

# 1993 Annual Report

**San Francisco Estuary  
Regional Monitoring  
Program  
for Trace Substances**

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





*The R/V David Johnston*

# **1993 Annual Report**

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**December 1, 1994**





San Francisco Estuary  
Regional Monitoring Program

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## Summary

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**T**his first annual report of the San Francisco Estuary Regional Monitoring Program contains the results of monitoring measurements made in 1993. Measurements of conventional water quality parameters and trace contaminant concentrations were made at 16 stations throughout the Estuary three times during the year: the wet period (March), during declining Delta outflow (May), and during the dry period (September). Water toxicity tests were conducted at 8 of those stations. Measurements of sediment quality and contaminant concentrations were made at the same 16 stations during the wet and dry sampling periods. Sediment toxicity was measured at 8 of those stations. Transplanted, bagged bivalve bioaccumulation and condition was measured at 11 stations during the wet and dry sampling periods.

### Water Monitoring

Total or near-total (dissolved + particulate, see text) arsenic, cadmium, selenium, and dissolved (0.45 µm filtered) arsenic, cadmium, copper, nickel, silver, and zinc in water were highest in the South Bay. In general, dissolved metals in water were usually lowest in the Central Bay due to ocean influences. Near-total nickel and total mercury in water were highest in the northern estuary (San Pablo and Suisun Bays). Dissolved chromium and lead were highest at the Sacramento and San Joaquin River confluence stations. Six of the ten dissolved trace metals were highest in March during high runoff. Dissolved and total arsenic, selenium, and near-total cadmium were highest in September.

Concentrations of trace organic contaminants are reported for the March sampling period. Total PAHs and PCBs were highest in the South Bay, but PCBs were also high in the Napa River. Dissolved PAHs were highest in the Central Bay, and dissolved PCBs were highest in the Napa River. Total and dissolved pesticides were highest in the Sacramento River and in the Extreme South Bay.

Concentrations of trace elements in water (except selenium) were usually closely related with other envi-

ronmental parameters. Total or near-total metals concentrations in water were most often associated with the amount of particulate material (TSS) in the water. Dissolved concentrations were usually associated with salinity or dissolved organic carbon (DOC) content. Dissolved PAHs were well correlated with TSS, but dissolved and total trace organic contaminants were poorly correlated with other water parameters.

Based on deviations from conservative mixing of fresh and salt water, three different patterns of possible sources of metals were identified in 1993. For dissolved chromium and lead, rivers and local runoff appeared to be important sources. For dissolved arsenic, cadmium, copper, and nickel year-round inputs from the South Bay appeared to be important sources. Dissolved mercury, selenium, and zinc were associated with local runoff in the South Bay during the wet period. Dissolved silver did not fit any of these patterns.

Although most contaminant concentrations were below water quality objectives, several trace contaminants were above the objectives at some stations. Comparisons to water quality objectives are used as a guide for evaluation of contaminant concentrations, but there are some differences in the way the RMP data are measured and that prescribed for regulatory purposes (see text). Concentrations of 5 metals in water were above EPA or Regional Basin Plan water quality objectives at six stations (see Table 30). Most of these elevated levels occurred at the northern estuary stations. Total PCB concentrations were above EPA human health objectives at all RMP stations. The pesticides chlordane, dieldrin, and DDTs were above the EPA objectives at several RMP stations, particularly at the northern-most, and river confluence stations.

Although some of the contaminant concentrations were above water quality objectives, water toxicity tests (96 hour algal growth and 48 hour bivalve larval development tests) did not indicate toxicity (sometimes inconclusive) associated with the water samples collected at any of the RMP stations in 1993. Exposure to Bay

water actually enhanced algal growth at most stations.

In addition to the Estuary-wide sampling, the Sacramento and San Joaquin Rivers were sampled upstream from their confluence. Stations in each river were sampled six times over a 6 week period of high flows. In the Sacramento River, seven of the ten dissolved metals measured had concentrations lower than those measured at the river confluence stations. Some metals concentrations in the San Joaquin River were higher, and some were lower than concentrations from the river confluence station. Metals concentrations in the Sacramento River were poorly related to river flow because the station at Rio Vista is under considerable tidal influence. In the San Joaquin River, flows were inversely related to 7 of 10 total metals concentrations.

### **Sediment Monitoring**

Concentrations of silver, mercury, and lead in sediment were highest in the South Bay. However, concentrations of most trace metals in sediments were highest in the northern estuary at stations with the finest (silt, clay) sediments. The northern estuary stations with the coarsest (sand, shell) sediments generally had the lowest metals concentrations. There were differences in concentrations of cadmium, lead, and selenium in sediments between the sampling periods, but no consistent trend as to which sampling period had higher values. In September, PAHs and PCBs in sediments were highest in the Central Bay, but pesticides in sediments were highest in the northern estuary and Extreme South Bay.

NOAA's Median Effects Ranges (ERM) for sediments were used as a guide for evaluation of sediment contaminant concentrations. Nickel was the only trace contaminant in sediment above the ERM guidelines, and it was high at all RMP stations. These high levels are probably due to natural, geologic sources.

Although sediment contaminant concentrations were below ERMs, sediment toxicity tests (10 day amphipod mortality, and 48 hour bivalve larval development in elutriates) indicated toxicity at all stations tested. Sediment factors that could have caused the toxicity were not investigated.

### **Bivalve Bioaccumulation**

Mussels, oysters, and freshwater clams were transplanted to the RMP stations to evaluate bioaccumulation of trace substances. Trace metals were bioaccumulated at nearly all RMP stations. However, arsenic, lead, and mercury did not appear to bioaccumulate. There was generally more bioaccumulation during the dry season than during the wet season. In September, PAHs, PCBs, and pesticides accumulated in all samples. Bioaccumulation of PAHs and pesticides was generally highest at the river confluence stations, and the Napa River. PCBs accumulated most at Redwood Creek.

There were substantial differences in the degree of bioaccumulation among the species. Oysters appeared to accumulate higher concentrations of trace metals than the other species, especially copper, which may be a natural phenomenon.

There are no established tissue contaminant standards for trace metal and organic contaminants. Therefore, comparisons to Median International Standards (MIS) for human consumption, or U.S. Food and Drug Administration (USFDA) action levels for trace organics are used to evaluate the bioaccumulation results. Concentrations of selenium were higher than MIS guidelines at all stations during the wet season. Other trace metal concentrations were higher than MIS guidelines at various stations during one or the other sampling period. However, none of the bivalves contained concentrations above the USFDA or National Academy of Sciences (NAS) guidelines for trace organic contaminants.

The transplanted bivalves survived well at all stations except in the Napa River where less than 35% survived during both sampling seasons. Measures of bivalve condition (dry weight, shell volume) indicated that bivalves deployed in the Central Bay grew significantly, but those at most other stations actually lost weight. Whether these differences were due to natural causes such as salinity or food supply, or to contamination, was not determined.

### **Pilot Studies**

Two pilot monitoring studies were conducted in 1993. A pilot study of Estuary hydrography and phytoplankton was conducted by scientists from the U.S.

Geological Survey in Menlo Park and U.C. Davis. Water column profiles at up to 37 stations were monitored along a transect of the Estuary run monthly between the South Bay and the Delta.

The primary objective of this study was to define physical (salinity, temperature, suspended particulate matter, and light penetration), chemical (dissolved oxygen) and biological (chlorophyll *a*) characteristics of Estuary water that may influence other chemical and biological reactions. A second objective was to investigate planktonic indicators of ecosystem structure and function.

The data collected in 1993 showed the extent and duration of the spring phytoplankton bloom in the South Bay, other localized blooms in the northern estuary, the stratification and mixing associated with the entrapment zone in the northern estuary, and mixing in the Estuary resulting from the high rainfall in 1993. Knowledge of the duration and extent of these natural features of the Estuary provide context for interpretation of the RMP contaminant data collected only 3 times per year.

Another pilot study of suspended sediment transport processes was conducted by the USGS in Sacramento. This study used continuous recording sensors at Point San Pablo and the Bay Bridge to measure the amount of suspended sediment in the water at mid-depth and near the bottom, as well as tide height.

The objectives of this study were to estimate which factors determine suspended solids concentrations in the Central Bay and to collect time series of suspended solids that are appropriate for continuous monitoring of suspended solids and for calibration and validation of numerical models.

The investigators determined that spring tides accounted for most of the variation in suspended solids concentrations at the stations monitored, not runoff from the Sacramento or San Joaquin Rivers, or semidiurnal and diurnal tides.

Comparisons were also made between measurements made by the continuous recordings and the RMP samples collected during the regular monitoring cruises. The different ways of measuring TSS were generally comparable, however only 3 measurements per year as made by the RMP could not provide the information of TSS variation actually occurring in the Estuary.

This information is important because as shown by the RMP data, total contaminant concentrations in Estuary water is largely dependent on the TSS in the water. This implies that the RMP measurements alone cannot determine accurately the range of contaminant concentrations without better characterizing the dynamics of TSS.

The RMP Pilot Studies are important to the developing RMP because they will help put RMP measurements into the perspective of Estuary processes and mechanisms at other time scales. The studies can relate those processes to the RMP measurements and will facilitate revision of sampling design and interpretation.

Summaries of other monitoring activities pertinent to regional monitoring are also included in the Report: a description of the Regional Board's Bay Protection Studies, the Sacramento Coordinated Monitoring Program, and a wetlands monitoring plan are included.



San Francisco Estuary  
Regional Monitoring Program

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# 1993 Annual Report

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Note: Tables in the *Pilot Studies* and *Other Monitoring Activities* sections follow an independent numbering scheme and are not included in this list.

# Introduction

## Background

This is the first annual report of the San Francisco Estuary Regional Monitoring Program (RMP). This new program focuses on pollutant concentrations in water, sediment, and tissues, and their potential effects at selected stations in the Estuary. Since this is the first report, the background of the RMP is presented.

In 1991, the San Francisco Bay Regional Water Quality Control Board (Regional Board) began pilot studies on contaminant concentrations and possible ecological effects in the Estuary as part of the State's Bay Protection and Toxic Clean-up Program (BPTCP). Those studies were intended to provide information about contaminant levels in the Bay, to locate "hot spots" in the Bay, and to provide information that would facilitate the

design of the RMP. The BPTCP pilot studies included analysis of contaminant concentrations in water, sediment, and transplanted bivalve tissues, and water and sediment toxicity testing (Taberski *et al.* 1992).

The RMP is the result of Resolution 92-043 of the Regional Board which initiated the Regional Monitoring Program for San Francisco Bay. In the spring of 1992, staff of the Regional Board met with potential RMP sponsors, the major dischargers to the Estuary, to discuss how to implement the RMP. The Regional Board requested the submission of a technical report from the major dischargers in the region on the water quality conditions in San Francisco Bay under the authority of Section 13267 of the California Water Code. It was agreed

### The Objectives of the RMP:

- To obtain baseline data describing the concentration 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 region, including, but not limited to wasteload allocation studies, model development, sediment quality objectives development, in-bay studies of dredged material disposal, Interagency Ecological Program (formerly IESP) water quality studies, primary productivity studies, local effects biomonitoring programs, and state and federal mussel watch programs.

that program sponsors would develop a cost allocation formula for approval by the Regional Board, and that the Aquatic Habitat Institute (now SFEI) would administer and manage the program in fulfillment of the Regional Board's requirement for the technical report on Bay water quality. In 1993, the RMP was sponsored by 46 federal agencies, local special districts, and private companies which hold permits from the Regional Board for discharge into the Estuary (Appendix 1).

The Regional Board and SFEI entered into a Memorandum of Understanding outlining roles and responsibilities for conducting the RMP. SFEI issued a Request for Qualifications in Fall, 1992 and selected Applied Marine Sciences of Livermore, CA, as the Program Contractor.

Regional Monitoring Program Objectives

The purpose of the program is to allow the Regional Board to evaluate the effectiveness of its water quality programs in meeting Basin Plan objectives including protection of the beneficial uses of the San Francisco Estuary. The RMP objectives are listed on the previous page.

The RMP was complemented by two pilot studies in 1993. A pilot study of hydrodynamics and phytoplankton in the Estuary was conducted by scientists at U.S. Geological Survey (USGS), Menlo Park, and UC Davis, and was co-sponsored by USGS, Department of Water Resources, and the RMP. A pilot study of sediment resuspension and transport in the Estuary was conducted by scientists at USGS, Sacramento, and was sponsored by the U.S. Army Corps of Engineers through the Long Term Management Strategy. Summaries of both pilot studies are included in this report.

Program Participants and Structure

The 1993 field collection and analysis program was conducted through a contract to Applied Marine Sciences in Livermore, California. A team of investigators conducted the field sampling and analysis (Table 1). Technical staff of the investigators are listed in the Acknowledgments.

Management of the RMP is structured to provide oversight, review, and advice from the sponsoring agencies and the Regional Board. As program managers and

Table 1. 1993 RMP Contractors and Principal Investigators.

Prime Contractors	Dr. Bob Spies and Dr. Andy Gunther, Applied Marine Sciences, Livermore, CA.
Trace Element Chemistry	Dr. Russ Flegal, UC Santa Cruz Dr. Eric Prestbo, Brooks-Rand, Seattle, WA.
Trace Organic Contaminant Chemistry	Dr. Bob Risebrough, UC Santa Cruz, Bodega Bay Institute Dr. Terry Wade, Texas A & M University
Water Toxicity Testing	Dr. Stephen Hansen, S. R. Hansen and Assoc., Concord, CA.
Sediment Toxicity Testing	Mr. John Hunt, Marine Pollution Lab, Granite Canyon, CA.
Bagged Bivalve Bioaccumulation	Mr. Dane Hardin, Marine Research Specialists, Soquel, CA.
Pilot Study on Water Quality and Phytoplankton	Dr. Jim Cloern, USGS, Menlo Park, CA. Dr. Alan Jassby, UC Davis Dr. Jane Caffrey, USGS, Menlo Park, CA.
Pilot Study on Sediment Transport	Dr. David Schoellhamer, USGS, Sacramento, CA.

administrators, SFEI provides objective management of the RMP, striking a balance between the needs of the dischargers and the regulators, as well as insuring the application of sound scientific principles in the RMP.

Two committees help oversee the RMP. The Steering Committee is composed of management representatives of the major groups of program sponsors: small, mid-size, and large municipal dischargers, industrial dischargers, cooling water dischargers, stormwater dischargers, dredged material dischargers, staff of the Regional Board, and SFEI. The Committee's purpose is to insure communication among the sponsors, Regional Board, and SFEI, provide input into the planning and execution of the RMP and in the use of the information. The Technical Program Review Committee is composed of technical representatives of each of the major groups of sponsors listed above. Staff of the Regional Board, other in-

terested regulatory agencies, and SFEI also participate. The role of the Technical Committee is to develop annual work plans and special studies consistent with the guidance of the Steering Committee and Regional Board, and to review data and reports produced by the RMP.

The 1993 RMP is part of a comprehensive Regional Monitoring Strategy (RMS) (San Francisco Estuary Project 1993) that focuses on all factors that impact the health of the Estuary. Implementation of the RMS will require broadening the focus of the current RMP, initiating new monitoring elements such as wetlands monitoring, and closer coordination with other major monitoring programs in the Estuary such as the Interagency Ecological Program, the Long Term Management Strategy, and USGS programs (also see Pilot Studies and Other Monitoring Activities sections).

## Methods of Sampling and Analysis

### Sampling Design

The 1993 sampling design was an extension of the BPTCP Pilot Studies conducted by the Regional Board in 1991 and 1992 (Taberski *et al.* 1992). Station locations and parameters sampled were determined based on information obtained from those studies, as well as others, and by a technical committee composed of Regional Board, SFEI, and RMP sponsoring agency staff. The station locations used in the RMP were not randomly chosen and may not be "representative" of the areas from which they were collected.

For the 1993 program, 16 locations in the Estuary were sampled (Figure 1). Table 2 lists the station names, codes, locations, and sampling dates for all 1993 RMP 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 station codes. For example, at the Extreme South Bay station, BA20 is the water station code and BA21 is the sediment station code.

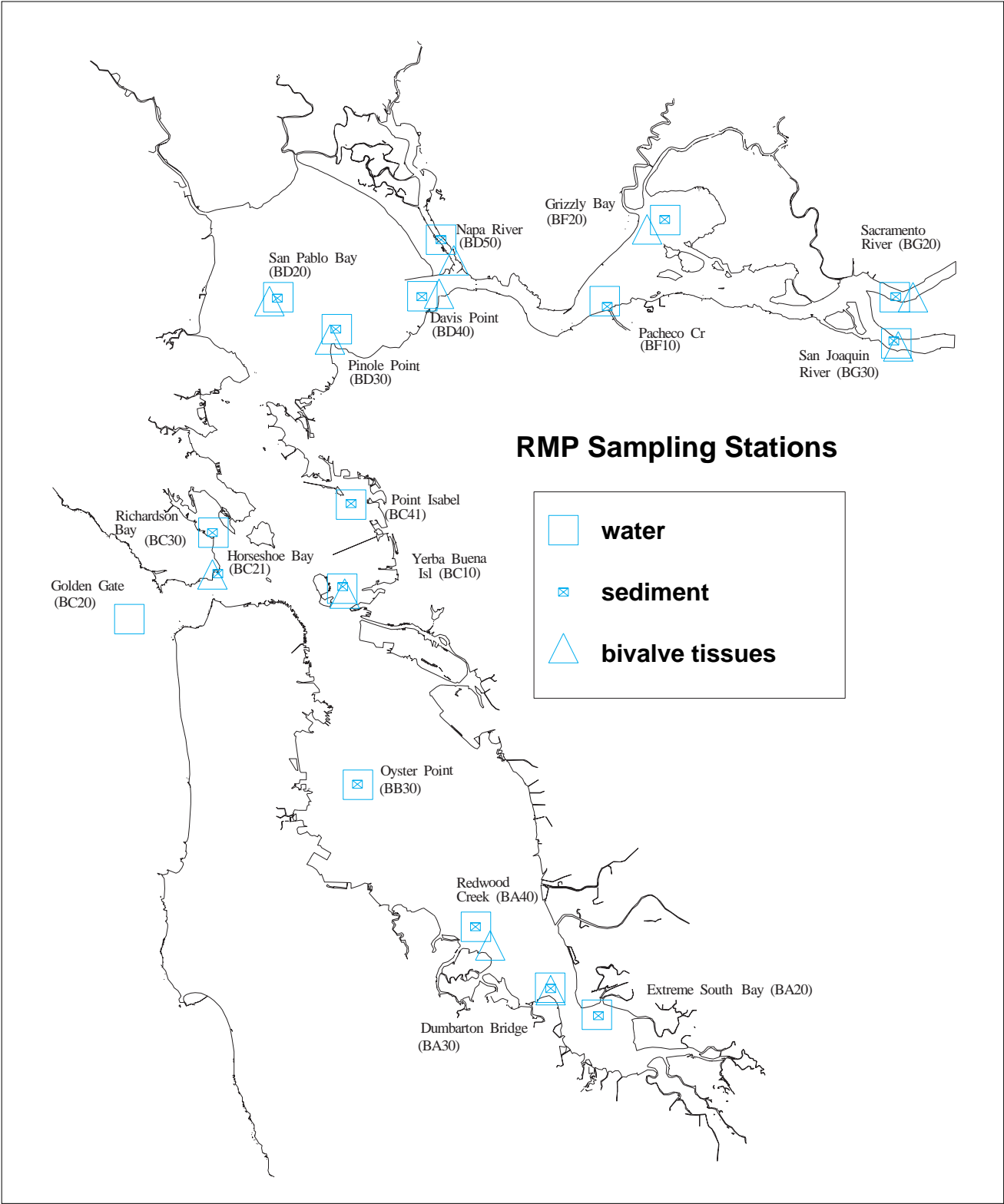
Five different types of samples were collected in 1993:

1. CONVENTIONAL WATER QUALITY PARAMETERS AND CHEMISTRY.
2. WATER TOXICITY.
3. SEDIMENT QUALITY CHARACTERISTICS AND CHEMISTRY.
4. SEDIMENT TOXICITY.
5. TRANSPLANTED, BAGGED BIVALVE BIOACCUMULATION AND CONDITION.

Complete listings of all chemical parameters measured in 1993 are on Tables 3, 4 and 5. Methods of collection and analysis are summarized below.

Sampling was conducted 3 times in 1993: during the wet period (March), a period of declining Delta outflow (May), and during the dry period (September). Logistic and scheduling constraints of this large, Estuary-wide program precluded sampling at consistent monthly or daily tidal cycles.

Replicate samples were not collected at any of the RMP stations. Consistent with the objectives of the RMP,



**Figure 1. Locations of 1993 Regional Monitoring Program Stations.** Station numbers are for water samples. Sediment and bivalve station numbers are slightly different (see Table 2).



**Table 2. Summary of RMP 1993 sampling stations and activities.**

Station Name	Station Code	Type of Sample	Measurements Made	Dates Sampled			Latitude			Longitude		
							deg	min	sec	deg	min	sec
Extreme South Bay	BA20	water	Q, M, T	Mar 2-5	May 24-27	Sep 13-16	37	29	41	122	05	20
	BA21	sediment	Q, M, O, T	Mar 9-12		Sep 20-23	37	29	38	122	05	15
Dumbarton Bridge	BA30	water	Q, M, O	Mar 2-5	May 24-27	Sep 13-16	37	30	54	122	08	07
	BA30	bioaccumulation	M, O, C	Feb-June		July-Nov	37	30	54	122	08	07
Redwood Creek	BA30	sediment	Q, M, O	Mar 9-12	May 24-27	Sep 20-23	37	30	54	122	08	07
	BA40	water	Q, M, O, T	Mar 2-5		Sep 13-16	37	33	40	122	12	34
Oyster Point	BA40	bioaccumulation	M, O, C	Feb-June	May 24-27	July-Nov	37	32	49	122	11	42
	BA41	sediment	Q, M, O, T	Mar 9-12		Sep 20-23	37	33	40	122	12	37
Yerba Buena Is.	BB30	water	Q, M	Mar 2-5	May 24-27	Sep 13-16	37	40	12	122	19	45
	BB30	sediment	Q, M, O	Mar 9-12		Sep 20-23	37	40	12	122	19	45
Golden Gate	BC10	water	Q, M, O, T	Mar 2-5	May 24-27	Sep 13-16	37	49	22	122	20	58
	BC10	bioaccumulation	M, O, C	Feb-June		July-Nov	37	49	22	122	20	58
Horseshoe Bay	BC11	sediment	Q, M, O, T	Mar 9-12	May 24-27	Sep 20-23	37	49	26	122	20	56
	BC20	water	Q, M, O	Mar 2-5		Sep 13-16	37	48	13	122	30	23
Richardson Bay	BC21	bioaccumulation	M, O, C	Feb-June	May 24-27	July-Nov	37	49	59	122	28	26
	BC21	sediment	Q, M, O, T	Mar 9-12		Sep 20-23	37	49	59	122	28	26
Point Isabel	BC30	water	Q, M	Mar 2-5	May 24-27	Sep 13-16	37	51	49	122	28	40
	BC32	sediment	Q, M, O	Mar 9-12		Sep 20-23	37	51	49	122	28	43
San Pablo Bay	BC41	water	Q, M	Mar 2-5	May 24-27	Sep 13-16	37	53	02	122	20	33
	BC41	sediment	Q, M, O	Mar 9-12		Sep 20-23	37	53	02	122	20	33
Pinole Point	BD20	water	Q, M	Mar 2-5	May 24-27	Sep 13-16	38	02	55	122	25	11
	BD20	bioaccumulation	M, O, C	Feb-June		July-Nov	38	02	55	122	25	71
Davis Point	BD22	sediment	Q, M, O	Mar 9-12	May 24-27	Sep 20-23	38	02	52	122	25	14
	BD30	water	Q, M, O, T	Mar 2-5		Sep 13-16	38	01	29	122	21	39
Napa River	BD30	bioaccumulation	M, O, C	Feb-June	May 24-27	July-Nov	38	01	00	122	22	03
	BD31	sediment	Q, M, O, T	Mar 9-12		Sep 20-23	38	01	29	122	21	43
Pacheco Creek	BD40	water	Q, M, O	Mar 2-5	May 24-27	Sep 13-16	38	03	07	122	16	37
	BD40	bioaccumulation	M, O, C	Feb-June		July-Nov	38	03	16	122	15	38
Grizzly Bay	BD41	sediment	Q, M, O	Mar 9-12	May 24-27	Sep 20-23	38	03	07	122	16	39
	BD50	water	Q, M, O, T	Mar 2-5		Sep 13-16	38	05	47	122	15	37
Sacramento River	BD50	bioaccumulation	M, O, C	Feb-June	May 24-27	July-Nov	38	04	56	122	14	50
	BD50	sediment	Q, M, O, T	Mar 9-12		Sep 20-23	38	05	47	122	15	37
San Joaquin River	BF10	water	Q, M	Mar 2-5	May 24-27	Sep 13-16	38	03	05	122	05	48
	BF10	sediment	Q, M, O	Mar 9-12		Sep 20-23	38	03	05	122	05	48
Grizzly Bay	BF20	water	Q, M, O, T	Mar 2-5	May 24-27	Sep 13-16	38	06	58	122	02	19
	BF20	bioaccumulation	M, O, C	Feb-June		July-Nov	38	06	29	122	03	22
Sacramento River	BF21	sediment	Q, M, O, T	Mar 9-12	May 24-27	Sep 20-23	38	06	58	122	02	21
	BG20	water	Q, M, O, T	Mar 2-5		Sep 13-16	38	03	34	121	48	35
San Joaquin River	BG20	bioaccumulation	M, O, C	Feb-June	May 24-27	July-Nov	38	03	35	121	48	50
	BG20	sediment	Q, M, O, T	Mar 9-12		Sep 20-23	38	03	34	121	48	35
San Joaquin River	BG30	water	Q, M, O, T	Mar 2-5	May 24-27	Sep 13-16	38	01	24	121	48	27
	BG30	bioaccumulation	M, O, C	Feb-June		July-Nov	38	01	04	121	48	41
	BG30	sediment	Q, M, O, T	Mar 9-12		Sep 20-23	38	01	24	121	48	27

Q = water or sediment quality (see Table 3)

O = trace organics

C = bivalve condition index

M = trace metals (see Table 4)

T = toxicity

and costs, within-station replication was traded off for samples in more Estuary locations. Thus, instead of estimates of variation within RMP stations, variation within larger areas of the Estuary can be used in assessing the Estuary's water and sediment condition by combining data from selected stations as replicates.

Not all parameters were measured at all RMP stations each sampling period. Sampling activities at each station are listed on Table 2. Water sampling was conducted during all 3 sampling periods. Water quality parameters and chemistry were measured at all stations, except that trace organics contaminants were only measured at the same 11 stations where bioaccumulation measurements were made. Water toxicity was measured at 8 stations each sampling period. Sediment sampling was

**Table 3. Conventional water quality parameters and sediment quality parameters measured during the 1993 RMP.**

<b>A. Conventional Water Quality Parameters</b>
Temperature
Salinity
Dissolved Oxygen (DO)
pH (acidity)
Total Suspended Solids
Dissolved Organic Carbon
Total Chlorophyll
Phaeophytin (chlorophyll degradation product)
<i>Nutrients:</i>
Dissolved Phosphates
Dissolved Silicates
Dissolved Nitrate
Dissolved Nitrite
Dissolved Ammonia
<b>B. Sediment Quality Parameters</b>
Percent Fine (<63µm dia)
Eh (reduction-oxidation potential)
pH
Temperature
Total Organic Carbon
Total Nitrogen

**Table 4. Trace elements analyzed in water, sediment, and bivalve tissues in the RMP Estuary sampling.**

	water	sediment	biota
Aluminum*		•	
Arsenic	•	•	•
Cadmium*	•	•	•
Chromium	•	•	•
Copper*	•	•	•
Cyanide	•		
Iron*		•	
Lead*	•	•	•
Manganese*		•	
Mercury	•	•	•
Nickel*	•	•	•
Selenium	•	•	•
Silver*	•	•	•
Tributyltin			•
Zinc*	•	•	•

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

conducted during the wet and dry periods only. Samples were collected from all RMP stations, and sediment toxicity was measured at 8 of those stations during the wet and dry periods. Bivalve bioaccumulation and condition were measured at 11 stations during the wet and dry sampling periods.

In addition to the Estuary stations, water samples were collected from the Sacramento and San Joaquin Rivers during a period of peak flow. Two locations in the Sacramento River and 3 locations in the San Joaquin River were sampled 6 times over a 2 month period in May and June. The samples were analyzed for water quality parameters and trace contaminants.

RMP sampling design will evolve over the next several years 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. Decisions about what is an adequate number of stations, what is reasonable statistical power, and what the cost constraints are will be made annually by the Steering Committee based on rec-

ommendations from the Program Manager and Technical Program Review Committee consistent with the goal of design optimization.

## Parameters Sampled

Water and sediment samples were collected from aboard the R/V DAVID JOHNSTON chartered through 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 for each sampling period required 3-5 days for completion.

Bagged bivalve deployment, maintenance, and retrieval was conducted using different vessels. In the January to June sampling period the M/V RINCON POINT, owned by the City of San Francisco, was used. In the June to September sampling period, the M/V BAY

MONITOR, owned by the East Bay Municipal Utility District was used.

### Water Sampling

In order to attain the low detection levels used in the RMP (Appendix Table 3.1), ultra-clean sampling methods were used in all sampling procedures (Flegal and Stukas 1987). The methods used in collection of water samples are described in detail in the RMP Quality Assurance Program Plan (SFEI 1993). Brief descriptions of the sampling procedures are included below.

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.

**Table 5. Trace organic compounds analyzed in water, sediment, and bivalve tissues**  
W = water, S = sediment T = tissues.

	W	S	T		W	S	T
<b>A. Petroleum Compounds</b>				<b>C. Synthetic Biocides</b>			
Alkanes, n-C12 to n-C32	•			Hexachlorocyclohexanes	•	•	•
Alkanes, n-C12 to n-C34		•	•	Chlordanes (including			
Phytane	•	•	•	heptachlor and heptachlor			
Total saturated and total				epoxide)	•	•	•
aromatic petroleum				DDTs	•	•	•
hydrocarbons	•	•	•	Dieldrin	•	•	•
				Aldrin	•	•	•
<b>B. Polynuclear Aromatic</b>				Endrin	•	•	•
<b>Hydrocarbons (PAHs)</b>				Mirex	•	•	•
Anthracenes	•	•	•	Endosulfan	•		
Acenaphthylene		•	•	Chlorpyrifos	•		
Acenaphthene		•	•	Dacthal	•		
Chrysenes	•	•	•	Toxaphene	•		
Dibenzothiozoles		•	•	<b>D. Synthetic Compounds</b>			
Fluorenes		•	•	<b>other than Biocides</b>			
Fluoranthenes	•	•	•				
Naphthalenes		•	•	Hexachlorabenzene	•	•	•
Perylenes	•	•	•	Polychlorinated terphenyls	•	•	•
Phenanthrenes	•	•	•	Polychlorinated biphenyls			
Pyrenes	•	•	•	(PCBs), selected congeners			
Total PAHs (sum of all				and total, or sum of			
compounds)	•	•	•	congeners	•	•	•

Total and dissolved fractions of Estuary water were collected. For trace organics, water was pumped by a Teflon impeller pump with Teflon tubing through a glass fiber filter (0.3  $\mu\text{m}$ ) providing a sample of particulate-associated contaminants. The water was then passed through 4 polyurethane foam plugs mounted in series which adsorbed the dissolved material. 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. Filtered water was obtained by placing an acid-cleaned polypropylene filter cartridge (Micron Separations, Inc., 0.45  $\mu\text{m}$  pore size) on the outlet of the pumping system. Unfiltered water was pumped directly into sample containers. 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 toxicity tests 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 toxicity testing laboratory. Two field blanks were collected each cruise.

### Sediment Sampling

Sediment sampling was conducted using a modified Van Veen grab with a surface area of 0.1  $\text{m}^2$ . The grab is made of stainless steel, and the jaws and doors are coated with dykon (formerly known as kynar) to improve chemical inertness. All scoops, buckets, and stirrers used to collect and composite sediments were also constructed of teflon or stainless steel coated with dykon.

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 temperature compensated 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.

### Bivalve Bioaccumulation Sampling

Bioaccumulation sampling consisted of collecting organisms from clean locations and deploying them to RMP sites in the Estuary (Table 2) for 90-100 days. Composites of tissue were made from 40-60 individual bivalves from each site before and after deployment for analyses of trace contaminants. Measurements of each animal's biological condition were also made before and after deployment.

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.

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 (see RMP Quality Assurance Program Plan for details).

The deployed samples were checked approximately half-way through the 90-day 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. Bivalve guts were not depurated before homogenization for tissues analyses, although gonads were removed from organisms for trace metal analyses.

## Analytical Methods

Analytical procedures are detailed in the RMP Quality Assurance Program Plan and summarized below.

### 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).

### Trace Elements

Total and dissolved (0.45  $\mu\text{m}$  filtered) concentrations of arsenic, chromium, mercury, and selenium were measured, and near-total and dissolved concentrations

of cadmium, copper, nickel, lead, silver, and zinc in water were measured.

Near-total concentrations were used in the RMP for consistency with the BPTCP pilot studies results. Total metals are usually extracted with boiling aqua regia (perchloric acid, and hydrofluoric acid) which removes virtually all metals from the sample. Near-total metals are extracted with a weak acid ( $\text{pH} < 2$ ) 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.

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 bromine chloride.

Trace metals (except for As, Hg, and Se) 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). Trace metals in sediments were analyzed with 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). 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).

Results for cadmium, copper, nickel, lead, silver, and zinc were reported by the laboratory in units of  $\mu\text{g/kg}$ . For use in this report, those values are reported as  $\mu\text{g/L}$ , 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 3.1, 3.2, and 3.3).

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.

### 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 florisil-column chromatography. Extract volumes were concentrated and analyzed by both electron-capture gas chromatography (Varian 3400 GC with 8100 autosampler) and by GC/MS (Saturn II, also with 8100 autosampler). A second column was used in the GC for initial confirmation of identity. Sediment and bivalve tissue samples were freeze-dried, mixed with kiln-fired sodium sulfate, and soxhlet-extracted with methylene chloride. Thereafter, the analytical sequence was identical to that described for water (Risebrough 1994).

### Water Toxicity

Water column toxicity was evaluated using a 48-hour mollusc embryo development test and a 96-hour algal growth test. These tests were performed according to ASTM standard methods. The mollusc test followed ASTM method E 724-89 (ASTM 1991). Larval *Mytilus edulis* were used in the March and September samples, and larval *Crassostrea gigas* were used in the May samples. Different species were used due to seasonal differences in larval availability. The algal growth test used *Thalassiosira pseudonana*, following ASTM method E 1218-90 (ASTM 1990). Controls used were filtered Bodega Bay water with the salinity adjusted using either de-ionized water or sea salt (Appendix Table 3.4). Reference toxicant tests ( $\text{CuCl}_2$ ) were performed for each population of test organisms used.

### Sediment Quality Characteristics

Eh was measured on board using a temperature compensated Eh meter (Corning 240). Sediment size fractions were determined by wet sieving through a 62  $\mu\text{m}$  screen (Folk 1990). Sediment total organic carbon and

total nitrogen was determined using a Leeman Labs 440 Elemental Analyzer following EPA method MARPCN-I.

### Sediment Toxicity

Two sediment toxicity tests were used: a 10 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 the March tests, where percent normally developed and percent mortality were the endpoints measured. Larval oysters (*Crassostrea gigas*) were used in the September samples where percent normally developed was used. Different species of bivalve larvae were used each sampling period due to seasonal availability of the larvae.

### 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 from total volume as measured by volume displacement in a beaker of water.

## Quality Assurance

Assurance that the RMP samples were collected, preserved, transported, analyzed, and reported with in-

tegrity and accuracy is of the highest importance to the success of the Program. The RMP Quality Assurance Program Plan provides the details for all aspects of RMP sampling and analysis and is available from SFEI upon request.

All participants and laboratories have, and use Standard Operating Procedures and maintain QA records. The SFEI Program Manager or Applied Marine Sciences Program Manager observed most aspects of the RMP sampling and analysis. QA documentation was submitted with all data reports. Summaries of QA results are presented in Appendix 3.

## Data Management and Analysis

Data generated by the RMP were transmitted to SFEI electronically, in various spreadsheet formats. These data are maintained at SFEI in an Oracle data base or in SAS (Statistical Analysis System) data sets. Data tables are included in the Appendices of this report and data in electronic form is available from SFEI upon request.

For the purposes of data analysis only, all contaminant concentrations below detection levels were transformed to values of one-half the method detection level.

The analyses presented in this report were conducted using the PC version of SAS (1989). Several SAS procedures were used: CLUSTER, CORR, REG, 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) are not presented in this report. Analyses of the ability of RMP monitoring data to accurately determine such differences suggested that samples from 3 sampling periods in one year may have low statistical power (the ability to detect actual differences). Additionally, those analyses were limited to only a few trace metals in water (copper and lead), and the sample sizes needed to determine statistical differences were different for each metal analyzed (SFEI, unpublished). No analysis of power for trace organics, toxicity, or bioaccumulation data has been conducted, and knowledge of sample sizes needed to achieve reasonable power are not known. Trends in contaminant concentrations over time are not rigorously

analyzed either, because only 3 time periods have been monitored. 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 toxicity tests 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 1993. 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.

In order to evaluate the contaminant concentrations measured, comparisons with water quality objectives and criteria, sediment quality guidelines, and tissue guidelines are made. These comparisons are used only as guidelines for evaluating contaminant concentrations in the Estuary, not for any regulatory purposes. In some cases, the measurements made by the RMP are different than those prescribed for regulatory purposes, thus the comparisons should be interpreted cautiously. Guidelines do not exist for some contaminants. The details and qualifications for the comparisons used in this report are included in the appropriate sections.







## Monitoring Results

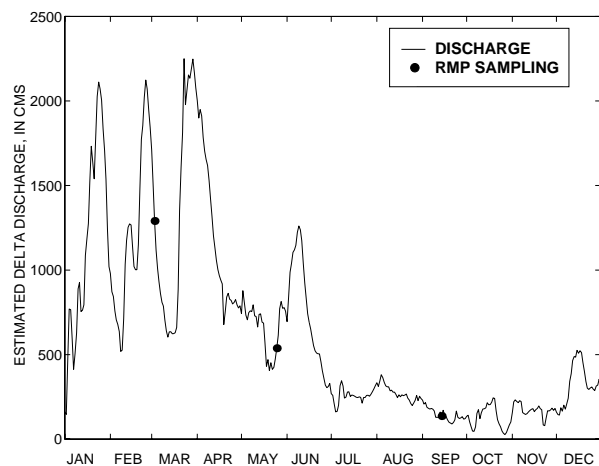


# Water Monitoring

## Conventional Water Quality

While the primary objective of the RMP water column sampling was to characterize concentrations of trace metals and organic contaminants, conventional water quality parameters were also analyzed to assess the general water quality characteristics of the Estuary. The parameters measured are listed in Table 3, and data are included in Appendix Table 2.1. These measurements are used in the following sections to evaluate general conditions in the Estuary during each sampling period, and to assess differences in pollutant concentrations among samples.

Sampling was conducted during March, May, and September in order to characterize the Estuary over a



**Figure 2. Estimated Delta outflow and times of RMP water sampling in 1993.**  
CMS = cubic meters per second.  
(courtesy USGS, Sacramento)

range of hydrologic conditions. The three sampling periods are shown on a plot of Delta outflow in Figure 2. Salinities for all stations at the three sampling periods are shown in Figure 3. Maximum salinities occurred at Golden Gate (BC20) and declined with distance north of the Golden Gate. The decline to the south, where fresh water inflows were much lower, was less. Throughout

the Estuary, salinities increased with each sampling period, as Delta outflow decreased. In the South Bay, the salinity gradient decreased over time as salinity values increased. The 5 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, from west of the Napa River (BD50) in March, to west of Grizzly Bay (BF20) in May, to west of the river stations (BG20 and BG30) in September.

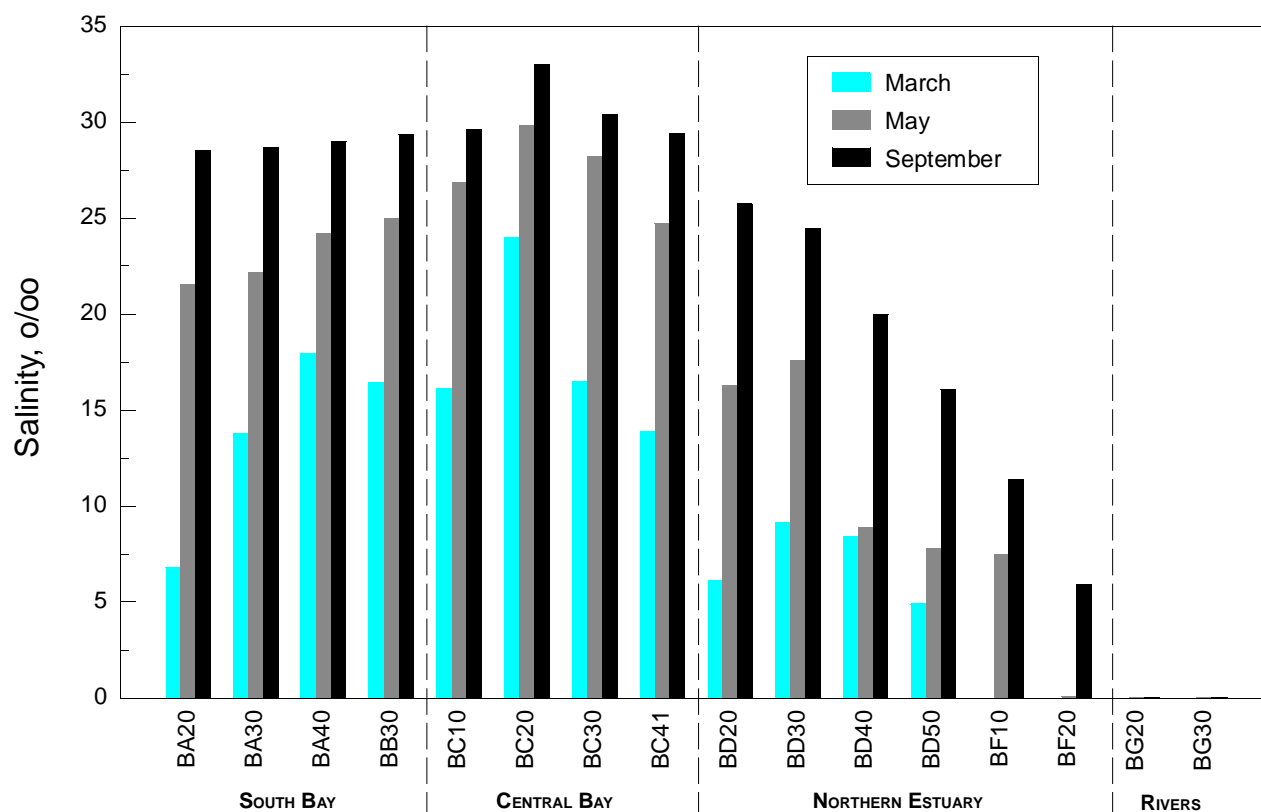
Total suspended solids (TSS) in the samples are shown in Figure 4. TSS concentrations ranged from 0 to 191 parts per million (mg/L, ppm). Concentrations were lowest at the Golden Gate (BC20) during all three sampling periods. The highest concentration was measured at San Pablo Bay (BD20) in May, and it was almost twice as high as the concentration in any other sample. In general, suspended solids were higher in the northern part of the Estuary than in the South Bay. No consistent differences between the three sampling periods were observed. The wide spatial and temporal variation in suspended solids concentrations points to the difficulties in generalizing the relationship of dissolved to total contaminant concentrations. For discussion of factors influencing suspended solids concentrations in the Estuary (see Pilot Studies section, *Sediment Transport*).

Dissolved organic carbon (DOC) concentrations are shown in Figure 5. Concentrations of DOC decreased over the course of the three sampling periods. DOC values were lowest at the Golden Gate (BC20), and increased going north into the Estuary as well as into South Bay.

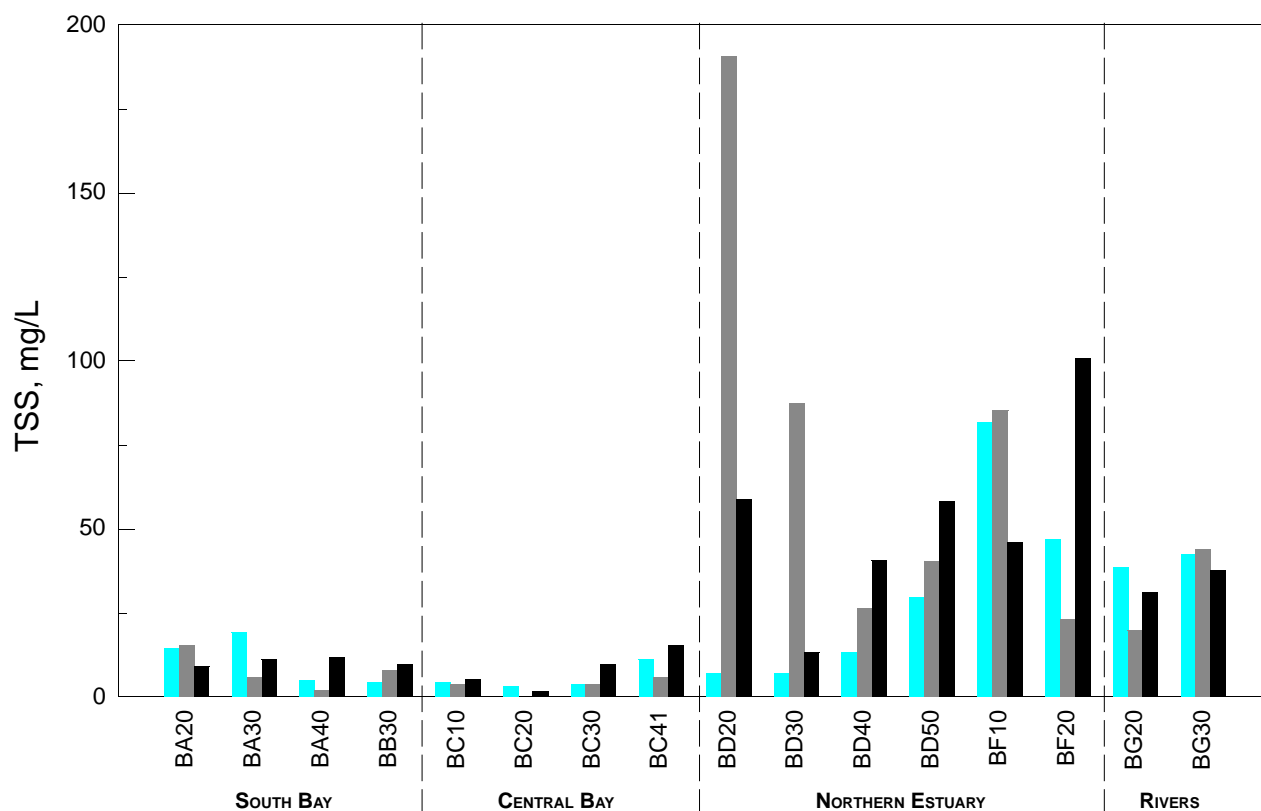
Nutrient concentrations were consistently highest at the Extreme South Bay (BA20) and Dumbarton Bridge (BA30) stations. As an example, phosphate concentrations are shown in Figure 6.

## Contaminants in Water

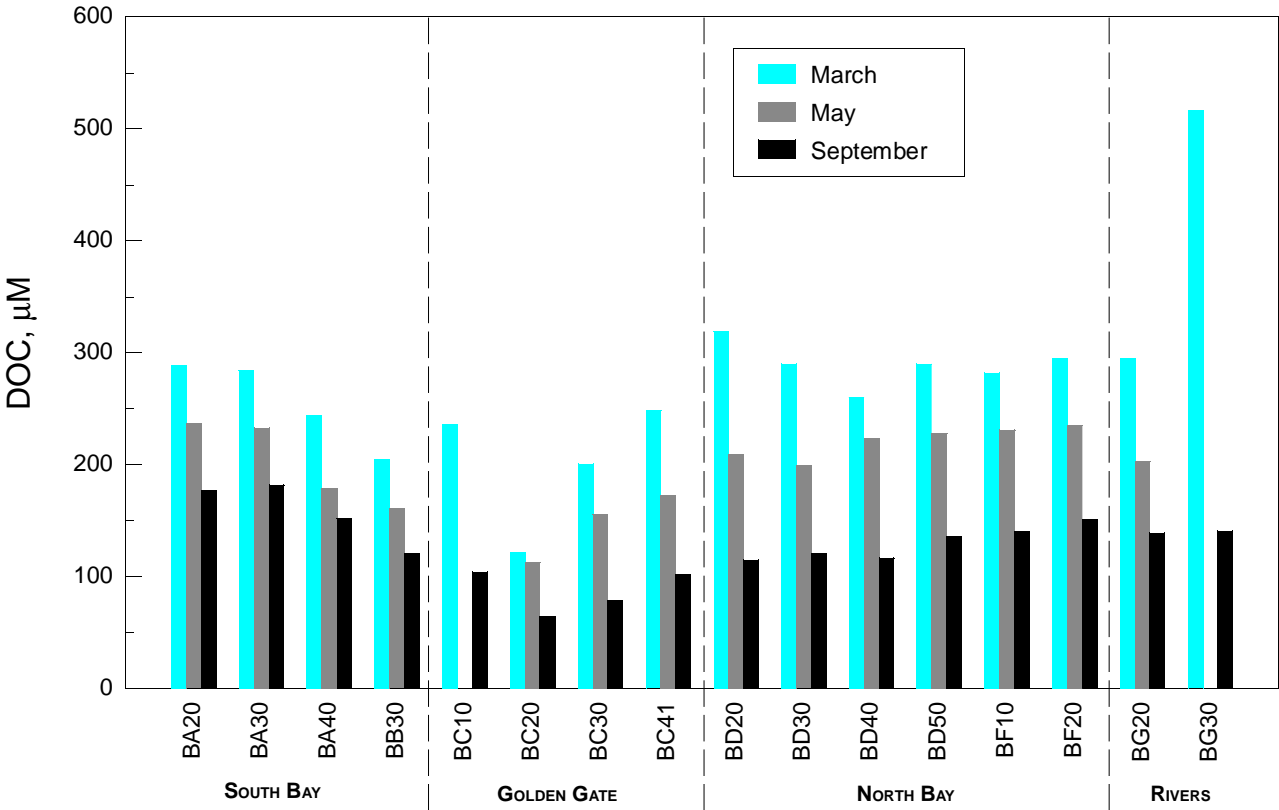
In order to make general spatial comparisons of trace contaminant concentrations, stations were grouped into



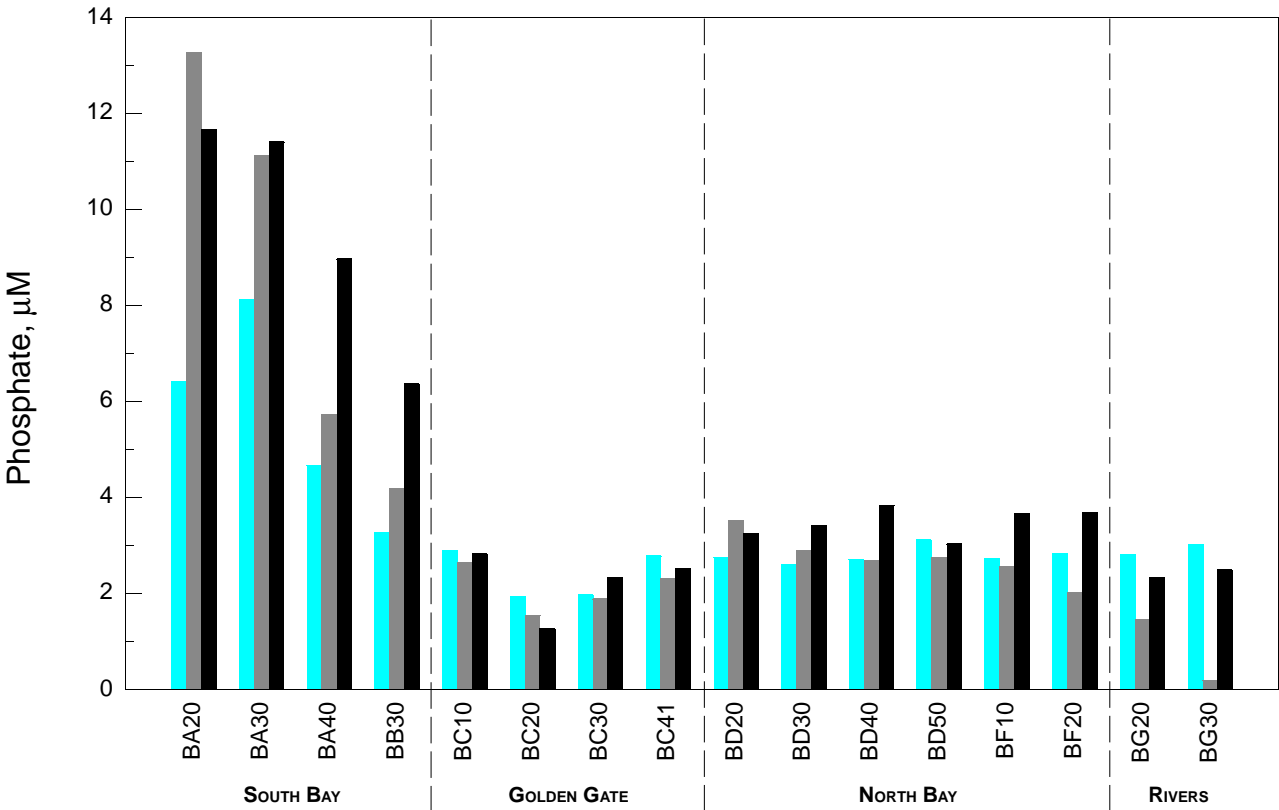
**Figure 3.** Salinity in parts per thousand (o/oo) at each RMP water station during the three water sampling periods of 1993. For station names and locations see Figure 1.



**Figure 4.** Total suspended solids in milligrams per liter (mg/L) at each RMP water station during the three sampling periods of 1993. For station names and locations see Figure 1.



**Figure 5.** Dissolved organic carbon in micromoles (µM) at each RMP water station during the three water sampling periods of 1993. For station names and locations see Figure 1. 1 µM of DOC = 12 µg/L



**Figure 6.** Phosphate concentration in micromoles (µM) at each RMP water station during the three water sampling periods of 1993. For station names and locations see Figure 1. 1 µM of phosphate = 31 µg/L.

