 201 32.3 0.9 7.6 1.0 24 0.0 107.0 11.5 13.8 170 C-1-3 54 8 10500 175 7 34 3 Sunnvvale 1/31/94 44 377 14 1 74 46 10.5 154 9 11 0 39.8 C-3-0 52.4 0.8 10000 7.4 26.0 1/31/94 328 172.9 12.7 1.6 8.0 85.6 30.9 San Jose 13.0 **BA10** Coyote Creek 4/18/94 19.6 5.9 27500 294 83.7 7.8 2.1 19.0 21.8 137.0 21.0 25.0 6.6 **BA20** South Bay 4/19/94 13.8 3.8 29000 280 61.5 4.7 7.8 1.5 14.8 24.0 131.7 18.0 30.7 BA30 Dumbarton Bridge 4/18/94 7.2 4.1 31700 240 33.0 2.4 8.1 9.5 25.7 78.1 20.0 22.8 1.1 BA40 Redwood Creek 4/18/94 6.9 8.1 31000 218 22.1 1.9 7.7 0.8 7.7 26.4 72.5 19.5 23.6 **BB15** San Bruno Shoal 4/18/94 9.6 3.2 270000 211 18.7 1.8 8.1 1.0 6.8 26.7 54.3 17.8 4.2 2.9 **BB30** Ovster Point 4/19/94 6.3 31500 193 17.5 1.5 8.1 1.3 6.0 27.1 49.9 18.0 13.0 4/20/94 32500 **BB70** 6.9 3.8 152 8.1 1.0 28.3 53.5 16.5 15.0 Alameda 14.4 1.2 3.8 BC10 Yerba Buena Island 4/20/94 170 12.5 0.9 8.1 3.7 28.4 59.9 25.5 3.6 3.6 16.5 11.4 BC20 Golden Gate 4/21/94 0.9 4.3 78 12.4 0.6 8.0 1.6 1.7 32.1 24.1 12.4 0.6 BC30 4/21/94 2.5 11.8 0.7 0.7 2.2 29.4 49.7 14.6 1.3 Richardson Bay 1.8 119 8.0 BC41 Point Isabel 4/20/94 ND 7.1 32000 144 4.0 0.5 8.3 1.4 1.7 28.1 60.0 17.0 4.0 BC60 Red Rock 4/21/94 1.7 3.5 134 15.6 0.8 8.1 7.9 0.6 2.6 26.9 69.8 15.7 1.2 BD15 Petaluma River 29000 337.0 4/26/94 189 0.9 4.7 22.3 135.4 18.0 1.8 9.1 13.3 8.2 BD20 4/26/94 26500 0.4 3.7 San Pablo Bay 0.8 6.9 173 21.9 8.0 21.9 137.0 1.5 81.0 13.9 BD30 Pinole Point 4/26/94 4.5 3.4 24000 160 21.3 1.6 8.1 2.3 3.5 22.1 88.0 14.8 76.4 4/26/94 7.4 28500 8.0 2.2 15.6 BD40 Davis Point 5.1 185 20.7 2.6 3.8 19.7 111.4 31.7 BD50 Napa River 4/27/94 6.2 3.6 20500 231 24.6 2.8 7.9 4.4 4.1 16.0 123.6 15.3 44.3 1.4 1.7 **BF10** Pacheco Creek 4/27/94 8.2 11500 246 34.8 4.2 79 2.4 4.0 8.6 160.7 15.6 84 0 1100 **BF20** 251 4.0 4.0 3.9 Grizzly Bay 4/27/94 6.7 8000 32.1 8.0 5.8 201.9 16.3 136.0 BF40 236 17.2 4/27/94 7.2 2.4 4600 34.2 3.2 185.1 470 Honker Bay 8.0 1.4 3.5 2.2 82.7 BG20 Sacramento River 4/28/94 7.6 2.8 1100 205 32.8 7.9 2.4 3.4 0.0 222.1 180 1.5 16.8 31.8 1.9 0.9 2.8 BG30 San Joaquin River 4/28/94 3.0 700 236 31.1 8.0 1.9 0.0 215.3 17.4 30.4 150 C-1-3 Sunnyvale 4/19/94 64.2 20.9 9000 824 61.4 19.4 7.8 14.2 78.3 6.3 232.6 20.0 57.3 1300 C-3-0 San Jose 4/19/94 41.6 8.4 17500 437 71.3 12.9 7.5 4.1 27.8 13.3 216.6 18.0 35.6 67.4 8/16/94 42300 299 19.9 24.0 **BA10** Coyote Creek 6.3 1.6 3.7 7.9 1.1 28.0 19.9 72.1 8/15/94 3.3 43200 **BA20** South Bay 1.3 237 7.9 0.7 34.0 15.3 17.0 27.1 34.1 2.4 15.3 BA30 Dumbarton Bridge 8/15/94 0.9 1.6 43600 227 28.7 2.1 8.0 12.5 29.5 12.5 23.0 45.1 1.2 29.9 **BA40** Redwood Creek 8/16/94 1.5 0.8 43800 209 28.4 2.4 8.1 0.4 10.1 10.1 23.0 21.1 BB15 San Bruno Shoal 8/15/94 2.8 0.2 42800 173 25.8 2.8 8.0 0.2 4.1 31.0 20.0 4.1 11.0 **BB30** Oyster Point 8/15/94 4.5 1.1 42300 148 30.8 3.8 7.9 0.7 6.7 31.0 6.7 20.0 8.9 152 **BB70** Alameda 8/17/94 3.4 1.9 42000 27.9 2.4 8.0 0.9 3.9 29.6 3.9 21.0 12.0 BC10 8/17/94 7.2 0.7 39500 0.8 2.9 29.2 Yerba Buena Island 133 12.7 0.0 2.9 19.0 8.1 8.3 Golden Gate 8/17/94 0.4 37500 8.0 30.2 1.7 BC20 1.8 92 14.0 0.8 0.2 1.9 1.9 15.0 38500 BC30 Richardson Bay 8/17/94 1.2 1.3 109 17.1 1.0 8.0 0.4 2.4 28.8 2.4 18.0 6.5 BC41 Point Isabel 8/18/94 0.1 6.3 38000 128 11.1 0.6 8.1 2.1 2.0 29.2 2.0 17.5 3.1 BC60 1.7 0.5 37400 17.0 7.9 0.2 2.0 29.0 17.0 9.8 Red Rock 8/18/94 105 1.0 2.0 **BD15** Petaluma River 8/22/94 12 3.8 34600 205 33.0 0.8 8.0 0.8 6.7 24 0 6.7 21.0 55.0 **BD20** San Pablo Bav 8/22/94 26 2.6 35100 131 23.3 1.3 8.0 4.0 3.6 25 4 36 19.0 69.3 34000 2.3 **BD30** Pinole Point 8/22/94 2.2 3.4 137 27.6 1.5 8.0 4.0 24.0 4.0 19.5 53.9 8/22/94 31900 7.9 4.6 22.5 BD40 Davis Point 2.2 2.1 159 32.9 2.6 1.5 20.0 48.3 4.6 Napa River 2.2 BD50 8/23/94 2.8 28100 186 30.4 2.6 7.9 2.4 4.7 19.8 4.7 20.0 121.8 **BF10** Pacheco Creek 8/23/94 2.7 17900 33.9 4.1 2.6 4.5 2.1 179 7.9 12.8 4.5 20.5 49.0 BF20 Grizzly Bay 8/23/94 0.9 4.7 16000 182 34.4 4.0 7.9 2.0 3.5 10.8 3.5 21.0 103.3 **BF40** Honker Bay 8/23/94 16 1.0 11000 178 24.3 3.0 79 0.9 4.0 7.2 40 22.0 34.9 420 BG20 Sacramento River 8/24/94 26 19 4900 166 19.3 13 80 14 32 29 32 21.5 16.3 8/24/94 3610 17.2 23.0 BG30 2.4 1.3 7.9 1.2 3.0 1.8 3.0 17.5 530 San Joaquin River 172 0.8 8/16/94 28.6 21100 159.4 7.8 2.6 70.4 13.6 70.4 23.0 C-1-3 Sunnyvale 1.6 687 8.6 44.9 C-3-0 San Jose 8/16/94 25.0 0.2 25700 375 155.9 10.6 7.7 0.3 28.4 16.5 28.4 23.0 200.5

Table 3.2. Dissolved concentrations of trace elements in water, 1994.. = Not Analyzed, ND = data not quantifiable

| BA10 Coyote Creek 1/31/94 0.0035 2.55 0.1074 0.16 2.85 0.0019 3.70 0.0926 0.46 BA20 South Bay 1/30/94 0.0052 2.60 0.0981 0.12 2.48 0.0018 2.37 0.0392 0.24 BA30 Dumbarton Bridge 1/30/94 0.0055 2.55 0.0992 0.14 2.32 0.0015 2.28 0.0363 0.25 BA40 Redwood Creek 1/31/94 0.0067 2.31 0.1000 0.13 2.17 0.0022 2.19 0.0288 0.21 BB15 San Bruno Shoal 1/30/94 0.0086 2.40 0.0878 0.13 1.92 0.0011 1.95 0.0172 0.38 BB70 Alameda 2/2/94 0.0029 2.08 0.6044 0.14 1.26 0.0011 1.95 0.0172 0.38 BC10 Yerba Buena Island 2/2/94 0.0023 1.60 0.0254 0.15 0.31 0.0014 | 6.36 1.64 1.45 1.34 1.09 1.17 0.89 1.52 0.28 0.62 0.72 0.54 1.02 0.82 0.75 |
|--|---|
| BA20 South Bay 1/30/94 0.0052 2.60 0.0981 0.12 2.48 0.0018 2.37 0.0392 0.24 BA30 Dumbarton Bridge 1/30/94 0.0055 2.55 0.0992 0.14 2.32 0.0015 2.28 0.0363 0.25 BA40 Redwood Creek 1/31/94 0.0067 2.31 0.1000 0.13 2.17 0.0022 2.19 0.0288 0.21 BB15 San Bruno Shoal 1/30/94 0.0086 2.40 0.0878 0.13 1.92 0.0011 1.95 0.0172 0.38 BB70 Alameda 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0011 1.95 0.0172 0.38 BC10 Yerba Buena Island 2/2/94 0.0023 1.60 0.0254 0.15 0.31 0.0013 0.46 0.0094 0.27 BC30 Richardson Bay 2/1/94 0.0042 1.97 0.0486 0.14 0.72 0.0099 | $\begin{array}{c} 1.64\\ 1.45\\ 1.34\\ 1.09\\ 1.17\\ 0.89\\ 1.52\\ 0.28\\ 0.62\\ 0.72\\ 0.54\\ 1.02\\ 0.82\\ 0.75\end{array}$ |
| BA30 Dumbarton Bridge 1/30/94 0.0055 2.55 0.0992 0.14 2.32 0.0015 2.28 0.0363 0.25 BA40 Redwood Creek 1/31/94 0.0067 2.31 0.1000 0.13 2.17 0.0022 2.19 0.0288 0.21 BB15 San Bruno Shoal 1/30/94 0.0077 2.42 0.0910 0.13 1.92 0.0011 1.95 0.0172 0.38 BB70 Alameda 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0011 1.95 0.0172 0.38 BC10 Yerba Buena Island 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0011 1.38 0.0179 0.35 BC20 Golden Gate 2/2/94 0.0023 1.60 0.0254 0.15 0.31 0.0013 0.46 0.0094 0.27 BC30 Richardson Bay 2/1/94 0.0042 1.97 0.0486 0.14 0.72 0.0009 | $\begin{array}{c} 1.45\\ 1.34\\ 1.09\\ 1.17\\ 0.89\\ 1.52\\ 0.28\\ 0.62\\ 0.72\\ 0.54\\ 1.02\\ 0.82\\ 0.75\end{array}$ |
| BA40 Redwood Creek 1/31/94 0.0067 2.31 0.1000 0.13 2.17 0.0022 2.19 0.0288 0.21 BB15 San Bruno Shoal 1/30/94 0.0086 2.40 0.0878 0.13 1.92 0.0015 1.86 0.0148 0.19 BB30 Oyster Point 1/30/94 0.0077 2.42 0.0910 0.13 1.91 0.0011 1.95 0.0172 0.38 BB70 Alameda 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0010 1.38 0.0179 0.35 BC10 Yerba Buena Island 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0010 1.38 0.0179 0.35 BC20 Golden Gate 2/2/94 0.0023 1.60 0.0254 0.15 0.31 0.0013 1.40 0.021 0.38 BC30 Richardson Bay 2/1/94 0.0042 1.97 0.0486 0.14 0.93 0.0015 | $\begin{array}{c} 1.34\\ 1.09\\ 1.17\\ 0.89\\ 1.52\\ 0.28\\ 0.62\\ 0.72\\ 0.54\\ 1.02\\ 0.82\\ 0.75\end{array}$ |
| BB15 San Bruno Shoal 1/30/94 0.0086 2.40 0.0878 0.13 1.92 0.0015 1.86 0.0148 0.19 BB30 Oyster Point 1/30/94 0.0077 2.42 0.0910 0.13 1.91 0.0011 1.95 0.0172 0.38 BB70 Alameda 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0010 1.38 0.0179 0.35 BC10 Yerba Buena Island 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0010 1.38 0.0179 0.35 BC20 Golden Gate 2/2/94 0.0023 1.60 0.0254 0.15 0.31 0.0013 0.46 0.0094 0.27 BC30 Richardson Bay 2/1/94 0.0040 1.88 0.0438 0.14 0.93 0.0015 1.02 0.015 0.33 BC41 Point Isabel 2/1/94 0.0042 1.72 0.0364 0.15 0.58 0.0010 < | 1.09 1.17 0.89 1.52 0.28 0.62 0.72 0.54 1.02 0.82 0.75 |
| BB30 Oyster Point 1/30/94 0.00/7 2.42 0.0910 0.13 1.91 0.0011 1.95 0.0172 0.38 BB70 Alameda 2/2/94 0.0043 2.51 0.0935 0.12 2.10 0.0011 1.95 0.0172 0.38 BC10 Yerba Buena Island 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0010 1.38 0.0179 0.35 BC20 Golden Gate 2/2/94 0.0023 1.60 0.0254 0.15 0.31 0.0013 0.46 0.0094 0.27 BC30 Richardson Bay 2/1/94 0.0042 1.97 0.0486 0.14 0.72 0.0009 0.95 0.0087 0.37 BC41 Point Isabel 2/1/94 0.0042 1.97 0.0486 0.14 0.93 0.0015 1.02 0.0150 0.32 BC60 Red Rock 2/6/94 0.0042 1.72 0.0364 0.15 0.58 0.0010 0.76 | 1.17 0.89 1.52 0.28 0.62 0.72 0.54 1.02 0.82 0.75 |
| BB10 Yathibita 2/2/94 0.0043 2.51 0.0353 0.12 2.10 0.0014 2.05 0.0364 0.35 BC10 Yerba Buena Island 2/2/94 0.0029 2.08 0.0604 0.14 1.26 0.0014 2.05 0.0304 0.35 BC20 Golden Gate 2/2/94 0.0023 1.60 0.0254 0.15 0.31 0.0013 0.46 0.0094 0.27 BC30 Richardson Bay 2/1/94 0.0040 1.88 0.0438 0.14 0.72 0.0009 0.95 0.0087 0.37 BC41 Point Isabel 2/1/94 0.0042 1.97 0.0486 0.14 0.93 0.0015 1.02 0.0150 0.32 BC60 Red Rock 2/6/94 0.0036 1.83 0.0890 0.31 2.58 0.0018 5.71 0.0181 0.31 BD15 Petaluma River 2/6/94 0.0037 1.79 0.0513 0.15 1.50 0.0013 1 | 0.89 1.52 0.28 0.62 0.72 0.54 1.02 0.82 0.75 |
| BC10 Golden Gate 2/2/94 0.0023 1.60 0.0254 0.14 1.20 0.0010 1.35 0.0173 0.33 BC20 Golden Gate 2/2/94 0.0023 1.60 0.0254 0.15 0.31 0.0010 1.35 0.0173 0.37 BC30 Richardson Bay 2/1/94 0.0040 1.88 0.0438 0.14 0.72 0.0009 0.95 0.0087 0.37 BC41 Point Isabel 2/1/94 0.0042 1.97 0.0486 0.14 0.93 0.0015 1.02 0.0150 0.32 BC60 Red Rock 2/6/94 0.0036 1.83 0.0890 0.31 2.58 0.0018 5.71 0.0181 0.31 BD15 Petaluma River 2/6/94 0.0037 1.79 0.0513 0.15 1.50 0.0013 1.47 0.0124 0.24 BD30 Pinole Point 2/6/94 0.0021 1.85 0.0513 0.13 1.30 0.0011 1.36< | 0.28 0.62 0.72 0.54 1.02 0.82 0.75 |
| BC30 Richardson Bay 2/1/94 0.0040 1.88 0.0438 0.14 0.72 0.0007 0.95 0.0087 0.37 BC41 Point Isabel 2/1/94 0.0042 1.97 0.0486 0.14 0.93 0.0015 1.02 0.0150 0.32 BC60 Red Rock 2/6/94 0.0042 1.72 0.0364 0.15 0.58 0.0010 0.76 0.0123 0.39 BD15 Petaluma River 2/6/94 0.0036 1.83 0.0890 0.31 2.58 0.0018 5.71 0.0181 0.31 BD20 San Pablo Bay 2/6/94 0.0021 1.85 0.0513 0.15 1.50 0.0013 1.47 0.0124 0.24 BD30 Pinole Point 2/6/94 0.0021 1.85 0.0513 0.13 1.30 0.0011 1.36 0.0098 0.25 BD30 Pinole Point 2/7/94 0.0020 1.74 0.0484 0.21 1.54 0.0018 1. | 0.62 0.72 0.54 1.02 0.82 0.75 |
| BC41 Point Isabel 2/1/94 0.0042 1.97 0.0486 0.14 0.93 0.0015 1.02 0.0150 0.32 BC60 Red Rock 2/6/94 0.0042 1.72 0.0364 0.15 0.58 0.0010 0.76 0.0123 0.39 BD15 Petaluma River 2/6/94 0.0036 1.83 0.0890 0.31 2.58 0.0018 5.71 0.0181 0.31 BD20 San Pablo Bay 2/6/94 0.0037 1.79 0.0513 0.15 1.50 0.0013 1.47 0.0124 0.24 BD30 Pinole Point 2/6/94 0.0021 1.85 0.0513 0.13 1.30 0.0011 1.36 0.0098 0.25 BD40 Davis Point 2/7/94 0.0020 1.74 0.0484 0.21 1.54 0.0018 1.56 0.0289 0.25 | 0.72 0.54 1.02 0.82 0.75 |
| BC60 Red Rock 2/6/94 0.0042 1.72 0.0364 0.15 0.58 0.0010 0.76 0.0123 0.39 BD15 Petaluma River 2/6/94 0.0036 1.83 0.0890 0.31 2.58 0.0018 5.71 0.0181 0.31 BD20 San Pablo Bay 2/6/94 0.0037 1.79 0.0513 0.15 1.50 0.0013 1.47 0.0124 0.24 BD30 Pinole Point 2/6/94 0.0021 1.85 0.0513 0.13 1.30 0.0011 1.36 0.0098 0.25 BD40 Davis Point 2/7/94 0.0020 1.74 0.0484 0.21 1.54 0.0018 1.56 0.0289 0.23 | 0.54 1.02 0.82 0.75 |
| BD15 Petaluma River 2/6/94 0.0036 1.83 0.0890 0.31 2.58 0.0018 5.71 0.0181 0.31 BD20 San Pablo Bay 2/6/94 0.0037 1.79 0.0513 0.15 1.50 0.0013 1.47 0.0124 0.24 BD30 Pinole Point 2/6/94 0.0021 1.85 0.0513 0.13 1.30 0.0011 1.36 0.0098 0.25 BD40 Davis Point 2/7/94 0.0020 1.74 0.0484 0.21 1.54 0.0018 1.56 0.0289 0.23 | 1.02 0.82 0.75 |
| BD20 San Pablo Bay 2/6/94 0.0037 1.79 0.0513 0.15 1.50 0.0013 1.47 0.0124 0.24 BD30 Pinole Point 2/6/94 0.0021 1.85 0.0513 0.13 1.30 0.0011 1.36 0.0098 0.25 BD40 Davis Point 2/7/94 0.0020 1.74 0.0484 0.21 1.54 0.0018 1.56 0.0289 0.23 | 0.82 0.75 |
| BD30 Pinole Point 2/6/94 0.0021 1.85 0.0513 0.13 1.30 0.0011 1.36 0.0098 0.25 BD40 Davis Point 2/7/94 0.0020 1.74 0.0484 0.21 1.54 0.0018 1.56 0.0289 0.23 | 0.75 |
| BD40 Davis Fullit 2/1/94 0.0020 1.74 0.0464 0.21 1.54 0.0016 1.50 0.0269 0.25 | 0 0 2 |
| BD50 Napa River 2/7/94 0.0016 1.83 0.0477 0.30 1.81 0.0017 1.91 0.0507 0.31 | 0.92 |
| BE10 Packero Creek 2/7/94 0.0025 1.62 0.0412 0.27 1.96 0.0014 1.71 0.0383 0.29 | 1.04 |
| BF20 Grizzly Bay 2/7/94 0.0019 1.56 0.0364 0.30 2.15 0.0016 1.80 0.0514 0.25 | 1.05 |
| BF40 Honker Bay 2/8/94 0.0024 1.77 0.0232 0.34 2.10 0.0018 1.34 0.0796 0.25 | 1.04 |
| BG20 Sacramento River 2/8/94 0.0029 1.70 0.0138 0.46 1.80 0.0020 1.04 0.1006 0.23 | 1.01 |
| BG30 San Joaquin River 2/8/94 0.0022 1.59 0.0142 0.41 2.25 0.0011 1.24 0.0837 0.27 | 0.97 |
| C-13 Sunnyvale 1/31/94 0.0014 2.30 0.0594 0.20 1.96 0.0020 4.12 0.2193 0.36 | 9.97 |
| C-3-0 San Jose 1/31/94 0.0012 2.10 0.0674 0.11 2.67 0.0036 6.63 0.2947 0.58 | 24.89 |
| BA10 Coyote Creek 4/18/94 0.0053 3.50 0.1076 0.22 4.89 0.0186 4.06 0.0893 0.39 | 3.82 |
| BA20 South Baly 4/19/94 0.0073 2.63 0.1097 0.16 4.96 0.0032 3.50 0.0706 0.53 BA30 Dumbaton Bridge 4/18/94 0.0051 2.85 0.1010 0.14 3.72 0.0022 2.68 0.0534 0.24 | 2.54 |
| BA30 Redwood Creek 4/18/94 0.0031 2.47 0.0835 0.12 3.11 0.0019 2.68 0.0559 0.29 | 0.95 |
| BB15 San Bruno Shoal 4/18/94 0.0046 2.63 0.0782 0.19 2.96 0.0020 2.32 0.0378 0.26 | 0.88 |
| BB30 Oyster Point 4/19/94 0.0045 2.17 0.0809 0.07 2.70 0.0022 1.83 0.0250 0.22 | 0.71 |
| BB70 Alameda 4/20/94 0.0029 2.12 0.0731 0.11 1.90 0.0016 1.61 0.0367 0.22 | 0.82 |
| BC10 Yerba Buena Island 4/20/94 0.0034 1.90 0.1035 0.13 1.42 0.0015 1.66 0.0538 0.27 | 1.39 |
| BC20 Golden Gate 4/21/94 0.0012 1.78 0.0564 0.09 0.33 0.0011 0.49 0.0092 0.24 | 0.21 |
| BC30 Richardson Bay 4/21/94 0.0019 1.74 0.0591 0.12 1.01 0.0013 1.04 0.0160 0.29 | 0.78 |
| BC41 Point isabel 4/20/94 0.0027 2.23 0.0015 0.14 1.33 0.0020 1.15 0.0003 0.27 BC60 Bod Book 4/20/94 0.0024 1.91 0.0664 0.12 1.20 0.0014 1.20 0.0145 0.22 | 0.46 |
| BC00 Red ROK 4/2/194 0.0024 1.51 0.0004 0.15 1.50 0.0014 1.20 0.014 0.23 BC15 Pataluma River 4/26/04 0.0044 2.09 0.0874 0.13 2.50 0.0018 2.32 0.0077 0.19 | 0.54 |
| BD20 San Pablo Bay 4/26/94 0.0034 1.95 0.0919 0.17 2.12 0.0017 1.63 0.0064 0.14 | 0.52 |
| BD30 Pinole Point 4/26/94 0.0030 1.90 0.0651 0.17 1.84 0.0015 1.58 0.0132 0.19 | 0.61 |
| BD40 Davis Point 4/26/94 0.0037 2.21 0.0675 0.26 2.20 0.0017 1.68 0.0305 0.23 | 0.77 |
| BD50 Napa River 4/27/94 0.0019 1.91 0.0632 0.36 2.62 0.0019 2.04 0.0107 0.22 | 0.92 |
| BF10 Pacheco Creek 4/27/94 0.0014 2.06 0.0446 0.14 2.69 0.0018 1.69 0.0059 0.23 | 0.64 |
| BF20 Grizzly Bay 4/27/94 0.0014 1.85 0.0394 0.15 2.75 0.0019 1.63 0.0051 0.20 | 0.54 |
| BF40 Honker Bay 4/2/194 0.0007 1.87 0.0258 0.38 2.56 0.0019 1.25 0.0196 0.14 | 0.54 |
| BG20 Sacramento River 4/28/94 0.0010 1.92 0.0224 0.77 2.30 0.0022 1.26 0.0705 0.22 BC20 Septimer 4/28/94 0.0004 1.70 0.0164 0.14 2.34 0.0015 0.00 0.0050 0.20 | 0.80 |
| C-1.3 Sun yvala 4/20/94 0.0004 1.79 0.0104 0.14 2.24 0.0013 0.99 0.0039 0.20 | 0.30 |
| $C_{-3}O$ San Jose 4/19/94 0.0121 3.17 0.1023 5.93 0.0084 8.80 0.8122 0.46 | 12.47 |
| BA10 Coyote Creek 8/16/94 0.0062 4.23 0.1017 0.41 4.46 0.0019 4.63 0.1077 0.34 | 1.43 |
| BA20 South Bay 8/15/94 0.0060 4.73 0.2016 0.24 3.85 0.0018 3.37 0.0531 0.26 | 0.77 |
| BA30 Dumbarton Bridge 8/15/94 0.0094 3.62 0.2170 0.19 3.67 0.0064 3.07 0.0402 0.28 | 0.62 |
| BA40 Redwood Creek 8/16/94 0.0052 2.74 0.1837 0.25 3.29 0.0010 2.67 0.0299 0.22 | 0.51 |
| BB15 San Bruno Shoal 8/15/94 0.0132 3.34 0.2022 0.21 2.75 0.0058 2.23 0.0061 0.29 | 0.50 |
| BB30 Oyster Point 8/15/94 0.0164 2.73 0.0910 0.23 2.27 0.0034 2.15 0.0161 0.35 | 0.67 |
| BC10 Vorthe Burge Island 8/17/94 0.0110 2.22 0.2050 0.24 2.51 0.0012 1.67 0.0515 0.17 BC10 Vorthe Burge Island 8/17/04 0.0015 2.81 0.1640 0.17 1.40 0.0007 1.47 0.0160 0.14 | 0.69 |
| BC10 relide Diden Cate 8/17/94 0.0045 2.01 0.1049 0.17 1.49 0.0007 1.47 0.0000 0.14 BC20 Coldan Cate 8/17/94 0.0015 1.28 0.1235 0.18 0.61 0.0003 0.73 0.0063 0.27 | 0.04 |
| BC30 Bichardson Bay 8/17/94 0.0030 2.43 0.1523 0.16 1.15 0.0005 1.11 0.0113 0.40 | 0.52 |
| BC41 Point Isabel 8/18/94 0.0027 2.38 0.1536 0.16 1.30 0.0006 1.12 0.0083 0.38 | 0.44 |
| BC60 Red Rock 8/18/94 0.0027 2.71 0.1285 0.17 1.09 0.0005 1.17 0.0098 0.44 | 0.44 |
| BD15 Petaluma River 8/22/94 0.0095 3.61 0.1911 0.28 3.42 0.0013 2.85 0.0054 0.29 | 0.50 |
| BD20 San Pablo Bay 8/22/94 0.0078 2.18 0.1573 0.20 1.88 0.0011 1.84 0.0112 0.16 | 0.57 |
| BD30 Pinole Point 8/22/94 0.0057 2.66 0.1655 0.24 1.99 0.0005 1.97 0.0059 0.21 | 0.57 |
| BD40 Davis Point 8/22/94 0.0066 3.19 0.1570 0.28 2.57 0.0011 2.15 0.0060 0.18 | 0.70 |
| BD50 Napa River 8/23/94 0.0032 3.29 0.1607 0.26 2.90 0.0007 2.47 0.0194 0.20 | 1.17 |
| BF10 Pacheco Creek 8/23/94 0.0029 2.45 0.1160 0.23 2.74 0.0008 1.91 0.0081 0.33 BF20 Crizek Pay 9/23/04 0.0027 2.34 0.0260 5.5 0.62 0.0009 4.50 0.021 0.21 | 0.66 |
| DF2U GHZZIY DBY 87/23/04 U.UU37 2.24 U.U269 U.58 2.63 U.UU08 1.88 U.U173 U.24 RE4U Honker Boy 87/23/04 0.0046 2.98 0.0722 0.20 2.40 0.0006 4.59 0.0040 0.20 | 0.50 |
| BG20 Sacramento River 8/24/94 0.0010 2.00 0.0733 0.20 2.40 0.00000 1.38 0.0042 0.20 | 0.41 |
| BG30 San Jaquin River 8/24/94 0.0004 2.47 0.032 0.5 210 0.0009 1.32 0.0000 0.12 | 0 41 |
| C-1-3 Sunnyvale 8/16/94 0.0030 3.85 0.0502 0.45 2.71 0.0126 5.45 0.3439 0.79 | 4.22 |
| C-3-0 San Jose 8/16/94 0.0029 4.34 0.1729 . 4.09 0.0432 7.22 0.1573 0.24 | E 0.0 |

Table 3.3. Total or near-total* concentrations of trace elements in water, 1994.. = Not Analyzed, ND = data not quantifiable

| Station | Station | Date | Ag* | As | Cd* | Cr | Cu* | Hg | Ni* | Pb* | Se | Zn* |
|---------------|-------------------------------|--------------------|--------|--------------|--------|---------------|--------------|--------|-------|--------------|------|--------------|
| Code | Name | | μg/L | μg/L | μg/L | μg/L | μg/L | μg/L | μg/L | μg/L | μg/L | μg/L |
| BA10 | Coyote Creek | 1/31/94 | 0.0658 | 2.95 | 0.0985 | 12.89 | 6.06 | 0.0376 | 12.22 | 3.46 | 0.42 | 25.65 |
| BA20 BA30 | South Bay Dumbarton Bridge | 1/30/94 | 0.0052 | 2.62 | 0.0904 | 4.86 | 3.40 | 0.0121 | 5.92 | 1.20 | 0.38 | 6.56 8.02 |
| BA40 | Redwood Creek | 1/31/94 | 0.0215 | 2.65 | 0.0895 | 1.69 | 2.64 | 0.0056 | 3.47 | 0.55 | 0.40 | 3.90 |
| BB15 | San Bruno Shoal | 1/30/94 | 0.0210 | 3.02 | 0.0819 | 4.93 | 3.19 | 0.0139 | 4.77 | 1.25 | 0.25 | 6.13 |
| BB30 | Oyster Point | 1/30/94 | 0.0169 | 2.33 | 0.0851 | 4.90 | 2.89 | 0.0127 | 4.43 | 0.97 | 0.33 | 5.33 |
| BB70 | Alameda | 2/2/94 | 0.0150 | 2.67 | 0.0848 | 1.68 | 2.39 | 0.0062 | 3.11 | 0.53 | 0.29 | 3.08 |
| BC10 BC20 | Yerba Buena Island | 2/2/94 | 0.0130 | 2.18 | 0.0628 | 1.07 | 1.68 | 0.0042 | 2.13 | 0.28 | 0.39 | 3.26 |
| BC20 BC30 | Richardson Bay | 2/2/94 | 0.0041 | 2 12 | 0.0200 | 1.80 | 1.50 | 0.0019 | 2 42 | 0.14 | 0.31 | 3.01 |
| BC41 | Point Isabel | 2/1/94 | 0.0112 | 1.91 | 0.0448 | 1.79 | 1.58 | 0.0057 | 1.96 | 0.49 | 0.32 | 2.93 |
| BC60 | Red Rock | 2/6/94 | 0.0054 | 1.79 | 0.0367 | 1.44 | 1.17 | 0.0045 | 1.89 | 0.37 | 0.37 | 2.31 |
| BD15 | Petaluma River | 2/6/94 | 0.0119 | 2.06 | 0.0847 | 4.57 | 2.86 | 0.0143 | 8.20 | 1.19 | 0.33 | 6.72 |
| BD20 | San Pablo Bay | 2/6/94 | 0.0095 | 2.00 | 0.0500 | 3.06 | 2.71 | 0.0096 | 4.12 | 0.88 | 0.25 | 4.94 |
| BD30 BD40 | Pinole Point Davis Point | 2/0/94 | 0.0118 | 2.24 | 0.0510 | 2 50 | 3.27 | 0.0183 | 4.08 | 0.64 | 0.39 | 5.81 4 13 |
| BD50 | Napa River | 2/7/94 | 0.0077 | 1.90 | 0.0505 | 3.55 | 0.60 | 0.0097 | 4.64 | 0.95 | 0.27 | 5.60 |
| BF10 | Pacheco Creek | 2/7/94 | 0.0073 | 1.85 | 0.0440 | 1.35 | 2.49 | 0.0060 | 3.00 | 0.45 | 0.28 | 3.45 |
| BF20 | Grizzly Bay | 2/7/94 | 0.0108 | 1.88 | 0.0343 | 3.21 | 3.28 | 0.0126 | 3.99 | 0.70 | 0.34 | 5.29 |
| BF40 | Honker Bay | 2/8/94 | 0.0107 | 1.80 | 0.0234 | 2.30 | 3.05 | 0.0062 | 2.85 | 0.59 | 0.28 | 4.15 |
| BG20 BG30 | Sacramento River | 2/8/94 | 0.0102 | 1.89 | 0.0224 | 1.44 | 3.01 | 0.0050 | 2.52 | 0.44 | 0.30 | 3.74 |
| C-1-3 | Sunnyvale | 1/31/94 | 0.0102 | 2 72 | 0.0184 | 5.78 | 4 30 | 0.0031 | 9.85 | 2.26 | 0.25 | 27.66 |
| C-3-0 | San Jose | 1/31/94 | 0.0468 | 2.46 | 0.0707 | 4.73 | 4.18 | 0.0217 | 10.98 | 1.69 | 0.59 | 43.40 |
| BA10 | Coyote Creek | 4/18/94 | 0.0395 | 3.01 | 0.1229 | 6.71 | 6.68 | 0.0027 | 8.49 | 1.94 | 0.36 | 14.23 |
| BA20 | South Bay | 4/19/94 | 0.0343 | 3.49 | 0.1273 | 5.75 | 6.35 | 0.0162 | 7.17 | 1.55 | 0.33 | 11.47 |
| BA30 | Dumbarton Bridge | 4/18/94 | 0.0191 | 2.86 | 0.1092 | 4.15 | 5.20 | 0.0115 | 5.74 | 1.31 | 0.32 | 8.63 |
| BA40 BB15 | Redwood Creek | 4/18/94 //18/07 | 0.0183 | 2.75 | 0.0983 | 3.43 | 4.28 | 0.0098 | 4.85 | 1.16 | 0.29 | 4.35 |
| BB30 | Ovster Point | 4/19/94 | 0.0176 | 2.28 | 0.0796 | 1.63 | 3.19 | 0.0058 | 3.24 | 0.43 | 0.29 | 2.43 |
| BB70 | Alameda | 4/20/94 | 0.0148 | 2.14 | 0.0733 | 1.46 | 2.60 | 0.0057 | 2.97 | 0.47 | 0.28 | 2.54 |
| BC10 | Yerba Buena Island | 4/20/94 | 0.0165 | 2.02 | 0.0951 | 1.78 | 2.34 | 0.0064 | 3.21 | 0.80 | 0.27 | 3.22 |
| BC20 | Golden Gate | 4/21/94 | 0.0036 | 2.35 | 0.0639 | 0.19 | 0.46 | 0.0015 | 0.60 | 0.05 | 0.26 | 0.44 |
| BC30 | Richardson Bay | 4/21/94 | 0.0059 | 1.85 | 0.0614 | 0.51 | 1.35 | 0.0026 | 1.39 | 0.15 | 0.23 | 1.55 |
| BC60 | Red Rock | 4/20/94 4/21/94 | 0.0090 | 2.04 | 0.0713 | 0.27 | 1.90 | 0.0031 | 1.62 | 0.15 | 0.25 | 1.11 |
| BD15 | Petaluma River | 4/26/94 | 0.1397 | 5.02 | 0.1474 | 44.89 | 20.75 | 0.1100 | 32.42 | 7.38 | 0.25 | 46.36 |
| BD20 | San Pablo Bay | 4/26/94 | 0.0581 | 2.99 | 0.0977 | 19.64 | 8.68 | 0.0474 | 11.90 | 4.35 | 0.25 | 19.67 |
| BD30 | Pinole Point | 4/26/94 | 0.0391 | 2.67 | 0.0860 | 11.90 | 6.78 | 0.0311 | 10.36 | 3.18 | 0.22 | 17.31 |
| BD40 | Davis Point | 4/26/94 | 0.0167 | 2.36 | 0.0766 | 4.78 | 4.06 | 0.0127 | 5.15 | 1.05 | 0.21 | 8.77 |
| BD50 BE10 | Napa River Pacheco Creek | 4/27/94 | 0.0389 | 2.93 | 0.0876 | 12.68 | 5.4Z 7.86 | 0.0360 | 10.50 | 3.28 | 0.20 | 14.37 |
| BF20 | Grizzly Bay | 4/27/94 | 0.0571 | 3.13 | 0.0740 | 20.56 | 10.94 | 0.0412 | 16.41 | 5.83 | 0.10 | 23.00 |
| BF40 | Honker Bay | 4/27/94 | 0.0236 | 2.55 | 0.0468 | 10.40 | 7.87 | 0.0256 | 8.41 | 2.57 | 0.19 | 16.09 |
| BG20 | Sacramento River | 4/28/94 | 0.0155 | 2.18 | 0.0442 | 7.01 | 5.82 | 0.0126 | 5.75 | 1.51 | 0.25 | 11.49 |
| BG30 | San Joaquin River | 4/28/94 | 0.0105 | 2.15 | 0.0266 | 3.69 | 3.82 | 0.0146 | 3.82 | 0.81 | 0.22 | 4.04 |
| C-1-3 | Sunnyvale | 4/19/94 | 0.1198 | 2.48 | 0.0426 | 8.60 | 5.32 | 0.0235 | 9.66 | 2.94 | 0.43 | 17.26 |
| C-3-0 BA10 | Covote Creek | 4/19/94 8/16/94 | 0.0494 | 3.1Z 4.53 | 0.1000 | 0.37 | 7.14 | 0.0215 | 14.24 | 2.00 | 0.45 | 20.94 |
| BA20 | South Bay | 8/15/94 | 0.0248 | 4.42 | 0.1750 | 4.96 | 5.67 | 0.0131 | 6.25 | 0.93 | 0.23 | 5.46 |
| BA30 | Dumbarton Bridge | 8/15/94 | 0.0260 | 3.94 | 0.1707 | 9.32 | 6.17 | 0.0561 | 7.73 | 1.66 | 0.32 | 7.82 |
| BA40 | Redwood Creek | 8/16/94 | 0.0147 | 3.59 | 0.1479 | 2.86 | 4.33 | 0.0086 | 4.23 | 0.64 | 0.28 | 3.29 |
| BB15 | San Bruno Shoal | 8/15/94 | 0.0233 | 3.60 | 0.1571 | 1.64 | 3.56 | 0.0153 | 3.31 | 0.35 | 0.38 | 2.20 |
| BB70 | Alameda | 8/17/94 | 0.0214 | 2 10 | 0.1407 | 2 22 | 3.16 | 0.0040 | 2.00 | 0.54 | 0.33 | 3 12 |
| BC10 | Yerba Buena Island | 8/17/94 | 0.0090 | 2.46 | 0.1268 | 1.17 | 2.02 | 0.0029 | 2.06 | 0.19 | 0.27 | 1.77 |
| BC20 | Golden Gate | 8/17/94 | 0.0034 | 1.69 | 0.0905 | 0.40 | 0.90 | 0.0012 | 1.03 | 0.13 | 0.30 | 0.74 |
| BC30 | Richardson Bay | 8/17/94 | 0.0061 | 2.06 | 0.0954 | 1.21 | 1.81 | 0.0033 | 1.85 | 0.29 | 0.22 | 1.47 |
| BC41 | Point Isabel | 8/18/94 | 0.0058 | 2.72 | 0.0990 | 0.52 | 1.73 | 0.0023 | 2.10 | 0.18 | 0.17 | 1.02 |
| BC60 BD15 | Red ROCK Petaluma Piver | 8/18/94 | 0.0075 | 2.01 | 0.1049 | 1.46 | 1.71 | 0.0043 | 1.92 | 0.35 | 0.33 | 1.65 |
| BD10 BD20 | San Pablo Bay | 8/22/94 | 0.0203 | 3.60 | 0.1770 | 14.08 | 7.98 | 0.0223 | 9.98 | 2.93 | 0.17 | 12 51 |
| BD30 | Pinole Point | 8/22/94 | 0.0245 | 3.53 | 0.1374 | 9.58 | 6.01 | 0.0270 | 6.83 | 1.91 | 0.20 | 9.15 |
| BD40 | Davis Point | 8/22/94 | 0.0220 | 3.62 | 0.1358 | 7.07 | 4.85 | 0.0141 | 6.03 | 1.61 | 0.22 | 7.85 |
| BD50 | Napa River | 8/23/94 | 0.0221 | 2.68 | 0.1370 | 8.88 | 6.61 | 0.0215 | 7.81 | 1.94 | 0.08 | 10.59 |
| BF10 | Pacheco Creek | 8/23/94 | 0.0165 | 3.11 | 0.0953 | 6.45 | 6.27 | 0.0164 | 6.58 | 1.46 | 0.16 | 8.13 |
| BF20 BE40 | Grizzly Bay Honker Bay | 0/23/94 8/22/01 | 0.0243 | 3.00 | 0.0990 | 14.35 5 00 | 9.07 1 91 | 0.0355 | 10.90 | 3.Ub 0 00 | 0.20 | 14.03 |
| BG20 | Sacramento River | 8/24/94 | 0.0030 | 2.65 | 0.0376 | 2.36 | 3.44 | 0.0045 | 2.85 | 0.45 | 0.16 | 2.75 |
| BG30 | San Joaquin River | 8/24/94 | 0.0024 | 2.54 | 0.0280 | 2.63 | 3.28 | 0.0044 | 2.17 | 0.41 | 0.06 | 2.40 |
| C-1-3 | Sunnyvale | 8/16/94 | 0.0277 | 4.61 | 0.0590 | 7.93 | 5.56 | 0.0521 | 10.23 | 2.19 | 0.70 | 11.74 |
| C-3-0 | San Jose | 8/16/94 | 0.1085 | 4.47 | 0.1786 | 28.26 | 13.05 | 0.0797 | 36.03 | 7.73 | 0.41 | 34.45 |

| 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
|-------------------|-------------|------------|-------------|--------------|---------------|----------------|----------|-------------|-------------------------------|---------------|------------------|--------------|-------------------|------------------|------------------|-------------|--------------|---------------|----------------|----------|-------------|-------------------------------|---------------|------------------|--------------|-------------------|------------------|------------|-------------|--------------|---------------|----------------|----------|-------------|---------|---------------|------------------|--------------|----------------------|
| BG30 | | BD50 | BD40 | BD30 | BD20 | BD15 | BC60 | BC20 | BC10 | BA40 | BA30 | BA10 | BG30 | BG20 | | BD40 | BD30 | BD20 | BD15 | BC60 | BC20 | | BA40 | BA30 | BA10 | BG30 | BG20 | BD50 | BD40 | BD30 | BD20 | BD15 | BC60 | BCNO | BB70 | BA40 | BA30 | BA10 | Station Code |
| San Joaquin River | Grizzly Day | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Red Rock | Golden Gate | Alameda Yerba Buena Island | Redwood Creek | Dumbarton Bridge | Coyote Creek | San Joaquin River | Sacramento River | Grizzly Rav | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Red Rock | Golden Gate | Alameda Verha Buena Island | Redwood Creek | Dumbarton Bridge | Coyote Creek | San Joaquin River | Sacramento River | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Red Rock | Coldon Coto | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | Station Name |
| 8/23/94 | 0/23/94 | 8/23/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/18/94 | 8/17/94 | 8/17/94 | 8/16/94 | 8/15/94 | 8/16/94 | 4/28/94 | 4/28/94 | 4/27/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/21/94 | 4/21/94 | 4/20/94 | 4/18/94 | 4/18/94 | 4/18/94 | 2/9/94 | 2/9/94 | 2/8/94 | 2/8/94 | 2/7/94 | 2/7/94 | 2/7/94 | 2/7/94 | 2/3/94 | 2/3/94 | 2/2/94 | 1/31/94 | 2/1/94 | Date |
| 245418 | 110076 | 221494 | 127526 | 304984 | 263468 | 158752 | 398508 | 183366 | 136028 | 3402220 | 1115000 | 233672 | 524826 | 175628 | 18/468 297728 | 364420 | 553908 | 199778 | 204600 | 135962 | 288860 | 354454 | 151968 | 140336 | 251128 | 79382 | 35473 | 50882 | 105765 | 105739 | 69868 | 67433 | 534709 | 47600 | 137248 | 81594 | 194211 | 719112 | Total Alkanes |
| 870 | 2007 | 12810 | 4236 | 3267 | 2770 | 2500 | | 1350 | 4302 | 2220 | 3590 | 5787 | 911 | 860 | 3177 | 2244 | 2694 | 1390 | 2227 | 3380 | 640 | 17287 | 3515 | 2580 | 3098 | 1054 | 1423 | 3308 | 3493 | 474 | 5575 | 1629 | 1720 | 3000 | 1546 | | 4869 | 2614 | Total PAHs |
| 160 | 290 | 3000 | 1210 | 764 | 640 | 500 | R | 400 | 922 | 720 | 1210 | 1397 | 341 | 220 | 613 | 624 | *1064 | 260 | 620 | 440 | 330 | 1537 | *940 | 702 | 818 | 383 | 395 395 | 652 | 597 | 90 | 482 | 200 | 649 | 181.1 | 289 | | 381 | 500 | Total LPAHs |
| 710 | 1107 | 9810 | 3026 | 2503 | 2130 | 2000 | R | 950 | 3380 | 1500 | 2380 | 4390 | 570 | 640 | 2725 | 1620 | *1630 | 1130 | 1607 | 2940 | 310 | 16320 | *2575 | 1878 | 2280 | 671 | 1028 | 2591 | 2896 | 384 | 5065 | 1428 | 1071 | 23/9 | 1257 | | 4489 | 2114 | Total HPAHs |
| | | | | | | | | | | | | | 61 | Ø S | 63 | 15 14 | *160 | Ø | Ø | Ø | 0 = | 140 | *150 | Ø | 65 | 54 | 30 2 | 74 | 71 | Ŋ | Ŋ | ∞ ; | 45 | 170 | 12 | | 68 | 69 | 1-Methylnaphthalene |
| N | 50 | 190 | 110 | 74 | N | N | 88 | Ş | 88 | 58 | 110 | 97 | | | | | | | | | | | | | | | | | | | | | | | | | | | 1-Methylphenanthrene |
| | | | | | | - | | | | | | | | | | | | • | | | | | | | | 45 | 89 | 57 | 102 | Ŋ | 67 | 17 | 90 78 | 200 | 14 | | 60 | 88 | 2-Methylnaphthalene |
| 23 | 58 | 310 | Se | ß | Ŋ | B | S | Ş | 82 | 5 C | 58 | Ŋ | Ø | Ø | o c | Q | *54 | Ø | Q | 230 | ND 4 | °, c | Q | 52 | 53 | 88 | 32 | j 14 | 45 | Ŋ | Ŋ | 4 | 88 | Ēē | 38 | | 7 | 10 | Anthracene |
| N S | 58 | 58 | 58 | Ŋ | Ŋ | B | 88 | Ş | 88 | 50 | 58 | Ŋ | Ø | o <u>s</u> | л с | o o | Ø | Ø | Ø | 97 | Z º | 81 | Q | Ø | ø | 20 | 000 | n ND | 19 | Ŋ | 51 | 48 | 11 0 | • 2 | 84 | | 121 | 57 | |
| | | | | | | | | | | | | | B | ۶ | ρĘ | 50 | Å | ND | Ŋ | Ø | o ē | ξc | B | ND | ND | 16 | 57 | 58 | S | 15 | 320 | 88 | ωυ | ۶Ę | 148 | | 398 | 73 | |
| N S | 58 | 120 | 58 | Ŋ | ß | Ŋ | 88 | Ş | 88 | 58 | 91 | 130 | Ø | Ø. | 03 71 | 50 | Q | 80 | 93 | 710 | 0 0 | 3100 | *130 | 110 | 72 | 14 14 | 33 | 58 | ;∞ | 14 | 532 | 169 | 42 | 20 | 189 | | 549 | 124 | |
| N S | 58 | 94 | 28 | Ŋ | ß | Ŋ | 88 | Ş | 88 | 58 | 58 | 120 | Ø | Ø S | 66 C | o o | Ø | Ø | 74 | 440 | 0 0 | 2100 | *120 | 68 | 66 | 12 | S - | 2 N | ; Þ | Ð | 429 | 85 | - 2 | 52 | 58 | | 331 | 59 | |
| N | 58 | 96 | 88 | ND | Ŋ | N | 88 | Ş | 88 | 58 | S | Ŋ | | | | | | | | | | | | | | 88 | 33 | 58 | S | Ŋ | 864 | 155 | ₽ ŧ | - Z | 19 | | 540 | 6 | |
| N S | 58 | 58 | 58 | Ŋ | Ŋ | B | 23 | Z i | 88 | 58 | 58 | Ŋ | Ø | ø | οc | o o | Ø | Q | Ø | 210 | 0 0 | 076 | Q | Ø | ø | 12 | 21 | 2 ND | 22 | 13 | 326 | 74 | 20 16 | | 144 | | 315 | 88 | |
| ND | 040 | 200 | 96 | 72 | Ð | B | 88 | Ş | 88 | 5 C | 79 | 130 | Ø | o S | 03 03 | 30 | Ø | Q | 80 | 280 | 00 | 1000 | Ø | Q | 55 | 56 | 80 | | 96 | Ŋ | 164 | 118 | 97 76 | 0110 | 95 | | 280 | 142 | |
| N S | 58 | 160 | Se | 61 | Ŋ | B | 88 | Ş | 88 | 5 C | 58 | 110 | Ø | Ø | D C | a | Q | Q | Q | 73 | o ē | 280 | *95 | Q | Ø | 88 | 33 | 50 | S | Ŋ | 32 | 7 | 4 0 | Ē | j∞ | | 23 | 46 | |
| 170 | 330 | 5200 | 2400 | 1400 | 1200 | 1000 | N S | 670 | 2500 | 1000 | 1300 | 2000 | 140 | 230 | 1000 | 910 | *890 | 520 | 930 | 620 | 310 | 2000 | *1100 | 850 | 940 | 170 | 341 | 1603 | 1373 | 250 | 1399 | 411 | 884 1 | 2021 | 560 | | 986 | 1017 | |
| N | 58 | 140 | S | ND | N | N | 88 | Ş | 88 | 58 | S | Ŋ | Ø | o S | 8 c | Q | Ø | Ø | Q | 290 | 0 0 | 2700 | *130 | Ø | 47 | 88 | 33 | 58 | S | Ŋ | 473 | 78 | N ⊳ | <u>-</u> د | 12 | | 406 | 9 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | 88 | 53 | 2 6 5 | S | Ŋ | 28 | S | 53 | 52 | 58 | | Ŋ | ND | |
| 160 | 000 | 2500 | 1100 | 069 | 640 | 500 | B | 400 | 840 | 720 | 1100 | 1300 | 280 | 220 | 550 | 570 | *850 | 260 | 620 | 210 | 330 | 1300 | •790 | 650 | 700 | 284 | 234 | 507 | 379 | 90 | 415 | 172 | 525 | 200 | 263 | | 246 | 334 | |
| 540 | | 3800 | 530 | 970 | 930 | 1000 | N 2 | 280 | 880 | 590 | 910 | 1900 | 430 | 410 | 1200 | 660 | *740 | 530 | 430 | 220 | | 1600 | *1000 | 850 | 1100 | 371 | 522 | 886 | 1374 | 92 | 476 | 195 | 36 | | S | | 541 | 494 | |

 Table 3.4. Dissolved Alkanes (total) and PAH concentrations in water samples. Units in pg/L (ppq).