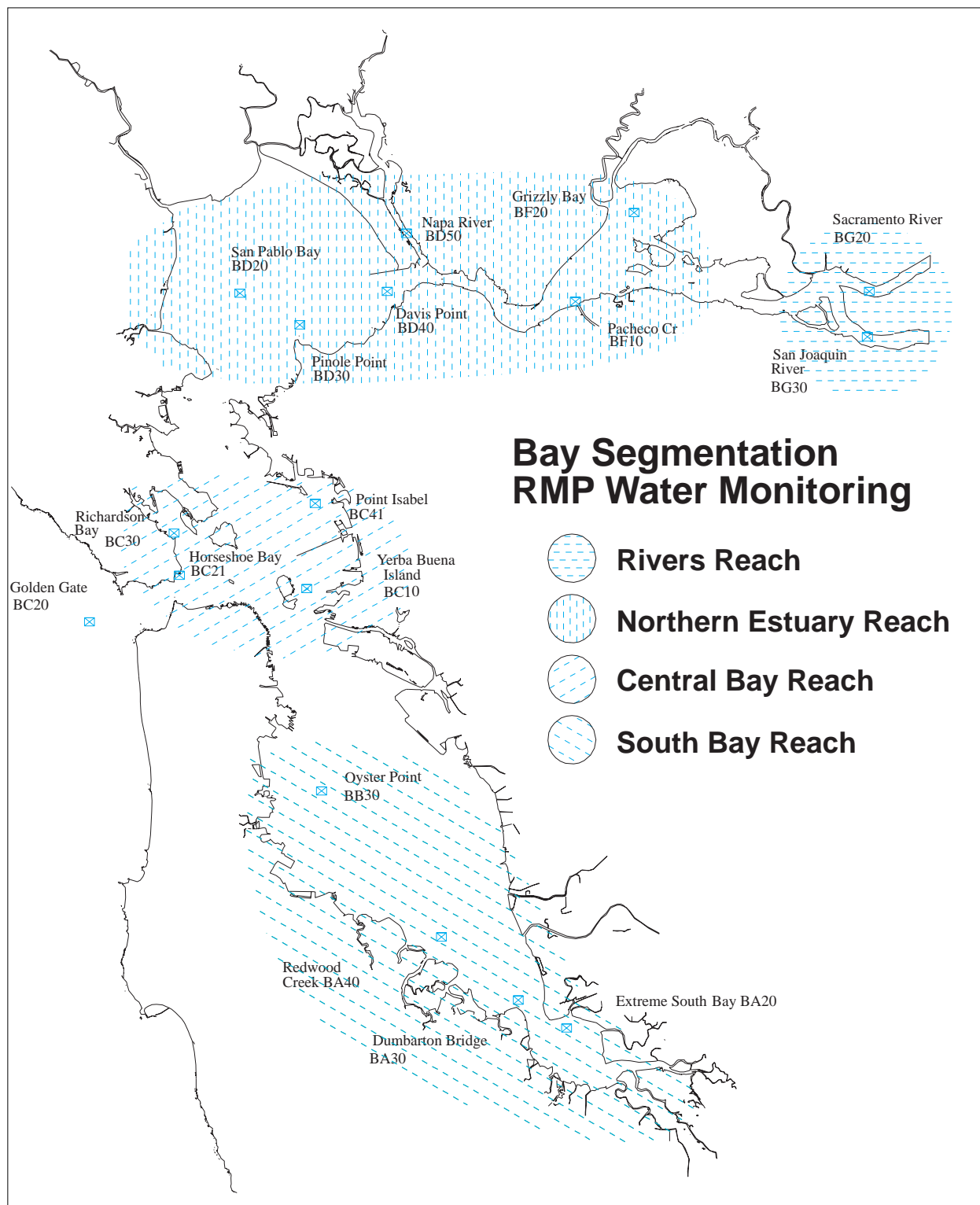


Figure 7. Estuary reaches used in spatial comparisons of contaminant concentrations in water.

four reaches; South Bay, Central Bay, northern estuary, and rivers (Figure 7). These groups were based on cluster analyses of all water quality measurements for each sampling period, as well as consideration of geographic features. The Golden Gate station (BC20) was not included in the reach comparisons, because it was used primarily as an indicator of water quality conditions in the oceanic waters outside the Estuary. Note that these reaches were used only for generalized comparisons of trace element concentrations in the water among the reaches, and that a different set of reaches was used in analyzing concentrations in sediment.

Many factors contribute to the variability in contaminant concentrations from station to station and over time (Kuwabara *et al.* 1989; Luoma and Phillips 1988). Some of these factors reflect conditions in the Estuary, such as Delta outflow or resuspension of sediments. Others reflect conditions specific to the sampling location, such as proximity to contaminant sources.

In an estuary, the degree of mixing of the two primary water sources, river water and ocean water, influences water column concentrations at all sites. Background concentrations for an estuary can be considered as a gradient from river background concentration to ocean background concentration, due to conservative mixing (Flegal *et al.* 1991). The degree of mixing, and thus the position on the gradient, can be determined by measurement of salinity. For each trace contaminant, dissolved concentrations were plotted against salinity to assess the importance of this background gradient in determining concentrations in the Estuary. Stations in the South Bay reach were distinguished from the other stations on the plots because of the difference in hydrologic factors influencing water quality in the South Bay compared to the rest of the Estuary.

The influence of salinity, suspended solids, or other water parameters on dissolved and total concentrations of each trace contaminant was evaluated using regression analysis to observe their general relationships. The sampling periods were treated separately in the regression analyses, because each sampling period was considered to represent a separate water mass in the Estuary with different water quality characteristics, as described above. Stations were not divided into reaches for the re-

gressions, and the Golden Gate station (BC20) was included.

In this report, the relationships described above are evaluated using only the data from the Regional Monitoring Program in 1993, which includes three samples at each location over the course of one year. It is expected that much of the temporal variability in the Estuary was not detected with this sampling frequency, and that other years may be different from 1993.

Water quality objectives currently in effect for the San Francisco Estuary include those adopted in the 1986 Basin Plan for the San Francisco Bay Region and for some substances, such as selenium, values in EPA's National Toxics Rule (February, 1993). In some cases, EPA criteria are used for comparison as well. Most water quality criteria for the protection of aquatic life are either 24-hour or four-day averages, which are not to be exceeded more than once in three years. The results presented in this report are single samples, and only represent one year, limiting these comparisons. Additionally, the near-total concentrations reported for many trace elements may be lower than would have resulted from the total recoverable analysis referenced in EPA criteria documents. The EPA has recommended using dissolved metals concentrations as objectives, so comparisons with dissolved concentrations can be made by the reader referring to the Figures in each section.

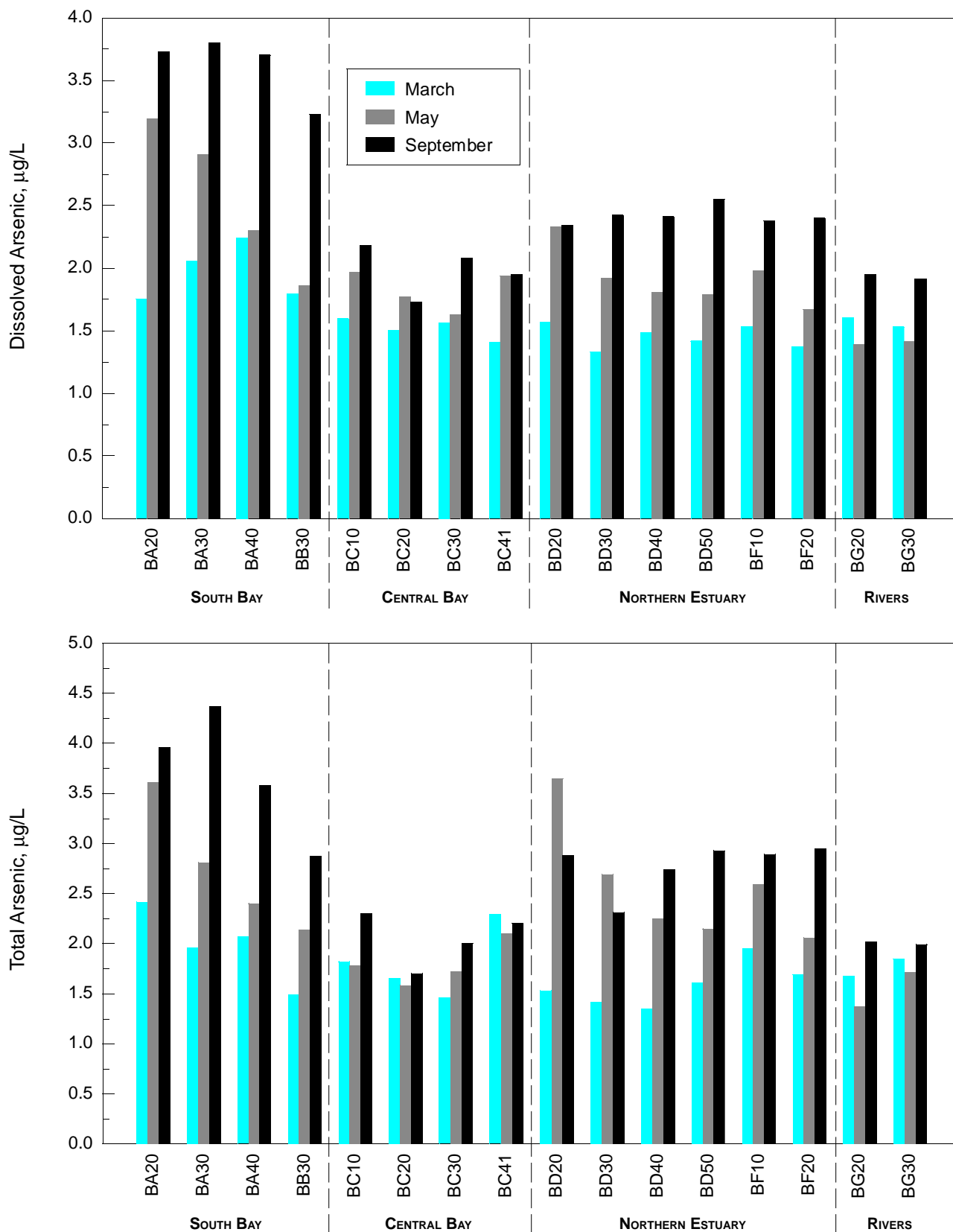
## Trace Metals

Total or near-total and dissolved (0.45  $\mu$ m filtration) concentrations of eleven trace elements were measured at sixteen RMP stations (Figure 1) in March, May, and September. Concentrations are listed in Appendix Table 2.2 and 2.3. Results are presented for each substance in the following sections, except for cyanide which was below detection limits (1.0 parts per billion (ppb)) in all samples.

### Arsenic

Total and dissolved arsenic concentrations for the three sampling periods are shown in Figure 8. Dissolved concentrations ranged from 1.32 to 3.80 parts per billion (ppb) and total concentrations ranged from 1.35 to 4.37 ppb. Compared to other substances, this range of con-

### Arsenic in Water 1993



**Figure 8.** Dissolved and total arsenic concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1.

centrations was quite narrow. The ratio of dissolved to total was generally quite high. In some cases dissolved concentrations were reported as higher than totals (see discussion in Analytical Methods).

Concentrations of both total and dissolved arsenic were variable among the sampling periods and Estuary reaches. Concentrations were highest in September, intermediate in May, and lowest in March. Dissolved arsenic was highest in the South Bay reach and lowest in the rivers reach. Total arsenic was highest in the South Bay reach and lowest in the rivers reach.

Plots of dissolved arsenic versus salinity are shown in Figure 18. In March, concentrations in the South Bay reach were only slightly higher than in the rest of the Estuary, and concentrations of arsenic did not appear to be influenced by salinity. In May and September, a separate gradient of arsenic versus salinity emerged in the South Bay, as the range of salinities in the South Bay decreased. In the northern estuary, concentrations were higher in the mid-range salinities. Elevated concentrations in the South Bay reach suggest a local source of

arsenic. The increasing degree of separation between concentrations in the South Bay reach and in the rest of the Estuary as the year progressed suggests a year-round source which exerts more influence on water quality as residence times in the South Bay increase during the dry season (Walters *et al.* 1985).

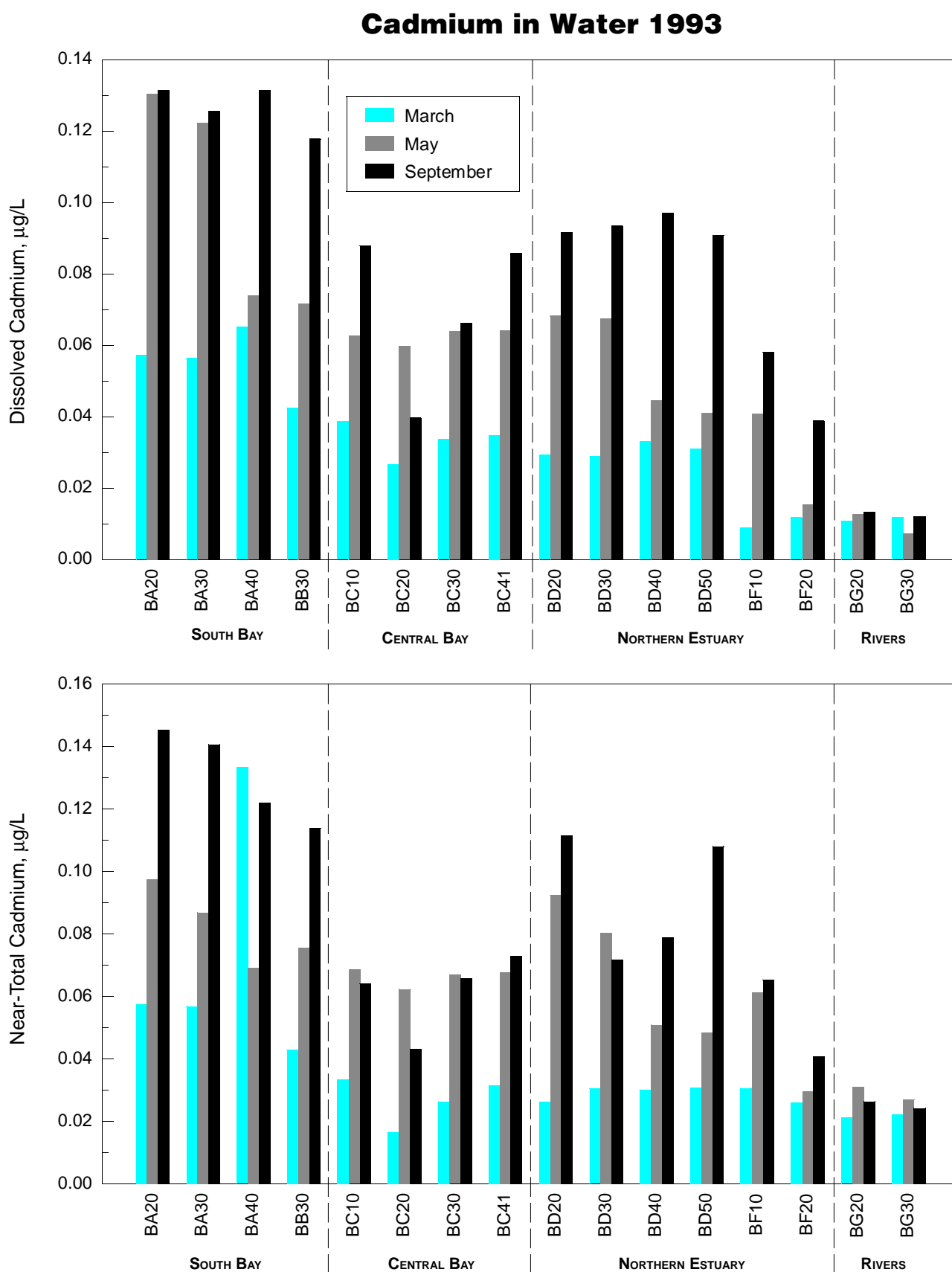
Regression analyses showed that salinity accounted for less than 20% of the variation in dissolved arsenic concentrations, and TSS accounted for less than 5% (Table 6). Salinity and TSS were not important factors in describing total arsenic concentrations either. Total arsenic was strongly correlated to dissolved arsenic in May and September, and the combination of TSS and dissolved arsenic accounted for over 90% of the variation in total arsenic for those sampling periods.

The water quality objective for waters downstream of Carquinez Strait for the protection of aquatic life is 36 ppb as a four-day average. For waters upstream of San Pablo Bay, the arsenic objective is 190 ppb (RWQCB 1986). Arsenic concentrations in all RMP water samples from 1993 were well below these objectives.

**Table 6.  $R^2$  values for regressions of salinity (Sal) and total suspended solids (TSS) against dissolved arsenic (dAs) concentrations and for dAs, Sal, and TSS against total arsenic concentrations, in each sampling period.**  $R^2$  is the proportion of the variation of dissolved or total As that is explained by each of the water parameters and combinations of them listed.

1. Dissolved arsenic n = 16			
	March	May	September
Sal	0.14	0.17	0.12
TSS	0.05	0.003	0.04
Best multi-parameter model	Sal 0.14	Sal TSS 0.24	Sal 0.12
2. Total arsenic n = 16			
	March	May	September
dAs	0.14	0.66	0.86
Sal	0.00	0.02	0.04
TSS	0.02	0.33	0.003
Best multi-parameter model	dAs TSS 0.20	dAs TSS 0.94	dAs TSS 0.92





**Figure 9.** Dissolved and near-total cadmium concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1.

## Cadmium

Near-total and dissolved cadmium concentrations for the three sampling periods are shown in Figure 9. Dissolved cadmium concentrations ranged from 0.007 to 0.131 parts per billion (ppb). Total cadmium concentrations ranged from 0.016 to 0.145 ppb. Dissolved concentrations were consistently a high proportion of total concentrations compared to many other metals. Dissolved concentrations were reported as higher than totals in several instances, which may be interpreted to mean that dissolved and totals were indistinguishable.

For both near-total and dissolved cadmium, concentrations were highest in September, intermediate in May, and lowest in March. The range of concentrations was lower in March as well, except for the single elevated near-total cadmium concentration at Redwood Creek (BA40). The lower concentrations in March probably reflect greater inflow of river water from the Delta with low cadmium concentration. There were also differences

between reaches for both dissolved and total cadmium. In both cases, average concentrations were highest in the South Bay reach and lowest in the rivers reach.

Plots of dissolved cadmium versus salinity are shown in Figure 18. During all three sampling periods, dissolved cadmium concentrations increased with salinity. The direction of the gradient is the opposite of that observed for many other substances, reflecting the fact that background concentrations for cadmium in ocean waters is higher than in fresh waters, particularly during periods of upwelling. In March, cadmium concentrations in the South Bay reach were somewhat elevated, but in May and September a clearly separate gradient emerged in the South Bay. Elevated concentrations in the South Bay suggest that local sources contributed to dissolved cadmium concentrations. In September, mid-range salinities in the northern estuary were elevated compared to the gradient defined by river and ocean mixing, as well.

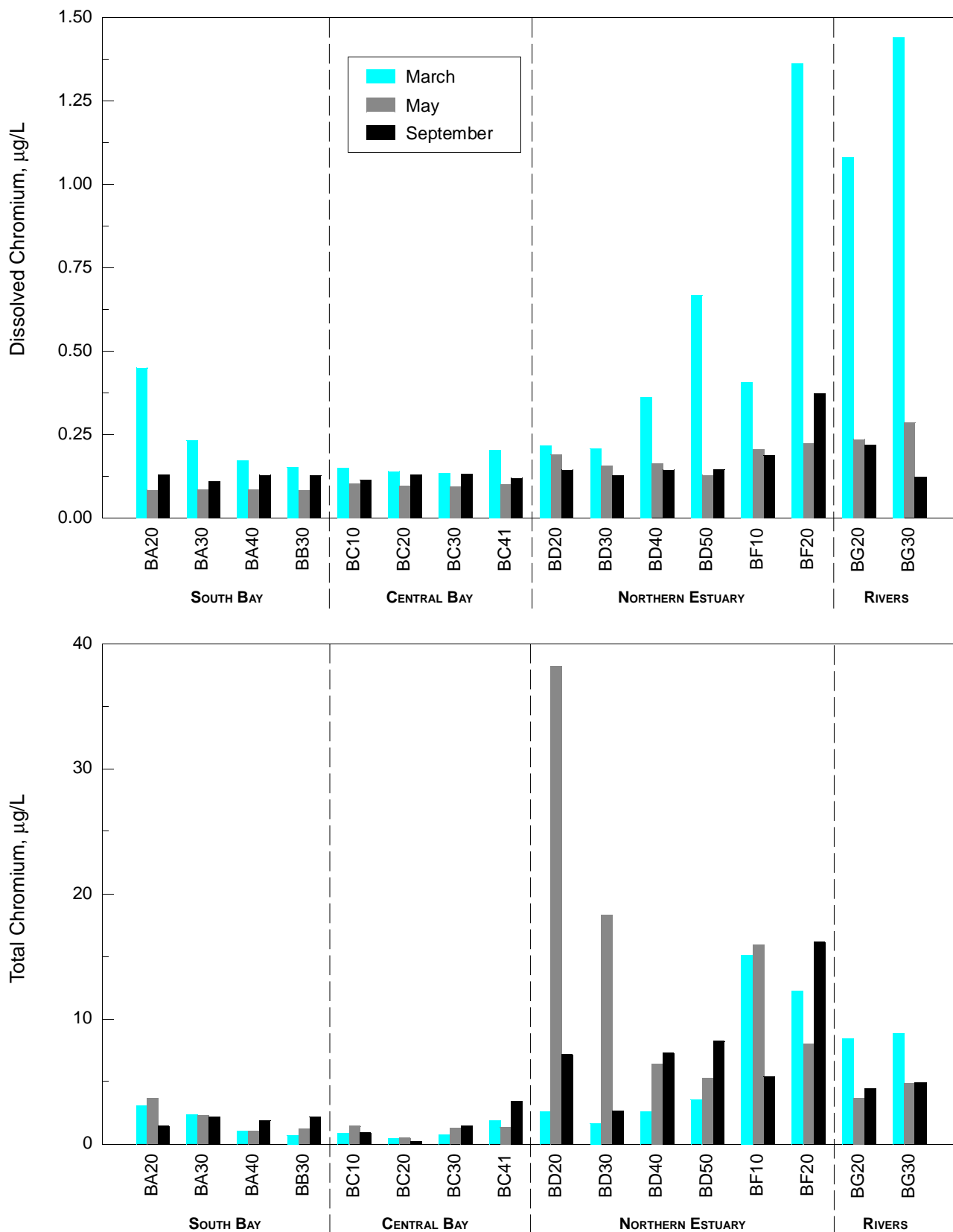
**Table 7.  $R^2$  values for regressions of salinity (Sal), total suspended solids (TSS), and phosphate ( $\text{PO}_4$ ) against dissolved cadmium (dCd) concentrations, and for dCd, Sal, TSS and  $\text{PO}_4$  against near-total cadmium concentrations, in each sampling period.  $R^2$  is the proportion of the variation of dissolved or near-total Cd that is explained by each of the listed water parameters and combinations of them.**

1. Dissolved cadmium n = 16			
	March	May	September
Sal	0.38	0.50	0.51
TSS	0.43	0.01	0.13
PO <sub>4</sub>	0.45	0.77	0.54
Best multi-parameter model	Sal TSS PO <sub>4</sub>	Sal TSS PO <sub>4</sub>	Sal TSS PO <sub>4</sub>
	0.86	0.98	0.82

2. Near-total cadmium n = 16			
	March	May	September
dCd	0.57	0.82	0.86
Sal	0.10	0.53	0.34
TSS	0.06	0.05	0.06
PO <sub>4</sub>	0.29	0.46	0.66
Best multi-parameter model	dCd TSS PO <sub>4</sub>	dCd TSS Sal	dCd PO <sub>4</sub>
	0.75	0.98	0.90

### Chromium in Water 1993



**Figure 10.** Dissolved and total chromium concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1.

Phosphate was included as a factor in the regression analyses in addition to salinity and TSS. It was expected that phosphate would be associated with cadmium from the discharge of treated wastewater, but not with cadmium of oceanic origin. Phosphate concentration and salinity accounted for roughly comparable portions of the variation in dissolved cadmium concentration in each sampling period (Table 7). For total cadmium, dissolved cadmium was the most important factor and TSS was the least important.

Cadmium concentrations in water were well below the water quality objective for waters downstream of Carquinez Strait of 9.3 ppb (RWQCB 1986) at all stations and during all three sampling periods. The objective for waters upstream of San Pablo Bay is hardness dependent (RWQCB 1986), but even at a hardness as low as 50 mg/L, the objective is 0.66 ppb, which is substantially higher than any of the measured concentrations in 1993.

## Chromium

Total and dissolved concentrations of chromium for the three sampling periods are shown in Figure 10. Dissolved concentrations ranged from 0.083 to 1.440 parts per billion (ppb) and total concentrations ranged from 0.210 to 38.20 ppb. The ratio of dissolved to total chromium varied widely, with the highest ratios occurring in the samples with the lowest total concentrations. The highest total chromium concentration was in the sample taken at the San Pablo Bay station (BD20) in May, and was twice as high as the concentration in any other sample. This same sample also contained by far the highest TSS concentration (see Figure 4).

There were differences in dissolved chromium concentrations between sampling periods, but not for total chromium. Dissolved concentrations were higher during March than during the two other sampling periods.

There were also differences for total and dissolved chromium among the reaches. For total chromium, average concentrations in the northern estuary and rivers reaches were higher than in the Central Bay and South

**Table 8.  $R^2$  values for regressions of salinity (Sal) and total suspended solids (TSS) against dissolved chromium (dCr) concentrations, and for dCr, Sal, and TSS against total chromium concentrations, in each sampling period.  $R^2$  is the proportion of the variation of dissolved or total Cr that is explained by each of the water parameters and combinations of them listed.**

1. Dissolved chromium  
n = 16

	March	May	September
Sal	0.59	0.79	0.36
TSS	0.39	0.20	0.62
Best multi-parameter model	Sal 0.59	Sal TSS 0.84	TSS 0.62

2. Total chromium  
n = 16

	March	May	September
dCr	0.50	0.16	0.68
Sal	0.67	0.06	0.37
TSS	0.93	0.97	0.96
Best multi-parameter model	dCr TSS 0.95	TSS 0.97	TSS 0.96

Bay reaches. Dissolved chromium was highest in the rivers reach, and lowest in the South Bay and Central Bay reaches. The decrease in March (the period with the highest Delta outflow) and the decrease from north to south through the Estuary suggests that river-borne chromium is an important source to the Estuary.

Plots of dissolved chromium versus salinity are shown in Figure 18. Concentrations of chromium generally decreased with increasing salinity. In March, chromium concentrations at low salinities were much higher than in May or September. The relationship between chromium concentrations and salinity was the same in the South Bay as in the northern estuary. The plots indicate that, for chromium, the mixing of higher concentration river water (or local inflows in the South Bay) with lower concentration ocean water describes much of the variability in dissolved concentrations.

Regression analyses confirmed that salinity explained much of the variation in dissolved chromium in March and May, but less in September (Table 8). TSS

was more important than salinity in September. TSS alone accounted for over 90% of the variation in total chromium in all three sampling periods, and was clearly a more important factor than salinity or dissolved chromium. Visual comparison of Figures 10 and 4 shows that the patterns of total chromium concentrations and TSS concentrations were quite similar.

Water quality objectives for chromium for the protection of aquatic life apply to chromium VI, the most toxic form of chromium. Since chromium VI concentrations were not measured, total chromium concentrations are compared here to the objectives. However, it should be noted that using total chromium overestimates chromium VI, confounding comparisons to the water quality objectives. The marine objective of 11 ppb (RWQCB 1986) as a four day average was above the concentrations measured downstream of Carquinez Strait in March or September. In May, concentrations were above the marine objective at Pinole Point (BD30) and San Pablo Bay (BD20). The fresh water objective of 50 ppb as a

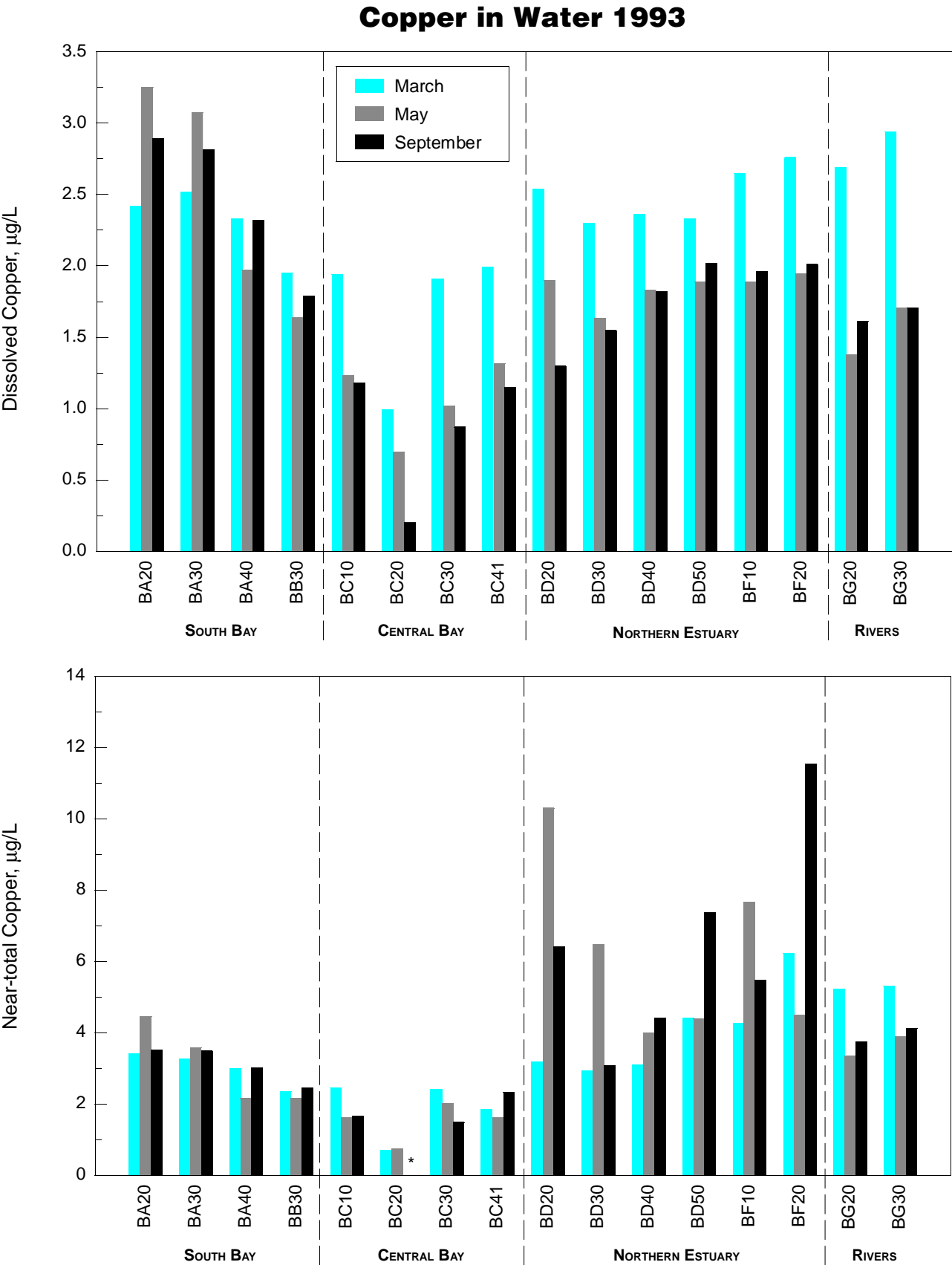
**Table 9.  $R^2$  values for regressions of salinity (Sal), dissolved organic carbon (DOC) and total suspended solids (TSS) against dissolved copper concentrations, and for dCu, Sal, DOC, and TSS against near-total copper concentrations, in each sampling period.**  $R^2$  is the proportion of the variation of dissolved or near-total Cu that is explained by each of the water parameters and combinations of them listed.

1. Dissolved copper  
n = 16

	March	May	September
Sal	0.74	0.01	0.03
DOC	0.67	0.58	0.93
TSS	0.37	0.003	0.03
Best multi-parameter model	Sal DOC 0.82	Sal DOC 0.87	Sal DOC 0.95

2. Near-total copper  
n = 16

	March	May	September
dCu	0.76	0.10	0.08
Sal	0.81	0.19	0.28
DOC	0.50	0.35	0.13
TSS	0.54	0.87	0.93
Best multi-parameter model	dCu Sal 0.84	TSS DOC 0.98	dCu TSS 0.97



**Figure 11.** Dissolved and near-total copper concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1. \* indicates missing value.

four day average, which applies to waters upstream of San Pablo Bay, was always above concentrations measured.

### Copper

Near-total and dissolved copper concentrations for the three sampling periods are shown in Figure 11. Near-total copper concentrations ranged from 0.7 to 11.6 ppb, and dissolved concentrations ranged from 0.2 to 3.25 ppb. Copper concentrations were lowest at the Golden Gate (BC20) and increased into the South Bay and northern estuary. The highest near-total concentrations were measured in Suisun and San Pablo Bays, while the highest dissolved concentrations were measured in the South Bay. The ratio of dissolved to near-total copper was quite variable from sample to sample.

There were differences in concentrations between sampling periods for dissolved copper, but not for near-totals. Dissolved copper concentrations were higher in March than during the May or September sampling periods. There were also differences between reaches for both dissolved and total copper. Dissolved copper was highest in the South Bay reach and lowest in the Central Bay reach. The northern estuary and rivers had the highest concentrations of total copper, and Central Bay had the lowest.

Plots of dissolved copper vs. salinity for each of the three sampling periods are shown in Figure 18. Copper concentrations generally decreased with increasing salinity. In March, there was a fairly linear relationship between salinity and dissolved copper concentrations throughout the Estuary. In May and September, a separate, steeper gradient of copper versus salinity emerged in the South Bay. At the same time the slope of the ocean-to-river copper gradient decreased. This suggests that during high flows, riverine and local runoff are important sources of dissolved copper, but during low flows, year-round sources have more of an impact in the South Bay than in the rest of the Estuary.

DOC was included as a factor in the regression analyses in addition to salinity and TSS because of the tendency of dissolved organic substances to bind copper (Coale and Bruland 1990; Kuwabara *et al.* 1989). For dissolved copper, DOC was consistently an important factor (Table 9), and the combination of DOC and salin-

ity was the best predictor of dissolved copper. For total copper, TSS was consistently the most important factor.

The Regional Board has proposed a site-specific objective for marine portions of the Estuary of 4.9 ppb total copper (Resolution 92-128). Copper concentrations were below 4.9 ppb at all stations with salinity greater than 5 ppt in March; but were above 4.9 ppb at Pacheco Creek (BF10), San Pablo Bay (BD20), and Pinole Point (BD30) stations in May; and at Grizzly Bay (BF20), the Napa River (BD50), and the San Pablo Bay (BD20) stations in September. Total copper concentrations were above the EPA marine criterion of 2.9 ppb at all stations outside of the Central Bay except for Oyster Point (BB30) and Redwood Creek (BA40), exceeded in May) in all three sampling periods. The EPA criterion for fresh water is hardness dependent, with a value of 6.5 ppb at a hardness of 50 mg/l and 12 ppb at a hardness of 100 mg/l, as four-day averages (U.S. EPA 1985a). Hardness was not measured in this study. However, even if hardness was as low as 50 mg/L, none of the measurements were above the fresh water criterion.

### Lead

Near-total and dissolved lead concentrations for the three sampling periods are shown in Figure 12. Near-total lead concentrations were always at least an order of magnitude greater than dissolved concentrations, and sometimes three orders of magnitude higher. Near-total lead concentrations ranged from 0.077 to 6.459 parts per billion (ppb), with the greatest concentrations in each sampling period occurring in the northern estuary. The highest concentration of near-total lead was measured at San Pablo Bay (BD20) in May, and was almost twice as much as any other sample. This was the same sample which had by far the highest suspended sediment concentration (see Figure 4).

Dissolved lead concentrations ranged from 0.003 to 0.289 ppb. In general, dissolved concentrations were lowest in Central Bay, particularly outside the Golden Gate (BC20), and increased with distance to the north and south of Golden Gate. The highest concentrations were measured at either the San Joaquin (BG30) or Sacramento River (BG20) station during all three sampling periods. Dissolved concentrations at the river stations were two

Lead in Water 1993

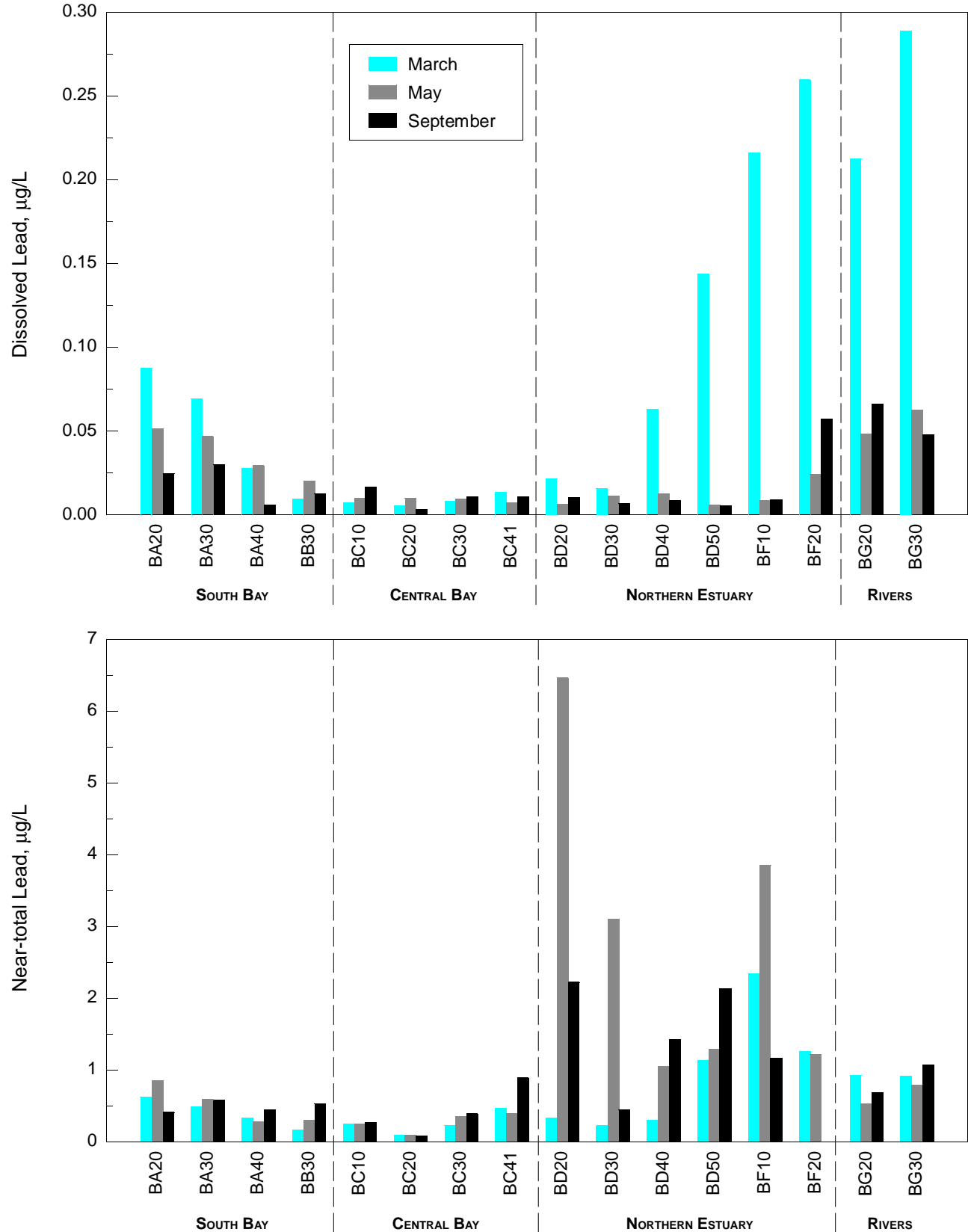


Figure 12. Dissolved and near-total lead concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1.



to three times higher in March than in May or September.

There were differences between sampling periods for dissolved lead. Concentrations were higher in March than in May or September. Near-total lead concentrations were not very different between sampling periods. There were also differences between reaches for both dissolved and total lead. Dissolved concentrations were highest in the rivers reach and lowest in Central Bay reach. For near-total lead, concentrations were higher in the northern estuary and rivers reaches than in the South Bay and Central Bay reaches.

Plots of dissolved lead vs. salinity are shown in Figure 18. Concentrations of lead generally decreased with increasing salinity. In March, lead concentrations were much higher in the northern estuary and rivers than in May or September. In the South Bay, as the range of salinities decreased, the range of lead concentrations decreased as well. In May there was a separate gradient of lead versus salinity in the South Bay, but in March and September the relationship of dissolved lead to sa-

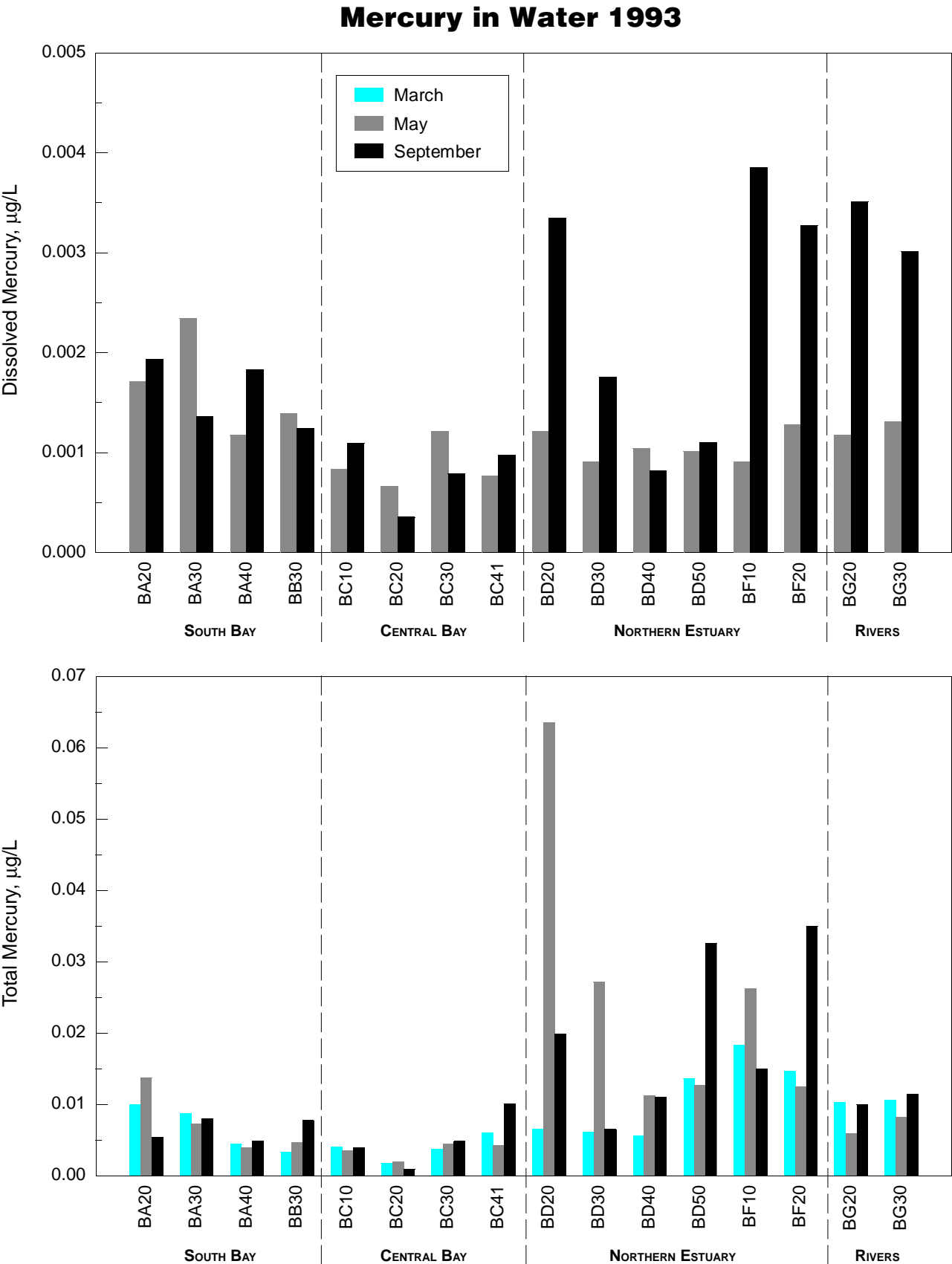
linity was the same in the South Bay as in the northern estuary.

Regression analysis showed that salinity accounted for 72% of the variation in dissolved lead in March, 12% in May, and 56% in September (Table 10). TSS was strongly correlated with dissolved lead concentrations in March, but weakly correlated in May and September. TSS accounted for over 90% of the variation in near-total lead concentrations in all three sampling periods. Visual comparison of Figures 12 and 4 shows that the patterns of total lead concentrations and TSS concentrations are quite similar. In March, both salinity and dissolved lead also accounted for over 50% of the variation individually, but in May and September these factors were not important.

The water quality objective for lead for waters downstream of Carquinez Strait is 5.6 ppb as a four-day average (RWQCB 1986). Near-total lead concentration were above this value once, at the San Pablo Bay station (BD20) in May. The fresh water objective for lead, which applies upstream of San Pablo Bay, is hardness depen-

**Table 10.  $R^2$  values for regressions of salinity (Sal) and total suspended solids (TSS) against dissolved lead (dPb) concentrations, and for dPb, Sal and TSS against near-total lead concentrations, in each sampling period.  $R^2$  is the proportion of the variation of dissolved or near-total Pb that is explained by each of the water parameters and combinations of them listed.**

1. Dissolved lead n = 16			
	March	May	September
Sal	0.72	0.12	0.56
TSS	0.75	0.06	0.15
Best multi-parameter model	Sal TSS 0.83	Sal TSS 0.25	Sal 0.56
2. Near-total lead			
	n = 16	n = 16	n = 15
	March	May	September
dPb	0.61	0.10	0.009
Sal	0.54	0.06	0.13
TSS	0.94	0.96	0.90
Best multi-parameter model	dPb TSS 0.96	TSS 0.96	Sal TSS 0.96



**Figure 13.** Dissolved and total mercury concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1. Dissolved mercury measurements for the March sampling period were outside quality control limits and were not used.

dent, with a value of 1.3 ppb as a four day average at a hardness of 50 mg/L (parts per million). Hardness was not measured in these samples. Near-total lead in one sample upstream of San Pablo Bay, Pacheco Creek (BF10) in March (2.34 ppb), could have been above the fresh water objective, depending on hardness.

### Mercury

Total and dissolved mercury concentrations for the three sampling periods are shown in Figure 13. Dissolved concentrations ranged from 0.0004 to 0.009 parts per billion (ppb), and total concentrations ranged from 0.0008 to 0.064 ppb. The highest concentration of total mercury, almost twice as high as in any other sample, was measured at San Pablo Bay (BD20) in May. This sample also had the greatest concentration of TSS (see Figure 4).

There were considerable differences among the sampling periods for dissolved mercury, but not for total mercury. Dissolved mercury concentrations were highest in March, intermediate in September, and lowest in May. Figure 13 also shows that the ratio of dissolved to

total mercury was higher in March than in the other two sampling periods. There were also differences among the reaches in both dissolved and total mercury. The Central Bay had the lowest concentrations of both dissolved and total mercury. The highest concentrations of dissolved concentrations were in the river and South Bay reaches, while the highest concentrations of total mercury were in the northern estuary.

Plots of dissolved mercury versus salinity for the three sampling periods are shown in Figure 18. In general, dissolved mercury concentrations decreased with increasing salinity, except in May, when there was no apparent relationship. The difference between the concentration versus salinity gradient in the South Bay and the northern estuary was greatest in March, and decreased as the dry season progressed in May and September. As the range of salinities in the South Bay decreased, the range of mercury concentrations decreased as well. This suggests that local runoff may have been an important source of dissolved mercury in the South Bay.

**Table 11. R<sup>2</sup> values for regressions of salinity (Sal) and total suspended solids (TSS) against dissolved mercury (dHg) concentrations, and for dHg, Sal and TSS against total mercury concentrations, in each sampling period.** R<sup>2</sup> is the proportion of the variation of dissolved or total Hg that is explained by each of the water parameters and combinations of them listed.

1. Dissolved mercury  
n = 16

	March	May	September
Sal	0.002	0.001	0.53
TSS	0.000	0.01	0.35
Best multi-parameter model	Sal 0.002	TSS 0.01	Sal TSS 0.56

2. Total mercury  
n = 16

	March	May	September
dHg	0.001	0.00	0.17
Sal	0.71	0.04	0.28
TSS	0.84	0.96	0.87
Best multi-parameter model	Sal TSS 0.89	TSS 0.96	dHg TSS 0.89

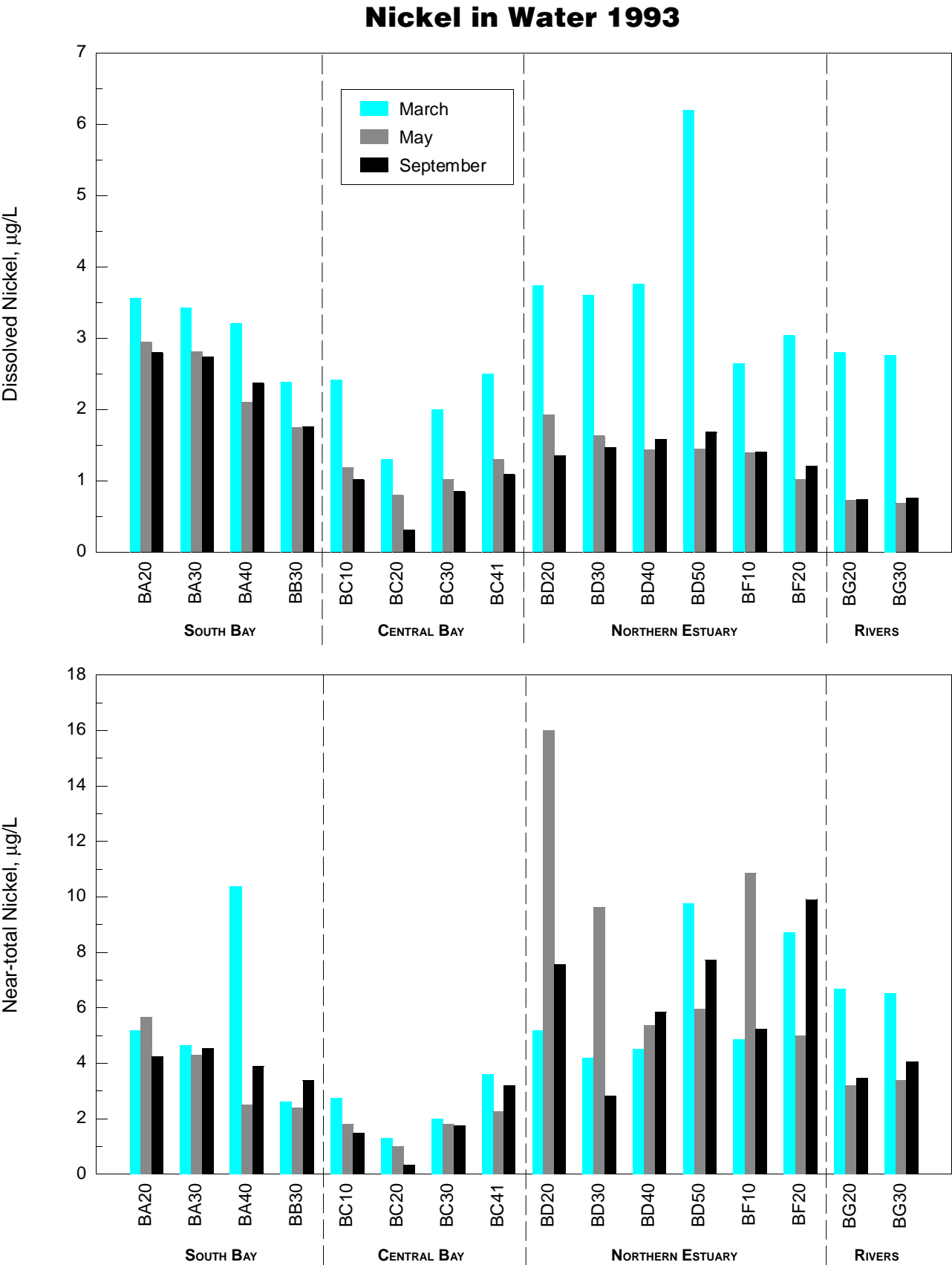


Figure 14. Dissolved and near-total nickel concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1.

Regression analyses showed that salinity was a better predictor of dissolved mercury concentrations in September than in March or May (Table 11). TSS accounted for 85% or more of the variability of total mercury concentrations. As observed in Figure 13, there was not a strong relationship between total and dissolved concentrations of mercury.

The water quality objective for waters both upstream and downstream of Carquinez Strait is 0.025 ppb total mercury as a 30 day average (RWQCB 1986), which is the same as the EPA criterion for marine waters (U.S. EPA 1985b). For fresh waters the EPA criterion is 0.013 ppb total mercury as a four-day average (U.S. EPA 1985b). Both criteria are based on human exposure through consumption of fish and shellfish, and EPA recommends that if the objective is exceeded, confirmatory testing of fish tissues be conducted. In March, concentrations in marine waters (salinity greater than 5 ppt) were below the marine criterion. In fresh waters (salinity less than 5 ppt), total mercury concentrations at the Napa River (BD50), Pacheco Creek (BF10), and Grizzly Bay

(BF20) stations were above 0.013 ppb. In May and September, the fresh water station were below the criterion. In May, San Pablo Bay (BD20), and Pinole Point (BD30) were above the criterion. In September, the Napa River (BD50) and Pacheco Creek (BF10) stations were above the marine criterion.

### Nickel

Near-total and dissolved nickel concentrations for all three sampling periods are shown in Figure 14. Dissolved nickel concentrations ranged from 0.31 to 6.19 ppb, and near-total nickel concentrations ranged from 0.33 to 15.98 ppb. Most of the highest measurements of near-total nickel occurred in San Pablo and Suisun Bays, although the concentration of near-total nickel was 10.4 ppb at Redwood Creek (BA40) during the March sampling period. The dissolved to near-total ratio was highly variable. Samples with the highest near-total nickel concentrations also had the highest ratio of dissolved to near-total concentrations. Dissolved concentrations were lowest at the Golden Gate (BC20) and at the Sacramento

**Table 12.  $R^2$  values for regressions of salinity (Sal) and total suspended solids (TSS) against dissolved nickel (dNi) concentrations, and for dNi, Sal and TSS against near-total nickel concentrations in each sampling period.**  $R^2$  is the proportion of the variation of dissolved or near-total Ni that is explained by each of the water parameters and combinations of them listed..

1. Dissolved nickel n = 16			
	March	May	September
Sal	0.18	0.12	0.09
TSS	0.01	0.006	0.01
Best multi-parameter model	Sal TSS 0.30	Sal TSS 0.16	Sal TSS 0.10

2. Near-total nickel n = 16			
	March	May	September
dNi	0.42	0.07	0.08
Sal	0.26	0.09	0.22
TSS	0.14	0.90	0.83
Best multi-parameter model	dNi TSS 0.51	dNi TSS 0.94	dNi TSS 0.98

(BG20) and San Joaquin (BG30) sampling stations during all three sampling periods.

The sampling periods were considerably different in dissolved, but not near-total nickel. Dissolved concentrations were higher in March than in May or September. For both dissolved and near-total nickel, there were obvious difference between average concentrations in the four reaches. The South Bay reach had the highest average concentration of dissolved nickel, and the Rivers reach had the lowest. For near-total nickel, the northern estuary had the highest concentrations, and the lowest average concentration was in the Central Bay.

Plots of dissolved nickel versus salinity are shown in Figure 18. In March, nickel concentrations decreased with increasing salinity throughout the Estuary. In May and September, a separate, steeper gradient of nickel versus salinity emerged in the South Bay. At the same time, concentrations at the upstream end of the Estuary decreased, approaching ocean concentrations. Concentrations increased at intermediate salinities, suggesting the importance of local sources, or physical and chemical processes other than conservative mixing of ocean and fresh water.

The influence of salinity and TSS on dissolved nickel concentrations was evaluated for each sampling period using regression analysis. Table 12 shows that neither salinity, TSS, nor a combination of the two explained more than 30% of the variation in dissolved nickel concentrations. For near-total nickel, dissolved nickel was the most important predictor in March, but TSS was by far the most important factor in May and September, explaining about 90% of the variation.

The water quality objective for nickel in waters downstream of Carquinez Strait is 7.1 ppb as a 24-hour average (RWQCB 1986). Subsequent to the adoption of the water quality objective, EPA issued a revised water quality objective for marine waters of 8.3 ppb (U.S. EPA 1986). The Basin Plan objective for fresh waters is 56 ppb as a 24-hour average (RWQCB 1986), and the EPA criterion is hardness dependent, with a value of 88 ppb as a four-day average at a hardness of 50 ppm.

Concentrations measured at Redwood Creek (BA40) in March, at San Pablo Bay (BD20), Pinole Point (BD30), and Pacheco Creek (BF10) in May, and at Grizzly Bay (BF20) in September were above the EPA marine crite-

riion. In addition, concentrations at San Pablo Bay (BD20) and the Napa River (BD50) were higher in September than the Basin Plan objective but lower than the EPA criterion. All fresh water concentrations were below these guidelines.

## Selenium

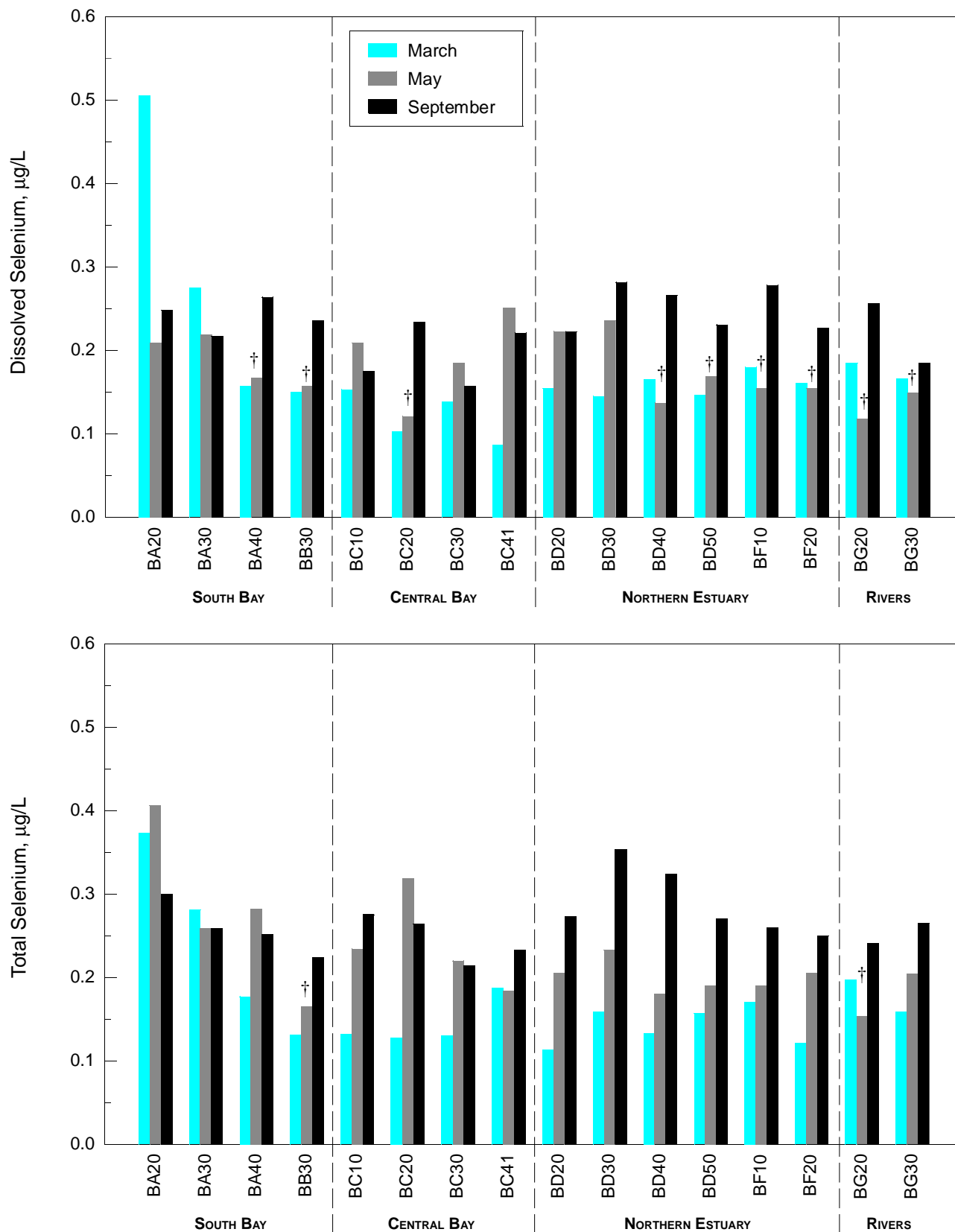
Total and dissolved concentrations of selenium for the three sampling periods are shown in Figure 15. Dissolved concentrations ranged from 0.087 to 0.505 parts per billion (ppb), and total concentrations ranged from 0.113 to 0.406 ppb. The ratio of dissolved to total selenium was higher, and less variable than for most other substances. Dissolved concentrations were reported as higher than total concentrations on several occasions, which can be interpreted to mean that they are indistinguishable. In March, selenium concentrations were highest in the Extreme South Bay (BA20) and Dumbarton Bridge (BA30) stations. In September, concentrations were higher at Pinole Point (BD30) and Davis Point (BD30) than in the rest of the Estuary.

There were considerable differences between sampling periods for both total and dissolved selenium. Total and dissolved concentrations were highest in September. Total selenium concentrations were higher in May than in March, but for dissolved selenium there was not an obvious difference between March and May. There were also differences between reaches for total selenium but not for dissolved. Total selenium concentrations were highest in the South Bay reach. There were no obvious differences between the other three reaches.

Plots of dissolved selenium versus salinity are shown in Figure 18. There was no consistent trend between salinity and selenium in the Estuary as a whole. In the South Bay, selenium decreased with increasing salinity. This gradient was most pronounced in March. As the range of salinities in the South Bay decreased in May and September, the range of selenium concentrations decreased as well, and fell within the range of concentrations observed in the rest of the Estuary. The distinct gradient in March suggests that local runoff may have been an important source of dissolved selenium in the South Bay.

Regression analysis showed that salinity never accounted for more than 25% of the variation of dissolved selenium, and total suspended solids (TSS) accounted

## Selenium in Water 1993



**Figure 15.** Dissolved and total selenium concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1. † indicates that measurements were between method detection and quantification limits and should be used cautiously.

for much less (Table 13). In spite of the fact that total and dissolved selenium concentrations appeared to be closely linked, dissolved selenium was only a good predictor of total selenium in March. The variation in total selenium was not well described by salinity or TSS during any of the sampling periods.

Selenium concentrations in all samples were well below the water quality criterion of 5 ppb selenium established by the EPA (National Toxics Rule, February 1993, 40 CFR 131.36(d)(10)).

### Silver

Near-total and dissolved silver concentrations for all three sampling periods are shown in Figure 16. Near-total silver concentrations were an order of magnitude higher in May than in the other two sampling periods, with a range from 0.014 to 0.142 parts per billion (ppb). The range in March was 0.002 to 0.010 ppb, and in September 0.0006 to 0.031 ppb. In May there was an increasing gradient of near-total silver with distance south of the Golden Gate (BC20). Concentrations in the north-

ern estuary were of similar magnitude, but there was no consistent spatial gradient. An increasing gradient with distance south of Golden Gate was also observed in March.

The lowest dissolved silver concentrations were in Central Bay, and the highest concentration was measured at the Sacramento River (BG30) in March, and in the South Bay in May and September. In September, dissolved concentrations at all four stations in the South Bay reach were at least twice as high as at any other stations.

Near-total silver concentrations were different in all three sampling periods, with concentrations generally highest in May, intermediate in March, and lowest in September. There were no obvious differences between sampling periods for dissolved concentrations. There were also differences among the reaches for dissolved silver but not for near-total. Dissolved silver concentrations were highest in the South Bay, and lowest in the rivers reach.

**Table 13. R<sup>2</sup> values for regressions of salinity (Sal) and total suspended solids (TSS) against dissolved and selenium (dSe) concentrations, and for dSe, Sal and TSS against total selenium concentrations, in each sampling period.** R<sup>2</sup> is the proportion of the variation of dissolved or total Se that is explained by each of the water parameters and combinations of them listed.

1. Dissolved selenium  
n = 16

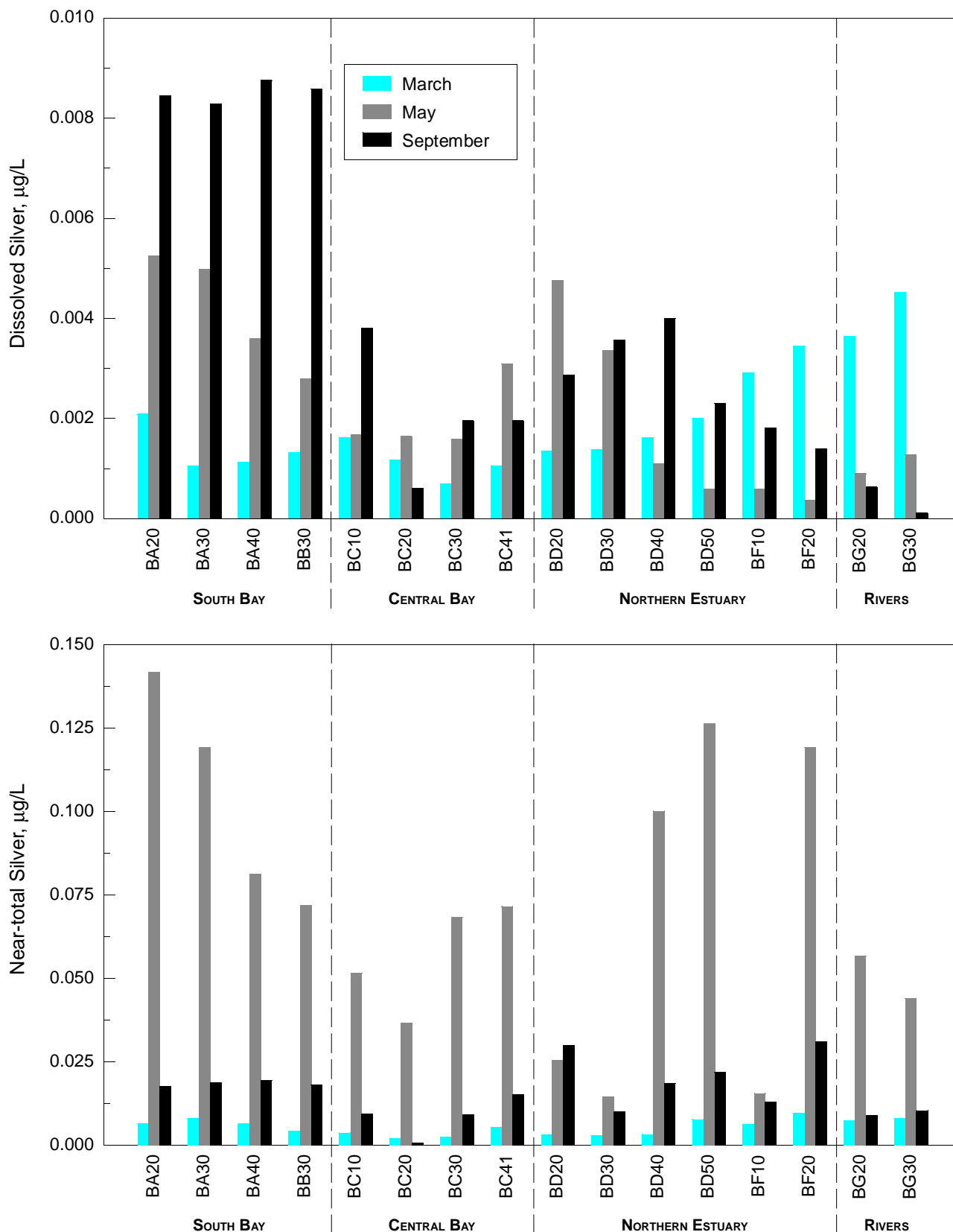
	March	May	September
Sal	0.05	0.19	0.02
TSS	0.004	0.07	0.01
Best multi-parameter model	Sal TSS 0.07	Sal TSS 0.35	Sal 0.02

2. Total selenium  
n = 16

	March	May	September
dSe	0.79	0.04	0.24
Sal	0.01	0.22	0.00
TSS	0.002	0.04	0.00
Best multi-parameter model	dSe 0.79	Sal 0.22	dSe 0.24



### Silver in Water 1993



**Figure 16.** Dissolved and near-total silver concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1.

Plots of dissolved silver versus salinity for March, May and September are shown in Figure 18. No consistent relationship between dissolved silver concentrations and salinity was observed. In March, dissolved silver decreased with increasing salinity throughout the Estuary. In May and September, dissolved silver concentrations were highest at intermediate salinities in the northern estuary. This suggests that other processes or sources were more important than the mixing of fresh and ocean water in determining concentrations. In the South Bay, silver concentrations increased as the year progressed, and were quite distinct from concentrations in the rest of the Estuary in September. This suggests that year-round sources of dissolved silver are important in the South Bay, and their influence is greater in summer when residence times are longer (Walters *et al.* 1985).

Neither dissolved nor near-total concentrations of silver were well correlated with either salinity or TSS (Table 14). For dissolved silver, these factors were most important in March, when each factor alone accounted for more than 50% of the variation in dissolved silver,

and salinity and TSS combined accounted for 70%. For near-total silver, TSS was consistently the most important factor, but it accounted for only 24 to 48% of the variation.

Concentrations of near-total silver were not above the water quality objective (RWQCB 1986) for marine waters (2.3 ppb silver) or for fresh waters (1.2 ppb) at any of the sampling stations in 1993.

## Zinc

Near-total and dissolved zinc concentrations for the three sampling periods are shown in Figure 17. Dissolved zinc concentrations ranged from 0.079 to 3.08 ppb, and the range of near-total zinc concentrations was from 0.25 to 30.4 ppb. Concentrations were lowest at the Golden Gate (BC20) and highest at San Pablo Bay (BD20).

There were differences between sampling periods for dissolved zinc concentrations, but not for near-totals. Dissolved zinc concentrations were higher in March than in May or September. There were also differences between reaches for both near-total and dissolved zinc.

**Table 14.  $R^2$  values for regression of salinity (Sal) and total suspended solids (TSS) against dissolved silver concentrations, and for dAg, Sal and TSS against near-total silver concentrations, in each sampling period.**  $R^2$  is the proportion of the variation of dissolved or near-total Ag that is explained by each of the water parameters and combinations of them listed.

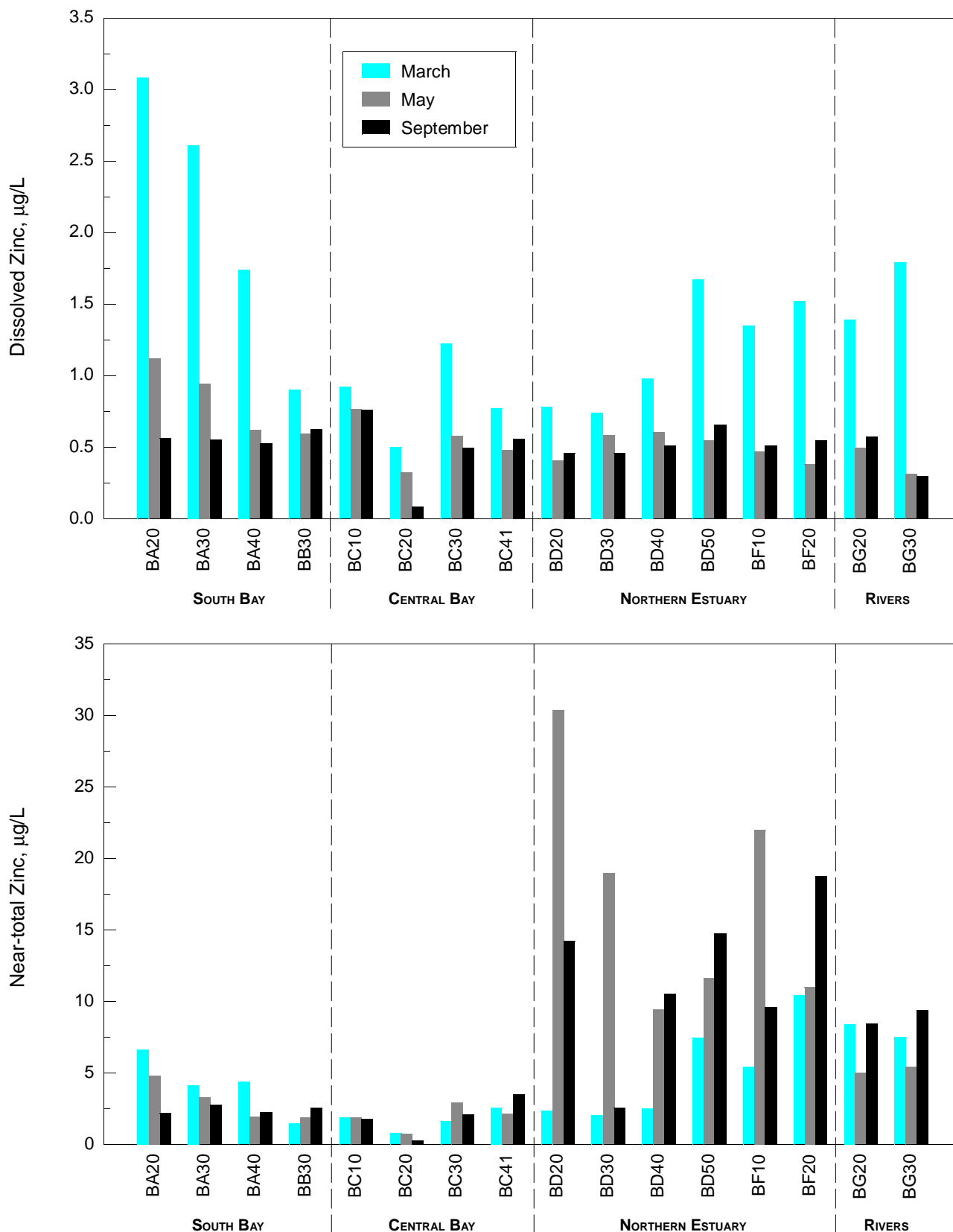
1. Dissolved silver  
n = 16

	March	May	September
Sal	0.67	0.28	0.29
TSS	0.57	0.04	0.17
Best multi-parameter model	Sal TSS 0.71	Sal Tss 0.41	Sal 0.29

2. Near-total silver  
n = 16

	March	May	September
dAg	0.43	0.02	0.08
Sal	0.37	0.003	0.01
TSS	0.40	0.24	0.48
Best multi-parameter model	dAg TSS 0.47	dAg Sal TSS 0.48	dAg Sal TSS 0.91

## Zinc in Water 1993



**Figure 17.** Dissolved and near-total zinc concentrations in water in parts per billion (ppb) at the 16 RMP stations for the three sampling periods in 1993. For station names and locations, see Figure 1.

For dissolved zinc, concentrations were highest in the South Bay reach, but there were no obvious differences between the other three reaches. Near-total zinc concentrations were higher in the northern estuary and rivers reaches than in the South Bay or Central Bay reaches.

Plots of dissolved zinc versus salinity are shown in Figure 18. Concentrations generally decreased with increasing salinity. In March, dissolved zinc concentrations were higher in the northern estuary than in May or September. A steeper gradient of dissolved zinc vs. salinity was present in the South Bay than in the rest of the Estuary. As the range of salinities in the South Bay decreased over the course of the year, the range of dissolved zinc concentrations decreased as well, and became less distinct from the gradient for the northern estuary. This suggests that local runoff was an important source of dissolved zinc in the South Bay. The higher concentrations throughout the Estuary in March suggest that runoff may be an important source of dissolved zinc.

Regression analysis showed that neither salinity nor TSS accounted for more than 20% of the variability in

dissolved zinc during any sampling period (Table 15). For near-total zinc, TSS was the most important factor, accounting for at least 90% of the variation in May and September. The greater importance of TSS in May and September may be due to the higher TSS concentrations at those times. Comparison of Figures 17 and 4 shows that the patterns of near-total zinc concentrations and TSS concentrations are quite similar.

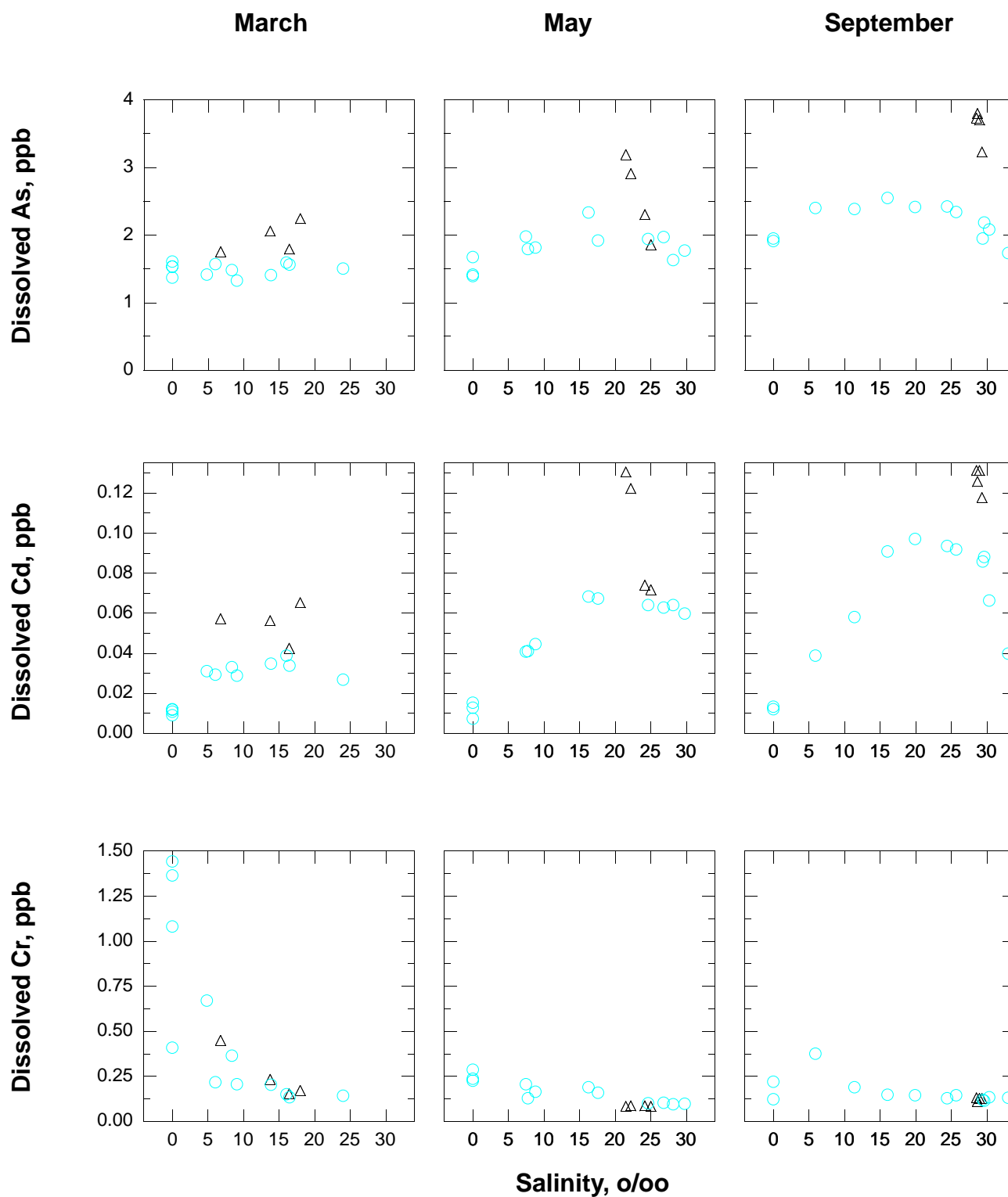
The water quality objective for zinc for the protection of aquatic life is 58 ppb, as a 24 hour average, for both marine and fresh waters (RWQCB 1986). Zinc concentrations in all samples in 1993 were below this objective.

### Summary of Trace Elements in Water

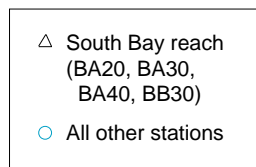
The results presented above showed that there was considerable variability in metals concentrations over space and time in 1993. Total (or near-total) concentra-

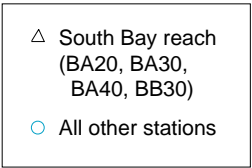
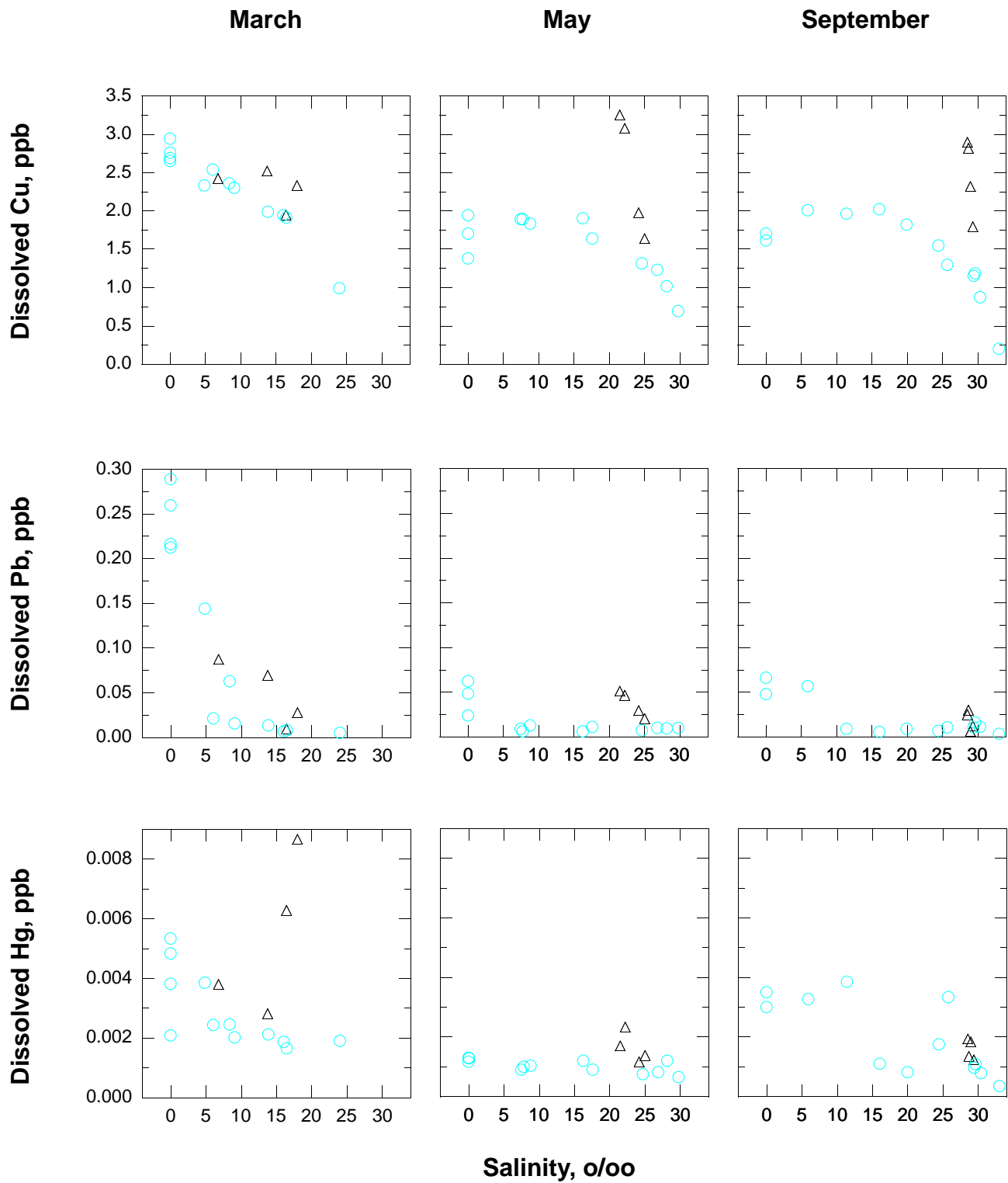
**Table 15. R<sup>2</sup> values for regressions of salinity (Sal) and total suspended solids (TSS) against dissolved zinc (dZn) concentrations, and for dZn, Sal and TSS against near-total zinc concentrations in each sampling period. R<sup>2</sup> is the proportion of the variation of dissolved or near-total Zn that is explained by each of the water parameters and combinations of them listed.**

1. Dissolved zinc n = 16			
	March	May	September
Sal	0.08	0.14	0.00
TSS	0.06	0.09	0.01
Best multi-parameter model	Sal 0.08	Sal TSS 0.18	Sal TSS 0.02
2. Near-total zinc n = 16			
	March	May	September
dZn	0.32	0.07	0.01
Sal	0.62	0.15	0.46
TSS	0.47	0.90	0.96
Best multi-parameter model	dZn Sal TSS 0.75	Sal TSS 0.91	TSS 0.96

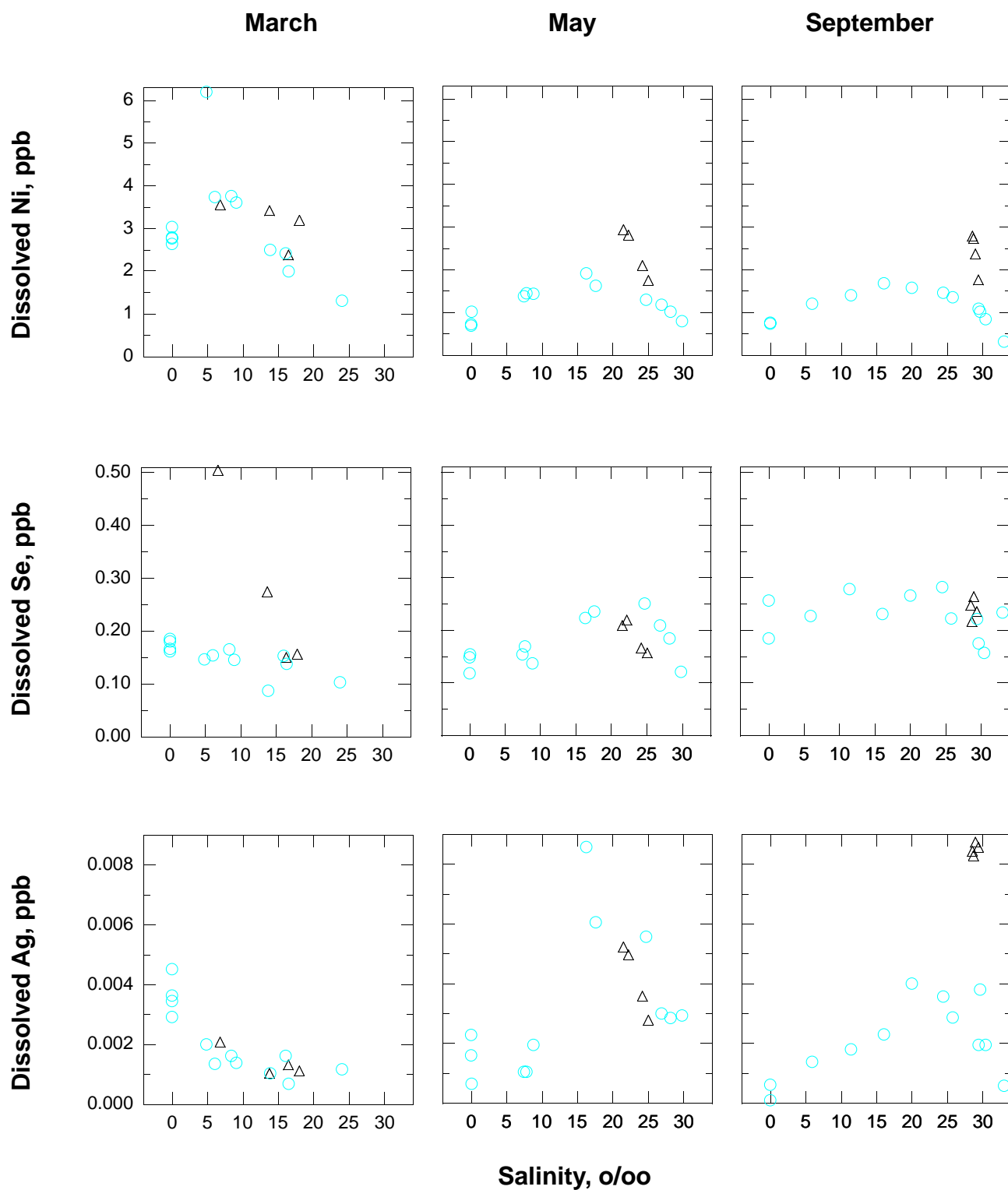


**Figure 18. (Page 1 of 4). Dissolved concentrations of ten trace metals versus salinity in parts per thousand (o/oo) for samples taken during March, May and September, 1993.** Plots are for arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), and zinc (Zn), in parts per billion (ppb).

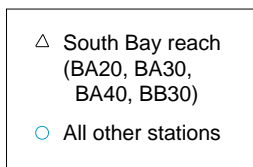


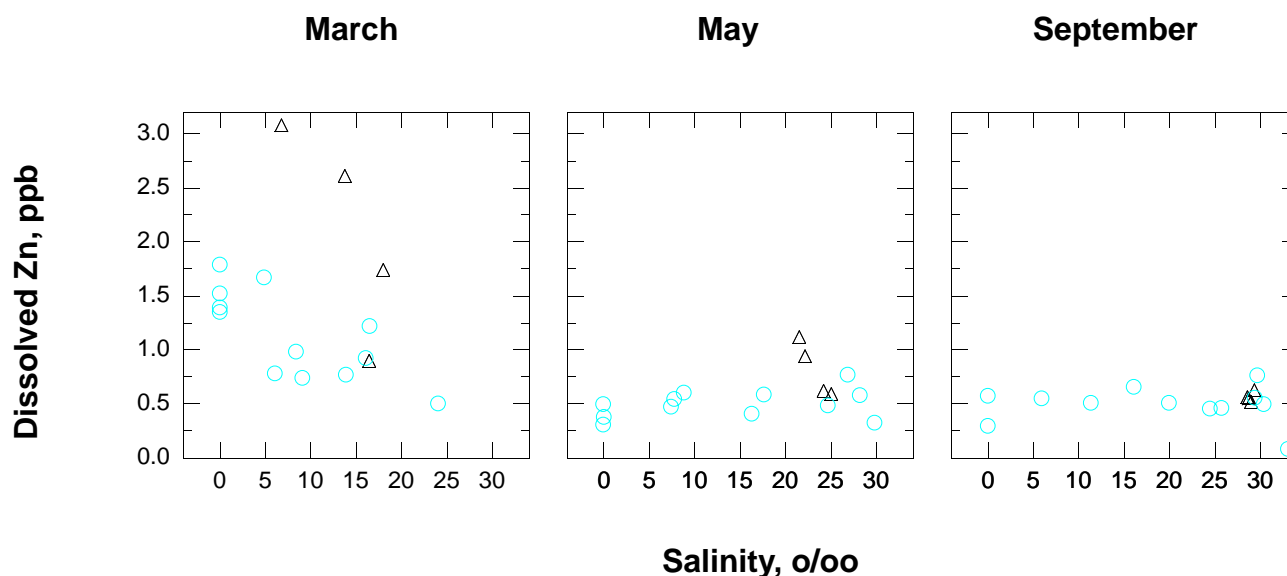


**Figure 18. (Page 2 of 4). Dissolved concentrations of ten trace metals versus salinity in parts per thousand (o/oo) for samples taken during March, May and September, 1993. Plots are for arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), and zinc (Zn), in parts per billion (ppb).**



**Figure 18. (Page 3 of 4). Dissolved concentrations of ten trace metals versus salinity in parts per thousand (o/oo) for samples taken during March, May and September, 1993. Plots are for arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), and zinc (Zn), in parts per billion (ppb).**





**Figure 18. (Page 4 of 4). Dissolved concentrations of ten trace metals versus salinity in parts per thousand (o/oo) for samples taken during March, May and September, 1993.** Plots are for arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), selenium (Se), silver (Ag), and zinc (Zn), in parts per billion (ppb).

△ South Bay reach  
(BA20, BA30,  
BA40, BB30)  
○ All other stations

tions typically ranged over two orders of magnitude and dissolved concentrations typically ranged over one order of magnitude. The ratio of dissolved to total was highly variable for all metals. For five substances, the highest total metal concentrations were measured in the sample from San Pablo Bay (BD20) in May, which was the sample with by far the highest TSS concentration.

In 1993 California experienced its first wet winter after a number of years of drought. As a result, there were lower salinities in much of the Estuary in March, which resulted in greater changes in the salinity profile of the Estuary over the course of the year (see Pilot Studies section, *Plankton and Water Quality*) than during the pilot RMP studies (1989 -1992) (Flegal *et al.* 1991; Flegal

**Table 16. Comparisons of RMP total or near-total trace metals in water (ppb) to previous data.**

Trace Metals	1978-1987 <sup>1</sup>	1989-90 <sup>2</sup>	RMP 1993
Cd	0.005-0.159	0.062-0.380	0.061-0.145
Cu	1.1-7.2	0.77-9.7	0.7-11.6
Pb	0.15-3.54	<0.08-6.65	0.077-6.45
Hg*	0-0.032	0.010-0.095	<0.001-0.064
Ni	1.22-11.28	1.21-15.90	0.33-15.98
Ag	0.003-0.10	0.007-0.345	0.001-0.142
Zn	1.4-17.4	0.77-22.3	0.25-30.4
Se*	-	<0.012-0.174	0.113-0.406

<sup>1</sup>Flegal *et al.* 1991b.

<sup>2</sup>Listed in Davis *et al.* 1993 for data from 1978-87.

\* Total concentrations



*et al.* 1994). These conditions provided an opportunity to evaluate the influence of salinity on spatial and temporal variations in contaminant concentrations in the Estuary.

Salinity is a reflection of the degree of mixing of fresh and salt water, and this mixing creates a gradient of contaminant concentrations as well. Lower salinities also indicate that a greater volume of fresh water is travelling through the Estuary, which reduces residence times of water and associated dissolved substances in the Estuary (Walters *et al.* 1985).

Spatial patterns in concentrations were similar for a number of substances. Dissolved metals concentrations were generally higher in the South Bay reach than in the other reaches for six substances: arsenic, cadmium, copper, nickel, silver, and zinc. Concentrations of total arsenic, cadmium and selenium were also highest in the South Bay reach. Dissolved chromium and lead concentrations were highest in the rivers reach. Near-total nickel and total mercury concentrations were highest in the northern estuary, which is where the highest suspended sediment concentrations were measured.

Concentrations in the Central Bay reach, which has the greatest influence of ocean waters, were generally lower than for the rest of the Estuary for dissolved copper, arsenic, mercury, and lead, and near-total copper and nickel. However, concentrations of dissolved cadmium, nickel, and silver and total cadmium were significantly lower in the rivers reach than in the rest of the Estuary.

Dissolved concentrations were higher during March than during May or September for six of the ten metals analyzed: chromium, copper, nickel, lead, mercury, and zinc. This is inconsistent with the notion that contaminant concentrations in the Estuary increase during dry weather, and suggests that the Sacramento River as well as local runoff may be important sources of these elements. Concentrations were highest in September for dissolved and total arsenic, cadmium, and selenium. Conversely, concentrations of dissolved cadmium and arsenic, and near-total cadmium, arsenic, selenium and silver were lowest in March. There was no significant difference between sampling periods for total (or near-total) concentrations of six of the substances analyzed.

TSS was the conventional water quality parameter which was most frequently significantly correlated to

pollutant concentrations. TSS accounted for more than 80% of the variation in concentrations of six total (near-total) metals in May and September: chromium, copper, lead, mercury, nickel, and zinc. For chromium, lead, and mercury, *r*-squared values were greater than 0.80 in March as well.

It was expected that salinity would be an important factor in explaining variability in trace element concentrations. However, in 21 of the 30 regressions between salinity and dissolved trace element concentration, salinity accounted for less than 50% of the variability. Salinity accounted for between 50 and 80% of the variability of dissolved concentrations of chromium, lead, silver and copper in March, cadmium and chromium in May, and cadmium, lead, and mercury in September. The plots of dissolved metals against salinity confirmed that the relationship was typically non-linear or non-conservative (Flegal *et al.* 1991). The deviations from linearity were useful in assessing the importance of localized sources of pollutants on ambient water quality.

When plotted against salinity, three general patterns of dissolved concentrations of metals were observed. For arsenic, cadmium, copper and nickel in March, there was one gradient of dissolved concentration versus salinity throughout the Estuary, but in May and September a separate, steeper gradient emerged in the South Bay. The increasing concentrations in the South Bay as the year progressed suggest that as fresh water inflows decrease, year-round sources of these substances exert more influence on ambient water quality. In the northern estuary these substances exhibited non-conservative gains at intermediate salinities. For copper and nickel, the initial, Estuary-wide gradient was steeper in March than during the other two sampling periods, suggesting that runoff and riverine sources of these substances are important factors in water quality throughout the estuary during wet weather.

In the second pattern, illustrated by chromium and lead, there was a strong decreasing gradient with increasing salinity in March, as well as non-conservative loss at intermediate salinities. In May and September the gradient was much flatter. This pattern suggests that riverine sources and local runoff were important factors contributing to concentrations of these substances in the Estuary.

In the third pattern, exhibited by mercury, selenium, and zinc, a separate, steeper gradient was observed in the South Bay in March, and as the range of salinities in the South Bay decreased over the course of the year, the range of dissolved metals concentrations decreased as well, and approached concentrations in Central Bay. This pattern suggests that local runoff in the South Bay is a more important source than year-round sources of these three trace metals, and that local runoff in the South Bay contributes proportionately more of these substances than do runoff and riverine sources in the northern estuary.

The plots of dissolved silver did not fall into any of these categories.

Due to the limited amount of data supporting these observations, they should be interpreted cautiously. Future results may serve to strengthen or invalidate these apparent trends.

While concentrations in most samples were lower than water quality guidelines, concentrations of some trace elements were above the guidelines. Total (or near-total) arsenic, cadmium, cyanide, selenium, silver and zinc were never above water quality objectives or criteria. Total chromium was above the chromium VI objective at two stations in May. Near-total copper concentrations were not above the proposed objective of 4.9 ppb at any stations in March, but were above 4.9 at three stations in May, and three stations in September. Near-total copper concentrations were above the EPA marine criterion of 2.9 ppb at all stations outside of the Central Bay except for Oyster Point (BB30) and Redwood Creek (BA40, in May) in all three sampling periods. For lead, the hardness-dependent fresh water objective appears to have been exceeded at one station in May. However, due to lack of hardness data, this could not be confirmed. The fresh water mercury objective was exceeded at three stations in March, and the marine criterion was exceeded at two stations in May and September. The marine criterion for nickel was exceeded at one station in March, three stations in May, and one station in September.

Comparison of 1993 RMP results with data from previous studies indicates similar trace metals concentrations in the Estuary since at least the late 1970s (Table 16). In general, concentrations are all within the same range of values previously reported. However, maximum copper, nickel, selenium, and zinc concentrations from

the RMP are higher than any other values listed. All of the concentrations from 1989-90 were highest in the South Bay except for copper which was highest in Grizzly Bay.

These comparisons do not account for differences in water years, season, or locations, but place the RMP results in a longer-term perspective. Rigorous analysis of long-term trends in space and time has not been conducted.

## Trace Organic Contaminants

Many trace organic contaminants were measured from the San Francisco Estuary (Table 5). These contaminants are grouped into 3 major types: polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides.

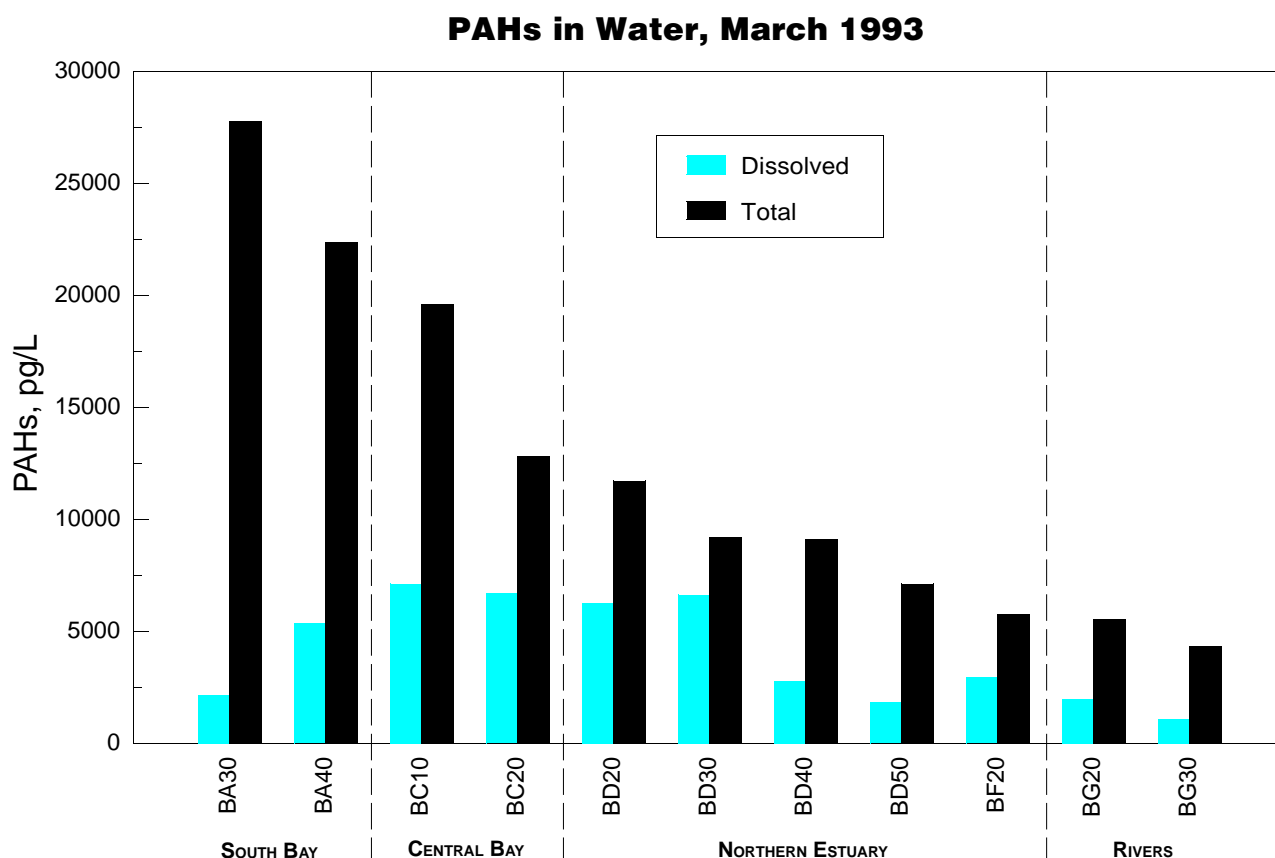
The following section includes reports of PAHs, PCBs and pesticides, as sums of numerous component compounds measured for each type of trace organic contaminants. These are described in each section. Concentrations of all individual trace organic compounds in water are listed in Appendix Tables 2.4, 2.5, and 2.6.

Water samples for trace organics analysis were collected during all 3 sampling periods: March, May, and September. However, only samples from the 11 stations that correspond to the bivalve bioaccumulation stations were analyzed for trace organic contaminants (Table 2). Data from the first sampling period in March are included in this report. Data from the other 2 sampling periods are incomplete and will be reported in 1994.

### Polynuclear Aromatic Hydrocarbons (PAHs)

PAHs are products from the incomplete combustion of petroleum. They include numerous 2 to 6 ring compounds with varying solubilities and toxicities. Eighteen separate PAH compounds were measured in the RMP water samples.

Total (dissolved + particulate) PAHs in water at the RMP stations ranged from 4,350 to 27,780 parts per quadrillion (ppq) (Figure 19). The highest concentration was measured at Dumbarton Bridge (BA30), and the lowest concentration was measured at the San Joaquin River (BG30). Total PAH concentrations were generally high-



**Figure 19. Total and dissolved polynuclear aromatic hydrocarbons (PAHs) concentrations in water (parts per quadrillion) at eleven RMP stations in March.** For station locations see Figure 1.

est in the South Bay and decreased gradually to the north into the rivers.

Dissolved PAHs ranged between 1,080 to 6,690 ppq with the highest concentration measured at Yerba Buena Is. (BC10) and the lowest concentration at San Joaquin River (BG30). In general, the Central Bay stations had higher concentrations of dissolved PAHs than the South Bay or Rivers.

The ratio of dissolved to total PAHs was not consistent at the RMP stations. Dissolved PAHs only contributed a small proportion to the total at Dumbarton Bridge (BA30), but contributed over 70% of the totals at Pinole Pt. (BD30).

Of the individual PAH compounds measured, fluoranthene had the highest total concentration (812 - 5,322 ppq) at all sites sampled. For dissolved compounds, fluoranthene was the highest at 6 of the stations (127 - 2,572 ppq), and phenanthrene was highest at 5 of the

stations (309 - 2,293 ppq). Both compounds were highest at Yerba Buena Is. (BC10) (Appendix Table 2.4).

Variations in salinity at the RMP stations accounted for about half of the variance of total PAHs, and the combination of salinity and DOC accounted for about 55% (Table 17). Salinity accounted for 43% of the variation in dissolved PAHs, and TSS accounted for 68% (Table 16). The combination of DOC and TSS explained about 69% of the variation. A plot of dissolved PAHs versus salinity shows that the highest PAHs were generally measured at the stations with the highest salinities (Figure 20).

Total PAHs in water at all of the RMP stations were below the EPA criterion for human health which is 31,000 ppq.

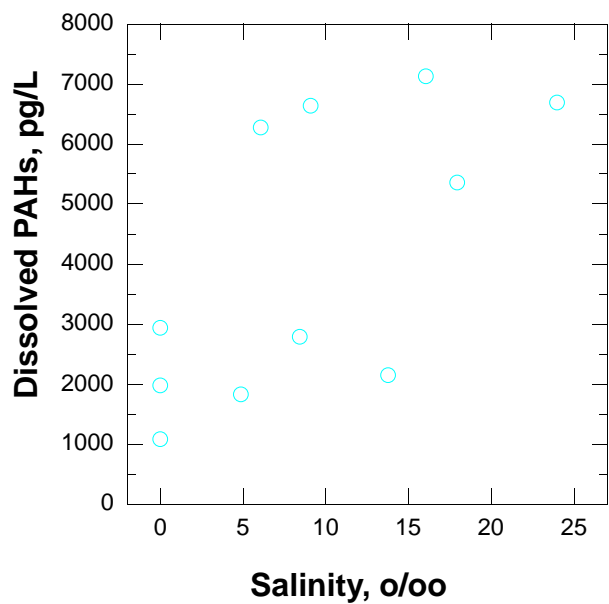


Figure 20. Relationships between dissolved PAHs and salinity measured in March 1993.