 ND = Not Detected, . = Not Analyzed, Q = Present but not quantifiable, LPAHs = Low molecular weight PAHs,

 HPAHs = High molecular weight PAHs, * = Highly variable surrogate recoveries. Data should be interpreted with caution.

Table 3.5. Total (particulate plus dissolved) Alkanes (total) and PAH concentrations in water samples. Units in pg/L (ppq). ND = Not Detected, . = Not Analyzed, Q = Present but not quantifiable, LPAHs = Low molecular weight PAHs, HPAHs = High molecular weight PAHs

* Highly variable surrogate recoveries. Data should be interpreted with caution.

| Pyrene | 14967 2146 | 42409 | 304 304 | 1755 5383 | 2311 | 13773 3735 | 4916 | 5339 | 1229 | 10900 | 9350 | *9800 | 3580 | 5100 | 220 | 35430 | 15530 | *10/40 FEED | 7980 | 10200 | 2410 | 18900 | 11910 | 3890 | 3240 | 1600 | 4/0 | 9100 | 9830 | 4870 | 3830 | 7100 | 1220 | 980 |
|------------------------|----------------------------------|----------------------------|-----------------------------------|----------------------------|---------------|-----------------------------|------------|-------------|--------------------|---------------|------------------|---------------|---------|--------------------|------------------|----------------|---------------|--------------------|------------|-------------|------------------|--------------|------------------|---------------|---------|--------------------|------------------|----------------------------|---------------|--------------|-------------|--------------------------|------------------|-------------------|
| Phenanthrene | 3593 587 | 19047 | 1424 940 | 1537 1541 | 1000 | 3903 1125 | 1673 | 1792 | 556 661 | 3500 | 3050 | *2990 | 1520 | 2300 | 940 940 | 8920 | 3760 | *3250 | 3100 | 3050 | 960 | 4100 | 3500 | 1500 | 1390 | 1120 | 000 | 2500 | 3140 | 1890 | 2200 | 4500 2110 | 520 | 440 |
| Methylanthracene | 9 9 | · 2 2 | | 0N 19 | 34 | | 65 | Q ! | | <u>-</u> | | | | | | | | | | | | | | | | | | | | | | | | |
| ənəıyq(bɔ-ɛ,ઽ,٢)onəbnl | 7050 1398 | 13025 | 516 89 | 739 2233 | 1238 | 6465 830 | 712 | 1192 | UN S | 8947 | 8300 | *9130 | 2920 | 3300 | 290 | 28000 | 12000 | 1//00 | 4900 | 6380 | 1300 | 16000 | 12000 | 4000 | 3300 | 200 | | 8000 | 7300 | 3400 | 2800 | 5040 | 410 | 420 |
| Fluoranthene | 11679 2180 | 50964 | 4907 1316 | 3067 4566 | 2988 | 10812 3584 | 4920 | 4818 | 957 1020 | 8840 | 8450 | *8700 | 4300 | 6600 | 1720 | 25930 | 11520 | *8590 5010 | 7700 | 7900 | 1930 | 14000 | 9700 | 4010 | 3700 | 3800 | 1130 | 7000 | 7900 | 4600 | 5400 | 12500 6700 | 1050 | 820 |
| Dibenz(a,h)anthracene | 589 48 | 1313 05 | 5 7 7 | 102 7 | 105 | 749 58 | 51 | 69 | UN 9 | 890 | 810 | *955 | 450 | 350 | 73.0 | 2900 | 1300 | 1100 | 580 | 800 | 200 | 5210 | 3900 | 1100 | 006 | 250 | 59 | 2300 | 2600 | 1361 | 1200 | 2760 2500 | 210 | 210 |
| Chrysene | 4949 2079 | 25501 | 976 324 | 1194 2152 | 979 | 5009 1184 | 1698 | 2321 | 950 670 | 0/0 2955 | 3100 | *3200 | 1000 | 1300 | 280 | 11080 | 4800 | 1700 | 2582 | 3493 | 006 | 5930 | 4479 | 1500 | 1200 | 420 | 230 | 2700 | 2800 | 1472 | 1396 | 3500 3198 | 657 | 490 |
| Benzo(k)fluoranthene | 3855 976 | 17386 | 587 140 | 649 1374 | 791 | 2979 759 | 955 | 1431 | 272 | 2600 | 2600 | *2900 | 0207 | 1200 | 210 | 9400 | 4000 | 1400 | 1800 | 2400 | 570 | 5000 | 4100 | 1500 | 1000 | 310 | 140 | 2300 | 2200 | 1200 | 1100 | 1900 2300 | 250 | 290 |
| Benzo(ghi)perylene | 8890 2127 | 276 | <u>م</u> | 15 2786 | 1502 | 7227 138 | 145 | 47 | | <u>-</u> | | | | | | | | | | | | 1600 | 1200 | 410 | 450 | 95 | 0 4 | 001 830 | 790 | 360 | 420 | 696 630 | 97 | 92 |
| Benzo(e)pyrene | 6248 1095 | 28710 | 894 209 | 1046 2237 | 1382 | 5406 1206 | 1501 | 2000 | n e | 500 6166 | 6168 | *7020 | 2220 | 2600 | 440 | 21074 | 9200 | *6300 2200 | 3900 | 5266 | 1200 | 11120 | 7900 | 2800 | 2300 | 640 | 310 | 5400 | 5000 | 2500 | 2000 | 3994 3800 | 530 | 530 |
| Benzo(b)fluoranthene | 9891 1727 | 42153 | 1407 295 | 1705 3187 | 1848 | 8536 1546 | 2159 | 2941 | ٥ å | 304 8772 | 8910 | *9930 | 3220 | 3900 | 710 | 32093 | 13080 | *9200 1660 | 5863 | 8171 | 1800 | 17130 | 12091 | 4200 | 3400 | 1000 | 010 | 7700 | 7500 | 3700 | 3100 | 6220 5900 | 880 | 006 |
| Benzo(a)pyrene | 6675 1114 | 1564 | 37 | 3 1988 | 320 | 6457 36 | 124 | α¦ | 57 16 | 3800 | Ð | ø | a | зc | 30 | 25000 | 8900 | 1500 | 350 | 1500 | | | | | | | | • | | | | | | |
| Benz(a)ສາຖ່າເຊດອາອ | 3304 536 | 9905 | 327 76 | 497 1352 | 523 | 3359 439 | 790 | 974 | 8 | 2300 | 2400 | *2300 | 170 | 1181 | 97 | 10000 | 4300 | *3000 | 2100 | 3054 | 610 | 5800 | 4100 | Q | g | 22 | | | 3800 | QN | 55 | 260 ND | 2 Q | QN |
| Anthracene | 59 57 | 55. | ž Z | 20 | 2 | 76 | 19 | 25 | ž Z | 27 | 16 | *12 |)6 7 | 16 NI | 23 | 17(| 62 | , 4, , 7 | 39 | 48 | 50 | 37 | 21 | JN | ž | 20 J | ZZ | NI 22 | 43 | 11 | ÷: | 78 24 | ΪŻ | N |
| 2-Methyinaphthalene | 914 162 | 3722 | 406 | 309 331 | 218 | 896 310 | 369 | 549 | 89 1 E J | 701 | | | | | | | | | | | | | | | | | | | | | | | . Q | Q |
| 1-Methylphenanthrene | | | | | | | | | | | | | | | | | | | | | | 517 | 420 | 110 | 67 | 22 | | 270 | 300 | 234 | 260 | 365 | gg | QN |
| ənəlsrifqsniyriəM-t | 600 125 | 2165 | 261 92 | 166 218 | 89 | 564 221 | 260 | 325 | 30 | 375 | 270 | *410 | 970 | 0/2 | 30 | 1100 | 480 | -53U | 366 | 433 | 100 | C | | | | | | | | | | | | |
| sHA9H IstoT | 78099 15426 | 233207 | 2768 | 10770 27266 | 13987 | 13512 | 17971 | 21130 | 3473 | 56170 | 50088 | *53935 | 19430 | 25531 | 4040 | 200907 | 84630 | ~5433U | 37755 | 49164 | 10920 | 100690 | 71380 | 23410 | 19490 | 8815 | 2003 | 45330 | 49720 | 23463 | 21301 | 48770 37128 | 5304 | 4732 |
| 201 SHA9J ISJOT | 5706 931 | 25484 | 1208 | 2039 2290 | 1333 | 6130 1802 | 2498 | 2920 | 6/4 062 | 302 4148 | 3482 | *3520 | 1713 | 2/36 | 1170 | 11720 | 4860 | 2404 | 3856 | 3963 | 1117 | 4987 | 4130 | 1610 | 1487 | 1202 | 000 | 2990 | 3870 | 2234 | 2570 | 5780 2715 | 520 | 440 |
| sHA9 IstoT | 83804 16357 | 258691 | 13388 3976 | 12810 29575 | 15354 | 76902 | 20535 | 24050 | 4147 5154 | 5134 60318 | 53570 | *57455 | 21143 | 1520/ | 5210 | 212627 | 89490 | "58584 20684 | 41611 | 53127 | 12037 | 105677 | 75510 | 25020 | 20977 | 10017 | 3433 0000 | 0900 48320 | 53590 | 25697 | 23871 | 54550 39843 | 5824 | 5172 |
| zənsxlA istoT | 1846829 536032 | 1515751 2731326 | 2982560 451981 | 2608892 3251647 | 363684 | 2443339 7904304 | 4360515 | 4386558 | 2583164 2360768 | 963018 | 703506 | 845718 | 551492 | 192850 | 3/0330 176632 | 3625530 | 1425702 | 53/8340 1806381 | 1974617 | 2815348 | 2017498 | 1820562 | 2084430 | 3818740 | 709718 | 136028 | 332803 070866 | 9/ 9000 1548492 | 1913818 | 1596644 | 1168826 | 221494 ววว6452 | 1091146 | 1608378 |
| Date | 2/1/94 1/31/94 | 2/2/94 2/3/94 2/3/94 | 2/3/94 | 2/7/94 2/7/94 | 2/7/94 | 2/7/94 1 | 2/8/94 | 2/8/94 | 2/9/94 | 4/18/94 | 4/18/94 | 4/18/94 | 4/20/94 | 4/20/94 | 4/21/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/27/94 | 4/27/94 | 4/28/94 | 8/16/94 | 8/15/94 | 8/16/94 | 8/17/94 | 8/17/94 | 8/1//94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/23/94 8/23/94 | 8/23/94 | 8/23/94 |
| emsN notist2 | Coyote Creek Dumbarton Bridge | Redwood Creek Alameda | Yerba Buena Island Golden Gate | Red Rock Petaluma River | San Pablo Bay | Pinole Point Davis Point | Napa River | Grizzly Bay | Sacramento River | Covote Creek | Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Island | Bed Rock | Petaluma River | San Pablo Bay | Pinole Point | Napa River | Grizzly Bay | Sacramento River | Covote Creek | Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Island | Golden Gate | Red Rock Petaluma River | San Pablo Bay | Pinole Point | Davis Point | Napa River הידילע Rav | Sacramento River | San Joaquin River |
| Station Code | BA10 BA30 | BB70 BB70 | BC20 | BC60 BD15 | BD20 | BD30 RD40 | BD50 | BF20 | BG20 | BA10 | BA30 | BA40 | BB70 | | BC60 | BD15 | BD20 | BD30 | BD50 | BF20 | BG20 | BA10 | BA30 | BA40 | BB70 | BC10 | BCZU | BD15 | BD20 | BD30 | BD40 | BD50 RF20 | BG20 | BG30 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | | |
|---------------------------------------|-------------|------------|--------------|---------------|----------------------------|-------------|--------------------|------------|--|------------------|--------------------|------------------|-------------|------------|-------------|--------------|---------------|----------------|---------------------|--------------------|---------|---------------|------------------|--------------|-------------------|------------------|--------------|-------------|--------------|---------------|----------------|-------------|-------------------|----------|---------------|------------------|--------------|--------|-----------|-----|
| ВG20 ВG30 | BF20 | BD50 | BD30 | BD20 | BD15 | BC20 | BC10 | BB70 | BA40 | BA30 | BG30 | BG20 | BF20 | BD50 | BD40 | BD30 | | | BC20 | BC10 | BB70 | BA40 | BA30 | BA10 | BG30 | | BD50 | BD40 | BD30 | BD20 | BD15 | | | 8870 | BA40 | BA 30 | BA10 | Statio | n Code | |
| Sacramento River San Joaquin River | Grizzly Bay | Napa River | Pinole Point | San Pablo Bay | Red Rock Petaluma River | Golden Gate | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | San Joaquin River | Sacramento River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Dahlo Bav | Botolumo Divor | Golden Gate | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | San Joaquin River | Sacramento River | Critzely Bay | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Bod Book | Coldon Coto | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | Statio | on | |
| 8/23/94 8/23/94 | 8/23/94 | 8/23/94 | 8/22/94 | 8/22/94 | 8/18/94 8/22/94 | 8/17/94 | 8/17/94 | 8/17/94 | 8/16/94 | 8/15/94 | 4/28/94 8/16/04 | 4/28/94 | 4/27/94 | 4/27/94 | 4/26/94 | 4/26/94 | 4/26/04 | 4/21/94 | 4/21/94 | 4/20/94 | 4/20/94 | 4/18/94 | 4/18/94 | 4/18/94 | 2/9/94 | 2/9/94 | 2/8/94 | 2/8/94 | 2/7/94 | 2/7/94 | 2/7/94 | 10/7/0 | 2/3/94 | 2/3/94 | 2/2/94 | 1/31/94 | 2/1/94 | Date | | |
| 173 89 | 198 | 180 | 157 | 219 | 114 158 | 130 | 185 | 229 | 215 | 415 | 312 | 241 | 306 | 343 | 587 | 470 | 313 | 321 | 161 | 430 | 1008 | 588 | 377 | 388 | 101 | 99 | 116 | 131 | 145 | 138 | 105 | 5 7 7 | αл 1 | 146 | 195 | 310 | 247 | Total | PCBs (SFI | EI) |
| | | | | | | | | | | | | | | | | | | | | | | | | | ۶¢ | οa | 7.6 | 11.6 | 4.1 | 4.7 | ç ع | ກ . ວິດ | | jρ | B | 43.6 | Ŋ | РСВ | 005/8 | |
| 2.6 1.3 | 3 . 3 . | 5.4 004 | а. Э. б | 11.0 | 1.2 | 3.7 | 5.4 | 4.6 | υ. Ου. Ου. Ου. Ου. Ου. Ου. Ου. Ου. Ου. Ο | ი. ი | 4.6 | 1.8 | 5.0 | 3.3 3 | 30.0 | л с - і | 0 0 0 k | ° Z | 58 | - - | ND | ND | 2.7 | 3.2 | | | | | | | | | | | | | | РСВ | 008 | |
| NAA | NA | NA | NA | NA | N N A | NA | NA | NA | NA | | 3.6 NA | 2.6 | ND | ND | B | 58 | z - u | ο α | 4.9 9 | B | 1.6 | 12.0 | Ŋ | 7.0 | 33 | 33 | < Z | Ŋ | Ζ | ND | 33 | 33 | 33 | : 3 | 3 | Ζ | ≤ | PCB | 015 | |
| 5.7 1.6 | 5.0 | 7.9 | 15.9 | 11.0 | 5.0 5.0 | 6.3 | 11.0 | 7.6 | 5.6 | 16.0 | 14.0 | 8.5 | 9.4 | 9.9 | 19.0 | 17.0 | | 10.0 | 4.6 | 20.0 | 2.7 | 14.0 | 10.0 | 6.4 | o ; | °, ¢ | QC | Ø | Q | 2.9 | 3.7 | 20 |).a | , S | 4.9 | 7.0 | 6.3 | PCB | 018 | |
| 8 8 | B | Z Z | 58 | B | 52 | 58 | ND | ß | 88 | 33 | 55 | 58 | 1.5 | 1.2 | 2.4 | 58 | 33 | 58 | 58 | 2.0 | Ŋ | 5.4 | Ŋ | Ŋ | | | | | | | | | | | | | | PCB | 027 | |
| | | | | | | | | | | | | | | | | | | | • | | • | | | | 2 a | 53 | 58 | 17.1 | ND | Ŋ | Z Z | | | ΒZ | 16.8 | ND | Ð | РСВ | 027/24 | |
| 22.0 5.3 | 18.0 | 9.7 | ч. 10 | 5 5 5 | 5 N - 5 | 0.8 1.4 | 4.2 | 5. 1 | 20.0 | 31 0 | 10 n | 9.5 | 6.1 | 6.5 | 32.0 | 12.0 | 0 IC.0 | 10 0 0 | ა ი ა თ | 14.0 | 12.0 | 28.0 | 9.8 | Ζ | N : | ۸ ر. | QQ | Ø | 4.1 | 4.1 | ₽₹ | 53 | S Z | ΒZ | Ş | Ø | Q | PCB | 028 | |
| | | | | | | | | | | | | | | | • | | | | • | | | | | | 88 | 58 | 38 | Ŋ | Ŋ | B | | л с л с | 4 0 2 0 2 0 | 19.2 | 22.4 | 14.6 | Ŋ | РСВ | 028/31 | |
| ŝŝ | S | 53 | 58 | S | 52 | 58 | ND | Ŋ | 8 | 33 | 32 | 58 | Ŋ | 1. . 1 | 1.9 | 23 | <u>л</u> 2 | 52 | 58 | ß | Ŋ | з.5 | Ŋ | 1.2 | 2.4 | ξ¢ | S | Ŋ | Ŋ | B | 88 | 58 | 52 | βZ | 23.4 | Ŋ | Ø | PCB | 029 | |
| 13.0 7.0 | 14.0 | 4.9 .9 | 3.0 | 4.5 | 2.0 | 6.3 | 3.1 | 3.1 3.1 | 15.0 | 21 0 | 30.0 9 7 | 23.0 | 27.0 | 33.0 | 70.0 | 31.0 | 7 1 | 1.0 | 9.7 | 26.0 | 6.9 | 46.0 | 34.0 | Ζ | | | | | | | | | | | | | | РСВ | 031 | |
| | | | | | | | | | | | | | | | • | | | | • | | | | | • | Ξ¢ | 2 ¢ | QC | B | Ø | Ø | Ø ē | 33 | 38 | ΒZ | S | Ø | Q | РСВ | 033 | |
| | | | | | | | | | | | | | | | • | | | | • | | • | • | | • | 0 0 | D Q | S | B | 1.7 | Ø | Ø | 58 | ξc | PE | Ş | Q | Ø | РСВ | 040 | |
| 8.1 3.2 | ບາ ເ | 6.3 4 | 1 UI 00 | 8.9 | 3.9 | 9.8 | 9.7 | 19.0 | 15.0 | 16.0 | 16.0 14 0 | 8.0 | 9.2 | 8.9 | 12.0 | 11.0 | » — л.с | 110 110 | ა. თ. 9 | 20.0 | 6.9 | 17.0 | 13.0 | 18.0 | 00 | 2 a | 2.0 | Ø | 4.7 | 3.0 | Ø | 2 6 | .19.4 | Ę | 4.8 | 8.8 | 9.7 | РСВ | 044 | |
| 4.0 5.3 | ω. | | ο σι - ω | 7.6 | 5.2 | 4.3 | 8.6 | 7.4 | 6.4 | 14.0 | 14 0 0 | 8.0 | 5.8 | 7.5 | 13.0 | 14.0 | 7 Y. U | 0.4 0.4 | ະ ⊾ດ | 22.0 | 11.0 | 13.0 | 10.0 | 8.6 | 88 | 58 | 38 | Ŋ | Ζ | Ø | Β¢ | - - - | 19.2 | 17.8 | B | Ŋ | Q | РСВ | 049 | |
| 5.5 5.5 | 2.4 | 15.0 | 7.2 | 10.0 | 7.0 | 6.2 | 14.0 | 13.0 | 12.0 | 13 0 | 15.0 22 N | 9.6 | 11.0 | 16.0 | 41.0 | 22.0 | 10.0 | 100 | α 0.3 | Ξ | 20.0 | 35.0 | 17.0 | Ζ | .0°.4 | 5 c | | Ø | Ø | 3.7 | Q E | 58 | 32.2 | 4.8 0 | 11.6 | 11.8 | 28.8 | PCB | 052 | |
| ŝŝ | Si | 53 | 58 | Si | 52 | 58 | Ŋ | ß | Z | 38 | | 58 | ß | B | B | 88 | 33 | 52 | 58 | ß | B | Ŋ | Ŋ | ß | | | | | | | | | | | | • | | РСВ | 060 | |
| • • | | | | | | • | | | | | | | | • | • | | | | • | | • | • | | • | Ø | D Q | QC | Ø | Ŋ | Ø | Ø | 20 | D C | a | Q | Ø | Q | РСВ | 060/56 | |
| 5.5 2.7 | 3.4 3.4 | 6.2 | 4.4 5 | 6.1 | 3 4 8 1 | 4.4 | 6.8 | 6.4 | 6.4 | 150 | 11 n | 5.2 | 6.3 | 8.1 | 13.0 | 8.7 | 7 0.0 | 4.4 | 4.4 | 14.0 | 24.0 | 14.0 | 8.2 | 13.0 | | | | | | • | | | | • | | • | • | РСВ | 066 | |
| | | | | | • | • | • | | | | • | • | | • | • • | | | • | • | • | • | • | | • | เก เ | 7.0 | 10.1 7 n | 11.8 | 18.2 | 10.3 | 8 9 | າ ເ 1 | <u>з</u> 9.0 | 14.4 | 13.5 | 19.7 | 23.4 | РСВ | 066/95 | |
| 4.1 3.2 | 3.4 | ω~ 54 | 4 6.3 | 8.9 | 4 4 5 5 | 5.9 | 8.3 | 7.4 | 3.7 | 32 0 | 14.0 13.0 | 8.6 | 7.7 | 14.0 | 37.0 | 26.0 | ດ ດ | ი. ან | ວ ດີດ | 16.0 | 10.0 | 26.0 | 9.3 | 13.0 | 1.2 | ° 4 | 2.0 | 2.6 | 2.4 | 2.2 | | - N | злα 22.α | 4.4 | 4.7 | 5.3 | 8.0 | РСВ | 070 | |
| 2.0 1.1 | 5.7 | 2.5 5 | 2.8 | 4.2 | 6.5 | ω ω ω | 4.4 | ß | 2.4 | 120 | ດ ດີ ດີ | 3.9 | 4.3 | 6.4 | 11.0 | 6.1 0 | л и О С | ין ת כ | ν.ω ν.ω | 6.9 | 3.9 | 10.0 | 4.6 | 7.5 | ω ί | <u>,</u> ג | QC | 1.2 | 1.4 | 1.6 | Ø | 2 6 | ο.α | ç Ç | 2.5 | 3.4 | 3.6 | PCB | 074 | |
| 1.9 1.2 | 4.1 | 2.8 | 3.0 | 2.9 | 2.2 | 2.4 | 3.0 | ß | S | 4 1 0 | 4 0 4 0 | 2.4 | 3.3 | 13.0 | 18.0 | 9.4 | 0 0 0 | 5 N 5 N | ο <u>1</u> 2 ο ω | 3.9 | 12.0 | 12.0 | <u>5</u> .1 | 5.4 | | | | | • | • | | | | • | | • | | PCB | 085 | |
| 2.4 0.9 | 2.9 | 1 i 2 k | SA | 1.7 | | 1.0 | 1.7 | 2.2 | -1 α .ω | ດ ເ | а4 л.С | 2.2 | 3.4 | 3.5 | 5.0 | 7.9 | υ 4 Ο | - د - ۱ | ч Ю ч Ю | 2.1 | 2.7 | 2.5 | -1 - 1 | 1.3 | | | | | | • | | | | • | | • | | PCB | 087 | |
| · . | | | | | • | | • | | | | | • | | • | • • | | | | • | | • | • | | • | 00 | D a | S | Ø | Ø | Ø | Ø | 2 6 | 0.1 14.7 | ç, | Ø | Ø | Q | РСВ | 087/115 | |

Table 3.6. Dissolved PCB concentrations in water samples, 1994.

. = Not Analyzed, ND = not detected, Q = Present but not quantifiable, M = Matrix interference. Units in pg/L (ppq).

| | LCL BUA | |
|-----------|-----------------|--|
| | 131 000 | ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ ۵۵٬۰۰۰ «۵۵٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰۰ ۵۰٬۰۰ |
| | PCB 149 | $\begin{array}{c} & 222, \\ & 0, \\ $ |
| | PCB 146 | ∞°aaa45aaa4,4,4,6aa · · · · · · · · · · · · · · · · · · |
| | PCB 141/179 | , 2000,0000,00000 · · · · · · · · · · · · · |
| | PCB 138 | 1122 1122 1122 1122 1122 1122 1122 112 |
| | PCB 137/176 | $\mathbb{Z}\mathbb{Z}\mathbb{Z}\mathbb{Z}\mathbb{Z}\mathbb{Z}\mathbb{Z}^{\infty}_{\mathbf{z}}\mathbb{Q}^{0,\widetilde{\mathbf{u}}}_{\mathbf{z},\mathbf{z}}\mathbb{Q}^{\widetilde{\mathbf{u}}}_{\mathbf{u}}$ |
| | PCB 137 | · · · · · · · · · · · · · · · · · · · |
| bdd) | PCB 132 | NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN |
| pg/L | PCB 129/178 | ααδααδδα |
| ts in | PCB 128 | 8 0 0 2 2 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| Uni | PCB 119 | · · · · · · · · · · · · · · · · · · · |
| nce. | PCB 118 | × 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| rfere | PCB 114/131/122 | |
| , inte | *11 904 | |
| latrix | | ĠĸġĠŧĊ∞►40,∞►∞∞∞∞ Σζζζζζζζζζζζζζζζζζζζζζζζζζζζζζζζζ |
| 2 | 22/011 839 | 647268.4 ω ω ω ν ν ν ν ν ν · · · · · · · · · · · |
| e, M | PCB 110 | $\begin{array}{c} & & & \\ & & & & \\ & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\$ |
| ifiabl | PCB 105/132 | 9 9 1 - 2 - 3 - 2 - 2 - 2 - 2 - 2 - 2 - 2 - 2 |
| Juant | PCB 105 | N N N N N N N N N N N N N N N N N N N |
| not c | PCB 103 | ······································ |
| t but | PCB 101/90 | 252 251 210 20 20 20 20 20 20 20 20 20 20 20 20 20 |
| esen | PCB 101 | 3,25,07,07 3,25,07,07,07 3,25,07,07,07,07,07,0 |
| = Pr | PCB 099 | 9. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2 |
| d, Q | 260 80d | 94549 947444 14444 154449 154449 154449 154449 15449 1 |
| tecte | PCB 095 | 55.7 55.7 55.7 55.7 55.7 55.7 55.7 55.7 |
| ot det | | 4 9 9 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 |
| = nc | Date | 2/1/(1/1/(2/2) |
| , ND | | land land land land ver ver ver |
| zed | Station | Creek and a state and a state and a state and a state |
| naly | | Arithmic Control Co |
| ot Aı | | Coy Durus Alas Alas Alas Alas Alas Alas Alas Ala |
| . = Nc | Station Code | BA10 BA10 BA30 BA30 BA30 BA30 BA30 BA30 BA30 BA3 |

.

23.2.6 7 7 2 8 7 0 0 D 3 7 7 3 9 9 CB 151/82

Table 3.6. Dissolved PCB concentrations in water samples, 1994. (Continued)

| BG30 | BG20 | BF20 | BD50 | BD40 | BD30 | BD20 | BD15 | BC60 | BC20 | BC10 | BB70 | BA40 | BA30 | BA10 | BG30 | BG20 | BF20 | BD50 | BD40 | BD30 | B D20 | BD15 | BC60 | BC20 | BC10 | BB70 | BA40 | BA 30 | BA10 | BG30 | BG20 | BF20 | BD50 | BD40 | BD30 | | BC60 | BC20 | BC10 | BB70 | BA40 | BA30 | BA10 | Stati | on | Cod | e |
|-------------------|------------------|-------------|------------|-------------|--------------|---------------|----------------|----------|-------------|--------------------|---------|---------------|------------------|--------------|-------------------|------------------|-------------|------------|-------------|--------------|---------------|----------------|----------|-------------|--------------------|---------|---------------|------------------|--------------|-------------------|------------------|-------------|--------------|----------------------|--------------|------------|--------------|-------------|--------------------|---------|---------------|------------------|--------------|-------|-----|-------|-------|
| San Joaquin River | Sacramento River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Red Rock | Golden Gate | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | San Joaquin River | Sacramento River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Red Rock | Golden Gate | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | San Joaquin River | Sacramento River | Grizzly Bay | Napa River | Davis Point | Pinole Point | | Red Rock | Golden Gate | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | Stat | ion | | |
| 8/23/94 | 8/23/94 | 8/23/94 | 8/23/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/18/94 | 8/17/94 | 8/17/94 | 8/17/94 | 8/16/94 | 8/15/94 | 8/16/94 | 4/28/94 | 4/28/94 | 4/27/94 | 4/27/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/21/94 | 4/21/94 | 4/20/94 | 4/20/94 | 4/18/94 | 4/18/94 | 4/18/94 | 2/9/94 | 2/9/94 | 2/8/94 | 2/8/94 | 2/8/94 | 2/7/94 | 217104 | 2/7/94 | 2/3/94 | 2/3/94 | 2/3/94 | 2/2/94 | 1/31/94 | 2/1/94 | Date | , | | |
| 4.6 | 11.0 | 11.0 | 11.0 | 8.9 | 11.0 | 11.0 | 8.9 | 5.9 | 5.8 | 9.9 | 11.0 | 9.7 | 23.0 | 14.0 | 18.0 | 13.0 | 18.0 | 20.0 | 27.0 | 26.0 | 24.0 | 24.0 | 32.0 | 7.6 | 16.0 | 110.0 | 35.0 | 25.0 | 29.0 | 13.0 | 12.2 | 8.6 | 17.6 | 16.8 | 14.6 | 10.0 | 9.9 | 6.6 | 28.9 | 15.4 | 20.5 | 35.7 | 25.4 | РСВ | 15 | i3 | |
| 1.3 | 3.2 | 3.6 | 1.3 | 1.5 | 1.0 | 1.0 | 1.1 | 2.1 | 4.0 | 1.9 | 6.2 | 6.6 | 1.7 | 3.8 | 3.4 | 5.1 | з.5 | B | 5.0 | 5.7 | 5.0 | 3.8 | 4.9 | 2.6 | 5.6 | 22.0 | 10.0 | 5.4 | 7.5 | | | | | | | | | | | | | | | РСВ | 15 | 6 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.9 | 0.9 | Ø | 1 0 .4 | 0 7 | 1 3 | | , o | Ø | 2.6 | Ø | 2.4 | 2.6 | <u>1</u> .5 | РСВ | 15 | 56/17 | 1/202 |
| R | 1.4 | 1.3 | Ŋ | Ŋ | B | Ŋ | B | B | Ŋ | Ŋ | 1.5 | 1.3 | 0.9 | 1.0 | <u>1</u> .5 | -1 -1 | 2.9 | Z | B | 2.1 | 2.2 | B | 1.8 | Ŋ | 1.7 | 5.8 | 2.6 | 2.5 | 3.4 | | | | | | | | | | | | | | | РСВ | 15 | 7 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Ø | Ø | Q | Z i | Ş¢ | οĘ | ξ¢ | a | Ŋ | Ø | Ŋ | B | Ø | Q | РСВ | 15 | 57/17 | 3/201 |
| ß | Ŋ | 1.5 | Ŋ | Ŋ | Ŋ | ß | 0.9 | ß | 0.8 | 0.9 | 1.7 | 1.0 | 3.4 | R | 1.7 | 0.9 | 1.6 | 2.8 | 2.9 | 1.8 | 1.6 | 2.4 | 3.6 | ß | 2.8 | 11.0 | 4.4 | 2.4 | 3.0 | Ŋ | Ø | Ø | S | z : | ິດ | Þ | ίD | B | Q | Ø | Ø | Ø | Ø | РСВ | 15 | 8 | |
| ß | 1. . 1 | Ŋ | Ŋ | Ŋ | Ŋ | ß | B | ß | 1.8 | Ŋ | 1.3 | Ŋ | ß | R | 1.4 | 1.0 | ω .1 | -1 .5 | 2.0 | 1.5 | -1 .5 | 1.7 | 7.6 | 1.3 | 3.4 | 28.0 | 2.4 | 2.3 | 2.3 | | | | | | | | | | | | | | | РСВ | 17 | 0 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1.5 | 0.7 | 0.7 | 1.0 s | 5 | 1 - | 4 C | ç o | Ø | 1.7 | Ø | 1.4 | 2.2 | 2.4 | РСВ | 17 | 70/19 | 0 |
| 1. 1 | 2.6 | 1.3 | 1.9 | з. 1 | 2.2 | 4.5 | а .5 | 2.3 | з. 1 | 3.2 | 6.6 | 3.7 | 5.2 | 2.8 | 3.9 | 3.8 | 8.6 | 7.7 | 4.3 | 7.8 | 6.0 | 8.8 | 20.0 | 4.1 | 8.2 | 54.0 | 11.0 | 6.7 | 9.1 | 1.2 | | Q | 1.2 | 0. | 1 - 4 0 | , c | a | Ŋ | Ø | Q | Ø | Z | 2.6 | РСВ | 17 | 4 | |
| 0.9 | 2.3 | 2.7 | Ŋ | 1.0 | Ŋ | 1.8 | 0.9 | ß | 1.3 | 1.9 | 4.5 | 2.6 | 1.1 | 1. 1 | 4.5 | 4.0 | 7.0 | 5.7 | 6.6 | 5.7 | 8.4 | 7.1 | 15.0 | 4.3 | 10.0 | 53.0 | 13.0 | 6.4 | 12.0 | 0.8 | 0.7 | 0.8 | 1 0 . 1 0 | 0.0 | | śρ | o a | Ø | Ø | Ø | Ø | 2.1 | 1.6 | РСВ | 17 | 7 | |
| 0.9 | 1.9 | 3.5 | ND | ND | ND | 1. .1 | 1.2 | Ŋ | R | 0.9 | 4.5 | 5.2 | 3.9 | 1.9 | 4.9 | 6.6 | 7.0 | 3.8 | 14.0 | 3.9 | 7.2 | 6.5 | 16.0 | 3.9 | 7.4 | 48.0 | 15.0 | 7.2 | 8.1 | 2.2 | 2.1 | 1.8 | 3 0 2 0 | ω ω ο | 30.9 0 | 2 N | , ≤ | Ζ | ≤ | Ζ | Ζ | 6.8 | 5. 1 | РСВ | 18 | 0 | |
| ß | B | Ŋ | B | Ŋ | B | B | ß | B | B | Ŋ | ND | Ŋ | R | Ŋ | 2.3 | 0.9 | 2.1 | 2.7 | 3.2 | 3.3 3 | 2.6 | 2.9 | 5.8 | 1.9 | 5.7 | 18.0 | 3.6 | з. 1 | з.5 | 2.4 | 2.0 | 2.2 | 2.0 | - 1 20 - 00 | 2.0 | ა. ი ი | ç,o | Ø | 3.6 | 2.2 | 2.7 | 5.3 | 4.5 | РСВ | 18 | 3 | |
| | | | | | | | | | | | | | | | | | • | | | | • | | | | | | | | | Ŋ | Ŋ | Ŋ | 2 | 3 | -1 Z | 53 | βB | ND | ND | Ŋ | Ŋ | B | Ø | РСВ | 18 | 5 | |
| 3.2 | 3.8 | ა .5 | 3.2 | 2.4 | 2.8 | 3.2 | 2.5 | 2.1 | 1.8 | 2.4 | 4.3 | 4.1 | 1.3 | 5.1 | 5.9 | з. 1 | 8.2 | 6.2 | 11.0 | 8.2 | 6.3 | 7.5 | 15.0 | 2.7 | 21.0 | 53.0 | 8.5 | 7.5 | 8.8 | 3.5 | 2.7 | 2.6 | 4.5 | 47 | 4.9 | 4 4 0 0 | ç, o | Ø | 3.8 | 2.4 | 3.9 | 8.9 | 7.2 | РСВ | 18 | 87 | |
| ß | 2.3 | ß | Ŋ | ß | B | 1. . 1 | ß | B | 1.5 | Ŋ | ß | Ŋ | з.5 | Ŋ | D | D | B | B | ß | Ŋ | 0.9 | ß | B | Ŋ | 1.2 | 1.2 | 2.2 | 1 .1 | 1.8 | Q | B | B | S | ξ¢ | 0 ह | 33 | 58 | Ø | Ø | ß | B | B | Ø | РСВ | 18 | 9 | |
| | | | | | | | | | | | | | | | | | • | | | | • | | | | | | | | | Ŋ | Ŋ | 1.2 | 2 | Z S | 30 | 53 | βB | ND | Ø | Ŋ | Q | B | Ø | РСВ | 19 |)1 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Z | Z | Ζ | Z ¢ | 03 | 3 | 23 | 3 | Ζ | Z | Z | Z | Ζ | Z | РСВ | 19 |)4 | |
| ß | -1 | Ŋ | ß | Ŋ | B | Ŋ | B | ß | ß | Ŋ | Ŋ | 1.4 | ß | Q | Ŋ | Ŋ | 6.1 | -1 -3 | ß | 9.9 | 3.2 | 1.7 | 1.3 | B | 1. .1 | 6.6 | Ŋ | 2.2 | 0.9 | | | | | | | | | | | | | | | РСВ | 19 | 95 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1.0 | 1.4 | B | 2.4 | 1 | ξ¢ | ۵. ۵ | 3.9 0.9 | 2.2 | Ø | 2.5 | 1.6 | 1.9 | Ø | РСВ | 19 | 95/20 | 8 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 0.8 | 0.8 | 0.7 | 1.0 | 0 n | 1.0 | | à, | Ø | Ø | Q | Q | 2.0 | 1.3 | РСВ | 19 | 96/20 | 3 |
| ß | Ŋ | ß | ß | ß | B | Ŋ | ß | Ŋ | Ŋ | ND | Ŋ | ND | ND | ND | ND | ND | B | B | ß | Ŋ | Ŋ | Ŋ | Ŋ | Ŋ | ND | 1.5 | ND | Ŋ | Ŋ | | | | | | | | | | | | | | | РСВ | 19 | 8 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1. .1 | 0.9 | 2.4 | 1.3 | 0.0 | | _ د ن د | à, | Ø | Ø | Ø | Ø | 2.1 | 2.2 | РСВ | 19 | 9 | |
| R | 1.5 | 1. 5 | -1 - 1 | N | B | Ŋ | B | B | 0.9 | 1.2 | N | 3.1 | 3.5 | Ŋ | 2.9 | 1.7 | B | Z | 0.8 | 16.0 | 7.9 | 2.3 | 8.1 | 2.0 | 1.3 | 29.0 | 6.1 | 5.0 | 3.9 | | | | | | | | | | | | | | | РСВ | 20 | 13 | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ND | Ŋ | 6.5 | Z i | 5 | 53 | 53 | 58 | Ŋ | ND | ND | Ŋ | ß | ND | РСВ | 20 | 15 | |
| 1.1 | 4.7 | 3.4 | 6.2 | 3.7 | 6.4 | 7.2 | 7.0 | 2.9 | 6.1 | 6.4 | 4.0 | 6.0 | з.1 | 6.6 | 8.2 | 8.3 | 11.0 | 8.8 | 21.0 | 7.8 | 11.0 | 7.9 | 11.0 | 8.4 | 9.7 | 20.0 | 11.0 | 10.0 | 11.0 | Z | Z | Ζ | z ; | z: | ≤₹ | 33 | 3 | Z | ≤ | Z | Z | Ζ | Ζ | РСВ | 20 | 6 | |
| Ŋ | Ŋ | Ŋ | 0.9 | ß | 1.7 | 1.5 | 0.9 | з 5 | ß | Ŋ | 1.7 | 3.9 | 1 .1 | 2.1 | -1 - -1 | Ŋ | 1.6 | B | ß | 1.3 | 2.7 | 1.5 | 1.4 | ß | Ŋ | 1.8 | ND | ND | 1.3 | 2.0 | 1.9 | 1.4 | 2.8 | י ב מי | 2 g 9 | 0.0 | о 12 о 07 | 3.2 | Ø | 2.8 | 1.7 | 2.2 | 1.9 | РСВ | 20 |)7 | |

Table 3.6. Dissolved PCB concentrations in water samples, 1994. (Continued)

. = Not Analyzed, ND = not detected, Q = Present but not quantifiable, M = Matrix interference. Units in pg/L(ppq).

Ľ

Appendices

| 1994. |
|----------------|
| water samples, |
| s in v |
| concentration |
| РСВ |
| Total |
| Table 3.7. |

. = Not Analyzed, ND = not detected, Q = Present but not quantifiable, M = Matrix interference. Units in pg/L(ppq).

| PCB 087/115 | 22.22 0 0 16.1 | a <u>%</u> a a a a | σ | | | |
|-------------------|---|--|---|--|---|-------------------|
| PCB 087 | | | 13.3 6.3 4.9 | 6.7 6.7 2.82 2.42 10.2 9.4 9.4 | 11.5 10.8 9.1 15.7 11.0 11.0 12.6 12.6 12.6 12.6 12.6 | 3.7 |
| PCB 085 | | | 48.4 26.1 18.2 18.2 | 20.9 5.0 5.0 60.9 35.0 35.0 | 22.22 33.7.3 57.75 57.8 7.2 22.8 22.8 22.8 22.8 22.8 22.8 22 | 5.7 |
| PCB 074 | 15.6 6.8 0.5 10.5 | 4.4 19.3 4.2 1.3 1.3 | 3.5 31.5 12.6 9.4 | 11.8 3.3 5.3 79.0 21.1 17.4 17.4 | 22222 2211.5 2211.5 225.5 225.5 225.5 225.5 225.5 225.5 210.6 210.6 210.6 210.6 210.6 210.6 210.6 210.6 210.6 210.6 210.6 210.6 210.6 210.7 210.6 210.7 210.6 210.7 210.6 210.7 210.7 210.6 210.7 210. | 5.0 |
| PCB 070 | 28.3 16.5 6.0 6.0 21.5 | 7.5 6.4 6.9 8.9 2.4 | 5.6 123.0 54.0 23.0 | 29.0 8.1 12.2 559.6 63.0 63.0 | 3 3 4 4 . 7 3 3 3 4 4 . 7 3 3 3 . 6 6 . 0 6 6 . 0 6 6 . 0 6 6 . 0 1 1 2 8 4 1 1 1 2 8 4 1 1 1 2 8 4 1 1 1 2 8 4 1 1 1 2 8 4 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 2 8 1 3 . 5 1 1 2 8 1 3 . 5 1 1 2 8 1 3 . 5 1 1 2 8 1 3 . 5 1 1 2 8 1 3 . 5 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 2 8 1 3 . 5 1 1 1 1 2 8 1 3 . 5 1 1 1 1 2 8 1 3 . 5 1 1 1 1 2 8 1 3 . 5 1 1 1 1 2 8 1 3 . 5 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 | 8.1 |
| PCB 066/95 | 74.3 31.0 64.8 9.1 55.2 | 25.2 109.3 25.4 30.7 78.8 | 15.2 | | | |
| PCB 066 | | · · · · · · · | 94.0 30.2 32.2 32.2 | 38.0 4.4 10.3 160.0 86.7 86.7 44.1 | 2593 16:2 2244 12294 7.0 25218 2511 2511 2511 2512 2513 2513 2513 2513 | 8.4 |
| PCB 060/56 | aaaaa <u>6</u> a <u>8</u> | a <u>+</u> aaaa | σ | | | |
| PCB 060 | | · · · · · · · | | | <u> </u> | Ð |
| PCB 052 | 4 년 년 - 8 8.1 년 - 8 8.3 년 - 8 8.3 년 - 8 8.3 년 - 8 8.4 년 - 8 8.6 년 | 0.8 0.8 | 3.4 0.00 9.0 22.0 | 3.3 3.0 5.0 5.0 5.0 5.0 | 0.000000000000000000000000000000000000 | 9.6 |
| 6t0 80d | 0.01.2.8.7.0.0 4.7.7.8.7.7.7.7.7.7.7.7.7.7.7.7.7.7.7.7. | 2.0 0.5 3 4.0 0.5 3 | 0.0 0.5 0.0 0.5 0.0 1.0 0 0 0 | | 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 | , o , o |
| | | 4 3 0 0 2 8 | | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | 2 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 | 2.2 |
| | 2 × 4 × 5 × 4 × 6 × 6 × 6 × 6 × 6 × 6 × 6 × 6 × 6 | 0 0 0 0 7 0 7 0 7 0 7 0 7 0 7 0 7 0 7 0 | 4 8 2 8 9 9 | 5753333354 5753338 57535 5753 575 575 575 575 575 575 575 | 5 - 6 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 7 | 9 |
| PCB 040 | i ← Z Z O O Z ~ | 0 - <u>5 5 0 </u> | ~ | | | |
| PCB 033 | o a a a ^c . a o | 000000 | 0 | <pre></pre> | | |
| PCB 031 | | | 33. 66. 44. | 9.7.9 36.11 83.1 82.1 82.1 82.1 82.1 82.1 82.1 82.1 82 | | 12. |
| PCB 029 | | ₽₽₽₽∞₽ | 2.0 0.7 0 0.7 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | 3.5 D 2 D 0 D 0 D 0 0 0 0 0 0 0 0 0 0 0 0 0 | °; | 2 |
| PCB 028/31 | 14.6 56.0 87.4 13.3 37.3 ND | 222222 | Q · · · · | | | |
| PCB 028 | 22.2 22.2 22.2 22.2 22.2 22.2 2 22.2 2 22.2 2 2 2 2 .2 2 .2 2 .2 2 .2 2 .2 2 .2 2 .2 2 .2 2 .2 2 .2 2 .2 10 0 10 0 | 5.7 33.3 8.6 0.0 4.2 | 2.9 47.0 21.8 55.0 30.0 | 27.0 6.5 9.3 54.3 54.3 52.0 52.0 34.5 | 38.1 13.2 59.0 59.0 8.4 8.3 8.3 21.1 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 22.0 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 | 8.3 |
| PCB 027/24 | 0.0 8.0 9.0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | ND 17.1 ND ND ND | g | | | |
| PCB 027 | | | . N N N N N N N N N N N N N N N N N N N | 0.000000401 | <u>;</u> | ₽₽ |
| PCB 018 | 0.9 0.4 0.0 0.0 0.0 0.7 0.0 0.7 0.0 0.7 | °.0000°. | Q 12.9 20.8 5.7 | 25.0 8.1 9.6 27.0 37.0 19.9 | 200 111111 200 200 200 200 200 200 200 2 | 2.8 |
| PCB 015 | | ₽≈≈₽≈≈ | MD 15.7 5.0 | 3.7 5.1 8.6 8.6 8.6 8.6 8.6 7.1 8.6 8.6 7.1 8.6 7.1 8.6 7.1 8.6 7.1 8.6 7.1 8.6 7.1 8.6 7.1 8.6 7.1 8.6 7.1 8.6 7.1 8.7 7.1 8.7 7.1 8.7 7.1 8.7 7.1 8.7 7.1 8.7 7.1 8.7 7.7 7.1 8.7 7.7 7.7 7.7 7.7 7.7 7.7 7.7 7.7 7.7 | 2.2 9.9 9.7 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 | AN |
| PCB 008 | | | 2.7 2.7 ND 2.7 | 2.0 ND 522.2 13.2 7.3 7.3 | 9.9 1111.7 111.7 111.9 11.9 | 3.0 |
| PCB 005/8 | A 17.8 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | 4.7 11.6 0 0 | σ | | | |
| Total PCBs (SFEI) | 1845 739 896 975 370 1401 | 526 2600 434 716 672 296 | 338 3194 1474 2408 1442 | 1535 230 5916 3526 3526 1934 1887 | 2435 850 8550 1815 1815 1928 1928 11218 11218 11218 1104 882 1104 1104 | 285 |
| and | //94 //94 //94 //94 //94 | /94 /94 /94 /94 | /94 8/94 8/94 0/94 | 0/94 1/94 5/94 5/94 5/94 5/94 5/94 | //94 88/94 6/94 6/94 7/94 7/94 7/94 2/94 2/94 2/94 2/94 2/94 2/94 2/94 2 | 3/94 |
| 0,00 | 5/13 5/3 5/3 5/3 5/3 5/3 5/3 5/3 5/3 5/3 5/ | 2/8 2/8 2/8 2/8 2/8 | 2/9 4/18 4/18 4/20 | | 244 244 247 244 247 247 247 247 247 247 | 8/2: |
| noitst2 | Durbarton Bridge Redwood Creek Alameda Yerba Buena Islanc Golden Gate Red Rock Petaluma River | San Pablo Bay Pinole Point Davis Point Napa River Grizzly Bay Sacramento River | San Joaquin River Coyote Creek Dumbarton Bridge Redwood Creek Alameda | Yerba Bulena Island Golden Gate Red Rock Petaluma River San Pablo Bay Davis Point Davis Point Napa River | Ginzty Bay Ginzzy Bay San Joaquin River San Joaquin River Coyote Creek Redwood Creek Alameda Alameda Alameda Alameda Red Rock Red Rock Red Rock Petaluma River San Pabio Bay Pinole Point Davis Point Napa River Ginzty Bay Sacramenth River Sacramenth River | San Joaquin River |
| Station Code | BA40 BB70 BC10 BC20 BC20 BC20 BC60 BD15 | BD20 BD30 BD40 BD50 BF20 BG20 | BG30 BA10 BA30 BA40 BB70 | BC10 BC20 BC60 BD15 BD20 BD20 BD20 BD20 BD20 BD20 BD20 BD20 | 85720 86720 86320 86320 86320 86320 86710 86710 86710 86720 86720 86720 86720 86720 86720 86720 86720 | BG30 |

| G20 S20 S20 S20 S20 S20 S20 S20 S20 S20 S | | | 00000000000000000000000000000000000000 | | Station Code |
|---|---|--|--|--|-----------------|
| avis Poi apa Riv rizzly Ba acramer an Joaq | an Pabl | inole Poi avis Poi irizzly Ba acramer oyote Cr oyote Cr | an Pabluma | oyote Cr umbarto edwood lameda lameda builden Bu ciden Bu ciden Bu inole Pc avis Poi avis avis avis avis avis avis avis avis | 0 |
| oint er ay nto River uin Rive | ate River Bay | nt Pr Nto River uin Rive uin Rive n Bridge | creek ate River Bay | n Bridge Creek ena Islar iate iate ate Bay bint Bay bint eek eek eek eek | Station |
| ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ ~ | DT - /8, 8, 8, 8, 9, 9, 9, 9, 9, 9, 9, 9, 9, 9, 9, 9, 9, | 8 8 8 4 4 4 4 4 4 | ы Б 4 4 4 4 4 4 4 4 4 4 4 4 | | |
| 22/94 22/94 23/94 23/94 23/94 23/94 23/94 | 17/94 17/94 17/94 18/94 22/94 22/94 | 26/94 27/94 27/94 28/94 16/94 15/94 | 20/94 20/94 21/94 21/94 26/94 26/94 | 1/94 3/94 3/94 3/94 3/94 7/94 7/94 7/94 7/94 8/94 8/94 8/94 8/94 9/94 9/94 9/94 | Date |
| 35.0 27.7 11.0 27.9 10.4 8.5 | 32.0 9.0 13.7 30.1 | 103.0 53.0 56.0 17.6 15.9 74.0 27.5 | 41.0 69.0 7.7 21.0 154.0 95.0 | 103.0 830.0 | PCB 095 |
| 13.5 10.3 1.3 1.6 1.6 | 10.1 1.1 1.2 23.9 | 20.7 20.7 36.3 36.3 10.2 21.6 21.6 | 29.0 19.3 16.2 2.4 6.0 82.6 82.6 38.7 | 2008 2008 2008 2008 2008 2008 2008 2008 | PCB 097 |
| 32.1 25.0 7.0 26.9 6.8 7.3 | 29.1 5.4 27.4 27.4 27.4 | 67.0 38.0 154.3 77.1 14.6 33.5 | 34.0 34.0 4.5 10.0 117.2 77.5 | 168.9 36.4 19.5 1.9.7 5.7 5.2 5.6.2 5.7 5.7 5.7 5.7 5.7 5.7 5.7 5.7 5.7 5.7 | PCB 099 |
| 56.0 42.7 11.0 36.0 17.7 22.9 | 48.0 12.4 32.7 88.0 | 155.0 76.0 88.0 106.0 24.1 21.6 137.0 82.0 43.1 | 9.5 247.0 247.0 144.0 | 147.0 590.0 | PCB 101 |
| | | | | 260.6 75.7 34.9 79.6 19.6 58.4 24.8 24.8 24.8 34.0 34.6 34.6 34.6 34.6 | PCB 101/90 |
| 888888 | | 888888888888888888888888888888888888888 | 8888888 | 555····· | PCB 103 |
| 15.9 3.1 8.6 4.0 3.4 | 40.4 | 32.3 32.3 11.2 58.0 37.0 | 42.0 20.3 3.6 8.1 122.8 68.1 | | PCB 105 |
| | | | | 321. 68.4 32.6 41.3 17.4 17.4 93.3 17.4 8.1 14.8 8.1 | PCB 105/132 |
| 91.0 76.0 14.0 74.0 24.0 20.2 | 62.0 26.6 15.0 33.8 89.0 | 170 92.0 140 140 42.0 44.0 204 135.7 73.0 | 123 76.0 84.0 13.8 30.0 270 175 | 10188 | PCB 110 |
| | | | | 401. 74.8 34.6 63.2 63.2 61.7 61.7 26.3 33.1 115.9 25.2 26.3 33.3 115.9 16.9 15.9 15.9 | PCB 110/77 |
| | | 888888888888888888888888888888888888888 | 8888888 | 555···· | PCB 114 |
| | | | | aaaaaaaaa ¹ ,aa, ^{7,} 8,4, | PCB 114/131/122 |
| 64.1 52.4 7.1 47.9 9.3 | 20.7 111.3 64.0 | 1111.0 77.0 119.9 33.7 30.0 179.1 91.0 | 109.0 56.0 8.2 25.5 290.0 181.0 | 474, 93.9 93.9 93.9 93.9 93.9 42.0 3.9 79.2 79.2 79.2 79.2 79.2 79.2 79.2 79 | PCB 118 |
| N N 1.9 | | 0.9 0.9 0.9 0.9 0.1 0.0 0.1 0.0 0.0 0.0 0.0 0.0 0.0 0.0 | | 2 → ω | PCB 119 |
| 2 2 1 N 9 1 2 | 29.14.21 | 20. 14. 3. 30. 10. | 42 2 N 11 0 9 | 140 123 140 155 155 155 155 155 155 155 155 155 15 | PCB 128 |
| ••••••• | | ω000 [∠] ν∠40 | οωο ^υ οωο | 2005 | PCB 120/178 |
| 37 5. 7. 6. | 29 71 29 | 59 56 52 28 | 44 49 10 164 | 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 2 2 2 3 1 5 0 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 | PCB 132 |
| | | | | πασ. | PCB 137 |
| | | | | - 3 0 - 1289,219,34 M M M M M M M M M M M M M M M M M M M | PCB 137/176 |
| 96. 78. 100 27. 25. | 77. 38. 17. 199 | 301 176 238 74. 332 332 89 | 223 132 131 15. 568 347 | 1 1766 91.1 91.1 1766. 91.1 176. 17.1 1366. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1376. 17.1 1377. 17.1 1377. 17.1 1377. 17.1 1377. 17.1 1377. 17.1 1377. 17.1 1377. 17.1 1377. 17.1 17.1 | PCB 138 |
| · · · · · · | | | | - · · · · · · · · · · · · · · · · · · · | PCB 141/179 |
| | | | | 222 112 112 222 112 112 112 112 | PCB 146 |
| 77 62 72 15 13 | 136 31 136 | 19 11: 11: 13: 20: 78 | 13, 92 11 336 197 | 990 174 174 174 174 174 174 174 174 | PCB 149 |
| 4 5. | 2329.411 m | 4 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 | .0 229 .0 99 .0 999 80 | ວິດີດີບໍ່ພິດ 4 ບໍ່ພິດ ບໍ່ພິດ ບໍ່ມີ ກັນ ຫຼັງ 2.4.4 | PCB 151 |
| ∞ 7 . | , N ຄົ ^{ດ ດ} ພິຫິຊີ | <u></u> | | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | DCB 151/92 |
| | | | | 5.8 5.8 5.8 5.8 5.8 5.8 5.8 5.8 5.8 5.8 | 1 00 131/02 |

Table 3.7. Total PCB concentrations in water samples, 1994. (Continued)

. = Not Analyzed, ND = not detected, Q = Present but not quantifiable, M = Matrix interference.