Polychlorinated Biphenyls (PCBs)

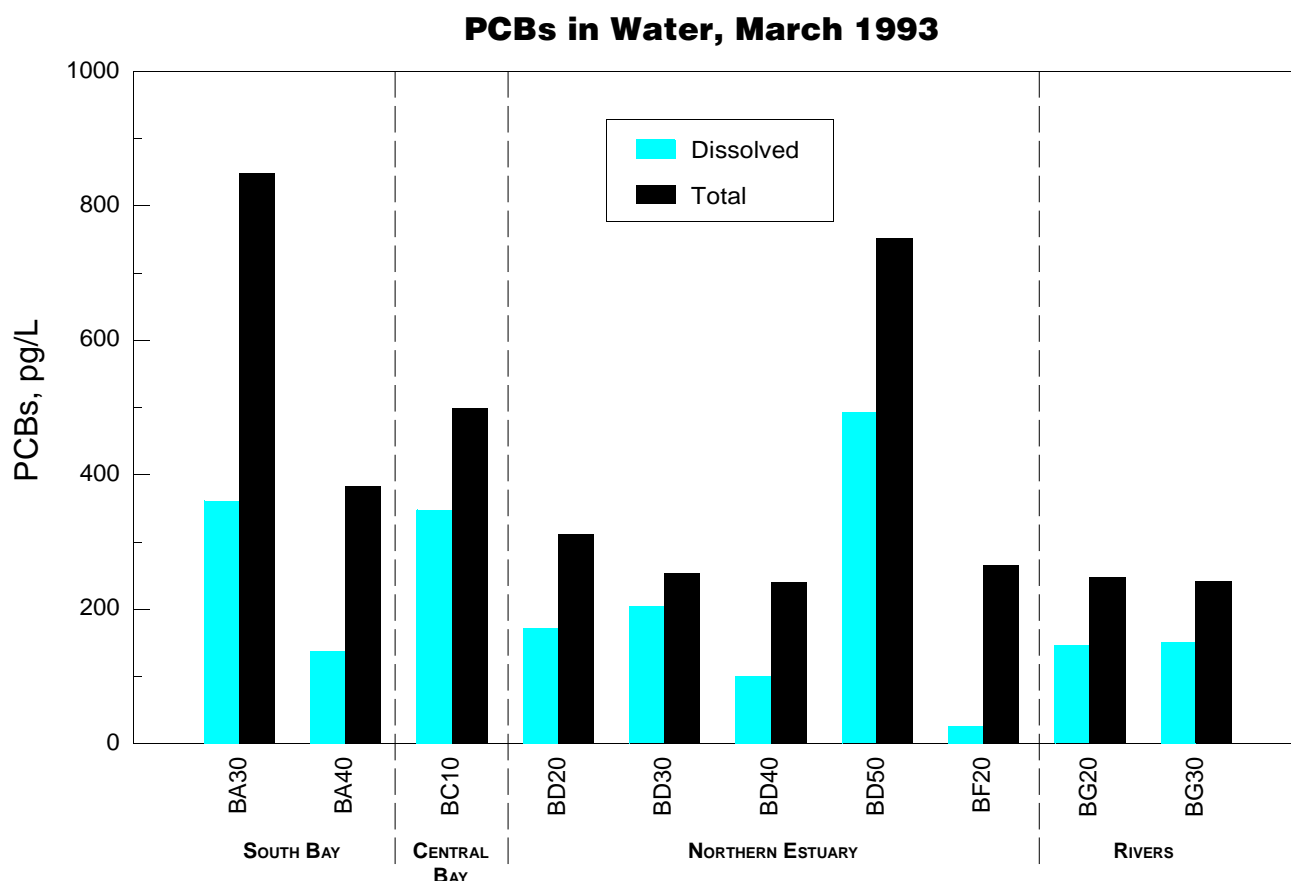
PCBs are a group of approximately 209 synthetic chlorinated hydrocarbon compounds, each called a congener. They are generally rather insoluble in water, persistent in the environment, and are known to be toxic. Fifty-four PCB congeners were analyzed in water and are listed in Appendix Table 2.5. The sum of those congeners are reported below.

Total (dissolved + particulate) PCBs in water at the RMP stations ranged between 239 to 2,935 parts per quadrillion (ppq) (Figure 21). The highest concentration was measured at the Golden Gate station (BC20). This was an unexpected result since that station is outside the Estuary. The data were verified, and it appears to be a valid sample. Within the Estuary the highest concentration of 847 ppq was measured at Dumbarton Bridge (BA30). Concentrations were also elevated in the Napa River (BD50).

Dissolved PCBs ranged between 26 to 492 ppq. The highest concentration was at the Napa River (BD50), and the lowest concentration was at Grizzly Bay (BF20). The

Table 17. R<sup>2</sup> values for regression of salinity (Sal), total suspended solids (TSS) and dissolved organic carbon (DOC) against dissolved and total PAH concentrations in the first sampling period. R<sup>2</sup> is the proportion of the variation of dissolved or total PAH that is explained by each of the water parameters and combinations of them listed.

1. Dissolved PAHs n = 11	
	March
Sal	.431
TSS	.677
DOC	.330
Best multi-parameter model	DOC TSS .685
2. Total PAHs n = 11	
	March
Sal	.503
TSS	.338
DOC	.156
Dissolved PAH	.107
Best multi-parameter model	DOC Sal .541



**Figure 21.** Total and dissolved polychlorinated biphenyls (PCBs) concentrations in water (parts per quadrillion) at selected RMP stations in March, Golden Gate station omitted (see text). For station locations see Figure 1.

ratio of total PCBs to dissolved PCBs was variable among the stations.

Dissolved PCBs in water were poorly related to salinity or DOC. Together they only accounted for 11% of the variation in dissolved PCBs (Table 18). Plots of dissolved PCBs vs. salinity (Figure 22) showed a generally linear relationship with higher concentrations at higher salinities. However, one point (dissolved PCB = 492 ppq) indicated a deviation from conservative mixing due to elevated concentrations at Napa River (BD50).

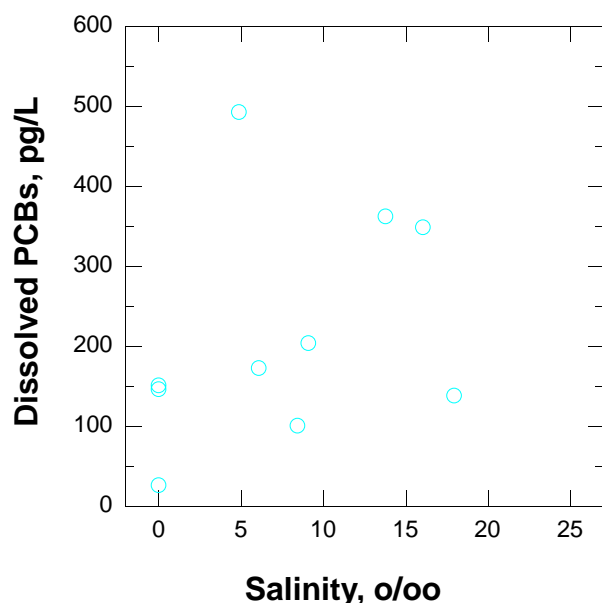
Total PCBs were also poorly related to water parameters, such as salinity or TSS. Together they only accounted for 34% of the variation in total PCBs. Differences in dissolved PCB concentrations accounted for 74% of the variation in total PCBs (Table 18).

Total PCB concentrations in water at the RMP stations were all above the EPA human health criterion which is 44 ppq. The sources of PCBs that cause these

elevated concentrations in the Estuary are poorly understood. The EPA criterion is based on a different way of calculating total PCBs than used in the RMP, thus RMP values are not directly comparable to the standard. EPA uses an Aroclor-based standard (Aroclors are mixtures of PCB congeners that were used commercially), whereas the RMP simply summed the congeners.

### Pesticides in Water

For this report, pesticides include insecticides, herbicides, fungicides, etc. used for biological control. Twenty-seven different pesticides were measured in water at the RMP stations (Appendix Table 2.6). These compounds are usually classified into several general types: chlordanes, chlorpyrifos, dacthal, DDTs, dieldrin, endosulfan, hexachlorobenzene, hexachlorocyclohexanes, oxadiazon, and toxaphene. The sum of all of those compounds is reported below.



**Figure 22. Relationships between dissolved PCBs and salinity measured in March 1993; Golden Gate station omitted.**

Total pesticides in water in March 1993 ranged between 1,629 and 9,011 parts per quadrillion (ppq) at the RMP stations (Figure 23). The highest concentrations were at the Sacramento River (BG20) and the lowest concentrations were at Richardson Bay (BC30). Dissolved pesticides ranged between 1,477 and 7,512 ppq. The highest concentrations were also in the Sacramento River. Dissolved pesticides contributed between 50-97% to total pesticides.

In general, total pesticides in water were lowest at the Golden Gate (BC20), in San Pablo Bay (BD20), and at Pt. Pinole (BD30). Concentrations increased into South Bay and into the northern estuary and rivers (except Grizzly Bay, BF20).

Dacthal (a herbicide) concentrations ranged between 12.2 and 5,484 ppq. Concentrations were highest at the Sacramento River (BG20) and at the San Joaquin (BG30) and Napa River (BD50) stations, contributing 32 to 61% of total pesticides. Oxydiazon (herbicide) concentrations ranged between 47.2 and 3,000 ppq, and contributed up to 46% of pesticides at Dumbarton Bridge (BA30), and 35% at Napa River (BD50) and San Joaquin River (BG30). DDTs (chlorinated pesticides) concentrations

ranged between 23.6 and 803 ppq, and were highest in Grizzly Bay (BF21) and at the Sacramento, San Joaquin, and Napa River stations. DDTs contributed up to 25% to total pesticides at Grizzly Bay (BF21). Chlorpyrifos (an organo-phosphate pesticide) concentrations ranged between 69.6 and 1,210 ppq, and contributed 24% of total pesticides at Yerba Buena Is. Chlordanes (chlorinated pesticides) concentrations ranged between 68 - 681 ppq, and contributed up to 9% of total pesticides at Dumbarton Bridge (BA30), (Appendix Table 2.6).

The elevated dacthal and DDTs in the northern Estuary, particularly at the River stations suggest those drainages as sources of those compounds.

Salinity and DOC were poorly correlated with dissolved pesticides (Table 19). The plot of dissolved pesticides vs. salinity (Figure 24) does not show conservative mixing similar to that observed for trace metals. Similarly, salinity and TSS were poorly correlated with total pesticides, but dissolved pesticides accounted for 96% of the variability in total pesticide concentrations.

Water quality criteria exist for all of the pesticides measured except for chlorpyrifos, dacthal and oxadiazon. Chlordanes (6 compounds) were above the water quality criterion of 81 ppq at all RMP stations except the San Joaquin River (BG30) and Pt. Pinole (BD30), and were highest at Dumbarton Bridge (BA30). However, the 6 chlordane compounds measured are a slightly different set of chlordanes than prescribed by the EPA criteria, therefore are not directly comparable. Dieldrin, a pesticide, was above the criterion of 140 ppq at most of the stations sampled, but occurred in the highest concentrations at the Sacramento River Station (BG20). Total DDTs (includes 7 isomers) was above the criterion of 600 ppq at the Sacramento River (BG20) and Grizzly Bay (BF20) stations.

## Summary of Trace Organic Contaminants

Although present in very low concentrations, trace organic contaminants were measured at all RMP stations. In general, there was a gradient of higher total trace organics concentrations in the South Bay, decreasing into the Central Bay. However, PCBs and pesticides were also

elevated in the Napa River, and pesticides were highest in the Sacramento River.

Dissolved pesticides composed a large proportion of totals, but dissolved PCBs and PAHs composed lower and more variable proportions of totals.

Dissolved and total PCBs and pesticides were poorly correlated with salinity, TSS, and DOC. These compounds are generally considered quite insoluble and closer associations with organic material were expected. PAHs were more closely related to those parameters, particularly salinity and TSS.

These observations demonstrate the complex geochemistry of trace organic contaminants in the Estuary. The trace organic results were measured during a very wet sampling period (March 1993) and may be somewhat unusual for the Estuary. It will be important to evaluate measurements from other sampling periods to document ranges of concentrations and changes in relationships with other water parameters in order to more fully understand trace organics in the Estuary.

The elevated concentrations of pesticides, particularly dieldrin and DDTs in the Sacramento River, Napa

River, and South Bay during the wet season suggest riverine sources to the Estuary. However, other pesticides, such as chlordanes and chlorpyrifos may have other non-point sources. The generally elevated PCB concentrations throughout the Estuary suggest ubiquitous sources.

There is very little information from previous studies for comparison to the RMP measurements. PCBs measured in water in the early 1970s produced a range of total PCBs from 400 to 6,600 ppq (Anderlini *et al.* 1975). More recently, ranges of total PCBs between 621 to 2139 ppq were reported (Risebrough 1994). The highest value was from the Extreme South Bay station (BA20). The RMP measurements reported herein (239 to 847 ppq, without Golden Gate) are within these previously reported ranges.

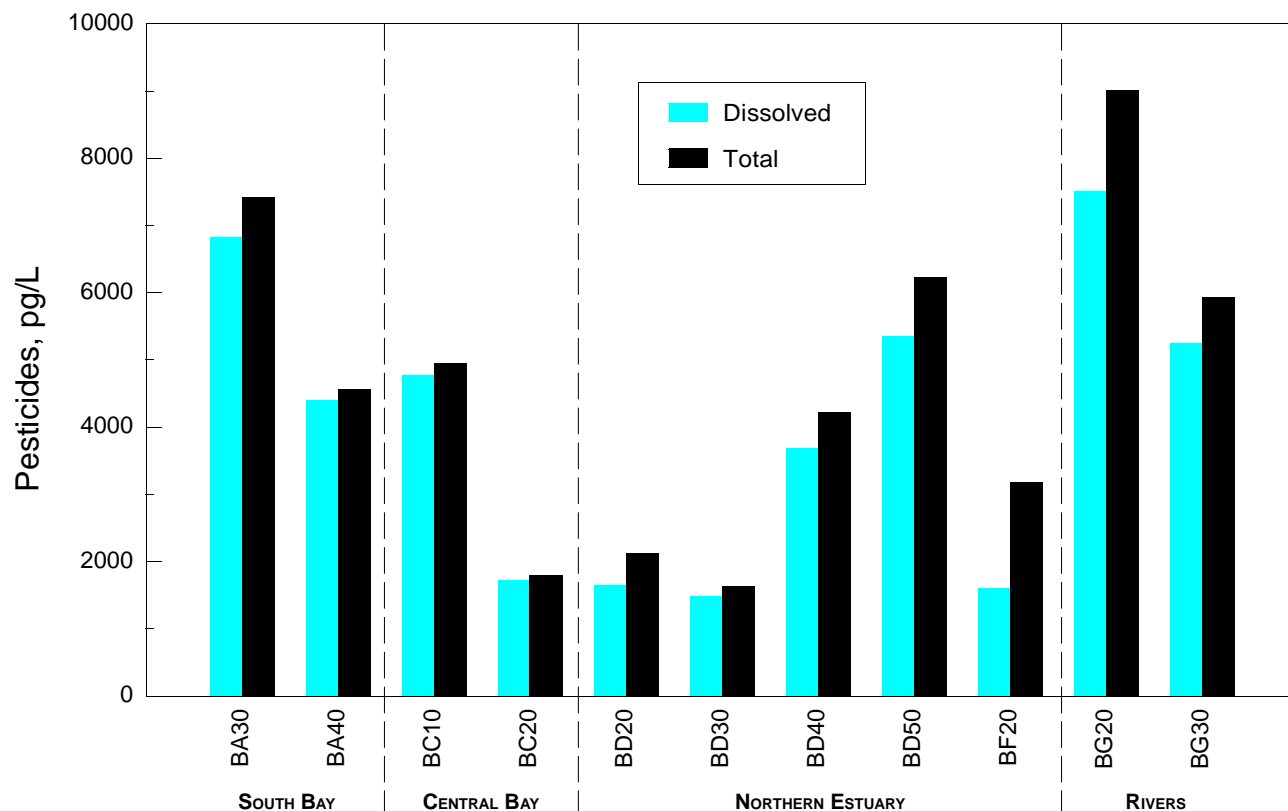
## Aquatic Toxicity

Toxicity of water collected at 8 of the RMP stations (listed in Table 2) was tested during the 3 sampling periods in March, May, and September. Two laboratory toxicity tests were conducted using bivalve larvae and uni-

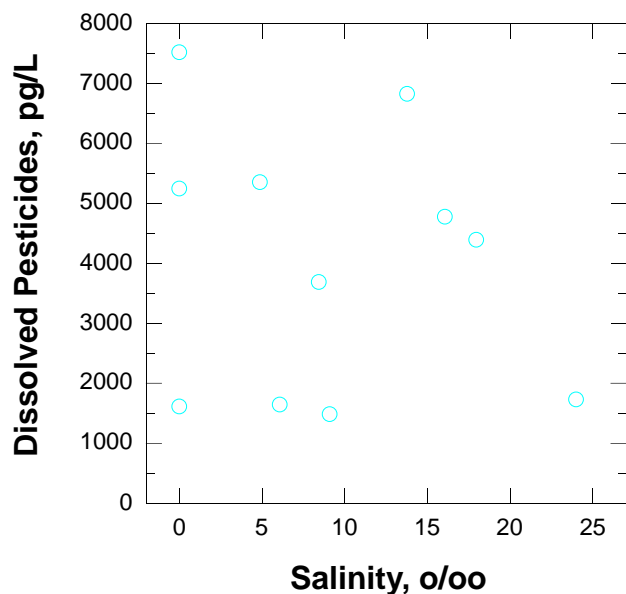
**Table 18.  $R^2$  values for regression of salinity (Sal), total suspended solids (TSS) and dissolved organic carbon (DOC) against dissolved and total PCB concentrations in the first sampling period.  $R^2$  is the proportion of the variation of dissolved or total PCBs that is explained by each of the water parameters and combinations of them listed.**

1. Dissolved PCBs n = 10 (Golden Gate excluded)	
	March
Sal	.113
TSS	.049
DOC	.031
Best multi-parameter model	Sal TSS .126
2. Total PCBs n = 10 (Golden Gate excluded)	
	March
Sal	.172
TSS	.016
DOC	.071
Dissolved PCBs (dPCBs)	.741
Best multi-parameter model	Sal, TSS, dPCBs .862

### Pesticides in Water, March 1993



**Figure 23.** Total and dissolved pesticide concentrations in water (parts per quadrillion) at selected RMP stations in March. For station locations see Figure 1.



**Figure 24.** Relationships between dissolved pesticides and salinity measured in March 1993.

cellular algae (detailed in Methods). For the 48-hour bi-valve larvae development test, larval mussels (*Mytilus edulis*) were used in March and September, and larval oysters (*Crassostrea gigas*) were used in May, due to differences in seasonal availability of the larvae. A 96-hour growth test using the unicellular alga *Thalassiosira pseudonana* was also conducted.

Reference toxicant tests, using copper, were conducted concurrently with the ambient aquatic tests. Control limits (mean EC value  $\pm$  2 s.d.) provide a means of determining the acceptability of individual tests. Reference toxicity test results that fall outside of the control limits usually invalidate the test results, or as interpreted below, are inconclusive (Appendix Table 3.4).

No toxicity relative to controls was observed in ambient water samples collected from any of the RMP stations during the three sampling periods (Figure 25).



**Table 19.  $R^2$  values for regression of salinity (Sal), total suspended solids (TSS) and dissolved organic carbon (DOC) against dissolved and total pesticide concentrations in the first sampling period.  $R^2$  is the proportion of the variation of dissolved or total pesticides that is explained by each of the water parameters and combinations of them listed.**

1. Dissolved Pesticides  
n = 11

	March
Sal	.033
TSS	.117
DOC	.070
Best multi-parameter model	Sal, TSS, DOC .188

2. Total Pesticides  
n = 11

	March
Sal	.115
TSS	.256
DOC	.098
Dissolved pesticides (dPest)	.957
Best multi-parameter model	TSS, dPest .99

However, ambient waters enhanced growth of *Thalassiosira* relative to controls (t-test,  $p < 0.05$ ), at nearly every station during every sampling period. Exceptions to this pattern were the San Joaquin River station (BG30) during the second and third sampling periods and the Sacramento River station (BG20) during the third sampling period (Figure 25). The cause of enhanced growth in ambient waters is not known.

The results of the bivalve test at Napa River (BD50) and Pinole Point (BD30) in March, and of the *Thalassiosira* tests at Napa River (BD50) and Pinole Point (BD30) in May were inconclusive, based on results of the reference toxicant tests. In these cases  $EC_{25}$  and  $EC_{50}$  values calculated from the reference toxicant test results were abnormally high, indicating relative insensitivity of test organisms (see Appendix Table 3.4).

Coefficients of variation (CV) provide a measure of the precision of toxicity tests, with values less than 0.5

indicating acceptable test precision. Separate CV's were calculated for  $EC_{50}$  and  $EC_{25}$  values for each species (Appendix Table 3.4). Data for each of the test endpoints were pooled, despite differences in test salinities and control water, as data are too limited, at this time, to calculate separate CV's for each test condition.

The CV values indicate that the precision of the bivalve larvae tests was considerably better than the precision of the unicellular alga test. Largely due to the relatively high CV values for the unicellular algae (0.71 for  $EC_{50}$  values and 0.57 for  $EC_{25}$  values), *Thalassiosira* is not being used in the 1994 RMP.

## River Monitoring

Water samples were collected upstream in the Sacramento and San Joaquin Rivers six times between April 30 and June 10, 1993, in order to characterize contami-

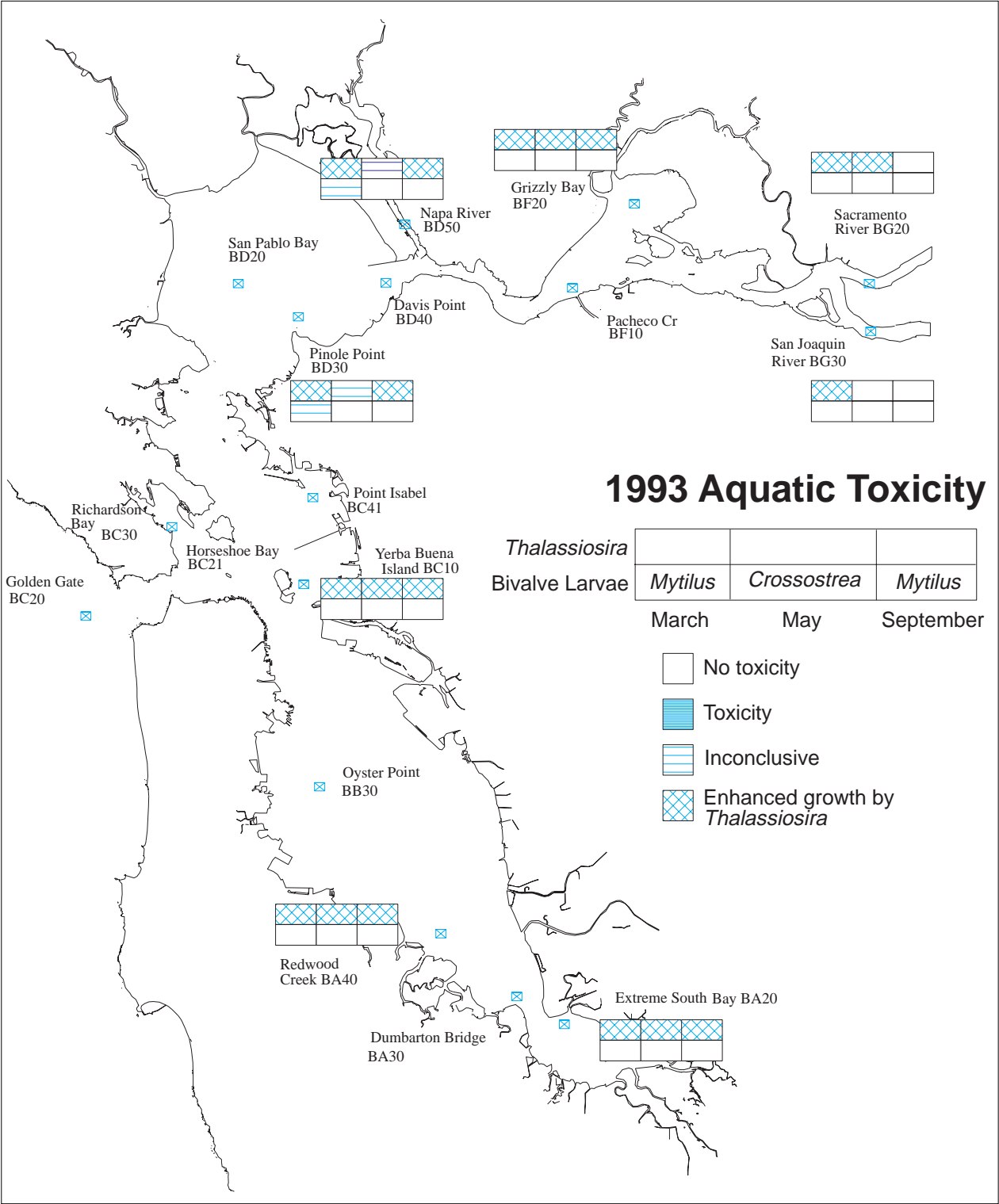


Figure 25. Results of aquatic toxicity testing for eight RMP station locations.

nant concentrations in the rivers. However, it should be noted that the concentrations measured during the river sampling are not necessarily representative of conditions throughout the year. For example, the figures in *Summary of the Sacramento Coordinated Monitoring Program*, included in this report, show higher concentrations of nickel and copper during high-flow periods.

Water samples were analyzed for 11 trace elements as well as conventional water quality parameters, including measurements of nutrients, primary productivity, dissolved oxygen, pH, and total suspended solids (TSS) (Appendix Tables 2.8, 2.9, and 2.10).

Two locations on the Sacramento and three locations on the San Joaquin were sampled (Figure 26). The sampling location on the Sacramento was moved downstream from Freeport to Rio Vista after the first three sampling events. On the San Joaquin, the sampling location was moved upstream from Stockton to Vernalis after the first three sampling events, and then to Manteca after the fourth sampling period. The changes in sampling location limit the comparability of the data, due to differences in the proximity of point sources, degree of tidal influence, and the relative position of diversions to each sampling station.

In the San Joaquin River, flows decreased over the six week sampling period from 4600 to 2400 cfs (Figure 27). Flows in the Sacramento River were an order of magnitude higher, and increased dramatically between the fourth and fifth sampling event. During the river sampling period, Delta outflows were about half the magnitude of peak outflows which occurred earlier in the year, but were considerably higher than the low flows later in the summer (Figure 2).

Plots of total or near-total and dissolved metals versus time for the San Joaquin and Sacramento rivers are shown in Figure 28 for ten trace metals (cyanide was always below the detection limit of 1.0 ppb). In general, concentrations in both rivers were rather consistent over the sampling period. For chromium, copper, lead, mercury, nickel, silver, and zinc, total or near-total concentrations were more variable and considerably higher than dissolved concentrations. For arsenic and selenium, dissolved concentrations were close to total concentrations, and there was more of a difference between concentrations in the two rivers than between dissolved and totals.

Mean concentrations were generally higher in the San Joaquin than in the Sacramento River in all cases except for near-total and dissolved cadmium and dissolved chromium.

The plots suggest that temporal (confounded by spatial) variability in each river was greater than the difference between the two rivers. In particular, on the San Joaquin River, concentrations of most substances increased substantially during the fourth sampling event, which was also the only sampling at Vernalis, the furthest upstream station. In general, concentrations appeared to decrease going downstream (highest at Vernalis, intermediate at Manteca and lowest at Stockton), however, since concurrent sampling never occurred, it is impossible to distinguish whether the observed differences are due to location or temporal variability.

Due to the substantial tidal influence at Rio Vista, samples taken at that location were not good indicators of contaminant levels coming into the Estuary from the Sacramento River. The influence of tidal currents on flow ranges from plus or minus 7,000 cfs at Freeport to plus or minus 350,000 cfs at Chipps Island (IESP 1993). At Rio Vista, the influence of the tides on flow is estimated at plus or minus 250,000 cfs (Larry Smith, USGS, personal communication), which is an order of magnitude greater than the flows in the Sacramento River during the sampling period (Figure 27).

In the San Joaquin River, there was a significant negative correlation between flow and total (or near-total) metal concentrations (Table 20) for all metals except arsenic, selenium and silver, suggesting that increased flows may decrease concentration through dilution. However, for dissolved metals (Table 21), the only significant and positive correlation was for zinc indicating that concentrations increased with increasing flow. Spatial variability may have obscured any relationship between flow and concentration, since the flow measurements were all from Vernalis, and sampling for metals took place at three distinct locations.

TSS concentrations ranged from 18 to 31 ppm in the Sacramento River (Freeport) and from 21 to 73 ppm in the San Joaquin River during the sampling period. For comparison, TSS in the Estuary samples ranged from 0 to 191 ppm over the three sampling periods. As with the Estuary sampling, TSS accounted for much of the varia-

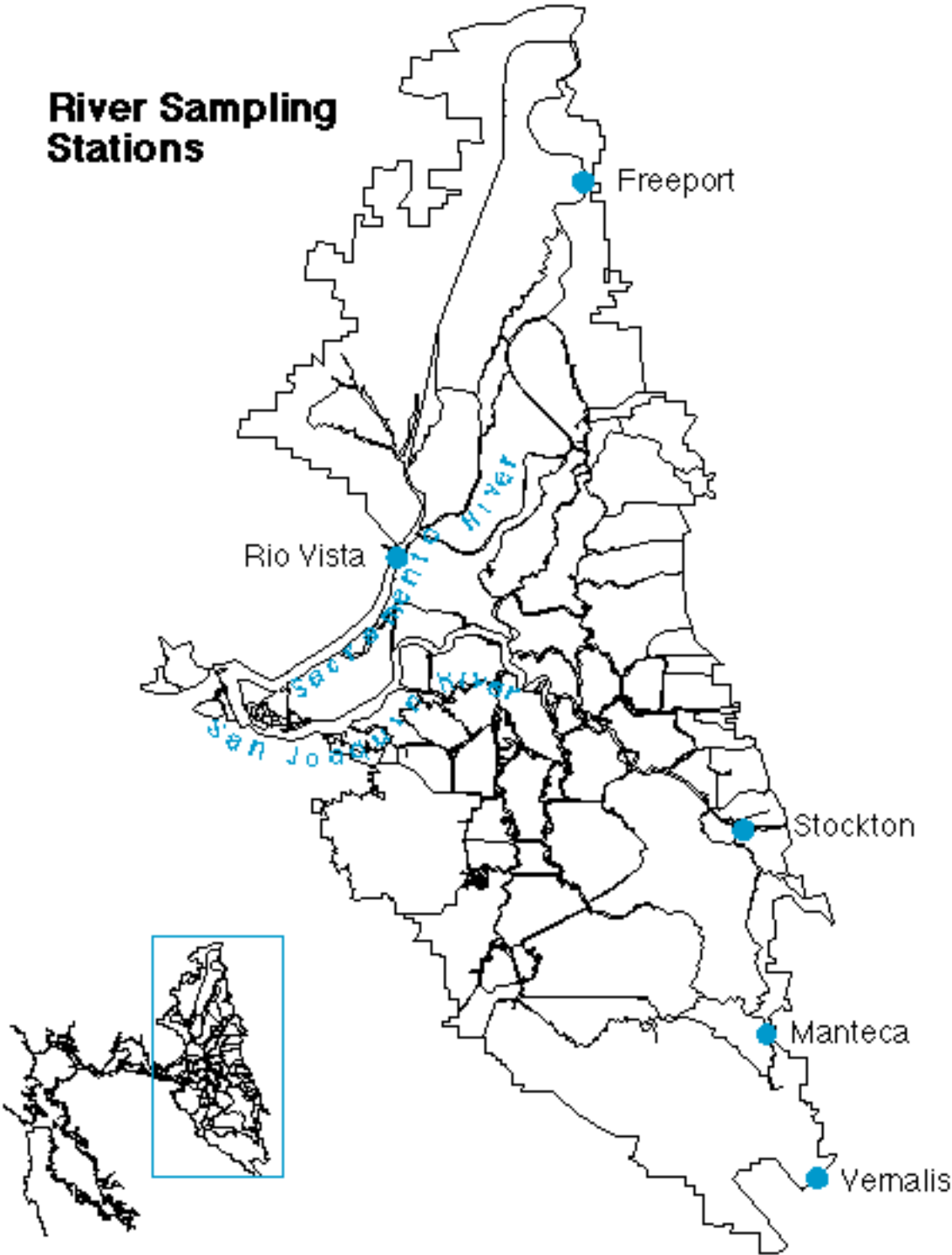
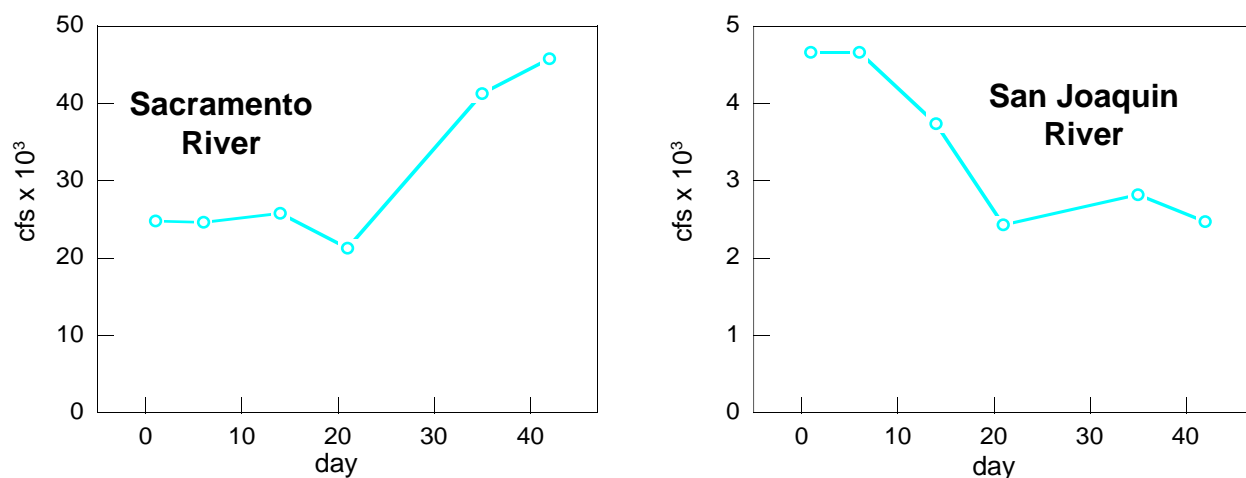


Figure 26. Locations of RMP river sampling stations.



**Figure 27. Flows in thousands of cubic feet per second for the Sacramento and San Joaquin Rivers on the days when RMP river sampling was conducted.** Day 1 = April 30, 1993. (Flow data courtesy of Department of Water Resources).

tion in total metals concentrations. For the San Joaquin samples, there were significant positive correlations between total (near-total) metals and TSS for cadmium, chromium, copper, lead, mercury, nickel, silver and zinc (Table 20).

Correlation coefficients between dissolved metals and DOC in the San Joaquin River were greater than 0.50 for arsenic, cadmium, copper, nickel, and zinc (Table 21). These relationships were not significant, based on the sample size ( $n=5$ ).

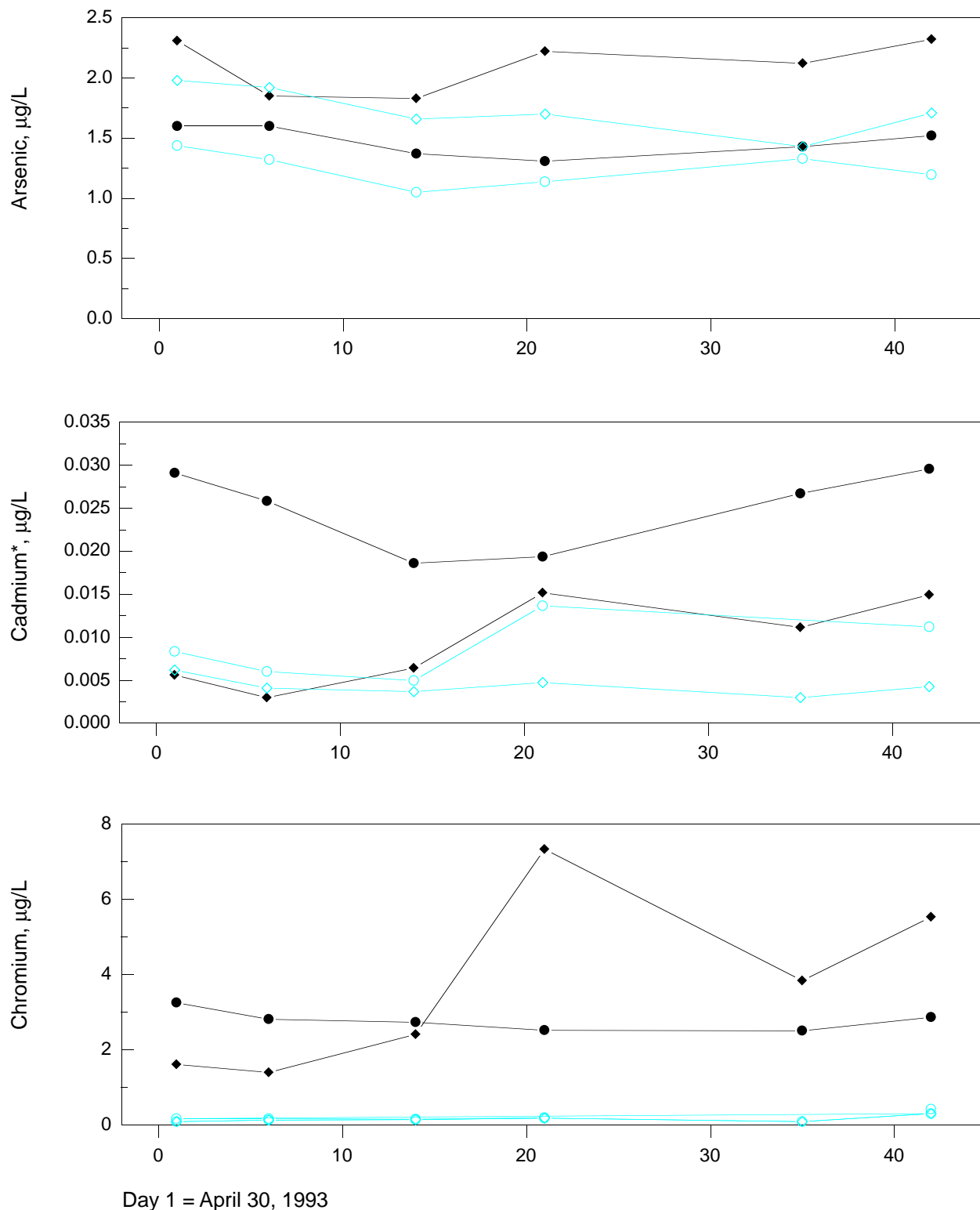
Correlation coefficients were not calculated for the Sacramento River due to the small sample size for samples taken at Freeport ( $n=3$ ).

Mean concentrations for each river were compared to concentrations measured in May at the respective River stations of the Estuary-wide sampling (BG20 or BG30) (Table 22). Results were, for the most part, the same order-of-magnitude. However, concentrations at the Sacramento River confluence station (BG20) were higher than concentrations at Freeport for dissolved cadmium, chromium, copper, nickel, lead, silver, and zinc, total chromium and near-total silver. Concentrations at the San Joaquin River confluence station (BG30) were higher than the upstream San Joaquin samples for dissolved and near-total cadmium, dissolved chromium, dissolved and near-total copper, and dissolved and near-total silver. Dis-

solved and total arsenic, dissolved nickel and mercury, and dissolved and total selenium were higher at the upstream San Joaquin stations than at the river confluence station. The greatest discrepancy in concentrations on both rivers were for silver, where mean near-total concentrations in the upstream river samples was an order-of-magnitude lower than concentrations at the river stations of the Estuary-wide sampling.

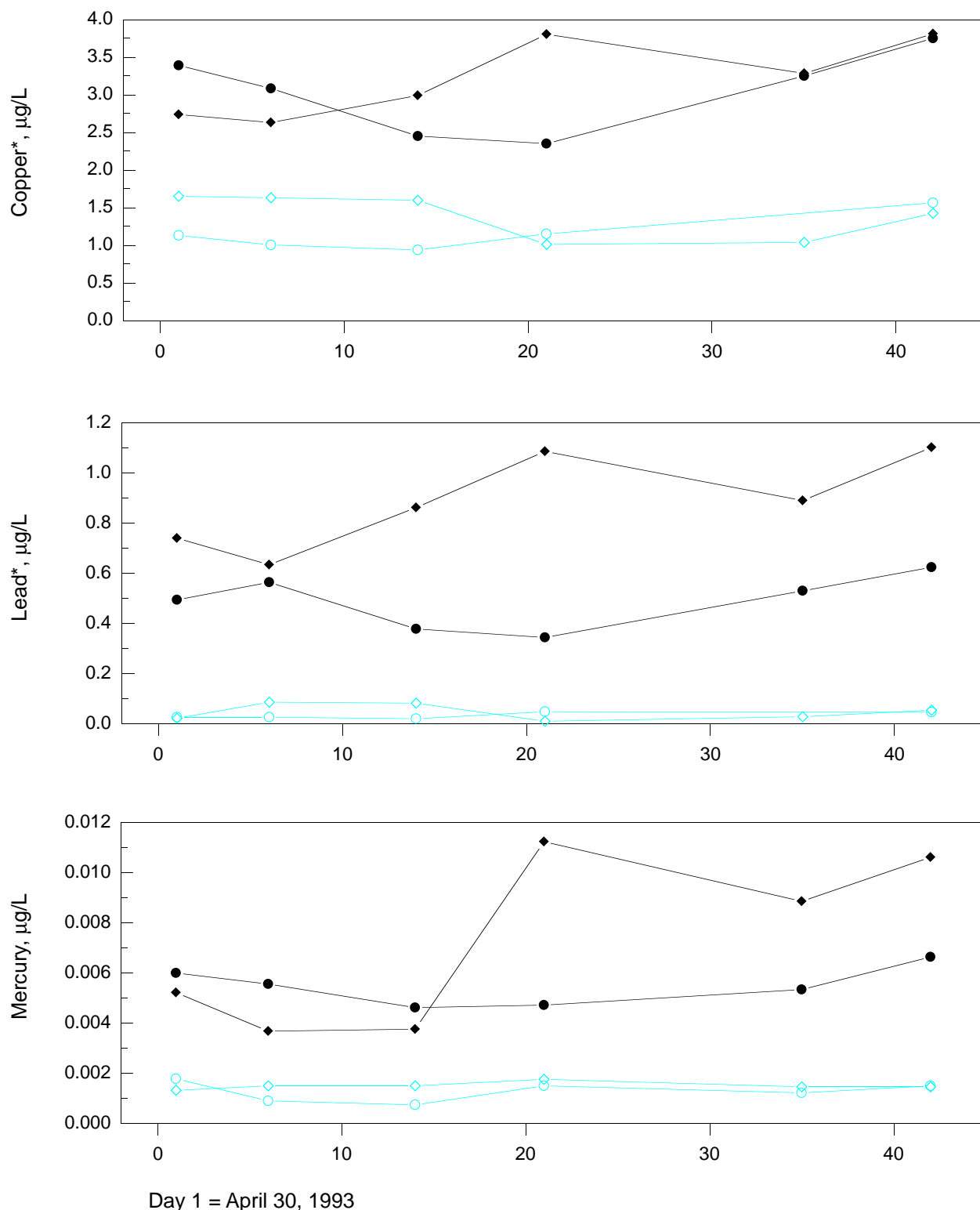


## Metal in Rivers 1993



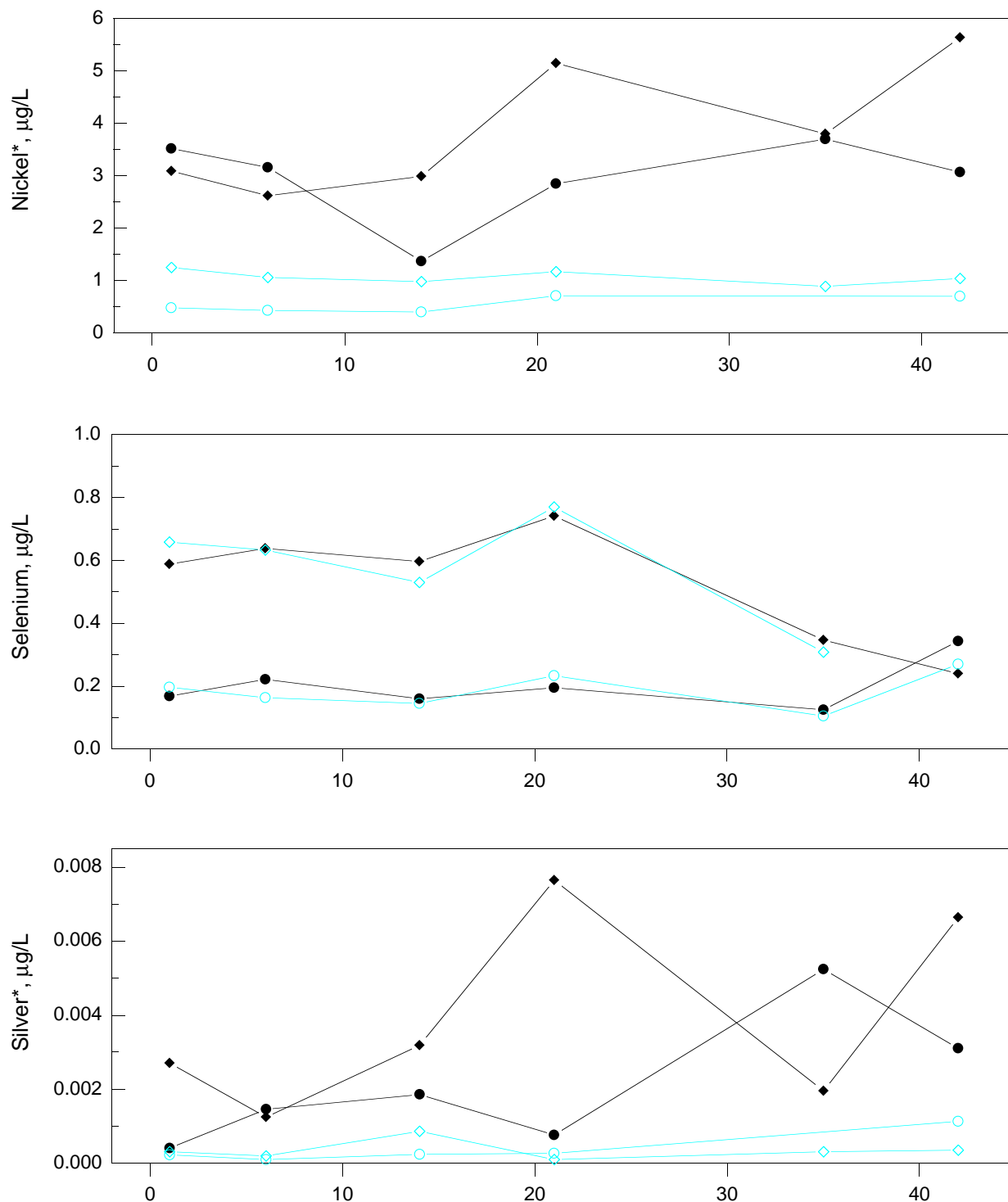
**Figure 28. (page 1 of 4). Dissolved and total concentrations (or near-totals = \*) of ten trace metals in the Sacramento and San Joaquin Rivers over the period April 30 to June 10, 1993. Concentrations are in parts per billion (ppb).**

## Metal in Rivers 1993

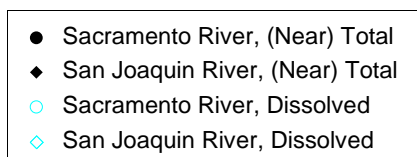


**Figure 28. (page 2 of 4). Dissolved and total concentrations (or near-totals = \*) of ten trace metals in the Sacramento and San Joaquin Rivers over the period April 30 to June 10, 1993. Concentrations are in parts per billion (ppb).**

## Metal in Rivers 1993



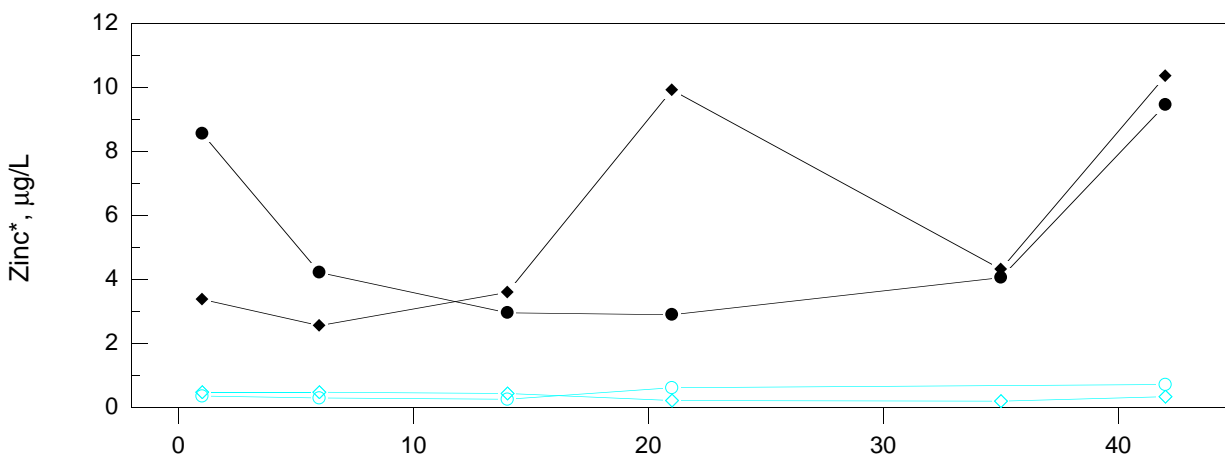
Day 1 = April 30, 1993



**Figure 28. (page 3 of 4). Dissolved and total concentrations (or near-totals = \*) of ten trace metals in the Sacramento and San Joaquin Rivers over the period April 30 to June 10, 1993. Concentrations are in parts per billion (ppb).**



## Metal in Rivers 1993



Day 1 = April 30, 1993

- Sacramento River, (Near) Total
- ◆ San Joaquin River, (Near) Total
- Sacramento River, Dissolved
- ◇ San Joaquin River, Dissolved

**Figure 28. (page 4 of 4). Dissolved and total concentrations (or near-totals = \*) of ten trace metals in the Sacramento and San Joaquin Rivers over the period April 30 to June 10, 1993. Concentrations are in parts per billion (ppb).**

**Table 20. Pearson correlation coefficients of total (or near-total) metals concentrations with flow and total suspended solids (TSS) for San Joaquin River samples. Asterisk (\*) indicates a significant correlation,  $\alpha = 0.05$ .**

	Flow n=6	TSS n=6
Arsenic	-0.417	0.532
Cadmium	-0.961*	0.978*
Chromium	-0.918*	0.951*
Copper	-0.962*	0.997*
Lead	-0.940*	0.978*
Mercury	-0.906*	0.927*
Nickel	-0.884*	0.976*
Selenium	0.408	-0.373
Silver	-0.744	0.885*
Zinc	-0.836*	0.959*

**Table 21. Pearson correlation coefficients of dissolved metals with flow and dissolved organic carbon (DOC) for San Joaquin River samples. Asterisk (\*) indicates a significant correlation,  $\alpha = 0.05$ .**

	Flow n=6	DOC n=5
Arsenic	0.732	0.781
Cadmium	0.393	0.808
Chromium	-0.613	-0.490
Copper	0.807	0.599
Lead	0.421	-0.245
Mercury	-0.563	-0.842
Nickel	0.342	0.629
Selenium	0.169	-0.106
Silver	0.147	-0.220
Zinc	0.860*	0.617

**Table 22. Comparison of mean concentrations of metals in Sacramento (Freeport only) and San Joaquin River samples to concentration at river stations (BG20 and BG30) of Estuary-wide sampling in May, 1993.** Results of upstream river sampling are presented as a mean  $\pm$  95% confidence interval ( $\bar{x} \pm CI$ ). Asterisk(\*) indicates that the concentration at BG20 or BG30 was outside the 95% confidence interval for the upstream sampling on that river. T in front of the symbol for each element indicates total (or near-total). The element symbol alone indicates “dissolved”. Concentrations are in parts per billion (ppb) or parts per trillion (ppt) as indicated.

		Sacramento River				San Joaquin River			
		$\bar{x} \pm CI$		BG20		$\bar{x} \pm CI$		BG30	
As,	ppb	1.27	$\pm$ 0.50	1.39		1.73	$\pm$ 0.21	1.41	*
TAs,	ppb	1.52	$\pm$ 0.33	1.37		2.11	$\pm$ 0.23	1.71	*
Cd,	ppt	6.43	$\pm$ 4.25	12.68	*	4.32	$\pm$ 1.13	7.22	*
TCd,	ppt	24.5	$\pm$ 13.3	30.9		9.38	$\pm$ 5.37	26.9	*
Cr,	ppt	0.17	$\pm$ 0.004	0.235	*	0.16	$\pm$ 0.08	0.285	*
TCr,	ppt	2.94	$\pm$ 0.70	3.68	*	3.69	$\pm$ 2.48	4.81	
Cu,	ppb	1.03	$\pm$ 0.25	1.38	*	1.39	$\pm$ 0.31	1.705	*
TCu,	ppb	2.98	$\pm$ 1.20	3.35		3.2	$\pm$ 0.54	3.90	*
Ni,	ppb	0.44	$\pm$ 0.10	0.72	*	1.7	$\pm$ 0.14	0.685	*
TNi,	ppb	2.68	$\pm$ 2.87	3.20		3.88	$\pm$ 1.30	3.38	
Pb,	ppt	23.64	$\pm$ 10.32	48.4	*	46.8	$\pm$ 33.8	62.27	
TPb,	ppt	477	$\pm$ 233	528		885	$\pm$ 195	788	
Hg,	ppt	1.15	$\pm$ 1.40	1.17		1.51	$\pm$ 0.15	1.31	*
THg,	ppt	5.39	$\pm$ 1.75	5.95		7.24	$\pm$ 3.60	8.13	
Se,	ppb	0.17	$\pm$ 0.07	0.118		0.58	$\pm$ 0.20	0.149	*
TSe,	ppb	0.18	$\pm$ 0.08	0.153		0.53	$\pm$ 0.20	0.204	*
Ag,	ppt	0.19	$\pm$ 0.21	0.89	*	0.36	$\pm$ 0.28	1.27	*
TAg,	ppt	1.24	$\pm$ 1.85	56.6	*	3.90	$\pm$ 2.75	44	*
Zn,	ppb	0.30	$\pm$ 0.12	0.494	*	0.35	$\pm$ 0.13	0.309	
TZn,	ppb	5.24	$\pm$ 7.30	5.00		5.68	$\pm$ 3.66	5.41	



*Preparing to deploy the CTD (conductivity, temperature, depth) instrument*



*Cleaning the sediment sampler between sites*

# Sediment Monitoring

A full complement of sediment measurements were made on samples collected from all 16 RMP stations during the wet (March) and dry (September) sampling periods. No sediment was collected from the Golden Gate station because of sampling difficulties. Instead, a station adjacent to the Golden Gate at Horseshoe Bay (BC21) was established for sediments.

Sediment parameters measured include sediment quality (sediment grain-size, organic content, etc.), trace elements, and trace organic contaminants. The parameters measured are listed on Tables 3,4, and 5, and are described fully in the subsequent sections.