Units in pg/L (ppq).

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Table 3.7. Total PCB concentrations in water samples, 1994. (Continued)

. = Not Analyzed, ND = not detected, Q = Present but not quantifiable, M = Matrix interference. Units in pg/L (ppq).

| PCB 207 | 12.4 | 0 7 1 1 | - c | °, C | 3.2 | 2.5 | 7.5 | 0.0 V | 4.6 | 5.2 | 4.0 | 4 c 8 0 | 2.0 | 2.3 | 3.9 | 3.2 0 | N 0 | | 8.6 8.6 | 12.7 | 0.0 0 | 2.5 | 5.5 | 1.2 | 2. u | 9.9 7.9 | 5.1 | 4.7 | 1.0 | - u | 0, 7 0, 7 | ן ער סירט | 3.0 | | 0.0 | 4. C | Q |
|-----------------|----------------|------------------|---------------|--------------------|-------------|----------|----------------|---------------|-------------|------------|-------------|------------------|--------------|------------------|---------------|----------|--------------------|-------------------------|----------------|---------------|---------------|----------------|-------------|------------------|-------------------|----------------------------------|---------------|---------|--------------------|-------------|---------------|---------------|--------------|-------------|------------|----------------------------------|-------------------|
| PCB 206 | Σ | 22 | 2 2 | Σ | Σ | Σ | Σ: | ΣΣ | Σ | Σ | Σ | Σ | 55.0 | 22.0 | 39.0 | 32.0 | 26.7 | 20.51 | 74.9 | 70.0 | 65.8 45.0 | 34.8 | 39.0 | 20.3 | 19.2 20.6 | 14.1 | 14.7 | 13.1 | 12.6 | 12.2 | 7.71 | 34.2 | 19.4 | 14.7 | 6.2 | 4.02 | 9.0 |
| PCB 205 | g | | | g | g | Q | α | | g | QN | 6.5 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| PCB 203 | | | | • | | | • | | • . | | | | . 64.9 | 7.3 | 53.1 | 36.6 | 31.3 | 4 ס אימ | 152.3 | 103.9 | 73.0 | 32.0 | 46.0 | 22.7 | 10.1 | 27.5 | 18.1 | 14.0 | 6.1 | 9.0 9.0 | 0.0 | 34.0 | 18.0 | 12.0 | 1.1 | 0. L7 0. L7 | 5.0 |
| PCB 199 | 200.5 | 43.4 | -4-0 0.4-0 | 11.0 | 5.3 | 9.4 | 33.7 | 11.1 50.0 | 13.9 | 22.9 | 14.7 | 0, 1 0, 1 | 0.0 | | | | | | | | | • • | | | | | • | | | | | | | | | | |
| PCB 198 | | | | • | | | | | | | | | 3.5 | 1.2 | 3.0 | 1.5 | ກ. ຊ | | 9.4 | QN | 22 | 6.0 | 3.0 | 3.4 | Ð, | 2 | Ð | Ð | 2 | 2 | 2 7 Z | + C | g | Q | ₽; | †. C | 20 |
| PCB 196/203 | 162.8 3.2 | υ.υ 1, υ | 0.11 1.0 | 0.0 | 2.0 | 7.5 | 26.8 2.5 | 0.8 C 01 | 7.1 | 19.0 | 10.3 | 7 90 7 90 | ÷. | | | | | | | | | | | | | | | | | | | | | | | | |
| PCB 195/208 | 80.2 | 4.4 | 0. a | 2.0 | 2.2 | 1.9 | 2.6 | 5.5 75.4 | 1.07 | 10.7 | 2.9 | 5.3 7 | | | | | | | | | | | | | | | | | | | | | | | | | |
| PCB 195 | | | | | | | | | | | | | . 14.9 | 8.7 | 9.0 | 9.9 1 | 9.7 | | 33.7 | 21.2 | 22.9 e E | 8.5 8 | 15.5 | 5.5 | 1. (| ۶Q | 2.5 | Ð | 2 | 2 | n Z | | Ð | Q | Q ä | 0.0 | 1.2 |
| PCB 194 | Σz | 2 2 | 2 2 | Σ | Σ | Σ | ≥ (| зc | Ø | Σ | Ø | 22 | 2 | | | | | | | | | | | | | | | | | | | | | | | | |
| PCB 191 | αġ | Ę | зĘ | <u>}</u> c | 1.8 | Q | ٥ | nn v | 2.0 | QN | 3.0 | 9 ; | | | | | | | | | | | | | | | | | | | | | | | | | |
| PCB 189 | 9.7 | | Ę | ¥ 4 | Ø | Ð | 1.7 | S S | o V O | 0.7 | Ø | g | y « | 2.7 | 5.8 | 2.5 | 4 0 | | 0.8 9 | 7.0 | 1.7 | 2 - | 3.5 | 1.4 | ND VD | 3.5 | Q | Q | Q I | Ω.[| n N N | 4 C | Z | Q | 2 a | 5 0 7 0 | ND |
| PCB 187 | 593.8 | 2.011 | 0.05 | 28.0 | 4.8 | 17.4 | 94.8 | 31./ | 26.5 | 49.6 | 41.1 | 6.0 | 148.8 | 69.5 | 108.5 | 60.7 | 75.0 | 5.9 7 8 1 | 257.5 | 166.3 | 168.2 | 82.2 82.2 | 118.2 | 34.1 | 24.9 | 57.3 | 32.1 | 33.3 | 15.4 | 4.7 | 10.1 61.5 | 65.2 | 36.8 | 28.4 | 3.2 | 40.04 a a f | 12.1 |
| PCB 185 | 17.7 | зŞ | Ę | 2 ¢ | Q | ø | 1.9 | Зď | g o | 1.4 | 0.8 | g | y . | | | | • | | | | | | | | | | | | • | | • | | | | | | • • |
| PCB 183 | 204.2 | 42.1 | 10.0 | 15.6 | 2.8 | 8.7 | 34.1 | 12.8 50.6 | 10.2 | 17.8 | 15.2 | 5.3 9 | 44.5 | 12.0 | 36.6 | 21.1 | 21.1 | 9. L | 85.9 | 62.6 | 47.3 | 19.7 | 39.1 | 4.5 | 6.6 | 8.9 | 4.1 | 2.1 | 9 ! | | UN C P | , 0 1 0 | 1.5 | 1.3 | Q d | 7.5 0 N | 0.4 |
| PCB 180 | 644.2 420 5 | 128.0 | 71.2 | 43.5 | 8.6 | 44.0 | 92.9 | 33.6 | 4.9 | 48.0 | 40.3 | 6.1 | 118.1 | 81.2 | 95.0 | 54.9 | 61.4 7.0 | 19.7 | 216.5 | 137.2 | 123.9 | 35.8 | 88.0 | 30.6 | 21.9 | 68.9 | 46.2 | 43.5 | 14.9 | | 19.U 62.2 | 90.1 | 42.0 | 34.0 | Ð, | 4 Ч.0 С. Ч. | 8.9 |
| PCB 177 | 186.0 | 30.0 1 1 F | 0.11 1.0 | 0.0 | 2.0 | 6.5 | 27.8 2.1 | 8.1 907 | 7.4 | 13.2 | 12.6 | 0.7 | 162.0 | 80.4 | 106.0 | 64.0 | 64.0 | 0.0 18.6 | 277.1 | 188.4 | 125.7 77 e | 88.7 | 117.0 | 38.0 | 31.5 | 37.1 | 34.6 | 37.5 | 15.9 | 4.2 | 14.U 66.0 | 67.8 | 46.0 | 30.0 | a ' | 100 | 9.0 |
| PCB 174 | 182.5 | 4.04 | 10.9 | 16.0 | ø | 10.0 | 25.4 | 9.4 70,4 | | 13.3 | 9.6 | 3.7 | 139.1 | 66.7 | 93.0 | 62.7 | 70.2 | 8./ 28.8 | 228.8 | 156.0 | 117.8 | 79.7 | 87.6 | 30.8 | 23.9 | 63.2 | 34.7 | 45.6 | 22.2 | 11.2 | 24.3 57 5 | 2.75 | 48.2 | 35.1 | 1.9 | υ αα | 6.5 |
| PCB 170/190 | 279.5 54.6 | 0.40 4 0.4 | 19.7 | 15.9 | 2.9 | 11.4 | 39.8 | 13.5 | 9.7 | 18.5 | 16.0 | 2.7 | 0.0 | | | | | | | | | | | | | | | | | | | | | | | | |
| PCB 170 | | | | | | | | | | | | | . 1.3 | 28.3 | 19.4 | 30.9 | 33.4 | 4.σ 4.τ | 91.7 | 76.5 | 33.5 77.0 | 37.5 | 44.1 | 12.0 | 9.3 | 32.0 | 12.0 | 17.3 | 8.4 | 6. 0. 1 | 1.7 | 35.0 | 21.0 | 14.0 | Q g | 2 B | 1.5 |
| PCB 158 | 62.4 | γ. α. | з° | 2.6 | g | ø | 8.7 | 2.8 9 0 | 0.0 | 3.9 | 3.6 | α, | 44.0 | 12.4 | 33.4 | 13.7 | 18.8 | | 70.4 1 | 41.6 | 39.8 | 24.8 | 38.6 | 4. | 5.7 | 14.4 | 6.9 | 7.0 | 3.1 | 8.0 | 0.0 | 16.0 | 9.9 | 5.1 | Ð, | 0.6 0.6 | 1.5 |
| PCB 157/173/201 | 60.5 | N N | 0. v | 50 | 1.1 | 2.5 | 8.6 0 | аţ | 2.5 | 4.4 | 3.2 | a (| 0. | | | | | | | | | | | | | | | | | | | | | | | | |
| PCB 157 | | | | | | | | | | | | | 20.4 | 9.2 | 13.6 | 8.1 | 6.5 • | | 17.0 | 23.2 | 10.8 | 6.4 | 11.1 | 4.2 | 4 0. | 3.4 | 1.3 | 3.4 | Q I | Q , | | 0.0 | 2.2 | 2.2 | Q ä | 0.0 0.0 | 1.5 |
| PCB 156/171/202 | 11.0 | α.u | 4.01 | 13.4 | 1.9 | 8.6 | 32.8 2.' | 9.1 50.1 | 6.6 | 15.2 | 11.9 | 2.9 | t. | | | | | | | | | | | | | | | | | | | | | | | | |
| PCB 156 | | | | | | | | | | | | | . 55 55 | 16.4 | 10.0 | 27.6 | 23.6 | 0 0 0 0 | 33.8 | 5.0 | 46.7 | 26.0 | 34.5 | 17.1 | 9.5 | 0.7 8.5 | 8.6 | 12.4 | 4.9 | 0.7 | 9.7 0.2 | 10 | 6.3 | 6.2 | 1.3 | 0.0 0.0 | 3.8 |
| PCB 153 |)58.6 22.7 | 23.1 | 50.4 0.70 | 2.67 | 15.2 | 12.9 | 68.0 | 0.00 | 51.7 | 36.4 | 7.0 | 8.8 | 79.0 | 35.0 | 15.0 | 40.0 | 26.0 | 14.4 | 04.0 | 14.0 | 26.0 | 0.08 | 18.0 | 38.0 | 58.0 | 63.0 | 96.7 | 75.0 | 38.9 | 17.8 | 16.9 0 E 0 | 710 | 92.0 | 74.9 | 11.0 | 58.U | 20.6 |
| | | 4 . | + - | | | 7 | ÷, | | + -+ | • | | | + 4 | . 4 | 4 | 4 | 4, | 4 4 | 4. | 4 3 | 4 • | 14 | 4 | 4 | 4 - | 1 4 1 - | 4 | 4 | 4 | 4. | 4 ~ | | . 0 | 4 | 4. | 4 ~ | 14 |
| Date | 2/1/9/ | 6/1.5/1 | 101212 | 26/8/2 | 2/3/94 | 2/7/9/ | 2/1/9/ | 76/1/2 | 2/8/92 | 2/8/94 | 2/8/94 | 2/9/97 | 4/18/9 | 4/18/9 | 4/18/9 | 4/20/9 | 4/20/9 | 4/21/9 | 4/26/9 | 4/26/9 | 4/26/9 | 4/27/9 | 4/27/9 | 4/28/9 | 4/28/9 | 8/15/9 | 8/16/9 | 8/17/9 | 8/17/9 | 8/11/9 | 8/18/9 | 8/22/0 | 8/22/9 | 8/22/9 | 8/23/9 | 8/23/9 | 8/23/9 |
| noitst2 | Coyote Creek | Dumparton Bridge | Neawood Creek | Yerba Buena Island | Golden Gate | Red Rock | Petaluma River | San Pablo Bay | Davis Point | Napa River | Grizzly Bay | Sacramento River | Covote Creek | Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Island | Golden Gate Red Rock | Petaluma River | San Pablo Bay | Pinole Point | Napa River | Grizzly Bay | Sacramento River | San Joaquin River | Cuyoue Creek Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Island | Golden Gate | Red Kock | San Pahlo Rav | Pinole Point | Davis Point | Napa River | Grizzly Bay Sacramento Diviar | San Joaquin River |
| eboO noitst8 | BA10 | BA30 | | BC10 | BC20 | BC60 | BD15 | 8020 | BD40 | BD50 | BF20 | BG20 | BA10 | BA30 | BA40 | BB70 | BC10 | BCZU | BD15 | BD20 | BD30 | BD50 | BF20 | BG20 | BG30 | BA30 | BA40 | BB70 | BC10 | BC20 | BC60 | | BD30 | BD40 | BD50 | BF 20 B G 20 | BG30 |

| I | | | | m | m | m | m | m | m | | | m , | | | חת | | , | | m | m | m | | | | יי ת | , | | Π | п | m | m • | | | , | m | m | | m , | . | | |
|---|--------------------|-------------|------------|-------------|--------------|---------------|----------------|----------|-------------|--------------------|---------|---------------|------------------|--------------|-------------------|----------------|------------|-------------|--------------|---------------|----------------|----------|-------------|---------------------|--------------|------------------|--------------|-------------------|------------------|-------------|------------|----------------|---------------|--------------------------|----------|-------------|--------------------|------------------|---------------|----------------------------------|-------------------------|
| | 3G30 | 3120 | BD50 | 3D40 | 3D30 | 3D20 | BD15 | 3C60 | BC20 | BC10 | 3B70 | 3A40 | AA30 | 3A10 | 020 | | BD50 | 3D40 | 3D30 | 3D20 | BD15 | 3C60 | 3020 | | 8A40 | 5A30 | 3A10 | 3G30 | 3G20 | 3F20 | | | | 0D15 | 3C60 | 3C20 | BC10 | 3B70 | A 4 0 | 3A10 | Station Code |
| | San Joaquin River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Red Rock | Golden Gate | Yerba Buena Island | Alameda | Redwood Creek | Dumharton Bridge | Covote Creek | San Inariin River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Red Rock | Golden Gate | Verha Rijena Ieland | Alameda | Dumparton Bridge | Coyote Creek | San Joaquin River | Sacramento River | Grizzly Bay | Napa River | Davis Point | San Pablo Bay | Petaluma River | Red Rock | Golden Gate | Yerba Buena Island | Alameda | Redwood Creek | Coyote Creek Dumharton Bridge | Station |
| | 0/23/94 8/23/94 | 8/23/94 | 8/23/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/18/94 | 8/17/94 | 8/17/94 | 8/17/94 | 8/16/94 | 8/15/94 | 8/16/94 | 4/28/94 | 4/2/194 | 4/27/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/21/94 | 4/21/94 | 4/20/04 | 4/18/94 | 4/18/94 | 4/18/94 | 2/9/94 | 2/9/94 | 2/8/94 | 2/8/94 | 2/8/04 | 2///94 | 2/7/94 | 2/7/94 | 2/3/94 | 2/3/94 | 2/3/94 | 2/2/04 | 2/1/94 1/31/94 | Date |
| | 97 | 120 | 95 | 20 | 97 | 104 | 00 | ω 1 | 54 | œ 0 œ - | 8 0 | 99 | 127 | 5 C | 8 Y 2 Z | 200 | 4 8 3 3 | 128 | 65 | 50 | 69 | 18 | ω <u>-</u> | 7 1 0 | 0 0 0 4 | 202 | 254 205 | 161 | 95 | 29 | 64 64 | о С 4 п | 04 20 | 56 | 46 | 4 | 58 | 50 0 | - A | 104 79 | Total Chlordanes (SFEI) |
| | 75.4 | 424.5 | 280.4 | 108.9 | 179.3 | 118.7 | 279.0 | 54.1 | 7.9 | 82.5 | 68.5 | 84.0 | 124.4 | 144.7 | 189.7 | 0.607 0.607 | 201.5 | 181.4 | 120.9 | 133.1 | 164.8 | 51.7 | 42.5 | 017.0 | 104.0 | 10.0 | 79.6 | 110.1 | 164.5 | 62.5 | 142.6 | 122 a | 184.9 | 121.4 | 31.2 | 24.4 | 91.1 | 62.3 | 7 7 | 201.8 | Total DDTs (SFEI) |
| | 859.0 | 1605.0 | 948.0 | 205.7 | 1083.0 | 1600.0 | 1256.0 | 550.0 | 1060.0 | 820.0 | 1255.0 | 1384.0 | 1458 0 | 1295.0 | 304.U 706.0 | 284.0 | 1330.0 | 1420.0 | 990.0 | 1440.0 | 950.0 | 5.9 | 1160.0 | 1188 0 | 1332.0 | 2424.0 | 1760.0 | 197.4 | 1125.9 | 222.5 | 837.7 | 003 1 | 1070.2 | 1346.4 | 961.0 | 547.3 | 1245.0 | 1320.6 | <u>134</u> лл | 7461.4 2552.2 | Total HCHs (SFEI) |
| | 20 | 20 | 21 | 6 | 26 | 17 | 21 | 8 | 9 | 24 | 27 | 26 | 22 | 17 | 10 | 4 0 | 16 | 19 | 22 | 9 | 12 | 6 | | о- ло | 103 | | သ ယ သ ယ | 34 | 24 | 16 | 23- | 1 2 2 | 22 | 4 <u>1</u> 4 <u>1</u> | 17 | - | 30 | 9 <mark>1</mark> | 9 r 9 4 o | 265 65 | Alpha-Chlordane |
| | 340.0 190.0 | 500.0 | 310.0 | 84.0 | 440.0 | 660.0 | 530.0 | 260.0 | 550.0 | 290.0 | 490.0 | 440.0 | 540.0 | 200.0 | 86 0 | 340.0 | 490.0 | 570.0 | 270.0 | 450.0 | 340.0 | 2.1 | 600.0 | 384 0 | 288.0 | 000.0 | 220.0 | 36.3 | 186.4 | 38.1 | 313.2 | 3510 | 497.0 | 636.6 | 563.1 | 348.5 | 415.6 | 456.5 | 409.0 | 584.1 658.9 | Alpha-HCH |
| | 99.0 59.0 | 160.0 | 190.0 | 37.0 | 270.0 | 320.0 | 230.0 | 190.0 | 300.0 | 330.0 | 290.0 | 220.0 | 290.0 | 160.0 | 24.U | 340.0 | 290.0 | 310.0 | 520.0 | 620.0 | 360.0 | 3.8 | 350.0 | 408 0 | 594.U 7 5 | 504.0 | 340.0 | 7.1 | N | 31.9 | 50.0 | лзр 1-1-4 | 114.1 | 121.9 | 113.0 | 85.8 | 156.9 | 137.1 | 107.6 | 318.1 230.3 | Beta-HCH |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 607.3 | 1416.0 | 364.1 | 601.9 | д73 г | | 552.6 | 224.2 | 66.3 | 1758.5 | 306.1 | 5434 | 1833.5 726.8 | Chlorpyrifos |
| | 5.7 | 14.0 | 8.6 | -1 -1 | 7.3 | 16.0 | 7.9 | 2.2 | 3.0 | 7.0 | 6.4 | 7.4 | 13.0 | 50 | л~ 4 00 | 4 0 2 0 | 7.1 7 | 17.0 | 4.4 | 2.2 | 5.2 | 1.4 | 23 | 5 C C | 2 2 | 0.01 | 4.6 | 4.1 | 5.7 | B | 6.4 | - C - R | 4.4 0 C | 7.3 | Q | Ð | 4.4 | 4 с СП С | ה ה הית | 10.2 4.3 | Cis-Nonachlor |
| | 500.0 | 440.0 | 370.0 | 410.0 | 190.0 | 270.0 | 210.0 | 41.0 | 77.0 | 79.0 | 220.0 | 190.0 | 200.0 | 340.0 | 730.0 | | 470.0 | 570.0 | 300.0 | 18.0 | 270.0 | N | 84.0 | | 240.0 | 320.0 | 30.0 | 3009.9 | 5208.2 | 1669.8 | 2147.7 | 1502 2 | 5299.0 | 6160.7 | 682.0 | 264.4 | 1506.0 | 1220.9 | 1174 1 | 6861.2 2148.9 | Dacthal |
| | ND 30.0 | 35.0 | 28.0 | 1.7 | 63.0 | 150.0 | 56.0 | B | ND | N S | 35.0 | 74.0 | 18 0 | 65.0 | 33 | Ë | 58 | R | ND | B | ND | 2 | 58 | 5 | SZ | ġ | 58 | | | | | | | | | | | | | | Delta-HCH |
| | 1200 | 1/00 | 1400 | 1100 | 480 | 650 | 730 | 240 | 260 | 540 | 1200 | 1100 | 8400 | 2500 | 7000 | 3500 | 4600 | 4500 | 1200 | ND | 2600 | N | 260 | 2800 | 1700 | | 3700 | 35187 | 46629 | 14686 | 5033 | 40902 10678 | C U 2 I I | 13797 | | | | | | 97628 18426 | Diazinon |
| | N 0.4 | | SD | 33.0 | 27.0 | Ŋ | ND | ND | ND | 16.0 | 6.8 | 18.0 | 74 | | 170.0 | 140.0 | 92.0 | 120.0 | 50.0 | 66.0 | 79.0 | 7.7 | 9.6 | 71 0 | 104.0 6.4 | 230.2 | 100.0 | 144.3 | 193.0 | 86.9 | 126.1 | 87 A | 131.9 | 95.1 | 37.1 | 14.4 | 151.7 | 107.5 | 119.0 | 205.4 145.3 | Dieldrin |
| | BB | ΞE | Ş | P | Ð | ND | B | Ŋ | B | 5 | Z i | S | 5 | 5 | 33 | Ēē | Β | B | Ŋ | Ð | Ŋ | B | 58 | 58 | SZ | Ξē | 58 | ND | Q | B | Ø | Þ₹ | ξ¢ | Q | Q | ND | B | o (| Ş¢ | οĘ | Endosulfan I |
| | 88 | | 58 | ND | Ŋ | ND | ND | ND | ND | 8 | Z | 5 | 5 | S | 33 | Ē | 58 | N | ND | N | ND | B | 23 | 33 | 52 | į | 50 | ND | Ø | Ŋ | Ø | D c | ē | δ | ND | ND | Ŋ | N a | ≤ ; | 58 | Endosulfan II |
| | 88 | ΞE | S | ND | Ŋ | ND | Ŋ | B | B | 2 | S | 88 | 33 | 3 | 33 | 5 e | 50 | B | ND | Ŋ | B | B | 23 | 53 | 32 | Ēē | ΒB | ND | ß | Ζ | 33 | ≤¢ |) ≤ | 3 | ND | Ŋ | B | 88 | 5 | ₹. | Endosulfan Sulfate |
| | 12.0 | 25.0 | S | 34.0 | 56.0 | 73.0 | 27.0 | 41.0 | Ê | Z : | 1.7 | 44.0 | 60.0 | 36.0 | 2 0 | | 20 | C E | R | CE | R | Ê | | 2 6 | л п | р Г П | 20 | | | | | | | | | | | | | | Endrin |
| | 26.0 | 29.0 | 27.0 | 6.3 | 31.0 | 20.0 | 26.0 | 8 .5 | 16.0 | 28.0 | 27.0 | 29.0 | 20.0 | 15.0 | 14.0 | 10.0 | 19.0 | 23.0 | 15.0 | 13.0 | 16.0 | 2.4 | | 18.0 | 13.0 | 12.0 | 20.0 | 89.6 | 21.6 | Ø | 21.5 | 11 2 | 10.0 | 10.5 | 17.0 | 0.9 | 14.5 | 9.0 | о л | ≤ø | Gamma-Chlordane |

. = Not Analyzed, ND = not detected, Q = Present but not quantifiable, M = Matrix interference, CE = coelution. Units in pg/L(ppq).

 Table 3.8. Dissolved Pesticide concentrations in water samples, 1994.

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. = Not Analyzed, ND = not detected, Q = Present but not quantifiable, M = Matrix interference, CE = coelution. Units in pg/L(ppq).

| Trifluralin | ₽¢ | ÿ | ₹a | Q | Q | | 1063.5 | 422.4 | 385.9 | 505.6 366 8 | 1947 1 | 1172.9 | | | | | • | | | | | | | | • | | | | | • | | | | | | | |
|--------------------|-------------------|---------------|-----------------|--------------------|-------------|-----------------|------------------|--------------|-------------|----------------|------------------|-------------------|--------------|------------------|---------------|---------|--------------------|------------|----------------|---------------|--------------|---------------------------|-------------|------------------|-------------------|--------------------|---------------|---------|--------------------|-------------|----------|----------------|---------------|---------------|------------|-------------|---------------------------------------|
| trans-Nonachlor | 28.6 15.6 | 0.01 a c f | 8.0 | 8.9 | 2.2 | 4.0 10 7 | 10.9 | 10.2 | 9.4 | 12.7 12.6 | 28.6 | 18.8 | 11.0 | 19.0 | 6.3 | 8.7 | 12.0 ND | 4 9 | 19.0 | 9.0 | 14.0 | 31.0 16.0 | 17.0 | 22.0 | 17.0 | 0.01 | 13.0 | 8.2 | 9.7 | 3.1 | 3.4 | 17.0 | 10.0 | 4.0 | 16.0 | 19.0 | 15.0 13.0 |
| ənənqexoT | 22 | | 22 | Q | Ð | | ŝ | 2 | Q | ON N | Ē | 2 | | | | | | | | | | | | | • | | | | | • | | | | | | | |
| TOO-'q,q | ٥٢ | 20 | 4.7 | ø | 3.7 | α, | 7.7 | ø | 1.3 | 3.8 | 104 | 3.7 | Q | Q | Q : | 2 | 22 | | 9.5 | Q | 9 | ON P | 11.0 | 13.0 | 12.0 | 13.U | | 11.0 | Ð | 9 : | Q I | 5.6 | 0.62 | 2 9 | 4.7 | 2 | 16.0 11.0 |
| UMQQ-'q,q | 13.0 8.1 | - 0 - 7 | o o | 20.0 | 4.8 | 4.9 - | - 6 | 8.3 | 6.9 | 6.4 6 | 0.0 | 2.8 | | | | | | | | | | | | | • | | | | | • | | | | | | | |
| ∃DD-'q,q | 61.8 37.1 | | 12.3 | 10.4 | 9.3 | ٥،، | 37.3 | 27.9 | 35.2 | 36.0 | | 54.8 | 41.0 | 30.0 | 32.0 | 46.0 | 18.0 o o | 23.0 | 29.0 | 25.0 | 20.0 | 29.0 30.0 | 44.0 | 58.0 | 69.0 | 30.0 | 12.0 | 14.0 | 21.0 | 7.9 | 9.4 | 38.0 | 31.0 | 40.0 | 37.0 | 42.0 | 65.0 34.0 |
| DDD-'q,q | 115.7 51 A | t 0 t 0 | 38.8 38.8 | 70.6 | 9.4 | 28.8 74.2 | 122.6 | 108.6 | 69.0 | 90.2 NN | 1 2 3 | 41.0 | 33.0 | 24.0 | 77.0 | 43.0 | 168.0 31.0 | 25.0 | 100.0 | 91.0 | 87.0 | 120.0 | 130.0 | 120.0 | 87.0 | 71.0 | 59.0 | 39.0 | 58.0 | Ð, | 40.0 | 190.0 | 55.U | 60.0 | 200.0 | 350.0 | 56.0 23.0 |
| Охусћіогаале | QN cc | | 19.1 | Q | ø | 7.6 UN | Ē | 2 | Q | 22 | Ē | 2 | 5.1 | 4.8 | 2 | 2 | 22 | Ē | 2 9 | Q | 99 | | 2 9 | 1.0 | 1.2 | | 6.9 | Q | Q | 3.2 | | 2.1 | | 2 2 | Ð | 7.2 | 3.4 3.2 |
| nozsibexO | 26464.5 5151 8 | a 1011 | 2274.6 | 3219.9 | 211.7 | 857.9 5086.7 | 5398.9 | 9682.4 | 4799.3 | 4163.1 | 2621.9 | 2801.9 | 150.0 | 17.0 | 2 | | 2.5 | CIN CIN | 20.0 | 66.0 | 20.0 | 0.0 22.0 | 160.0 | 140.0 | 17.0 | | 17.0 | 56.0 | 180.0 | 100.0 | 40.0 | ND VD | 160.0 | 150.0 | 250.0 | 130.0 | 77.0 92.0 |
| TOD-'q,o | 22 | | 22 | Q | Ð | 22 | g | 9 | Q | | Ē | Ξ | Q | Q | 2 | 2 | | Ē | 2 2 | Q | 99 | | 2 9 | Q | 2 | | 29 | 9 | Q | 9 | 2 | 2 | | 2 2 | Ð | 2 | 29 |
| a,9'-DDE | σc | ÿ | δa | ø | σ | ٥ç | 5 K 1 (C) | 3.2 | 3.7 | 2.6 7 | 0.0 | 4.2 | 1.1 | Ð | 2 | 1.0 | 2.9 | Ē | 1. 1.3 | 1.1 | 0.9 | 1.4 4.0 | 1.5 | 1.9 | 1.7 | | 29 | Q | Q | 2 | Ð, | 8. r 4. r | / . / | c 6 | 3.7 | 3.5 | 3.9 1.8 |
| DDD-'q,o | 24.3 16.6 | 0.0 2 | 9.9 9.9 | 10.1 | 2.0 | 2.5 5.5 | 13.8 | 9.6 | 13.8 | 10.0 | σ | 6.5 | 4.5 | 16.0 | 16.0 | 14.0 | 27.0 1 6 | - c | 25.0 | 16.0 | 13.0 | 31.0 | 23.0 | 29.0 | 20.0 | 13.0 | 13.0 | 4.5 | 3.5 | 2 | 4.7 | 42.0 | n ç | 7.0 | 35.0 | 29.0 | 15.0 5.6 |
| Mirex | | | | | | | | | | | | | Q | Q | 2 | 2 | 22 | Ē | 22 | Q | 2 | | 2 9 | Q | 2 | | 29 | Q | Q | 9 : | 2 | 2 | | 2 2 | Ð | 2 | |
| Μethylchlorpyrifos | | | . DN | QN | Ð | | . C | 2 | ø | Q Z | <u>j</u> c | P | | | | | | | | | | | | | | | | | | | | | | | | | |
| Hexachlorobenzene | 2.0 8.1 | | о. С | Q | ø | Q y | 7 7 | 3.0 | 6.5 | 5.4 6.9 | 0.0 | 29.4 | 6.5 | 4.5 | 3.6 | 3.0 | 5.0 ч | 10 | 4.8 | 5.3 | 6.4 | 6.4 7.7 | 7.8 | 12.0 | 26.0 7.0 | 7.0 | 11.0 | 2.1 | 8.9 | 7.0 | 4.3 | 9.3 | 13.0 | 2 2 | 11.0 | 11.0 | 12.0 9.3 |
| Heptachlor Epoxide | σ₽ | ₫ 0 | ₽₽ | Q | Ð | UN 2 | 2. <u>+</u> C | ď | ø | ac | 14 7 | 14.9 | 180.0 | 132.0 | 29.0 | 2 | 9.3 0 | 9 G 9 G | 17.0 | 17.0 | 9.8 | 37.0 | 25.0 | 27.0 | 32.0 | α.α Ο Γς | 12.0 | 5.2 | QN | 16.0 7.0 | 5.9 | 11.0 | 24.0 | 1.1 | 14.0 | 19.0 | 34.0 29.0 |
| Heptachlor | | | | | | | | | | | | | Q | Q | Q. | . i | 22 | 2 5 | 22 | QN | 9; | 2.1 UN | g | QN | g ; | α.υ Ο C C F | 5.3 | 6.9 | 19.0 | 3.6 | 3.1 1 | 4.7 | 0.71 | 0.1 | 8.1 | 5.8 | 11.0 ND |
| HOH-smms9 | 6559.2 1662 0 | 810.3 | 727.0 | 672.5 | 113.0 | 284.9 587 0 | 790.5 | 471.9 | 498.5 | 474.5 152 5 | 939.6 | 154.0 | 1200.0 | 1224.0 | 450.0 | 1.0 | 396.0 | UD 2 | 250.0 | 370.0 | 200.0 | 540.0 550.0 | 650.0 | 290.0 | 330.0 | 8/0.0 610.0 | 650.0 | 440.0 | 200.0 | 210.0 | 100.0 | 440.0 | 4/0.0 | 310.0 83.0 | 420.0 | 910.0 | 1000.0 610.0 |
| Date | 2/1/94 | 10/0/0 | 2/3/94 | 2/3/94 | 2/3/94 | 2/7/94 | 2/7/94 | 2/7/94 | 2/8/94 | 2/8/94 | 2/9/94 | 2/9/94 | 4/18/94 | 4/18/94 | 4/18/94 | 4/20/94 | 4/20/94 | 4/21/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/27/94 | 4/28/94 | 4/28/94 | 8/16/94 8/15/04 | 8/16/94 | 8/17/94 | 8/17/94 | 8/17/94 | 8/18/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/23/94 | 8/23/94 | 8/23/94 8/23/94 |
| noitst2 | Coyote Creek | Dedwood Creek | Alameda | Yerba Buena Island | Golden Gate | Red Rock | San Pablo Bav | Pinole Point | Davis Point | Napa River | Sacramento River | San Joaquin River | Coyote Creek | Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Island | Red Rock | Petaluma River | San Pablo Bay | Pinole Point | Davis Point Nana River | Grizzly Bav | Sacramento River | San Joaquin River | Coyote Creek | Redwood Creek | Alameda | Yerba Buena Island | Golden Gate | Red Rock | Petaluma River | San Pablo Bay | Davis Point | Napa River | Grizzly Bay | Sacramento River San Joaquin River |
| eboD noitet2 | BA10 BA30 | | BB70 | BC10 | BC20 | BC60 BC60 | | BD30 | BD40 | BD50 | BG20 | BG30 | BA10 | BA30 | BA40 | BB70 | BC10 | BC60 | BD 15 | BD20 | BD30 | BD40 | BF20 | BG20 | BG30 | DV30 | BA40 | BB70 | BC10 | BC20 | BC60 | BD 15 | | BD40 | BD50 | BF20 | BG20 BG30 |

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 | |
|--------|------------------|-------------|------------|-------------|--------------|---------------|----------------|----------|-------------|-------------------------------|---------------|------------------|--------------|-------------------|------------------|-------------|------------|-------------|--------------|---------------|-------------------|-----------|-----------------|----------|---------------|------------------|--------------|-------------------|------------------|-------------|------------|-------------|--------------|----------------|----------|-------------|--------------------|--------------|---------------|-------------------|--------------|-------------------------|
| | BG20 | BF20 | BD50 | BD40 | BD30 | BD20 | BD15 | BC60 | | | | BA30 | BA10 | BG30 | BG20 | BF20 | BD50 | BD40 | BD30 | BD20 | | | BC10 | 8870 | BA40 | BA30 | BA10 | BG30 | BG20 | BF20 | BD50 | BD40 | | | BC60 | BC20 | BC10 | BB 70 | BA40 | BA30 | RA10 | Station Code |
| | Sacramento River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Red Rock | Golden Gate | Alameda Verha Buena Ieland | | Dumbarton Bridge | Coyote Creek | San Joaquin River | Sacramento River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Pablo Bav | Detaluma Diver | Bod Book | Coldon Coto | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | San Joaquin River | Sacramento River | Grizzly Bay | Napa River | Davis Point | Dinole Doint | San Dahlo Bay | Red Rock | Golden Gate | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Covote Creek | Station |
| | 8/23/94 | 8/23/94 | 8/23/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/22/94 | 8/18/94 | 8/17/94 | 8/17/94 | 0/17/04 | 8/15/94 | 8/16/94 | 4/28/94 | 4/28/94 | 4/27/94 | 4/27/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/26/07 | 4/21/94 | 4/20/94 | 4/20/94 | 4/18/94 | 4/18/94 | 4/18/94 | 2/9/94 | 2/9/94 | 2/8/94 | 2/8/94 | 2/8/94 | 2/7/04 | 2/7/94 | 2/7/94 | 2/3/94 | 2/3/94 | 2/3/94 | 2/2/94 | 2/1/34 1/31/94 | 2/1/94 | Date |
| 10 | 132 195 | 175 | 173 | 55 | 130 | 162 | 138 | 49 | л л | 104 | | 181 | 204 | 108 | 128 | 181 | 175 | 180 | 209 | 116 | α / c - α | , a | 103 | 69 | 164 | 310 | 410 | 184 | 95 | 59 | 89 | 53 | 144 | 144 61 | 61 | 9 | 84 | 72 | 66 | 127 | 311 | Total Chlordanes (SFEI) |
| r -0.0 | 282.5 | 737.3 | 417.4 | 373.7 | 790.6 | 607.7 | 925.0 | 132.9 | 9 69 | 203.5 | - 44 | 430.0 | 660.7 | 430.4 | 591.6 | 1167.2 | 784.5 | 592.4 | 828.3 | 814.4 | 1111 8 | 03.1 | 353.8 | 167.5 | 381.0 | 277.2 | 525.9 | 364.4 | 270.2 | 375.3 | 340.6 | 305.8 | 1973 4 | 308.5 | 114.2 | 61.6 | 194.4 | 193.7 | 91.9 | 394.3 | 1598 1 | Total DDTs (SFEI) |
| 000.1 | 1506.0 883 1 | 1661.6 | 976.9 | 216.5 | 1112.3 | 1623.4 | 1284.9 | 558.1 | 1067.9 | 1260.3 | 1400.0 | 1487.8 | 1338.3 | 708.9 | 386.8 | 1359.5 | 1373.3 | 1433.5 | 1003.9 | 1498.0 | 1051.0 | 1103.7 | 1197.7 | //0.5 | 1353.3 | 2440.5 | 1799.6 | 197.4 | 1125.9 | 226.1 | 842.1 | 905.0 | 1082 6 | 13/3.5 | 975.1 | 547.3 | 1284.3 | 1320.6 | 1345.5 | 2559.4 | 7509.3 | Total HCHs (SFEI) |
| 10 | 2 2 2 5 | 42 | 43 | 13 | 34 | 32 | 3 i 1 | 121 | 12 | 0 G 0 G | 2 4 4 6 | 2 0 | ი ე | 21 | 27 | 37 | 33 | 32 | 50 | 20 | ہ ص | s u | ა ^{კკ} | 20 18 | 52 | 44 | 63 | 41 | 24 | 25 | 29 | 15 - | 4 4 | 30 | 22 | Ν | 36 | 15 | 24 | 37 | 104 | Alpha-Chlordane |
| £00.0 | 346.8 | 512.0 | 318.8 | 87.7 | 454.0 | 669.0 | 535.8 | 265.6 | 553.2 | 494.1 204 8 | 444.0 | 546.8 | 209.3 | 86.0 | 70.0 | 346.6 | 502.0 | 576.1 | 275.9 | 461.0 | 103.1 | 421.0 | 388.8 | 192.0 | 292.6 | 603.8 | 225.6 | 36.3 | 186.4 | 39.4 | 314.6 | 351.9 | 102.4 | 802 / | 565.9 | 348.5 | 424.0 | 456.5 | 409.6 | 661.6 | 500 5 | Alpha-HCH |
| 00.0 | 118.0 66 0 | 163.6 | 201.0 | 41.2 | 277.3 | 328.6 | 233.5 | 191.5 | 303.0 | 340.0 | 220.0 | 302.0 | 172.0 | 291.9 | 26.8 | 344.9 | 294.3 | 312.5 | 523.3 | 635.0 | 376 0 | 100 0 | 412.9 251 5 | 427.5 | 605.0 | 606.7 | 351.0 | 7.1 | ß | 31.9 | 50.0 | 53.6 | 1123 | 123.6 | 114.6 | 85.8 | 156.9 | 137.1 | 125.6 | 231.1 | 318 1 | Beta-HCH |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | 640.0 | 1416.0 | 390.8 | 618.6 | 488.7 | 640 4 | 679.1 737 3 | 231.0 | 66.3 | 2184.5 | 326.0 | 543.4 | 2779.7 | 2054 2 | Chlorpyrifos |
| 0.0 | 8.9 0.3 | 22.5 | 18.1 | 6.2 | 13.8 | 25.9 | 13.9 | 4.0 | 3 C | 9.0 9 | 0.0 | 19.0 | 26.0 | 8.2 | 9.2 | 16.5 | 18.1 | 24.3 | 21.4 | 10.4 | 2 - 2 - 3 + | | 12.2 | 1.4 | 10.8 | 27.0 | 32.6 | 5.7 | 5.7 | 3.7 | 9.2 | 4.6 | 30 R | 35.9 | 1.2 | 0.4 | 10.5 | 7.2 | 6.6 | 13.3 | 32 4 | Cis-Nonachlor |
| 0.0 | 518.5 | 471.0 | 394.0 | 427.0 | 206.0 | 288.0 | 230.0 | 73.0 | 84 1 | 220.0 | 210.0 | 240.0 | 470.0 | 771.0 | 631.0 | 761.0 | 477.8 | 592.0 | 327.0 | 61.0 | 200.0 | 91.U | 178.0 | 220.0 | 249.8 | 326.1 | 51.0 | 3010.5 | 5208.2 | 1710.4 | 2148.8 | 1519.4 | 5717 0 | 6344.1 | 699.3 | 264.4 | 1515.0 | 1232.8 | 1174.1 | 2193.9 | 7001 A | Dacthal |
| ē | 38.0 | 64.0 | 28.0 | 1.7 | 63.0 | 150.0 | 68.0 | 5 | 17 | 35.0 | 24.0 | 18.0 | 65.0 | P | P | ND | Ŋ | ND | 2 i | 33 | 33 | ΒZ | 5 C | NU | 58 | P | ND | | | | | | | | | | | | | | | Delta-HCH |
| - 200 | 1200 | 1700 | 1400 | 1100 | 480 | 650 | 730 | 240 | 260 | 540 | 1000 | 1100 | 2500 | ND | 2500 | 6200 | 4600 | 4500 | 1200 | | 0061 | 2000 | 2800 | 1700 | ND | 5600 | 3700 | 35259 | 46629 | 14786 | 5050 | 10688 | 13057 | 13925 | NA | R | NA | NA | | 18469 | 5 UU8 0 | Diazinon |
| P. 0 | 2 N | 7.4 | B | 37.0 | 27.0 | 7.6 | 5.3 | 3 - 0 | | 15./ 16.0 | 4 - C | 13.8 | SB | 179.0 | 179.5 | 165.0 | 105.0 | 131.0 | 73.0 | 80.0 | 107.0 | 13.7 7 | 93.0 | 66.4 | 124.0 | 257.2 | 123.0 | 149.6 | 193.0 | 93.7 | 130.3 | 92.2 | 135.3 | 120.5 | 42.1 | 14.4 | 171.1 | 107.5 | 119.4 | 151.6 | 2024 г | Dieldrin |
| ē | 50 | B | ND | ND | ß | 5 | Si | 33 | 33 | S C | Ēē | 5 C | S | D | ND | Ŋ | ND | B | S | 33 | 33 | 58 | 5 C | S | S | B | ND | ß | Q | B | Ø | 0 0 | 2 6 | ວຂ | Q | Ð | ß | Ø | ZD | ₽₹ | 5 | Endosulfan I |
| ē | S S | P | ND | ND | D | N I | Z i | 58 | 33 | ŝē | BB | ΒZ | 58 | P | Ş | ß | B | B | S i | 33 | 33 | Ξē | 5 C | N | Ş | Ş | ND | D | Q | Ş | Ø | 0 0 | S≧ | ΞC | Q | B | B | Ð | Ζ | o; | 34 | Endosulfan II |
| ē | ΒB | B | ND | Ŋ | N | N | Si | 33 | 33 | S C | Ēē | 5 C | S | Ŋ | ß | ß | ß | ß | Si | 33 | 33 | Ξē | βB | | S | ß | ND | Ζ | ND | Ζ | 3 | ≤ ¢ | S | 33 | 3 | ND | Ŋ | B | B | ≤₹ | S | Endosulfan Sulfate |
| 14.0 | | 25.0 | ND | 34.0 | 56.0 | 73.0 | 27.0 | 41 0 | | ۲ ۲ | 44.0 | 60.0 | 36.0 | С Ш | Ê | ĉ | Ĉ | ĥ | Ê | 26 | | | 200 | с Г | 2 Ch | ĥ | CE | | | | | | | | | | | | | | | Endrin |
| 00.0 | 29.9 38 0 | 45.0 | 54.0 | 17.3 | 42.0 | 39.0 | 39.0 | 13.9 | ол. л | 32.1 | 20.04 10.0 | 35.U | 54.0 | 21.7 | 27.0 | 41.0 | 37.0 | 34.0 | 46.0 | 30.0 | 83 A | | 28.0 | 12.0 | 28.0 | 41.0 | 53.0 | 96.2 | 21.6 | 11.4 | 29.2 | 19.3 | 41 7 | 38.2 3 | 22.2 | 2.3 | 20.2 | 17.0 | 22.5 | 18.1 | 45 0 | Gamma-Chlordane |

Table 3.9. Total Pesticide concentrations in water samples, 1994. (Continued)

. = Not Analyzed, ND = not detected, Q = Present but not quantifiable, M = Matrix interference, CE = coelution. Units in pg/L(ppq).

| Trifluralin | σc | 9 Q | ø | 9 | | 902.7 | 1063.5 | 422.4 302.2 | 512.5 | 388.0 | 1947.1 | 1225.2 | | | | | | | | | | | | | | | | | | | | | | | | |
|--------------------|----------------------------------|---------------|---------|--------------------|----------------|----------------|---------------|-----------------------------|----------------|-------------|------------------|-------------------|----------------------------------|---------------|---------|--------------------|-------------|----------------------------|---------------|--------------|---------------------------|-------------|------------------|-------------------|--------------------|---------------|---------|--------------------|-------------|--------------------|---------------|--------------|-------------|------------|-------------|---------------------------------------|
| trans-Nonachlor | 129.2 26.2 | 12.8 | 14.1 | 17.4 | 4.0 6.0 | 25.3 | 14.4 | 30.9 14 0 | 21.0 | 18.7 | 28.6 | 26.8 | 45.0 | 35.3 | 16.0 | 21.3 | 1.9 | 54 0 | 20.0 | 49.0 | 45.0 37.0 | 41.0 | 30.6 | 23.5 | 90.0 20.0 | 27.0 | 15.9 | 12.9 | 4 0 0 1 | 20.0 | 0.02 | 19.5 | 11.6 | 31.0 | 33.0 | 19.9 17.2 |
| Toxaphene | 99 | 2 | Q | Q ! | 22 | 22 | Ð | 22 | 2 9 | Q | Ð | N | | | | | | | | | | | | | | | | | | | | | | | | |
| TOO-'q,q | 26.9 30 1 | ø | 19.5 | σ | 10.8 | 97.3 | 14.5 | 66.2 23.1 | 11.1 | 3.3 | 10.4 | 30.5 | 0.00 CIN | 2 | Q | Q | 5.6 | 48.5 | 36.0 | 98.0 | 29.0 54 0 | 109.0 | 27.0 | 12.0 | 0.50 | | 25.0 | Q | 14.0 | NU E2 E | 0.00 | 46.0 | 36.0 | 51.7 | 11.0 | 34.0 41.0 |
| UMQQ-'q,q | 309.7 49.5 | 21.7 | ø | 35.8 | 8.0 8.0 | 66.5 | 23.5 | 120.7 20.0 | 32.7 | 28.0 | 23.7 | 19.4 | | | | | | | | | | | | | | | | | | | | | | | | |
| ∃00-'q,q | 1130.1 155 1 | 49.7 | 65.3 | 51.8 | 22.4 13.5 | 318.5 | 110.4 | 530.5 | 166.7 | 225.7 | 191.9 | 236.1 | 115.0 | 129.0 | 60.0 | 88.0 | 20.9 | 39.0 819.0 | 355.0 | 290.0 | 189.0 270.0 | 454.0 | 298.0 | 269.0 | 388.0 | 72.0 | 50.0 | 43.0 | 20.9 | 40.4 | 357.0 | 240.0 | 210.0 | 37.0 | 282.0 | 121.0 |
| QQQ-'q,q | 339.5 189.0 | 37.0 | 95.6 | 121.5 | 23.2 | 558.1 | 176.6 | 578.9 134.7 | 138.7 | 102.5 | 52.1 | 76.2 | 124.0 | 207.0 | 82.0 | 229.0 | 35.0 | 38.0 183.0 | 351.0 | 367.0 | 300.0 | 490.0 | 210.0 | 113.0 | 1/9.0 | 59.0 | 108.0 | 88.0 | 28.0 | 80.U | 152.0 | 432.0 | 108.0 | 273.0 | 398.0 | 0.20 36.0 |
| Oxychlordane | 32 g 32 g | Q | 19.1 | 2 | ٥'n | 2 Q | 2 | σ₽ | 2 | Ð | 2 | 5. | - 0 7 8 | 2 | Q | 9 | 2 | | 2 | 2 | с. с ю. а | <u>P</u> | 1.0 | 1.2 | Z D Q | 7.7 | Ð | 9 | 3.2 | | - J | 22 | Ð | 2 | 7.2 | 3.2 3.2 |
| nossibexO | 26938.8 5252 2 | 1701.8 | 2316.6 | 3244.4 | 211.7 873 2 | 6186.5 | 5434.5 | 9813.5 4839.2 | 4208.9 | 4278.6 | 2621.9 | 2802.6 | 50.0 | 7.6 | Q | 2.5 | 31.0 | 44 N | 111.0 | 36.0 | 72.6 | 163.3 | 157.0 | 17.0 | 93.U 30 D | 17.0 | 56.0 | 180.0 | 100.0 | 0.10 | 214 0 | 130.0 | 159.0 | 250.0 | 130.0 | 144.0 |
| TOO-'q,o | 25 | 2 | Q | 2 | 22 | 22 | a | 22 | 2 | 9 | 9 | Ξ | 2 2 | 2 | Q | Ð | 2 | 2 2 | 2 | 2 | 22 | 2 2 | Q | 2 | 2 2 | 2 2 | Q | 2 | 2 2 | | | 22 | Q | 2 | 2 2 | 2 2 |
| 300-'q,o | 45.7 3 4 | Q | σ | σ | 9.0 0 | 14.4 4.4 | 6.3 | 26.2 7 2 | 8.5 | 10.7 | 5.9 | 20 L | 4 C | 2 | 2.1 | 4.8 | 2 | 0.9 | 9.4 | 7.3 | 5.9 9.9 | 9.2 | 6.6 | 5.4 | 7.11.7 2 6 | 2 ZD | g | 1.7 | 22 | Ξç | 7 7 | 9.6 | 4.9 | 3.7 | 5.3 1 | 4.4 |
| QQQ-'q,o | 56.0 16.8 | 5.2 | 13.4 | 21.1 | 4.6 7 | 77.3 | 20.4 | 71.6 20.6 | 15.7 | 33.2 | 9.8 | 13.2 | 33.0 | 45.0 | 23.4 | 32.0 | 1.6 | 3./ | 63.0 | 66.0 | 69.0 69.0 | 105.0 | 50.0 | 31.0 | 29.0 | 13.0 | 20.5 | 9.5 | 6.7 | 0.001 | 19.0 | 63.0 | 14.8 | 52.0 | 41.0 | 7.6 |
| Мігех | | | | | | | | • | | | | . 4 | | 2 | Q | Ð | 2 | | 2 Q | Q ! | | 29 | QN | 2 | | | Q | 9 | 22 | | | 2 9 | QN | 9 | | ₽₽ |
| Methylchlorpyrifos | | | Q | 2 | 22 | <u>}</u> . | 2 | ₽⊂ | 9 9 | Q | ø | N | | | | | | | | | | | | | | | | | | | | | | | | |
| Hexachlorobenzene | 34.8 14.6 | ø | 1.0 | 9 | αĘ | 24.6 | 14.0 | 48.8 11.5 | 15.3 | 21.8 | 15.1 | 9.77 | 0.0 0.0 | 7.4 | 6.5 | 8.8 | 5.2 | 58.8 8.8 | 33.3 | 28.4 | 20.4 20.5 | 44.8 | 26.0 | 42.0 | | 11.0 | 2.1 | 8.9 | 7.0 | 4 C | 9.9 13 0 | 5.5 | 3.1 | 15.8 | 11.0 | 12.5 |
| Heptachlor Epoxide | αĘ | ð | Q | 2 | 22 | 14.6 | a | σc | øø | σ | 14.7 | 14.9 | 148.0 | 38.0 | 12.0 | 9.3 | 2.9 | 20.6 | 33.0 | 42.8 | 41.4 | 42.0 | 31.2 | 32.0 | 14.0 26.3 | 19.5 | 5.2 | Q | 18.0 | 0. | 0.11 | 13.0 | 1.1 | 14.0 | 19.0 | 24.0 29.0 |
| Heptachlor | | | | | | | | | | | | | - C | 2 | 4.1 | 9 | 2 | UN 14 0 | 2.1 | Q. | 1.2 8 | 3.5 0.5 | 1.3 | g ; | 10.5 | 5.3 | 7.8 | 19.0 | 3.6 • | ں۔ ح | 17.0 | 7.6 | 5.0 | 13.1 | 5.8 | 1.0 |
| HOH-smmsÐ | 6600.7 1666 7 | 810.3 | 727.0 | 703.4 | 113.0 | 602.3 | 791.3 | 476.4 | 477.5 | 154.8 | 939.6 | 154.0 | 1230.0 | 455.7 | 151.0 | 396.0 | 211.2 | 4.6 252 7 | 402.0 | 204.7 | 544.9 577 0 | 668.0 | 290.0 | 331.0 | 892.U 621 0 | 664.0 | 441.2 | 203.6 | 210.0 | 101.0 | 475.8 | 318.0 | 85.9 | 429.1 | 922.0 | 617.1 |
| Date | 2/1/94 1/31/94 | 2/2/94 | 2/3/94 | 2/3/94 | 2/3/94 | 2/7/94 | 2/7/94 | 2/7/94 2/8/94 | 2/8/94 | 2/8/94 | 2/9/94 | 2/9/94 | 4/10/94 | 4/18/94 | 4/20/94 | 4/20/94 | 4/21/94 | 4/21/94 | 4/26/94 | 4/26/94 | 4/26/94 | 4/27/94 | 4/28/94 | 4/28/94 | 8/16/94 8/15/04 | 8/16/94 | 8/17/94 | 8/17/94 | 8/17/94 | 0/10/94 0/22/04 | 8/22/94 | 8/22/94 | 8/22/94 | 8/23/94 | 8/23/94 | 0/23/94 8/23/94 |
| noitst2 | Coyote Creek Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Island | Golden Gate | Petaluma River | San Pablo Bay | Pinole Point Davis Point | Napa River | Grizzly Bay | Sacramento River | San Joaquin Kiver | Coyote Creek Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Island | Golden Gate | Red Kock Petaluma River | San Pablo Bay | Pinole Point | Davis Point Nana River | Grizzly Bay | Sacramento River | San Joaquin River | Coyote Creek | Redwood Creek | Alameda | Yerba Buena Island | Golden Gate | Red Rock | San Pahlo Rav | Pinole Point | Davis Point | Napa River | Grizzly Bay | sacramento River San Joaquin River |
| Station Code | BA10 BA30 | BA40 | BB70 | BC10 | BC20 | BD15 | BD20 | BD30 BD40 | BD50 | BF20 | BG20 | BG30 | BA30 BA30 | BA40 | BB70 | BC10 | BC20 | BC60 BD15 | BD20 | BD30 | BD40 | BF20 | BG20 | BG30 | BA10 BA30 | BA40 | BB70 | BC10 | BC20 | | | BD30 | BD40 | BD50 | BF20 | BG30 |

| | | | Mytil | us edulis | Mysic | lopsis bahia |
|-----------------|---------------------------------|--------------------|------------------------------|------------------------------|--------------------|--------------------|
| Otation | | | Mean % normal Development | Mean % normal Development | Mean % Survival | Mean % Survival |
| Code | Station Name | Date | Control | 100% Ambient Water | Control | 100% Ambient Water |
| C-3-0 | San Jose | 2/1/94 | 80 | 79 | 90 | 90 |
| C-1-3 | Sunnyvale | 2/1/94 | 84 | 82 | 90 | 87.5 |
| BA10 | Coyote Creek | 2/1/94 | 81 | 89 | 90 | 95 |
| BA40 | Redwood Creek | 2/2/94 | 95 | 96 | 90 | 82.5 |
| BB70 | Alameda | 2/3/94 | 97 | 97 | 90 | 100 |
| BC10 | Yerba Buena | 2/3/94 | 96 | 97 | 90 | 92.5 |
| BD30 | Pinole Point | 2/7/94 | 72 | 95 | 82.5 | 80 |
| BC60 | Red Rock | 2/7/94 | 89 | 86 | 95 | 72.5 |
| BD15 | Petaluma River | 2/7/94 | 64 | 92 | 82.5 | 87.5 |
| BF20 | Grizzly Bay | 2/8/94 | 67 | 73 | 90 | 90 |
| BD50 | Napa River | 2/8/94 | 71 | 77 | 87.5 | 62.5 |
| BG20 | Sacramento River | 2/9/94 | 69 | 71 | 87.5 | 95 |
| BG30 | San Joaquin River | 2/9/94 | 74 | 73 | 87.5 | 72.5 |
| | | | Crasso | strea ninas | Mysi | lonsis hahia |
| | | | 0/4350 | Strea gigas | iny sic | |
| | | | Mean % normal Development | Mean % normal Development | Mean % Survival | Mean % Survival |
| Station Code | Station Name | Date | Control | 100% Ambient Water | Control | 100% Ambient Water |
| C-3-0 | San Jose | 8/16/94 | 67 | 72 | 97.5 | 100 |
| C-1-3 | Sunnyvale | 8/16/94 | 70 | 73 | 97.5 | 100 |
| BA10 | Coyote Creek | 8/16/94 | 73 | 74 | 88 | 85 |
| BA40 | Redwood Creek | 8/16/94 | 68 | 70 | 95 | 93 |
| BB70 | Alameda | 8/17/94 | 70 | 84 | 95 | 93 |
| BC10 | Red Rock | 8/17/94 | 70 | 73 | 95 | 100 |
| BD30 | Yerba Buena | 8/17/94 | 70 | 78 | 95 | 95 |
| BC60 | Petaluma | 8/22/94 | 81 | 88 | 100 | 95 |
| BD15 | Pinole Point | 8/22/94 | 84 | 88 | 100 | 100 |
| BF20 | Grizzly Bay | 8/22/94 | 81 | 85 | 100 | 90 |
| | | | | | | |
| BD50 | Napa River | 8/23/94 | 84 | 81 | 100 | 93 |
| BD50 BG20 | Napa River San Joaquin River | 8/23/94 8/24/94 | 84 85 | 81 82 | 100 98 | 93 93 |

Table 3.10. Water Toxicity Data for 1994 RMP Cruises.

Table 3.11. Conventional water quality parameters for river station samples, 1994. For conversion of μ M to μ g/L, use the following atomic weight multipliers: P = 31; C = 12; N = 14; Si = 28.

| River | Station | Date | Ammonia | Chlorophyll-a | Conductivity | OQ | DOC | Nitrate | Nitrite | Hd | Phaeophytin | Phosphate | Salinity | | | |
|-------------|-----------|---------|---------|-------------------|--------------|------|-----|---------|---------|-----|-------------------|-----------|------------------------------|-------|------|------|
| | | | μM | mg/m ³ | mho | mg/L | μM | μM | μМ | pН | mg/m ³ | μМ | ⁰ / ₀₀ | | | |
| San Joaquin | Manteca | 4/7/94 | ND | 31.1 | 600 | 10.6 | 266 | 117.17 | 1.4 | 8.2 | 3.1 | 4.1 | 0 | 218.2 | 19.0 | 77.4 |
| San Joaquin | Manteca | 4/13/94 | ND | 12.6 | 700 | 8.6 | 281 | 104.86 | 1.4 | 8.0 | 3.9 | 4.4 | 0 | 218.5 | 22.0 | 74.7 |
| San Joaquin | Manteca | 5/6/94 | 3.0 | 9.0 | 650 | 7.9 | 210 | 89.08 | 1.5 | 7.8 | 3.3 | 4.0 | 0 | 244.6 | 18.8 | 67.1 |
| San Joaquin | Manteca | 5/11/94 | 1.0 | 4.8 | 360 | 8.0 | 220 | 80.56 | 1.2 | 7.9 | 2.3 | 3.3 | 0.5 | 160.7 | 20.9 | 66.9 |
| San Joaquin | Manteca | 5/18/94 | 13.4 | 5.2 | 600 | 8.0 | 224 | 116.43 | 2.7 | 7.8 | 2.9 | 3.6 | 0.5 | 235.3 | 18.7 | 55.2 |
| San Joaquin | Manteca | 5/25/94 | ND | 9.2 | 550 | 8.4 | 208 | 83.84 | 1.9 | 8.1 | 3.4 | 2.9 | 0 | 232.6 | 21.4 | 58.3 |
| Sacramento | Rio Vista | 4/7/94 | 20.3 | 1.2 | 160 | 8.6 | 144 | 20.45 | 1.2 | 7.9 | 0.8 | 2.5 | 0 | 182.2 | 16.0 | 11.2 |
| Sacramento | Rio Vista | 4/13/94 | 21.1 | 1.7 | 170 | 8.2 | 156 | 23.94 | 1.5 | 8.6 | 1.2 | 2.7 | 0 | 169.9 | 18.0 | 14.8 |
| Sacramento | Rio Vista | 5/6/94 | 19.4 | 2.2 | 145 | 7.9 | 157 | 21.64 | 1.5 | 8.4 | 0.6 | 2.6 | 0 | 173.3 | 17.7 | 12.1 |
| Sacramento | Rio Vista | 5/11/94 | 21.3 | 1.1 | 140 | 7.5 | 153 | 27.86 | 1.6 | 7.6 | 0.8 | 2.8 | 0 | 200.6 | 19.0 | 14.8 |
| Sacramento | Rio Vista | 5/18/94 | 19.7 | 2.6 | 170 | 7.2 | 144 | 27.06 | 1.6 | 7.7 | 1.0 | 2.8 | 0 | 189.5 | 19.1 | 14.0 |
| Sacramento | Rio Vista | 5/25/94 | 12.0 | 6.6 | 160 | 7.7 | 134 | 21.03 | 1.8 | 8.1 | 1.2 | 2.5 | 0 | 119.0 | 19.5 | 29.0 |

| 1994. |
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| samples, |
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| Table 3.12. | Dissolve | d concen | trations (| of trace | elemei | nts for | river s | tation sa | mples | , 1994. | | |
|-------------|-----------|----------|------------|----------|--------|---------|---------|-----------|-------|---------|------|------|
| River | Station | Date | Ag | As | Cd | ර් | Cu | Hg | ïZ | Pb | Se | Zn |
| | | | μg/L | µg/L | μg/L | hg/L | μg/L | hg/L | µg/L | μg/L | µg/L | µg/L |
| San Joaquin | Manteca | 4/7/94 | 0.0032 | 1.53 | 0.0306 | 0.26 | 1.10 | 0.0130 | 1.09 | 0.2191 | 2.51 | 0.26 |
| San Joaquin | Manteca | 4/13/94 | 0.0063 | 1.72 | 0.0388 | 0.21 | 1.20 | 0.0110 | 1.17 | 0.4010 | 2.25 | 0.36 |
| San Joaquin | Manteca | 5/6/94 | 0.0036 | 1.35 | 0.0375 | 0.27 | 0.90 | 0.0120 | 1.06 | 0.1708 | 0.71 | 0.25 |
| San Joaquin | Manteca | 5/11/94 | 0.0092 | 1.31 | 0.0278 | 0.21 | 0.90 | 0.0120 | 0.78 | 0.3761 | 0.68 | 0.29 |
| San Joaquin | Manteca | 5/18/94 | 0.0029 | 1.64 | 0.0439 | 0.27 | 0.90 | 0.0075 | 1.10 | 0.1690 | 1.92 | 0.29 |
| San Joaquin | Manteca | 5/25/94 | 0.0023 | 1.52 | 0.0353 | 0.25 | 0.90 | 0.0086 | 06.0 | 0.1534 | 1.08 | 0.22 |
| Sacramento | Rio Vista | 4/7/94 | 0.0078 | 1.76 | 0.1576 | 0.25 | 1.50 | 0.0100 | 0.85 | 0.3573 | 0.16 | 0.74 |
| Sacramento | Rio Vista | 4/13/94 | 0.0059 | 2.05 | 0.1910 | 0.28 | 1.70 | 0.0055 | 1.01 | 0.4917 | 0.19 | 1.06 |
| Sacramento | Rio Vista | 5/6/94 | 0.0156 | 1.82 | 0.1668 | 0.34 | 1.60 | 0.0120 | 0.96 | 0.5047 | 0.21 | 0.87 |
| Sacramento | Rio Vista | 5/11/94 | 0.0207 | 1.91 | 0.1874 | 0.31 | 1.70 | 0.0130 | 1.03 | 0.6050 | 0.24 | 1.22 |
| Sacramento | Rio Vista | 5/18/94 | 0.0143 | 1.97 | 0.1757 | 0.31 | 1.60 | 0.0140 | 0.96 | 0.4597 | 0.15 | 0.83 |
| Sacramento | Rio Vista | 5/25/94 | 0.0062 | 1.97 | 0.1855 | 0.33 | 1.70 | 0.0086 | 1.04 | 0.5589 | 0.12 | 0.96 |
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| 1994. |
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| - µg/L | 4 8.62 9 7.35 | 0 7.34 3 7.84 | 3 6.69 | 2 6.09 | 6 3.57 | 3 4.16 | 9 4.03 | 5 5.05 | 2 4.27 | 5 6.00 |
|-------------|----------------------------|----------------------------|-------------|-------------|------------|------------|------------|------------|------------|------------|
| Se µg/l | 2.5, 1.89 | 0.7(0.8) | 1.5 | 1.3 | 0.16 | 0.2 | 0.29 | 1.2 | 0.2 | 0.1 |
| Pb* µg/L | 1.12 1.00 | 1.01 1.03 | 0.86 | 0.78 | 0.21 | 0.29 | 0.32 | 0.37 | 0.34 | 0.49 |
| Ni* µg/L | 5.98 5.49 | 5.45 5.28 | 4.95 | 4.48 | 2.27 | 2.65 | 2.76 | 3.15 | 2.90 | 3.99 |
| Hg µg/L | 0.1100 0.0719 | 0.0745 0.0990 | 0.0606 | 0.0690 | 0.0256 | 0.0229 | 0.0350 | 0.0414 | 0.0277 | 0.0533 |
| Cu* μg/L | 4.00 3.80 | 3.50 3.50 | 3.30 | 3.00 | 2.50 | 2.80 | 2.80 | 3.10 | 3.10 | 3.60 |
| Cr µg/L | 5.84 5.09 | 7.21 5.71 | 5.38 | 5.31 | 1.80 | 2.16 | 2.37 | 2.79 | 2.57 | 3.74 |
| Cd* µg/L | 0.1168 0.0916 | 0.0998 0.1003 | 0.0980 | 0.0658 | 0.2191 | 0.2731 | 0.2369 | 0.2753 | 0.2747 | 0.3187 |
| As µg/L | 2.06 2.06 | 2.09 1.73 | 2.03 | 1.80 | 1.85 | 1.98 | 2.11 | 1.57 | 2.09 | 2.32 |
| Ag* μg/L | 0.0847 0.0739 | 0.0718 0.1117 | 0.0489 | 0.0259 | 0.0228 | 0.0240 | 0.0232 | 0.0703 | 0.0305 | 0.0385 |
| Date | 4/7/94 4/13/94 | 5/6/94 5/11/94 | 5/18/94 | 5/25/94 | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 |
| Station | Manteca Manteca | Manteca Manteca | Manteca | Manteca | Rio Vista |
| River | San Joaquin San Joaquin | San Joaquin San Joaquin | San Joaquin | San Joaquin | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento |

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|---|------------------------|-------------------------|----------------|--|
| Joaquin Joaqui | River | = not a | le 3.15. | River Joaquin Joaquin Joaquin Joaquin ra mento ra mento ra mento |
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| 1799808 1419576 1058504 612354 1556729 1055083 252980 283264 274246 506885 307840 356593 | Total Alkanes | int PAH: | ite plus | 266 2121852 21852 21852 212179 212179 212179 255583 37038 37038 26828 37038 26828 37038 26828 37038 |
| 7776 6251 7508 10268 6152 5298 13880 7383 8583 9464 10214 | Total PAHs | not qui s, HPA | diss | 17 Total PAHs 21946 1640 21948 21948 21948 21949 |
| 1269 1035 1081 1338 1002 1243 2102 25783 22102 2548 22445 2536 | Total LPAHs | antiria vHs = I | olved) | 1923 1891 1891 1891 1891 1891 1891 1891 |
| 6375 5215 6427 5150 4055 8097 5282 6483 6916 6483 8307 | Total HPAHs | bie, ivi High n | total , | 3 103 10 10 10 10 10 10 10 10 10 10 10 10 10 |
| 106 Q 151 146 56 259 184 223 | 1-Methylphenanthrene | = Iviat nolecu | Alkan | 1. 1. 1. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. 2. |
| 262 142 201 237 159 195 195 195 76 359 340 335 335 | 2-Methylnaphthalene | ilar we | es and | 208 209 209 209 209 209 209 209 209 209 209 |
| 103 88 86 123 144 166 224 221 131 131 264 222 222 | Anthracene | errerer sight P | d PAH | 2240 2240 2240 2240 2240 2240 2240 2240 |
| 286 284 267 172 188 422 233 227 301 309 | Benz(a)anthracene | AHs | conc | 7 5 6 6 9 3 5 5 6 2 3 8 8 8 8 8 7 7 8 8 6 9 3 5 4 0 1 5 6 8 8 8 7 7 4 0 1 5 6 9 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 8 |
| 364 125 234 200 152 72 72 72 345 88 318 318 301 44 | Benzo(a)pyrene | Units | entrat | 194 44 44 44 44 44 44 44 44 44 44 44 44 4 |
| 1125 1027 959 1393 851 703 539 479 708 708 704 821 812 | Benzo(b)fluoranthene | n pg/L | tions i | $ \begin{array}{c} & 2 \\ & 2 \\ & 2 \\ & 4 \\ & 2 \\ & 0 \end{array} \begin{array}{c} & 3 \\ & 2 \\ & 3 \\ & 2 \\ & 5 \end{array} \begin{array}{c} & 0 \\ & 9 \\ & 9 \\ & 9 \end{array} \begin{array}{c} & 3 \\ & 6 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \end{array} \begin{array}{c} & 3 \\ & 6 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \end{array} \begin{array}{c} & 3 \\ & 6 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \end{array} \begin{array}{c} & 3 \\ & 6 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \end{array} \begin{array}{c} & 3 \\ & 6 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \end{array} \begin{array}{c} & 3 \\ & 6 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \end{array} \begin{array}{c} & 3 \\ & 6 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \\ & 5 \end{array} \begin{array}{c} & 3 \\ & 6 \\ & 5 \\ & $ |
| 594 692 487 425 428 229 186 333 409 333 516 | Benzo(e)pyrene | - (ppq | in rive | $ \overset{4}{{}_{\omega}} \overset{\omega}{{}_{0}} $ |
| 52 10 75 75 286 286 2164 286 2165 276 ND 204 | Benzo(ghi)perylene | | er stat | $\Omega \stackrel{1}{\underline{5}} \leq \stackrel{1}{\underline{7}} \stackrel{0}{\underline{6}} \stackrel{0}{\underline{6}} \stackrel{2}{\underline{6}} \stackrel{2}{\underline{6}} \stackrel{2}{\underline{6}} \stackrel{2}{\underline{6}} \stackrel{2}{\underline{6}} \stackrel{2}{\underline{6}} \stackrel{2}{\underline{5}} \Omega \stackrel{1}{\underline{6}} \stackrel{2}{\underline{5}} \stackrel{2}{\underline{6}} 2$ |
| 551 398 495 649 486 345 373 373 172 282 282 282 351 | Benzo(k)fluoranthene | | ion sa | 50 $\begin{array}{c} 162\\ 67\\ 67\\ \end{array}$ $\begin{array}{c} 142\\ 67\\ 85\\ 67\\ \end{array}$ $\begin{array}{c} 142\\ 67\\ 85\\ 67\\ \end{array}$ $\begin{array}{c} 142\\ 67\\ 85\\ 67\\ 85\\ 67\\ 85\\ 85\\ 85\\ 85\\ 85\\ 85\\ 85\\ 85\\ 85\\ 85$ |
| 972 999 853 1149 662 599 440 434 701 678 678 930 | Chrysene | | ample | 122 12 12 12 12 12 12 12 12 12 12 12 12 |
| 301 18 219 2 2 0 2 0 236 57 67 236 30 186 186 | Dibenz(a,h)anthracene | | s, 199 | $ \bigcup_{D} \bigcup_{i=1}^{2} \bigcup_{i=1}^{$ |
| 307 401 1711 2352 1160 417 2780 2038 1709 2682 2502 2853 | Fluoranthene | | <u>4</u> | 307 307 307 307 401 307 307 401 1897 1897 1399 900 900 917 46 |
| 568 Q 341 592 335 294 76 59 357 25 25 112 273 | Indeno(1,2,3-cd)pyrene | | | $ \begin{array}{c} \underset{N}{\overset{1}{}} \underset{N}{\overset{1}{}} \underset{m}{\overset{1}{}} \underset{m}{}} \underset{m}{\overset{m}} \underset{m}{\overset{1}{}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}}{}} \underset{m}{\overset{m}} \underset{m}{\overset{m}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}} \underset{m}{\overset{m}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}} \underset{m}{\overset{m}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}} \underset{m}}{\overset{m}} \underset{m}{\overset{m}} \underset{m}{\overset{m}}} \underset{m}{\overset{m}} \underset{m}}{\overset{m}} \underset{m}}{\overset{m}} \underset{m}}{\overset{m}} \underset{m}{\overset{m}} \underset{m}}{\overset{m}} \underset{m}}{\overset{m}}} \underset{m}}{\overset{m}} \underset{m}}{\underset{m}} \underset{m}}$ |
| | Methylanthracene | | | 중중중중중중중중중중중중 Methylanthracene |
| 798 806 725 827 554 732 3798 1748 1748 1748 1756 | Phenanthrene | | | 42 Phenanthrene 370 370 32463 3463 3463 3463 3463 3463 3463 346 |
| 1256 1262 786 1325 548 1008 2571 1493 1194 1802 2131 | Pyrene | | | 241 296 297 297 297 297 297 276 276 277 276 277 276 276 276 276 27 |

Table 3.14. Dissolved total Alkanes and PAH concentrations in river station samples, 1994

LPAHs = Low molecular weight PAHs, HPAHs = High molecular weight PAHs

ND = not detected, Q = Present but not quantifiable, M = Matrix interference, Units in pg/L (ppq)

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| 4. | Units in pg/L (ppq). |
|--|---|
| Table 3.16. Dissolved PCB concentrations in river station samples, 199 | ND = not detected, Q = Present but not quantifiable, M = Matrix interference, |

| PCB 129/178 | 99 | ₽ | ₽ | ø | 1.4 | ø | 3.6 | 1.1 | 4.1 | 4.1 | 1.2 | 0.0 |
|-----------------|-------------|-------------|-------------|-------------|-------------|--------------|------------|------------|------------|------------|--------------|------------|
| PCB 128 | - 2 | 4 | <u>е</u> | a | Ņ | 2 | 9 | N | Ņ | ۰ ۲. | . | <u>م</u> |
| | 4.0 | | 5 | е. | 5 | ر | 4 | 9. | - | 7 | 5 | 5 |
| PCB 118 | 32 | 42 | 73 | 19 | 107 | 57 | N N | 14 | ÷ | Ö | 4. | <u>о</u> |
| PCB 114/131/122 | a | 3 | ø | Ø | Ø | Ø | R R | ğ | о | ø | é a | Ø |
| PCB 110/77 | 10.0 | 9.7 | 4.6 | 5.6 | 5.1 | 5.0 | 49. | 16. | 11. | 7.8 | 10. | 7.3 |
| PCB 105/132 | 10.5 | 15./ | 12.2 | 10 | 9.1 | 7.9 | 29.1 | 19.4 | 18.3 | 8.2 | 48.7 | 17.1 |
| PCB 105 | 29 | Z | 2 | Ð | Ð | ₽ | ₽ | ₽ | ₽ | Ð | ₽ | g |
| PCB 101/90 | 7.7 | 6.4 | 8.9 | 9 | 11.9 | 11.5 | 79.4 | 23.4 | 9.4 | 11.3 | 13.5 | 6 |
| PCB 099 | 18.9 2.1 | 24 | 36.9 | 12.9 | 18 | 16.2 | 16.2 | 7.1 | 4.5 | 4.5 | 8.2 | 5.3 |
| PCB 097 | 5.2 | ç | 5.3 | 2.1 | 6.8 | 3.9 | 13.9 | 3.1 | 2.6 | 2.4 | 1.6 | ø |
| PCB 087/115 | g | Z | 9 | g | ø | g | 50.3 | Q | Q | Q | 4.8 | g |
| PCB 074 | 1.5 | Э | ø | ø | ø | 2.8 | 13.3 | 7.2 | 3.2 | 2.4 | 2.6 | 1.7 |
| PCB 070 | 12.2 | 13.2 | 26.2 | ø | 22.5 | 20.2 | 30 | 19.1 | 8.7 | 7 | 7.7 | 5.6 |
| PCB 066/95 | 13.3 | 11.5 | 20.5 | 9.7 | 16.2 | 13.3 | 49.4 | 29.4 | 15.2 | 13 | 12.9 | 8.6 |
| PCB 060/56 | 20.7 | 28.8 | 49.2 | 16.3 | 33.9 | 27.3 | Q | œ | e | 2.3 | 3.4 | 7 |
| PCB 052 | Σ | R | g | Σ | Σ | Σ | 73.2 | Σ | 64.4 | Σ | Σ | Σ |
| PCB 049 | σ. | 4.8 | ø | g | ø | Σ | 24.8 | ø | ø | Q | Q | Q |
| PCB 044 | 8.8 9.8 | 8.4 | 5.2 | 4 | 9.3 | 5.9 | 26.3 | 10.4 | 4.6 | ø | 9 | 5.3 |
| PCB 040 | 6.1 0 | 2.2 | 9.8 | 7 | 7.1 | 8.3 | <u>-</u> | 6.3 | 2.7 | 9 | 4.4 | ი |
| PCB 031 | σ | R | 48.6 | Q | Q | ø | 42.8 | ø | Ø | Q | ø | Q |
| PCB 029 | Ð | Э | 2.7 | g | Ø | g | Q | Q | Q | 2.2 | g | g |
| PCB 028/31 | 29 | Z | g | g | Q | Q | Q | Q | Q | Ð | Q | Q |
| PCB 028 | 4.9 | с., | g | 3.6 | Ø | 2.1 | 35.8 | 4.5 | 2 | 4.4 | 8.5 | 2.4 |
| PCB 027/24 | 9.6 | | 19.9 | 12 | 15.2 | 16 | 6.4 | 7.9 | 24.1 | 14.1 | 22 | 11.5 |
| PCB 018 | a | Э | 4.8 | ø | ø | ø | 12.9 | œ | 8.9 | 6.9 | 6.6 | 3.8 |
| PCB 015 | 27.6 | Э | ø | ø | 87.8 | 42.4 | 38.3 | 17.7 | 47.2 | 18.4 | Q | Ø |
| PCB 005/8 | 6.4 | Э | 12.4 | 23.6 | 14.1 | 10.6 | 13.8 | 9.9 | ø | 25.8 | 15.7 | 6 |
| Date | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 |
| noitst8 | Manteca | Manteca | Manteca | Manteca | Manteca | Manteca | Rio Vista | Rio Vista |
| River | San Joaquin | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento |

Table 3.17. Total (particulate plus dissolved) PCB concentrations in river station samples, 1994.

ND = not detected, Q = Present but not quantifiable, M = Matrix interference, Units in pg/L (ppq).

| - | | | | | | | | | | | | | |
|----------------|--------|-------------|-------------|-------------|-------------|-------------|-------------|------------|------------|------------|------------|------------|------------|
| 871/621 | ьсв | 15 | 13.9 | 12.6 | 8.2 | 13.8 | 7 | 5.4 | 2.2 | 1.4 | 1.4 | 2.2 | 2.3 |
| 128 | ьсв | 15.3 | 19.9 | 25.4 | 11.6 | 15.4 | 14.7 | 7.4 | 3.7 | 2.8 | 2.1 | 2.1 | 2.7 |
| 811 | ьсв | 52.7 | 68.5 | 105.5 | 35.9 | 116.3 | 65.8 | 6.7 | 18.6 | 15.5 | 7.9 | 7 | 12.3 |
| 114/131/122 | ьсв | ø | ø | ø | ø | ø | ø | ø | ø | ø | ø | ø | ø |
| 22/011 | ьсв | 22.2 | 22.9 | 29.4 | 18.7 | 13.4 | 14.3 | 60.1 | 23.1 | 15.7 | 10.7 | 13.1 | 12.6 |
| 102/135 | ьсв | 60 | 31 | 32.3 | 18.8 | 19.9 | 22.8 | 43.5 | 28 | 29.5 | 15.7 | 56 | 24.1 |
| 901 201 | ьсв | Ð | 9 | ₽ | Ð | Ð | Ð | Ð | Ð | Ð | 9 | ₽ | ₽ |
| 06/101 | ьсв | 19.6 | 18.5 | 26.9 | 17.7 | 25.6 | 21.7 | 93.7 | 27.9 | 14.3 | 13.5 | 18.3 | 14.9 |
| 660 | ьсв | 30.4 | 40.9 | 52.9 | 23.2 | 32 | 29.3 | 19.6 | 7.1 | 7.6 | 4.5 | 9.8 | 7.7 |
| 260 | ьсв | 15 | 8.5 | 31.6 | 12.9 | 25.6 | 18.2 | 17.1 | 3.1 | 2.6 | 2.4 | 1.6 | ø |
| 911/280 | ьсв | g | Q | Q | Q | Ø | Q | 50.3 | g | g | Q | 4.8 | ₽ |
| † 20 | ьсв | 4.4 | 2.5 | 4.3 | 1.7 | 2.3 | 7.6 | 15.1 | 8.1 | 4.9 | 2.4 | 2.6 | 1.7 |
| 020 | ьсв | 33 | 32.5 | 57.6 | 22.5 | 33.2 | 39.4 | 33.1 | 20.9 | 10.2 | 7 | 7.7 | 7.1 |
| <u>9</u> 6/990 | ьсв | 23.6 | 21.6 | 32.9 | 16.3 | 25.5 | 23.1 | 56.8 | 33.6 | 18.3 | 16.8 | 16.7 | 12 |
| 99/090 | ьсв | 85.3 | 28.8 | 152.1 | 71 | 33.9 | 101.1 | 14.3 | 18.3 | 16.5 | 7.3 | 13.8 | 17.1 |
| 062 | ьсв | 25.5 | ø | 19.5 | Σ | ø | Σ | 90.6 | Σ | 64.4 | Σ | Σ | ≥ |
| 670 | ьсв | 8.2 | 4.8 | 11.5 | 2.9 | ø | Σ | 33.7 | ø | ø | Q | Q | g |
| 440 | ьсв | 13.7 | 8.4 | 11 | 6.5 | 9.3 | 5.9 | 29.1 | 14.5 | 4.6 | ø | 9 | 5.3 |
| 040 | ьсв | 16.6 | 17 | 21.2 | 19.5 | 21.6 | 26.1 | 6 | 16.6 | 9.2 | 9 | 13.3 | 13.1 |
| 150 | ьсв | σ | ø | 48.6 | Q | Ð | Ø | 42.8 | ø | Ø | Q | ø | ₽ |
| 029 | ьсв | ø | ø | 2.7 | Ð | ø | Ð | ø | ø | ø | 2.2 | ø | ø |
| 15/820 | ьсв | Ð | Q | Q | 9 | Q | 9 | Q | Q | Q | Q | Q | g |
| 028 | ьсв | 7.9 | 3.1 | ø | 3.6 | ø | 2.1 | 35.8 | 4.5 | 5 | 4.4 | 8.5 | 2.4 |
| 057/24 | ьсв | 9.6 | 11 | 19.9 | 12 | 15.2 | 16 | 6.4 | 7.9 | 24.1 | 14.1 | 22 | 11.5 |
| 810 | ьсв | ø | ø | 4.8 | Ø | ø | Ø | 12.9 | 8 | 8.9 | 6.9 | 9.9 | 3.8 |
| 910 | ьсв | 27.6 | Ø | Ø | Ø | 87.8 | 42.4 | 38.3 | 17.7 | 47.2 | 18.4 | Q | ø |
| 8/900 | ьсв | 22.4 | 16.5 | 26.7 | 35 | 34.1 | 30.5 | 22.9 | 21.9 | 11.9 | 25.8 | 33.1 | 24.3 |
| | ətsD | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 |
| uc | Statio | Manteca | Manteca | Manteca | Manteca | Manteca | Manteca | Rio Vista |
| | River | San Joaquin | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento |
| San Joaq | River | ND = r |
|------------|------------|------------|------------|------------|-----------------|-----------|
| quin Mante | quin Mante | tuin Mante | quin Mante | luin Mante | Station | not detec |
| ca 5/18/9 | ca 5/11/9 | ca 5/6/9 | ca 4/13/9 | ca 4/7/9 | Date | ted, Q = |
| 94 N | 94 N | 4 Z | 94 N | 4 N | PCB 132 | : Pre |
| | Z | | S | M | PCB 137/176 | sen. |
| ø | 5.1 | Q | 5.5 | 5.8 | PCB 138 | t but i |
| 30.4 | 9.6 | 33.8 | 14.4 | 12.8 | PCB 141/179 | not qu |
| 12.6 | 1.4 | ° 7.1 | + 4.1 | 3.2 | PCB 146 | uantif |
| 96.8 | 38.3 | 160.9 | 79.6 | 56.9 | PCB 149 | iable, |
| 18.2 | 8.3 | 9 11.8 | 6.7 | 7 | PCB 151/82 | ≤ = |
| 29.4 | 11.5 | 23.8 | 11.5 | 12.9 | PCB 153 | Matrix |
| 9.5 | 6.6 | 9.4 | 10.8 | 8.5 | PCB 156/171/202 | inter |
| Ŋ | 1.7 | 6.4 | Ŋ | 1.5 | PCB 157/173/201 | fere |
| Ø | Q | Q | Ø | Q | PCB 158 | nce, |
| 1.7 | 2.2 | Q | 5.9 | 3.9 | PCB 170/190 | Uni |
| Ŋ | ъ | Q | Q | Q | PCB 174 | ts in p |
| Q | Ø | Q | Q | 1 | PCB 177 |)g/L |
| B | Ø | B | Ø | Q | PCB 180 | (ppq) |
| 2.3 | 2.8 | Q | Q | 1.1 | PCB 183 | |
| Ζ | ≤ | Σ | Ξ | Μ | PCB 185 | |
| 16.7 | 5.7 | 12.9 | 4.4 | 7.5 | PCB 187 | |
| Ζ | 0.8 | B | 5.7 | 3.6 | PCB 189 | |
| 0.8 | з .5 | Ø | Q | Q | PCB 191 | |
| ≤ | Ζ | ≤ | Ζ | Μ | PCB 194 | |
| 1. 5 | 1.6 | 2.1 | 2.4 | 1.6 | PCB 195/208 | |
| Ø | Ø | B | 1.5 | 2.3 | PCB 196/203 | |
| Ø | Ø | Ø | 1.5 | 1.9 | PCB 199 | |
| B | Ŋ | B | Ŋ | ND | PCB 205 | |

Table 3.16. Dissolved PCB concentrations in river station samples, 1994. (Continued)

| Sacramento | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento | San Joaquin | River |
|------------|------------|------------|-------------|------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Rio Vista | Rio Vista | Rio Vista | Rio Vista | Rio Vista | Rio Vista | Manteca | Manteca | Manteca | Manteca | Manteca | Manteca | Station |
| 5/25/94 | 5/18/94 | 5/11/94 | 5/6/94 | 4/13/94 | 4/7/94 | 5/25/94 | 5/18/94 | 5/11/94 | 5/6/94 | 4/13/94 | 4/7/94 | Date |
| B | B | ß | ß | B | ß | B | B | ß | B | ß | B | PCB 132 |
| Σ | Σ | Σ | Σ | Σ | B | Σ | Σ | Σ | Σ | Σ | ≤ | PCB 137/176 |
| 5.8 | 7.4 | œ | 9.7 | 13.7 | 26 | 1.9 | Ø | 5.1 | Ø | ე ე | 5.8 | PCB 138 |
| 1.5 | 3.6 | ω | ω | 7 | з.1 | 20.5 | 30.4 | 9.6 | 33.8 | 14.4 | 12.8 | PCB 141/179 |
| ND | Ø | 1.4 | 1.2 | ND | Ŋ | 6.5 | 12.6 | 1.4 | 7.1 | 4.1 | 3.2 | PCB 146 |
| 11.3 | 11.9 | 6.9 | 13.8 | 22.7 | ß | 70.5 | 96.8 | 38.3 | 160.9 | 79.6 | 56.9 | PCB 149 |
| 7.7 | 11.9 | 8.4 | 8.9 | 14.3 | Ŋ | 5.7 | 18.2 | 8.3 | 11.8 | 6.7 | 7 | PCB 151/82 |
| 14.6 | 12.9 | 7.1 | 14.3 | 14.9 | 21.7 | 24.4 | 29.4 | 11.5 | 23.8 | 11.5 | 12.9 | PCB 153 |
| 6 | Σ | 12.5 | ≤ | Σ | 4 | 5.8 | 9.5 | 6.6 | 9.4 | 10.8 | 8.5 | PCB 156/171 |
| ß | 2.9 | ß | Q | ß | Σ | ß | ß | 1.7 | 6.4 | ß | 1.5 | PCB 157/173 |
| Ø | Ø | Ø | 0.3 | Ø | 0.8 | Ø | Ø | Ø | Ø | Ø | Q | PCB 158 |
| 1.2 | 2 | 1.2 | 1.9 | 2.1 | 1.4 | 2.3 | 1.7 | 2.2 | Ø | 5.9 | 3.9 | PCB 170/190 |
| Ŋ | ND | 0.9 | R | ND | Ŋ | ND | Ŋ | J | Q | Ø | Q | PCB 174 |
| Ø | Ø | 0.7 | 0.5 | - | Ŋ | Ø | Q | Ø | Q | Q | - | PCB 177 |
| Ν | 2.8 | 2.2 | 3.2 | 2.7 | Σ | B | B | Ø | B | Ø | Q | PCB 180 |
| 1.2 | 1.9 | 1.6 | 2.1 | 2.8 | 4.1 | 1.3 | 2.3 | 2.8 | Q | Q | 1.1 | PCB 183 |
| 0.8 | 1.5 | Ŋ | -1 - 1 | 1.2 | Ŋ | ß | Σ | ≤ | Ζ | Σ | Μ | PCB 185 |
| з. 1 | 3.6 | 2.5 | 2.3 | 7 | з. 8 | ≤ | 16.7 | 5.7 | 12.9 | 4.4 | 7.5 | PCB 187 |
| 4.2 | B | 1.9 | Σ | Σ | 3.2 | 6.8 | Σ | 0.8 | B | 5.7 | 3.6 | PCB 189 |
| 0.8 | Q | 3.7 | B | D | Σ | ω | 0.8 | з.5 | Q | Q | Q | PCB 191 |
| Ζ | ≤ | ≤ | Ζ | Ζ | Ζ | ≤ | Ζ | Ζ | Ζ | Ζ | Μ | PCB 194 |
| 1.4 | 2.4 | 4.2 | 4 | 0.9 | 0.5 | 2.5 | 1.5 | 1.6 | 2.1 | 2.4 | 1.6 | PCB 195/208 |
| 2.2 | Q | 1.6 | Q | Ŋ | | Ŋ | Ø | Ø | Ŋ | 1.5 | 2.3 | PCB 196/203 |
| Q | Q | Q | 0.8 | Q | 0.5 | Q | Q | Ø | Q | 1.5 | 1.9 | PCB 199 |
| R | B | B | B | B | Σ | B | B | B | B | B | ND | PCB 205 |
| Σ | Σ | Σ | Σ | Σ | Σ | 12 | Σ | Σ | Σ | Σ | Z | PCB 206 |
| ND | Ŋ | Q | <u>1</u> .5 | Ŋ | Σ | Q | ND | Ŋ | Ŋ | Ŋ | ND | PCB 207 |

Table 3.17. Total (particulate plus dissolved) PCB concentrations in river station samples, 1994. (Continued)

ND = not detected, Q = Present but not quantifiable, M = Matrix interference, Units in pg/L (ppq).

| Sacran | Sacran | Sacran | Sacran | San Jo | San Jo | San Jo | San Jo | San Jo | River | |
|------------------------|-----------------|------------------|-------------------|------------|---------|---------|---------|---------|-------|-------------|
| nento I | nento i | hento l | iento l | aquin | aquin I | aquin l | aquin I | aquin I | | |
| Rio Vista Rio Vista | Rio Vista | Rio Vista | Rio Vista | Manteca | Manteca | Manteca | Manteca | Manteca | Stati | on |
| 5/18/94 5/25/94 | 5/6/94 | 4/13/94 | 3/23/94 4/7/94 | 5/18/94 | 5/11/94 | 5/6/94 | 4/13/94 | 4/7/94 | Date | |
| 888 | ΒS | S | 53 | 58 | B | Ð | B | D | РСВ | 132 |
| 333 | Ξ | 3 | ≤≤ | ≤ ≤ | Ζ | Ζ | Ζ | Ν | РСВ | 137/176 |
| 13.9 13.9 | 17.3 | 24.6 | 9.2 40.3 | 25.2 | 20 | 29.1 | 20.7 | 48.4 | РСВ | 138 |
| 1.5 ° | ა ე. ე | 9.1 9.1 | 6.3 | 47.4 | 26.2 | 69.6 | 37 | 32.8 | РСВ | 141/179 |
| ם מ <u>-</u> | 4.3 | 1 : 4 | 1.7 | 12.6 | 1.4 | 7.1 | 17.9 | 12.5 | РСВ | 146 |
| 8.5 17 15.7 | 20 | 28.6 | 193.0 7 | 263.1 | 156.2 | 438.1 | 236.7 | 199.4 | РСВ | 149 |
| 11.9 12.4 | 11.7 | 16.9 | 6.4 | 33.1 | 16.7 | 23.2 | 18.1 | 16.4 | РСВ | 151/82 |
| 18.2 22 | 22.9 | 21.8 | 34.8 | 62.9 | 34.8 | 60.2 | 47.8 | 42.3 | РСВ | 153 |
| 4.9 10.5 | Δ Δ Δ | 3.8 3.8 | 12.9 | 18.7 | 13.2 | 19 | 19.2 | 14.9 | РСВ | 156/171/202 |
| ND 22 N | δ | Ø | 0 ° | မ ကိုပ် | 4.9 | 1 | 3.6 | 1.5 | РСВ | 157/173/201 |
| 000 | ο. ₃ | Q S Q | 0. | 2.1 | Ø | 2.1 | Ø | Q | РСВ | 158 |
| 3 4 3. 3.1 5 K | 4.9 | сл ; С | 4.6 | 1.7 | 51.6 | 101.8 | 96.1 | 70.2 | РСВ | 170/190 |
| 1.3 3.4 | 12.00 0 | - <u>1</u> .5 | 2 0 3 0 | 17.1 | 15.5 | 8.3 | 12.1 | 18.7 | РСВ | 174 |
| 2.5 | 2.6 | 2.8 | -1 G | 6.1 | з .3 | 3.7 | з.8 | 4.4 | РСВ | 177 |
| 7.5 7.5 | 9.7 | 6.6 | 22 | 22.9 | 17.2 | Σ | Q | Q | РСВ | 180 |
| 1.9 1.2 | 2.1 | 3.9 .9 | 5.0 | 10.3 | 6.8 | 4.5 | 6.2 | ъ | РСВ | 183 |
| 0.8 1.5 | ; <u>-</u> | 1.2 ¢ | ο.α | 12.5 | 14.9 | 31.7 | 15.5 | 25.2 | РСВ | 185 |
| 4.5 7.5 | 7.3 | 12.6 | 8 1 8 1 | 37.3 | 21.4 | 35.1 | 25.5 | 27.6 | РСВ | 187 |
| 4.2 Q .9 | à, | o : | 4 σ. 6 | ç o | 1.6 | 0.7 | 5.7 | 4.3 | РСВ | 189 |
| 5.8 5.8 | 1.7 | 0.9 | 0 v | 3.7 | ა ა | Q | 1.5 | 1.8 | РСВ | 191 |
| 333 | Ξ | Z | ≤ | 12.4 | Ζ | 27.5 | 12.5 | 23.4 | РСВ | 194 |
| 6.6 | 4.8 2.4 | 6.2 | 5.4 | 9.2 | 9.6 | 13.2 | 10.7 | 7.9 | РСВ | 195/208 |
| 5.8 7 | 2.4 2.4 | 2.4 | ა. ი ი | 11.5 | 10.4 | 10.3 | 13.3 | 11.9 | РСВ | 196/203 |
| 1.7 5.8 2.4 | 4 4 4 .4 | 1.9 | 2.9 | 10.8 | 9.5 | 14.2 | 13.6 | 11.1 | РСВ | 199 |
| ₽₽⊴ | S | Ø | ی ر ۲ د | 0.9 | 1.8 | 1.8 | 1.2 | Q | РСВ | 205 |
| <u> </u> | ≤ ≤ | 33 | ≤ 3.1 | 12.8 | Ζ | 23.8 | 17 | 14.8 | РСВ | 206 |
| Z Q Z | 1.01 7.7 | 1.4 | | Q | Ø | 4.3 | Q | Ø | РСВ | 207 |
| | | | | | | | | | | |

| 1994. |
|--------------|
| samples, |
| · station |
| river |
| ntrations ir |
| e concer |
| Pesticid |
| Dissolved |
| Table 3.18. |

ND = not detected, Q = Present but not quantifiable, M = Matrix interference, Units in pg/L (ppq).

| Trifluralin | 4486 | 8286 | 6519 | 5440 | 3939 | 3775 | Ð | 327 | 151 | 337 | 403 | 144 |
|--------------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|------------|------------|------------|------------|------------|
| trans-Nonachlor | 178 | 223 | 282 | 201 | 283 | 240 | 28 | 17 | 16 | 28 | 40 | 16 |
| ənənqasvoT | σ | ø | ø | ø | ø | ø | Ð | Ð | Ð | Ð | Ð | Q |
| TOO-'q,q | 183 | Σ | ø | Σ | Σ | Σ | Q | 4 | ø | 10 | 10 | 5 |
| UMQQ-'q,q | g | Q | Q | 4 | Q | Q | 39 | 15 | 13 | 10 | 15 | 8 |
| P,p,-DDE | 1239 | 1559 | 2070 | 1072 | 1193 | 1398 | 57 | 129 | 112 | 147 | 149 | 104 |
| DDD-'q,q | 290 | 423 | ø | Σ | 371 | Σ | 38 | 61 | 70 | 91 | 114 | 86 |
| Oxychlordane | ₽ | Ð | Ð | ₽ | ø | ₽ | ₽ | ₽ | ₽ | ₽ | ₽ | Ð |
| nozsibexO | 336 | 1054 | 285 | 681 | 986 | 384 | 1321 | 960 | 539 | 3498 | 1627 | 890 |
| TDD-'q,o | ø | Σ | ø | ø | ø | ø | ₽ | ø | ø | ø | ø | ø |
| Ap-'q,o | 35 | 49 | 71 | 32 | 75 | 54 | Ð | 5 | ო | 4 | 7 | 4 |
| DDD-'q,o | 154 | 211 | 171 | 170 | 151 | 140 | 32 | 22 | 30 | 48 | 34 | 31 |
| Methylchlorpyrifos | Q | Q | g | Ð | Ð | Ð | Ð | Ð | Ð | Ð | Ð | Ð |
| Heptachlor Epoxide | Q | Q | g | Ø | Ð | Ø | Ð | Ð | Ø | Ð | Ø | ø |
| HOH-smmsÐ | 228 | ø | 14 | 743 | 144 | 137 | Ø | Ø | Ð | Ø | Ø | ø |
| Gamma-Chlordane | 50 | 84 | 72 | 71 | 56 | 57 | 19 | 59 | 61 | 31 | 58 | 28 |
| II nsîlusobn∃ | Q | Q | Q | Ð | ~ | Ð | Ð | Ð | Ð | Ð | Ð | Ð |
| l nsîlusobn∃ | Q | Q | Q | Ð | Ð | Ð | Ð | Ð | Ð | Ð | Ð | Ð |
| Dieldrin | 443 | 493 | 513 | 318 | 426 | 388 | 83 | 134 | 146 | 208 | 263 | 159 |
| nonissiQ | 5062 | 6629 | 1539 | 7837 | 26355 | 8785 | 5807 | 5090 | 3481 | 15556 | 10463 | 7037 |
| Dacthal | 2762 | 3856 | 3019 | 4091 | 2637 | 1800 | 1924 | 2380 | 1235 | 2881 | 1670 | 850 |
| Cis-Nonachlor | σ | Σ | ø | Σ | Σ | Σ | Ð | Ø | 2 | 12 | 7 | 18 |
| Chlorpyrifos | 15380 | 12603 | 8944 | 14002 | 13006 | 5047 | 776 | 1894 | 1385 | 1432 | 2059 | 975 |
| Beta-HCH | 33 | ø | ø | 430 | 53 | 46 | Ø | Ø | Ð | Ø | Ð | ø |
| НОН-вирія | 87 | ø | 16 | 271 | 46 | 45 | 13 | ø | ø | ø | ø | ø |
| Alpha-Chlordane | σ | Σ | 77 | 258 | Σ | Σ | 94 | 148 | 61 | 123 | 138 | 98 |
| əteD | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 |
| Station | Manteca | Manteca | Manteca | Manteca | Manteca | Manteca | Rio Vista |
| River | San Joaquin | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento |

Table 3.19. Total (particulate plus dissolved) Pesticide concentrations in river station samples, 1994.