The relationships of 4 trace elements (copper, mercury, nickel, selenium), and three types of trace organics (PAHs, PCBs, pesticides) to sediment type will be examined in detail as examples of how different contaminants are related to sediment type and to facilitate interpretation of sediment metals concentrations.

Regression analysis was used to evaluate the relationships between trace metals concentrations and sediment type. This analysis indicates how much of the variation in the sediment contaminant concentrations was attributable to various sediment quality parameters (percent fine, TOC, etc.).

There are currently no Basin Plan objectives or other regulatory criteria for sediment contaminant concentrations in the Estuary. As a guide to interpretation of sediment contaminant concentrations, Effects Range-Median (ERM) values are used (Long and Morgan 1990, Long *et al.* 1993). These values are based on data compiled from numerous studies (modelling, laboratory, and field 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 effects. The assumption of the approach is that if enough data are accumulated, a pattern of increasing incidence of biological effects should emerge with increasing contaminant concentrations. For ERM values, incidences of effects were greater than 75%, and occasionally 100%, at concentrations above the ERM values. However, relatively weak relationships between concentrations and effect were identified for mercury, nickel, PCBs, and DDTs.

Concentrations above the ERM values are interpreted to indicate “probable effects” at those concentrations. The ERM guidelines generally agree within a factor of 3 with guidelines developed using other methods (e.g. EPA draft sediment criteria).

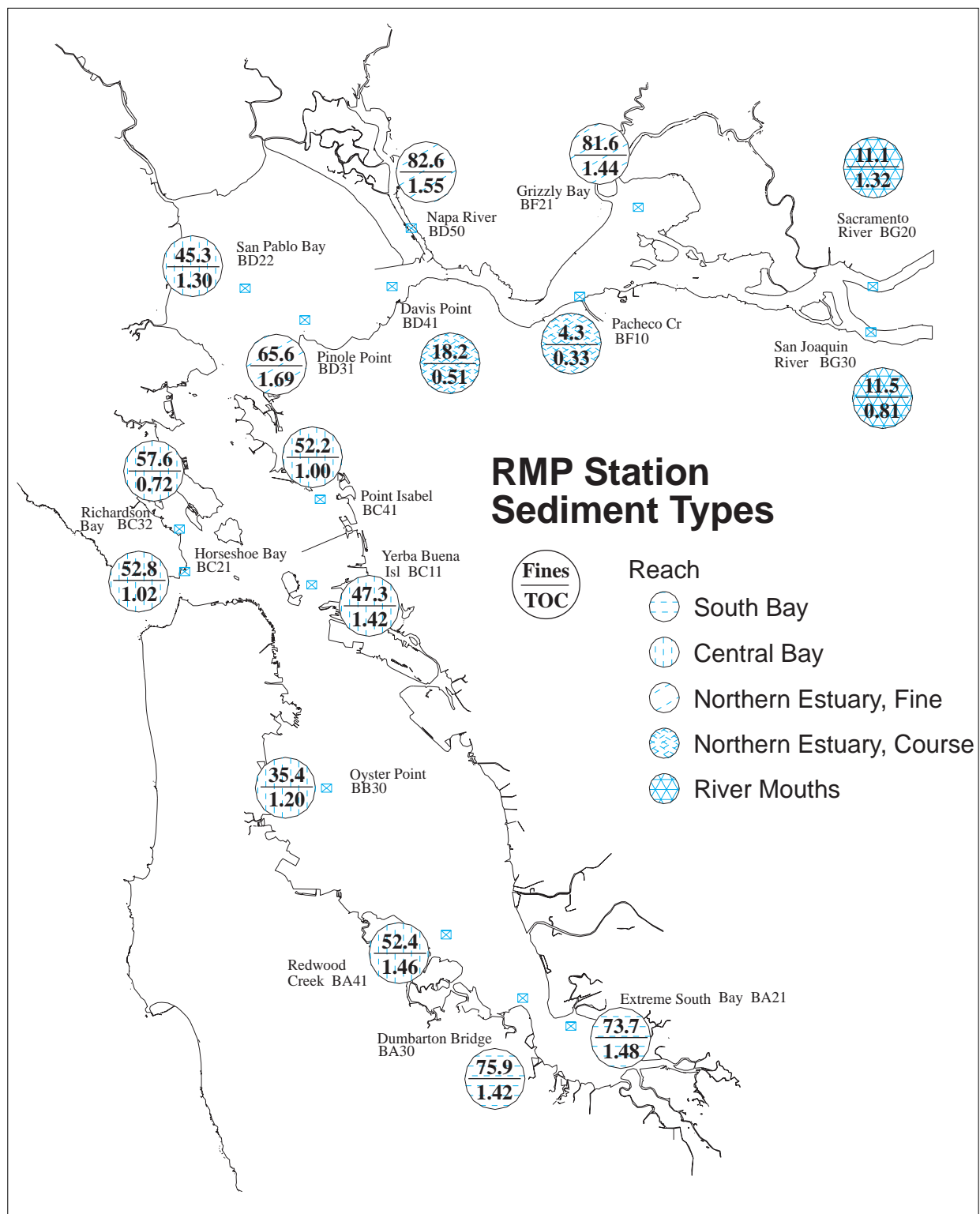
The guidelines are intended to be used as informal screening tools in environmental assessments. Thus, in this report, ERM guidelines are used as a guide to evaluate the RMP sediment data. ERMs hold no regulatory meaning. Research to date neither supports nor disproves any of these values for the San Francisco Estuary.

## Sediment Quality Parameters

Understanding the patterns of sediment contaminant concentrations at the RMP stations requires knowledge of the type of sediment at each station sampled. Trace contaminant concentrations vary naturally depending on sediment grain-size, organic content, and reduction-oxidation characteristics, and it is necessary to account for this variation when comparing concentrations throughout the Estuary.

Sediment quality measurements included percent fine sediments (<63  $\mu\text{m}$  dia.), percent total organic carbon (TOC), total nitrogen (TN), and reduction-oxidation potential (Eh). Cluster analysis of sediment characteristics (percent fines and TOC) at the RMP sites identified 5 groups of RMP stations. The stations in each group had similar sediment characteristics (Figure 29). Since these groupings also reflect geographic areas of the Estuary, they are termed “reaches” in this section of the report. However, it is important to note that these reaches are only based on data from the RMP stations and may not be representative of the entire geographic area of which they are a part. There may be considerable variation in sediment types at other unsampled locations in the same geographic area as the reaches used herein.

The reaches are: the two South Bay stations (BA21 and BA30) with fine-grained sediments (71-77% fines) and moderately high organic content (TOC=1.41-1.50%), the Central Bay stations with moderate grain-size (27-67% fines) and TOC content (0.5-1.62%), except for sta-



**Figure 29. Sediment types at the RMP stations based on annual average percentages of fines and TOC at each station.** Estuary reaches shown were determined using cluster analysis and are used in evaluating spatial differences in sediment contaminant concentrations.

**Table 23. Means and coefficients of variation (CV) for several sediment parameters, n=2 sampling periods.** Percent sand is >62µm dia, percent fines is <63µm dia, C:N is ratio of TOC: TN, all units, except C:N, are percent dry weight.

Station Number	Station Name	Water Depth (m)	Percent Sand		Percent Fines		TOC		TN		C:N	
			Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
BA21	Extreme South Bay	5.5	26.2	10.5	73.7	3.7	1.48	1.9	0.182	21.0	8.3	19.1
BA30	Dumbarton Bridge	7.0	24.1	8.2	75.9	2.6	1.42	1.0	0.173	12.3	8.3	11.3
BA41	Redwood Creek	2.5	47.6	10.4	52.4	9.4	1.46	16.0	0.164	13.8	9.1	29.5
BB30	Oyster Point	9.0	64.6	2.0	35.4	3.6	1.20	21.2	0.115	30.7	11.3	50.3
BC11	Yerba Buena Island	6.0	52.7	13.1	47.3	14.6	1.42	19.9	0.146	2.4	9.7	17.5
BC21	Horseshoe Bay	39.0	47.2	76.1	52.8	68.1	1.02	72.1	0.143	38.2	6.7	39.3
BC32	Richardson Bay	1.0	42.4	6.2	57.6	4.5	0.72	43.2	0.094	11.3	7.6	32.7
BC41	Point Isabel	1.5	47.8	45.6	52.2	41.9	1.00	3.6	0.119	8.3	8.4	4.8
BD22	San Pablo Bay	3.0	54.7	40.7	45.3	49.2	1.31	1.6	0.137	11.9	9.6	13.5
BD31	Pinole Point	6.5	34.4	1.1	65.6	0.6	1.69	14.7	0.150	16.6	11.6	30.9
BD41	Davis Point	6.5	81.8	3.5	18.2	15.7	0.51	1.4	0.065	23.9	8.0	25.3
BD50	Napa River	4.0	17.4	39.4	82.6	8.3	1.55	0.0	0.166	3.4	9.3	3.4
BF10	Pacheco Creek	4.0	95.7	1.0	4.3	23.0	0.33	72.9	0.028	50.5	11.0	27.4
BF21	Grizzly Bay	3.0	18.4	70.8	81.6	16.0	1.44	4.9	0.143	5.5	10.1	0.5
BG20	Sacramento River	8.0	88.9	9.7	11.1	77.7	1.32	87.9	0.085	56.1	14.0	42.2
BG30	San Joaquin River	5.0	88.5	10.4	11.5	79.9	0.81	54.1	0.066	17.1	11.9	38.8

tion BC21 in March which had finer sediments (that station was relocated during the September sampling period in order to obtain a sample more easily). The northern estuary composed 2 very different reaches: a fine sediment reach (fines=65-90%; TOC=1.39-1.86%), and a coarse sediment, low TOC reach (fines=3-20%; TOC=0.16-0.51%). The stations at the mouths of the Sacramento and San Joaquin Rivers had coarse grained sediments (fines=<5-18%; TOC=0.5-2.14%).

Averages and coefficients of variation for all of the sediment quality parameters measured are shown on Table 23. The ratio of TOC to TN (C:N) provides a measure of the quality of organic material; higher values indicate more degraded or refractory organic material and

lower values indicate more labile or fresh sources of organic material. Data is listed in Appendix Table 2.11.

Correlations between the sediment quality parameters measured are shown on Table 24. Fine sediments generally contained higher concentrations of organic material. TOC and TON were significantly correlated, but Eh was not significantly correlated with either grain-size or organic content. Eh was significantly correlated with pH.

The South Bay and northern estuary fine sediment reaches had similar sediment types with higher percent fines than the other reaches. Similarly, the northern estuary coarse sediment stations and the river stations were similar, with lower percentages of fine sediment than the

**Table 24. Product moment correlation coefficients (r) for sediment characteristics.** n=16, r>.62 is significant at  $\alpha=.01$ \*, r>.50 is significant at  $\alpha=.05$ .

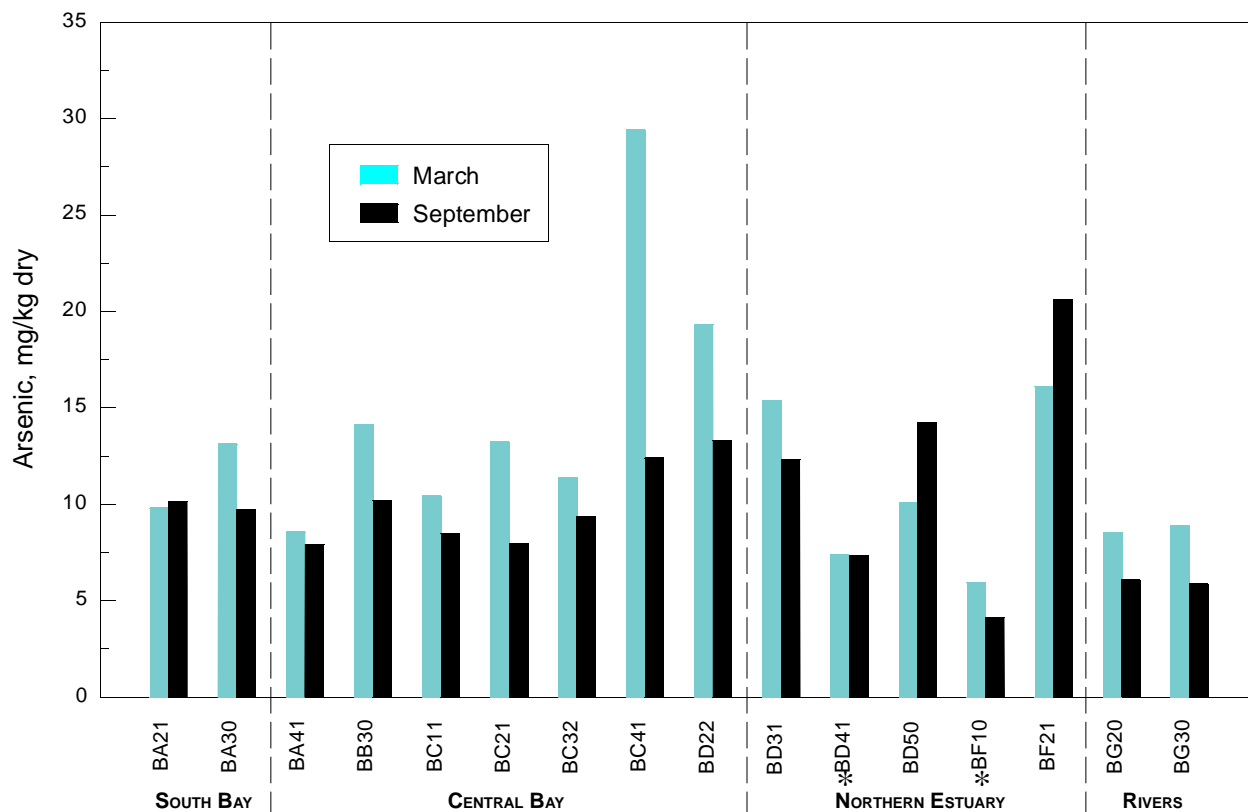
	<u>Fine</u>		<u>TOC</u>		<u>TN</u>		<u>Eh</u>	
	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept
FINE								
TOC	.40	.88*						
TN	.80*	.88*	.76*	.92*				
Eh	.14	.28	.34	.19	.23	.15		
pH	-.26	—	.12	—	-.10	—	-.83*	—

**Table 25. Product moment correlation coefficients (r) for sediment characteristics and trace metal concentrations.** n=16, r>.62 is significant at  $\alpha=.01$ \*, r>.50 is significant at  $\alpha=.05$ .

Trace Metals	<u>Sediment Characteristics</u>							
	<u>Fine</u>		<u>TOC</u>		<u>TN</u>		<u>Eh</u>	
	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept
Ag	.34	.79*	.34	.82*	.91*	.48	-.35	-.001
As	.41	.71*	.41	.66*	.52	.24	.20	.56
Cd	.24	.56	.24	.49	.30	.27	.18	.30
Cr	.72*	.62	.72*	.58	.46	.49	.03	.32
Cu	.75*	.80*	.75*	.80*	.63*	.67*	-.02	.36
Hg	.38	.94*	.38	.92*	.92*	.34	-.07	.18
Ni	.57	.54	.57	.59	.38	.47	.02	.32
Pb	.76*	.86*	.76*	.78*	.79*	.74*	-.26	-.16
Se	.38	.57	.39	.56	.34	.71*	.06	.60
Zn	.79*	.84*	.79*	.84*	.72*	.68*	-.14	.29



## Arsenic in Sediment 1993



**Figure 30. Total arsenic concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \* indicates northern estuary coarse sediment station**

other reaches. There was no obvious difference in fines at the RMP stations between the 2 sampling periods.

## Trace Elements in Sediments

Concentrations of 10 trace metals were measured at each RMP station (Table 4). In addition, aluminum, cobalt, iron, manganese, and vanadium were measured at each station in March, and aluminum was measured in September. Concentrations of those metals will not be presented in this portion of the report, but are listed in Appendix Table 2.12.

Concentrations of cadmium, copper, chromium, nickel, lead, silver, and zinc were measured as 'near-total' concentrations rather than total extractable concentrations. Arsenic, mercury, and selenium were measured

as total extractable concentrations (see Methods for discussion).

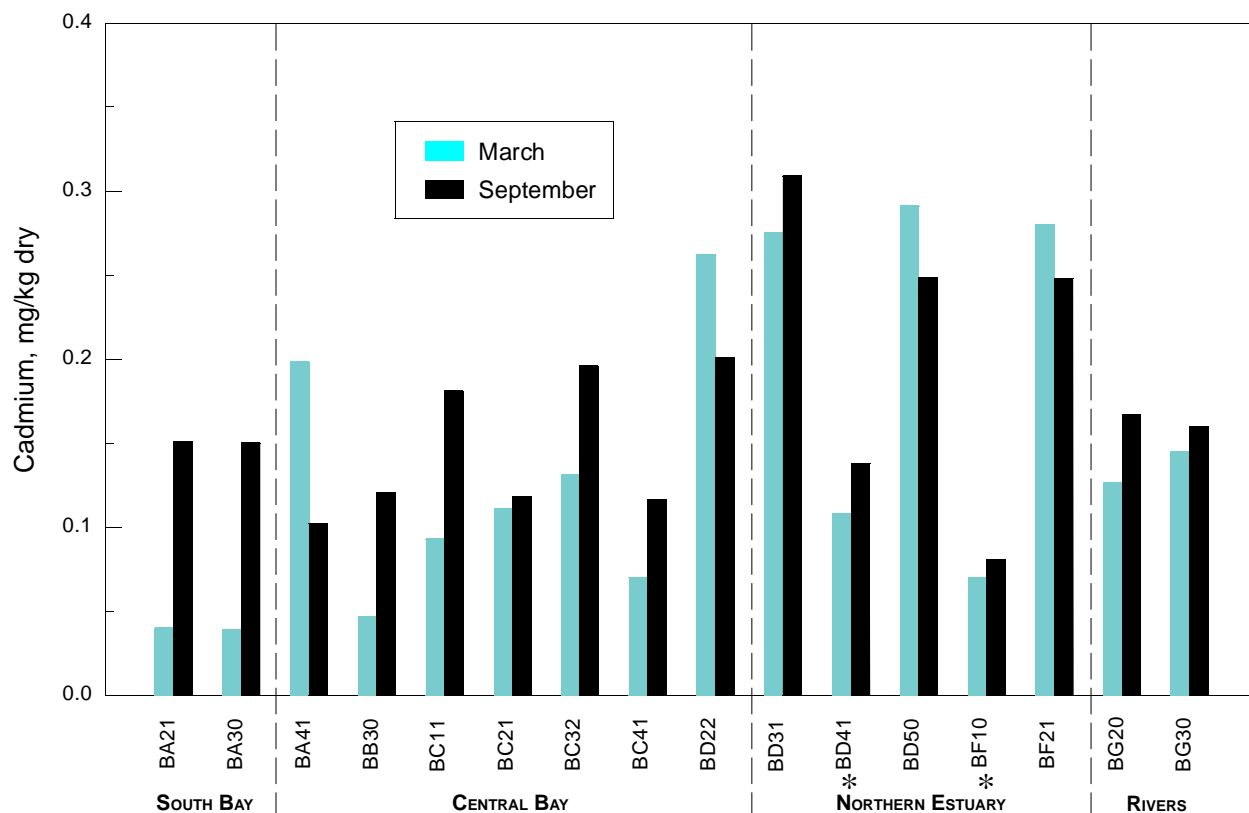
## Arsenic

Arsenic (As) concentrations in San Francisco Estuary ranged between 4.2 and 29.4 parts per million (ppm) (Figure 30). Concentrations were highest at Pt. Isabel (BC41) in March, and at Grizzly Bay (BF21) in September. The lowest concentration was at Pacheco Creek (BF10) in September.

Average arsenic concentrations were higher at the northern estuary fine sediment stations than at other reaches. Arsenic levels were higher in March than in September.

Arsenic concentrations were directly related to sediment type; the highest concentrations were measured at stations with the finest sediments. However, concentra-

## Cadmium in Sediment 1993



**Figure 31. Near-total cadmium concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \*indicates northern estuary coarse sediment stations**

tions were only significantly correlated to fines and TOC in the September samples (Table 25). Together, fines and TOC accounted for only about 18% of the variation in arsenic concentrations in March, and about 51%, in September (regression analysis). The reasons for these seasonal differences are not known.

All arsenic concentrations were below the ERM value of 70 ppm.

### Cadmium

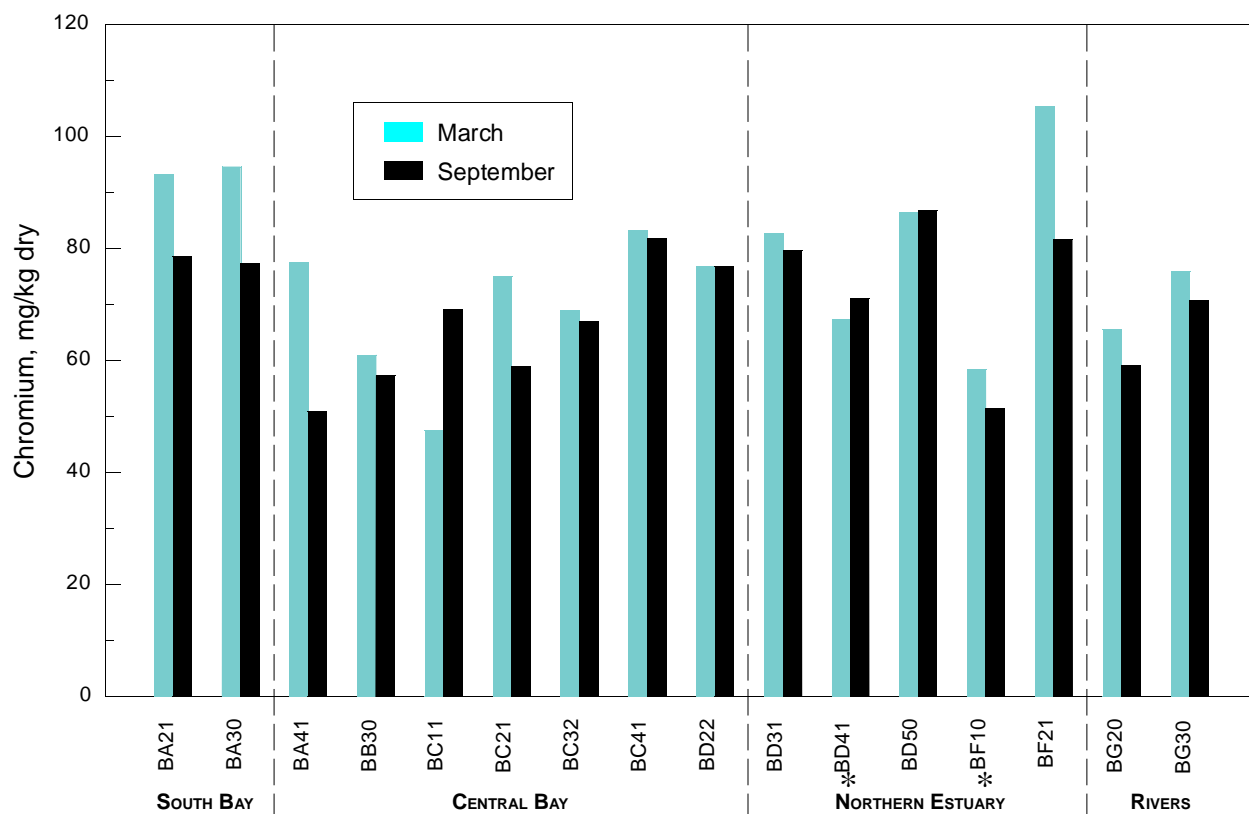
Concentrations of cadmium (Cd) in sediments at the RMP stations ranged between 0.04 and 0.31 ppm (Figure 31). The highest concentrations occurred in the Napa River (BD50) in March, and at Pinole Pt. (BD31) in September. The lowest concentrations were measured at the South Bay sites in March.

On average, the northern estuary fine sediment stations had higher cadmium concentrations than the other reaches. Cadmium concentrations were usually higher in September than in the March samples.

Cadmium in sediment was directly related to sediment type. However, cadmium was not significantly correlated to any sediment parameter except fines in September (Table 25). Fines and TOC accounted for only 13% of the variance in cadmium in March, and for 31% of the variation in September (regression analysis). Causes of these poor correlations to sediment type are not known.

None of the stations had cadmium concentrations above the ERM of 9.6 ppm.

## Chromium in Sediment 1993



**Figure 32. Near-total chromium concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \*indicates northern estuary coarse sediment stations**

### Chromium

Chromium (Cr) concentrations in sediment at the RMP ranged between 47.5 and 105.3 ppm (Figure 32). The highest concentrations were measured in Grizzly Bay (BF21) in March, and in the Napa River (BD50) in September. The lowest concentrations were measured at Yerba Buena Is. (BC11) in March.

Average chromium concentrations were higher at the northern estuary fine-sediment stations and at the South Bay stations than at the other reaches. Concentrations were usually higher in March than in September.

Chromium concentrations were directly related to sediment types. Chromium was significantly correlated with fines and TOC during both sampling periods (Table 25). Fines and TOC together accounted for 53% of the variation in chromium in March, and 39% in September (regression analysis).

Chromium concentrations at all RMP stations were below the ERM value of 370 ppm.

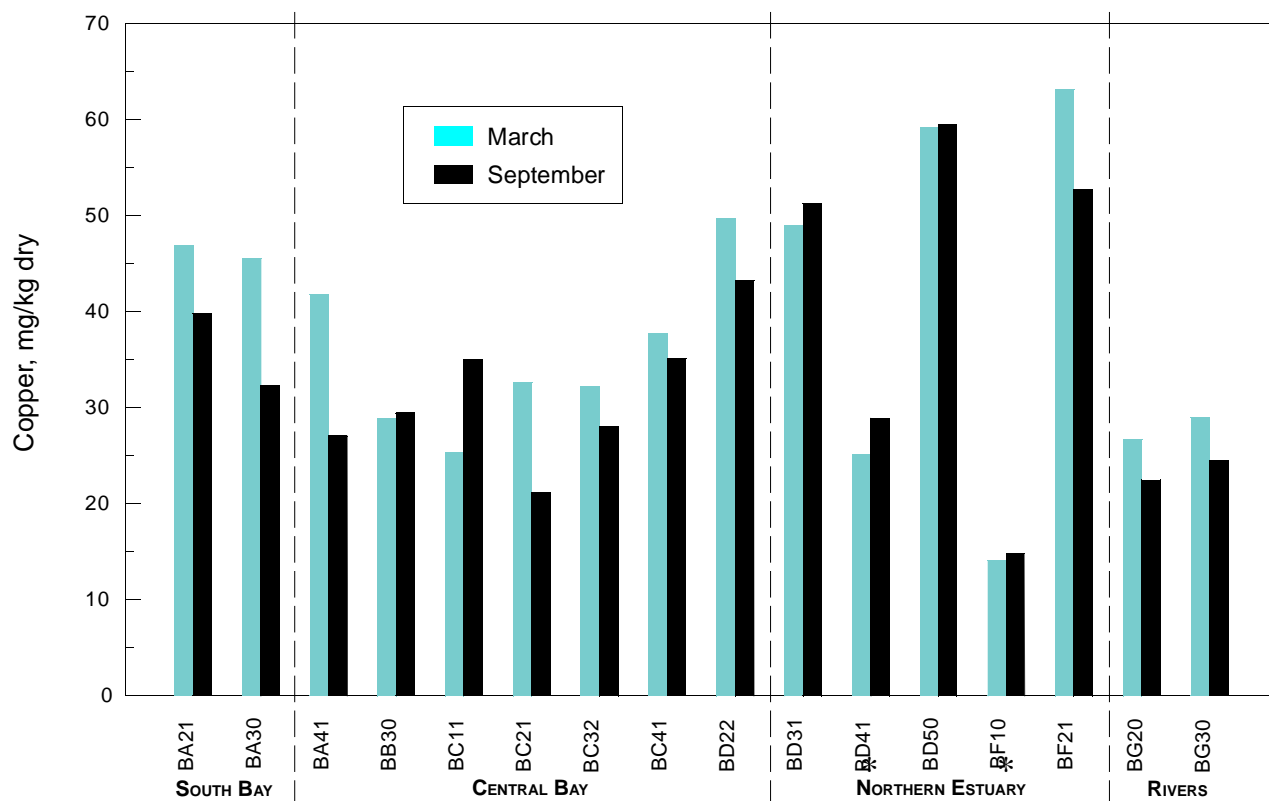
### Copper

Copper (Cu) concentrations in sediment at each RMP station are shown on Figure 33. Concentrations ranged between 14.1 and 63.2 ppm. The highest concentrations were at Grizzly Bay (BF21) in March, and in the Napa River (BD50) in September. The lowest concentrations were at Pacheco Creek (BF10) during both sampling periods.

Average copper concentrations were higher at the northern estuary fine sediment stations than at the other reaches. Concentrations tended to be higher in March than in September.

Copper concentrations in sediments were directly related to sediment type. Copper was significantly cor-

## Copper in Sediment 1993



**Figure 33. Near-total copper concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \***indicates northern estuary coarse sediment stations

related with fines, TOC, and TN in all samples collected (Table 25). Copper appeared to be related linearly to percent fines and TOC in sediments (Figure 34). Together, variation in fines and TOC accounted for at least 60% of the variability in copper concentrations among the stations (regression analysis).

All copper concentrations were well below median effects level, ERM of 270 ppm.

### Lead

Lead (Pb) concentrations in San Francisco Estuary ranged between 5.6 and 41.2 ppm (Figure 35). The highest concentrations were measured at the Extreme South Bay (BA21) in both sampling periods. The lowest concentration was measured at Pacheco Creek (BF10) in March.

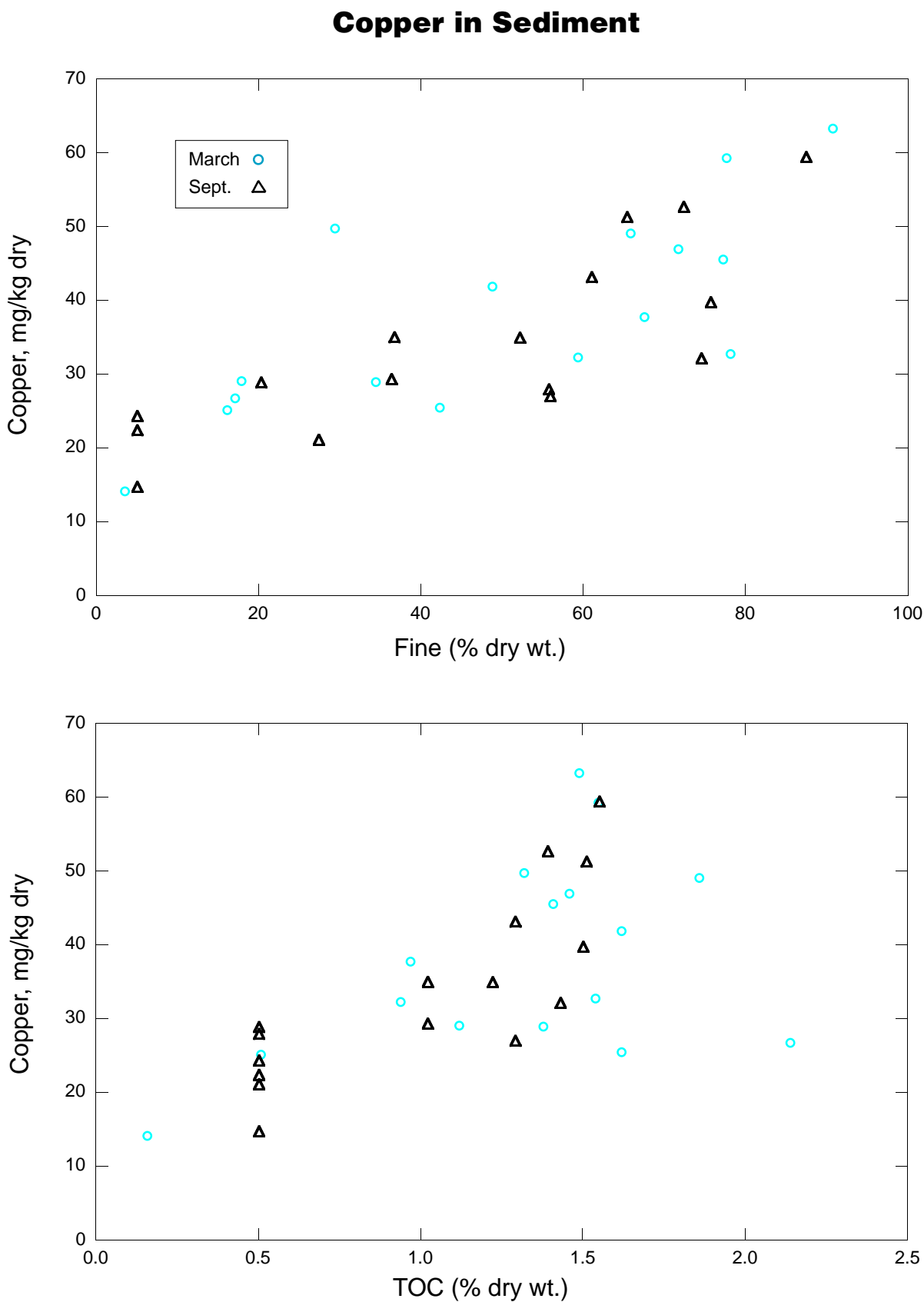
Average lead concentrations were higher in the South Bay reach than in the other reaches. Concentrations were by far higher in March than in September. The reasons for this pronounced seasonality is unknown.

Lead concentrations were directly related to sediment type, and lead was significantly correlated with fines, TOC, and TN during both sampling periods (Table 25). Together fines and TOC accounted for 60-74% of the variation in lead concentrations in the two sampling periods respectively.

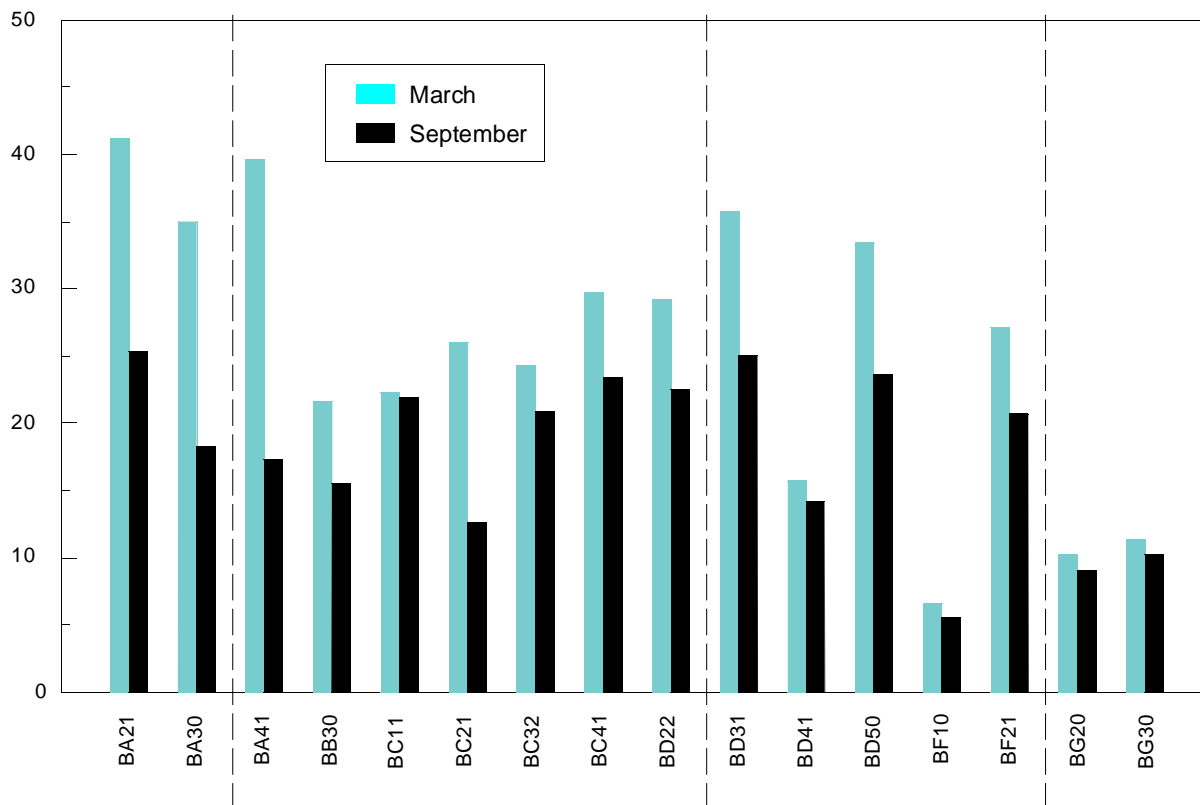
None of the lead concentrations measured was above the ERM of 223 ppm.

### Mercury

Mercury (Hg) concentrations ranged between 0.031 and 0.472 ppm at the RMP stations (Figure 36). The highest concentrations were at Pinole Pt. (BC32) in March



**Figure 34.** Relationships between copper in sediments and sediment grain-size (Fine), and organic material (TOC = total organic carbon) at all 16 RMP stations from both sampling periods.



**Figure 35. Near-total lead concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \*** indicates northern estuary coarse sediment stations

and at Dumbarton Bridge (BA30) in September. The lowest concentration was at Pacheco Creek (BF10) in March.

Average concentrations of mercury in sediment were highest at the South Bay stations. Concentrations tended to be higher in September than in March.

Mercury concentrations were directly related to sediment type. However, the relationships between mercury and sediment type were different each sampling period. Mercury concentrations and sediment types (fines, TOC) appeared to have a curvilinear relationship in March (Figure 37). Those relationships appeared to be more linear in September, and mercury was significantly correlated with fines and TOC (Table 25). Mercury was also significantly correlated with TN. Fines and TOC together only accounted for 14% of the variation in mercury concentrations in March, but accounted for 92% of the variation in mercury in September. Reasons

for these differences between the sampling periods are unclear.

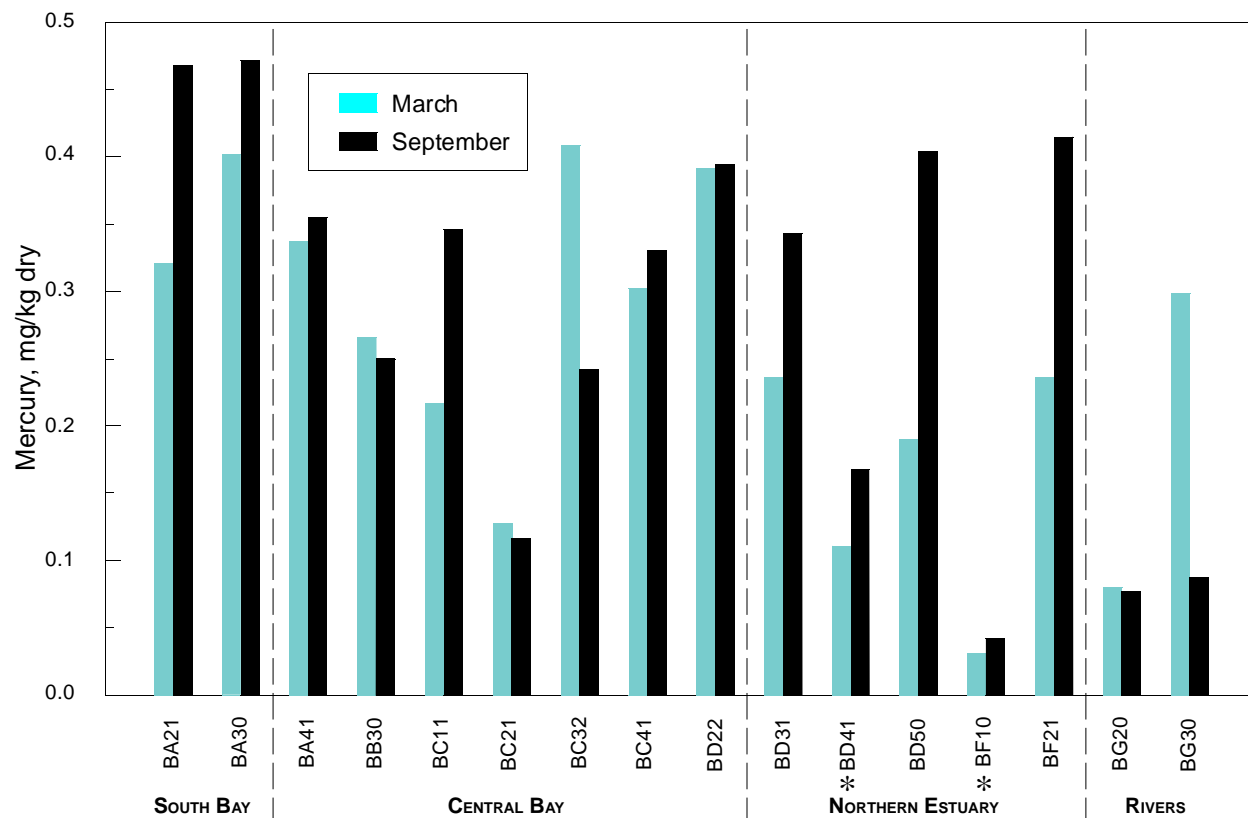
All mercury measurements made in sediments were well below the ERM of 0.710 ppm.

#### Nickel

Nickel (Ni) concentrations in sediments at the RMP sites ranged between 48.2 and 104.5 ppm (Figure 38). The highest concentrations were at Grizzly Bay (BF21) in March and at the Napa River (BD50) in September. The lowest concentration was at Pacheco Creek (BC11) in March.

On average, nickel concentrations were highest at the northern estuary fine sediment stations. Concentrations were usually higher in March than in September but showed little seasonal variation at some stations.

## Mercury in Sediment 1993



**Figure 36. Total mercury concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \*indicates northern estuary coarse sediment stations**

As with most other metals, nickel concentrations were directly related to sediment type. Nickel appeared to be slightly curvilinear in relation to fines and TOC during both sampling periods (Figure 39). Nickel concentrations were significantly correlated with fines and TOC during both cruises (Table 25). However, those two sediment parameters together accounted for only 35% of the variability in nickel concentrations (regression analysis).

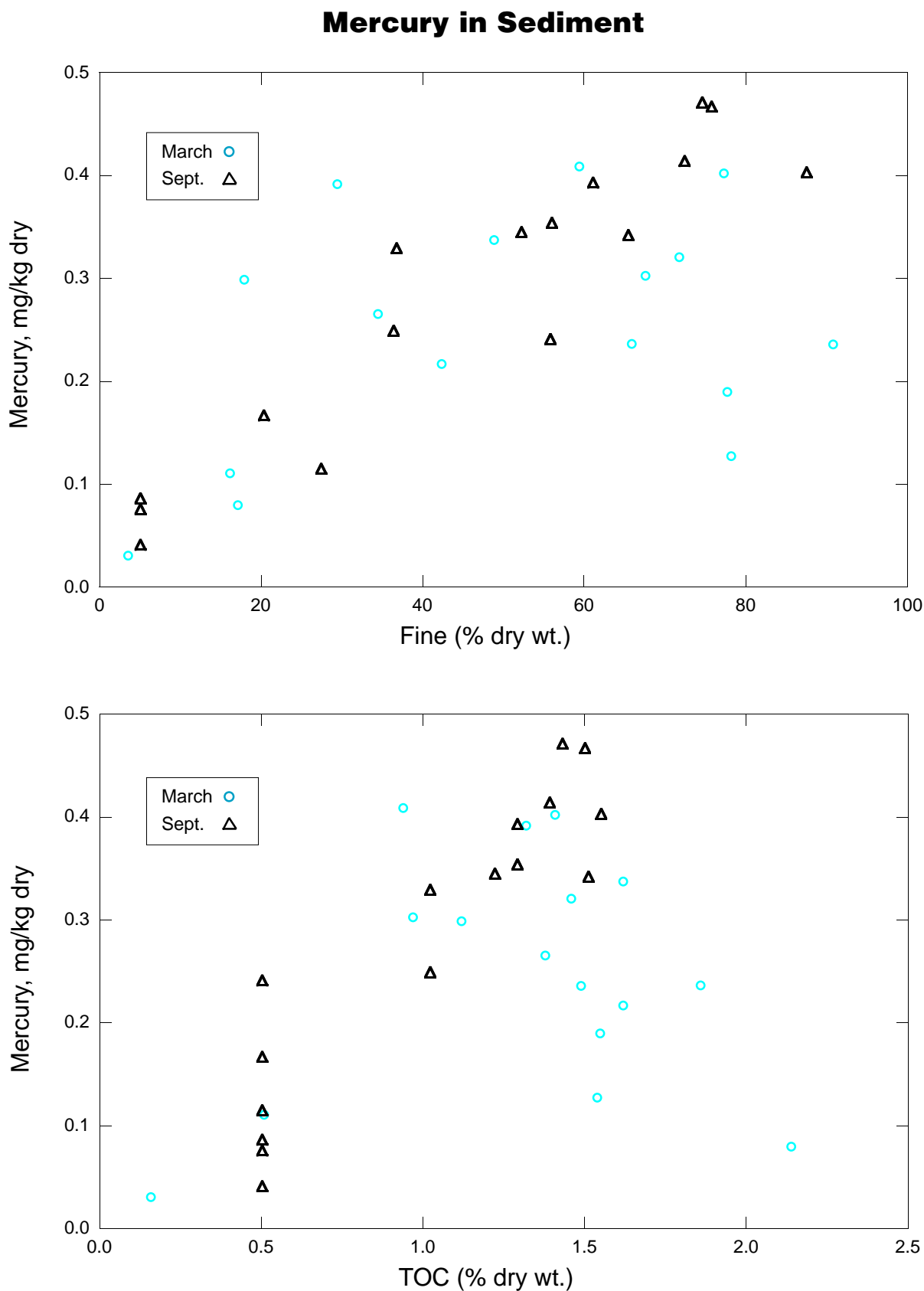
Nickel concentrations were above the ERM of 51.6 ppm at all stations except BA41 in March and BC11 in September. It was the only metal in sediments that was generally above ERM values. The factors that contribute to the elevated nickel concentrations in San Francisco Estuary sediments are poorly understood. However, it is generally believed that these levels are due to natural geological sources.

### Selenium

Selenium (Se) concentrations in sediment ranged between 0.07 and 3.30 ppm (Figure 40). Concentrations were highest at Horseshoe Bay (BC21) and San Pablo Bay (BD22) in March and at Grizzly Bay (BF21) in September. Concentrations were lowest at Pacheco Creek (BF10) in March.

Average selenium concentrations were higher at the northern estuary fine sediment stations than the other reaches. However, there was a considerable seasonal difference, with concentrations being much higher in September than in March. Factors that could cause such seasonality are not understood.

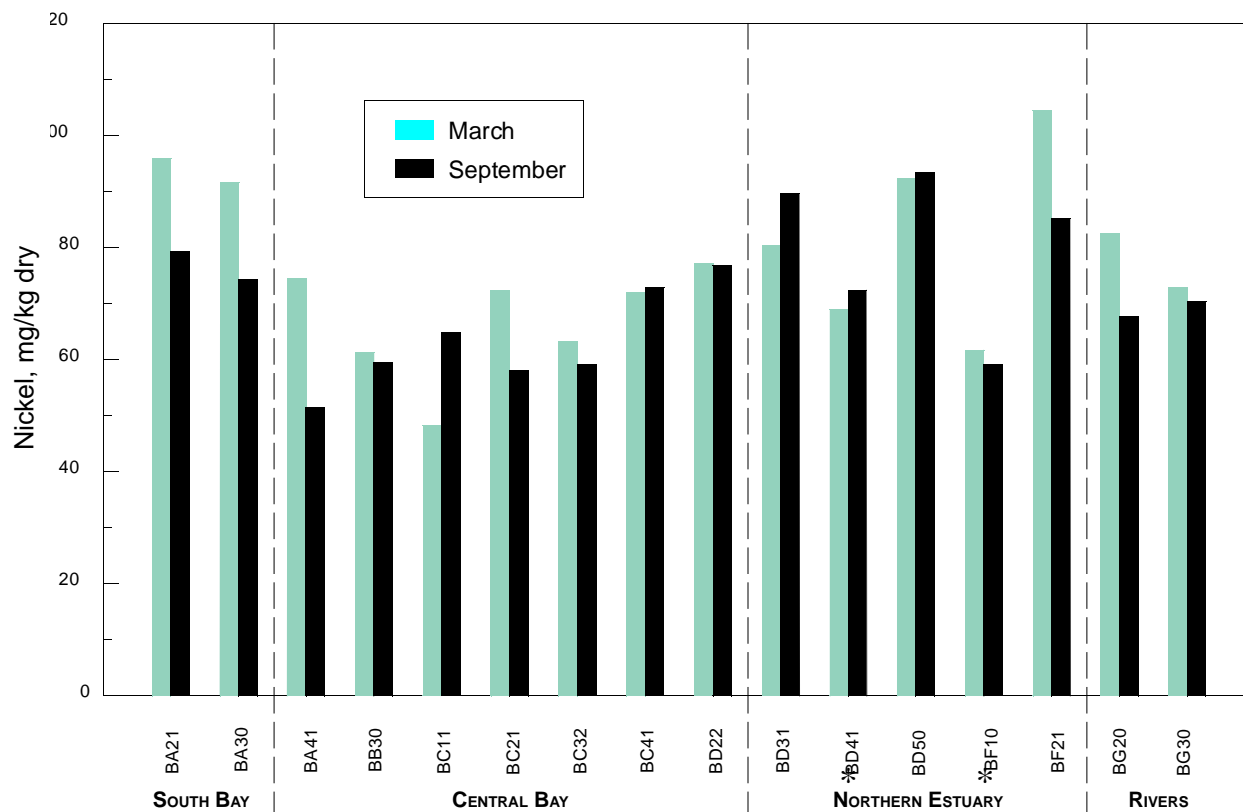
Selenium concentrations exhibited different relationships with sediment type in each sampling period (Figure 41). In March, selenium was linearly related to fines



**Figure 37.** Relationships between mercury in sediments and sediment grain-size (Fine), and organic material (TOC = total organic carbon) at all 16 RMP stations from both sampling periods.



## Nickel in Sediment 1993



**Figure 38. Near-total nickel concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \*indicates northern estuary coarse sediment stations**

and TOC, but was not significantly correlated with any sediment parameters (Table 25). In September, selenium was significantly correlated with all sediment parameters, but appeared to be non-linearly related to fines and TOC. Two stations, Grizzly Bay (BF21) and Napa River (BD50), had higher than expected concentrations, if a linear relationship is assumed to be normal. Regression analysis showed that fines and TOC only accounted for between 26-34% of the variation in selenium concentrations. Reasons for the differences in the relationship between selenium and sediment types between the 2 sampling periods are not understood.

There are no effects range guidelines for selenium.

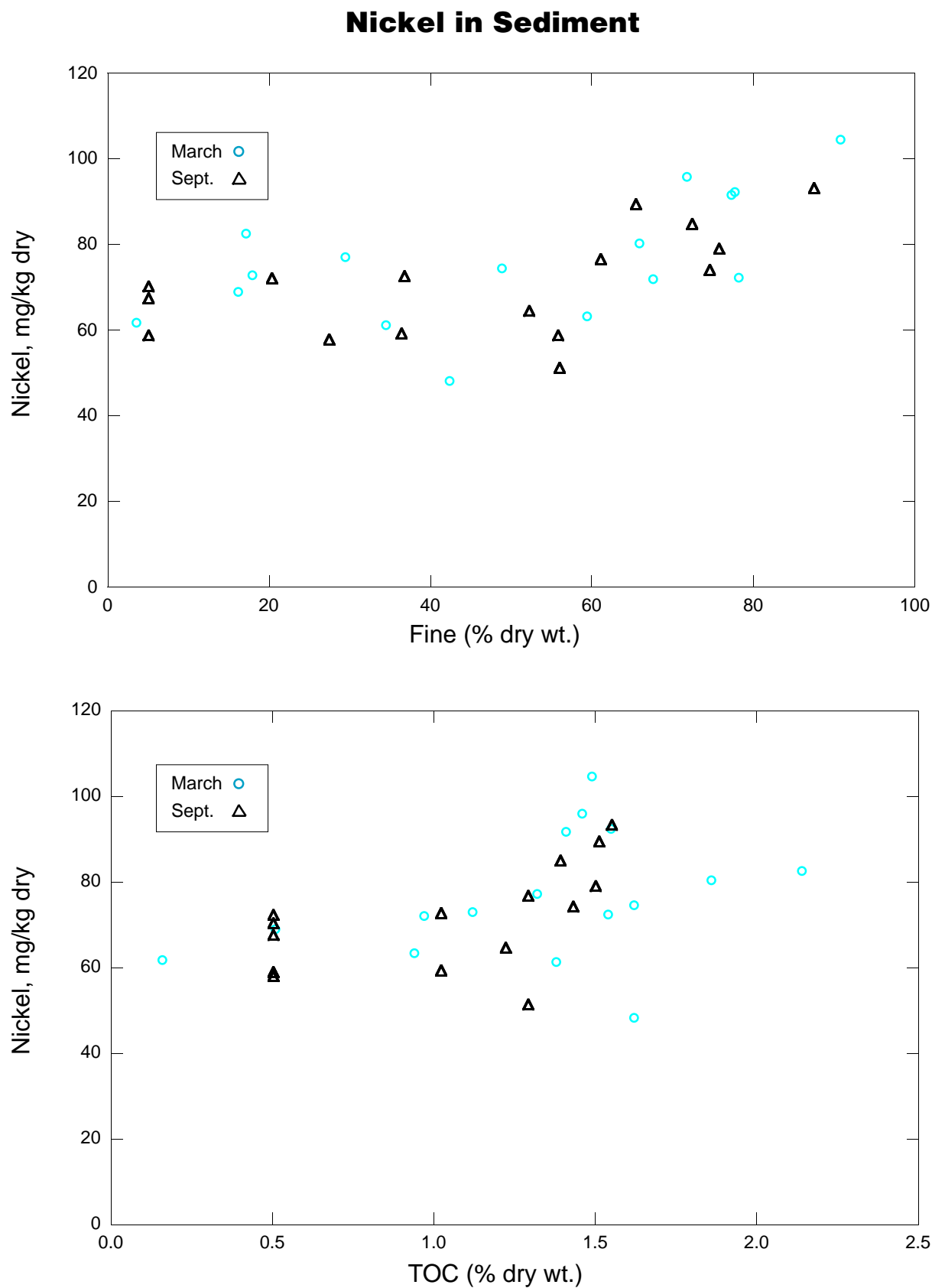
### Silver

Silver (Ag) concentrations in sediment at each RMP station are shown in Figure 42. Concentrations ranged

between 0.03 and 1.18 ppm. The highest concentrations were measured at Redwood Creek (BA41) in March and at the Extreme South Bay (BA21) in September. The lowest concentration was measured at Pacheco Creek (BF10) in March.