ND = not detected, Q = Present but not quantifiable, M = Matrix interference, Units in pg/L (ppq).

| Trifluralin | 4812 | 8735 | 6888 | 5648 | 4180 | 3912 | Q | 327 | 151 | 337 | 403 | 150 |
|--------------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|-------------|------------|------------|------------|------------|
| trans-Nonachlor | 296 | 397 | 530 | 289 | 472 | 327 | 43 | 21 | 23 | 50 | 43 | 21 |
| Toxaphene | 2 | Ð | Ð | ₽ | ₽ | ₽ | ₽ | ₽ | ₽ | ₽ | ₽ | QN |
| TOO-'q,q | 670 | 1028 | 488 | 210 | 382 | Σ | Ð | 4 | 8 | 14 | 10 | 10 |
| UMOO-'q,q | Ð | 126 | Ð | 4 | 109 | Ð | 39 | 15 | 13 | 10 | 28 | 8 |
| ∃DD-'q,q | 6348 | 7494 | 8810 | 5079 | 6330 | 5982 | 198 | 294 | 294 | 355 | 278 | 391 |
| DDD-'q,q | 565 | 802 | 408 | 223 | 730 | Σ | 43 | 77 | 75 | 106 | 126 | 118 |
| Oxychlordane | g | Q | Ð | Ð | Ø | Ð | Ð | Ð | Ð | Ð | Ð | QN |
| nozeibexO | 4058 | 1370 | 406 | 1320 | 1012 | 1179 | 1321 | 960 | 539 | 3498 | 1627 | 948 |
| TDD-'q,o | 357 | Ø | Ø | Ø | Ø | Ø | Ø | Ø | Ø | Ø | Ø | ø |
| o,p'-DDE | 161 | 190 | 269 | 138 | 195 | 185 | 4 | œ | œ | 9 | 1 | 11 |
| DDD-'q,o | 262 | 401 | 354 | 271 | 306 | 248 | 32 | 30 | 36 | 56 | 49 | 60 |
| Methylchlorpyrifos | 99 | QN | Ð | Ð | ₽ | Ð | Ð | Ð | Ð | Ð | Ð | DN |
| Heptachlor Epoxide | Ð | Ø | Q | Ø | Ð | Ø | Ø | Ø | Ø | Ð | Ø | ø |
| HOH-smmsĐ | 228 | Ø | 14 | 743 | 144 | 137 | ø | ø | Ð | ø | ø | ø |
| Gamma-Chlordane | 100 | 170 | 150 | 116 | 150 | 106 | 19 | 99 | 70 | 40 | 58 | 37 |
| II nsilusobn∃ | ₽! | QN | 28 | Ð | ~ | Ð | Ð | Ð | Ð | Ð | Ð | DN |
| Endosulfan I | 9 | Q | Σ | Ð | Ø | Ø | Ð | Ð | Ð | Ø | Ð | QN |
| Dieldrin | 511 | 569 | 637 | 376 | 508 | 454 | 343 | 139 | 149 | 213 | 268 | 167 |
| nonissiQ | 5230 | 6769 | 1599 | 7943 | 26485 | 9012 | 5807 | 5106 | 3481 | 15556 | 10463 | 7100 |
| Dacthal | 2821 | 3891 | 3070 | 4132 | 2673 | 1800 | 1924 | 2380 | 1235 | 2881 | 1670 | 861 |
| Cis-Nonachlor | σ | 106 | ø | Σ | Σ | Σ | Ð | - | ო | 13 | ი | 20 |
| Chlorpyrifos | 16181 | 13214 | 9549 | 14759 | 13400 | 5264 | 801 | 1928 | 1388 | 1474 | 2087 | 1018 |
| Beta-HCH | 33 | Ø | Ø | 430 | 53 | 46 | ø | ø | ₽ | ø | ₽ | ø |
| HOH-sdqlA | 87 | Ø | 16 | 271 | 46 | 45 | 13 | Ø | Ø | Ø | Ø | ø |
| Alpha-Chlordane | 69 | 104 | 161 | 301 | 83 | 49 | 94 | 153 | 62 | 128 | 143 | 108 |
| Date | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 | 4/7/94 | 4/13/94 | 5/6/94 | 5/11/94 | 5/18/94 | 5/25/94 |
| Station | Manteca | Manteca | Manteca | Manteca | Manteca | Manteca | Rio Vista | Rio Vista 4 | Rio Vista | Rio Vista | Rio Vista | Rio Vista |
| River | San Joaquin | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento | Sacramento |

| . = no | 3.20. General ot measured. nc |) data = . | data not % gravel | s of sedim ∶available a | ent sample at time of pri | s, 1994. nting. D | epth, salii | nity, dissol | ved o | oxygen, | , and temp | erature | from C | D. |
|-----------------|----------------------------------|--------------------|-------------------------------|----------------------------|-------------------------------------|-----------------------------|--------------------------|-------------------|----------------|-----------------|-------------------|-----------------|-----------------|------------|
| Station Code | Station Name | Date | % gravel & shell (>2mm) | % sand (2mm-63μm) | % silt (63μm - 4 μm) | % clay (< 4μm) | % fines (clay + silt) | Eh @ 2.5 cm mV | рН | salinity psu | temperature °C | TOC % dry | Depth m | DO mg/l |
| BA21 | South Bay | 2/16/94 | ° | 2 œ | 22 | د م 59 | ۶۵ 1 | -64 | | 25.20 | 11.7 | 0.835 | ი კ. ა 8 | 0 00 |
| BA41 | Redwood Creek | 2/16/94 | N | 10 | 23 | 65 | 88 | -55 55 | | 27.26 | 11.4 | 0.800 | မ အ | ω (|
| BB15 | San Bruno Shoal | 2/15/94 | 4 | 27 | 21 | 48 | 69 | -49 | • | 27.70 | 11.2 | 0.330 | 11.0 | 8 |
| BB30 | Oyster Point | 2/15/94 | ς ω | 1 0 0 3 | אכ מכ | r 29 | ۰3 م | -47 26 | | 27.88 | 11.3 | 0.720 | ۰ م م | 0 00 |
| BC11 | Yerba Buena Island | 2/15/94 | 17 | 41 | 11 | 32 | 43 | -58 | | 27.91 | 11.6 | 0.760 | 6.0 | ο ο |
| BC21 | Horseshoe Bay | 2/14/94 | 0 | 35 | 27 | 38 | 65 | -43 | • | 29.89 | 11.9 | 1.047 | 12.8 | 8 |
| BC32 | Richardson Bay | 2/14/94 | 0 | 24 | 2.41 | 34 | 75 | -35 | • | 29.47 | 11.6 | 0.743 | 2.0 | 000 |
| | Point Isabel | 2/14/94 | ກດ | 08 0 | 2 3 4 | ے م | л ⁰ 4 | -35 -71 | | 20.82 | 11.1 | ND ND | о л Л | ωα |
| BD22 | San Pablo Bay | 2/11/94 | <u> </u> | 00 | 35 | 56 | 91 | -49 | • | 24.11 | 11.4 | 1.230 | 3.8 | œ (|
| BD31 | Pinole Point | 2/11/94 | <u>ب</u> د | 1 1 5 | 28 | 56 | 37 84 | -45 | | 22.42 | 11.1 | 1.310 | 7 .0 | 000 |
| BD50 | Napa River | 2/11/94 | 00 N | 2 2 | 19 | 70 | 68 7 | မ် သိ မ် | | 12.24 | 10.3 | 1.605 | 2.5 | 99 |
| BF10 | Pacheco Creek | 2/10/94 | 2 | 75 | 7 | 17 | 24 | -16 | | 6.47 | 10.3 | 0.254 | 2.8 | 9 |
| BF21 | Grizzly Bay Honker Bay | 2/10/94 | 00 | <u>- N</u> | 2 3 1 2 1 | 72 89 | 100 100 | -44 -50 | | 5.77 3 57 | 10.6 | 1.464 1 650 | 20 20 | 10 0 |
| BG20 | Sacramento River | 2/10/94 | 0 | 69 | | 20 | 31 | -45 | • | 0.30 | 9.9 | 0.528 | 7.8 | 8 |
| BG30 | San Joaquin River | 2/10/94 | 0 | 55 | 20 | 25 | 45 | -56 | • | 0.54 | 10.7 | 0.483 | 5.5 | 9.00 |
| C-1-3-0 | Sunnyvale | 2/16/94 ว/16/04 | ی د | an 13 | no data ع | no data | 787 | -76 | | 18 80 | 12.5 12.5 | 1.628 ก ววุล | 1.0 1 8 | 7 7 |
| вА21 | South Bay | 8/29/94 | ω | თ (| 21 21 | 71 | 92 | -22 | 6.8 | 30.59 | 21.7 | 1.260 | 2.8 | o - |
| BA30 | Dumbarton Bridge | 8/29/94 | , O | ģω | 31 | - 66 | -2 - | -19 | 7.4 | 31.49 | 21.2 | 1.030 | о.5 Э.5 | , O |
| BB15 | San Bruno Shoal | 0/29/94 8/29/94 | ω ແ | 40 | 20 | 37 37 | 57 | -6 -6 | 7.4 | 31.64 | 20.3 | 0.620 | ۲.3 11.5 | იი |
| BB30 | Oyster Point | 8/29/94 | 2 | 36 | 20 | 41 | 61 | եր | 7.2 | 31.73 | 19.8 | 1.170 | 7.3 | 6 |
| BB70 | Alameda | 8/30/94 | 0 | 30 | 200 | 44 | 70 | -26 | 0.00 0.1 | 31.84 | 19.0 | 0.947 | 9.0 | 10 |
| BC11 | Horseshoe Bay | 0/29/94 8/29/94 | 0 N | 45 45 | 25 | 4× 30 | 55 5 | - I 3 7 | ი. ე. თ. | 32.32 | 10.4 16.3 | 0.837 | 9.8 0.8 | б ~ |
| BC32 | Richardson Bay | 8/29/94 | 0 | 25 | 41 | 34 | 75 | . 0 | 6.8 | 31.88 | 17.1 | 0.870 | 1.8 | റ |
| BC60 | Point Isabel Red Rock | 8/29/94 8/26/94 | 13 0 | 8 - - 3 | 4 1 | 40 | 2 87 | -25 | 7.6 | 31.64 31.94 | 17.6 16.8 | 0.960 | 10.3 | o ~ |
| BD22 | San Pablo Bay | 8/26/94 | 0 | 12 | 36 | 51 | 87 | -12 | 6.8 | 26.24 | 19.6 | 1.050 | 3.0 | 6 |
| BD31 | Pinole Point | 8/26/94 | o د | 0 <u>1</u> 5 | 27 | 4 0 0 0 | 4 05 005 | 22 | ט ט 1 ט | 28.29 | 18.6 | 1.320 | л б о б | ກດ |
| BD50 | Napa River | 0/20/94 8/26/94 | 7 | ω <u>°</u> | 23 | 68 | 91 | -'2' | 7.1 | 24.33 21.70 | 19.0 20.1 | 1.330 | 2.5 | თი |
| BF10 | Pacheco Creek | 8/25/94 | 0 | 80 | ζœ | 13 23 | 21 | |).) | 18.28 | 20.5 | 0.470 | 4.5 | 10 |
| BF21 | Grizzly Bay | 8/25/94 | 0 0 | د د | 3 Ci | 62 | 86 86 | -11 20 | 6.9 | 12.72 | 20.6 | 1.470 | r C | 1 - |
| BG20 | Sacramento River | 8/25/94 | 00 | 50 | 17 | 3 0 3 0 | 50 97 | -13 | 7.2 | 2.77 | 21.0 21.7 | 0.890 | ე. ე.კ | |
| BG30 | San Joaquin River | 8/25/94 | 0 | 66 | 13 | 21 | 34 | 17 | 6.7 | 2.96 | 22.2 | 0.540 | 6.8 | . 7 |
| C-3-0 | Sunnyvale San Jose | 8/30/94 8/30/94 | 00 | 60 0 0 0 0 | 15 14 | 26 | 44 40 | -26 22 | 6.2 | 14.49 25.38 | 21.7 22.3 | 1.390 | 0.5 | 6 4 0 |
| I | | | | | | | | | | | | | | I |

 Table 3.21. Concentrations of trace elements for sediment samples, 1994.

 * = near total concentrations were measured instead of total.

| ב ו | מן וחומו החווהבוו | li auui s | אסוס | וונממי | | ופונמת | 2 | | | | | | | | |
|-------------|--------------------|-----------|-------|--------|-------|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Station | Station Name | Date | Ag* | AI* | As | Cd* | °, | Cu* | Fe* | Hg | Mn* | *!Z | Pb* | Se | Zn* |
| Code | | | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg | mg/Kg |
| BA21 | South Bay | 2/16/94 | 0.56 | 34491 | 11.5 | 0.16 | 98.6 | 54.5 | 47654 | 0.370 | 1490 | 70.3 | 23.5 | 0.72 | 118 |
| BA30 | Dumbarton Bridge | 2/16/94 | 0.41 | 23572 | 10.5 | 0.16 | 65.8 | 41.7 | 35358 | 0.273 | 1029 | 48.4 | 15.6 | 0.51 | 91 |
| BA41 | Redwood Creek | 2/16/94 | 0.66 | 33613 | 13.8 | 0.33 | 120.1 | 54.9 | 43892 | 0.370 | 576 | 65.8 | 22.0 | 0.95 | 117 |
| BB15 | San Bruno Shoal | 2/15/94 | 0.32 | 33478 | 7.6 | 0.16 | 81.8 | 27.3 | 33183 | 0.172 | 385 | 45.1 | 11.7 | 0.32 | 66 |
| BB30 | Oyster Point | 2/15/94 | 0.51 | 36686 | 9.7 | 0.29 | 91.1 | 38.4 | 38009 | 0.265 | 480 | 70.3 | 14.4 | 0.68 | 89 |
| BB70 | Alameda | 2/15/94 | 0.45 | 45440 | 12.0 | 0.16 | 90.7 | 43.9 | 45415 | 0.306 | 461 | 64.0 | 19.2 | 0.56 | 103 |
| BC11 | Yerba Buena Island | 2/15/94 | 0.30 | 21989 | 8.3 | 0.30 | 70.6 | 25.1 | 24008 | 0.216 | 267 | 47.5 | 11.5 | 0.35 | 65 |
| BC21 | Horseshoe Bay | 2/14/94 | 0.31 | 30989 | 11.3 | 0.17 | 113.4 | 38.4 | 43104 | 0.224 | 388 | 75.2 | 23.5 | 0.45 | 89 |
| BC32 | Richardson Bay | 2/14/94 | 0.28 | 27594 | 9.4 | 0.17 | 103.0 | 34.6 | 42071 | 0.289 | 373 | 65.5 | 15.3 | 0.54 | 84 |
| BC41 | Point Isabel | 2/14/94 | 0.30 | 33525 | 8.2 | 0.10 | 113.5 | 43.7 | 49879 | 0.305 | 411 | 79.3 | 19.3 | 0.62 | 102 |
| BC60 | Red Rock | 2/14/94 | 0.01 | 14815 | 8.2 | 0.04 | 51.5 | 11.1 | 28835 | 0.044 | 450 | 73.8 | 8.4 | 0.47 | 50 |
| BD22 | San Pablo Bay | 2/11/94 | 0.32 | 35846 | 10.5 | 0.20 | 69.2 | 52.8 | 41673 | 0.361 | 484 | 67.4 | 16.0 | 0.92 | 111 |
| BD31 | Pinole Point | 2/11/94 | 0.51 | 43972 | 10.4 | 0.25 | 100.8 | 55.7 | 48729 | 0.381 | 510 | 82.9 | 25.1 | 0.97 | 123 |
| BD41 | Davis Point | 2/11/94 | 0.07 | 23359 | 5.7 | 0.11 | 72.3 | 22.1 | 38020 | 0.098 | 426 | 61.9 | 13.4 | 0.39 | 73 |
| BD50 | Napa River | 2/11/94 | 0.40 | 48376 | 12.0 | 0.23 | 92.7 | 68.3 | 53696 | 0.418 | 1037 | 88.4 | 22.4 | 1.03 | 137 |
| BF10 | Pacheco Creek | 2/10/94 | 0.05 | 24647 | 5.3 | 0.11 | 64.3 | 19.1 | 35196 | 0.068 | 460 | 92.3 | 8.0 | 0.43 | 66 |
| BF21 | Grizzly Bay | 2/10/94 | 0.33 | 53559 | 12.1 | 0.26 | 70.0 | 67.1 | 56027 | 0.364 | 911 | 114.6 | 23.0 | 0.84 | 131 |
| BF40 | Honker Bay | 2/10/94 | 0.36 | 56490 | 11.1 | 0.28 | 106.8 | 68.1 | 63325 | 0.446 | 1118 | 113.4 | 23.7 | 1.01 | 131 |
| BG20 | Sacramento River | 2/10/94 | 0.07 | 31889 | 5.2 | 0.21 | 84.1 | 27.2 | 37181 | 0.149 | 471 | 113.2 | 9.8 | 0.33 | 76 |
| BG30 | San Joaquin River | 2/10/94 | 0.08 | 32621 | 9.5 | 0.18 | 95.0 | 35.5 | 40650 | 0.206 | 514 | 76.6 | 12.4 | 0.58 | 63 |
| C-1-3 | Sunnyvale | 2/16/94 | 1.11 | 46785 | 7.9 | 0.48 | 170.6 | 94.6 | 82760 | 0.413 | 1250 | 130.8 | 45.4 | 0.87 | 222 |
| C-3-0 | San Jose | 2/16/94 | 0.13 | 14891 | 7.0 | 0.18 | 81.0 | 22.0 | 29996 | 0.072 | 2817 | 68.6 | 10.6 | 0.30 | 61 |
| BA21 | South Bay | 8/29/94 | 0.38 | 27977 | 9.9 | 0.15 | 93.7 | 42.2 | 37106 | 0.364 | 902 | 100.0 | 22.9 | 0.41 | 130 |
| BA30 | Dumbarton Bridge | 8/29/94 | 0.40 | 28097 | 10.8 | 0.19 | 0.06 | 46.4 | 39637 | 0.386 | 661 | 103.0 | 24.6 | 0.35 | 133 |
| BA41 | Redwood Creek | 8/29/94 | 0.32 | 24831 | 7.8 | 0.16 | 74.4 | 35.4 | 25035 | 0.243 | 536 | 77.0 | 16.4 | 0.38 | 102 |
| BB15 | San Bruno Shoal | 8/29/94 | 0.35 | 24388 | 6.5 | 0.16 | 77.0 | 31.1 | 27702 | 0.248 | 299 | 76.7 | 16.6 | 0.30 | 93 |
| BB30 | Oyster Point | 8/29/94 | 0.30 | 24137 | 8.7 | 0.19 | 82.1 | 33.2 | 32047 | 0.236 | 390 | 86.4 | 16.4 | 0.27 | 101 |
| BB70 | Alameda | 8/30/94 | 0.40 | 26998 | 9.9 | 0.23 | 95.4 | 39.1 | 35225 | 0.332 | 291 | 90.0 | 25.1 | 0.26 | 117 |
| BC11 | Yerba Buena Island | 8/29/94 | 0.24 | 24086 | 8.9 | 0.20 | 79.0 | 47.7 | 29622 | 0.263 | 289 | 75.1 | 17.7 | 0.35 | 120 |
| BC21 | Horseshoe Bay | 8/29/94 | 0.20 | 20347 | 13.3 | 0.21 | 75.8 | 28.0 | 29992 | 0.216 | 287 | 79.4 | 23.1 | 0.27 | 88 |
| BC32 | Richardson Bay | 8/29/94 | 0.21 | 20599 | 10.7 | 0.21 | 75.7 | 34.8 | 30464 | 0.373 | 272 | 75.7 | 17.4 | 0.31 | 94 |
| BC41 | Point Isabel | 8/29/94 | 0.21 | 18666 | 12.3 | 0.13 | 78.4 | 37.8 | 33042 | 0.267 | 296 | 83.0 | 20.4 | 0.30 | 107 |
| BC60 | Red Rock | 8/26/94 | 0.01 | 8584 | 8.6 | 0.03 | 49.7 | 8.0 | 27112 | 0.015 | 541 | 63.7 | 9.3 | 0.02 | 56 |
| BD22 | San Pablo Bay | 8/26/94 | 0.24 | 23185 | 16.8 | 0.25 | 79.8 | 48.4 | 34437 | 0.380 | 497 | 91.8 | 19.6 | 0.10 | 116 |
| BD31 | Pinole Point | 8/26/94 | 0.39 | 30975 | 20.2 | 0.44 | 97.8 | 62.5 | 45019 | 0.435 | 422 | 110.5 | 29.6 | 0.39 | 148 |
| BD41 | Davis Point | 8/26/94 | 0.05 | 15945 | 6.9 | 0.10 | 80.7 | 17.7 | 30384 | 0.076 | 350 | 73.6 | 13.2 | 0.12 | 75 |
| BD50 | Napa River | 8/26/94 | 0.27 | 31022 | 16.6 | 0.24 | 97.7 | 59.1 | 41484 | 0.349 | 1059 | 108.0 | 23.1 | 0.66 | 139 |
| BF10 | Pacheco Creek | 8/25/94 | 0.06 | 15384 | 7.1 | 0.16 | 71.6 | 20.3 | 27035 | 0.127 | 316 | 76.3 | 9.1 | 0.12 | 72 |
| BF21 | Grizzly Bay | 8/25/94 | 0.29 | 40855 | 12.6 | 0.32 | 112.1 | 62.1 | 45722 | 0.359 | 739 | 115.4 | 23.6 | 0.42 | 141 |
| BF40 | Honker Bay | 8/25/94 | 0.26 | 35083 | 13.7 | 0.41 | 125.2 | 71.9 | 39246 | 0.296 | 964 | 124.6 | 22.7 | 0.33 | 165 |
| BG20 | Sacramento River | 8/25/94 | 0.13 | 26362 | 11.4 | 0.32 | 93.0 | 42.3 | 36660 | 0.154 | 682 | 106.4 | 24.2 | 0.13 | 114 |
| BG30 | San Joaquin River | 8/25/94 | 0.05 | 19285 | 9.3 | 0.21 | 81.7 | 30.7 | 32394 | 0.216 | 332 | 79.2 | 27.1 | 0.20 | 75 |
| C-1-3 | Sunnyvale | 8/30/94 | 0.28 | 18749 | 7.5 | 0.30 | 75.2 | 34.8 | 26248 | 0.236 | 467 | 81.1 | 28.0 | 0.54 | 112 |
| C-3-0 | San Jose | 8/30/94 | 0.98 | 27009 | 8.0 | 0.68 | 107.7 | 57.8 | 38405 | 0.543 | 559 | 118.6 | 41.2 | 0.42 | 163 |

| | | BAGGERBED BECCO | Station Code |
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| 1482 1250 281 1582 813 3345 3089 2708 884 884 | 578 915 989 743 77 | 1524 1524 1594 1592 1553 1928 1928 1553 1554 1172 1284 1172 12879 17037 12879 17237 12277 22777 1724 1724 1724 1724 1724 1 | Total Alkanes |
| 4344 900 114 722 215 807 441 317 64 | 1437 2250 1407 2328 1961 2040 2040 | 7632 5218 3027 6085 6085 6085 6085 6085 6085 6085 6085 | Total PAHs |
| 129 14 129 14 14 14 14 14 14 14 14 14 14 14 14 15 | - 74 292 328 218 218 | 22285 2285 2285 2285 2285 2285 2285 228 | Total LPAHs |
| 2 2 2 447 58 372 442 140 245 245 245 244 | / 3/ 1118 715 1148 999 1332 1109 | 3746 2131 2715 2715 2715 3151 3151 3151 3151 3151 2718 2717 61 530 530 530 530 530 217 1475 904 107 1272 1272 | Total HPAHs |
| ND 4.2 0 1.2 | n 5 9 6 7 3 5 4 ▲ 6 5 8 0 5 4 N | 22.6 12.0 13.7 18.2 18.2 14.5 14.5 14.5 14.5 14.5 14.5 14.5 14.5 | 1-Methylnaphthalene |
| ND 2.1 | 15.4 7.3 20.6 12.5 | 43.4 26.0 27.4 66.0 18.8 54.8 54.8 54.8 54.8 18.8 27.4 18.8 27.4 18.8 27.4 18.8 27.5 10.0 19.6 19.6 19.6 19.6 11.7 1.7 1.7 1.7 | 1-Methylphenanthrene |
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| Z 3 3 5 - 3 Z 4 6 Z 4 D - 3 3 - 4 5 D 5 - 2 0 | 4 8 7 6 5 6 4 4 8 7 6 5 6 4 5 5 7 0 0 0 | 22.1 10.2 15.7 15.9 7.9 7.9 7.9 7.9 7.9 7.9 7.9 7.9 7.9 7 | 2,6-Dimethylnaphthalene |
| ND 8.4 10.8 7.8 8.1 10.8 7.8 6.4 | 9.5 9.5 11.7 12.3 9.7 | 21.4 19.3 117.4 19.3 117.4 19.3 119.0 119.1 119.1 119.1 119.1 119.1 22.9 9.5 22.9 9.5 22.9 9.5 22.9 9.5 22.9 9.5 22.9 19.6 22.9 9.5 22.9 19.5 22.9 22.9 22.9 22.9 22.9 22.9 22.9 2 | 2-Methylnaphthalene |
| NDD 2.3 NDD 2. | 12.0 10.6 13.9 18.1 | 23.3 19.3 32.8 32.8 11.4 21.2 21.2 21.2 21.1 21.2 21.2 21.1 3.4 21.2 21.2 21.2 21.2 21.2 21.2 21.2 21 | Acenaphthene |
| N 1.4 3.2 ND 22.8 ND 4.7 ND 4.7 ND 7 ND 7 ND 7 ND 7 ND 7 ND 7 ND 7 ND | 16.9 13.5 13.5 | 42.8 NDD 11.2 NDD 11.2 11.2 11.2 11.2 11.2 11.2 11.2 11 | Acenaphthylene |
| 2 19.4 1.7 4.0 9.0 2.8 ND | 2 2 8 3 5 . 3 9 . | 92.3 61.1 72.8 72.8 72.8 72.8 72.8 72.8 72.8 72.8 | Anthracene |
| ND 243.6 5.0 30.5 38.7 13.6 13.6 | 70.5 75.6 139. <u>5</u> 135.9 110.8 130.6 | 1153 1153 1153 1153 1153 1153 1153 1153 | Benz(a)anthracene |
| 433.3 9.5 56.4 28.4 23.7 3.1 | 2178.4 196.9 | 808.2 431.9 574.3 309.3 309.3 409.3 573.4 573.4 184.6 184.6 184.6 1746.1 91.0 202.5 202.5 13.9 202.5 13.9 202.5 13.9 202.5 20. | Benzo(a)pyrene |
| ND 268.C 59.7 43.8 9.9 45.7 21.5 21.5 21.5 21.5 2.6 | 87.3 123.1 86.3 135.2 97.6 125.7 | 477.5 2245.2 216.5 216.5 216.5 216.5 216.5 216.5 216.5 26.5 26.5 26.5 26.5 26.5 26.5 26.5 2 | Benzo(b)fluoranthene |
| 8.4 200.2 20.2 2.8 | 90.2 134.3 87.6 107.3 125.9 124.2 | 515.2 272.5 352.5 375.2 | Benzo(e)pyrene |
| ND 448.7 48.4 7.5 83.2 33.8 3.6 | 130.3 1130.3 192.2 168.3 168.3 | 734.1 355.7 434.0 3263.7 2263.7 2263.7 1421.8 315.6 3315.6 3315.6 3315.6 3315.6 3315.6 3315.6 3315.6 3315.6 3315.6 3315.6 3315.7 14.2 251.1 149.3 149.2 21.2 14.2 21.2 14.2 21.2 14.2 21.2 14.2 21.2 14.2 21.2 14.2 21.2 14.2 21.2 21 | Benzo(ghi)perylene |
| 268.0 59.7 43.8 9.9 45.7 21.5 21.5 2.6 | 87.3 123.1 86.3 135.2 97.6 97.6 125.7 125.2 | 495.7 265.5 251.8 309.8 309.8 309.8 309.8 309.8 309.8 309.8 309.8 309.8 309.8 309.8 261.4 174.8 273.5 273.5 273.5 273.5 10.7 13.9 10.7 13.9 8.2 10.7 13.9 8 5.2 10.7 13.9 8 10.7 13.7 9 6.2 13.7 19.5 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.9 10.7 10.7 10.9 10.7 10.9 10.7 10.7 10.7 10.7 10.7 10.7 10.7 10.7 | Benzo(k)fluoranthene |
| 11.9 1.2 1.9 1.9 1.9 1.9 1.9 1.9 1.0 1.9 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 | 4 7 9 9 8 4 7 9 4 5 8 4 5 6 5 9 | $\begin{array}{c} 30.8\\ 16.3\\$ | Biphenyl |
| 22.1 2.3 2.3 2.5 2.1 2.5 2.5 2.5 2.5 2.5 2.3 | 37.2 72.4 70.4 52.7 | 186.6 88.2 123.8 85.7 865.7 865.7 865.7 85.3 61.6 137.5 125.0 125.0 125.0 125.4 125.4 12.5 12.5 12.5 12.5 12.5 12.5 8.5 5.4 65.2 8.5 5.4 61.6 | C1-Chrysenes |
| N N N A N N N 0.2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | 9.8 3.9 10.3 20.3 | 222.5 112.4 9.4 12.4 9.4 12.4 9.4 12.4 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.4 12.5 9.5 12.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 9.5 12.5 12.5 12.5 12.5 12.5 12.5 12.5 12 | C1-Diben |
| 160.5 91.9 25.6 29.3 29.3 29.3 3.6 | 83.4 111.8 68.5 125.1 121.8 184.0 131.0 | 359.1 193.4 152.6 152.6 152.6 131.7 308.3 9.3 260.9 68.3 10.4 99.1 125.7 133.0 92.9 92.9 10.4 99.2 | C1-Fluoran_Pyr |
| ND 7.9 ND 10.1 | 14.5 14.2 14.2 14.2 10.3 | 30.8 31.4 30.8 31.5 31.5 31.5 31.5 31.5 31.5 31.5 31.5 | C1-Fluorenes |
| ND 9.6 | 10.2 9.4 17.3 17.3 21.7 21.7 | 53.3 29.4 217.5 21.5 21.5 21.5 21.5 21.5 2 | C1-Naph-thalenes |

Units µg/kg, dry weight (ppb). ND = not detected.

Units $\mu g/kg$, dry weight (ppb). ND = not detected.

| Pyrene | 220.9 | 76.3 876.3 | 493.8 | 701.3 | 381.4 | 919.0 | 842.2 | 848.6 10.7 | 198.6 | 169.4 | 28.9 | 303.9 | 72.1 386.0 | 264.7 | 25.4 | 13.8 | 395.6 242.6 | 310.6 248.6 | 351.4 | 233.5 | 343.0 308.2 | 421.1 | 383.8 | 291.4 | 1.0 | 0.700 | 18.7 | 111.0 | 43.4 | 110.3 | /1.8 11 6 | 6.9 |
|--------------------------|----------------|----------------|-----------------|--------------|--|---------------|----------------|--------------------------|---------------|--------------|-------------|----------------------------|---------------------|---------------------------|------------------|-------------------|----------------|-----------------------------------|-----------------|--------------|-------------------------------|---------------|----------------|--------------|---|-----------------|---------------------------------|------------|---------------|-------------|--------------------------------|-------------------|
| Phenanthrene | 310.6 1 | 264.0 | 194.9 | 232.8 | 4 - 3.9 - 149.6 | 291.7 | 244.4 | 300.5 4.8 | 275.4 1 | 48.0 | 8.9 | 96.8 | 105.3 | 77.8 | 7.7 | 3.5 | 92.9 | 92.0 78.3 | 147.8 | 67.3 | 139.2 136.2 | 256.3 | 96.1 | 86.6 | | 100.9 | 50.9 6 0 | 31.2 | 8.3 | 34.9 | 170 | 2.4 |
| Perylene | 250.4 | 122.0 | 82.0 | 122.8 | 66.4 | 144.2 | 135.8 | ND.8 | 231.3 | 42.4 | 9.9 | 115.0 | 14.8 230 8 | 122.0 | 14.8 | 54.8 | 86.7 | 63.2 45.7 | 59.6 | 44.9 | 63.8 60.0 | 69.6 | 74.9 | 49.5 | ND 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 | 0.001 | 0.00 9 6 | 41.0 | 10.2 | 65.0 | 52.U | 24.3 |
| ənəlsdinqsN | 98.3 | 40.9 70.3 | 32.6 | 53.9 | 25.7 | 57.0 | 46.8 | 45.7 2.2 | 92.2 | 13.0 | 4.9 | 43.6 | 1.1 53 8 | 30.4 | 4.9 | 3.9 | 33.6 | 25.5 18 4 | 24.9 | 18.2 | 29.1 25.7 | 30.6 | 24.5 | 21.3 | n S | 00 | | 14.8 | 4.3 | 12.8 | 10.1 8 0 8 | 0.0 2.5 |
| ənəıyq(bɔ-ɛ̃,오́,෦)onəbnl | 596.9 | 394.5 | 216.3 | 278.3 | 301.0 123.8 | 276.5 | 307.1 | 419.1 12.8 | 689.5 | 82.1 | 13.9 | 187.6 | 12.1 257 6 | 135.3 | 18.7 | 6.6 | 272.8 | 185.4 90.3 | 167.2 | 119.7 | 169.7 126.1 | 145.6 | 105.1 | 103.2 | ND 252 | 4.000 | 4 0 0 0 0 0 0 | 46.5 | 6.5 | 62.4 | 24.1 22 8 | 2.7 |
| Fluorene | 30.7 | 13.0 22.6 | 19.6 | 15.8 | 4 J. | 28.0 | 21.5 | 4. LZ | 20.6 | 5.4 | 2.5 | 15.0 | 38./ 21.2 | 12.1 | 1.6 | QN | 11.6 | 9.8 10.8 | 12.8 | 6.7 | 16.6 14.7 | 24.8 | 11.9 | 10.0 | , zc | 2.5 | - 4 | 7.2 | 3.5 | 7.7 | 9.7 9 8 | ND 0.0 |
| Fluoranthene | 839.7 576.0 | 742.5 | 356.8 | 537.4 | 286.4 | 723.2 | 632.1 | 047.0 7.9 | 815.2 | 121.5 | 22.9 | 234.4 | 8.18 0.000 | 204.2 | 19.6 | 10.6 | 278.3 | 231.8 | 284.1 | 168.6 | 263.8 272 1 | 365.8 | 306.5 | 217.2 | 0.9 | 7.000 | 12.2 | 85.1 | 50.0 | 84.3 | 6.26 20.6 | 5.3 |
| Dibenzothiophene | 25.6 | 19.7 | 13.9 | 16.8 | 30.9 11.7 | 20.5 | 20.1 | c. LZ | 21.5 | 5.4 | 1.3 | 10.1 | α.α 7 α.α | 7.6 | QN | QN | 7.2 | 6. 6. с | 8.7 | 3.4 | α | 17.8 | 5.2 | 5.8 | n ç | 4. L | n UN | 2.7 | QN | 3.5 | | |
| Dibenz(a,h)anthracene | 60.5 | 24.9 | 22.3 | 25.2 | 40.2 12.8 | 33.9 | 35.0 | 42.U 3.0 | 59.2 | 11.9 | 1.6 | 19.3 | 0.1.8 1.7 | 14.4 | 3.4 | 1.3 | 26.1 | 19.8 8 8 | 19.0 | 12.7 | 21.4 16.8 | 20.2 | 9.9 | 9.4 | nn v | 0.00 | 0.0 20.0 | 4.6 | 0.9 | 7.6 | 0.0 0.0 | °, Q |
| Chrysene | 465.9 | 226.3 326.3 | 166.5 | 179.7 | 337.1 115.6 | 292.2 | 282.1 | 337.0 21.4 | 394.7 | 55.0 | 9.1 | 118.2 | 12.3 | 99.4 | 14.8 | 7.0 | 119.4 | 157.7 99.4 | 116.1 | 72.5 | 171.9 | 160.1 | 107.8 | 101.1 | ND | 219.0 | 40.7 | 57.9 | 13.5 | 41.8 | 17.0 | 3.2 |
| С4-Рһел_Апthr | 34.6 | 22.9 | 10.2 | 9.0 | 4.2 14.2 | 22.7 | 28.3 | 23.2 | 53.8 | 48.7 | 5.5 | 44.9 | 64 5 64 5 | 37.6 | 7.3 | QN | 22.9 | 9.2 | 16.3 | 6.9 | 14.8 10.2 | 18.2 | 20.1 | 11.1 | nz ; | 0.04 | 9. 6. | 11.7 | 7.4 | 16.0 | c،11 د ه | 9.2 5.3 |
| c4-Naph thalenes | 22.6 | 24.9 | 8.6 | 7.1 | 10.4 | 21.4 | 22.5 | ND VD | 26.4 | 11.6 | 4.1 | 38.2 | 0.0 0.0 | 38.5 | Q | QN | 6.2 1 | 1.3 | 10.2 | 7.6 | 10.6 10.9 | 15.8 | 20.7 | 21.4 | n S S | , i 1 | - 4 | 15.4 | 9.1 | 9.2 | 16.2 | [†] . O |
| C4-Chrysenes | 25.5 12.7 | 19.4 | 10.9 | 14.3 | 6.4 10.7 | 15.7 | 18.6 | 2.9 | 64.4 | 16.7 | 2.9 | 31.2 | 3.4 ЛО Б | 24.5 | 5.8 | QN | 26.8 | 9.7 6.4 | 17.4 | 7.6 | 21.0 27 E | 25.5 | 6.6 | 6.5 | ND Z | 1.00 | 0.0 | 3.4 | QN | 13.2 | nn v | ND 0.0 |
| C3-Phen_Anthr | 48.0 | 34.3 | 16.3 | 22.6 | 16.8 16.8 | 36.0 | 38.7 | 7.8L | 50.8 | 34.6 | 5.9 | 56.6 | 53.8 20.8 | 53.0 | 8.0 | QN | 31.5 | 14.2 17.8 | 25.6 | 12.6 | 31.1 31.4 | 32.1 | 33.6 | 19.9 | | 0.00 1 | 24.7 9 0 | 16.7 | 7.4 | 24.9 | 13.3 | 3.3 |
| c3-Naph-thalenes | 60.9 | 45.2 | 8.5 | 20.4 | 40.3 | 32.3 | 24.0 | 18.4 ND | 26.6 | 11.8 | 5.8 | 44.6 | 10.4 מאל | 32.1 | 6.0 | QN | 17.3 | 16.8 20.2 | 18.0 | 9.6 | 20.7 10 6 | 27.4 | 21.2 | 18.6 | ND ND | 0.07 | 5.4 | 20.1 | 9.1 | 17.2 | 18.4 1.4 | n. DN |
| C3-Fluorenes | 27.3 | 26.7 | Q | 3.4 | 19.0 | 16.1 | 28.8 | 7.61 DN | 27.5 | 14.3 | 4.7 | n S S S S S | 13.3 63.5 | 31.9 | QN | QN | 23.4 | 16.6 22 1 | 24.6 | 12.5 | 12.7 31 5 | 23.2 | 21.1 | 32.9 | n Z Z | 4 - 4 4 • | 10.1 | 15.8 | 9.9 | 25.6 | 16.9 | ND ND |
| n9diQ-£ጋ | 17.8 | 17.0 | 8.0 | 10.3 | 5.7 | 14.4 | 20.0 | ND ND 8 | 15.6 | 7.3 | 2.9 | 18.1 | ч. 1 2 г. 1 2 | 19.8 | 3.6 | QN | 10.6 | 4. G | 7.1 | 4.8 | 7.8 8.2 | 11.8 | 7.8 | 8.0 | n S S S S S | 7.0 | 7.0 UD | 7.6 | 4.5 | 0.0 | ກິດ ກັດ | ND 4.0 |
| C3-Chrysenes | 16.8 | 9.4 12.8 | 3.9 | 5.9 | 4.0 | 10.8 | 14.3 | 8.4 DND | 7.4 | 3.4 | Q | 8.2 • | 5.0 4.01 | t 9 5 | QN | QN | 3.3 | | 2.4 | QN | | | QN | Q I | n c | 2 C | NDN V | g | QN | 3.2 | | ND ND |
| -C2-Phen_Anthr | 115.5 | 77.0 | 45.1 | 55.3 | 39.6 | 83.2 | 76.0 | 64.7 2.8 | 74.4 | 33.2 | 6.3 | 58.3 | 1.UC | 44.7 | 5.8 | 5.1 | 34.0 | 29.8 25.0 | 41.8 | 26.4 | 39.1 48.7 | 74.3 | 48.1 | 35.7 | n ND VD | 4/.1 | 4.00 7.00 | 20.1 | 9.2 | 22.0 | 13.0 | 9.0 3.7 |
| c2-Naph-thalenes | 44.2 | 25.3 | 18.2 | 20.9 | 39.5 14.9 | 32.1 | 26.7 | 23.6 ND | 23.6 | 11.5 | 4.3 | 41.9 | 13.1 | 2.9.62 | 6.0 | QN | 16.8 | 15.2 13.5 | 14.1 | 10.2 | 17.1 15.8 | 23.6 | 15.4 | 18.6 | UN 2 | 1.01 | 1. - | 15.3 | 5.5 | 12.3 | 10.9 | ND 0 |
| C2-Fluorenes | 50.4 | 20 18.8 | 7.8 | 11.9 | 11.7 | 23.7 | 7.8 | 9.0 ND | 25.4 | 9.1 | 3.4 | 37.7 | 10 G | 26.9 | 3.8 | QN | 20.0 | 13.4 | 16.9 | 7.1 | 12.8 16.0 | 21.7 | 19.2 | 10.2 | UN VD | 4. 7. | *. CN | 9.0 | 4.4 | 12.5 | ю. С. ч | 2.2 ND |
| n9diQ-SC | 35.0 | 9.0 16.0 | 9.5 | 12.7 | 11.5 | 21.3 | 17.4 | ND / 1 | 18.8 | 7.5 | 2.3 | 18.7 | 78.7 | 16.6 | 2.7 | QN | 8.2 | 6.4 7 | 9.5 | 4.5 | 8.6 11 1 | 17.7 | 7.1 | 7.9 | , zo | - 0 | 8.0 UD | 5.2 | 2.7 | 6.5 | 8.4 20.4 | 2 g |
| c2-Chrysenes | 80.9 | 59.2 | 27.0 | 39.4 | 23.2 | 58.6 | 68.1 | 42.0 3.6 | 48.5 | 31.6 | 4.6 | 48.9 | 707 | 43.8 | 6.4 | 3.5 | 39.1 | 23.7 | 40.8 | 14.3 | 29.5 40.0 | 46.7 | 24.1 | 15.8 | ND 2 | 0.10 | 3.6.2 | 14.5 | 6.0 | 33.6 | 10.4 4.6 | 1.8 |
| rdfnA_n9d-tO | 166.6 | 145.5 | 101.4 | 105.7 | 77.6 | 157.0 | 124.0 | 134.6 4.7 | 130.7 | 38.4 | 7.0 | 66.8 | 38.1 83.2 | 61.4 | 5.9 | 3.9 | 52.7 | 50.6 46.8 | 77.0 | 36.0 | 74.9 81.0 | 138.2 | 58.7 | 47.9 | | 7.71 | 3 5 | 21.2 | 9.9 | 23.8 | 16.4 | م.» ND |
| Date | 2/15/94 | 2/15/94 | 2/15/94 | 2/15/94 | 2/14/94 | 2/14/94 | 2/14/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/10/94 | 8/30/94 | 8/30/94 8/30/94 | 8/30/94 | 8/29/94 | 8/30/94 8/20/04 | 8/29/94 | 8/29/94 | 8/29/94 | 8/26/94 | 0/20/24 | 8/26/94 | 8/26/94 | 8/25/94 | 8/25/94 | 8/25/94 | 8/25/94 |
| emsV noitst∂ | South Bay | Redwood Creek | San Bruno Shoal | Oyster Point | Yerba Buena Island | Horseshoe Bay | Richardson Bay | Point Isabel Red Rock | San Pablo Bay | Pinole Point | Davis Point | Napa River | Pacheco Creek | GIIZZIY Day Honker Bav | Sacramento River | San Joaquin River | South Bay | Dumbarton Bridge Redwood Creek | San Bruno Shoal | Oyster Point | Alameda Verha Buena Island | Horseshoe Bay | Richardson Bay | Point Isabel | Red Rock | Sam Papio Bay | Davis Point | Napa River | Pacheco Creek | Grizzly Bay | Honker Bay Secremento Diver | San Joaquin River |
| Station Code | BA21 | BA41 | BB15 | BB30 | BC11 | BC21 | BC32 | BC60 BC60 | BD22 | BD31 | BD41 | BD50 | BF 10 BF 21 | BF40 | BG20 | BG30 | BA21 | BA30 RA41 | BB15 | BB30 | BB70 BC11 | BC21 | BC32 | BC41 | BC60 | | | BD50 | BF10 | BF21 | BF40 | BG30 |

| BA33 BB441 BB441 BB441 BB441 BB441 BB441 BB441 BB441 BB441 BB421 B | Station Code |
|---|-----------------|
| San Bruno Shoal Oyster Point Alameda Yerba Buena Island Horseshoe Bay Richardson Bay Pacheco Creek Grizzily Bay Honker Bay San Joaquin River San Joaquin River San Joaquin River San Joaquin River San Joaquin River San Bruno Shoal Oyster Point Alameda Yerba Buena Island Horseshoe Bay Pinole Point Bay Richardson Bay Pinole Point Davis Point Napa River Pacheco Creek Grizzily Bay Richardson Bay Pinole Point Davis Point Napa River Pacheco Creek Grizzily Bay Honker Bay Honker Bay Sacramento River San Joaquin River San Joaquin River | Station |
| 2/16/94 2/15/94 2/15/94 2/15/94 2/15/94 2/15/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/10/94 2/10/94 2/10/94 2/10/94 2/10/94 8/30/94 8/30/94 8/30/94 8/29/94 8/29/94 8/29/94 8/26/94 8/26/94 8/25/94 8/25/94 | Date |
| 35.4.42 36.4.52 3.99 24.85 22.98 24.85 24.85 24.85 24.61 10.46 0.61 9.89 18.48 11.44 41.29 12.98 11.44 41.26 13.53 19.18 11.44 41.26 13.53 19.18 11.44 41.26 26.2 2.6.2 1.61 1.61 0.9 1.61 | Total PCBs |
| ₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽₽ | PCB 007/9 |
| NND | PCB 008/5 |
| *************************************** | 5 PCB 015 |
| 1.2 0.38 0.38 0.38 0.43 0.45 0.61 0.55 0.61 0.55 0.62 0.62 0.62 0.62 0.62 0.65 0.62 0.65 0.62 0.62 0.62 0.76 0.26 0.26 0.26 0.26 0.26 0.26 0.26 0.2 | PCB 016/32 |
| | 5 PCB 018 |
| | 5 PCB 022/51 |
| *************************************** | 5 PCB 024/27 |
| *************************************** | 5 PCB 025 |
| | 5 PCB 026 |
| | 5 PCB 028 |
| ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ | 5 PCB 029 |
| | PCB 031 |
| | 5 PCB 033/53/20 |
| 1.22 0.62 0.62 0.62 0.55 0.55 0.55 0.55 0.55 0.55 0.55 0.5 | PCB 037/42/59 |
| 699999999999999999999999999999999999999 | 5 PCB 040 |
| | PCB 041/64 |
| | PCB 044 |
| | 5 PCB 045 |

Units $\mu g/kg$, dry weight (ppb). ND = not detected, M = Matrix interference.