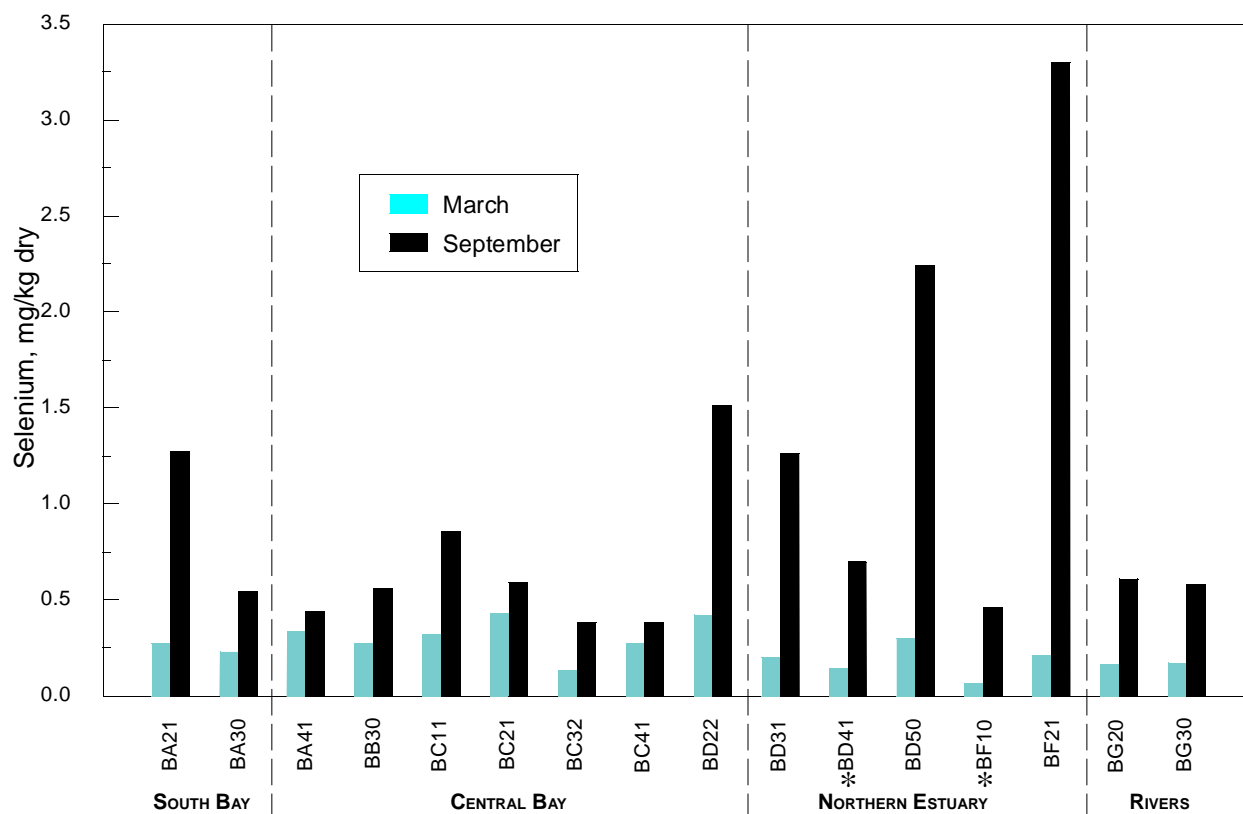
Average silver concentrations were higher in the South Bay than in the other reaches. Concentrations were quite similar between the sampling periods, with the notable exception of Redwood Creek (BA41).

Silver concentrations in sediments were directly related to sediment type (Table 25). However, there were differences in the magnitude of the correlations between the two sampling periods. Silver was significantly correlated with TN in March, and with fines and TOC in September (Table 24). These differences may be due to elevated silver at the Redwood Creek station during the March cruise. Together, fines and TOC accounted for



**Figure 39.** Relationships between nickel in sediments and sediment grain-size (Fine), and organic material (TOC = total organic carbon) at all 16 RMP stations from both sampling periods.

## Selenium in Sediment 1993



**Figure 40. Total selenium concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \*indicates northern estuary coarse sediment stations**

16% of the variation in silver measured in March, and 69% in September.

All silver concentrations were below the ERM value of 3.7 ppm.

### Zinc

Zinc (Zn) concentrations in the sediment of the Estuary ranged between 54.4 and 151.5 ppm (Figure 43). The highest concentrations were measured in Grizzly Bay (BF21) in March and in the Napa River (BD50) in September. The lowest concentration was at Pacheco Creek (BF10) in September.

Average zinc concentrations were higher at the northern estuary fine-sediment stations than at the other reaches. Concentrations in March were usually higher than in September.

Zinc concentrations were directly related to sediment type. Concentrations were significantly correlated with fines, TOC, and TN during both sampling periods (Table 25). Fines and TOC together accounted for between 63-75% of the variation in zinc measurements respectively (regression analysis).

None of the stations had zinc concentrations above the ERM of 410 ppm.

## Discussion of Sediment Trace Metals

Concentrations of all trace metals measured in sediments at the RMP stations were directly related to sediment type (Table 25). All trace metals were positively correlated to fines, TOC and TN. Chromium, copper, nickel, lead, and zinc were always significantly corre-

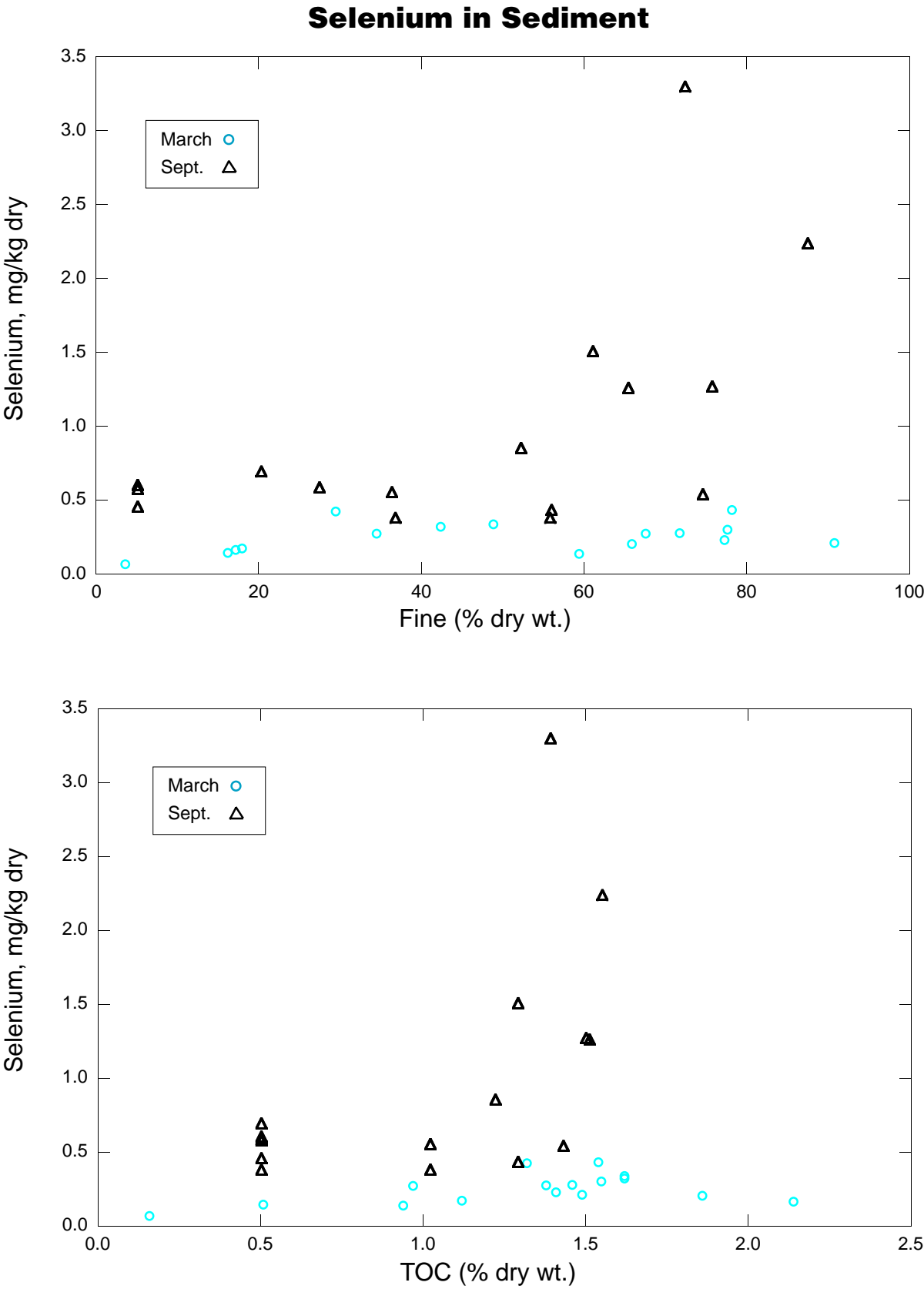
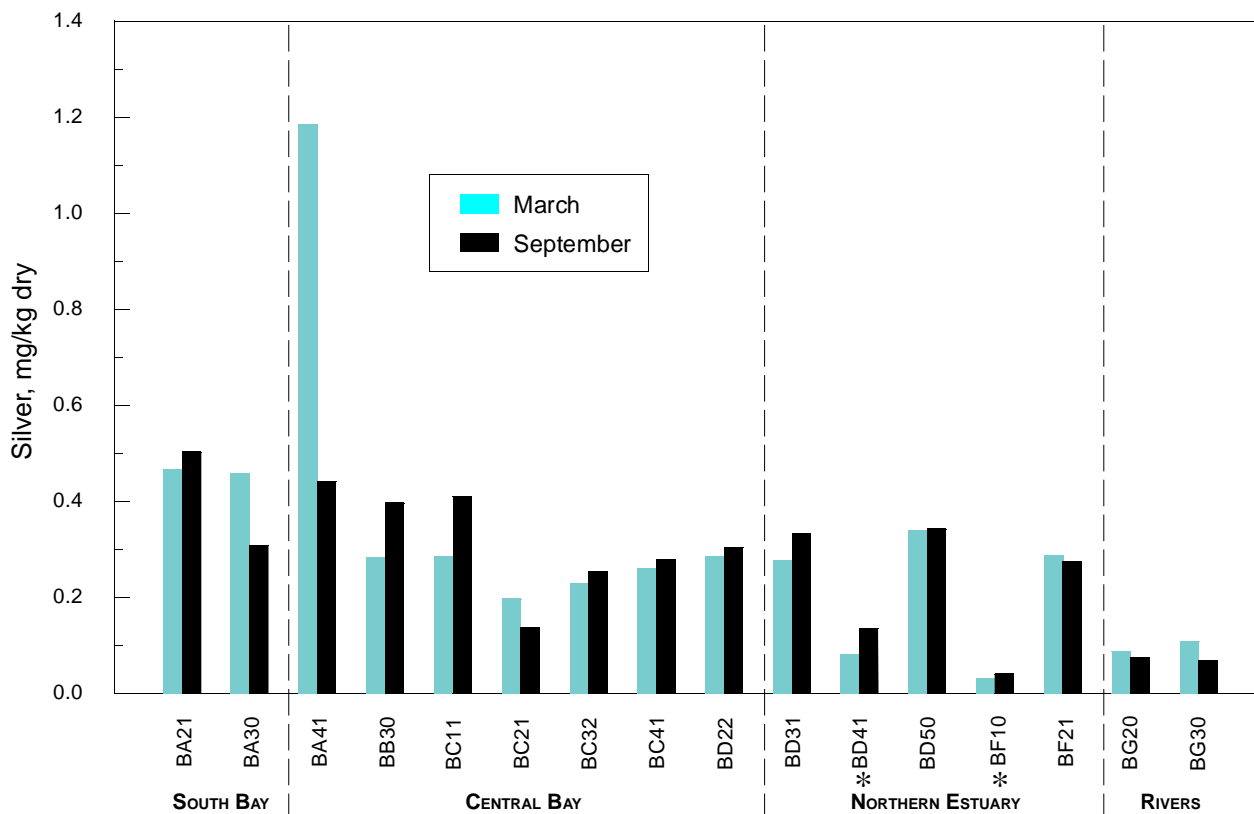


Figure 41. Relationships between selenium in sediments and sediment grain-size (Fine), and organic material (TOC = total organic carbon) at all 16 RMP stations from both sampling periods.

## Silver in Sediment 1993



**Figure 42. Near-total silver concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \*indicates northern estuary coarse sediment stations**

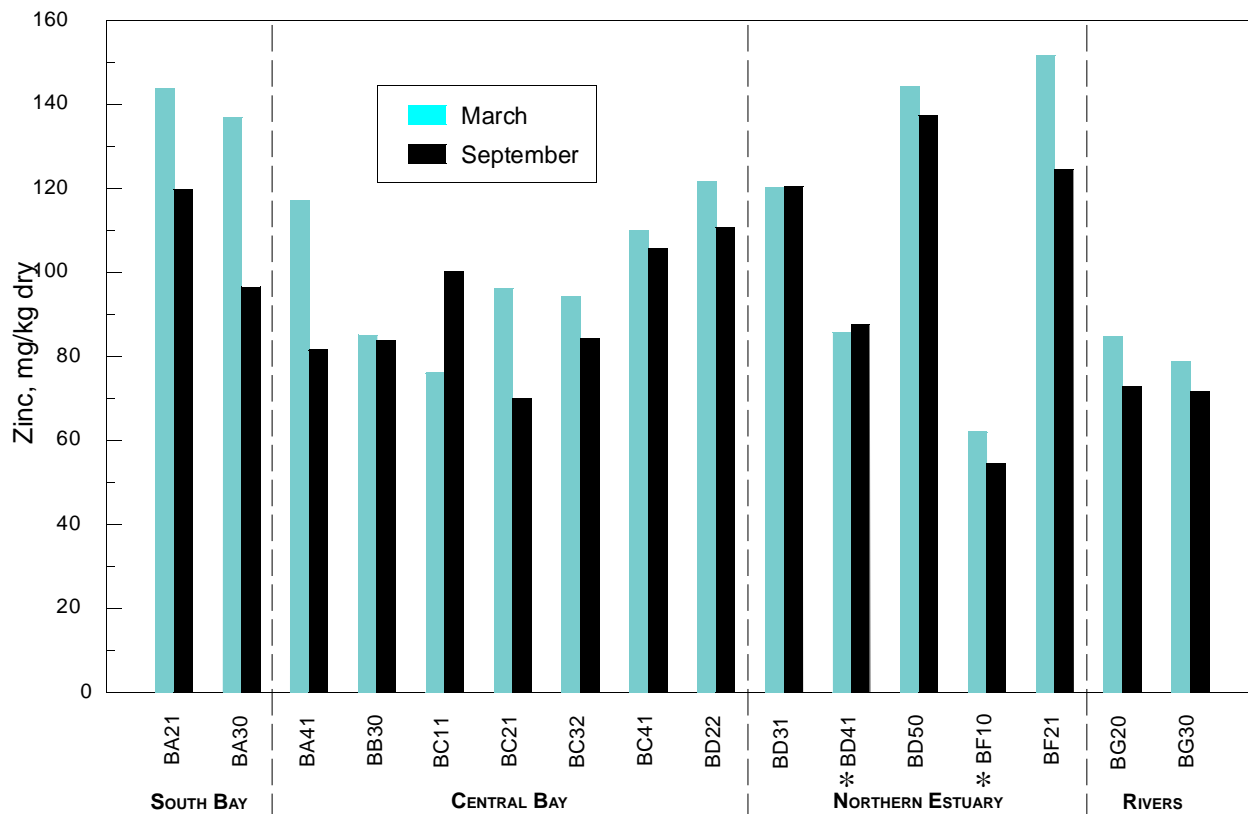
lated with fines and TOC. Silver, arsenic, mercury, and selenium were significantly correlated with fines and TOC during the September sampling period, but not during the March sampling period. Cadmium was only significantly correlated with fines in September. For mercury, lead, and selenium there was obvious variation in the form and strengths of their relationships to sediment type between the two sampling periods. All other metals measured showed consistent linear relationships between metal concentration, fines and TOC.

These relationships to sediment type help to explain the patterns of trace metals concentrations observed at the RMP stations. Cadmium, chromium, copper, nickel, and zinc were highest at the stations with the finest sediment grain-sizes; the northern estuary fine-sediment stations (BD31, BD50, BF21). Grizzly Bay (BF21) had the highest concentrations of those metals in March, and

Napa River (BD50) had the highest concentrations (except cadmium) in September. Conversely, these metals were lowest at the stations with the largest proportions of sand, the northern estuary coarse sediment stations (BF10, BD41). However, three metals, silver, mercury, and lead had the highest average concentrations at the South Bay stations (BA21 and BA30). Although these stations had moderately fine sediments, the higher than expected concentrations of these metals suggest direct sources of these metals in the South Bay.

Because of the complex nature of sediments, it is difficult to discriminate differences in metal concentrations smaller than the range of concentrations in a given sediment type. Several years of RMP data may provide more accurate information about how to account for sediment types when assessing metal concentrations.

## Zinc in Sediment 1993



**Figure 43. Near-total zinc concentrations (ppm dry wt.) at the 16 RMP stations in March and September, 1993. \*indicates northern estuary coarse sediment stations**

There appeared to be seasonal (wet vs. dry period in 1993) variation in cadmium, lead, and selenium. Lead was generally higher in March, cadmium and selenium were higher in September. While there were some indications that other metals were higher in one season or another, these seasonal differences only represent data for one year, albeit an unusually wet year.

Nickel was the only metal measured that was above the ERM levels, and it was above the guideline at nearly all stations sampled.

Comparisons of RMP sediment trace metals values to those from the 1991-92 BPTCP Pilot Study indicates that the RMP values are generally similar (Table 26). Maximum Cd, Cu, and Pb in sediments measured during the RMP were lower than the maximum values reported during the Pilot. However, maximum values of Ni, Ag, and Zn were higher during the RMP.

The 1970-87 values include samples from highly contaminated sites in the Estuary.

## Trace Organic Contaminants in Sediment

A large number of trace organic contaminants were measured in the sediments of San Francisco Estuary (Table 5). In this report, these contaminants are grouped into 3 main types: petroleum compounds, polychlorinated biphenyls (PCBs), and pesticides. Each of these types includes numerous individual compounds. The data are listed in Appendix Tables 2.13, 2.14 and 2.15. Sediment samples for analysis of trace organic contaminants were collected from all RMP stations during the March and September sampling periods (Table 2). However, only data from September 1993 are reported in this report.

**Table 26. Comparisons of trace metals (ppm) in sediments to previous studies.**

Trace Metals	1970-1987 <sup>1</sup>	1991-92 <sup>2</sup>	RMP 1993
Cd	0.02-17.3	0.12-0.74	0.04-0.3
Cu	1-1500	22-124.4	14.1-63.2
Pb	1-10,000	8.1-109.8	5.57-41.2
Hg	<0.01-6.80	-	0.031-0.472
Ni	-	50.9-92.4	48.2-104.5
Ag	<0.01-16	0.10-1.16	0.03-1.18
Zn	-	73-137.4	54.4-151.5

<sup>1</sup>Compiled by Davis *et al.* 1991.<sup>2</sup>Flegal *et al.* 1994.

Information from the other sampling periods will be included in the 1994 report.

### Petroleum Hydrocarbons

Several types of petroleum hydrocarbons were measured in sediments. These include total petroleum hydrocarbons (TPH), alkanes, and polynuclear aromatic hydrocarbons (PAHs).

TPHs and alkanes are not generally considered to be problem contaminants. Therefore, their distribution and concentrations are only briefly described.

TPHs are a measure of the total amount of petroleum in sediments, including aromatic and aliphatic compounds. However, TPHs may include some biological compounds. There are no effects range guidelines for TPHs.

TPHs in sediments collected in September 1993 ranged between 13.2 and 63.4 ppm (Appendix Table 2.13). The highest concentration was in the Napa River (BD50) and the lowest concentration was at Pacheco Creek (BF10).

Alkanes are straight-chain or branched-chain waxy hydrocarbon compounds. They may be of various origins, including synthetic, petroleum, or biogenic. Alkanes are generally considered to be non-toxic, but may provide microbial substrate. There are no effects range guidelines for alkanes in sediment.

Alkanes in sediments sampled in September ranged between 335 and 2167 ppm (Appendix Table 2.13). The highest concentration was in Grizzly Bay (BF21) and the lowest was Pacheco Creek (BF10). Generally, con-

centrations were highest at the northern estuary and river stations.

### Polynuclear Aromatic Hydrocarbons (PAHs)

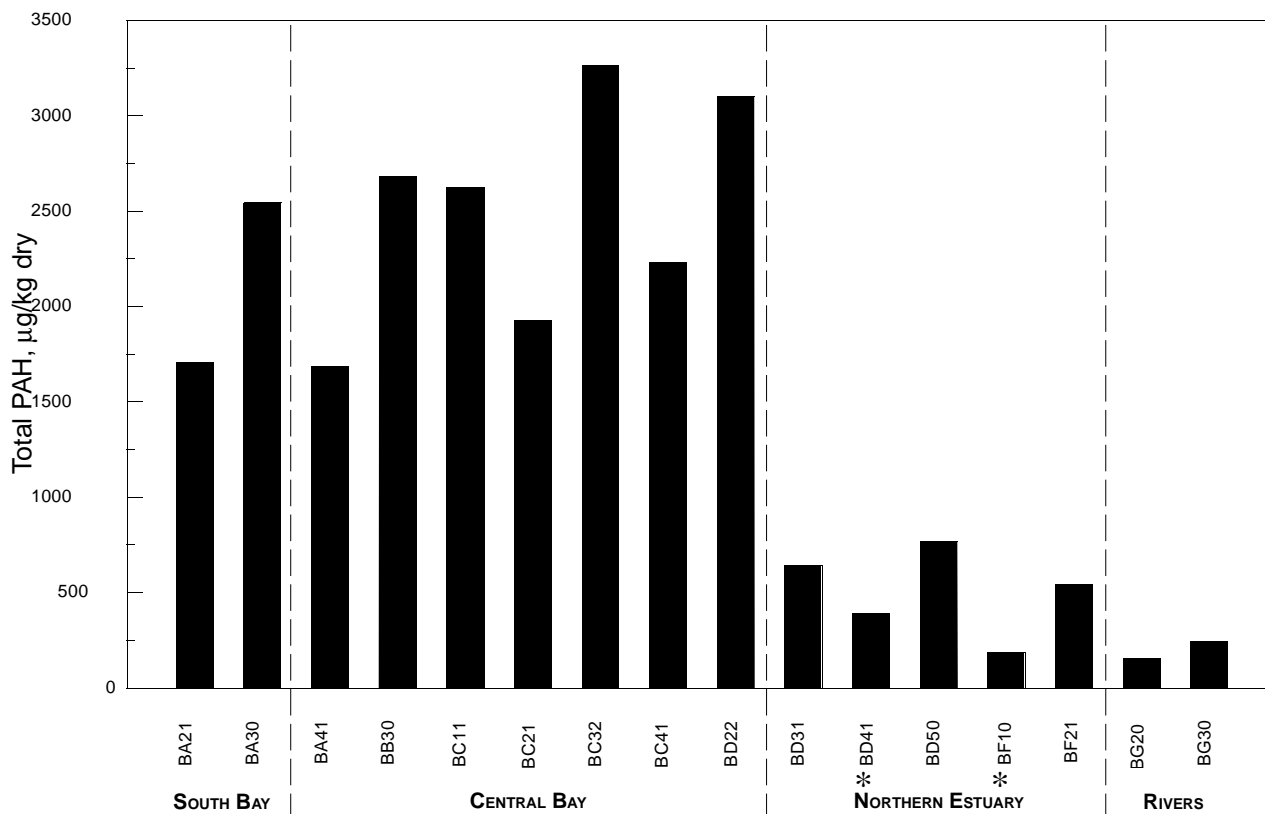
PAHs are the combustion products of petroleum compounds. These compounds are a component of TPHs and are the most commonly reported petroleum compounds in monitoring programs largely because they are among the most toxic components of petroleum hydrocarbons. Thirty-nine PAH compounds were analyzed in the sediment samples, ranging from 2 to 6 ring compounds of varying solubility, including methylated compounds. The sum of those compounds are reported as total PAHs.

Total PAH concentrations in sediments ranged between 155.3 and 3,270.0 ppb (Figure 44). The highest concentrations were from Richardson Bay (BC32), and the lowest concentrations were from the Sacramento River (BG20). Generally, PAH concentrations were an order of magnitude higher in sediments from San Pablo Bay south than at stations in northern San Pablo Bay into the Rivers.

Pyrene was the individual PAH compound with the highest concentration at all RMP stations (range 16.5 to 561.7 ppb), except Pacheco Creek (BF10) where phenanthrene was highest (18.0 ppb). Phenanthrene, fluoranthene, pyrene, and benzo(a)pyrene were the PAHs in highest concentrations at all RMP stations (Appendix Table 2.13).

Total PAHs were directly related to sediment type (except Eh), but were not significantly correlated to any

### PAHs in Sediment, September 1993



**Figure 44. Total polynuclear aromatic hydrocarbons (PAHs) concentrations (ppb, dry wt.) at the RMP sediment stations in September 1993. \*indicates northern estuary coarse sediment stations**

sediment quality characteristics measured (Table 26). Plots of fines and TOC vs. PAHs demonstrate considerable scatter in their relationship (Figure 45). Fines and TOC in sediment accounted for only 22% of the variation in PAHs (regression analysis).

Total PAHs in sediments at the RMP stations were well below the ERM value of 44,790 ppb.

#### Polychlorinated Biphenyls (PCBs)

PCBs were briefly described in the water organics section of this report (page 47). Seventy-seven PCB congeners were analyzed in sediment and are listed in Appendix Table 2.14. The sum of those congeners, or total PCBs are reported from September 1993.

PCBs in sediments ranged between 0.7 to 59.6 ppb (Figure 46). The highest concentration was measured at

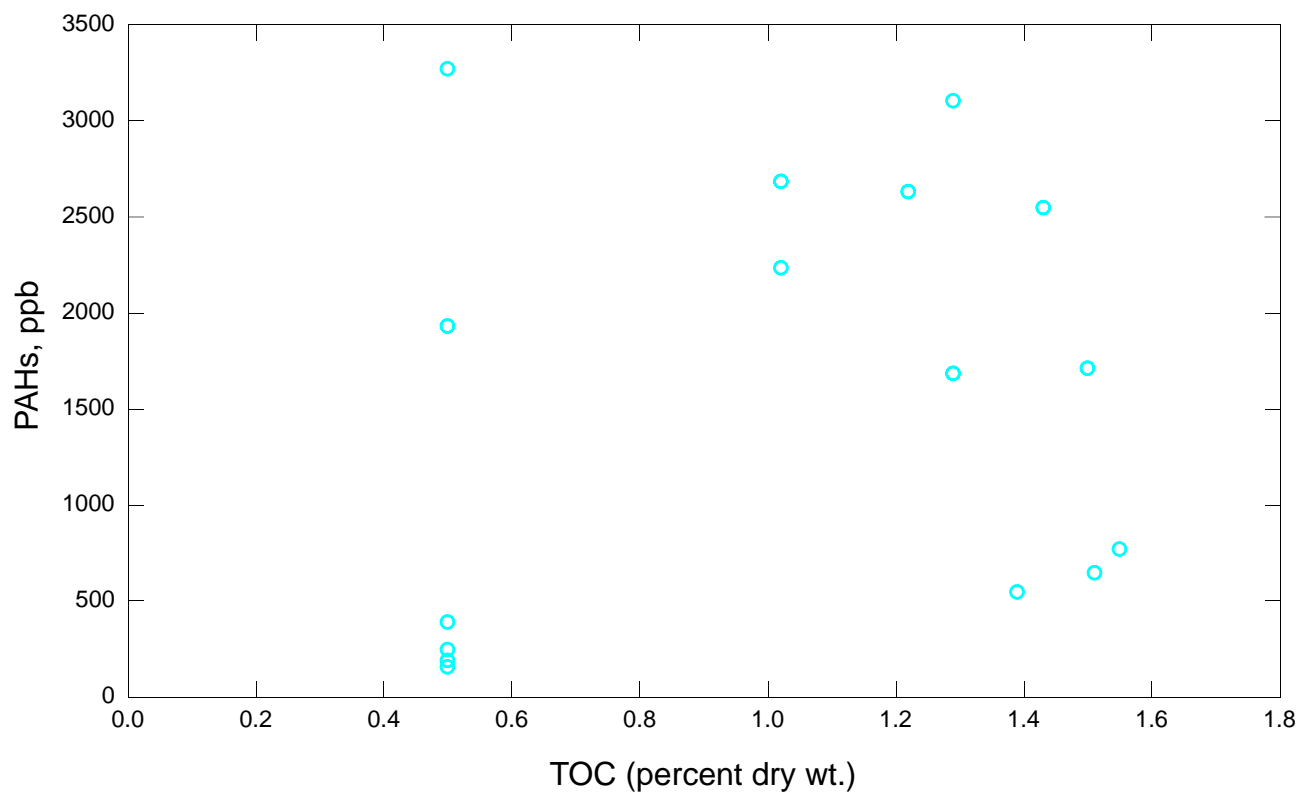
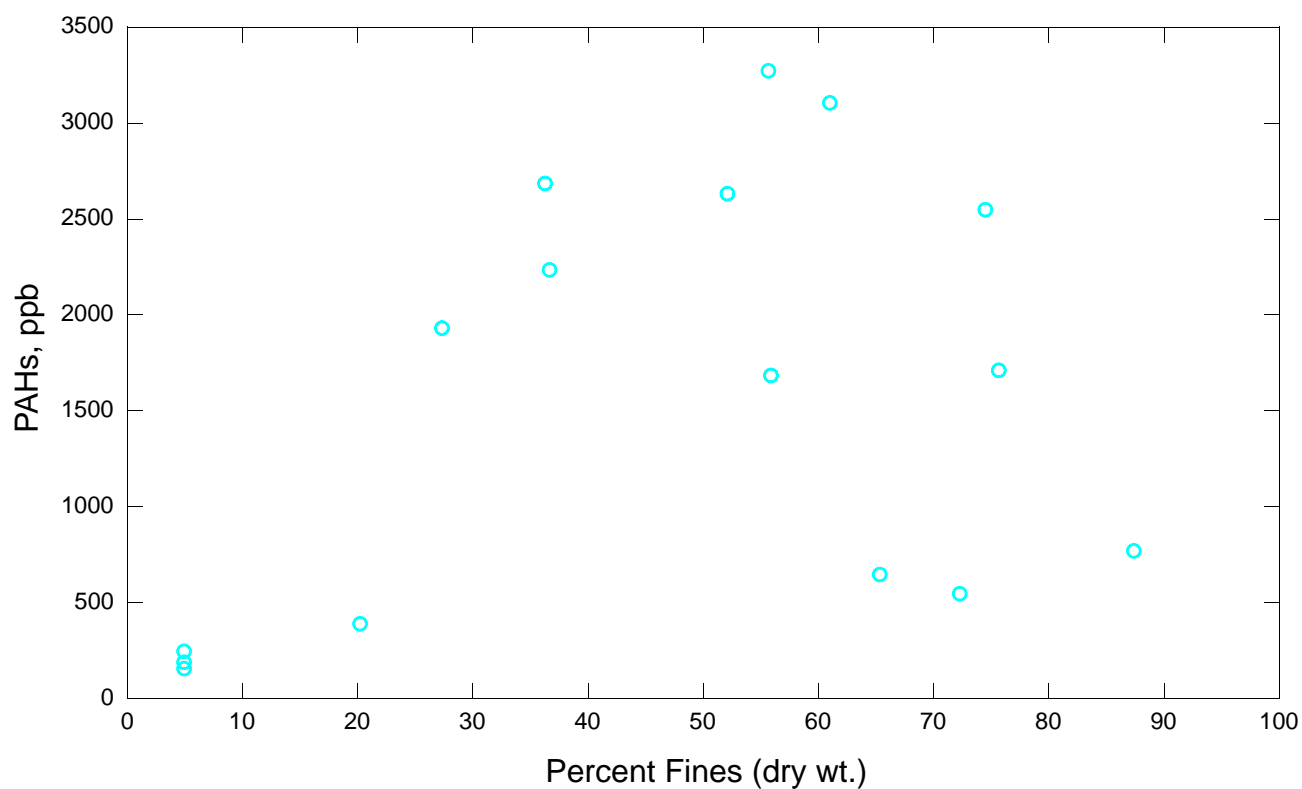
Pt. Isabel (BC41), and the lowest concentration was measured at Pacheco Creek (BF10).

In general, the highest concentrations were in the Central Bay, and the lowest concentrations were in the northern estuary, particularly at the coarse sediment sites.

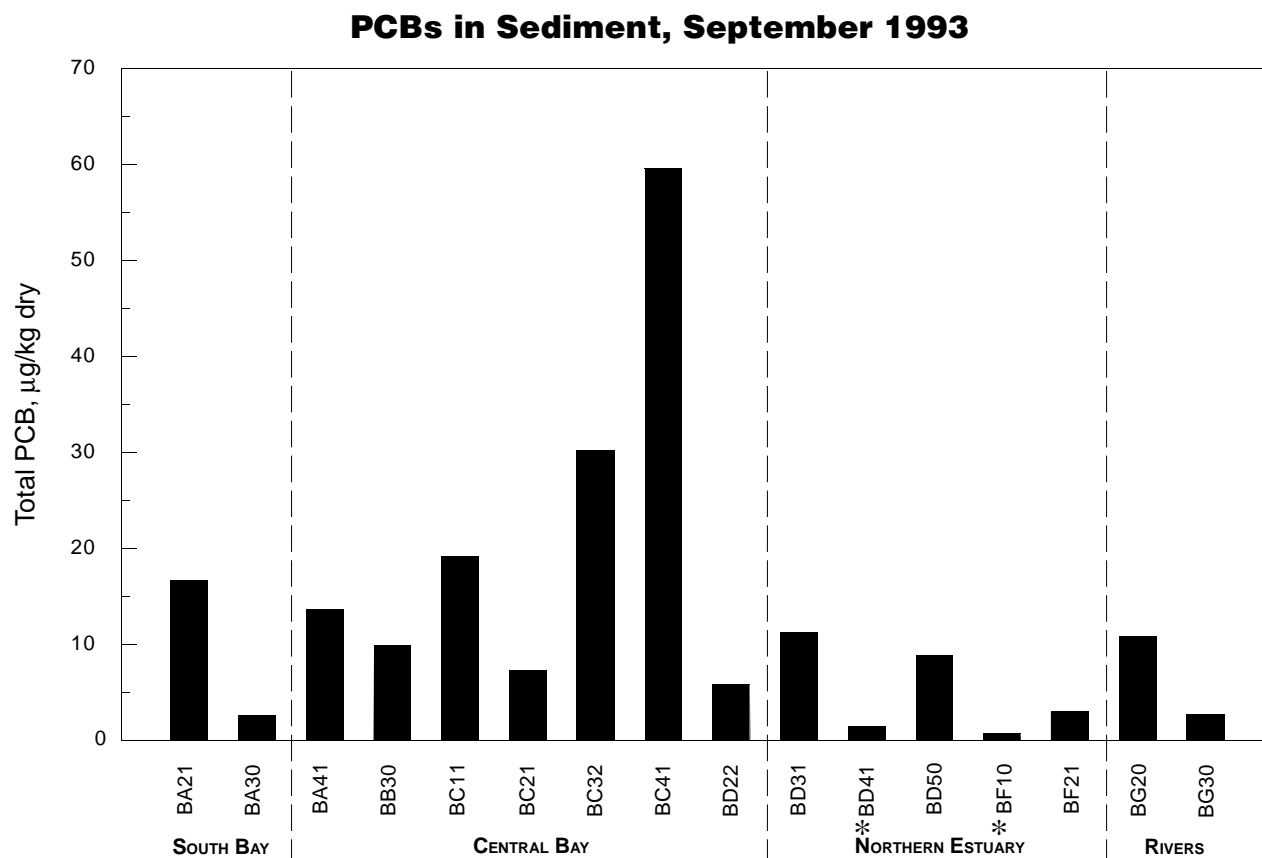
PCB concentrations in sediment were poorly related to sediment type. Correlations between PCB concentrations and percent-fines or TOC were very low (Table 27, Figure 47). Together, fines and TOC accounted for only 1% of the variability in PCB concentrations. The reasons for these poor relationships are not understood or expected. PCBs are generally insoluble in water and were expected to be partitioned into the organic fraction of the sediment.

PCBs in sediments were below the ERM guideline of 180 ppb at all stations.



**PAHs in Sediment, September 1993**

**Figure 45. Relationships between total PAHs and sediment type; percent fines and total organic carbon (TOC).**



**Figure 46. Total polychlorinated biphenyls (PCBs) concentrations (ppb, dry wt.) at the RMP sediment stations in September 1993. \*indicates northern estuary coarse sediment stations**

## Pesticides

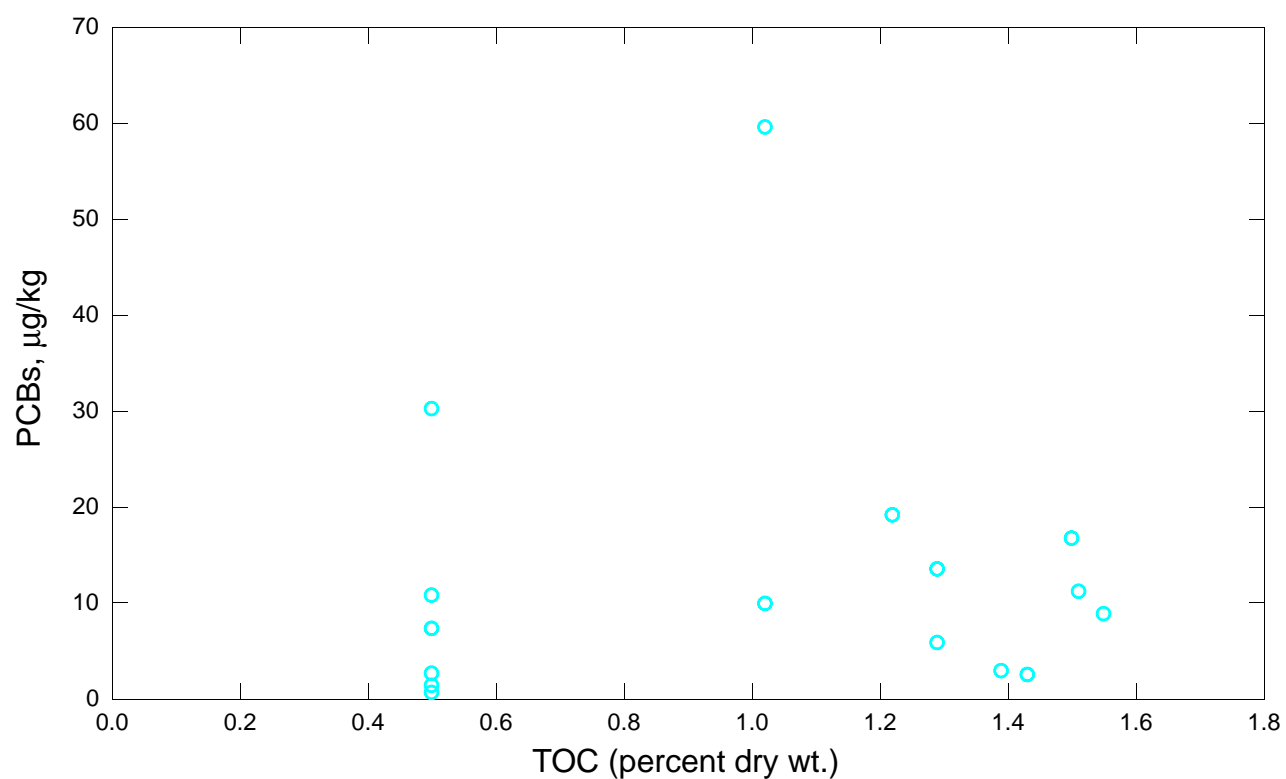
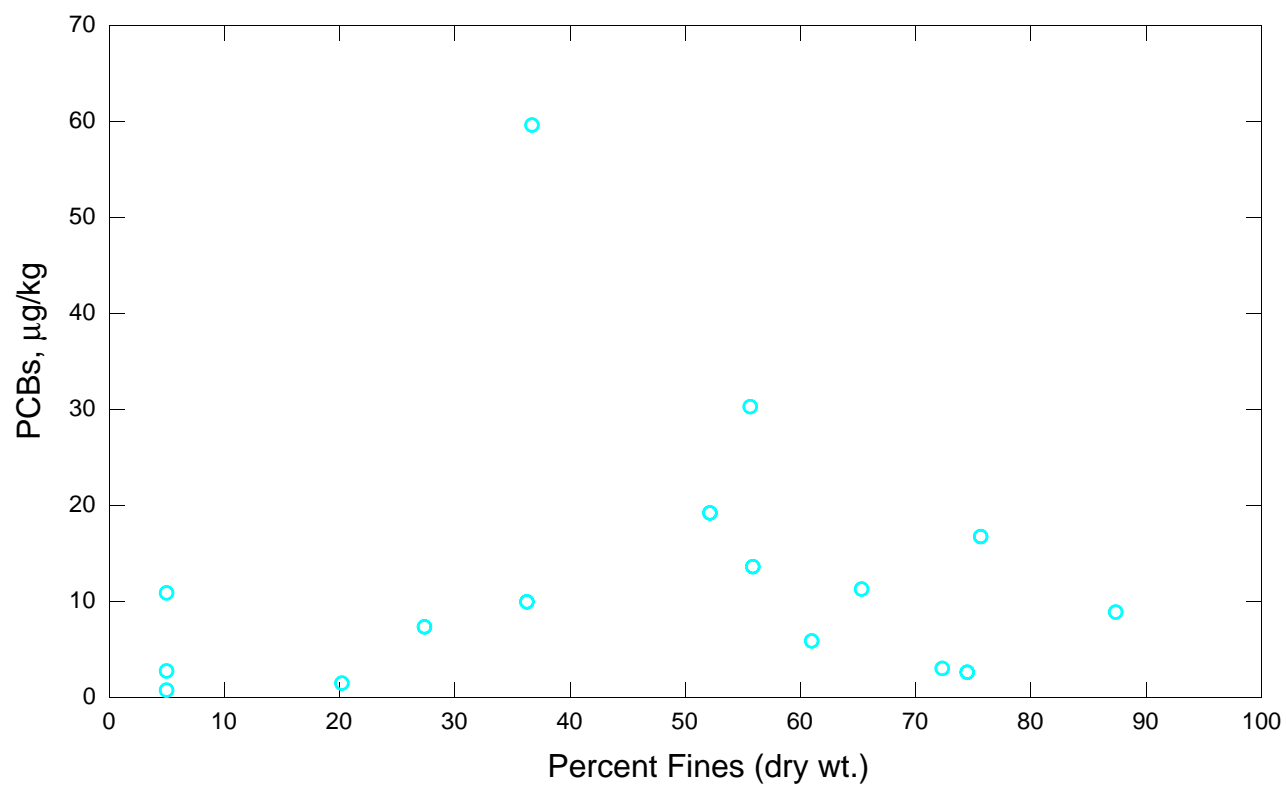
Pesticides were generally described on page 49. Twenty-two pesticide compounds were measured in sediment at the RMP stations (Table 5). These compounds include several general types: aldrin, chlordanes, DDTs, dieldrin, endrin, hexachlorobenzene, hexachlorocyclohexanes, and mirex. Total pesticides are the sum of those compounds.

Total pesticides in sediments collected in September ranged between 0.4 to 5.8 ppb (Figure 48). The highest concentration occurred at Pt. Pinole (BD31) and the lowest concentration was at Pacheco Creek (BF10). In general, the highest concentrations were at the northern estuary fine sediment stations, but concentrations were also high at the Extreme South Bay (BA21). The lowest concentrations were at the northern estuary coarse sediment stations.

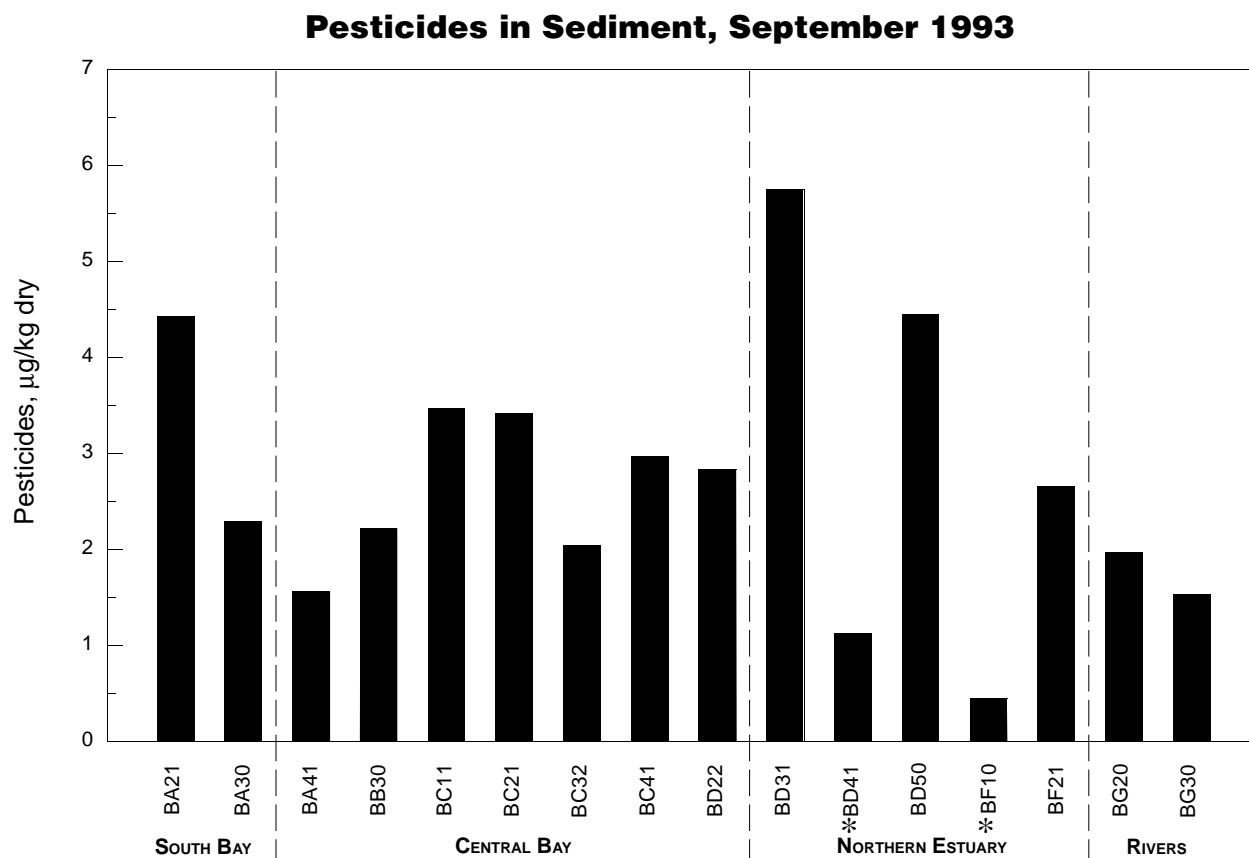
DDTs includes 6 isomers of persistent chlorinated pesticides. They contributed the largest proportion to total pesticides at all stations sampled. Concentrations of total DDTs ranged between 0.04 to 4.75 ppb. They were highest at Pt. Pinole (BD40) contributing 82% to total pesticides, and were lowest at Pacheco Creek (BF10). All other pesticide compounds occurred in concentrations below 1.0 ppb (Appendix Table 2.15).

Total pesticides were directly related to sediment type and were significantly correlated to percent fine, TOC, and TN in the sediment (Table 27, Figure 49). Together, fines and TOC accounted for 45% of the variation in pesticide concentrations in the sediments.

There are no sediment quality guidelines for total pesticides, but there are guidelines for some of the component compounds. DDTs were below the ERM guide-

**PCBs in Sediment, September 1993**

**Figure 47. Relationships between total PCBs and sediment type; percent fines and total organic carbon (TOC).**

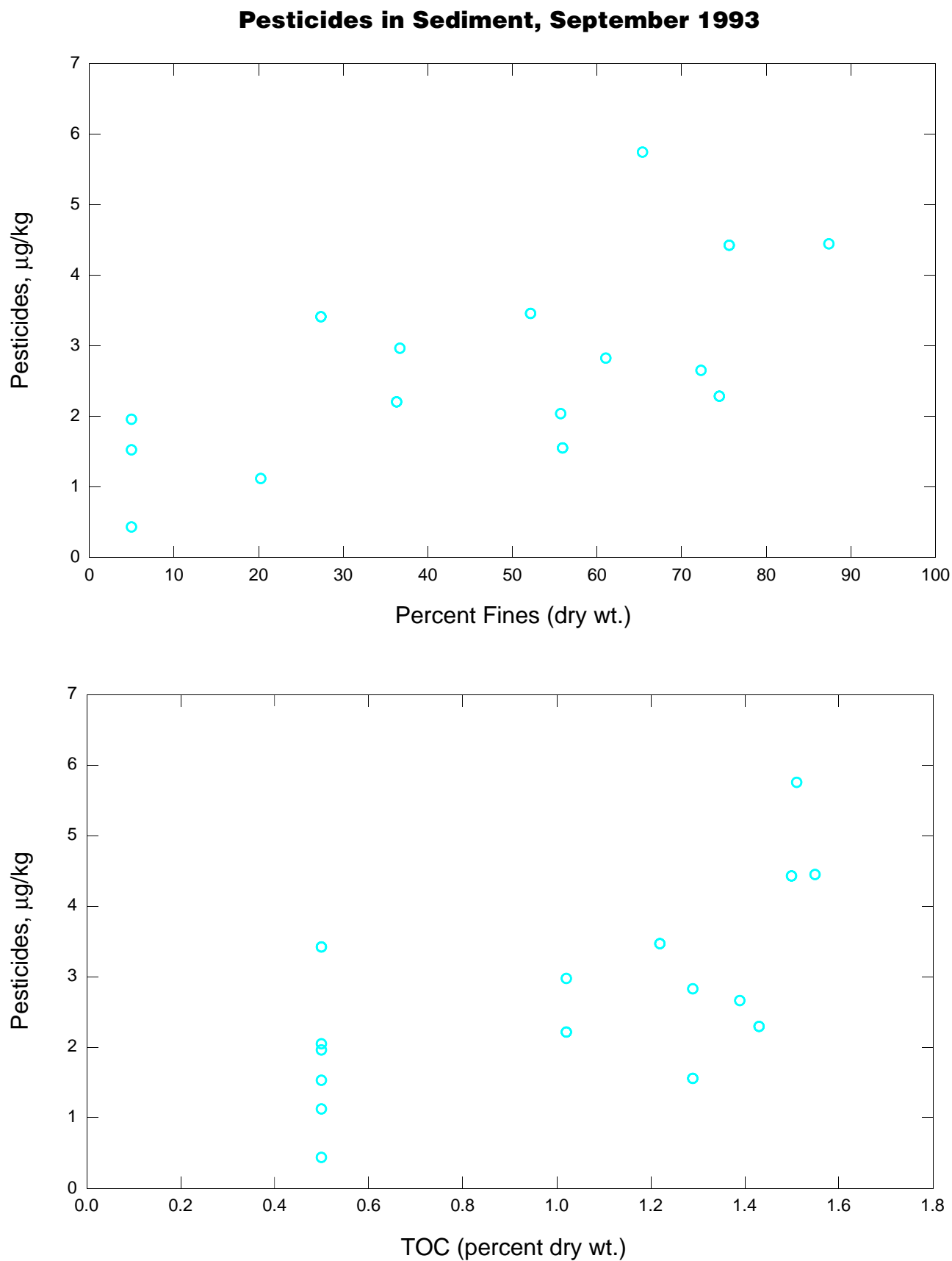


**Figure 48.** Total pesticide concentrations (ppb, dry wt.) at the RMP sediment stations in September 1993. \*indicates northern estuary coarse sediment stations

**Table 27.** Product moment correlation coefficients (r) for trace organic contaminants and sediment characteristics, September 1993.

	Fine	TOC	TN	Eh
Total PAHs	.39	.21	.41	-.21
Total PCBs	.08	.03	.10	-.22
Total Pesticides	.64*	.66*	.64*	.21

\*significant at  $\alpha=0.05$ ,  $n=16$ .



**Figure 49. Relationships between total pesticides and sediment type; percent fines and total organic carbon (TOC).**

line of 46.1 ppb at all stations, and chlordane was below the ERM of 6 ppb at all stations.

## Summary of Trace Organics in Sediment

PAHs and PCBs measured in September were both highest at the Central Bay stations at Pt. Isabel and Richardson Bay, and for PAHs into San Pablo Bay. They were both lowest at the northern estuary and river stations. Therefore, PAHs and PCBs in sediments are associated with the most urbanized areas of the Estuary. Pesticides were highest at Pt. Pinole and Napa River and lowest at the northern estuary coarse sediment stations.

Pesticides were significantly correlated with sediment type (fine, TOC, TN), being highest at the stations with the finest sediments. However, PAHs and PCBs were poorly correlated with sediment types. Higher correlations with sediment types were expected for PAHs and PCBs as those contaminants usually tend to partition into the organic fractions of sediments. The reasons for this apparent lack of relationships are not understood.

All trace organic contaminants in sediments were below the ERM.

Trace organic contaminants in sediments were measured during the BPTCP Pilot Studies at many of the same stations as the RMP. The maximum values from the RMP were all well below the maximum values reported during the Pilot Studies. Maximum values reported during the Pilot for PAHs were 6,260 ppb at Yerba Buena Island, PCBs were 117 ppb at Davis Pt., and DDTs were 31 ppb off Pt. Isabel (Risebrough 1994). Much higher concentrations were reported at highly contaminated sites (Davis *et al.* 1991).

## Sediment Toxicity

The toxicity of estuarine sediment to animals exposed in controlled laboratory settings is commonly used to indicate the potential for ecological effects of those sediments (Swartz 1987; DeWitt *et al.* 1989).

In 1993, sediment toxicity was measured at eight of the RMP stations (Figure 50) during the wet (March) and dry (September) sampling periods. Two different tests were used: a 10-day mortality test using the estuarine

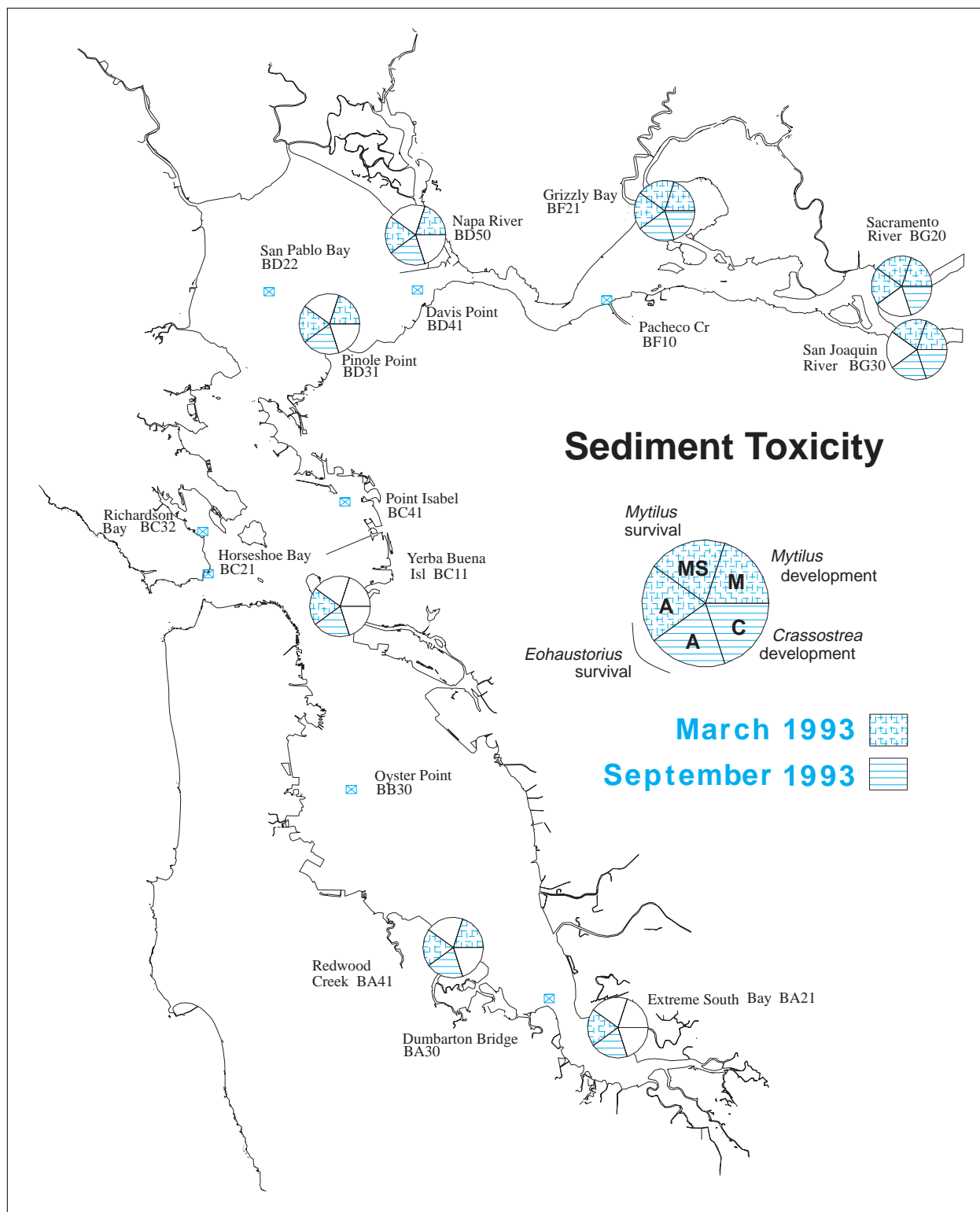
amphipod *Eohaustorius estuarius* exposed to whole sediment, and a sediment elutriate test where larval bivalves were exposed to the material dissolved from whole sediment in a shaken water extract (described in Methods). Larval mussels (*Mytilus edulis*) were used in the March tests, where percent normally developed and percent mortality were the endpoints measured. Larval oysters (*Crassostrea gigas*) were used in the September samples, where only development was measured. Different species of bivalve larvae were used each sampling period because the larvae are only available during those seasons.

The organisms were also exposed to a reference toxicant (cadmium chloride) that had dependable responses.  $EC_{50}$  and  $LC_{50}$ s for those tests, as well as other QA information is listed in Appendix Table 3.5.

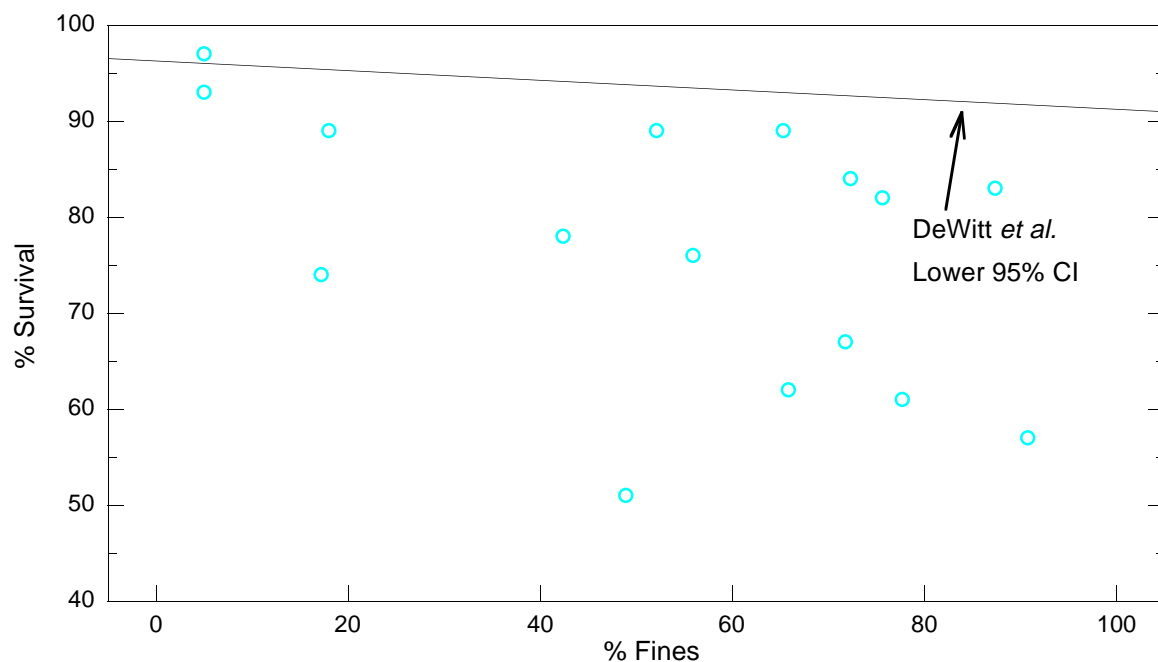
Sediment toxicity was indicated by statistically significant differences between each endpoint and controls (analysis of variance).

The controls used for these tests was sediment from the Yaquina Bay Estuary in Oregon (home sediment) for *Eohaustorius*, and Granite Canyon, CA filtered seawater for the bivalve larval tests. The home sediment used in the amphipod test was 99% sand with 0.25% TOC, while the RMP stations ranged between 24 and 97% sand (Table 23). Previous work with this species has shown that in clean sediments there is a slight increase in mortality in fine sediments compared to coarse ones (DeWitt *et al.* 1989). Therefore, the lower 95% confidence interval from those studies, is used as another guide to interpreting amphipod toxicity tests using the fine sediments sampled at the RMP stations (Figure 51).

All RMP stations indicated sediment toxicity based on one or more endpoints, during both sampling periods (Figure 50; data in Appendix Table 2.16). During the March sampling period, all stations except the San Joaquin River (BG30) had significant amphipod mortality compared to the home sediment control. In September, except for the Sacramento River station (BG20), all stations had significant toxicity compared to home sediment control. Results compared to home sediment controls were similar to expected survival on clean sediments with the same particle-size composition as the RMP stations (Figure 51). The point above the expected 95% CI is the March BG30 station which was not toxic com-



**Figure 50.** Chart showing results of sediment toxicity testing at selected RMP stations. Shaded portions indicate significant toxicity compared to controls, unshaded portions indicate no significant toxicity.



**Figure 51.** Plot showing survival of *Eohaustorius* in RMP station sediment samples and the expected lower 95% confidence interval (CI) for survival based on previous studies using clean sediments of similar grain-sizes. (DeWitt *et al.* 1989.)

**Table 28.** Product moment correlation coefficients (*r*) between sediment toxicity endpoints and sediment characteristics. \* indicates significant value,  $\alpha=0.05$ ,  $n=8$

Sampling Period	<i>Eohaustorius</i> survival %		<i>Mytilis</i> larvae survival development		<i>Crassostrea</i> larvae development
	March	Sept.	March		September
% Fine	-.71*	-.74*	.33	.31	.79*
TOC	-.26	-.74*	.05	.08	.86*
TN	-.73*	-.83*	.64*	.60	.93*



pared to home sediment. The other station that was non-toxic compared to home sediment (BA20 in September) is below the line.

Both *Mytilus* larval endpoints were significantly different from control at three stations, Grizzly Bay (BF21) and the river stations (BG20, BG30). One of the *Mytilus* larval endpoints (survival or development) was significantly lower than controls at all stations except for Yerba Buena (BC11) and Extreme South Bay (BA21). Both tests, and all 3 endpoints (amphipod mortality, mussel survival and development) indicated significant toxicity at Grizzly Bay (BF21) and Sacramento River (BG20).

During the September sampling period, all RMP stations tested, except the San Joaquin River station (BG30), showed significantly reduced amphipod survival. Significantly lower development by oyster larvae exposed to elutriates occurred at the three most upstream stations, Grizzly Bay (BF21) and the river stations (BG20, BG30). Both amphipod mortality and oyster development were significantly reduced at BF21 and BG30.

Amphipod survival was systematically lower in March than in September, including the controls. The reasons for this apparent seasonal difference in not known.

Overall, there was a general trend for more toxicity in the northern estuary than in the South Bay. Four to five of the five endpoints (both times, all endpoints) indicated toxicity at most upstream stations; sediment at Grizzly Bay (BF21) was toxic in all tests, each time sampled.

The four endpoints used were variously correlated to sediment type at the RMP stations (Table 28). Amphipod survival was usually significantly correlated with percent fines, TOC (except in March), and TN in sediments. The two mussel endpoints were not significantly correlated with any sediment parameters, but oyster development was significantly correlated with fines, TOC, and TN in sediments.

## Discussion of Sediment Toxicity

Interpretation of the results of sediment toxicity testing from 1993 have several limitations. Most importantly, for the amphipod tests, a San Francisco Estuary “control” needs to be utilized. Although the use of previous

data (Figure 51) facilitates interpretation, comparisons of survival on fine Estuary sediments rather than survival on coarse Yaquina Bay sediment would be an improvement. The San Francisco Bay Regional Board is currently evaluating several prospective reference sites for such use.

The use of saltwater elutriates of freshwater sediments from the Sacramento and San Joaquin Rivers also confounds interpretation.

The apparent toxicity of sediments in the Estuary has been reported in several previous studies, most recently in the BPTCP Pilot studies (Taberski *et al.* 1992). Particularly at sites where sediment contamination is low, most investigators believe that the toxicity may be caused by natural factors, perhaps algal toxins, but this has not been determined.

The question of which sediment components may be causing the observed sediment toxicity cannot be answered from monitoring data alone. Sediments are mixtures of numerous potential causative agents that tend to co-vary (several compounds all high at the same places) and even the most sophisticated numerical analytical methods usually cannot identify a single compound that could be a causative agent. Since many sediment contaminants were correlated with sediment types, correlations between toxicity endpoints and sediment types, as seen for the amphipod tests also confound interpretation. Strong evidence of cause would require additional dose-response testing to verify the results of any correlations, or rigorous toxicity identification evaluations.

Correlations between toxicity endpoints and trace contaminant concentrations in sediment are not presented in this report. The questions raised above, and the availability of limited information on sediment parameters (sediment characteristics, trace metals, and trace organics from September) precludes a more rigorous analysis of those relationships.

## Bivalve Bioaccumulation

Bioaccumulation is defined as the accumulation of a substance (usually a contaminant) in the tissues of an organism at levels greater than in the surrounding environment. This component of the Regional Monitoring Program includes measurements of bioaccumulation, condition, and survival in transplanted bivalves. Bivalves were collected from uncontaminated sites and transplanted to 11 stations in the Estuary during the wet season (February through May) and the dry-season (June through September). Contaminant concentrations in the animal's tissues, and the animal's biological condition 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 (see Methods for details).

It has long been known that bivalves will accumulate contaminants to 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) and others (Young *et al.* 1976; Wu and Levings 1980; Hummel *et al.* 1990; Martinic *et al.* 1992). Measurements of contaminant accumulation in transplanted bivalves provide the program with time-integrated measurements of water-borne contaminants. Unlike water samples taken at three distinct sampling events, bivalves are exposed to contaminants for 90-100 days.

In the absence of any established tissue contaminant standards for trace metal and organic contaminants, comparisons to Median International Standards (MIS) for human consumption, the National Academy of Sciences (NAS) contaminant level recommendations, and U.S. Food and Drug Administration (USFDA) action levels for trace organic contaminants are used. These tissue contaminant guidelines are used only for evaluation purposes. It should be stressed that no toxicological consequences can or should be ascribed to the bioaccumulation data, since few, if any human or ecosystem health

risk assessments have been undertaken based on bivalve contamination.

USFDA has issued action levels and a tolerance for harmful substances at or above which it will take legal action to remove contaminated fish or shellfish from the market. NAS developed recommendations for maximum concentrations of toxic substances in freshwater animal tissue to protect both the animals containing the toxic substance and any animals that prey on the contaminated organisms. Another set of guidelines which is suitable for comparisons with RMP bioaccumulation results is EPA's integrated risk information system (IRIS) data base which contains the reference doses and cancer potency values for some of the metals, PAHs, PCBs, and pesticides measured in RMP bivalves. The data base contains Clean Water Act criteria for tissue contaminant levels which are based on cancer risks above one in one million over a 70-year lifetime. Cancer risk can only be determined if consumption levels are known. No estimates of shellfish consumption have yet been obtained for the Bay Area, however. Median International Standards are not enforceable in the United States, but they do give an estimate of what other countries have decided are undesirable concentrations of trace elements in shellfish (Nauen 1983).

Discussion of the following results relies heavily on comparisons with historical data from other studies which utilized different methods.

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). The NOAA Status and Trends Program measured contaminant concentrations in resident mussels and oysters (O'Connor 1992). Wherever possible, comparisons are made between the RMP results and those of other investigators on similar deployment durations and sites.

Data generated for this component of the RMP are listed in Appendix Tables 2.17 to 2.20.

## Trace Metals

### Arsenic

Arsenic did not accumulate appreciably above  $T_0$  concentrations at any station in either the wet season or the dry season (Figure 52). Moreover, bivalves deployed at several stations had lower concentrations of arsenic

national Standard (MIS) of 1.4 ppm wet weight (or 9.8 ppm dry weight) during the wet season. Dry-season concentrations were higher than the MIS for all stations (including the source sites at Bodega Head, Tomales Bay, and Lake Isabella), except for the Dumbarton Bridge (BA 30), Yerba Buena (BC10), San Pablo Bay (BD20), and Napa River (BD50) stations. The IRIS data base indicates that bivalve concentrations at all stations were above



*Preparing to install bivalve anchors near Larkspur*

than did  $T_0$  specimens in the corresponding deployment period. Tissue concentrations throughout the Estuary ranged from 6.15 ppm dry weight at Davis Point (BD40) and 16.06 ppm in Grizzly Bay (BF20) during the wet season and 8.23 ppm at the Dumbarton Bridge station (BA30) to 18.60 ppm at Davis Point (BD40) and the San Joaquin River (BG30).

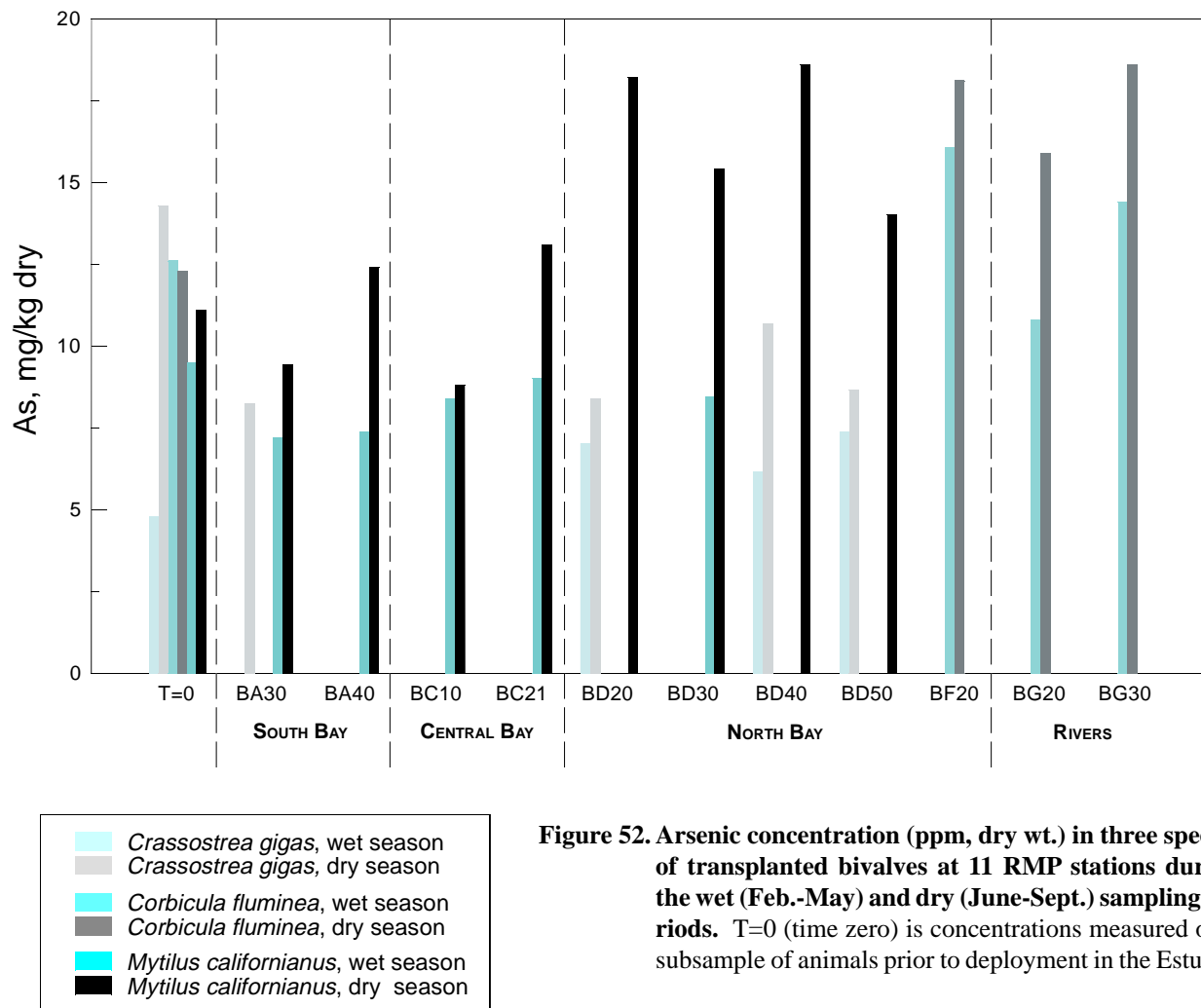
Arsenic concentrations in clams at the Sacramento and San Joaquin River stations (BG20, BG30) and in Grizzly Bay (BF 20) were higher than the Median Inter-

the recommended tissue levels for arsenic of 0.0175 ppb which is based on a one in one million estimated incremental increase of cancer risk over a lifetime.

### Cadmium

Bivalves at some stations accumulated cadmium above background levels, although results from the dry-season deployment suggest that the amount of accumulation varies inconsistently between bivalve species (Figure 53). Wet-season concentrations of cadmium in oys-

## Arsenic in Bivalve Tissues

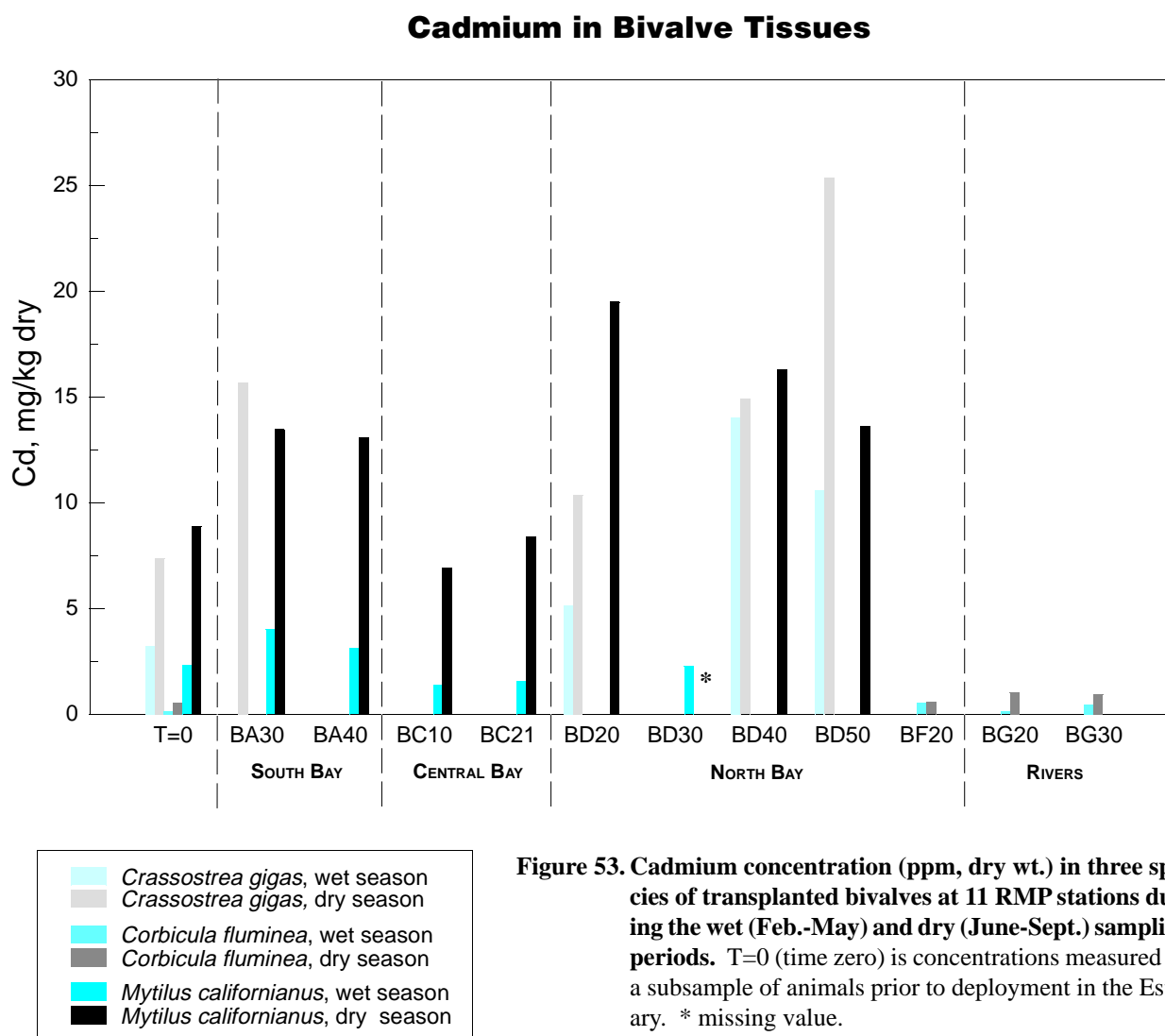


ters at Davis Point (BD40) and Napa River (BD50) and in clams in Grizzly Bay (BF20) and at the San Joaquin River station (BG30) exceeded  $T_0$  concentrations by approximately 3–6 times. During the dry-season deployment a 2–3 times elevation of cadmium concentrations occurred in oysters at the Dumbarton Bridge (BA30), Davis Point (BD40), and Napa River (BD50) stations (although not in mussels from this station), in clams in the Sacramento (BG20) and San Joaquin Rivers (BG30), and in mussels in San Pablo Bay (BD20) (although not in oysters from this station).

RMP results indicate that the relationship between oyster and mussel cadmium concentrations was highly variable. The highly inconsistent nature of cadmium bio-

accumulation among species is substantiated by comparable data from Stephenson (1992) and O'Connor (1992). No species-specific patterns can be discerned from any of the aforementioned studies. With the exception of the Napa River station (BD50), cadmium concentrations were generally consistent with those previously reported for transplanted bivalves in San Francisco Bay.

During the wet season, cadmium concentrations in bivalve tissue were higher than Median International Standards only at the Davis Point (BD40) and Napa River (BD50) stations. Dry season concentrations at all stations, except Yerba Buena Island (BC10), Horseshoe Bay (BC21), Grizzly Bay (BF20), and the River stations



**Figure 53. Cadmium concentration (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the wet (Feb.-May) and dry (June-Sept.) sampling periods.** T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary. \* missing value.

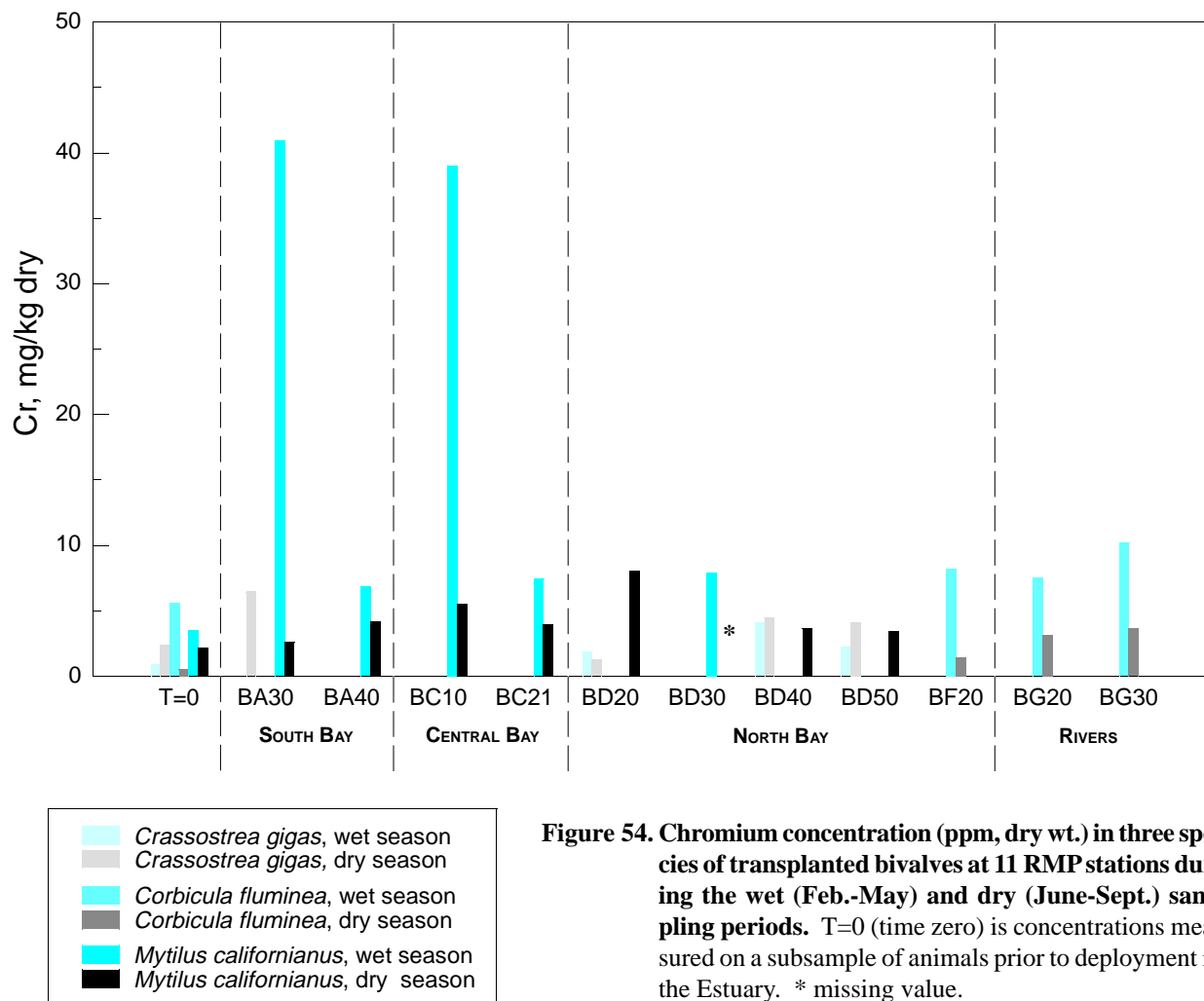
(BG20, BG30), were higher than Median International Standard of 7 ppm dry weight, by a factor of two to three.

### Chromium

Chromium concentrations were generally higher at all stations during the wet-season deployment than during the dry-season deployment, although this was not true for oysters at the Davis Point (BD40) and Napa River (BD50) stations (Figure 54). Mussels at the Dumbarton Bridge, Yerba Buena Island, Horseshoe Bay, and Richardson Bay stations (BA30, BC10, BC21, BC30) accumulated chromium during the wet-season to levels two to ten times higher than those prior to deployment, with the highest concentrations of 40.9 and 39.0 ppm

noted at Dumbarton Bridge (BA30) and Yerba Buena Island (BC10), respectively. Oysters exhibited similar increases in chromium concentrations, with the Davis Point (BD40) station being the highest at ten times the Tomales Bay background concentration. Bioaccumulation of chromium to more than twice the  $T_0$  concentration was noted during the dry-season deployment at the Dumbarton Bridge (BA30) station for oysters but not for mussels, and at the San Pablo Bay (BD20), Grizzly Bay (BF20), and River (BG20, 30) stations. The dry-season concentrations at the latter three stations, however, were lower than the wet-season concentrations. Generally higher concentrations of chromium during the wet-season deployment compared to the dry-season de-

## Chromium in Bivalve Tissues



**Figure 54. Chromium concentration (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the wet (Feb.-May) and dry (June-Sept.) sampling periods. T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary. \* missing value.**

ployment is consistent with the association between chromium and particles suspended in the water column during high storm flows.

With several exceptions, the concentrations of chromium were similar to those previously reported for all three species of transplanted bivalves from San Francisco Bay and Delta sites (Phillips 1988; Stephenson 1992). However, the wet-season values for mussels from the Dumbarton Bridge (BA30) and Yerba Buena Island (BC10) stations exceeded all previous values by approximately 7 times.

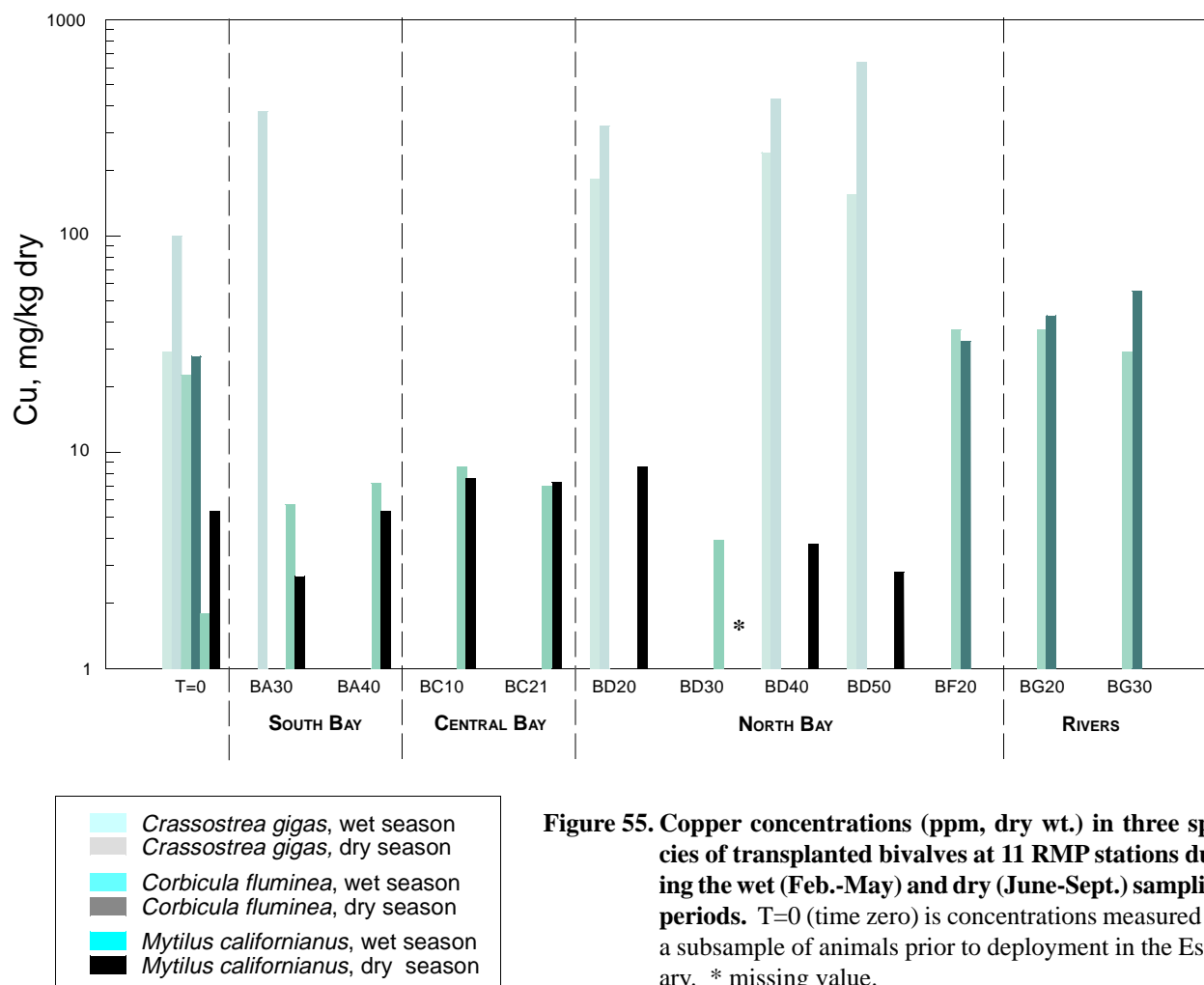
No MIS values for chromium exist.

## Copper

Spatial patterns of copper bioaccumulation were species-specific (Figure 55). Bioaccumulation occurred in oysters at levels five to eight times  $T_0$  concentrations during the wet season deployment at all sites, and in mussels at levels two to four times above pre-deployment concentrations. Clams did not show notably higher copper concentrations than prior to their deployment. Only oysters accumulated copper during the dry-season deployment (between three and six times background concentration).

The concentrations of copper were generally within the historic ranges for bivalves transplanted to the San Francisco Estuary (Phillips 1988; Stephenson 1992), al-

## Copper in Bivalve Tissues



**Figure 55. Copper concentrations (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the wet (Feb.-May) and dry (June-Sept.) sampling periods. T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary. \* missing value.**

though the dry-season concentration in oysters at Napa River station (BD50) exceeded those previously reported. Copper concentration in oysters exceeded those in mussels from the same stations by an average factor of 130, compared to the factors of 32 and 25 by which oysters exceeded mussels, as reported by O'Connor (1992) and Stephenson (1992), respectively (Table 29).

Most Estuary concentrations of copper in bivalves were below standards set by various countries. Only oysters in San Pablo Bay (BD20), at Davis Point (BD40), and the Napa River (BD50) during both deployment periods, and at Dumbarton Bridge (BA30) during the dry season, were higher than Median International Standards.

## Lead

Lead concentrations were higher during the dry-season deployment at all stations except for the Grizzly Bay station (Figure 56). During the dry-season, however, relative increases in lead concentrations were lower than during the wet season deployment with only the San Pablo Bay (BD20) station showing an appreciable increase of 2.7 times above background. Wet-season lead concentrations for mussels ranged from a low of 0.02 ppm at Point Pinole (BD30) to a high of 2.16 ppm at Redwood Creek (BA40), with initial pre-deployment concentrations of 0.45 ppm. Increases of lead concentrations during the wet season between two and four times occurred at all stations and all species, with the excep-

## Lead in Bivalve Tissues

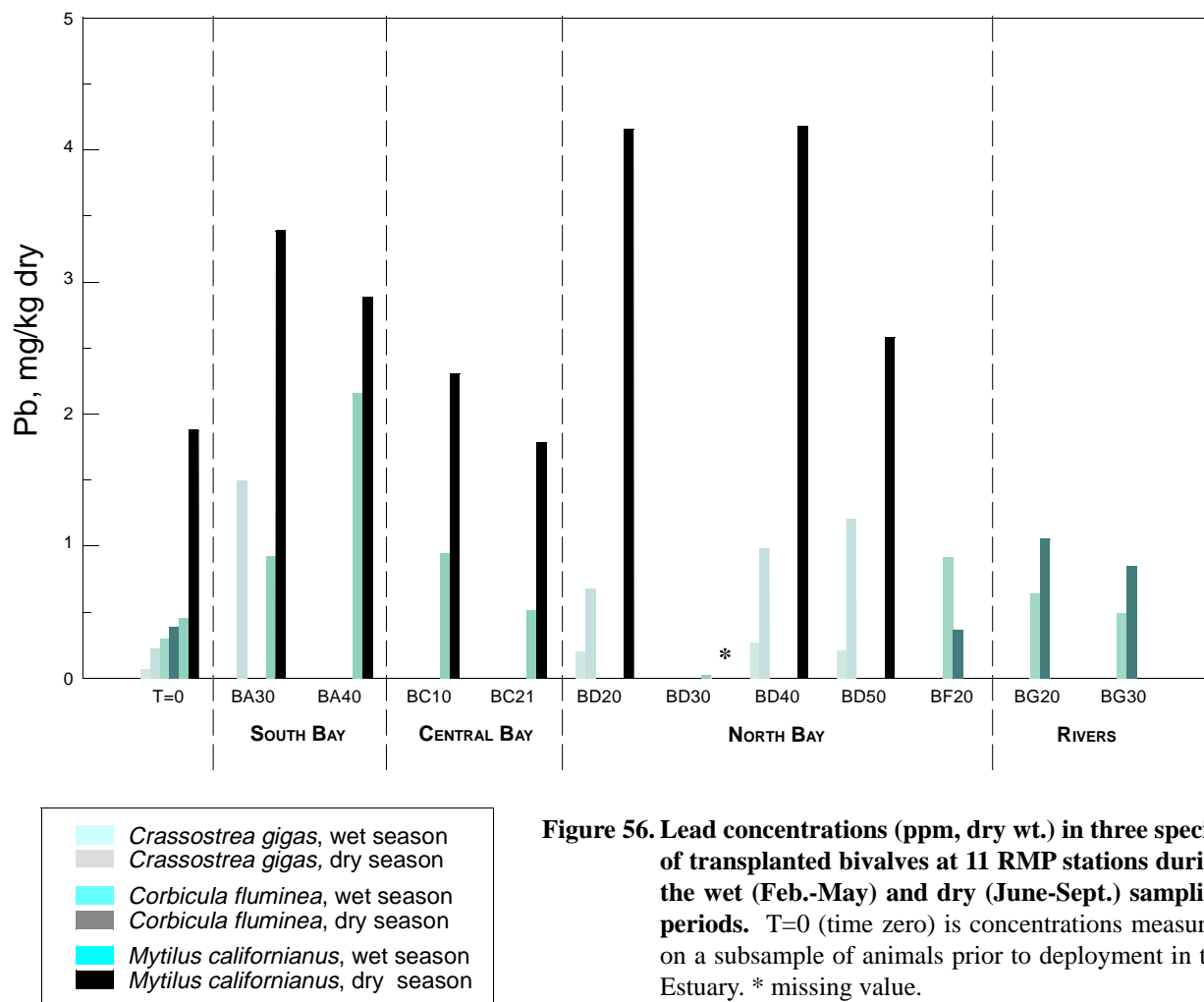


Figure 56. Lead concentrations (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the wet (Feb.-May) and dry (June-Sept.) sampling periods. T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary. \* missing value.

tion of Horseshoe Bay (BC10) and Point Pinole (BD30) for mussels and the San Joaquin River (BG30) station for clams.

Lead concentrations are similar to those reported previously for all three bivalve species from similar sites in the Estuary (Phillips 1988; Stephenson 1992), except that the concentrations for the River stations are approximately half those of Stephenson (1992). Concentrations of lead in mussels exceeded those in oysters by an average of four times, virtually identical to the factors reported by O'Connor (1992) and Stephenson (1992).

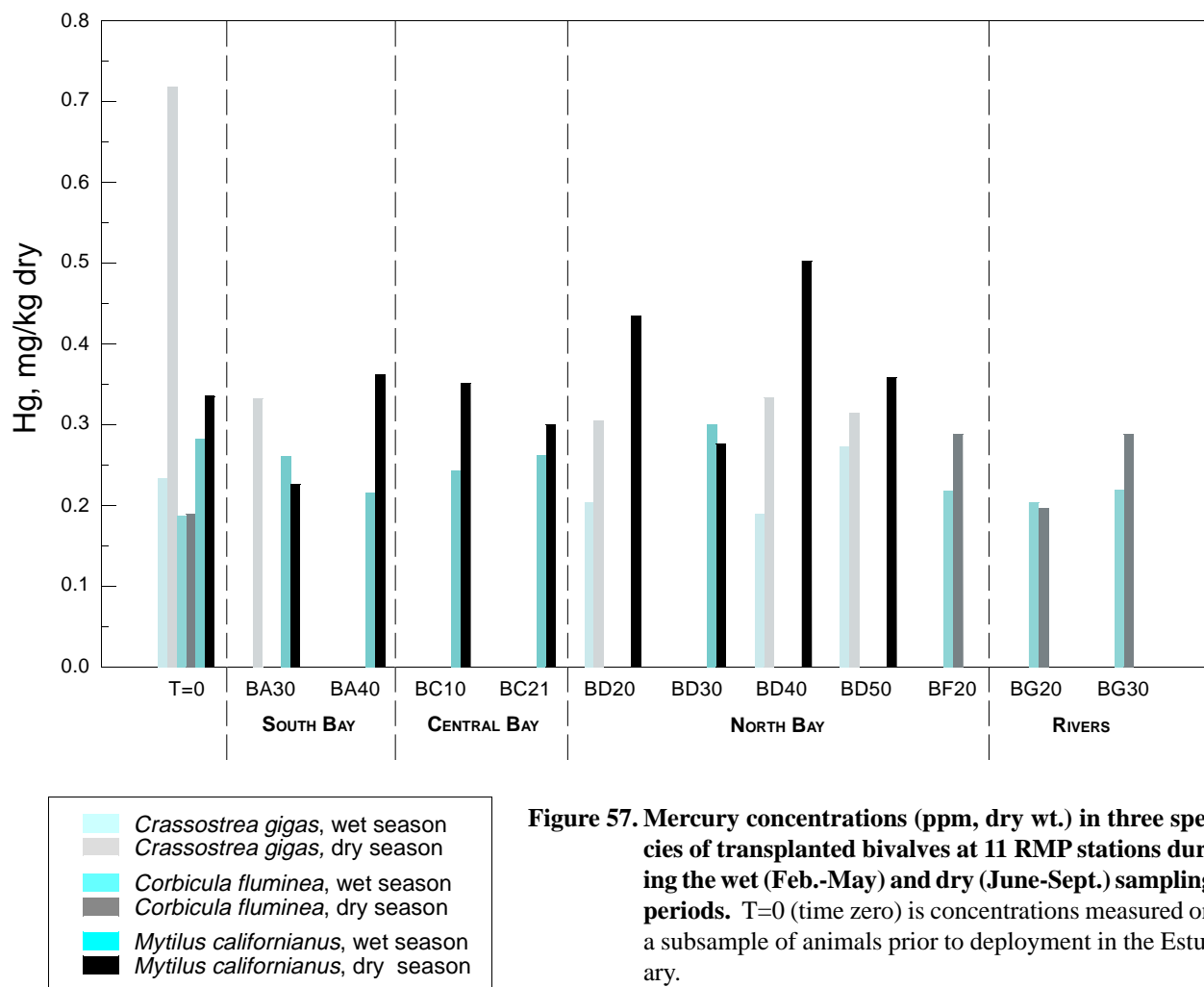
All RMP stations exhibited considerably lower lead concentrations than the Median International Standard of 14 ppm dry weight.

## Mercury

There was no consistent pattern of temporal variation in mercury concentrations among stations, nor did bioaccumulation occur (Figure 57). Concentrations ranged from 0.187 to 0.434 ppm dry weight. Moreover, mercury concentrations in all three species of transplanted bivalves were well within ranges reported by Phillips (1988) and Stephenson (1992), although the dry-season  $T_0$  concentrations for oysters were much higher than other reported control values (Stephenson, 1992). Concentrations of mercury in mussels exceeded those in oysters by an average factor of 1.3, although oysters exceeded mussels at the Dumbarton Bridge station (BA30). This



## Mercury in Bivalve Tissues



**Figure 57. Mercury concentrations (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the wet (Feb.-May) and dry (June-Sept.) sampling periods.** T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary.

is similar to the factors of approximately 1.5 and 1.8 times by which mercury concentrations were higher in mussels than in oysters, as reported by O'Connor (1992) and Stephenson (1992), respectively.

All stations were considerably below the Median International Standard for mercury of 3.5 ppm, but higher than the recommended Clean Water Act criterion for tissue consumption of 0.146 ppb.

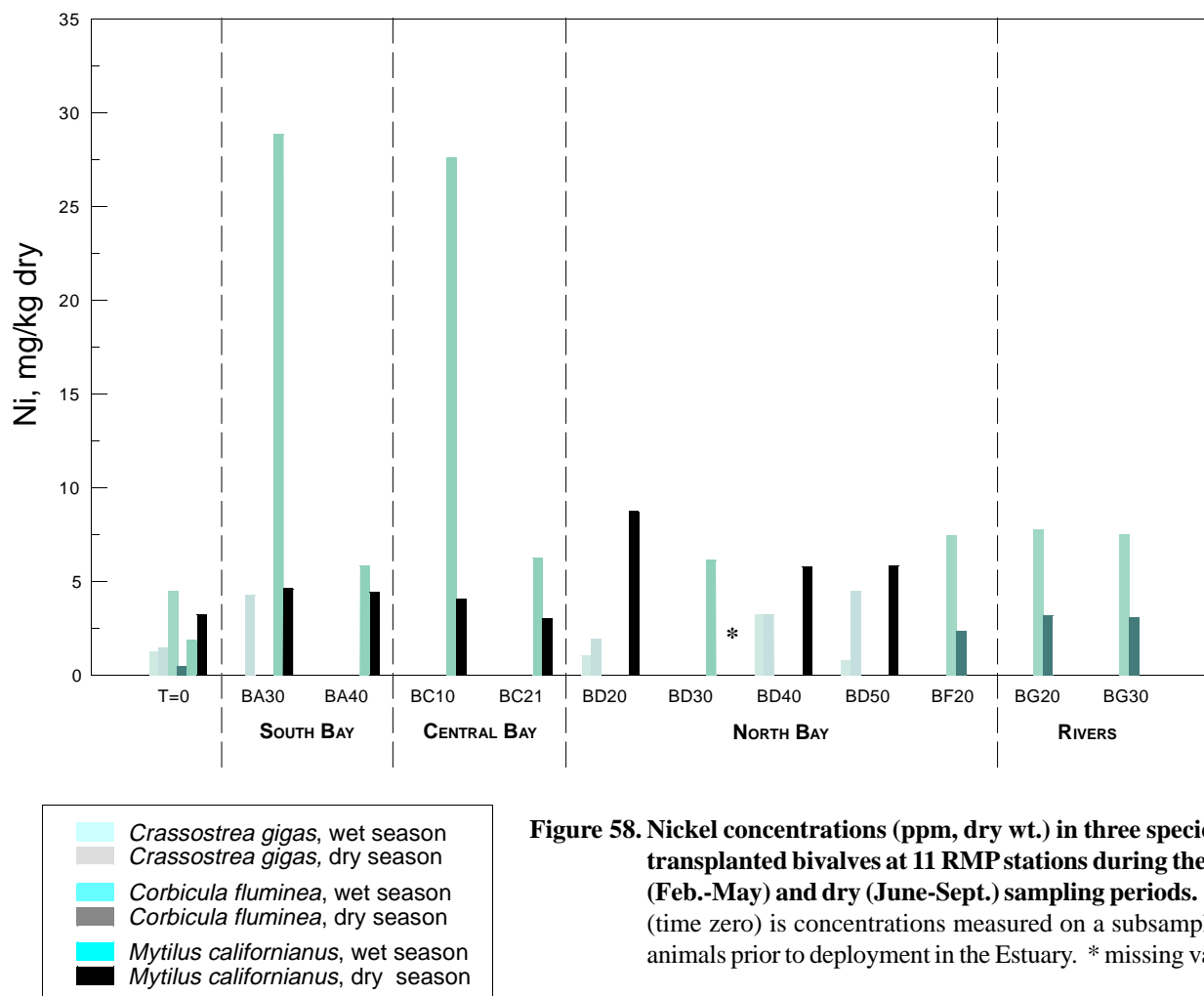
### Nickel

The spatial and temporal patterns of nickel bioaccumulation were very similar to those for chromium (compare Figure 54 and Figure 58). Nickel concentrations were higher at all stations during the wet-season

deployment than during the dry-season deployment, although this was not true for oysters at the San Pablo Bay (BD20), Davis Point (BD40), and Napa River (BD50) stations. Concentrations exceeding five times those in the T<sub>0</sub> specimens were measured during the wet-season deployment at the Dumbarton Bridge (BA30) and Horseshoe Bay (BC10) stations and during the dry-season deployment in San Pablo Bay (BD20) in mussels (but not in oysters).

Nickel concentrations are similar to historic ranges (Stephenson 1992) for transplanted mussels from San Francisco Bay, although the ratios for differences between mussels and oysters differ considerably from other findings.

## Nickel in Bivalve Tissues



**Figure 58. Nickel concentrations (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the wet (Feb.-May) and dry (June-Sept.) sampling periods. T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary. \* missing value.**

No international standards exist for nickel to which RMP results could be compared, but the recommended Clean Water Act criterion of 100 ppb was exceeded at all stations.

### Selenium

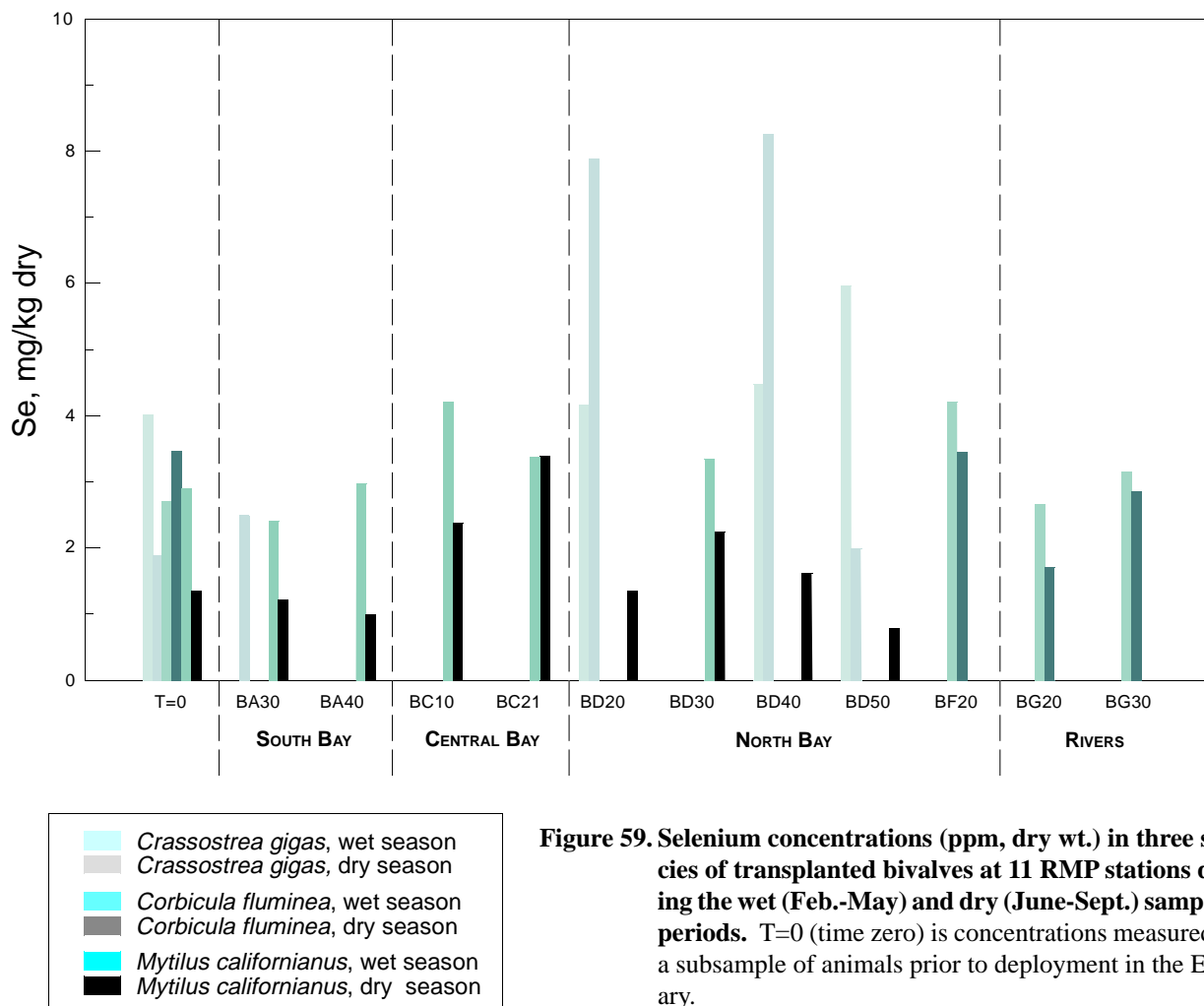
Bioaccumulation levels greater than twice the background occurred only during the dry-season deployment (Figure 59). Selenium concentrations in mussels ranged from 1.5 to 2.5 times those in  $T_0$  samples only at Yerba Buena (BC10), Horseshoe Bay (BC21), and Point Pinole (BD30) stations. Oysters accumulated selenium in San Pablo Bay (BD20) and Davis Point (BD40) at levels four times above background, with barely elevated concen-

trations noticeable at the Napa River (BD50) station. Selenium concentrations in clams were lower after than prior to deployment in Grizzly Bay (BF20) and the Rivers (BG20, 30).