| PCB 101/90 | 1.38 1.48 1.44 0.9.9 0.65 0.65 0.67 0.67 0.67 0.67 0.67 0.67 0.67 0.67 | 2 2 |
|---------------|--|---------------------------------------|
| PCB 100 | $\overset{\circ}{}\overset{\circ}$ | 2 2 |
| PCB 099 | 0.93 0.64 0.64 0.64 0.67 0.64 0.64 0.64 0.64 0.64 0.64 0.64 0.64 | 2 2 2 |
| PCB 097 | °. 6 6 7 7 7 8 8 9 9 9 9 9 9 9 9 9 9 9 9 9 9 9 | 2 2 |
| PCB 092 | 0.58 0.58 0.57 0.56 0.56 0.00 0.56 0.00 0.00 0.00 0.00 | a a |
| PCB 088 | 88888888888888888888888888888888888888 | 22 |
| PCB 087/115 | ⁶ , | a a |
| PCB 085 | 222222222222222222222222222222222222222 | 99 |
| PCB 084 | 222222222222222222222222222222222222222 | a a |
| PCB 083 | N N N N N N N N N N N N N N N N N N N | ₽₽ |
| PCB 082 | $\begin{smallmatrix} & 0 \\ & $ | a a |
| PCB 074 | $\overset{O}{=} \overset{O}{=} \overset{O}$ | 9 9 2 |
| PCB 070 | $\begin{smallmatrix} 0.8\\ 0.8\\ 0.8\\ 0.6\\ 0.6\\ 0.6\\ 0.8\\ 0.8\\ 0.8\\ 0.8\\ 0.8\\ 0.8\\ 0.8\\ 0.8$ | 2 Q |
| PCB 066 | ND 0.55 0.67 0.67 0.55 0.55 0.55 0.43 0.00 0.43 0.43 0.43 0.67 0.67 0.67 0.67 0.56 0.56 0.56 0.56 0.55 0.56 0.00 0.00 | 9 9 |
| PCB 060/56 | 1.74 1.79 1.79 1.79 1.00 1.74 1.00 1.74 1.01 1.02 1.74 1.02 1.02 1.02 1.02 1.02 1.02 1.02 1.02 | ND 0.51 |
| PCB 052 | 1.67 1.67 0.52 0.69 0.45 0.45 0.45 0.34 0.34 0.34 0.65 0.37 0.65 0.37 0.65 0.73 0.73 0.73 0.73 0.73 0.73 0.73 0.73 | 9 9 |
| PCB 049 | 0.66 0.54 0.66 0.66 0.48 0.48 0.74 0.037 0.37 0.37 0.37 0.37 0.07 | a a |
| PCB 047/48/75 | 1.29 0.7 0.76 0.76 0.76 0.76 0.76 0.76 0.76 | 2 2 2 |
| PCB 046 | | a a |
| əteD | 2/16/94 2/15/94 2/15/94 2/15/94 2/15/94 2/15/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/11/94 2/10/94 8/30/94 8/30/94 8/30/94 8/30/94 8/30/94 8/29/94 8/29/94 8/25/94 8/25/94 8/25/94 | 8/25/94 8/25/94 |
| noitst2 | South Bay Dumbarton Bridge Redwood Creek San Bruno Shoal Oyster Point Alameda Yerba Buena Island Horseshoe Bay Richardson Bay Richardson Bay Richardson Bay Pinole Point Davis Point Davis Point Pacheco Creek Grizzly Bay Honker Bay San Bruno Shoal Oyster Point Alameda Yerba Buena Island Horseshoe Bay Red Rock San Buuna Island Horseshoe Bay Richardson Bay Pinole Point Davis Poin | Sacramento River San Joaquin River |
| Station Code | BA21 BA21 BA21 BA31 BA31 BC31 BC32 BC32 BC31 BC31 BC31 BC31 BC31 BC31 BC31 BC31 | BG20 BG30 |

| BG30 | BG20 | BF40 | BF21 | BF10 | BD50 | BD41 | BD31 | BD22 | BC60 | BC41 | BC32 | BC21 | BC11 | BB 70 | BB30 | BB 15 | BA41 | BA30 | BA21 | BG30 | BG20 | BF40 | BF21 | BF10 | BD50 | BD41 | BD31 | BD22 | BC60 | BC41 | BC32 | BC21 | BC11 | BB70 | BB30 | BB 15 | BA41 | BA30 | BA21 | Stat | ion | Cod | е |
|-------------------|------------------|------------|-------------|---------------|------------|-------------|--------------|---------------|----------|--------------|----------------|---------------|--------------------|---------|--------------|-----------------|---------------|------------------|-----------|-------------------|------------------|------------|-------------|---------------|------------|-------------|--------------|---------------|----------|--------------|----------------|---------------|--------------------|----------|--------------|-----------------|---------------|------------------|-----------|------|----------------|-------|-------|
| San Joaquin River | Sacramento River | Honker Bay | Grizzly Bay | Pacheco Creek | Napa River | Davis Point | Pinole Point | San Pablo Bay | Red Rock | Point Isabel | Richardson Bay | Horseshoe Bay | Yerba Buena Island | Alameda | Oyster Point | San Bruno Shoal | Redwood Creek | Dumbarton Bridge | South Bay | San Joaquin River | Sacramento River | Honker Bay | Grizzly Bay | Pacheco Creek | Napa River | Davis Point | Pinole Point | San Pablo Bay | Red Rock | Point Isabel | Richardson Bay | Horseshoe Bay | Yerba Buena Island | Alameda | Oyster Point | San Bruno Shoal | Redwood Creek | Dumbarton Bridge | South Bav | Stat | ion | | |
| 8/25/94 | 8/25/94 | 8/25/94 | 8/25/94 | 8/25/94 | 8/26/94 | 8/26/94 | 8/26/94 | 8/26/94 | 8/26/94 | 8/29/94 | 8/29/94 | 8/29/94 | 8/29/94 | 8/30/94 | 8/29/94 | 8/30/94 | 8/30/94 | 8/30/94 | 8/30/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/14/94 | 2/14/94 | 2/14/94 | 2/14/94 | 2/15/94 | 2/15/94 | 2/15/94 | 2/15/94 | 2/16/94 | 2/16/94 | Date | 9 | | |
| ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.63 | 0.61 | ND | 0.43 | ND | ND | ND | Ŋ | ND | ND | ND | ND | ND | ND | 0.3 | ND | Ŋ | ND | ND | ND | ND | ß | 0.38 | ND | ND | 0.54 | ND | РСВ | 10 |)5 | |
| ND | Ð | B | B | ß | B | B | B | B | ND | B | B | B | B | 0.48 | Ð | B | B | B | B | ND | ND | ND | B | ND | ß | 1.69 | B | ND | ND | Ð | ß | ß | ß | ND | B | B | B | ß | S | PCB | 5 10 | 07/10 | 8/144 |
| 0.39 | 0.45 | 1.85 | 2.12 | 1.29 | 2.09 | 0.49 | 4.56 | 2.45 | ND | 2.65 | 2.44 | 1.84 | 2.58 | 4.65 | 2.47 | 2.38 | 2.46 | 2.77 | 3.24 | ND | Ŋ | ND | 1.11 | ND | 0.84 | ND | 0.86 | Ŋ | Ŋ | 0.75 | 0.7 | 0.85 | 0.93 | -1 -1 | 0.83 | 0.43 | 1.73 | 1.57 | 2.65 | PCB | 1 [.] | 10/77 | |
| ND | ß | ß | 0.51 | ß | 0.52 | ß | 1.32 | ß | ND | 0.62 | 0.58 | 0.62 | 0.92 | 1.9 | 0.67 | 1.08 | 0.84 | 0.96 | 1.15 | Ŋ | ND | ND | ß | ND | ß | ß | 0.77 | Ŋ | Ŋ | 0.5 | 0.51 | 0.58 | 0.54 | 0.8 | 0.59 | ß | 1.42 | 1.62 | 1.82 | РСВ | 1 1 | 18 | |
| ND | ß | Ζ | ≤ | ß | Ζ | ≤ | ≤ | ≤ | ND | ≤ | ≤ | ≤ | ≤ | ND | ≤ | Ŋ | ≤ | ≤ | ≤ | Ŋ | B | ß | ß | ND | ≤ | ß | ND | ß | Ŋ | ß | ≤ | ND | ND | ND | Ζ | ß | ND | N i | ZD | РСВ | 12 | 28 | |
| ND | Ð | B | B | B | B | B | B | B | ND | B | ND | B | ND | ND | Ð | B | Ð | B | ND | ND | B | B | B | ND | B | B | ND | Ð | ND | Ð | B | ND | ND | ND | ND | B | ND | ß | ZD | РСВ | 12 | 29 | |
| ND | ß | ß | ß | ß | ß | ß | ß | ß | Ŋ | ß | Ŋ | Ŋ | ß | Ŋ | ß | ß | ß | ß | B | Ŋ | ß | ß | ß | Ŋ | ß | ß | B | ß | B | ß | ß | Ŋ | Ŋ | Ŋ | B | ß | Ŋ | ß | ZD | РСВ | 13 | 36 | |
| ND | Ŋ | 0.63 | 0.81 | 0.69 | 0.96 | Ð | 0.64 | 1.26 | ND | 0.94 | 1.ω | 1.44 | ND | 1.25 | 1.24 | ß | 1.16 | 1.75 | 1.99 | ND | ß | Ð | ß | ND | Ŋ | Ð | D | B | D | Ð | ND | ND | ND | ND | ND | Ð | ND | S | ZD | PCB | 1 | 37/17 | 6 |
| ND | 0.41 | 0.67 | 1.07 | 0.33 | 0.97 | 0.29 | 2.43 | 0.77 | ND | 1.15 | 0.83 | 1.33 | 1.78 | 3.21 | 1.28 | 1.51 | 1.25 | 1.48 | 1.8 | ND | 0.35 | 1.32 | 2.45 | ND | 1.83 | 0.42 | 1.54 | 1.38 | ND | 1.69 | 1.14 | 1.46 | 1.96 | 2.46 | 2.23 | 0.87 | 2.95 | 3.54 | 3.84 | PCB | 1 | 38/16 | 0 |
| ND | Ð | B | B | Ð | B | Ð | 0.56 | Ð | Ð | Ð | B | Ð | B | 0.85 | Ð | Ð | Ð | Ð | B | Ð | Ð | B | B | Ð | B | B | 0.38 | Ð | B | Ð | B | Ð | B | Ð | B | Ð | 0.48 | B | 0 6 | PCB | 14 | 41/17 | 9 |
| ND | ND | Ŋ | ND | ND | ND | Ŋ | Ŋ | Ŋ | ND | ND | ND | ND | ND | 0.77 | ND | Ŋ | Ŋ | Ŋ | Ŋ | Ŋ | Ŋ | ND | ND | ND | ND | ND | 0.28 | Ŋ | Ŋ | ND | ND | Ŋ | ND | ND | B | ND | 0.43 | 0.49 | Z | РСВ | 14 | 16 | |
| ND | ND | ND | ND | ND | ND | ND | 1.15 | ND | ND | ND | ND | 0.54 | 0.96 | 1.69 | 0.45 | 0.86 | ND | 0.47 | 0.6 | ND | ND | ND | ND | ND | 0.68 | ND | 0.95 | ND | ND | 0.64 | 0.65 | 0.9 | 1.09 | 1.05 | 1.28 | 0.4 | 1.52 | 1.71 | 1 56 | РСВ | 14 | 49/12 | 3 |
| ND | Ð | B | B | Ð | B | B | B | B | Ð | B | B | ND | ND | 0.72 | ND | Ŋ | ß | Ŋ | ND | ß | B | B | B | Ð | B | B | 0.43 | B | B | B | B | ND | 0.4 | 0.46 | 0.9 | B | P | N i | S | РСВ | 15 | 51 | |
| ND | 0.36 | 0.88 | 1.15 | 0.34 | 1.14 | Ŋ | 2.72 | 0.91 | ND | 1.4 | 1.11 | 1.25 | 2.13 | 3.7 | 1.46 | 1.65 | 1.47 | 1.66 | 2.06 | Ŋ | Ŋ | 1.35 | 1.84 | ND | 2.3 | 0.39 | 1.84 | 1.06 | Ŋ | 1.66 | 1.23 | 1.77 | 2.37 | 2.54 | 2.2 | 0.9 | 3.56 | 3.86 | 4 4 4 | РСВ | 1 | 53/13 | 2 |
| ND | ND | ND | ND | ND | ND | ND | Ŋ | ND | ND | ND | ND | ND | ND | 0.65 | ND | ND | ND | ND | 0.48 | ND | ND | ND | ND | ND | ND | ND | ND | ND | Ŋ | ND | ND | ß | 0.41 | 0.48 | ND | ND | ND | 0.51 | ZD | PCB | 1 | 56/17 | 1 |
| ND | Ŋ | ß | ß | Ŋ | ß | ß | ß | ß | Ŋ | Ð | ND | ND | ND | ß | ND | ND | ND | ND | ß | ß | ß | ß | ß | Ŋ | ß | ß | ß | ß | ß | ß | ß | ND | ND | 0.58 | D | ND | 0.87 | N | z | PCB | 15 | 58 | |
| ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ß | ß | ß | ND | B | B | ß | B | ND | ND | ND | ND | Z | ND | ND | ND | Z | Z | ND | ND | ND | ND | ND | ND | ND | ND | B | ß | ZD | РСВ | 16 | 67 | |
| Z | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | ≤ | Z | ≤ | Z | ≤ | ≤ | ND | Ŋ | ≤ | ≤ | ND | ≤ | ND | ≤ | Z | ≤ | Z | ≤ | Z | ≤ | Ζ | ≤ | Ζ | Ζ | Z | Ξ | PCB | 17 | 70/19 | 0 |
| ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | B | B | B | ND | B | B | B | B | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | ND | 0.44 | B | ND | ZD | ND | B | 0.43 | ZŊ | РСВ | 17 | 72 | |

Table 3.23. PCB concentrations in sediment, 1994. (Continued)

Units µg/kg, dry weight (ppb). ND = not detected, M = Matrix interference.

| PCB 209 | | Z | Q | QN | 22 | | Q | QN | a 2 | 20.0 | | 2 Q | Q | QN | Q | | | | Z | Q | Q | | | Z | Q | Q | Q | QN | Q | Q ! | Q I | | | 2 Q |
|-----------------|--------------------|---------------|-----------------|--------------|--------------------------------|---------------|----------------|--------------|----------|-------------------------------|-------------|-------------|---------------|-------------|------------|------------------|--------------------------------|------------------|---------------|-----------------|--------------|---------|--------------------|----------------|--------------|----------|---------------|--------------|-------------|------------|---------------|--------------------|------------------|-------------------|
| PCB 206 | | | Q | Q | 99 | | Q | QN | 9 | | | | Q | QN | Q | 22 | | | 22 | Q | Q | | | 22 | Q | QN | Q | Q | Q | Q : | Q : | Q Z | | 22 |
| PCB 205 | | C ON | Q | QN | 0.95 ND | | g | QN | 2 | | | 2 Q | Q | QN | Q | 22 | | | Z | QN | Q | 2 | | Z | Q | QN | Q | QN | Q | Q ! | Q I | Q Z | | 22 |
| PCB 201 | UN v | 1.04 0.74 | Ð | 0.37 | 0.78 | | 0.61 | 0.48 | ₽¦ | 0.5 7 | | 1.02 | Ð | 0.95 | Ð | 22 | | | 22 | 0.96 | Ð | 1.13 | 00.1 | Q | Ð | Q | Ð | 0.55 | 9 | 2 | 2 | 9 | | 29 |
| PCB 200 | | | Q | Q | 22 | | 2 | QN | 22 | | | ŻŻ | Q | QN | Q | 22 | | | 22 | QN | Q | | | 22 | Q | QN | Q | Q | Q | Q ! | Q : | | | 2 Q |
| PCB 196/203 | ND 75 | 0.54 | Q | 0.39 | 0.55 | 4.0 | Q | QN | 22 | | | ŻŻ | Q | QN | Q | 22 | | | 22 | QN | Q | 0.6 | | 22 | Q | QN | Q | 0.51 | Q | Q ! | Q : | | | 2 Q |
| PCB 195/208 | | | Q | QN | 22 | | g | QN | 22 | | | 2 Q | Q | QN | Q | 22 | | | Z | QN | Q I | | | Z | Q | QN | Q | QN | Q | Q ! | Q I | Q Z | | 22 |
| PCB 194 | UN ND | 0.5 | Q | 0.47 | 0.51 0.6 | | 0.37 | QN | 22 | | | 2 Q | Q | QN | Q | 22 | | | 2 Z | QN | Q | 0.6 | | 2 Z | Q | Q | Q | Q | Q | Q ! | Q I | Q Z | | 22 |
| PCB 191 | 99 | 22 | Q | Ð | 0.62 288 | ND ND | 2 | QN | | | | 22 | QN | QN | Ð | | | Ē | 2 | QN | Q ! | | | 2 | 9 | QN | 9 | Q | Q | ₽: | Q ! | ₽₽ | | 22 |
| PCB 189 | Q Z | 2 Q | QN | Q | 99 | 2 | 2 | Q | | | | 22 | Q | QN | Q | 22 | | Ż | g | QN | Q ! | | | g | Q | Q | Q | Q | g | ₽: | Q : | | | 29 |
| PCB 187/182/159 | 1.2 | 1.02 | QN | 0.63 | 0.78 | 0.52 | Q | 0.55 | a So | 0.03 | | 0.65 | Q | QN | Q | 22 | | 0.63 | 0.51 | 0.47 | 0.5 | 1.24 | 0.43 | 0.4 | 0.51 | Q | Q | 0.94 | g | ₽: | Q : | | | 29 |
| PCB 185 | DN C | ND 04.0 | QN | Q | 99 | 2 2 2 | Q | QN | | | | 2 2 2 | QN | QN | Q | | | | 2 Z | Q | Q ! | | | 2 Z | Q | QN | Q | Q | Q | 9 : | Q ! | | | 22 |
| PCB 183 | | NDN | QN | Q | | | g | Q | 22 | | | 2 Q | Ð | Q | Q | 22 | | ŻŻ | 2 Z | QN | Ð | 0.64 | NDN | 2 Z | Q | Q | Q | Q | g | Q : | 9 | Q 2 | | 22 |
| PCB 180 | 1.77 | 1.52 | 0.45 | 0.98 | 1.54 1.66 | | 0.8 | 0.86 | | 0.05 | | 1.46 | Q | 1.5 | 1.76 | 22 | UN 4 | 0.88 | 0.83 | 0.81 | 0.9 | 2.11 | 0.82 | 0.72 | 0.84 | Q | 0.49 | 1.56 | Q | 0.85 | Q į | 0.63 | 0.30 | ON ON |
| PCB 178 | 22 | 22 | Q | Q | ND 75 | 1.5 | Q | Q | ND VD | CI.I | | 2 g | QN | QN | Q | 22 | | | g | Q | Q ! | | | 2 | Q | QN | Ð | Q | Q | ₽ : | Q I | 22 | | 29 |
| PCB 177 | 0.69 | 0.61 | QN | Q | 0.68 | 0.59 | 0.45 | 0.64 | | | | 29 | QN | QN | Q | 22 | | Ē | 2 | 0.53 | Q Z | 0.87 | 0.0 | Q | Q | QN | Q | Q | Q | ₽: | Q ! | | | 29 |
| PCB 174 | | 0.56 | QN | 0.4 | 0.58 | 0.4 | Q | Q | | UN 0 0 | | 22 | QN | QN | Q | | | | g | QN | Q į | 0.74 | | g | Q | QN | Q | 0.44 | g | 9 : | Q : | | | 2 9 |
| Date | 2/16/94 2/16/94 | 2/15/94 | 2/15/94 | 2/15/94 | 2/15/94 2/14/94 | 2/14/94 | 2/14/94 | 2/14/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/10/94 8/30/04 | 8/30/94 | 8/30/94 | 8/30/94 | 8/29/94 | 8/30/94 | 0/23/34 8/29/94 | 8/29/94 | 8/29/94 | 8/26/94 | 8/26/94 | 8/26/94 | 8/26/94 | 8/26/94 | 8/25/94 | 8/25/94 °/75/04 | 8/25/94 | 8/25/94 |
| Station | South Bay | Redwood Creek | San Bruno Shoal | Oyster Point | Alameda Verha Bijena Island | Horseshoe Bav | Richardson Bay | Point Isabel | Red Rock | San Pablo Bay Dinole Doint | Davis Point | Napa River | Pacheco Creek | Grizzly Bay | Honker Bay | Sacramento River | San Joaquin River South Bay | Dumharton Bridge | Redwood Creek | San Bruno Shoal | Oyster Point | Alameda | Horseshoe Bav | Richardson Bay | Point Isabel | Red Rock | San Pablo Bay | Pinole Point | Davis Point | Napa River | Pacheco Creek | Grizzly Bay | Sacramento River | San Joaquin River |
| Station Code | BA21 BA21 | BA41 | BB15 | BB 30 | BB70 BC11 | BC21 | BC32 | BC41 | BC60 | | | BD50 | BF10 | BF21 | BF40 | BG20 | D650 B021 | BA30 | BA41 | BB15 | BB30 | | BC 1 | BC32 | BC41 | BC60 | BD22 | BD31 | BD41 | BD50 | BF10 | BF21 DE40 | BG20 | BG30 |

| BG30 | | BF21 | BF10 | BD50 | BD41 | BD31 | | BC41 | BC32 | BC21 | BC11 | BB70 | BB30 | | BA30 | BA21 | BG30 | BG20 | BF40 | BF21 | BF10 | BD50 | BD41 | BD31 | BD22 | | | | | 8870 | BB30 | BB15 | BA41 | BA21 BA30 | Station Code |
|-------------------|------------------|-------------|---------------|------------|-------------|--------------|---------------|--------------|----------------|---------------|--------------------|---------|--------------|-----------------|--------------------|--------------|-------------------|------------------|------------|-------------|---------------|------------|-------------|---------------|---------------|-----------|---------------------|----------------|--------------------|-----------------------|--------------|-----------------|---------------|-------------------------------|--------------------|
| San Joaquin River | Sacramento Diver | Grizzly Bay | Pacheco Creek | Napa River | Davis Point | Pinole Point | San Dable Bav | Point Isabel | Richardson Bay | Horseshoe Bay | Yerba Buena Island | Alameda | Oyster Point | San Bruno Shoal | Dumbarton Bridge | South Bay | San Joaquin River | Sacramento River | Honker Bay | Grizzly Bay | Pacheco Creek | Napa River | Davis Point | Pinole Point | San Pablo Bav | Red Rock | Point leabel | Disherdoon Bow | Terba Duena Island | Alameda | Oyster Point | San Bruno Shoal | Redwood Creek | South Bay Dumbarton Bridge | Station |
| 8/25/94 | 8/25/04 | 8/25/94 | 8/25/94 | 8/26/94 | 8/26/94 | 8/26/94 | 8/26/94 | 8/29/94 | 8/29/94 | 8/29/94 | 8/29/94 | 8/30/94 | 8/29/94 | 8/30/94 | 8/30/94 8/30/94 | 8/30/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/10/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/11/94 | 2/11/04 | 2/14/94 | 2/14/94 | 2/14/94 | 2/15/94 | 2/15/94 | 2/15/94 | 2/15/94 | 2/16/94 2/16/94 | Date |
| 8 | 33 | 5 Z | 1.13 | ß | N S | 0.57 | <u>s</u> z | ŞB | B | ND | Ŋ | 0.26 | Z d | Si | 32 | 0.22 | Ð | ND | 0.63 | Ŋ | Ŋ | 1.44 | N S | с л | Z Z | 58 | 33 | | 200 | 0.35 | 0.47 | ß | 0.47 | 1.71 1.24 | Total Chlordanes |
| 0.88 | 3 A.SO | 3.91 | 2.62 | 3.7 | 0.73 | 5.04 | | 2.97 | 2.46 | 33.9 | 2.64 | 3.66 | 1.97 | s 0. 20 | 1.05 | 0.30 0.35 | 0.2 | 1.25 | 6.96 | 10.4 | 0.48 | 6.48 | 1.18 | 37 | 2.64 | | ч. 1 1 5 | × 1 × 0 × 0 | о. 104 г | 4.87 | 2.72 | 1.09 | 3.96 | 6.13 5.71 | Total DDTs |
| R S S | 33 | ΒB | Ş | Ŋ | N | 23 | <u>z</u> z | ŞÖ | B | 0.27 | ND | 0.57 | Z ; | 0 29 | ŞZ | E | 0.37 | 0.23 | 0.9 | 1.96 | 0.26 | 1.05 | 0.25 | 0.36 | 0.31 | 0.16 | 0.42 | 0.79 | 0.19 | 0.59 | 2.95 | 0.21 | 0.34 | 1.21 0.25 | Total HCHs |
| 58 | 33 | 58 | ß | ND | B | 53 | <u>s</u> z | 58 | ŝ | 0.43 | Ð | 0.53 | 0.33 | Ş | ΞZ | ; Z | 0.19 | ND | Ş | 0.55 | B | B | 2 S | 016 | 58 | 58 | 33 | Ēē | | 3 Z | ZD | ß | Ş | 0.4 0.27 | Aldrin |
| 5 | 33 | SB | 0.36 | ND | B | Se | S C | 38 | B | ND | B | ND | Z | Ş | ΞZ | 0.22 | B | ND | 0.3 | B | B | 0.38 | Z | Ş | 88 | 5 | 33 | Ēē | ŝē | ΒZ | Z | B | ß | 0.4 0.26 | Alpha-Chlordane |
| 5 | 33 | 58 | ß | ND | B | Ş | SZ | 58 | S | Ŋ | ß | Ŋ | Z ä | S | 32 | iZ | 0.37 | 0.23 | 0.9 | 1.56 | 0.26 | 1.05 | 0.25 | 0.36 | 0.31 | 0 - 16 | 33 | | 3 | 0.25 | 0.67 | 0.21 | 0.34 | 0.59 ND | Alpha-HCH |
| 58 | 33 | ΒZ | R | Ŋ | B | 5 | <u>z</u> z | ŝ | Ş | ND | Ð | 0.57 | Z ; | 0 2 9 | ŞZ | j | B | ND | Ð | B | ND | Z | Z i | 3 | 2 | 5 | 33 | Ēē | 33 | ΒZ | 1.47 | B | B | 8 8 | Beta-HCH |
| 58 | 33 | 58 | 0.19 | Ð | B | 0.29 | ŝē | 58 | ŝ | ND | Ð | 0.26 | 5 | 5 | 32 | ; Z | B | ND | Ş | B | P | 0.31 | ND | 0.25 | 58 | 58 | 33 | Ēē | 58 | ΒZ | ZD | ß | 0.47 | 0.58 0.39 | Cis-Nonachlor |
| 58 | 33 | 58 | Ş | Ð | B | 53 | ŝē | 58 | ŝ | ß | Ð | Ŋ | 5 | 5 | 32 | ; Z | B | ND | Ş | B | B | B | 5 | 3 | 58 | 58 | 33 | Ēē | 58 | ΒZ | 0.44 | ß | Ş | 8 8 | Delta-HCH |
| 58 | 33 | 58 | 0.25 | ß | S | 0.29 | SE | 58 | S | ß | ß | 0.28 | | 0. 10 1 | 32 | 0.22 | ß | 0.19 | 0.51 | 0.8 | ß | 0.79 | 0.2 | ດ : ນີ້ເ | 5 a | | 0.34 | 0.42 | 0.04 | 0.39 | 0.51 | 0.22 | 0.55 | 0.88 0.44 | Dieldrin |
| 8 | 33 | ΒB | ß | ß | N | B | ΞZ | ŞQ | P | ß | ND | ß | Z d | Ş | SZ | S | ß | ND | ß | 0.52 | B | Z | 5 | S | 0.25 | 5 | 33 | ŝē | 58 | 0.4 | N | B | ß | 1.28 0.65 | Endrin |
| 2 a | 33 | SB | 0.29 | Ŋ | B | 0.28 | ΞZ | jZ | B | ß | B | B | Z á | 5 | 32 | B | P | ß | B | B | B | 0.38 | Z S | 0. 27 7 | 23 | 58 | 33 | ο Ο Ο | 25 | 0.35 | B | ß | B | 0.31 0.59 | Gamma-Chlordane |
| 2 a | 33 | SB | B | Ŋ | Z i | 33 | ΞZ | jZ | B | 0.27 | B | B | Z á | 5 | 32 | B | P | B | B | 0.4 | B | B | Z á | 5 | 23 | | 0.42 | 0.07 | 0.19 | 0.34 | 0.37 | ₽ | B | 0.62 0.25 | Gamma-HCH |
| 88 | 33 | ΒB | B | ND | Z i | 38 | ΒZ | S | R | ND | Ŋ | Ŋ | Z d | S | ŞZ | B | Ŋ | ND | B | B | P | Z | 2 a | Ş | 88 | 58 | 33 | 52 | Ēē | ΒZ | 0.47 | B | Ŋ | 8 8 | Heptachlor |
| 88 | 33 | 5 C | Ð | Ŋ | Z i | 58 | ΒZ | S | B | ND | Ŋ | Ŋ | Z Z | 5 | 52 | B | Ŋ | ND | Ŋ | ND | Z | Z | Z Z | 5 | 58 | 58 | 33 | BB | Ēē | 5 C | B | ß | Ŋ | 8 8 | Heptachlor Epoxide |
| ND | 0.44 | 0.98 | Ŋ | ND | Z (| о 7 5 С | ΒZ | S | Ŋ | ND | Ŋ | ND | Z Z | 5 | 32 | B | Ŋ | ND | 0.6 | 1.04 | P | Z | ND 2 | 0.35 | 88 | | | | 32 | 5 C | D | ß | Ŋ | 8 8 | Hexachlorobenzene |
| 8 | 33 | ΒB | Ŋ | Ŋ | Z i | Ş | ΒZ | B | B | ND | Ŋ | 0.25 | Z d | 5 | ŞZ | B | Ŋ | ND | Ŋ | ND | Ŋ | P | 2 a | 5 | B | 38 | 33 | BB | Ēē | ΒZ | B | P | Ŋ | 88 | Mirex |
| 88 | 33 | ΒB | P | ND | N I | 0.27 | ΒZ | Ş | B | 0.23 | 0.18 | 0.26 | S S | S | 32 | S | Ŋ | Ŋ | Ŋ | 0.38 | P | P | N S | 0.14 | 0.29 | | 0.32 | 0.44 | 0.00 | 0.36 | B | B | 0.36 | 0.44 0.34 | o,p'-DDD |
| 88 | 33 | ΒB | B | ND | Z i | 58 | ΒZ | S | B | Ŋ | Ŋ | Ŋ | S S | 5 | 32 | S | Ŋ | Ŋ | 0.41 | 0.56 | B | B | N S | 0 19 | 58 | 58 | 33 | ΒZ | | 2 2 2 2 2 | 0.67 | ß | D | 88 | o,p'-DDE |
| 88 | 33 | ΒÖ | 0.16 | B | Z i | B | ΒZ | Ş | P | 0.82 | D | Ŋ | Z Z | S | 32 | B | Ŋ | Ŋ | Ŋ | ND | Z | Z | Z Z | 3 | 22 | 58 | 33 | | 2 | 5 C | Z | B | B | 8 8 | o,p'-DDT |
| 88 | 33 | 5 Z | Ð | Ŋ | Z i | 53 | ΒZ | S | B | ND | Ŋ | Ŋ | Z Z | 5 | ΞZ | B | Ŋ | ND | ß | ß | P | Z | Z Z | 3 | B | 58 | 33 | Ë | Ēē | 5 Z | D | P | D | 88 | Oxychlordane |
| 0.46 | | 2.13 | 1.2 | 2.21 | 0.41 | 2.99 | | 2.03 | 1.53 | 2.26 | 1.52 | 1.93 | 1.21 | C | 1.55 | 1.84 | 0.2 | 0.44 | 2.66 | 4 | 0.27 | 3.09 | 0.37 | л 54 | 1.28 | | א ר. שי. א מו | 2.11 | | 2.39 | 1.05 | 0.57 | 2.11 | 3.01 2.89 | p,p'-DDD |
| 0.42 | 1.10 | 1.78 | 1.26 | 1.49 | 0.32 | 1.78 | | 0.94 | 0.72 | 1.15 | 0.94 | 1.13 | 0.76 | 0.25 | 1.1 0.81 | 1.51 | Ŋ | 0.81 | 3.27 | 4.3 | 0.21 | 2.84 | 0.39 | 1 | 1.07 | | 1.00 | 2 | 10.02 | 1.34 | _ | 0.52 | 1.49 | 2.68 2.48 | p,p'-DDE |
| 88 | 53 | βB | ß | ND | N I | 58 | ΒZ | S | 0.21 | 29.4 | ND | 0.34 | ND | 0.27 | 32 | B | Ŋ | ND | 0.62 | 1.11 | B | 0.55 | 0.42 | 0 7 0 | 88 | | 0.00 | 20.23 | | 0.78 | Z | ND | ND | 8 8 | p,p'-DDT |
| 88 | 33 | βB | 0.29 | ND | Z i | 58 | 5 Z | S | R | ND | Ŋ | Ŋ | Z Z | 3 | z z | B | ND | ND | 0.33 | ß | B | 0.37 | Z Z | 3 | 58 | 53 | 33 | 5 e | Ēē | 5 C | Z | Ŋ | ND | 0.42 ND | trans-Nonachlor |

| | | | Mean | % Su | rvival | Mean | % No | ormal |
|---------|--------------------|-----------------|------|----------|--------|-------|----------|-------|
| Station | | | Eoha | austo | rius | M | ytilus | 5 |
| Code | Station Name | Collection Date | | $\pm sd$ | | | $\pm sd$ | |
| Control | N/A | N/A | 97 | ± | 4.5 | 98 | ± | 2.3 |
| BA21 | South Bay | 2/15/95 | * 56 | ± | 16.7 | 98 | ± | 2.9 |
| BA41 | Redwood Creek | 2/15/95 | * 63 | ± | 16.8 | 93 | ± | 4.8 |
| BB15 | San Bruno Shoal | 2/15/95 | * 72 | ± | 14.4 | 96 | ± | 6.8 |
| BB70 | Alameda | 2/15/95 | * 53 | ± | 26.6 | * 66 | ± | 27.2 |
| BC11 | Yerba Buena Island | 2/14/94 | 83 | ± | 18.2 | 93 | ± | 4.1 |
| BC21 | Horshoe Bay | 2/14/94 | 83 | ± | 5.7 | 90 | ± | 4.2 |
| BC60 | Red Rock | 2/11/94 | 96 | ± | 2.2 | 97 | ± | 2.5 |
| BD30 | Pinole Point | 2/11/94 | * 72 | ± | 7.6 | 99 | ± | 1.2 |
| BD50 | Napa River | 2/11/94 | * 68 | \pm | 9.7 | 94 | ± | 5.8 |
| BF21 | Grizzly Bay | 2/10/94 | * 72 | ± | 15.7 | 84 | ± | 10.3 |
| BG20 | Sacramento River | 2/10/94 | 85 | \pm | 7.9 | * 1 | ± | 1.8 |
| BG30 | San Joaquin River | 2/10/94 | 82 | ± | 7.6 | * 0 | ± | 0.3 |
| Control | N/A | N/A | 86 | ± | 10.8 | 76 | ± | 15.9 |
| BA21 | South Bay | 8/30/94 | 75 | ± | 17.7 | 67 | ± | 11.7 |
| BA41 | Redwood Creek | 8/30/94 | 78 | ± | 9.7 | 72 | ± | 9.5 |
| BB15 | San Bruno Shoal | 8/30/94 | 86 | ± | 8.2 | 72 | ± | 7.0 |
| BB70 | Alameda | 8/30/94 | 82 | ± | 7.6 | 67 | ± | 17.2 |
| BC11 | Yerba Buena Island | 8/29/94 | 83 | ± | 5.7 | 64 | ± | 6.4 |
| BC21 | Horshoe Bay | 8/29/94 | 87 | ± | 5.7 | 60 | ± | 8.7 |
| BC60 | Red Rock | 8/26/94 | 87 | ± | 18.2 | 67 | ± | 4.6 |
| BD40 | Davis Point | 8/26/94 | 86 | ± | 13.9 | 71 | ± | 10.5 |
| BD50 | Napa River | 8/26/94 | 76 | ± | 6.5 | ** 10 | ± | 7.3 |
| BF21 | Grizzly Bay | 8/25/94 | 87 | ± | 6.7 | ** 9 | ± | 8.7 |
| BG20 | Sacramento River | 8/25/94 | 82 | ± | 15.2 | ** 2 | ± | 2.3 |
| BG30 | San Joaquin River | 8/25/94 | 83 | ± | 7.6 | ** 1 | ± | 0.4 |

| Table 3.25. | Means and | standard | d deviations | of % Sur | vival, usi | ng Eoh | austorius | est | uarius |
|-------------|-------------|------------|--------------|--------------------|------------|---------|-----------|-----|---------|
| (an amphi | pod), and % | Normal | Developmen | it, using <i>I</i> | Mytilus e | dulis 🛛 | embryos | (am | ussel), |
| for 1994 R | MP sedimer | nt cruises | 5. | | | | | | |

* Significantly different from controls based on ANOVA and Dunnett's statistical tests (alpha = 0.05). ** Significantly different (p<0.001) from controls based on a separate-variance t-test (1 tailed, alpha = 0.05).

| Units ex | pressed as dry weight. | | | | | | | | | | | | | | | | | | |
|-------------|------------------------------|---------|----------|------------|------------|------------|-------|------------|------------|---------|----------|------|------------|----------|-------------|-------------|---------------|----------|--------------|
| Station Coc | le Station | Date | Species | Ag uq/q | ۳d/d AI | As µa/a | Cd | Cr ua/a | Cu µa/a | Hg | Ni Ni | Pb | Se uq/q | Zn Zn | DBT ng/g | MBT ng/g | TBT * ng/g | ТРТ % | TTBT ng/g |
| BA10 | Covote Creek | 5/4/94 | oyster | 6.78 | 246.33 | 9.93 | 9.47 | 1.70 | 466.86 | 468.00 | 1.86 | 0.73 | 4.18 | 1252.56 | 104.00 | ND | 171.00 | 118.00 | ND |
| BA30 | Dumbarton Bridge | 5/4/94 | mussel | 0.43 | 292.14 | 11.30 | 6.32 | 4.79 | 6.26 | 269.00 | 4.79 | 0.72 | 2.86 | 173.88 | 89.30 | ND | 134.00 | 70.00 | ND |
| BA40 | Redwood Creek | 5/4/94 | mussel | 0.54 | 346.12 | 10.10 | 6.08 | 6.47 | 8.18 | 255.00 | 6.13 | 0.61 | 3.24 | 167.95 | 80.60 | ND | 139.00 | 107.00 | ND |
| BB71 | Alameda | 5/4/94 | mussel | 0.41 | 486.99 | 12.97 | 6.42 | 18.41 | 8.83 | 348.33 | 15.46 | 1.54 | 3.19 | 279.78 | 52.00 | ND | 153.77 | 73.33 | ND |
| BC10 | Yerba Buena Island | 5/4/94 | mussel | 0.25 | 486.14 | 14.80 | 6.21 | 3.89 | 8.72 | 282.00 | 4.05 | 0.74 | 4.14 | 219.94 | 117.00 | ND | 415.00 | 120.00 | ND |
| BC21 | Horseshoe Bay | 5/5/94 | mussel | 0.40 | 407.30 | 14.33 | 6.11 | 5.04 | 8.19 | 265.33 | 4.96 | 1.21 | 4.48 | 221.93 | 40.40 | ND | 101.17 | 76.33 | ND |
| BC60 | Red Rock | 5/5/94 | mussel | 0.50 | 634.14 | 10.30 | 7.15 | 7.30 | 8.69 | 348.00 | 6.60 | 2.59 | 2.96 | 367.97 | 76.70 | ND | 124.00 | 92.00 | ND |
| BD15 | Petaluma River | 5/5/94 | oyster | 9.13 | 483.96 | 11.70 | 14.13 | 3.06 | 523.55 | 373.00 | 2.75 | 0.88 | 4.11 | 1304.17 | 427.00 | 213.00 | 416.00 | 113.00 | ND |
| BD15 | Petaluma River | 5/5/94 | mussel | 0.67 | 1199.09 | 13.50 | 8.56 | 80.93 | 22.02 | 249.00 | 64.41 | 2.08 | 1.58 | 291.79 | 84.90 | ND | 123.00 | 98.00 | ND |
| BD20 | San Pablo Bay | 5/5/94 | oyster | 6.69 | 261.14 | 13.00 | 9.40 | 2.60 | 426.45 | 493.00 | 2.56 | 0.67 | 5.19 | 1207.69 | 91.50 | ND | 314.00 | 116.00 | ND |
| BD30 | Pinole Point | 5/5/94 | mussel | 0.33 | 987.97 | 15.20 | 9.24 | 9.37 | 10.19 | 336.00 | 8.15 | 2.90 | 2.75 | 369.52 | 100.00 | ND | 198.00 | 118.00 | ND |
| BD40 | Davis Point | 5/6/94 | oyster | 8.68 | 471.33 | 8.12 | 9.85 | 3.98 | 638.03 | 423.00 | 3.42 | 0.97 | 4.88 | 1529.41 | 85.00 | ND | 200.17 | 65.33 | ND |
| BD50 | Napa River | 5/5/94 | oyster | 5.09 | 411.42 | 10.50 | 13.93 | 2.90 | 683.65 | 592.00 | 3.06 | 0.76 | 3.56 | 1809.51 | 112.00 | ND | 232.00 | 116.00 | ND |
| BF20 | Grizzly Bay | 5/6/94 | clam | 0.37 | 791.38 | 24.50 | 1.51 | 6.78 | 52.87 | 276.00 | 7.12 | 1.00 | 2.99 | 114.56 | 156.00 | ND | 337.00 | 113.00 | ND |
| BG20 | Sacramento River | 5/6/94 | clam | 0.21 | 983.87 | 21.20 | 1.88 | 11.53 | 57.69 | 239.00 | 11.12 | 1.17 | 2.47 | 108.21 | 119.00 | ND | 189.00 | 94.00 | ND |
| BG30 | San Joaquin River | 5/6/94 | clam | 0.19 | 936.74 | 31.30 | 0.18 | 3.40 | 58.14 | 228.00 | 2.59 | 1.08 | 2.53 | 94.92 | 96.60 | ND | 167.00 | 95.00 | ND |
| T-0 | Lake Isabella | 1/17/94 | clam | 0.10 | 40.57 | 21.80 | 0.59 | 2.31 | 38.17 | 192.00 | 1.32 | 0.18 | 1.78 | 76.93 | 59.60 | ND | 49.50 | 109.00 | ND |
| T-0 | Tomales Bay | 1/17/94 | oyster | 8.39 | 192.68 | 12.10 | 8.73 | 5.39 | 259.21 | 395.00 | 4.16 | 0.18 | 3.45 | 745.22 | 95.10 | ND | 108.00 | 119.00 | ND |
| T-0 | Bodega Head | 1/17/94 | mussel | 0.24 | 43.32 | 17.40 | 8.15 | 5.92 | 6.11 | 262.00 | 5.74 | 0.71 | 3.38 | 243.63 | 86.20 | ND | 85.40 | 92.00 | ND |
| BA10 | Coyote Creek | 9/12/94 | oyster | 8.19 | 269.00 | 7.92 | 10.10 | 9.26 | 371.00 | 204.21 | 5.55 | 0.70 | 3.38 | 1650.00 | B | ZD | 147.00 | 69.00 | ND |
| BA30 | Dumbarton Bridge | 9/12/94 | mussel | 0.40 | 328.00 | 14.75 | 5.22 | 12.88 | 6.84 | 365.35 | 10.92 | 3.31 | 2.99 | 315.00 | B | Z | 104.00 | 70.00 | ND |
| BA40 | Redwood Creek | 9/12/94 | mussel | 0.42 | 235.00 | 7.91 | 2.62 | 13.07 | 4.95 | 873.02 | 11.14 | 2.90 | 3.07 | 269.00 | ZD | B | 88.00 | 69.00 | B |
| BB71 | Alameda | 9/12/94 | mussel | 0.29 | 199.67 | 13.53 | 6.85 | 2.78 | 3.43 | 334.14 | 2.28 | 1.37 | 2.97 | 183.00 | 57.35 | ND | 172.33 | 74.67 | ND |
| BC10 | Yerba Buena Island | 9/12/94 | mussel | 0.59 | 349.00 | 12.11 | 5.08 | 7.03 | 5.35 | 254.93 | 6.24 | 2.55 | 4.15 | 183.00 | 60.05 | ND | 234.00 | 34.00 | ND |
| BC21 | Horseshoe Bay | 9/13/94 | mussel | 0.29 | 228.33 | 13.42 | 2.66 | 2.14 | 3.68 | 235.15 | 1.34 | 1.31 | 4.68 | 122.33 | 36.67 | ND | 176.00 | 67.33 | ND |
| BC60 | Red Rock | 9/13/94 | mussel | 0.21 | 349.00 | 11.76 | 9.95 | 4.68 | 3.61 | 351.26 | 4.07 | 1.69 | 3.66 | 192.00 | 57.51 | ND | 214.00 | 67.00 | ND |
| BD15 | Petaluma River | 9/13/94 | oyster | 0.73 | 120.00 | 6.12 | 19.90 | 2.79 | 191.00 | 356.78 | 1.25 | 0.26 | 2.06 | 1030.00 | B | ND | 129.00 | 80.00 | ND |
| BD15 | Petaluma River | 9/13/94 | mussel | 0.19 | 103.00 | 8.15 | 1.77 | 45.75 | 3.95 | 248.94 | 22.29 | 0.88 | 2.49 | 124.00 | D | ZD | 94.10 | 72.00 | ND |
| BD20 | San Pablo Bay | 9/13/94 | oyster | 3.05 | 105.00 | 5.01 | 15.12 | 11.62 | 188.00 | 137.50 | 8.96 | 0.21 | 2.66 | 764.00 | B | ZD | 176.00 | 75.00 | ND |
| BD30 | Pinole Point | 9/13/94 | mussel | 0.26 | 298.00 | 9.36 | 4.63 | 11.10 | 6.49 | 1935.78 | 9.16 | 1.78 | 4.05 | 271.00 | B | B | 142.00 | 79.00 | B |
| BD40 | Davis Point | 9/14/94 | oyster | 2.68 | 151.33 | 8.93 | 12.62 | 4.26 | 236.33 | 193.05 | 2.02 | 0.39 | 1.91 | 906.00 | D | ZD | 261.67 | 73.00 | ND |
| BD50 | Napa River | 9/14/94 | oyster | 2.10 | 90.00 | 8.39 | 20.46 | 43.43 | 198.00 | 201.30 | 28.32 | 0.18 | 3.56 | 997.00 | 141.88 | N | 670.00 | 75.00 | B |
| BF20 | Grizzly Bay | 9/14/94 | clam | 0.14 | 79.00 | 6.83 | 0.46 | 9.70 | 27.80 | 247.62 | 7.67 | 0.30 | 1.63 | 57.00 | 147.52 | ZD | 294.00 | 81.00 | ND |
| BF20 | Grizzly Bay | 9/14/94 | oyster | 3.52 | 242.00 | 8.67 | 7.90 | 154.80 | 543.00 | 159.44 | 113.00 | 0.55 | 1.94 | 3268.00 | 89.40 | Z | 486.00 | 83.00 | B |
| BG20 | Sacramento River | 9/14/94 | clam | 0.14 | 248.00 | 33.36 | 0.31 | 1.91 | 31.17 | 250.00 | 1.29 | 0.22 | 2.23 | 64.00 | 174.32 | ND | 336.00 | 79.00 | ND |
| BG30 | San Joaquin River | 9/14/94 | clam | 0.13 | 220.00 | 23.02 | 0.49 | 1.69 | 29.30 | 220.93 | 1.41 | 0.19 | 1.36 | 69.00 | 264.69 | ZD | 442.00 | 93.00 | ND |
| T-0 | Lake Isabella | 6/2/94 | clam | 0.03 | 84.00 | 22.26 | 0.34 | 0.46 | 26.48 | 130.77 | 0.51 | 0.10 | 1.59 | 38.00 | ND | ND | ND | 86.00 | R |
| T -0 | I omales Bay / Dabob Bay, WA | 6/2/94 | oyster | 5.20 | 66.00 | 11.89 | 49.41 | 1.43 | 152.00 | 412.61 | 1.88 | 0.23 | 2.47 | 1228.00 | Ë | | 147.00 | 54.00 | BR |
| | budeya Head | 012134 | IIIUSSEI | 0.21 | 00.00 | - 04 | 4.30 | 0.02 | 0.00 | 200.00 | 0.30 | 1.07 | 2.30 | 223.00 | ND | N | 03.10 | 02.00 | ł |

* TBT is expressed in nanograms of tin per gram of dry weight tissue.

Units in µg/kg, dry weight (ppb). T-0 = time of deployment of the bivalve species from the source indicated under station name heading. ND = Not Detected.

| C1-Naph-thalenes | 29.6 | 25.0 | 10.4 | 11.4 | 32.2 | 32.4 | 145.6 | 96.6 | 27.3 | 9.2 | 9.9 | 10.1 | 9.5 | 9.4 | 11.6 | 64.7 | 46.4 | 39.9 | 45.6 | 27.6 | 30.0 | 15.3 | 14.4 | 21.4 | 39.8 | 16.2 | 23.8 | 20.3 | 32.2 | 1.87 | 6.7L | 19.4 | 20.7 | 14.3 | 30.9 | 13.3 |
|----------------------------|--------------|------------------|---------------|----------|-------------------------------------|---------|----------------------------|----------------------------|---------------|--------------|--------------------|------------|-------------|------------------|-------------------|--------------|-------------|-------------|--------------|------------------|---------------|-------------------------------|---------------|---------|----------------------------|----------------|---------------|--------------|--------------|-------------|----------------|-------------------|--|----------------|---------------|----------------------------|
| C1-Fluorenes | 28.4 | Q | QN | 5.4 | 15.0 5.7 | , DN | Q | QN | 49.6 | 5.5 | 12.5 | 15.2 | 13.1 | 11.6 | 11.9 | 29.7 | 36.6 | QN | QN | Q | 14.9 | UN 14 2 | 7.0 | QN | QN | Z | 12.5 | Z | 19.1 | 77 | 1.41 | 10.3 | 22.5 | 2 | 12.8 | Q |
| C1-Fluoran_Pyr | 176.8 | 18.1 | 17.0 | 10.9 | 22.0 19 7 | 42.1 | 736.6 | 66.4 | 276.1 | 13.6 | 133.3 | 146.8 | 102.8 | 51.0 | 56.6 | 76.8 | 63.0 | 5.5 | 90.1 | 12.9 | 14.8 | 12.4 | 14.0 | 16.0 | 47.8 | g | 63.4 | 22.5 | 90.4 | 186.8 | 09.3 | 80.4 | 64.0 | ² q | 27.2 | 28.4 |
| C1-Diben | 17.4 | QN | Q | Q | | g | Q | Q | 32.3 | g | 21.0 | 17.3 | 7.9 | 6.4 | 10.3 | QN | 12.5 | QN | Q | 2 | a i | | 2 | QN | Q | Q I | 2 | Z | 15.1 | 18.2 | 0.0 | 5.9 14 | Z Z Z | Z | QN | Ð |
| c1-Chrysenes | 75.7 | Q | 4.3 | 5.1 | 10.2 ND | 2 | 359.2 | QN | 121.1 | 6.3 | 66.2 | 67.2 | 35.9 | 34.6 | 27.3 | g | Q | QN | 46.9 | Q Z | n i | | Q | QN | Q | a | 57.3 | Q | 117.8 | 51.0 5.1 | 0.07 | 61.U | 37.75 | g | QN | 13.1 |
| lynənqi8 | 7.6 | 4.8 | 2.9 | 3.0 | 9.2 | 11.3 | 41.0 | 29.0 | 11.9 | 3.1 | 3.4 | 4.7 | 2.7 | 2.7 | Q | 6.7 | 13.2 | 4.9 | 14.9 | 0.0 | 9.7 | 200 | 3.7 | QN | 17.3 | 7.5 | 9.4 | Q | Q ç | 13.3 | - • | 4. / 9. / 6 | o: - CN | 5.4 | QN | Q |
| Benzo(k)fluoranthene | 138.2 | 14.7 | 7.7 | 8. 4. | 12.2 8 8 | 20.8 | 477.8 | 45.5 | 152.5 | 5.5 | 54.7 | 57.5 | 13.4 | 7.4 | 5.1 | QN | 11.4 | QN | 71.0 | 4.7 | 9.9 9 | 0 C 0 C | 3.5 | 5.4 | 25.6 | g | 54.1 | 4.6 | 48.0 | 9.00 | 0.7 | 39.9 | 2 C | 2 ON | DN | 10.5 |
| Benzo(ghi)perylene | 54.7 | 19.2 | 12.3 | 14.7 | 17.2 | 22.7 | 253.7 | 61.5 | 56.4 | 8.2 | 26.4 | 30.1 | 13.4 | 7.8 | 0.9 | Q | QN | QN | 36.8 | 9.9 | 0, 1 0, 1 | 2.7 2.7 | 3.9 | 6.7 | 22.2 | g | 23.3 | 5.1 | 17.3 | 0.0L | | 0.9L | 2 C | 2 S Z | Q | Ð |
| Benzo(e)pyrene | 210.9 | 15.6 | 7.9 | 9.2 | 13.6 10.3 | 22.2 | 696.3 | 48.4 | 206.7 | 6.3 | 79.8 | 82.8 | 28.7 | 16.5 | 13.1 | 3.1 | 12.3 | QN | 98.4 | 5.8 | 21 | 3.6 | 3.9 | 5.7 | 41.7 | 5.8 | 64.2 - 2 | 5.8 | 52.5 22.5 | 0.00 | 19.2 | 01.0 | 18.4 | DN 2 | 2.6 | 9.8 |
| Benzo(b)fluoranthene | 139.6 | 14.9 | 7.8 | 8.5 | 12.3 8 0 | 21.0 | 482.7 | 46.0 | 154.1 | 5.5 | 55.1 | 58.1 | 13.6 | 7.4 | 5.1 | QN | 11.5 | Q | 71.0 | 4.7 | 9.9 | 0.0 0.0 | 3.5 | 5.4 | 25.6 | g | 54.1 | 4.6 | 48.0 | 55.9 | c. / | 39.9 | 4 C | 2 ON | QN | 10.5 |
| Benzo(a)pyrene | 59.1 | 18.7 | 9.6 | 12.0 | 15.7 11 8 | 25.1 | 213.5 | 52.5 | 62.0 | 9.1 | 30.6 | 31.0 | 9.9 | 4.6 | 3.0 | g | Q | QN | 35.2 | 5.5 | 8.5 0 | 0.0 1 1 | 4.8 | 6.5 | 13.3 | g | 27.3 | 5.4 | 25.4 | 0.22 | | 18.3 | 000 | ; Q | QN | g |
| Benz(a)anthracene | 109.0 | 15.2 | 8.7 | 14.2 | 19.7 15.6 | 30.7 | 498.4 | 82.8 | 111.3 | 11.2 | 65.7 | 59.5 | 25.8 | 23.5 | 12.2 | 3.3 | 15.5 | 15.4 | 33.2 | 8.2 | 11.2 | L.O.L | 7.2 | 9.0 | 17.3 | 5.9 | 31.8 2.2 | 80 80 | 57.7 | L.001 | 10.1 | 0.00 0 2 0 2 0 | 31.9 | , 0.4 , 0.4 | QN | 14.3 |
| enesendinA | 14.9 | 13.2 | 6.6 | 8.6 | 17.3 | 16.0 | 70.8 | 30.8 | 23.4 | 7.1 | 13.5 | 13.5 | 13.0 | 8.1 | 6.7 | 4.6 | 7.5 | 4.9 | 6.0 | 5.0 | 4 (2 - | 4.0 4.0 | 5.3 | 4.4 | 4.1 | 2.7 | 9.9 | 7.8 | 10.9 | 15.2 | 0.0 | 0.0 | 0.7 4.6 | 2.4 | 2.6 | 2.9 |
| Acenaphthylene | 6.0 | 4.8 | 2.1 | 2.6 | 5.7 3.7 | 5.4 | 26.1 | 22.5 | QN | 3.3 | 3.6 | 4.4 | 3.4 | 3.1 | QN | g | g | g | Q | 2 | 2 | | 2 | Q | g | 2 | 2 | Z | 9 g | | | | 2 Z | 2 Q | QN | Q |
| Acenaphthene | 8.3 | 4.6 | Q | 3.6 | 13.0 7 5 | 6.6 | QN | Q | 9.1 | 2.7 | 2.7 | g | Q | g | Q | g | QN | QN | Q | Q I | a i | UN C | 4.8 | QN | Q | 2 | 2 | Q I | Ð, | 4. L L | | | ם ג Z Z | 2 | Q | g |
| 9n9lsritiqsnlydt9M-S | 16.9 | 18.4 | 7.4 | 7.1 | 19.8 21.5 | 19.4 | 75.2 | 64.4 | 17.6 | 5.5 | 5.5 | 5.5 | 5.2 | 5.1 | 7.7 | 39.8 | 26.7 | 31.3 | 23.3 | 16.2 | 17.5 | 6.2L | 9.7 | 12.2 | 21.1 | 9.2 | 14.3 | 11.3 | 15.4 | 9.01 | 0.01 | 10.9 | 10.1 | 7.0 | 18.8 | 7.2 |
| 9n9lsdthqsnlydt9miD-8,2 | 9.2 | 6.2 | 4.1 | 3.0 | 6.2 | 0.0 | 57.: | 26. | 15.: | 3.6 | 3.5 | 4.1 | 2.7 | 2.7 | IJN | 14. | 12.: | IJ | IJN | 7.6 | 0.7 | 0. A | 5.0 | IJN | 17.5 | z | 6.1 | 0.0 | 13. | Z Z | רי הית | NL S L | | 5.0 | 8.0 | 5.6 |
| 9nəlsdthqsnlydtəmirT-2,5,2 | QN | QN | QN | 2.9 | | Z | QN | QN | QN | QN | 6.0 | Q | QN | QN | 3.8 | 9.0 | QN | QN | QN | Q Z | n i | | 2 Z | QN | QN | Q | Q I | Z | Q ; | 1.01 | | | 2 Z | 2 Q | 6.6 | g |
| 1-Methylphenanthrene | 13.1 | Q | Q | Q | DN 8 | g | Q | Q | Q | Q | 11.1 | 8.4 | Q | g | 6.5 | 18.5 | Q | Q | Q | 2 | 2 s | | 2 | Q | Q | g | 2 | Z | g | 18.3 | 2.6 | | 17.3 | 2 2 2 | 18.7 | Ð |
| ənəlsritiqsniydta⊖r | 12.8 | 6.6 | 3.0 | 4.4 | 12.4 | 13.0 | 70.4 | 32.2 | 9.7 | 3.7 | 4.5 | 4.7 | 4.3 | 4.3 | 3.9 | 24.9 | 19.7 | 8.6 | 22.2 | 11.4 | 12.5 | 9.9 1 | 5.3 | 9.2 | 18.7 | 7.0 | 9.5 | 0.0 | 13.7 | 1.21 | | 0.0 • | οα 4. ις | 7.4 | 12.1 | 6.2 |
| sHA93 IntoT | 584 | 94 | 52 | 64 | 92 72 | 147 | 2264 | 324 | 677 | 49 | 299 | 315 | 124 | 81 | 59 | 20 | 82 | 15 | 308 | 36 | 38 | 4 C 7 C | 28 | 41 | 115 | 9 | 238 | 34 | 257 | 383 | 1.000 | 239 | 711 | ; ◄ | Q | 60 |
| 2HA9H IstoT | 1594 | 210 | 109 | 140 | 238 | 308 | 6175 | 690 | 1900 | 109 | 816 | 920 | 461 | 262 | 203 | 124 | 378 | 19 | 739 | 75 | 83 | 88 | 72 | 91 | 306 | 21 | 571 | 78 | 621 | 9711 | 4 - 4 7 - 7 | 5/3 | 3 Z U | , 4 , 4 | 29 | 214 |
| 2HA9J IstoT | 172 | 108 | 48 | 67 | 158 155 | 161 | 703 | 393 | 184 | 58 | 92 | 88 | 57 | 42 | 47 | 221 | 199 | 122 | 148 | 67 | 92 | 2 2 2 | 70 | 50 | 120 | 49 | 82 | 73 | 122 | 177 | | 99 | ο 10 | 4 (| 104 | 51 |
| sHA9 IstoT | 1775 | 320 | 158 | 209 | 400 318 | 474 | 6899 | 1093 | 2092 | 168 | 914 | 1013 | 521 | 306 | 252 | 347 | 581 | 143 | 887 | 173 | 1/5 | 271 | 144 | 143 | 426 | 70 | 656 | 155 | 746 | 1358 | 492 | 641 | 403 352 | 47 | 134 | 266 |
| zenskih listoT | 9637 | 4760 | 8610 | 13261 | 5060 5749 | 12703 | 57823 | 25072 | 16210 | 4708 | 14957 | 18479 | 5112 | 1611 | 1711 | 42299 | 36857 | 4882 | 5752 | 3473 | 3601 | 3412 4568 | 1428 | 1133 | 2330 | 1652 | 2090 | 1545 | 3074 | 11869 | 1600 | 6450 | 48845 2037 | 1311 | 1389 | 1857 |
| Species | oyster | nussel | nussel | nusse | nussel | nussel | oyster | nussel | oyster | nussel | oyster | oyster | clam | clam | clam | clam | oyster | nussel | oyster | nussel | nussel | nussel | nussel | nussel | oyster | nusse | oyster | nusse | oyster | oyster | clam | oyster alam | clam clam | nussel | clam | oyster |
| Date | 4/94 | 4/94 n | 4/94 n | 4/94 n | 4/94 n | 5/94 n | 5/94 | 5/94 n | 5/94 | 5/94 n | 6/94 | 5/94 | 6/94 | 6/94 | 6/94 | 17/94 | 17/94 | 17/94 n | 12/94 | 12/94 n | 12/94 n | 12/94 0 | 13/94 n | 13/94 n | 13/94 | 13/94 n | 13/94 | 13/94 n | 14/94 | 13/94 | 14/94 | 14/94 | 14/94 14/94 | 26/94 n | 2/94 | 2/94 |
| | 2 | 2 | 5 | 2 | יי פי | Ω Ω | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 5 | 1 | 1 | 1/ | /6 | /6 | 6 | 50 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 6 | 5 0 | 2/2 | 9 | IA 6/ |
| emsN noitst≳ | Coyote Creek | Jumbarton Bridge | Redwood Creek | Alameda | rerba Buena Island Jorseshoe Bay | Redrock | ^o etaluma River | ^o etaluma River | San Pablo Bay | Pinole Point | Davis Point | Vapa River | Brizzly Bay | Sacramento River | San Joaquin River | .ake Isabela | romales Bay | 3odega Head | Coyote Creek | Jumbarton Bridge | Kedwood Creek | Alameda Yerha Buena Island | Horseshoe Bay | Rock | ^o etaluma River | oetaluma River | San Pablo Bay | Pinole Point | Davis Point | Vapa Kiver | STIZZIY BAY | Srizzly Bay | sacramento rriver Nan Inaguin River | sodega Head | .ake Tsabella | romales Bay / Dabob Bay, W |
| station Code | BA10 (| BA30 L | BA40 | BB71 , | BC10 | BC60 F | BD15 F | BD15 | BD20 \$ | BD30 } | BD40 1 | BD50 | BF20 (| BG20 % | BG30 { | T-0 | - - | 1-0 -1 | BA10 (| BA30 1 | BA40 | BC10 / | BC21 F | BC60 1 | BD15 1 | BD15 1 | BD20 | BD30 | BD40 | | | BFZU | BGZU S | 1-0-F | T-0 I | |

Units in µg/kg, dry weight (ppb). T-0 = the time of deployment of the bivalve species from the source indicated under station name heading. ND = Not Detected. Table 3.27. PAH concentrations in bivalve tissues, 1994. (Continued)

| T-0 | | T-0 | | BF2C | BF2C | BD50 | BD40 | BD30 | BD20 | BD15 | BD15 | BC60 | BC21 | BC10 | BB71 | BA40 | BA30 | BA10 | T-0 | T-0 | T-0 | BG3C | BG20 | BF20 | BD50 | BD40 | BD30 | BD20 | BD15 | BD15 | BC60 | BC21 | BC10 | BB71 | | BA1C | Station Code |
|-----------------------------|---------------|-------------------|-------------------|---------------|---------------|------------|-------------|----------------|-----------------|------------------|------------------|----------|---------------|--------------------|----------|---------------|------------------|--------------|-------------|-------------|--------------|---------------------|--------------------|-------------|--------------|-------------|--------------|-----------------|------------------|------------------|---------|---------------|--------------------|-------------|----------------------|------------------|---------------------------|
| Tomales Bay / Dabob Bay, WA | Lake Isabella | Bodena Head | San loaduin Divor |) Grizzly Bay |) Grizzly Bay | Napa River | Davis Point |) Pinole Point |) San Pablo Bay | 5 Petaluma River | 3 Petaluma River | Red Rock | Horseshoe Bay | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Covote Creek | Bodega Head | Tomales Bay | Lake Isabela |) San Joaquin River |) Sacramento River | Grizzly Bay | 1 Napa River | Davis Point | Pinole Point |) San Pablo Bay | i Petaluma River | i Petaluma River | Redrock | Horseshoe Bay | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Station Name |
| 6/2/94 | 6/2/94 | 5/26/9/ | 9/14/9/ | 9/14/9 | 9/14/94 | 9/13/94 | 9/14/94 | 9/13/94 | 9/13/94 | 9/13/94 | 9/13/94 | 9/13/94 | 9/13/94 | 9/12/94 | 9/12/94 | 9/12/94 | 9/12/94 | 9/12/94 | 1/17/94 | 1/17/94 | 1/17/94 | 5/6/94 | 5/6/94 | 5/6/94 | 5/5/94 | 5/6/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/4/94 | 5/4/94 | 5/4/04 | 5/4/94 | Date |
| oyster | clam | 4 mussel | dam 4 | 4 oyster | 4 clam | 4 oyster | 4 oyster | 4 mussel | 4 oyster | 4 mussel | 4 oyster | 4 mussel | 4 mussel | 4 mussel | 4 mussel | 4 mussel | 4 mussel | 4 oyster | 4 mussel | 4 oyster | 4 clam | clam | clam | clam | oyster | oyster | mussel | oyster | mussel | oyster | mussel | mussel | musse | mussel | mileso | oyster | Species |
| 24.6 | 27.7 | | л 90.0 О | 35.4 | 43.3 | 99.1 | 48.8 | ND | 20.7 | ND | ND | Ŋ | Ŋ | Ŋ | Ŋ | R | Ŋ | B | ND | 56.2 | 45.7 | 30.4 | 42.0 | 39.0 | 39.3 | 44.9 | 10.1 | 63.6 | ND | 156.4 | Ŋ | 14.0 | 18.8 | 9.0 | 0 | 38.5 | C1-Phen_Anthr |
| ND | Ş | Ş | | 58.4 | 31.7 | 52.9 | 58.9 | ND | 63.4 | ND | ND | ND | ND | ND | ND | ND | ND | 48.2 | ND | ND | B | 17.1 | 16.8 | 26.8 | 44.0 | 53.6 | ND | 76.9 | ND | 256.8 | ND | 10.0 | 8.9 | 6.2 | 200 | 44.6 | C2-Chrysenes |
| 10.9 | 16.2 | ŞZ | | 41.6 | 18.7 | 58.7 | 39.9 | ND | 32.0 | ND | ND | ND | ND | ND | ND | ND | ND | 24.5 | ND | 28.6 | 26.5 | 26.1 | 28.4 | 25.1 | 57.5 | 65.8 | ND | 89.2 | ND | 213.6 | ND | ND | 14.9 | 9.2 | 38 | 43.2 ND | C2-Diben |
| ND | 60.4 | ND 4 | | 60.1 | 97.6 | 52.1 | 54.9 | ND | 39.0 | ND | ND | ND | ND | ND | ND | D | ND | D | ND | 95.8 | 110.1 | 69.1 | 59.3 | 107.1 | 59.4 | 65.9 | 13.1 | 162.2 | ND | ND | ND | 9.2 | 16.8 | 94 | 38 | 56.9 | C2-Fluorenes |
| 17.6 | 28.0 | 13.6 | 21.0 | 18.7 | 18.3 | 28.1 | 29.7 | ß | 19.6 | 21.4 | ß | 23.2 | 13.8 | 15.5 | 23.8 | 21.0 | 20.5 | 34.0 | 13.5 | 41.3 | 45.6 | 16.3 | 10.3 | 13.4 | 17.5 | 15.0 | 12.8 | 38.7 | 161.9 | 176.5 | ND | 20.5 | 30.8 | 13.7 | 10.1 | 40.0 | C2-Naph-thalenes |
| 26.5 | 48.3 | N S | 878 878 | 69.8 | 65.9 | 170.3 | 73.7 | D | 50.9 | B | D | ND | Ð | B | D | ß | B | 51.4 | B | 94.8 | 159.6 | 48.8 | 50.4 | 77.0 | 107.3 | 136.7 | 10.8 | 218.9 | 117.3 | 407.2 | ND | 20.7 | 26.9 | 9 3 3 | | 71.9 ND | C2-Phen_Anthr |
| ND | 58 | Ş | 32 | 58 | Ŋ | D | ß | ND | ß | ND | ND | ND | ND | D | ND | D | ND | D | ND | ß | B | Ŋ | Ŋ | D | 9.7 | 5.8 | ND | ß | ß | ND | ND | ND | B | B | 38 | 38 | C3-Chrysenes |
| 10.4 | 16.2 1 | 33 | 38 | 54.0 1 | 33.9 1 | 64.3 1 | 39.2 1 | ND | 40.1 | ND | ND | ND | ND | ND | ND | ND | ND | 32.0 | ND | 19.9 | 36.8 4 | 50.9 1 | 31.8 | 37.4 2 | 98.4 1 | 103.1 1 | ND | 135.6 4 | ND | 346.6 | ND | ND | 15.2 | 999 | 33 | 64.7 1 | C3-Diben |
| ND 2 | 32 3 | | | 28.3 | 47.2 | 61.3 | 121.3 | D | D | D | D | D | D | Ŋ | Ŋ | Ŋ | Ŋ | B | Ŋ | B | 100.4 | 95.7 | 239.8 | 239.7 | 167.2 | 29.1 | 23.4 | 192.8 | D | D | ND | 49.7 | 50.4 | 36.2 | 58 | ND 4.4 | C3-Fluorenes |
| 32.5 | 31.7 | 40.1 | лу 6 | 25.0 | 32.1 | 92.2 | 62.2 | ND | 51.6 | ND | ND | 39.9 | 22.8 | 15.5 | 23.9 | 35.0 | 27.7 | D | 21.9 | 63.3 | 54.1 | 22.1 | 30.6 | 20.9 | 58.4 | 64.2 | 27.3 | 67.3 | 171.2 | 311.4 | ND | 22.6 | 32.0 | 23.3 | 1л. о | 36.7 36.1 | C3-Naph-thalenes |
| 36.4 | 42.8 | | 76.4 | 114.3 | 57.6 | 195.6 | 100.4 | ND | 80.0 | ND | ND | ND | ND | B | Ŋ | B | Ŋ | 75.9 | ND | 52.9 | 70.5 | 76.5 | 92.1 | 105.0 | 106.8 | 165.3 | ND | 252.0 | ND | 458.2 | ND | 10.3 | 12.6 | | | 88.4 | C3-Phen_Anthr |
| ZD | Ż | ŞZ | | ZD | ND | ZD | ND | ND | ND | D | ND | ND | ND | ND | ND | D | ND | ZD | Ŋ | ZD | ZD | ND | ND | ND | ND | ZD | D | ND | ND | ND | ND | D | B | 58 | 58 | ΒB | C4-Chrysenes |
| 15.6 | 21.7 | 18.9 | 113 g | 50.0 | 22.3 | 61.9 | 47.0 | ND | 24.4 | ND | ND | ND | 15.9 | B | Ŋ | Ŋ | ND | ZD | ND | 78.5 | 56.0 | 94.5 | 55.7 | 71.7 | 51.2 | 125.8 | ND | 61.0 | ND | 163.0 | ND | 13.4 | 25.3 | 21.4 | | оло DN D | C4-Naph thalenes |
| 25.4 | 31.0 | ND 4 | 80.U | 92.9 | 61.6 | 129.5 | 69.7 | ND | 79.7 | ND | ND | ND | ND | ND | ND | ND | Ŋ | 57.8 | Ŋ | 74.0 | 125.3 | 62.1 | 61.1 | 82.4 | 91.8 | 140.8 | Ŋ | 197.0 | ND | 444.2 | ND | ND | 15.1 | Z Z | | 97.9 | C4-Phen_Anthr |
| 24.7 | z i | | 42 7 9. 7C | 78.8 | 39.5 | 142.8 | 63.8 | 10.6 | 54.0 | ND | 33.0 | 10.3 | 6.2 | 8.6 | 10.7 | ND | 9.6 | 87.5 | ND | 43.3 | 16.3 | 31.4 | 34.9 | 55.2 | 91.0 | 77.0 | 13.3 | 163.0 | 58.9 | 431.2 | 36.4 | 17.7 | 22.4 | 11.4 | 2 0 0 | 118.5 | Chrysene |
| ND | z i | | 33 | , N 1 0 | ND | ZD | 4.4 | ND | 2.9 | ND | ND | ND | Ŋ | Ŋ | ND | Ŋ | Ŋ | ZD | ND | ND | Ŋ | ND | 0.7 | 0.9 | 3.4 | ω .ω | ND | 5.7 | ND | 23.3 | Ŋ | 2.6 | 1 4 | 0.9 | | 3.0 | Dibenz(A,H)-Anthracene |
| 1 : 4 : | ; | z : | - 0 | - <u>-</u> | 2.4 | 5.9 | 3.6 | 4.0 | 2.7 | Ŋ | ND | 2.1 | 2.0 | 2.0 | 2.0 | ZD | ND | B | 1.8 | 3.6 | 2.2 | 2.1 | 1 .5 | 3.2 | 4.5 | 3.4 | 1.4 | 7.9 | 10.1 | 21.2 | 4.0 | з.5 | 3. 8 | - | 4 N 0 C | 9.4 | Dibenzo-thiophene |
| 95.5 | 12.0 | Z 2 | 40 4 40 4 | 96.4 | 153.0 | 324.9 | 142.5 | 15.1 | 102.9 | 4.9 | 43.0 | 14.9 | 15.7 | 18.2 | 13.1 | 13.3 | 10.0 | 119.4 | 3.3 | 186.0 | 46.8 | 28.1 | 36.0 | 95.6 | 210.1 | 182.3 | 19.3 | 411.1 | 84.6 | 1099.4 | 45.5 | 28.4 | 53.8 | 20.4 | 10.0 | 271.2 | Fluoranthene |
| ND | 4 л (| | 7 N D | ZD | ND | 16.9 | 9.6 | ND | ND | ND | ND | ND | 5.4 | 6.9 | ND | ZD | 6.1 | B | ND | 13.8 | 11.1 | ND | ND | 3.7 | 5.7 | 3.7 | 2.7 | 10.4 | 29.4 | 39.6 | 11.7 | 10.2 | 14.3 | ω. 6 | | ло. 10.6 | Fluorene |
| N N N | 3 | 33 | | 9.3 | 2.9 | 6.1 | 10.2 | ND | 13.5 | ND | ND | 4.5 | 2.8 | ND | 5.4 | 4.8 | 3.7 | 10.3 | ND | ND | ND | 2.3 | 2.8 | 5.2 | 14.3 | 12.6 | 4.1 | 28.3 | 38.0 | 137.5 | 12.6 | 6.6 | о СЛ | 8.7 | 20 - - 00 + 00 | 16.2 | Indeno(1,2,3, -CD) Pyrene |
| 11.0 | 21.1 | 10.0 | 10.7 | 19.1 | 13.5 | 25.8 | 24.6 | 18.6 | 21.6 | 13.8 | 30.9 | 13.6 | 11.2 | 14.9 | 23.4 | 27.0 | 26.6 | 54.9 | 51.2 | 57.8 | 43.3 | 8.6 | 7.7 | 9.3 | 11.9 | 9.1 | 10.3 | 41.3 | 94.9 | 152.8 | 30.4 | 27.1 | 25.2 | 12.6 | 11 2 | 25.2 | Naph thalene |
| N N N | 4 2 | Z Z | 7 7 3 | 40.4 | 14.1 | 34.0 | 33.5 | 4.0 | 40.0 | ND | 18.0 | 5.2 | 3.3 | ND | 5.2 | ZD | 3.2 | 14.4 | ND | 9.4 | 12.7 | 5.3 | 5.8 | 14.0 | 53.3 | 33.7 | 5.0 | 90.2 | 34.4 | 316.8 | 14.2 | 6.5 | 7.3 | 4.9 | ∆ c | 8 8 8 8 | Perylene |
| 18.2 | 11.6 | л - + т + 8 | 10.0 | 16.0 | 17.1 | 83.2 | 34.4 | 17.6 | 14.8 | 8.7 | 9.9 | 10.8 | 19.8 | 15.2 | 12.6 | 13.9 | 15.3 | 26.7 | 21.5 | 48.6 | 48.8 | 9.7 | 8.7 | 13.0 | 25.4 | 28.0 | 16.1 | 45.2 | 62.9 | 170.4 | 34.2 | 38.4 | 35.4 | 16.0 | 20 20 24 | 47.1 | Phenan threne |
| 48. | | | ол. | 116. | 146. | 298 | 117. | 14. | 102. | 7.3 | 66. | 17.: | 17. | 16.1 | 16. | 16. | 13. | 161. | Z | 88.{ | 41.: | 91.8 | 114. | 185. | 229. | 194. | 21.4 | 459. | 138. | 1544 | 57.: | 30. | 53.0 | 27. | 10. | 423. | Pyrene |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 1 |

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|---------------|---------|-------------------------|------------|------------|---------|---------|---------|---------|--------|------------|-------------|----------|------------|---------|----------|----------|--------|----------|---------|----------|--------|--------|----------|--------------|----------------|------------|-------------|----------|---------|----------|----------|-----------|-----------|---------|----------|----------|-------------------|
| PCB 066 | Ð | Q 2 | 0.77 | t Q | 2.8 | Q | 24.2 | 2 | 9.8 | 0.9 | 21.0 | 2.3 | 24.4 | 1.7 | 1.3 | 1.7 | Q | Q | 25.0 | 17.7 | 5.1 | 9.7 | 17.7 | 1.6 | 1.5 | 2: | <u>`</u> | 2 | 4. | 4.3 | 2.6 | 1.5 | 15.1 | 3.5 | 3.6 | g | 2.1 |
| PCB 060/56 | Ð | 4. 1 8. 0 | 4 t 1 d | . 0.1 | 1.8 | 3.6 | 21.9 | g | 8.7 | 1.5 | 4 · 9 · | 1.5 | 5.0 | 3.0 | 1.0 | 4.0 | 7.1 | g | 11.4 | 2.3 | 2.7 | 4.0 | 2.0 | 1.3 | 2.1 | 0.0 0.0 | 0 I 10 I | 2.7 | с. С | 4.1 | 10.8 | 2.7 | 8.1 | 4.0 | 6.8 | g | 3.0 3.0 |
| PCB 052 | 24.8 | 15.3 | ہ ۔ 1.3 | 12.5 | 5.2 | 8.3 | 43.5 | 8.0 | 21.1 | 2.8 | 0.0 | 9.9 | 19.5 | 15.3 | 14.1 | g | Q | 1.2 | 8.8 | 5.3 | 4.7 | 6.3 | 6.8 | 2.3 | 3.7 | Z | 9.7 7.7 | 4. 9. | 4.2 | 4.2 | 5.5 | 9.4 | 3.8 | 13.3 | 11.8 | g | 3.8 2.0 |
| PCB 049 | 10.3 | Q r | 0.7 | t Q | 2.0 | 3.3 | 11.4 | 9 | 7.4 | 1.2 | 6.1 | 2.5 | 3.5 | 3.0 | Q | g | Q | 9 | 6.7 | 3.9 | 3.5 | 4.7 | 5.8 | 2.3 | 3.8 | g | 7.7 | 4 | 3.0 | 3.4 | 4.8 | 7.0 | 2.3 | 12.4 | 7.0 | 2.3 | 3.0 1.7 |
| PCB 047/48/75 | ₽ | 2 | 4 c | - 2 | g | Q | Q | g | 2 | 0.9 | 0.9 | 1.6 | 1.6 | 0.7 | Σ | g | Q | g | 4.1 | 2.4 | 2.4 | 2.8 | 3.4 | 1.4 | 2.0 | 2 ! | 2 ; | Q.7 | 1.4 | 2.3 | Q | g | Q | Q | 1.6 | g | 2.9 ND |
| PCB 046 | 14.9 | 9.1 | n.⊂ ∽ ⊂ | 4 6 8 0 | 3.8 | 6.5 | 29.8 | 7.9 | 14.3 | 2.4 | 4 | 4 | 2 | g | 3.1 | g | Q | 2.0 | Q | Q | Q | Q | Q | g | 2 | 2 ! | 2 | Z | g | g | Q | g | 1.9 | Q | Q | g | 99 |
| PCB 045 | ₽ | 2 g | | | g | Q | Q | g | 2 | 2 | 2 ! | Z | g | 0.6 | Q | g | Q | Σ | Q | Q | Q | Q | Q | g | 2 | 2 ! | 2 | Z | g | g | Q | g | Q | Q | Q | g | 99 |
| PCB 044 | 13.5 | 9.4 4.0 | 10 | 0.0 | 2.9 | 4.6 | 22.1 | 6.0 | 7.2 | 2.1 | 5.7 | 4 | 12.6 | 5.9 | 9.5 | 6.8 | Q | Q | 9.2 | 4.2 | 4.6 | 4.2 | 4.5 | 2.2 | 3.3 | 2 | 3.6 | 4 0 | 2.9 | 4.3 | 6.5 | 9.7 | 4.1 | 18.1 | 10.3 | Q | 5.5 2.1 |
| PCB 041/64 | Σ | ≥ : | 2 2 | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ: | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ: | Ξ: | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | Σ | ΣΣ |
| PCB 040 | 10.6 | 7.7 | 0.0 7 | - Q | 2.0 | 3.5 | 22.0 | g | 6.5 | 1.0 | 2.5 | 2.4 | g | Q | 0.8 | g | Q | g | Q | g | Q | g | Q | g | 2 | 2 | 2; | 2.0 | Q | 2 | 2.9 | 1.5 | 2.0 | Q | Q | g | 2 2 |
| PCB 037/42/59 | ₽ | ₽; | 0. 1 | | g | Q | Q | g | g | 7.3 | 8 9 9 | 5.6 | 3.3 | 1.7 | Σ | g | Q | g | Q | 1.5 | 1.7 | 1.9 | 1.8 | 1.2 | 2.1 | g | 9.7 7 | 4. | 1.6 | 2.4 | 2.0 | 4.7 | Q | Q | 8.9 | g | 2.7 ND |
| PCB 033/53/20 | ₽ | 2.1 | | | g | Q | Q | g | 2 | g | 0.8 | 2 | 2 | g | g | g | Q | g | Q | g | Q | g | Q | g | 2 | 2 | 2 | P | g | g | Q | 1.0 | Q | 1.6 | 1.9 | g | 2.2 ND |
| PCB 031 | Ð | 93 | - o | o No | 2 | Q | Q | Q | Q | 2.1 | 10.7 | 11.3 | Σ | Σ | Σ | g | Q | Q | 3.6 | 1.6 | 4.6 | 2.8 | 6.6 | Q | Z | 2 ! | 2 | Z | Q | Q | 5.8 | 15.3 | 3.3 | 10.8 | 7.9 | Q | 2.7 ND |
| PCB 029 | ₽ | 9; | | | 2 | Q | Q | Q | g | 2 | 1.5 | Z | 1.3 | 0.5 | Q | g | Q | g | Q | Q | Q | g | Q | g | 2 | 2 | 2 | P | g | 9 | Q | g | Q | Q | Q | Q | 22 |
| PCB 028 | ₽ | 5.5 | N 7 | - 4 | 1.6 | 2.6 | 12.0 | g | 5.7 | 0.7 | 2.9 | 4 | 4 | g | 1.5 | g | Q | g | 5.3 | 2.0 | 2.2 | Ð | 2.0 | 0.9 | 1.7 | 2 | с. 2. ч | 4. | 1.6 | g | 2.0 | 1.0 | Q | 4.9 | 2.2 | g | 2 2 |
| PCB 026 | ₽ | Q Z | | | 2 | Q | Q | Q | Q | g | 0.8 | 2 | g | Q | 1.3 | g | Q | Q | Q | g | Q | Q | Q | Q | Z | 2 | 2 | Z | Q | g | Q | Q | Q | Q | 1.8 | Q | 1.3 ND |
| PCB 025 | ₽ | 9 3 | | o da | 2 | Q | Q | 2 | 2 | 2 | 1.2 | Z | 2.0 | 0.7 | 1.8 | 9 | g | g | g | g | Q | Q | Q | Q | 2 | 2 | 2 | P | g | 9 | Q | 1.4 | Q | Q | 1.9 | 2 | 2.5 ND |
| PCB 024/27 | ₽ | 2 | | | g | Q | Q | g | g | 2 | 2 | Z | 1.9 | Q | 0.7 | 2 | Q | Q | Q | g | Q | g | Q | Q | 2 | 2 | 2 | Z | Q | 2 | Q | 2.7 | Q | Q | Q | g | 22 |
| PCB 022/51 | Ð | g 3 | 0.0 | 2 R | 2 | Q | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 6.0 | 2 | 2 | Q | g | Q | g | Q | Q | g | Q | 2 | 2 | 2 | Z | Q | 2 | g | 2 | Q | Q | 1.8 | 2 | 2 2 |
| PCB 018 | 1.9 | 0.0 | | 22 | g | g | g | 2 | 2 | 2 | 8.0 | DZ : | - 1.3 | 2.3 | 3.3 | Ð | g | g | g | g | g | g | g | 0.6 | 2 | | | Z | g | g | g | 1.0 | Q | 1.6 | 4.0 | 2 | 2 2 |
| PCB 016/32 | 2 0 | 23 | | | 2 | 2 | Z | 2 | 2 | | 0.0 | | 3.0 0.0 | 5.1 | 6.4 | g | 2 | 2 | 2 | g | g | g | 1.3 | Z | 2 | Z | | | | g | g | 0.0 | g | 6.2 | 5.7 | 5.1 | 2.5 D |
| PCB 015 | DZ 0 | | | | Z | Z | Z | Z | Z | | z | Z | | - | 0.0 | Z | UZ O | Z | Z | Z | Z | Z | Z | Z | 2 | Z | z: | z : | Z | Z | Z | Z | Z | Z | 3.1.6 | Z: | 2 2 - 0 |
| PCB 008/5 | Z 0 | Z Z | | žZ | | Z | Z | Z: | Z: | | 8 6 6 | | | z | Z : | z | z | Z | Z | z | Z | Z | Z | z | | z: | | z : | z | z | Z | z | Z | N N | 0.1. | ≥. | - 0 |
| 6/200 804 | Z | ZZ | zz | zz | z | z | Z | Z : | Z | z, | | : ~ : | z | Z | | z | Z | Z | z | Z Ŧ | z | z | Z | Z | Z: | z | z | z : | z | Z | 1 | z | Z | 4 | Z: | z | - Z |
| Total PCBs | 766. | 504.4 | 262.5 | 457.6 | 242.(| 359. | 2289. | 554. | 786. | 184. | 629 | 481.2 | 387.5 | 289. | 309. | 122.3 | 84.6 | 15.1 | 573.(| 470.4 | 416. | 392.8 | 393. | 169. | 243. | 184. | 223.0 | 202 | 260.4 | 335. | 372. | 275. | 461.3 | 428.4 | 424. | 20.6 | 140.1 |
| spidi⊐ % | 19.7 | 18.6 | 7 67 | 12.8 | 12.2 | 18.3 | 8.7 | 26.3 | 35.1 | 7.8 | 13.7 | 5.9 | 15 | - | 11.3 | 29.3 | 41.9 | 13 | 8.1 | 8.9 | 9.3 | 8.3 | 7.6 | 7.53 | 80. 0 80. 0 | 4 ; 5 ; | 1.01 | 0.01 | 9.3 | 8.6 | 10.7 | 16 | 12.1 | 16.5 | 15.3 | 7.6 | 15.6 16 |
| Species | yster | lassel | lesel | ussel | ussel | ussel | yster | lassel | yster | lassel | yster | yster | am | am | lam | lam | yster | ussel | yster | ussel | ussel | ussel | ussel | lasse | lassel | yster | ussel | yster | usse | yster | yster | lam | yster | lam | lam | lassel | lam vster |
| | 0 | E 1 | E 8 | E E | E | 5 | • | E | • | 5 | • | • | | | | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 · | о • | Е + • | • | 5 | • | 4 | 4 | 4 | 4 | 4 | 4 | |
| Date | 5/4/94 | 5/4/94 | 20/1/2 | 5/4/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/2/37 | 5/2/37 | 2/9/9/2 | 26/9/94 | 5/6/97 | 2/9/97 | 5/6/97 | 1/17/9 | 1/17/9 | 1/17/9 | 9/12/9 | 9/12/9 | 9/12/9 | 9/12/9 | 9/12/9 | 9/13/9 | 9/13/9 | 9/13/9 | 9/13/9 | 8/13/9 | 9/13/9 | 9/14/9 | 9/13/9 | 9/14/9 | 9/14/9 | 9/14/9 | 9/14/9 | 5/26/9 | 6/2/94 |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | av. WA |
| | | ge | | and | | | | | | | | | | er | er | | | | | ge | | | and | | | | | | | | | | | er | er | | abob B; |
| Station | reek | on Bridg | Creek | iena Isl | e Bay | ~ | River | River | o Bay | oint | Int | er | ay | nto Riv | quin Riv | oella | Bay | Head | reek | on Bridç | Creek | | iena Isl | e Bay | j | Niver | L KIVer | o bay | oint | int | er | ay | ay | nto Riv | quin Riv | Head | oella Bav / D |
| | oyote C | Jumbarto | lameda | erba Bu | orsesho | ed Rock | etaluma | etalume | an Pab | inole P | Javis Po | Iapa Kiv | srizzly B | acrame | an Joac | ake Isal | omales | todega I | oyote C | Jumbarto | edwood | lameda | ʻerba Bu | lorsesho | ted Roci | etalumé | etalumé | an Fab. | inole P | avis Po | lapa Riv | Srizzly B | irizzly B | acrame | an Joac | todega I | ake Isa omales |
| ebo) noiteiz | 410 C | 430 430 | 271 0 | . > | 221 H | C60 R | 015 Р | 015 F | 220 S | 030 130 | 040 | | F20 | G20 S | 330 S | - - | - 0-' | о. С | 410 C | 430 D | 440 R | 371 A | 310 Y | C21 F. | 2.60 | 015 F | - CIU | | 330 F | 040 L | 250 N | F20 G | F20 G | G20 S | 330 S | ш. о. | - 1 L 2 9 |
| | a l | àà | ñä | ыщ | Щ | щ | щ | щ | щ | H ا | ы р | n i | ñ ۵ | ñ | ы, | - | - | - | à | à | à | B | щ | ĕ | щ | ы р | מ מ | d | Ш | щ | В | ā | ā | ñ | ۳, | - 1 | |

| ND = not de | Table 3.28. |
|------------------------------------|---|
| tected, M = Matrix interference | PCB congeners, total PCBs |
| . Units in ng/g (ppb), dry weight. | , and lipid content in bivalve tissues, |
| | 1994. (Continued) |

T-0 indicates the time of bivalve deployment into the Estuary from source indicated under station name heading.

| T -0 | BG30 | BG20 | BF20 | BD50 | BD40 | BD30 | BD20 | BD15 | BD15 | BC60 | BC21 | BC10 | BB71 | BA40 | BA30 | BA 10 | T-0 | T-0 | T-0 | BG30 | BG20 | BF20 | BD50 | BD40 | BD30 | BD20 | BD15 | BD15 | BC60 | BC21 | BC10 | BB71 | BA40 | BA 30 | BA 10 | Statio | n Code |
|---|---------------------|---------------------------------|---------------|------------|-------------|--------------|---------------|----------------|----------------|----------|---------------|--------------------|---------|---------------|------------------|--------------|-------------|-------------|---------------|-------------------|------------------|-------------|------------|-------------|--------------|---------------|----------------|----------------|----------|---------------|--------------------|---------|---------------|------------------|--------------|------------------|-------------|
| Bodega Head Lake Isabella Tomales Bay / Dabob Bay, WA | San Joaquin River | Grizzly bay Sacramento River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Petaluma River | Red Rock | Horseshoe Bay | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | Bodega Head | Tomales Bay | Lake Isabella | San Joaquin River | Sacramento River | Grizzly Bay | Napa River | Davis Point | Pinole Point | San Pablo Bay | Petaluma River | Petaluma River | Red Rock | Horseshoe Bay | Yerba Buena Island | Alameda | Redwood Creek | Dumbarton Bridge | Coyote Creek | Statio | n |
| 5/26/94 6/2/94 6/2/94 | 9/14/94 | 9/14/94 9/14/94 | 9/14/94 | 9/13/94 | 9/14/94 | 9/13/94 | 9/13/94 | 9/13/94 | 9/13/94 | 9/13/94 | 9/13/94 | 9/12/94 | 9/12/94 | 9/12/94 | 9/12/94 | 9/12/94 | 1/17/94 | 1/17/94 | 1/17/94 | 5/6/94 | 5/6/94 | 5/6/94 | 5/5/94 | 5/6/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/4/94 | 5/4/94 | 5/4/94 | 5/4/94 | 5/4/94 | Date | |
| mussel clam oyster | clam | clam | clam | oyster | oyster | mussel | oyster | mussel | oyster | mussel | mussel | mussel | mussel | mussel | mussel | oyster | mussel | oyster | clam | clam | clam | clam | oyster | oyster | mussel | oyster | mussel | oyster | mussel | mussel | mussel | mussel | mussel | mussel | oyster | Specie | es |
| 1.6 1.2 | 5.9 | 88 | 58 | Ŋ | 3.1 | 2.2 | з. 1 | 2.6 | Ŋ | 2.5 | 1.8 | 6.4 | B | Ŋ | B | Ŋ | Ŋ | ND | Ŋ | ND | 13.2 | ND | 4.1 | 6.7 | 1.5 | Ŋ | Ŋ | Ŋ | B | Ŋ | Ŋ | 3.1 | 8.3 | ND | ND | РСВ (| 070 |
| 888 | 58 | 0.0 2.7 | η <u>1</u> .ω | 7.9 | ß | ß | 1.5 | ß | ß | ß | 0.9 | 4.0 | 2.7 | 3.2 | з.8 | 7.8 | ß | ß | ß | 0.8 | 0.7 | 2.2 | 2.4 | 4.0 | 1.0 | 6.5 | ß | 22.0 | з.5 | 2.0 | ß | 2.1 | 5.3 | 7.7 | 10.6 | РСВ (|)74 |
| 1.6 ND | 3.9 | 10.1 | 15 9 | 4.7 | 2.4 | 3.0 | 3.0 | 4.5 | Ð | 2.6 | 2.3 | 5.0 | 4.4 | 4.7 | 6.8 | 3.2 | D | Ŋ | B | 4.6 | 6.0 | 10.6 | 4.8 | 8.3 | 2.1 | 3.0 | B | 15.7 | 2.3 | 1.3 | 3.4 | 3.1 | 4.4 | 3.3 | 4.0 | РСВ (|)82 |
| 1.2 1.2 | 2.6 | 3.4 3.4 | 2.6 | 3.8 | 3.0 | D | 2.8 | Ŋ | Ŋ | D | 0.6 | 2.9 | 3.8 | з. 5 | 3.8 | Ŋ | D | Ŋ | 1.1 | ND | 1.3 | 3.2 | 5.0 | 4.8 | D | Ŋ | D | D | B | Ŋ | Ŋ | 1.8 | 2.2 | ND | ND | РСВ (|)83 |
| ND ⁴ .α | 13.6 | 6.4 | 10.7 | 4.0 | 5.0 | 7.0 | 6.8 | 8.2 | Ŋ | 4.3 | 2.2 | 3.9 | 5.8 | 6.4 | 8.1 | Ŋ | D | ND | Ŋ | 9.4 | 10.1 | 6.8 | 10.6 | 13.0 | 5.2 | Ŋ | Ŋ | 42.6 | B | Ŋ | Ŋ | 5.3 | 12.4 | ND | ND | РСВ (|)84 |
| 888 | 2.0 | 88 | 58 | Ŋ | 2.3 | 1.4 | 1.8 | Ŋ | Ŋ | Ŋ | 1.0 | 2.8 | 2.4 | Ŋ | з. 1 | Ŋ | Ŋ | Ŋ | Ŋ | ND | 1.3 .3 | ND | 2.1 | 2.2 | 0.8 | Ŋ | Ŋ | Ŋ | Ŋ | ND | ND | 1.7 | 2.3 | ND | ND | РСВ (|)85 |
| 1.2 3.4 | 4.6 | 5.1 .1 | 12.5 | 6.1 | 5 .5 | 6.1 | 5.6 | 3.7 | 5.1 | 3.7 | 3.4 | 7.8 | 7.0 | 6.9 | 8.1 | 8.1 | ß | ß | 2.0 | 3.0 | 2.3 | 4.6 | 6.4 | 8.4 | 2.7 | 19.7 | 11.0 | 70.7 | 7.9 | 6.5 | 16.6 | 6.2 | 8.4 | 19.7 | 21.2 | PCB (| 087/115 |
| N -1 N | 4.3 | 5.0 0 | 4.2 | 5.2 | 4.0 | з.5 | 5.3 | 3.8 | Ŋ | 3.4 | 2.0 | 4.1 | 4.3 | 4.7 | 5.2 | 8.0 | Ŋ | ND | Ŋ | 3.2 | 3.2 | 6.3 | 6.5 | 8.6 | ω. 3 | 16.6 | 10.4 | D | 6.2 | 2.8 | 7.4 | 3.8 | 8.5 | ND | ND | РСВ (|)88 |
| 1.3 1.3 | 6.7 | 7.9 | 12.1 | 8.9 | 10.2 | 6.4 | 12.8 | 7.0 | 6.8 | 9.3 | 5.6 | 7.2 | 9.8 | 8.6 | 10.2 | 14.6 | ND | 4.1 | Ŋ | 3.1 | 6.5 | 6.9 | 14.7 | 17.2 | 4.5 | 37.5 | 20.8 | ND | ND | 6.8 | ND | 7.6 | 7.3 | ND | ND | РСВ (|)92 |
| 3.6 3.6 | 12.0 | 0.0 14.8 | 8.9 | 7.6 | 6.2 | 5.3 | 7.4 | ປາ ເປັ | з.5 | 4.7 | 3.1 | 9.1 | 9.4 | 11.0 | 9.8 | 10.0 | D | ND | Ŋ | 10.3 | 10.4 | 15.3 | 9.6 | 11.8 | 4.2 | ND | D | D | B | ND | ZD | 6.4 | 8.0 | ND | ND | РСВ (|)97 |
| 3.9 3.9 | 6.9 | 0.4 11.0 | 7.9 | 4.6 | 12.1 | 8.5 | 15.4 | 8.4 | 6.9 | 12.1 | 6.8 | 2.5 | Ŋ | 3.9 | 6.2 | 21.9 | 1.3 | 7.0 | ß | 12.6 | 3.2 | 9.4 | 21.1 | 10.8 | 7.2 | 42.9 | 27.6 | 58.5 | 16.9 | 9.0 | ß | 9.8 | 6.9 | ß | B | РСВ (|)99 |
| 888 | 58 | 88 | 58 | Ŋ | ND | Ŋ | Ŋ | Ŋ | Ŋ | ß | Ŋ | Ŋ | B | Ŋ | B | ß | ß | ND | ß | Ŋ | D | ND | Ŋ | ß | D | ß | ß | ß | S | Ŋ | ß | Ŋ | Ŋ | ß | ß | PCB 1 | 100 |
| 4.4.1 5.85 | 15.7 | 19.2 | 11.3 | 14.9 | 17.8 | 13.9 | 22.9 | 12.1 | 10.8 | 17.0 | 11.4 | 20.2 | 23.5 | 23.1 | 24.4 | 36.4 | 1.1 | 6.3 | 5.7 | 10.6 | 11.5 | 12.8 | 25.5 | 31.0 | 9.3 | 68.6 | 43.0 | 180.5 | 29.6 | 17.1 | 33.1 | 20.2 | 25.1 | 38.3 | 59.9 | PCB 1 | 101/90 |
| 1.7 1.5 | ŞÖ | 4 4 .3 0 | 4.7 | 4.5 | 4.5 | 3.0 | 1.9 | 2.0 | Ŋ | 2.8 | 1.5 | 5.7 | 5.2 | 6.8 | 8.0 | 8.6 | 2.3 | 2.6 | 1.4 | 5.6 | 2.7 | 3.9 | 7.6 | 7.6 | з. 1 | 26.2 | 20.5 | 100.3 | 12.4 | 8.8 | 15.9 | 6.4 | 6.7 | 21.1 | 27.6 | PCB 1 | 105 |
| ND 15.1 16.6 | 26.3 | 6.8 | 2.8 | 8.3 | 27.7 | 25.8 | 18.8 | 19.3 | 30.0 | 14.2 | 11.0 | 8.8 | 9.7 | 9.2 | 11.0 | 13.8 | B | ß | 3.0 | 4.6 | 0.5 | 6.7 | 12.6 | 12.2 | 4.5 | Ŋ | 12.2 | 62.2 | B | 4.9 | Ŋ | 7.9 | 11.4 | ND | 21.9 | PCB [·] | 107/108/144 |
| 5.4 0 | 19.3 | 20.3 21.9 | 12.0 | 24.1 | 18.4 | 15.5 | 26.0 | 14.0 | 9.3 | 15.0 | 9.0 | 23.4 | 23.7 | 24.4 | 27.3 | 33.2 | Ŋ | 8.3 | 5.2 | 11.7 | 21.4 | 20.4 | 26.3 | 35.9 | 10.5 | 32.9 | 23.7 | 109.7 | 29.2 | 17.6 | 21.1 | 18.0 | 26.2 | 27.5 | 66.4 | PCB 1 | 110 |
| ND 7.0 6.7 | 18.6 | 31.0 27.5 | 19.0 | 35.1 | 12.8 | 9.9 | 14.9 | 8.0 | 7.5 | 11.3 | 8.0 | 30.8 | 29.7 | 32.2 | 39.9 | 47.3 | -1 :-1 | 6.5 | 22.7 | 16.9 | 11.8 | 28.3 | 19.8 | 31.7 | 7.2 | 45.7 | 31.5 | 155.9 | 22.9 | 14.9 | 32.4 | 19.9 | 38.9 | 41.6 | 61.1 | PCB 1 | 118 |
| 888 | 5.0 | 2.1 | 4 1 4 0 | 3.6 | 3.4 | 3.1 | 2.5 | 2.9 | Ŋ | 2.7 | 1.0 | 5.5 | 4.7 | 6.8 | 7.5 | 5.4 | D | Ŋ | B | 4.9 | 2.6 | 4.9 | 5.8 | 6.3 | 2.2 | 9.1 | 8.0 | 28.0 | 5.8 | 3.4 | 7.5 | 3.2 | 6.7 | 8.4 | 7.4 | PCB 1 | 128 |
| 888 | 2.8 | 2.1 | , 1 .4 | Ŋ | Ŋ | D | B | Ŋ | Ŋ | D | B | ND | B | Ŋ | B | Ŋ | D | ß | B | 1.6 | 0.6 | ND | D | Ŋ | D | Ŋ | D | D | B | ND | Ŋ | ND | Ŋ | ND | ND | PCB 1 | 129 |
| 888 | 58 | ΒZ | ŞÖ | Ŋ | ND | B | ZD | Ŋ | B | B | Ŋ | ND | B | Ŋ | B | B | D | ß | Ŋ | ND | Ŋ | ND | 9.3 | 3.9 | 2.0 | Ð | Ŋ | Ŋ | Ŋ | Ŋ | Ŋ | 2.4 | B | ND | B | PCB 1 | 136 |
| 6.5 ND 3.3 | 3.0 | 8 e | 58 | Ŋ | Ŋ | 2.7 | Ŋ | 7.6 | Ð | 2.4 | B | Ŋ | B | B | 1.3 | Ð | B | 8 | 1.3 | Ŋ | 3.9 | ND | 8 | 0.6 | 8 | D | B | 7.3 | B | Ŋ | D | 0.6 | 0.5 | D | 1.4 | PCB 1 | 137/176 |
| 2.1 7.8 7.5 | 36.8 | 49.0 38.0 | 18.9 | 36.2 | 36.4 | 40.2 | 36.4 | 27.8 | 18.0 | 31.0 | 21.7 | 43.2 | 45.3 | 51.4 | 56.1 | 56.7 | ß | 10.5 | 17.3 | 26.0 | 18.4 | 32.1 | 45.0 | 56.6 | 21.6 | 106.7 | 91.1 | 336.2 | 56.9 | 35.1 | 66.6 | 38.9 | 52.0 | 80.6 | 98.1 | PCB 1 | 138/160 |
| 1.4 | ο 0.3 | о.9 7.1 | 4.3 3 | 5.7 | 5.7 | 4.7 | Ŋ | 3.1 | 3.7 | 2.7 | 1.7 | 4.9 | 6.2 | 6.5 | 7.2 | 8.4 | Ŋ | Ŋ | Z | 4.7 | 3.8 | 3.3 | 6.7 | 10.6 | 2.9 | 12.4 | 12.8 | 43.7 | 7.5 | 3.4 | 5.1 | 4.3 | 6.8 | 9.4 | 12.0 | PCB ² | 141/179 |
| N : 1 N | , 01 0 0 0 | 5.6 | 4.3 | 6.2 | 6.1 | 4.4 | 7.7 | 4.1 | Ŋ | 5.0 | 3.9 | 8.6 | 9.2 | 9.2 | 12.0 | 9.7 | ß | ß | 2.5 | 3.5 | 4.2 | 5.4 | 9.2 | 13.7 | 3.8 | Ŋ | B | 85.0 | Ŋ | 7.5 | 14.4 | 8.4 | 14.0 | ND | 26.4 | PCB 1 | 146 |
| 1.2 3.0 3.2 | 18.8 | 30.7 16.1 | 9.2 | 21.8 | 25.0 | 14.8 | 29.7 | 12.3 | 13.7 | 19.4 | 12.3 | 18.4 | 25.0 | 24.3 | 23.3 | 36.8 | ND | 9.1 | ND | 11.1 | 11.2 | 14.5 | 29.5 | 32.7 | 10.2 | Ŋ | 53.2 | ND | ND | N | 33.7 | 20.3 | 21.5 | ND | ND | PCB [·] | 149/123 |

T-0 indicates the time of bivalve deployment into the Estuary from source indicated under station name heading.

| PCB 209 | 2 | Q | Q | 0.6 | 0.8 | Q | g | ₽ | Q | g | Q | Σ | Σ | 1.4 | Q | 1.0 | Q | Q | Q | Q | Q | Q | Q | 1.3 | 9 ! | | | Ş | S | 2 | Q | Q | 1.5 | Ð | 1.8 | Q I | <u>g</u> | Q |
|-----------------|--------------|------------------|---------------|---------|--------------------|---------------|----------|----------------|----------------|---------------|--------------|-------------|------------|-------------|------------------|-------------------|---------------|-------------|-------------|--------------|------------------|---------------|---------|--------------------|---------------|------------|----------------------------------|---------------|--------------|-------------|------------|-------------|-------------|------------------|-------------------|-------------|---------------|-------------------|
| PCB 206 | 9 | Q | Q | Q | Q | g | g | g | g | g | g | 1.0 | g | g | Q | 0.7 | Q | Q | Q | Q | g | Q | g | g | 2 | 2 | | | Ē | 2 | Q | Q | Q | Q | Q | 2 | 2 | Q |
| PCB 205 | 9 | Q | Ð | Q | Q | Q | g | Q | Q | g | g | Q | Q | g | Q | Q | Q | 2.6 | Q | Q | g | Q | Q | Q | 9 ! | | | | S | 2 | Q | Q | Q | Q | Q | Q I | g ! | Q |
| PCB 201 | 1.6 | Q | Q | 1.9 | 0.8 | Q | Q | Ð | Q | 2.4 | 0.8 | 1.0 | 2.0 | 2.0 | 0.9 | 1.2 | Q | Q | Q | Q | Ð | Q | g | g | 0.7 | Z Z | - CIV | | Ē | 3.5 | Q | 1.5 | Q | 2.3 | 1.8 | Q I | g : | 1.2 |
| PCB 200 | 2.0 | 2.3 | 1.6 | 1.1 | Q | 0.8 | g | Q | Q | Q | g | 1.5 | 1.3 | g | Q | 1.0 | Q | Q | Q | Q | 1.6 | Q | 1.5 | Q | 9 ! | | | | S | 2 | Q | Q | 1.7 | g | 1.6 | Q I | g ! | Q |
| PCB 196/203 | 2 | Q | 1.0 | 0.6 | Q | Q | Q | g | Q | g | Q | Q | g | 2.3 | 1.6 | 1.8 | Q | Q | g | Q | g | Q | Q | Q | 2 | 2 | | Ē | S | g | Q | 1.9 | Q | 2.6 | 2.7 | Q I | 2 | D |
| PCB 195/208 | 2 | 2 | Q | Q | Q | g | Q | Q | g | g | Q | 0.8 | Q | Q | Q | Q | Q | Σ | Q | 4.8 | Q | Q | Q | Q | 2 | la ' | 0.4 0.4 | 5 | | 2 | 7.6 | Q | 3.8 | Q | Q | Q I | 2 : | 14.6 |
| PCB 194 | 2.1 | 1.0 | 1.0 | 0.7 | 0.8 | Q | g | Ð | Q | g | Ð | 0.8 | Q | 9 | Q | 9 | Q | Q | Q | Q | g | Q | g | Q | 2 | | | Ş | S | g | Q | Q | Q | g | Q | Q I | 2 | Ŋ |
| PCB 191 | 9 | Q | 0.5 | Q | Q | Ð | g | Q | Ð | g | g | 1.2 | g | 1.9 | g | g | Q | g | g | Q | g | Q | Q | g | 2 | 2 | | | 2 Z | 2 | Q | Q | Q | Q | Ð | g | 2 | Q |
| PCB 189 | 2 | 2 | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q | Q | g | Q | Q | Q | Q | Q | Q | g | Q | Q | Q | 2 | | | Ē | S | 2 | Q | Q | Q | g | Q | Q I | 2 | R |
| PCB 187/182/159 | 43.3 | 29.0 | 19.3 | 11.5 | 21.0 | 11.4 | 17.8 | 143.2 | 24.9 | 44.2 | 5.5 | 23.9 | 15.9 | 8.1 | 6.1 | 5.3 | 1.6 | 4.5 | Q | 24.9 | 17.5 | 16.5 | 14.9 | 13.4 | 2.0 | 2.2 | N A | 0 - 10 | 2.0 9.0 | 5.7 | 13.5 | 5.5 | 21.2 | 12.1 | 3.7 | Q : | 2 | Q |
| PCB 185 | 2 | g | 0.7 | Q | Q | Q | g | Q | Q | g | Q | Q | Q | g | 0.5 | g | Q | Q | g | Q | g | Q | Q | Q | 2 | | | Ē | S | 2 | Q | Q | 1.8 | g | Q | Q | 2 | a |
| PCB 183 | 8.3 1 | 9.5 | 8.3 | 5.3 | 9.5 | 4.7 | 6.9 | 31.3 | 7.8 | 10.2 | 2.4 | 7.1 | 4.7 | 5.4 | 3.8 | 3.3 | 1.3 | Q | Q | 6.2 | 7.3 | 7.0 | 6.7 | 6.2 | 0.7 | | | Ē | S | 2 | 3.6 | 3.2 | 6.2 | 6.2 | Q | g | 2 | Ŋ |
| PCB 180 | 46.2 | 35.6 | 30.9 | 15.5 | 46.2 | 12.9 | 18.6 | 117.8 | 21.5 | 45.6 | 6.9 | 39.2 | 36.3 | 28.2 | 38.7 | 47.4 | 7.2 | Q | g | 17.9 | 22.3 | 24.2 | 17.6 | 23.8 | 2.2 | 6.7 | | , 4 1 1 | 2 4 | 6.2 | 22.7 | 13.8 | 37.8 | 46.6 | 33.2 | g | 0.9 | R |
| PCB 178 | 2 | Q | Q | 1.7 | Q | Q | g | Q | Q | g | 0.9 | 3.4 | 2.8 | g | 1.2 | 1.5 | Q | Q | Q | Q | g | 3.3 | 2.8 | Q | 2 | | | Ş | S | g | 3.2 | 1.5 | Q | 3.2 | Q | Q I | 2 | Ŋ |
| PCB 177 | 12.5 | 9.2 | 6.5 | 3.7 | 6.8 | 3.2 | 5.3 | 41.1 | 7.6 | 12.5 | 1.7 | 7.3 | 4.9 | 2.9 | 1.7 | 2.1 | 1.8 | Q | g | 8.0 | 7.0 | 6.2 | 5.2 | 4.8 | 0.6 | | | 2 C | | g | 4.6 | 2.2 | 7.1 | 4.6 | Q | Q I | g ! | Q |
| PCB 174 | 9 | Ð | Q | Q | Q | Q | g | Q | Q | g | Q | 1.6 | g | Q | 1.2 | 1.0 | Q | Σ | Q | Q | Q | Q | Q | g | 2 | | | Ē | g | 2 | Q | Q | Q | g | Q | g | Ð. | 1.7 |
| PCB 172 | 9 : | P | 0.7 | 0.6 | Q | Q | Q | Q | Q | g | Q | 0.9 | g | Q | Q | Q | Q | Q | Q | Q | 1.3 | Q | Q | g | 2 | | | S | g | 2 | Q | Q | Q | g | Q | 9 | 2 | N |
| PCB 170/190 | 10.5 | 6.2 | 3.9 | 2.3 | 5.5 | 2.8 | 4.9 | g | 11.7 | 7.4 | 1.7 | 5.9 | 2.3 | 4.4 | 3.2 | 2.9 | 2.3 | Q | 1.5 | 9.2 | 6.6 | 5.8 | 6.0 | 4.6 | 4.7 0.0 | 0.0 | 0.02 | 1 00 | 10.9 | 13.9 | 7.0 | 4.5 | 4.9 | 6.6 | 13.7 | 4.8 | 6.5 | 6.4 |
| PCB 167 | 2 | Q | g | 1.2 | g | Q | 2.7 | g | Q | g | Q | 2.7 | 2.1 | g | 1.7 | 2.9 | g | Q | g | Q | 2.5 | Q | g | g | 2 | | | - - - | g | 2 | g | Q | Q | g | 2.4 | g | 2 | R |
| PCB 158 | 3.1 | 4 4 | 3.6 | 2.4 | g | 1.9 | g | g | Q | 4.5 | 1.1 | 3.0 | 2.2 | 2.4 | 0.5 | 1.1 | Q | Q | Q | 2.8 | 3.5 | 3.5 | 3.2 | 3.2 | 2 | | | Ē | g | g | 2.1 | 1.2 | 2.6 | 2.4 | Q | Q ! | 2 | N |
| PCB 156/171 | 9 | 2 | 2.6 | 1.9 | g | Q | g | g | Q | g | 2.3 | 2.7 | 1.8 | 2.8 | 1.1 | 3.9 | Q | Q | Q | Q | 4.1 | 4.6 | 2.5 | 4.4 | 6.0 | 0. L | | S | 6 | 3.5 | Q | 2.4 | 1.7 | 2.1 | Q | Q ! | 2 | N |
| PCB 153/132 | 142.7 | 98.1 | 63.0 | 51.1 | 73.6 | 41.2 | 69.5 | 450.8 | 93.3 | 151.0 | 25.3 | 80.3 | 66.6 | 44.5 | 31.9 | 34.8 | 31.8 | 16.1 | 4.7 | 85.9 | 65.3 | 61.4 | 57.5 | 50.7 | 29.4 | 39.1 | 0.10 | 65.4 | 36.4 | 59.2 | 45.4 | 28.0 | 65.2 | 44.4 | 55.3 | 3.3 | 17.7 | 10.1 |
| PCB 151 | Q : | QN | 9.4 | 7.2 | Q | Q | g | Q | Q | g | 3.5 | 13.2 | 10.0 | 4.9 | 5.1 | 2.1 | 1.8 | Q | Q | 9.5 | 7.4 | 5.5 | 7.1 | 6.4 | 3.7 | 4 • 0 0 | 4 α υα | 8.7 | 4.2 | 7.0 | 4.3 | 3.6 | 8.1 | 6.1 | 7.4 | Q a | 2.0 | R |
| Species | oyster | musse | mussel | mussel | mussel | mussel | mussel | oyster | mussel | oyster | mussel | oyster | oyster | clam | clam | clam | clam | oyster | mussel | oyster | mussel | mussel | mussel | musse | mussel | mussel | oyster | ovster | mussel | ovster | oyster | clam | oyster | clam | clam | mussel | clam | oyster |
| Ðate | 5/4/94 | 5/4/94 | 5/4/94 | 5/4/94 | 5/4/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/5/94 | 5/6/94 | 5/5/94 | 5/6/94 | 5/6/94 | 5/6/94 | 1/17/94 | 1/17/94 | 1/17/94 | 9/12/94 | 9/12/94 | 9/12/94 | 9/12/94 | 9/12/94 | 9/13/94 | 9/13/94 | 9/13/94 0/13/04 | 9/13/94 | 9/13/94 | 9/14/94 | 9/13/94 | 9/14/94 | 9/14/94 | 9/14/94 | 9/14/94 | 5/26/94 | 6/2/94 | 6/2/94 |
| | | | | | 7 | | | | | | | | | | | | | | | | | | | 5 | | | | | | | | | | | | | | ob Bay, wA |
| noi1≋tS | Coyote Creek | Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Islanc | Horseshoe Bay | Red Rock | Petaluma River | Petaluma River | San Pablo Bay | Pinole Point | Davis Point | Napa River | Grizzly Bay | Sacramento River | San Joaquin River | Lake Isabella | Tomales Bay | Bodega Head | Coyote Creek | Dumbarton Bridge | Redwood Creek | Alameda | Yerba Buena Islant | Horseshoe Bay | Ked Kock | Petaluma River Detaluma Pivar | San Pablo Bav | Pinole Point | Davis Point | Napa River | Grizzly Bay | Grizzly Bay | Sacramento River | San Joaquin River | Bodega Head | Lake Isabella | Tomales Bay / Dab |
| Station Code | BA10 | BA30 | BA40 | BB71 | BC10 | BC21 | BC60 | BD15 | BD15 | BD20 | BD30 | BD40 | BD50 | BF20 | BG20 | BG30 | T-0 | T-0 | T-0 | BA10 | BA30 | BA40 | BB71 | BC10 | BC21 | BC60 | | BD20 | BD30 | BD40 | BD50 | BF20 | BF20 | BG20 | BG30 | 0 0 1 1 | Ģ ¢ | - P |

| ble 3.29. Pesticide concentrations in biv | a lve tissues, 1994. |
|--|----------------------------------|
|) = not detected, M = Matrix interference. U | Jnits in ng/g (ppb), dry weight. |
| 0 = not detected, M = Matrix interference. U | Jnits in ng/g (ppb), dry weight. |

T-0 indicates the time of bivalve deployment into the Estuary from source indicated under station name heading.

| BB/1 Alart BB/1 Alart BB/1 Alart BB/1 Hors BC21 Hors BC21 Hors BC21 Hors BC21 Hors BC20 Sart BD15 Petal BD20 Sart BD20 Sart BC20 Sart BC21 Cate BC21 Netwee BC21 Hors BC210 Petal BD215 Petal BD200 David BD210 Pirat BD200 Grizz BC20 Sart BD200 Grizz | BA10 D Covo |
|---|---|
| a Buena Island a Sushoe Bay Rock e Point Pablo Bay Pablo Bay Isabella Isabella Sabena Island amento River Uoaquin River Isabella Isabella Bay Bay Pablo Bay Pablo Bay | barton Bridge |
| 5/4/94 5/4/94 5/4/94 5/5/94 5/5/94 5/5/94 5/5/94 5/6/94 1/17/94 5/6/94 1/17/94 9/12/94 9/12/94 9/12/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 9/13/94 | 5/4/94 5/4/94 |
| mussel mussel mussel mussel mussel oyster oyster oyster oyster mussel mu | oyster Species |
| 20,93 26,52 20,93 26,52 26,52 25,52 45,16 55,76 55,76 55,76 55,76 55,76 55,76 55,76 55,76 55,76 55,76 55,76 55,76 55,76 52,41 53,00 52,45 73,00 52,15 23,15 23,15 23,15 23,15 23,15 25,15 | Total Chlordanes |
| 512.5.47 512.5.7 512.5.7 512.5.7 512.5.7 512.5.7 512.5.2 52.5.8 52.5.9 52.5.2 52.5.5.5.5 | Total DDTs |
| 3.0.682 3.0.682 7.7.67 7.6.69 9.9.9 9.9.9 9.9.9 9.9.9 15.62 2.2.97 7.37 7.37 7.37 7.37 7.37 7.37 7.37 7 | Total HCHs |
| 1.21 1.22 1.25 1.2.25 1.2.25 1.2.25 1.2.25 1.2.25 1.28 1.28 1.28 1.28 1.28 1.28 1.28 1.28 | Aldrin |
| 10.25 6.38 15.58 18.79 88.79 13.40 6.71 13.27 14.31 14.42 15.88 15.88 15.88 15.88 15.88 15.88 15.88 15.78 6.29 16.71 15.29 5.29 5.34 6.21 1.257 1.257 5.265 5.1655 | Alpha-Chlordane |
| 11.247 11.247 11.247 11.2487 11.2487 11.248 11.257 11.256 11.266 11.266 11.266 11.2688 11.2688 11.2688 11.2688 11.2688 11 | Alpha-HCH |
| 1.13 0.28 0.28 0.27 0.28 0.27 0.28 0.27 0.28 0.27 0.28 0.27 0.28 0.02 0.28 0.02 0.28 0.02 0.28 0.02 0.02 | Beta-HCH |
| 3.3.3 3.3.3 3.3.3 3.3.3 3.3.3 3.3.3 3.3.3 3.3.3 3.3.4 3.3.4 3.3.4 3.3.9 4.3.5 5.8 4.3.5 5.8 4.3.5 5.8 4.3.5 5.8 4.3.5 5.8 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5.5 5 | Cis-Nonachlor |
| | |
| | 금금 Delta-HCH |
| ND 2.2.8 ND 2.2.8 ND 2.2.8 ND 2.2.8 ND 2.2.8 ND 2.2.8 ND 54.14.6 5.4.14.6 1.25 14.66 1.25 14.66 1.25 14.66 1.277 ND 14.57 1.64 1.64 1.64 1.64 1.64 1.64 1.64 1.64 | Delta-HCH |
| ND 20.08 2.79 ND 20.08 2.79 ND 22.38 ND ND 22.38 ND ND 24.34 1.55 ND 54.14 10.58 ND 14.56 ND 14.56 ND ND 5.81 ND 14.56 ND 14.56 ND 14.56 ND 14.56 ND 14.57 0.8 ND 14.57 0.8 ND 14.56 ND 14.66 ND 14.56 ND 14.56 ND 14.56 ND 14.56 ND 14.56 ND 14.56 ND 14.56 ND 15.89 1.54 ND 5.81 ND 14.56 ND 14.56 ND 15.81 ND 14.56 ND 15.81 ND 14.56 ND 15.81 ND 14.56 ND 15.81 ND 14.56 ND 15.81 ND 15.81 ND 14.56 ND 15.81 ND 15.81 ND 15.81 ND 14.52 ND 15.52 0.33 ND 15.52 0.33 ND 15.52 0.58 | B Delta-HCH 22.55 13.77 1.37 Endrin |
| $\begin{array}{rrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrrr$ | Delta-HCH 23:55 18:03 1:37 |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | B Delta-HCH 23:55 13:0 18:03 3:76 13:76 Endrin 23:55 1:37 16:27 6 6 amma-Chlordar 5:51 22 6 amma-HCH |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | B Delta-HCH 22 B 23 Dieldrin 1.3 Fndrin 1.3 Camma-Chlordar 5.5 6 6 6 7 Gamma-HCH 8 B 8 Heptachlor |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | B Delta-HCH 29 B 29 B 13 Findrin 13 78 13 Camma-Chlordar 15 642 642 Gamma-HCH 10 Heptachlor 25 10 10 Heptachlor |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | B Delta-HCH 29 Dieldrin 29 Dieldrin 137 Endrin 137 Gamma-Chlordar 55 Gamma-HCH ND Heptachlor 256 N 106 Mirex |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | Belta-HCH 20 Delta-HCH 20 Dieldrin 20 B 21 Findrin 21 Findrin 21 Gamma-Chlordar 25 Gamma-HCH 25 Heptachlor 25 Heptachlor 25 Mirex 25 Mirex 26 No |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | B O Delta-HCH 22 36 Dieldrin 23 76 Endrin 1.3 7 Gamma-Chlordar 5.5 6 6 6.5 6 A 76 6 Gamma-HCH 1.25 6 Heptachlor 25 16 Heptachlor 25 16 Heptachlor 25 8 0,p'-DDD 1.37 38 0,p'-DDE |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | B O Delta-HCH 29 60 Dieldrin 29 37 Endrin 137 16 27 137 16 Gamma-Chlordar 55 64 Gamma-HCH 100 Heptachlor Epstechlor 25 16 Mirex 25 10 Mirex 25 10 o,p'-DDD 10 38 o,p'-DDE 59 10 o,p'-DDT |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | B O Delta-HCH 29 60 Dieldrin 29 37 Endrin 137 16 27 137 16 Gamma-Chlordar 55 64 Gamma-HCH 100 16 Heptachlor 256 0 Mirex 256 0 Mirex 256 0 o,p'-DDD 257 0 o,p'-DDT 259 0 o,p'-DDT |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | B C Delta-HCH 28 0 Delta-HCH 28 0 Dieldrin 137 16 Endrin 137 16 Gamma-Chlordar 137 16 Gamma-HCH 137 16 Heptachlor 14 26 0 15 14 o,p'-DDD 16 0,p'-DDT 15 24 76 15 24 76 16 p.p'-DDD |
| $ \begin{array}{cccccccccccccccccccccccccccccccccccc$ | No Delta-HCH 229 100 100 Dieldrin 100 Endrin 110 No 110 |
| $ \begin{array}{llllllllllllllllllllllllllllllllllll$ | No Delta-HCH 2295 130 137 16.25 137 16.25 137 16.25 137 16.25 137 16.25 137 16.25 137 16.25 137 16.25 137 16.25 137 16.25 148 Gamma-HCH 149 Heptachlor 151 ND 152 170 153 ND 154 387 155 ND 152 160 153 ND 154 247 155 ND 160 0.p'-DDT 160 p.p'-DDD 1125 160 1100 p.p'-DDT |

APPENDIX 4

Trace Organic Summary

Table 4.1. Summary of PAH concentrations in water.Data from two laboratories (UCSC and Bodega Bay Institute) are combined.

| Parameter | Total Number of Observations | Frequency of detection (%) | Median (pg/l) | Maximum (pg/l) |
|----------------------------|------------------------------------|----------------------------|---------------|----------------|
| Total PAHs | | | 24.05 | 258.69 |
| Low Molecular Weight PAHs | | | 2.29 | 25.48 |
| High Molecular Weight PAHs | | | 21.30 | 233.21 |
| Carcinogenic PAHs | | | 9.80 | 118.47 |
| 1-Methylnaphthalene | 30 | 90 | 0.26 | 2.17 |
| 1-Methylphenanthrene | 15 | 67 | 0.23 | 0.52 |
| 2-Methylphenanthrene | 15 | 93 | 0.31 | 3.72 |
| Anthracene | 45 | 76 | 0.15 | 1.70 |
| Phenanthrene | 45 | 98 | 1.67 | 19.05 |
| Benz(a)anthracene | 45 | 73 | 0.52 | 10.00 |
| Chrysene | 45 | 98 | 1.50 | 25.50 |
| Fluoranthene | 45 | 98 | 4.82 | 50.96 |
| Pyrene | 45 | 96 | 4.87 | 42.41 |
| Benzo(a)pyrene | 30 | 63 | 0.04 | 25.00 |
| Benzo(b)fluoranthene | 45 | 96 | 3.22 | 42.15 |
| Benzo(e)pyrene | 45 | 96 | 2.24 | 28.71 |
| Benzo(k)fluoranthene | 45 | 98 | 1.20 | 17.39 |
| Dibenz(a,h)anthracene | 45 | 93 | 0.46 | 5.21 |
| Benzo(ghi)perylene | 30 | 83 | 0.32 | 8.89 |
| Indeno(1,2,3,-cd)pyrene | 45 | 91 | 2.92 | 28.00 |

TOTAL (Dissolved + Particulate)

| Paramater | Total Number of Observations | Number of Records Quantified | Frequency of Detection (%) | Median (pg/l) | Maximum (pg/l) | Paramater | Total Number of Observations | | | | |
|-------------------|------------------------------------|------------------------------------|-------------------------------|------------------|-------------------|-----------------|------------------------------------|--------|------|-----|-------|
| Total PCBs (SFEI) | 45 | 45 | 100 | 975 | 9233 | PCB 183 | 45 | 40 | 68 | 10 | 204 |
| PCB 138 | 45 | 45 | 100 | 89 | 951 | PCB 156 | 30 | 30 | 100 | 10 | 134 |
| PCB 153 | 45 | 45 | 100 | 88 | 1059 | PCB 087 | 30 | 30 | 100 | . 9 | 58 |
| PCB 110 | 30 | 30 | 100 | 80 | 270 | PCB 196/203 | 15 | 15 | 100 | 9 | 163 |
| PCB 149 | 45 | 43 | 96 | 70 | 445 | PCB 137/176 | 15 | 8 | 53 | 9 | 34 |
| PCB 101 | 30 | 30 | 100 | 52 | 247 | PCB 018 | 45 | 37 | 82 | 9 | 50 |
| PCB 118 | 45 | 43 | 96 | 49 | 474 | PCB 105 | 45 | 29 | 64 | 8 | 123 |
| PCB 180 | 45 | 44 | 86 | 46 | 644 | PCB 158 | 45 | 38 | 84 | 7 | 70 |
| PCB 187 | 45 | 45 | 100 | 41 | 594 | PCB 008 | 30 | 28 | 93 | 7 | 52 |
| PCB 177 | 45 | 44 | 86 | 35 | 277 | PCB 195/208 | 15 | 15 | 100 | Ω1 | 80 |
| PCB 101/90 | 15 | 15 | 100 | 35 | 261 | PCB 129/178 | 15 | 13 | 87 | Ω | 111 |
| PCB 174 | 45 | 44 | 86 | 34 | 229 | PCB 005/8 | 15 | 9 | 60 | J. | 88 |
| PCB 095 | 30 | 30 | 100 | 34 | 154 | PCB 157 | 30 | 26 | 87 | 4 | 23 |
| PCB 110/77 | 15 | 15 | 100 | 33 | 401 | PCB 207 | 45 | 41 | 91 | ω | 13 |
| PCB 151 | 30 | 30 | 100 | <u>α</u> | 66 | PCB 157/173/201 | 15 | 13 | 87 | ယ | 61 |
| PCB 066/95 | 20 20 | 20 20 | 100 | 2 C 2 C | 395 | PCB 195 | 4 0 | ° 9 | n 63 | א נ | 4 2 4 |
| PCB 031 | 30 | 30 | 100 | 280 | 8.3 | PCB 137 | 30 | 2 c | 77 | → r | ۍ « |
| PCB 099 | 45 | 45 | 100 | 27 | 169 | PCB 189 | 45 | 24 | 53 | - | 10 |
| PCB 105/132 | 15 | 15 | 100 | 23 | 322 | PCB 119 | 30 | 17 | 57 | - | 8 |
| PCB 203 | 30 | 30 | 100 | 22 | 152 | PCB 015 | 30 | 12 | 40 | 0 | 33 |
| PCB 170 | 30 | 29 | 97 | 22 | 192 | PCB 027 | 30 | 6 | 20 | 0 | ъ |
| PCB 052 | 45 | 39 | 87 | 22 | 171 | PCB 027/24 | 15 | 01 | 33 | 0 | 184 |
| PCB 070 | 45 | 45 | 100 | 21 | 178 | PCB 028/31 | 15 | 6 | 40 | 0 | 87 |
| PCB 085 | 30 | 30 | 100 | 21 | 61 | PCB 029 | 45 | 8 | 18 | 0 | 23 |
| PCB 028 | 45 | 40 | 89 | 20 | 107 | PCB 033 | 15 | | 7 | 0 | ω |
| PCB 044 | 45 | 42 | 93 | 17 | 91 | PCB 040 | 15 | თ | 33 | 0 | 19 |
| PCB 170/190 | 15 | 15 | 100 | 16 | 279 | PCB 060 | 30 | 0 | 0 | 0 | 0 |
| PCB 049 | 45 | 39 | 87 | 14 | 82 | PCB 060/56 | 15 | ω | 20 | 0 | 21 |
| PCB 199 | 15 | 15 | 100 | 14 | 201 | PCB 087/115 | 15 | 0 | 40 | 0 | 143 |
| PCB 132 | 45 | 30 | 67 | 14 | 164 | PCB 103 | 30 | 0 | 0 | 0 | 0 |
| PCB 156/171/202 | 15 | 15 | 100 | 13 3 | 211 | PCB 114 | 30 | | ¦ω | 0 | 4 |
| PCB 206 | 45 | 30 | 67 | 13 | 75 | PCB 114/131/122 | 15 | 4 | 27 | 0 0 | 7 |
| PCB 151/82 | 15 | 15 | 100 | | 196 | PCB 185 | 15 | ı თ | 40 | c | 18 |
| PCB 097 | 45 | 45 | 100 | 12 | 100 | PCB 191 | 15 | J | သ | 0 | ω |
| PCB 146 | 15 | 14 | 93 | 11 | 149 | PCB 194 | 15 | 0 | 0 | 0 | 0 |
| PCB 074 | 45 | 42 | 93 | 11 | 06 | PCB 198 | 30 | 13 | 43 | 0 | 9 |
| PCB 128 | 45 | 42 | 93 | 10 | 141 | PCB 205 | 15 | - | 7 | 0 | 7 |
| | | | | | | | | | | | |

Table 4.2. Summary of total PCB concentrations in water. Data from two laboratories (UCSC and Bodega Bay Institute) are combined.

| Paramater | Total Number of Observations | Frequency of Detection (%) | Median (pg/l) | Maximum (pg/l) |
|-------------------------|---------------------------------|-------------------------------|------------------|-------------------|
| Total Chlordanes (SFEI) | 45 | 100 | 127 | 410 |
| Total DDTs (SFEI) | 45 | 100 | 374 | 1598 |
| Total HCHs (SFEI) | 45 | 100 | 1198 | 7509 |
| Alpha-Chlordane | 45 | 100 | 31 | 104 |
| Alpha-HCH | 45 | 100 | 410 | 802 |
| Beta-HCH | 45 | 98 | 226 | 635 |
| Chlorpyrifos | 15 | 100 | 640 | 2184 |
| Cis-Nonachlor | 45 | 98 | 10 | 36 |
| Dacthal | 45 | 100 | 470 | 7092 |
| Delta-HCH | 30 | 40 | 0 | 150 |
| Diazinon | 41 | 90 | 1900 | 98003 |
| Dieldrin | 45 | 93 | 92 | 257 |
| Endosulfan I | 45 | 0 | 0 | 0 |
| Endosulfan II | 45 | 2 | 0 | 3 |
| Endosulfan Sulfate | 45 | 0 | 0 | 0 |
| Endrin | 30 | 37 | 0 | 73 |
| Gamma-Chlordane | 45 | 100 | 30 | 96 |
| Gamma-HCH | 45 | 100 | 476 | 6601 |
| Heptachlor | 30 | 77 | 4 | 22 |
| Heptachlor Epoxide | 45 | 71 | 14 | 199 |
| Hexachlorobenzene | 45 | 89 | 12 | 78 |
| Methylchlorpyrifos | 11 | 0 | 0 | 0 |
| Mirex | 30 | 3 | 0 | 11 |
| o,p'-DDD | 45 | 100 | 23 | 109 |
| o,p'-DDE | 45 | 78 | 5 | 46 |
| o,p'-DDT | 45 | 0 | 0 | 0 |
| Oxadiazon | 45 | 93 | 144 | 26939 |
| Oxychlordane | 45 | 40 | 0 | 33 |
| p,p'-DDD | 45 | 100 | 139 | 579 |
| p,p'-DDE | 45 | 100 | 160 | 1130 |
| p,p'-DDMU | 15 | 93 | 24 | 310 |
| p,p'-DDT | 45 | 76 | 25 | 109 |
| Toxaphene | 15 | 0 | 0 | 0 |
| trans-Nonachlor | 45 | 100 | 24 | 129 |
| Trifluralin | 15 | 53 | 388 | 1947 |

Table 4.3. Summary of total pesticide concentrations in water. Data from two laboratories(UCSC and Bodega Bay Institute) are combined.

| Number of Rings | Parameter | Frequency of Detection (%) | Median (μg/kg) | Maximum (μg/kg) |
|--------------------|-------------------------------|-------------------------------|-------------------|--------------------|
| | Total PAHs | | 2000 | 7632 |
| | LPAHs | | 244 | 953 |
| | HPAHs | | 1713 | 6837 |
| | CPAHs | | 762 | 3277 |
| 2 | 1-Methylnaphthalene | 78 | 6 | 21 |
| 2 | 2,3,5-Trimethylnaphthalene | 78 | 4 | 16 |
| 2 | 2,6-DimethyInaphthalene | 88 | 6 | 22 |
| 2 | 2-Methylnaphthalene | 85 | 9 | 33 |
| 2 | Biphenyl | 98 | 8 | 31 |
| 2 | Naphthalene | 98 | 25 | 98 |
| 3 | 1-Methylphenanthrene | 93 | 12 | 66 |
| 3 | Acenaphthene | 80 | 9 | 46 |
| 3 | Acenaphthylene | 85 | 12 | 54 |
| 3 | Anthracene | 93 | 25 | 161 |
| 3 | Dibenzothiophene | 80 | 7 | 31 |
| 3 | Fluorene | 90 | 12 | 43 |
| 3 | Phenanthrene | 98 | 94 | 414 |
| 4 | Ben(a)anthracene ^c | 98 | 97 | 372 |
| 4 | Chrysene ^c | 98 | 112 | 466 |
| 4 | Fluoranthene | 100 | 233 | 840 |
| 4 | Pyrene | 100 | 306 | 1221 |
| 5 | Ben(a)pyrene ^c | 98 | 181 | 808 |
| 5 | Ben(b)fluoran ^c | 98 | 107 | 478 |
| 5 | Ben(e)pyrene | 98 | 113 | 531 |
| 5 | Ben(k)fluoran ^c | 98 | 109 | 496 |
| 5 | Dibenz(a,h)anthracene | 95 | 14 | 60 |
| 5 | Perylene | 95 | 63 | 250 |
| 6 | Bghiperylene | 98 | 153 | 920 |
| 6 | Indeno(1,2,3-cd)pyrene | 98 | 125 | 690 |
| 2 | C1-Naphthalenes | 85 | 16 | 53 |
| 2 | C2-Naphthalenes | 90 | 15 | 47 |
| 2 | C3-Naphthalenes | 90 | 18 | 61 |
| 2 | C4-Naphthalenes | 88 | 11 | 42 |
| 3 | C1-Diben | 73 | 7 | 25 |
| 3 | C2-Diben | 85 | 8 | 35 |
| 3 | C3-Diben | 88 | 8 | 31 |
| 3 | C1-Fluorenes | 83 | 11 | 36 |
| 3 | C2-Fluorenes | 88 | 11 | 50 |
| 3 | C3-Fluorenes | 83 | 16 | 63 |
| 3 | C1-Phen Anthr | 95 | 56 | 223 |
| 3 | | 98 | 39 | 116 |
| 3 | C3-Phen Anthr | 93 | 23 | 80 |
| 3 | C4-Phen Anthr | 95 | 15 | 119 |
| 4 | | 98 | 53 | 187 |
| 4 | | 98 | 29 | 01 17 |
| 4 | | б 3 | 3 | 17 |
| 4 | C4-Chrysenes | 88 | 12 | 04 277 |
| 4 | UT-Fluoran Pyr | 98 | 97 | 3// |

Table 4.4. Summary of PAH concentrations in sediment. Concentrations in $\mu g/kg$ dry weight.

^c = Carcinogen

| Parameter | Frequency of Detection (%) | Median (μg/kg) | Maximum (μg/kg) | Parameter | Frequency of Detection (%) | Median (μg/kg) | Maximum (μg/kg) |
|-----------------|-------------------------------|-------------------|--------------------|-----------------|-------------------------------|-------------------|--------------------|
| Total PCBs | 100 | 11.0 | 41.2 | PCB 178 | 10 | 0.0 | 1.5 |
| PCB 153/132 | 83 | 1.4 | 4.4 | PCB 22/51 | 8 | 0.0 | 1.5 |
| PCB 138/160 | 88 | 1.3 | 3.8 | PCB 045 | 8 | 0.0 | 0.9 |
| PCB 110/77 | 80 | 1.1 | 4.7 | PCB 082 | 8 | 0.0 | 0.6 |
| PCB 180 | 78 | 0.8 | 2.1 | PCB 087/115 | 8 | 0.0 | 0.9 |
| PCB 060/56 | 80 | 0.6 | 2.4 | PCB 100 | 8 | 0.0 | 0.7 |
| PCB 101/90 | 53 | 0.5 | 2.0 | PCB 209 | 8 | 0.0 | 0.8 |
| PCB 118 | 58 | 0.5 | 1.9 | PCB 044 | 5 | 0.0 | 0.6 |
| PCB 187/182/159 | 55 | 0.5 | 1.2 | PCB 107/108/144 | 5 | 0.0 | 1.7 |
| PCB 037/42/59 | 58 | 0.4 | 1.6 | PCB 158 | 5 | 0.0 | 0.9 |
| PCB 052 | 58 | 0.4 | 1.7 | PCB 172 | 5 | 0.0 | 0.4 |
| PCB 149/123 | 50 | 0.2 | 1.7 | PCB 185 | 5 | 0.0 | 0.9 |
| PCB 099 | 48 | 0.0 | 1.3 | PCB 191 | 5 | 0.0 | 2.9 |
| PCB 016/32 | 45 | 0.0 | 3.2 | PCB 205 | 5 | 0.0 | 1.0 |
| PCB 201 | 40 | 0.0 | 1.6 | PCB 018 | 3 | 0.0 | 0.7 |
| PCB 137/176 | 35 | 0.0 | 2.0 | PCB 026 | 3 | 0.0 | 0.5 |
| PCB 177 | 33 | 0.0 | 0.9 | PCB 033/53/20 | 3 | 0.0 | 0.7 |
| PCB 066 | 28 | 0.0 | 0.7 | PCB 046 | 3 | 0.0 | 0.7 |
| PCB 8/5 | 25 | 0.0 | 2.3 | PCB 088 | 3 | 0.0 | 0.4 |
| PCB 047/4875 | 25 | 0.0 | 3.2 | PCB 7/9 | 0 | 0.0 | 0.0 |
| PCB 174 | 25 | 0.0 | 0.8 | PCB 015 | 0 | 0.0 | 0.0 |
| PCB 092 | 23 | 0.0 | 1.4 | PCB 24/27 | 0 | 0.0 | 0.0 |
| PCB 196/203 | 20 | 0.0 | 0.8 | PCB 025 | 0 | 0.0 | 0.0 |
| PCB 049 | 18 | 0.0 | 1.0 | PCB 029 | 0 | 0.0 | 0.0 |
| PCB 083 | 18 | 0.0 | 1.1 | PCB 040 | 0 | 0.0 | 0.0 |
| PCB 194 | 18 | 0.0 | 0.6 | PCB 041/64 | 0 | 0.0 | 0.0 |
| PCB 031 | 15 | 0.0 | 1.1 | PCB 084 | 0 | 0.0 | 0.0 |
| PCB 105 | 15 | 0.0 | 0.6 | PCB 085 | 0 | 0.0 | 0.0 |
| PCB 070 | 13 | 0.0 | 1.0 | PCB 128 | 0 | 0.0 | 0.0 |
| PCB 097 | 13 | 0.0 | 0.8 | PCB 129 | 0 | 0.0 | 0.0 |
| PCB 141/179 | 13 | 0.0 | 0.8 | PCB 136 | 0 | 0.0 | 0.0 |
| PCB 151 | 13 | 0.0 | 0.9 | PCB 167 | 0 | 0.0 | 0.0 |
| PCB 156/171 | 13 | 0.0 | 0.6 | PCB 170/190 | 0 | 0.0 | 0.0 |
| PCB 183 | 13 | 0.0 | 0.6 | PCB 189 | 0 | 0.0 | 0.0 |
| PCB 028 | 10 | 0.0 | 0.7 | PCB 195/208 | 0 | 0.0 | 0.0 |
| PCB 074 | 10 | 0.0 | 0.9 | PCB 200 | 0 | 0.0 | 0.0 |
| PCB 146 | 10 | 0.0 | 0.8 | PCB 206 | 0 | 0.0 | 0.0 |

Table 4.5. Summary of PCB concentrations in sediment. Concentrations in μ g/kg dry weight.

| | | Frequency of | Median | Maximum |
|---------------|--------------------|---------------|----------------|----------------|
| Group | Parameter | Detection (%) | (μg/kg) | (μg/kg) |
| DDTs | o,p'-DDD | 38 | 0 | 0.52 |
| | o,p'-DDE | 13 | 0 | 0.67 |
| | o,p'-DDT | 8 | 0 | 2.19 |
| | p,p'-DDD | 95 | 1.55 | 5.18 |
| | p,p'-DDE | 93 | 1.09 | 4.30 |
| | p,p'-DDT | 33 | 0 | 29.40 |
| | Total DDTs | | 2.85 | 33.90 |
| Aldrins | Aldrin | 23 | 0 | 0.55 |
| | Dieldrin | 53 | 0.20 | 0.88 |
| | Endrin | 13 | 0.00 | 1.28 |
| | Total Aldrins | | 0.22 | 2.56 |
| Chlordanes | Alpha-Chlordane | 15 | 0 | 0.40 |
| | Cis-Nonachlor | 20 | 0 | 0.58 |
| | Gamma-Chlordane | 20 | 0 | 0.59 |
| | Heptachlor Epoxide | 0 | 0 | 0.00 |
| | Heptachlor | 3 | 0 | 0.47 |
| | Oxychlordane | 0 | 0 | 0.00 |
| | trans-Nonachlor | 10 | 0 | 0.42 |
| | Total Chlordanes | | 0 | 1.71 |
| HCHs | Alpha-HCH | 40 | 0 | 1.56 |
| | Beta-HCH | 8 | 0 | 1.47 |
| | Delta-HCH | 3 | 0 | 0.44 |
| | Gamma-HCH | 25 | 0 | 0.62 |
| | Total HCHs | | 0.22 | 2.95 |
| Miscellaneous | Mirex | 3 | 0 | 0.25 |

Table 4.6. Summary of pesticide concentrations in sediment. Concentrations in $\mu \text{g/kg}$ dry weight.

| Number of Rings | Parameter | Total number of Observations | Frequency of Detection (%) | Median (μg/kg) | Maximum (μg/kg) |
|--------------------|---------------------------------------|---------------------------------|-------------------------------|-------------------|--------------------|
| 2 | 1-Methylnaphthalene | 33 | 100 | 9.01 | 70.38 |
| 2 | 2,3,5-Trimethnaphthalene | 4 | 12 | 0 | 15.11 |
| 2 | 2,6-Dimethnaphthalene | 27 | 82 | 6.07 | 57.18 |
| 2 | 2-Methylnaphthalene | 33 | 100 | 12.86 | 75.19 |
| 2 | Biphenyl | 28 | 85 | 7.08 | 41.04 |
| 2 | Naphthalene | 33 | 100 | 19.73 | 152.76 |
| 3 | 1-Methylphenanthrene | 8 | 24 | 0 | 18.25 |
| 3 | Acenaphthene | 12 | 36 | 0 | 12.95 |
| 3 | Acenaphthylene | 14 | 42 | 0 | 26.10 |
| 3 | Anthracene | 33 | 100 | 7.76 | 70.76 |
| 3 | Dibenzothiophene | 28 | 85 | 2.12 | 21.18 |
| 3 | Fluorene | 20 | 61 | 3.72 | 39.62 |
| 3 | Phenanthrene | 33 | 100 | 16.08 | 170.40 |
| 4 | Benz(a)anthracene ^c | 33 | 100 | 19.66 | 498.43 |
| 4 | Chrysene ^c | 31 | 94 | 34.94 | 431.21 |
| 4 | Fluoranthene | 33 | 100 | 42.99 | 1099.40 |
| 4 | Pyrene | 33 | 100 | 85.72 | 1543.95 |
| 5 | Benzo(a)pyrene ^c | 32 | 97 | 11.80 | 213.50 |
| 5 | Benzo(b)fluoranthene ^C | 32 | 97 | 9.41 | 482.73 |
| 5 | Benzo(e)pyrene | 33 | 100 | 18.35 | 696.31 |
| 5 | Benzo(k)fluoranthene ^c | 32 | 97 | 9.41 | 477.75 |
| 5 | Dibenz(a,h)anthracene ^c | 14 | 42 | 0 | 23.25 |
| 5 | Perylene | 30 | 91 | 8.84 | 316.81 |
| 6 | Benzo(ghi)perylene | 32 | 97 | 13.40 | 253.72 |
| 6 | Indeno(1,2,3, -cd)pyrene ^c | 28 | 85 | 6.08 | 137.51 |
| 2 | C1-Naphthalenes | 33 | 100 | 21.51 | 145.57 |
| 2 | C2-Naphthalenes | 30 | 91 | 20.46 | 176.50 |
| 2 | C3-Naphthalenes | 28 | 85 | 30.61 | 311.42 |
| 2 | C4-Naphthalenes | 19 | 58 | 21.44 | 162.95 |
| 3 | C1-Fluorenes | 21 | 64 | 11.60 | 49.61 |
| 3 | C2-Fluorenes | 17 | 52 | 9.15 | 164.35 |
| 3 | C3-Fluorenes | 16 | 48 | 0 | 492.78 |
| 3 | C1-Phen_Anthr | 20 | 61 | 13.98 | 156.39 |
| 3 | C2-Phen_Anthr | 22 | 67 | 48.82 | 407.16 |
| 3 | C3-Phen_Anthr | 18 | 55 | 12.58 | 458.18 |
| 3 | C4-Phen_Anthr | 17 | 52 | 15.06 | 444.16 |
| 4 | C1-Chrysenes | 20 | 61 | 10.16 | 359.24 |
| 4 | C2-Chrysenes | 19 | 58 | 8.94 | 256.79 |
| 4 | C3-Chrysenes | 2 | 6 | 0 | 9.74 |
| 4 | C4-Chrysenes | 0 | 0 | 0 | 0 |
| 4 | C1-Fluoran_Pyr | 32 | 97 | 51.02 | 736.64 |
| 5 | C1-Diben | 11 | 33 | 0 | 32.34 |
| 5 | C2-Diben | 16 | 48 | 0 | 213.59 |
| 5 | C3-Diben | 16 | 48 | 0 | 346.61 |

Table 4.7. Summary of bivalve PAH data. Concentrations in μ g/kg dry weight. Data for three species of bivalves are combined.

| 4.8. | Summary of bivalve PCB data. Concentrations in μ g/kg dry weight | t. |
|------|--|----|
| | Data for three species of bivalves are combined. | |

| Parameter | Frequency of Detection (%) | Median (μg/kg) | Maximum (μg/kg) | Parameter | Frequency of Detection (%) | Median (μg/kg) | Maximum (μg/kg) |
|-----------------|-------------------------------|-------------------|--------------------|---------------|-------------------------------|-------------------|--------------------|
| Total PCBs | 100 | 393 | 2289 | PCB 007/9 | 15 | 0 | 3 |
| PCB 153/132 | 100 | 57 | 451 | PCB 008/5 | 6 | 0 | 2 |
| PCB 138/160 | 100 | 40 | 336 | PCB 015 | 9 | 0 | 2 |
| PCB 118 | 100 | 28 | 156 | PCB 016/32 | 30 | 0 | 7 |
| PCB 110 | 100 | 23 | 110 | PCB 018 | 33 | 0 | 4 |
| PCB 180 | 97 | 23 | 118 | PCB 022/51 | 12 | 0 | 2 |
| PCB 101/90 | 100 | 20 | 180 | PCB 024/27 | 9 | 0 | 3 |
| PCB 149/123 | 82 | 18 | 53 | PCB 025 | 24 | 0 | 2 |
| PCB 187/182/159 | 97 | 13 | 143 | PCB 026 | 9 | 0 | 2 |
| PCB 107/108/144 | 88 | 11 | 62 | PCB 029 | 12 | 0 | 2 |
| PCB 099 | 88 | 8 | 59 | PCB 031 | 45 | 0 | 15 |
| PCB 097 | 76 | 7 | 15 | PCB 033/53/20 | 15 | 0 | 2 |
| PCB 092 | 85 | 7 | 38 | PCB 040 | 48 | 0 | 22 |
| PCB 052 | 97 | 7 | 44 | PCB 041/64 | 0 | 0 | 0 |
| PCB 087/115 | 100 | 6 | 71 | PCB 045 | 6 | 0 | 1 |
| PCB 146 | 85 | 6 | 85 | PCB 046 | 45 | 0 | 30 |
| PCB 170/190 | 97 | 6 | 21 | PCB 070 | 42 | 0 | 13 |
| PCB 084 | 73 | 6 | 43 | PCB 085 | 42 | 0 | 3 |
| PCB 141/179 | 97 | 6 | 44 | PCB 100 | 0 | 0 | 0 |
| PCB 105 | 94 | 6 | 100 | PCB 129 | 15 | 0 | 3 |
| PCB 183 | 79 | 5 | 31 | PCB 136 | 12 | 0 | 9 |
| PCB 128 | 97 | 5 | 28 | PCB 137/176 | 33 | 0 | 8 |
| PCB 151 | 76 | 5 | 13 | PCB 167 | 27 | 0 | 3 |
| PCB 044 | 97 | 5 | 22 | PCB 172 | 12 | 0 | 1 |
| PCB 177 | 82 | 5 | 41 | PCB 174 | 9 | 0 | 2 |
| PCB 088 | 88 | 4 | 17 | PCB 178 | 33 | 0 | 3 |
| PCB 082 | 94 | 4 | 16 | PCB 185 | 9 | 0 | 2 |
| PCB 049 | 85 | 3 | 12 | PCB 189 | 0 | 0 | 0 |
| PCB 060/56 | 94 | 3 | 22 | PCB 191 | 9 | 0 | 2 |
| PCB 066 | 79 | 3 | 25 | PCB 194 | 18 | 0 | 2 |
| PCB 074 | 76 | 2 | 22 | PCB 195/208 | 18 | 0 | 8 |
| PCB 158 | 64 | 2 | 4 | PCB 196/203 | 24 | 0 | 3 |
| PCB 156/171 | 61 | 2 | 5 | PCB 200 | 36 | 0 | 2 |
| PCB 028 | 79 | 2 | 12 | PCB 201 | 48 | 0 | 3 |
| PCB 037/42/59 | 61 | 2 | 12 | PCB 205 | 0 | 0 | 0 |
| PCB 083 | 55 | 1 | 5 | PCB 206 | 6 | 0 | 1 |
| PCB 047/48/75 | 55 | 1 | 6 | PCB 209 | 21 | 0 | 2 |

| | Frequency of | Median | Maximum |
|--------------------|---------------|----------------|------------------|
| Parameter | detection (%) | (μg/kg) | (μ g/kg) |
| Aldrin | 64 | 0.87 | 12.25 |
| Alpha-Chlordane | 100 | 10.25 | 88.79 |
| Alpha-HCH | 88 | 1.67 | 10.36 |
| Beta-HCH | 33 | 0.00 | 3.92 |
| Cis-Nonachlor | 100 | 7.51 | 83.99 |
| Delta-HCH | 9 | 0.00 | 2.25 |
| Dieldrin | 100 | 11.84 | 54.14 |
| Endrin | 52 | 0.61 | 10.58 |
| Gamma-Chlordane | 100 | 9.15 | 68.26 |
| Gamma-HCH | 94 | 2.11 | 14.86 |
| НСВ | 30 | 0.00 | 6.36 |
| Heptachlor Epoxide | 58 | 0.71 | 4.05 |
| Heptachlor | 6 | 0.00 | 3.03 |
| o,p'-DDD | 100 | 4.59 | 46.69 |
| o,p'-DDE | 91 | 2.64 | 25.19 |
| o,p'-DDT | 91 | 2.61 | 21.11 |
| Oxy chlordane | 73 | 0.95 | 6.31 |
| p,p'-DDD | 100 | 57.15 | 589.23 |
| p,p'-DDE | 100 | 66.93 | 734.87 |
| p,p'-DDT | 97 | 5.51 | 50.46 |
| Trans-Nonachlor | 100 | 9.79 | 77.63 |
| Mirex | 42 | 0.00 | 4.12 |

Table 4.9. Summary of bivalve Pesticide data. Based on dry weight data (ng/g).Data for three species of bivalves are combined.