Selenium concentrations in all three species of transplanted bivalves were similar to historical values reported by Phillips (1988) and Stephenson (1992), except that the dry-season concentrations in oysters from the northern estuary stations were nearly twice as high as values reported for the same area by Stephenson (1992).

During the wet season deployment, selenium concentrations were higher than the Median International Standard at all stations. Dry season concentrations were higher at all stations except at Dumbarton Bridge (BA30)

## Selenium in Bivalve Tissues



**Figure 59.** Selenium concentrations (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the wet (Feb.-May) and dry (June-Sept.) sampling periods. T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary.

where only mussels were below international standards, Redwood Creek (BA40), San Pablo Bay (BD20) (mussels only), Davis Point (BD40) (mussels only), the Napa River (BD50), and the Sacramento River (BG20) stations.

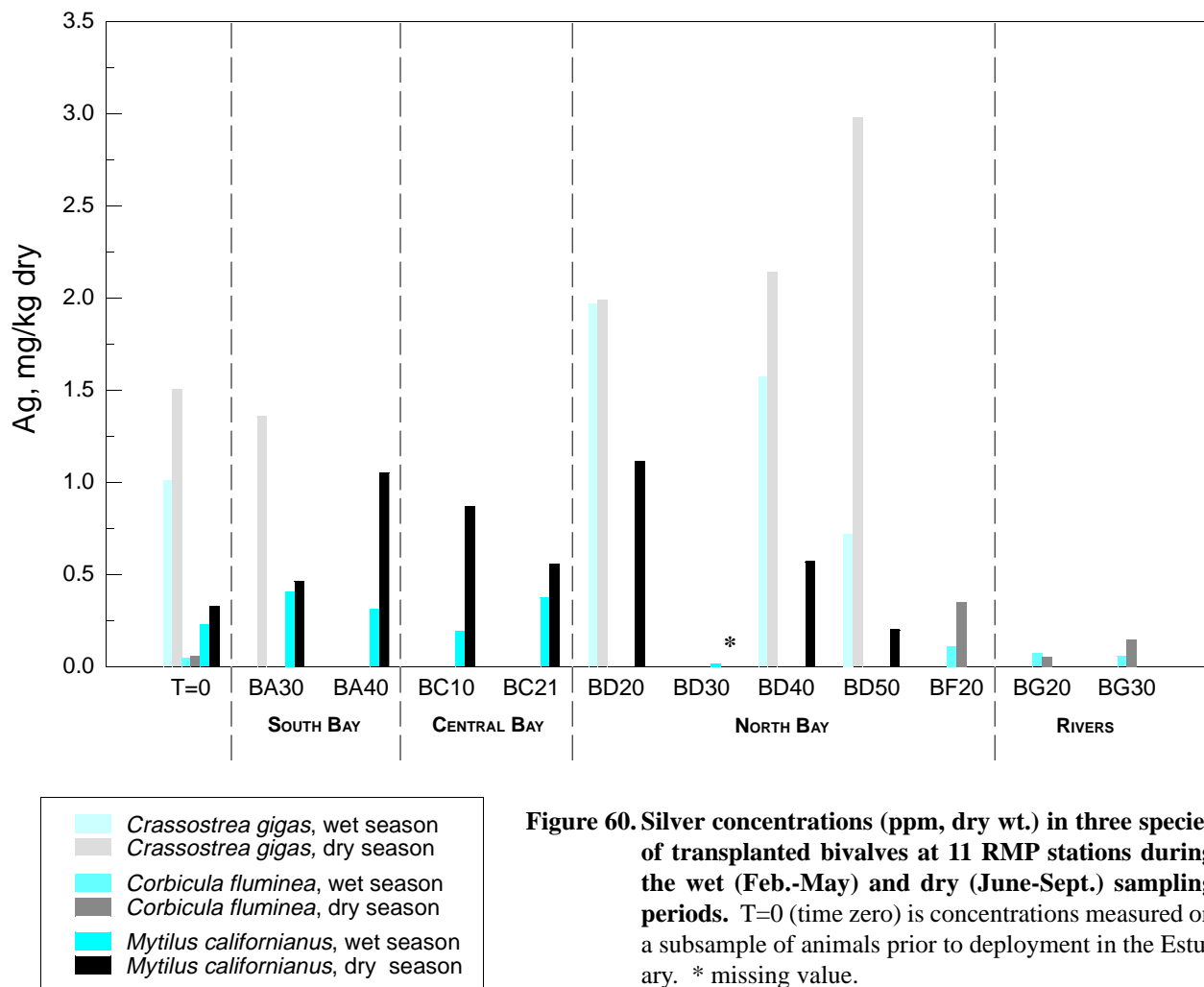
### Silver

Silver concentrations were generally greater in the dry-season deployment than in the wet-season deployment, and bioaccumulation was more prevalent during the dry-season deployment (Figure 60). Notable bioaccumulation between 2.5 and 8.5 times above background was observed during the wet-season deployment only in San Pablo (BD20) and Grizzly Bays (BF20), whereas

during the dry-season deployment mussels accumulated silver at Redwood Creek (BA40)(3 times background), Yerba Buena Island (BC10)(2.6 times background), and San Pablo Bay (BD20)(3.4 times background). Oysters accumulated about twice the background concentration at the Napa River (BD50) station, while clams accumulated silver to levels 2.6 and 5.8 times higher than background in Grizzly Bay (BF20) and the Sacramento River (BG20), respectively.

Silver concentrations in two of the three species of transplanted bivalves were similar to those previously reported. Concentrations in mussels were within the historical range of approximately 0.9–4.35 ppm reported by California State Mussel Watch (Phillips 1988), but

## Silver in Bivalve Tissues



**Figure 60. Silver concentrations (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the wet (Feb.-May) and dry (June-Sept.) sampling periods.** T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary. \* missing value.

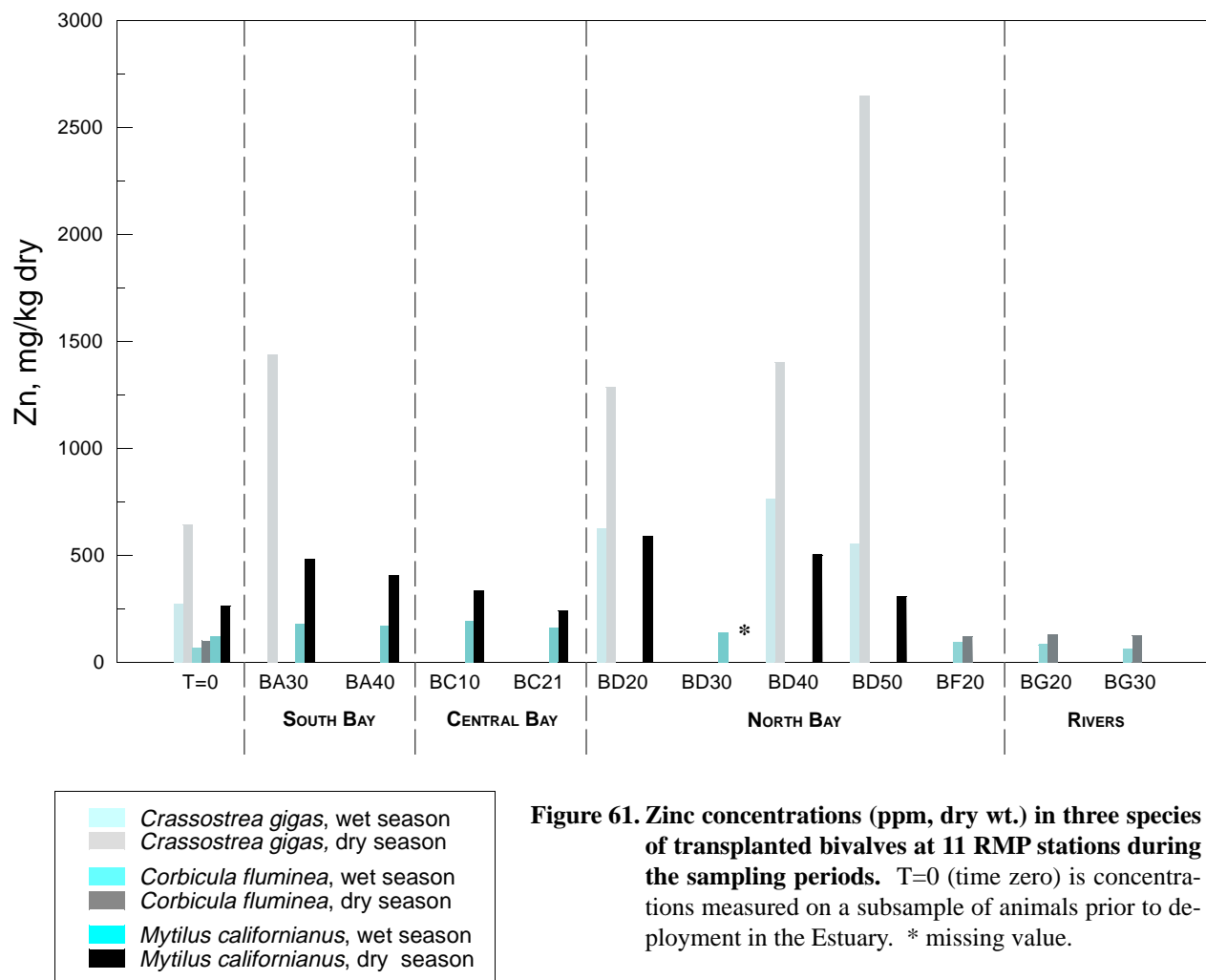
tended to be slightly higher than concentrations reported by Stephenson (1992). Data for clams were within the range of concentrations reported by Phillips (1988) and Stephenson (1992). RMP concentrations of silver in oysters were consistently lower than the 3.7 ppm minimum concentration found by Stephenson (1992). Silver concentrations were higher in oysters than in mussels from the same station, with an average factor of 4.7 for the differences. This compares to the factors of approximately 15 (O'Connor 1992) and 16.7 (Stephenson 1992) by which silver concentrations in oysters exceeded those in mussels.

No international standards exist for silver.

### Zinc

Zinc concentrations were greater in the dry-season deployment than in the wet-season deployment, with large differences occurring in the T<sub>0</sub> samples for oysters and mussels and at the Dumbarton Bridge, Redwood Creek, San Pablo Bay, and Napa River stations (Figure 61). Nevertheless, bioaccumulation occurred during both deployment periods. In the wet-season deployment, bioaccumulation at levels approximately twice the background concentrations occurred at the San Pablo Bay, Davis Point, and Napa River stations, and in the dry-season deployment only oysters but not mussels accumulated zinc at twice to four times the background level. Both oysters and mussels accumulated twice as much

## Zinc in Bivalve Tissues



**Figure 61.** Zinc concentrations (ppm, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the sampling periods. T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary. \* missing value.

zinc as shown at pre-deployment levels in San Pablo Bay and at Davis Point.

Some zinc measurements for mussels and oysters exceeded historical concentrations, although concentrations of zinc in clams were similar to those previously reported.

Zinc concentrations during the wet season were higher than Median International Standards of 490 ppm at only three stations (oysters in San Pablo Bay, at Davis Point, and the Napa River). The same phenomenon was observed during the dry season, with oysters exceeding the Median International Standard on a consistent basis at all stations where they were deployed, but mussel concentrations also exceeding the international standard of

490 ppm in San Pablo Bay (BD20) and at Davis Point (BD40).

## Discussion of Trace Metal Bioaccumulation

Given only one year of data and the constraints imposed on interpretation of spatial patterns by the use of three species in different parts of the Estuary, a discussion of results must be necessarily limited. Nevertheless, several points deserve emphasis. First, wet-season concentrations of chromium and nickel in mussels at the Dumbarton Bridge (BA30) and Yerba Buena Island

(BC10) stations were especially high. Concentrations of both metals were five to eight times greater than concentrations prior to deployment. Moreover, the concentrations of nickel at these stations exceeded historic values by approximately three times, and the concentrations of chromium exceeded historic values by approximately seven times. The dry-season zinc concentration in oysters at the Napa River (BD50) station was more than four times greater than the  $T_0$  concentration and twice the concentration measured from the same site during the Pilot Program. Concentrations of most other metals were generally within historic ranges. These results suggest several points regarding trace metals bioaccumulation in the San Francisco Estuary:

- Trace metal concentrations in transplanted bivalves may be more likely to exceed background concentrations by a great amount during the wet season in southern and central portions of the Estuary than in the dry season in those and other reaches.

- Wet-season concentrations of chromium and nickel and dry-season concentrations of zinc may be increasing over time at some stations in the Estuary, although more data are necessary to confirm this.

- Concentrations of nickel, chromium, copper, lead, and zinc are sometimes much higher at various locations in San Francisco Bay than they are at uncontaminated background locations.

Concentrations of several metals were similar to the Pilot Program (Stephenson 1992), and the NOAA Mussel Watch project (O'Connor 1992) with respect to differences in trace metal concentrations between mussels and oysters from the same locations (Table 29). Arsenic and lead were consistently higher in mussels than oysters in all three studies, by factors ranging from 1.1 to 2.2 for arsenic and 2.3 to 6.1 for lead. Conversely, copper, silver, and zinc were consistently higher in oysters in all three studies by factors ranging from 13 to 227, 1.8 to 73, and 2.2 to 40, respectively. For other metals, results from within San Francisco Bay (i.e. the RMP and the Pilot Program) generally displayed reasonably consistent differences between species, while the NOAA Mussel Watch project showed opposite species bioaccumulation ratios for chromium, nickel, and selenium.

The degree of comparability between species for many of the trace metals is noteworthy because it may allow consideration in design improvements once the data base has grown to a level that provides sufficient information for program review and revisions. At that time, issues such as time-bulking, use of the native oyster *Ostrea lurida*, changes in replication, the collection of environmental data at the bivalve sites, and analysis of whole organisms without gonad removal may benefit the program review.

## Trace Organics

Organic contaminants in bivalve tissues were measured during the wet and dry season. They fall into three general categories: polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides.

The following section includes reports of PAHs, PCBs, and pesticides expressed as sums of numerous component compounds measured for each type of trace organic contaminant. Concentrations of all individual trace organic compounds are listed in Appendix Tables 2.18 to 2.20. Trace organics results in bivalve tissues are available for the dry-season deployment only.

### Polynuclear Aromatic Hydrocarbons (PAHs)

PAHs are products from the incomplete combustion of petroleum products. They include numerous two to six ring compounds with varying solubilities and toxicities. Forty-three individual PAH compounds were measured in the RMP tissue samples. Their concentrations at each RMP station are listed in Appendix Table 2.18.

PAHs in mussel tissue ranged from 13.9 ppb at Davis Point (BD40) to 45.6 ppb at Horeshoe Bay (BC21), while concentrations in oysters ranged from 43.7 ppb in San Pablo Bay (BD20) to 203.9 at the Napa River (BD50). Clams ranged from 78.4 ppb in the San Joaquin River (BG30) to 102.9 ppb in Grizzly Bay (BF20) (Figure 62). The region from the Redwood Creek (BA40) station north to Yerba Buena Island (BC10), and the area around Davis Point (BD40) and the Napa River (BD50) had higher bioaccumulation of PAHs than the other locations in the Bay.

**Table 29. Comparisons between RMP and historical bioaccumulation data.**

Trace Metal	1993 RMP		Pilot Program (1)		NOAA (2)	
	Difference (3)	Factor	Difference (3)	Factor	Difference (3)	Factor
Arsenic	M>O	1.1	M>O	1.3	M>O	1.4
	M>O	2.2	M>O	1.1		
	M>O	1.7	M>O	1.1		
	M>O	1.6	M>O	1.6		
			M>O	1.5		
Cadmium	O>M	1.2	O>M	1.1	O>M	2.0
	M>O	1.9	M>O	1.2		
	M>O	1.1	M>O	1.4		
	O>M	1.9	M>O	1.2		
			M>O	1.2		
Chromium	O>M	2.5	M>O	5.4	M>O	5.6
	M>O	6.6	M>O	1.2		
	O>M	1.2	M>O	3.9		
	O>M	1.2	M>O	2.0		
			M>O	1.2		
Copper	O>M	141	O>M	20	O>M	32
	O>M	37	O>M	36		
	O>M	115	O>M	13		
	O>M	227	O>M	51		
			O>M	38		
Lead	M>O	2.3	M>O	3.5	M>O	3.7
	M>O	6.1	M>O	3.1		
	M>O	4.3	M>O	4.5		
	M>O	3.3	M>O	2.5		
			M>O	2.4		
Mercury	O>M	1.5	M>O	1.8	M>O	1.5
	M>O	1.4	M>O	1.6		
	M>O	1.5	M>O	2.5		
	M>O	1.1	O>M	1.4		
			M>O	1.2		
Nickel	M>O	1.1	NA (4)	NA (4)	O>M	3.0
	M>O	4.6				
	M>O	1.8				
	M>O	1.3				
Selenium	O>M	2.0	O>M	2.7	M>O	1.5
	O>M	5.9	O>M	1.5		
	O>M	5.1	O>M	1.2		
	O>M	2.5	O>M	2.7		
			O>M	1.7		
Silver	O>M	2.9	O>M	14	O>M	15
	O>M	1.8	O>M	31		
	O>M	3.8	O>M	12		
	O>M	15	O>M	48		
			O>M	73		
Zinc	O>M	3.0	O>M	3.6	O>M	40
	O>M	2.2	O>M	5.8		
	O>M	2.8	O>M	4.2		
	O>M	8.6	O>M	8.4		
			O>M	5.5		

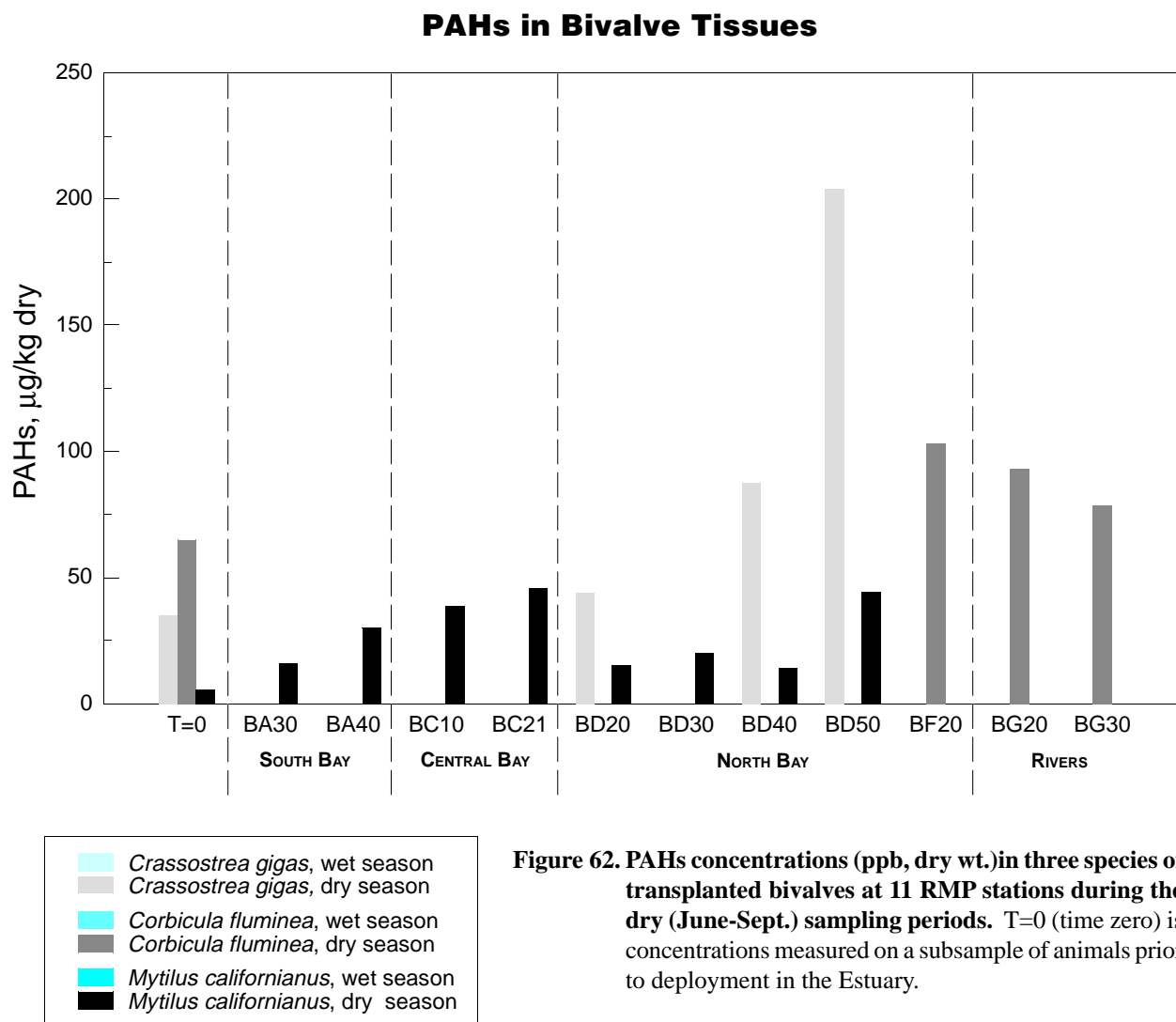
## Notes:

(1) = Stephenson 1992

(2) = O'Connor 1992

(3) = M&gt;O, mussels greater than oysters; O&gt;M, oysters greater than mussels

(4) = not analysed



**Figure 62. PAHs concentrations (ppb, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the dry (June-Sept.) sampling periods. T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary.**

This pattern is similar to that observed by Stephenson (1992). Moreover, the RMP results are similar to Stephenson's regarding the consistently higher concentrations of total PAHs in oysters than in mussels, but conflict with those of O'Connor (1992) who found that mussels exceeded oysters by a factor of 1.8.

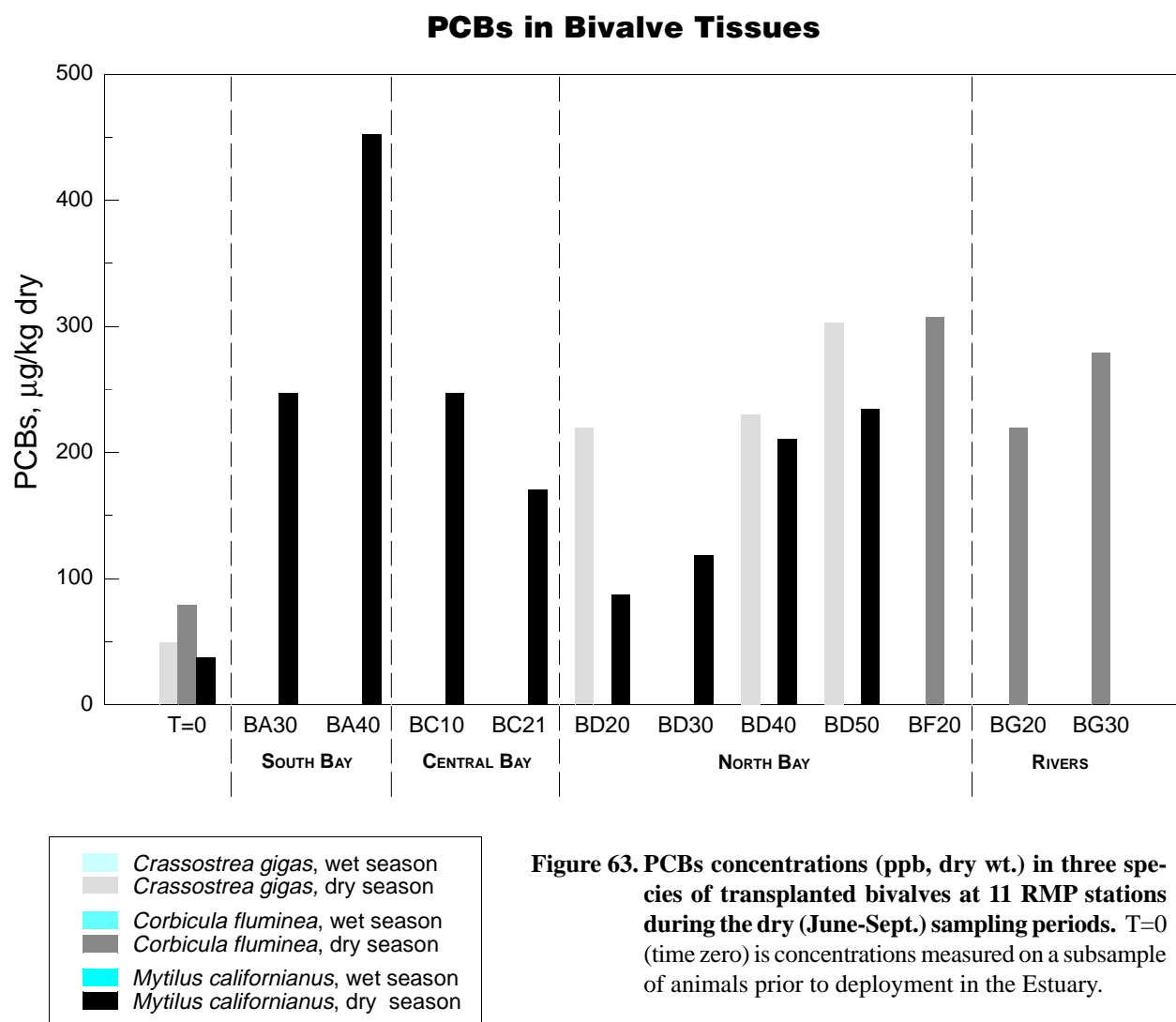
No USFDA or NAS guidelines exist for any PAH compounds. The IRIS data base, however, does contain tissue criteria for most of the PAHs measured. For example, the Clean Water Act criterion for anthracenes, pyrene, phenanthrene, fluorene, and acenaphthylene is 0.031 ppb in tissue. This criterion is based on a cancer risk of above one in one million cases from consuming

seafood tissue over a 70-year lifetime. All RMP stations showed concentrations above that level.

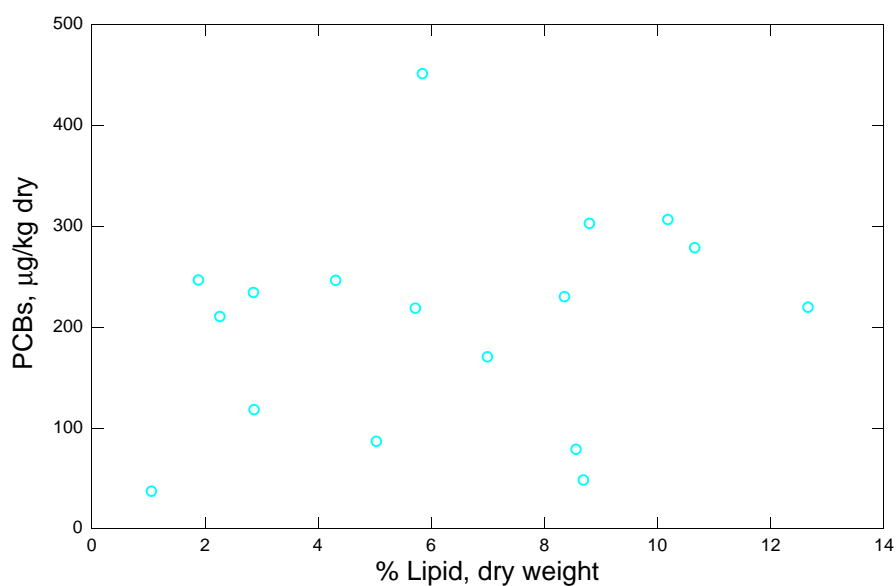
#### Polychlorinated Biphenyls (PCBs)

PCBs are a group of approximately 209 synthetic chlorinated hydrocarbon compounds, each called a congener. The use of PCBs is now severely restricted and slowly phased out, primarily because of highly toxic, carcinogenic, and teratogenic effects of many congeners. PCBs were used in a variety of industrial applications, including insulation in electrical capacitors and transformers, hydraulic fluids, paints, additives, adhesives, and caulking compounds. Like other chlorinated synthetic compounds, PCBs are very persistent in the envi-

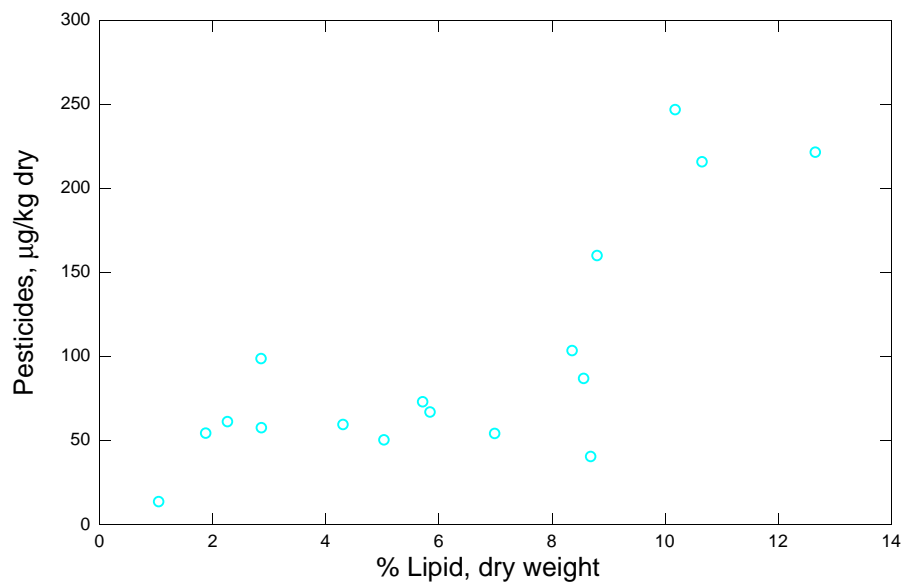
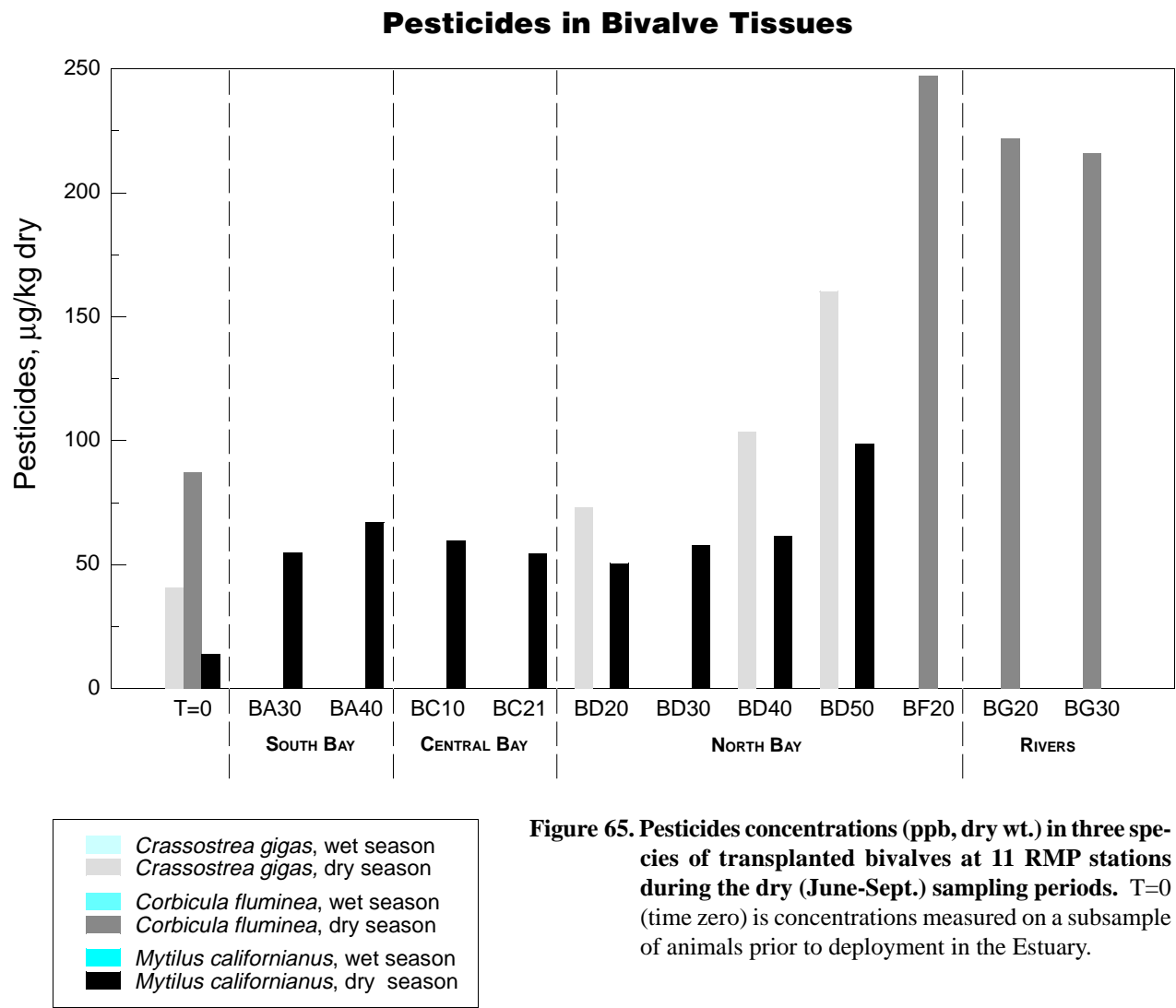




**Figure 63. PCBs concentrations (ppb, dry wt.) in three species of transplanted bivalves at 11 RMP stations during the dry (June-Sept.) sampling periods. T=0 (time zero) is concentrations measured on a subsample of animals prior to deployment in the Estuary.**



**Figure 64. Plot of PCBs versus lipid content of 3 species of transplanted bivalves at 11 RMP stations during the dry (June-Sept.) sampling periods.**



ronment and are biomagnified in the food web. Seventy-seven PCB congeners were analyzed in bivalve tissues and are listed in Appendix Table 2.19.

The available data from the 1993 dry-season show that PCBs bioaccumulated between two to twelve times above background levels in all three bivalve species at all locations (Figure 63). As Figure 64 shows, PCBs were poorly associated with the lipid fraction. Mussels represented the two extremes in tissue concentrations. Mussels deployed in San Pablo Bay (BD20) had PCB concentrations more than twice as high as those taken from the Bodega Head reference station and analyzed prior to deployment (87 ppb vs. 37 ppb), while those at Redwood Creek (BA40) accumulated PCBs at 12 times the background concentration (451 ppb vs. 37 ppb) (Figure 63). Central Bay, most northern estuary, and River Stations had intermediate concentrations between three and seven times above background.

Tissue concentrations of total PCBs at all stations were well below consumption guidelines established by USFDA (14 ppm dry weight) and below NAS recommendations (35 ppm dry weight). The IRIS data base indicates, however, that PCB concentrations at all locations exceeded the recommended criterion of 7.9 ppq for an estimated incremental increase of cancer risk of one in one million cases over a lifetime.

### Pesticides

Seven different pesticides and pesticide groups were measured in bivalve tissue at 11 stations. Unlike pesticides measured in water, only insecticides and no herbicides or fungicides were measured in tissue. The insecticide compounds are usually classified into several categories: chlordanes, DDTs, hexachlorocyclohexanes, aldrin, dieldrin, endrin, and mirex. Total pesticides in bivalves are expressed as the sum of these seven categories. Most of the pesticides measured in bivalve tissue are chlorinated compounds and have been banned or restricted in the U.S. for some time. However, like PCBs, they are extremely persistent in the environment and exhibit various toxicities and carcinogenicities. Pesticides are highly lipophilic in bivalves, as the strong correlation ( $r=0.76$ ) between total pesticides and lipid tissue content shows (Figure 66).

Total pesticides in September were highest in Grizzly Bay and the River stations (216 to 246 ppb dry weight)(Figure 65). All other stations exhibited intermediate concentrations between 45 and 90 ppb dry weight in mussels and up to 160 ppb in oysters. In side-by-side deployments of mussels and oysters, the latter species showed greater accumulation of all measured pesticides combined by an average factor of 1.8.

DDTs (7 isomers) were by far the greatest contributors to the total pesticide fraction in bivalve tissue for all species at all stations. DDT contributed 44% of the total pesticide fraction at the Napa River station (BD50) and a high of 79% at the Davis Point station (BD40) in oysters. Endrin and mirex were only rarely detected in trace quantities, while dieldrin was present in almost all samples at low levels (between 0.1 and 1.6 ppb at San Pablo Bay (BD20) and the Napa River station (BD50), respectively. It should be noted, however, that chlordane was accumulated by mussels and not by oysters in side-by-side deployments. This finding is in contrast with the Pilot Program (Stephenson 1992) which found a near one-to-one correspondence between mussels and oysters.

Pesticides in bivalve tissue did not occur in excess of USFDA guidelines of 2.1 ppm dry weight. As a pesticide example contained in the IRIS data base, dieldrin has a tissue consumption criterion of 71 ppq which represents a one in one million estimated incremental increase of cancer risk over a lifetime. All RMP stations exceeded this criterion.

## Discussion of Trace Organics Bioaccumulation

Unlike trace metal uptake by bivalves, trace organics uptake was more consistent, both among species and stations, indicating either a more uniform distribution of trace organics or different uptake and depuration kinetics. With the exception of chlordane in oysters, all other organic trace contaminants bioaccumulated to levels considerably above background concentrations at almost all stations.

The observed patterns confirm that trace organics are bioavailable throughout the Estuary. It serves as one of several measurement components that will assist in

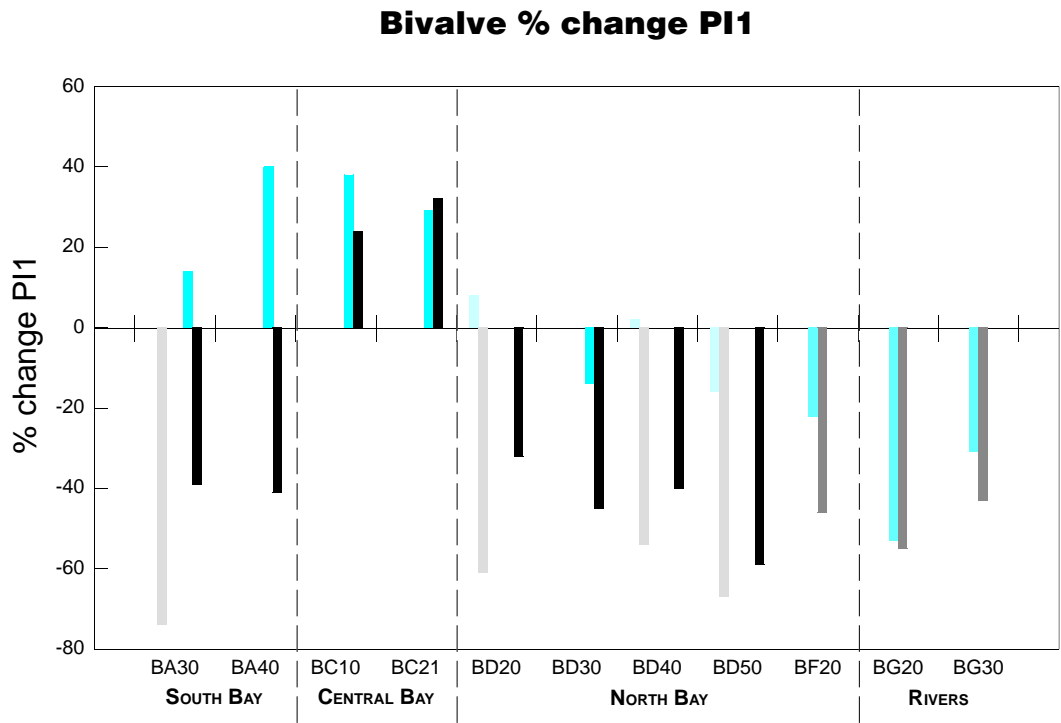


Figure 67. Percent change in the condition index PI1 in 3 species of transplanted bivalves following exposure to Estuary water during the wet (Feb.-May) and dry (June-Sept.) sampling periods.

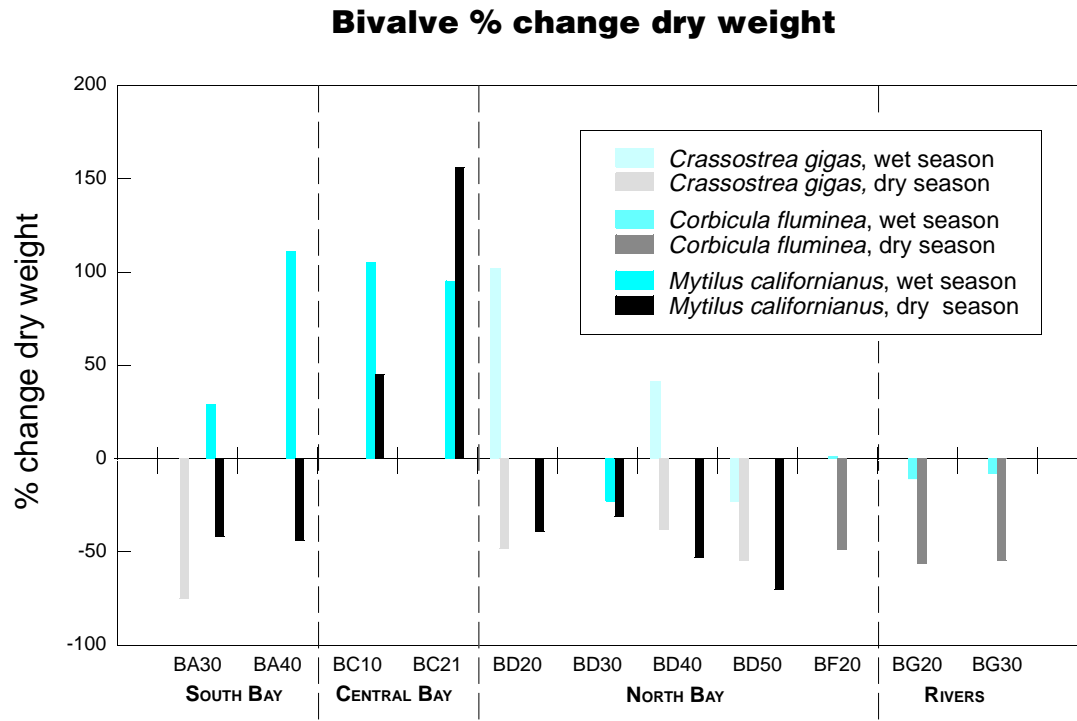
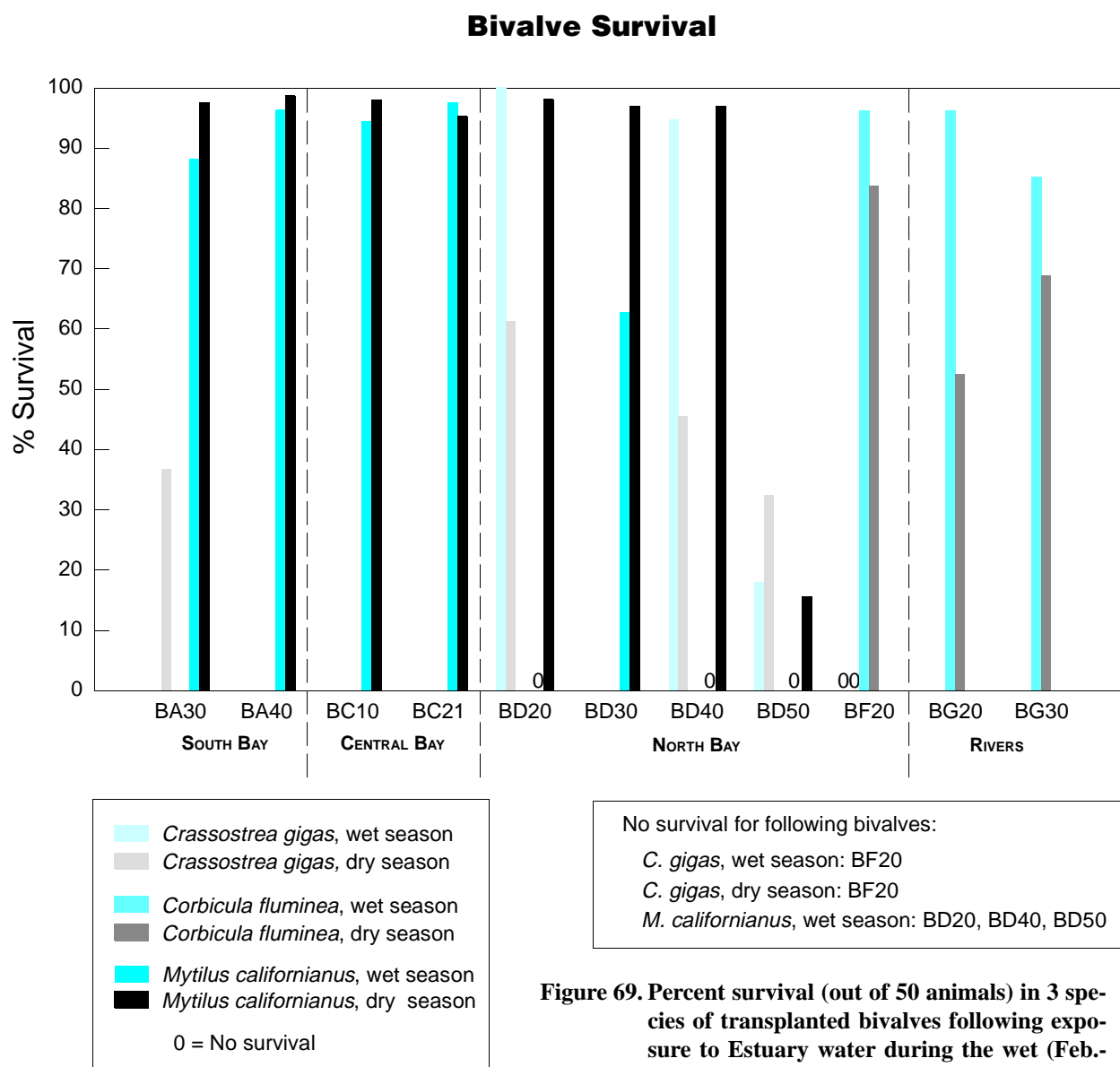


Figure 68. Percent change in tissue dry weight in 3 species of transplanted bivalves following exposure to Estuary water during the wet (Feb.-May) and dry (June-Sept.) sampling periods.



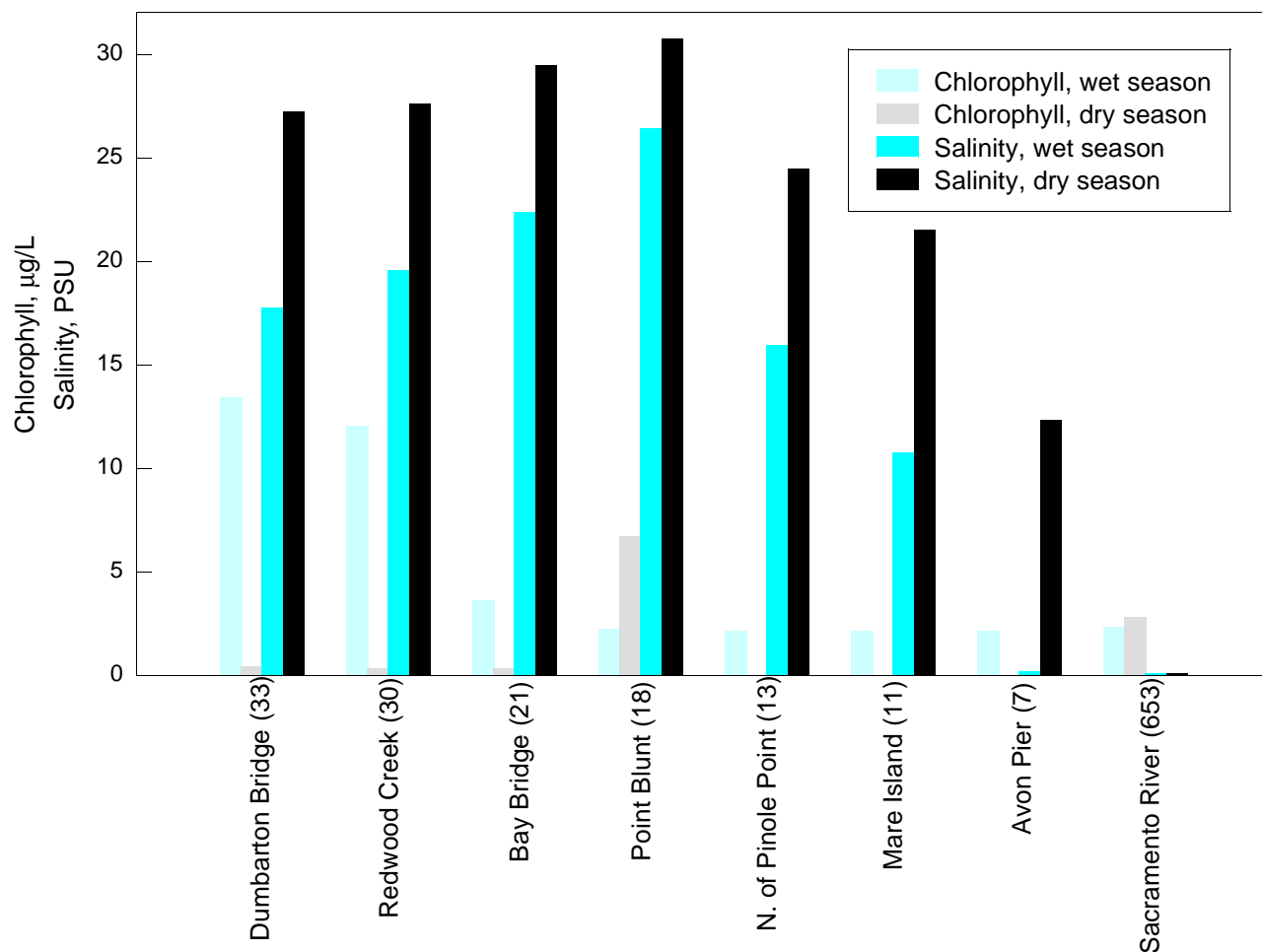
**Figure 69. Percent survival (out of 50 animals) in 3 species of transplanted bivalves following exposure to Estuary water during the wet (Feb.-May) and dry (June-Sept.) sampling periods.**

the interpretation of all information collected by the RMP. As with trace metals, statistical evaluation of station differences is not possible under the current design, since all bivalves were composited into one sample from each station, and therefore no variation estimates could be obtained.

Bioaccumulation by all three bivalve species was quite consistent with respect to PCBs, indicating that no equilibrium had yet been reached during the deployment

period. This is consistent with Pilot Program findings where time series experiments showed linear increases with time. Stephenson (1992) showed that PAHs, however, show decreases or leveling-off after two months of deployment, and this may explain the higher variation of 1993 PAH concentrations among the different bivalve species. The same phenomenon was observed with respect to chlordane, where oysters at two out of three stations actually had lower tissue concentrations than back-

### Chlorophyll and Salinity 1993



**Figure 70. Average (over all water column intervals in four months) chlorophyll *a* and salinity measured at USGS stations that correspond to RMP bioaccumulation stations.** (See summary of Pilot Study on Water Quality and Plankton, in this report)  
PSU= Practical Salinity Unit.

ground. Stephenson (1992) found that, unlike PCBs, chlordanes reached a peak concentration after two months and subsequently declined. The dry-season RMP samples were deployed for three months, which may explain the low oyster concentrations.

Time-series comparisons with older PCB data sets that are based on Aroclor mixtures are possible, although they potentially have large errors associated with them (Eganhouse and Gossett 1991). State Mussel Watch data

are based on Aroclor 1248, 1254, and 1260 mixtures, while RMP data are the sum of individual congeners. Generally, 1993 results were within the same historical range as reported by the California State Mussel Watch Program (Phillips 1988) and the more comparable data reported by Stephenson (1992) for the RMP Pilot. More rigorous comparisons between data sets will be conducted in the future as more RMP data become available.

## Bivalve Condition and Survival

The biological condition of transplanted bivalves following exposure to Estuary water provides evidence that the animals were healthy and capable of bioaccumulation, and of the effects of exposure on their general health. Bivalve condition was evaluated based on measurements of dry tissue weight and on a condition index, PI1, which is the ratio of dry tissue weight to shell cavity volume (Pridmore *et al.* 1990).

At most stations, bivalves decreased in condition (PI1) during both deployments, although increases in condition occurred during the wet-season deployment at the Dumbarton Bridge, Redwood Creek, Yerba Buena Island, Horseshoe Bay, and Davis Point stations (BA30, BA40, BC10, BC21, BD20, and BD40) (Figure 67). During the dry-season deployment, increases in the condition index occurred only at Yerba Buena and Horseshoe Bay (BC10 and BC21). Where no increases in PI1 were recorded, the decreases were least during the wet-season deployment, suggesting that environmental conditions were most favorable during the wet season.

Increases in dry tissue weight accompanied all increases in PI1, but increases in dry weight did not always result in increased PI1 (compare Figure 67 with Figure 68). These discrepancies may be explained by increases in shell size while the organisms were gaining little weight or even losing weight (Appendix Table 2.21). Such an increase in shell size with an accompanying decrease in tissue weight has previously been noted in bivalves transplanted into San Francisco Bay and was especially prevalent during the late summer (Kinetic Laboratories, Inc. 1984).

Bivalve survival was high at most stations, although some stations displayed consistently low survival (Figure 69). Survival of mussels was consistently near or above 90% at Dumbarton Bridge (BA30), Redwood Creek (BA40), Yerba Buena Island (BC10), and Horseshoe Bay (BC21) stations during both deployments, and in San Pablo Bay, Point Pinole, and Davis Point (BD20, BD30, and BD40) during the dry-season deployment. Dry-season survival of mussels at the Napa River station (BD50) was slightly greater than 15%. During the wet-season deployment, mussels had approximately 60%

survival at Point Pinole, but did not survive at the other northern estuary stations. Oysters had high wet-season survival at two of the northern estuary stations, but fewer than 20% of them survived at the Napa River station, and none survived in Grizzly Bay. During the dry-season deployment, oysters had less than 65% survival at Dumbarton Bridge, in San Pablo Bay, Davis Point, and Napa River, and did not survive in Grizzly Bay. Clams had greater than 85% survival at all stations during the wet-season deployment, with dry-season survival varying between 53–84%.

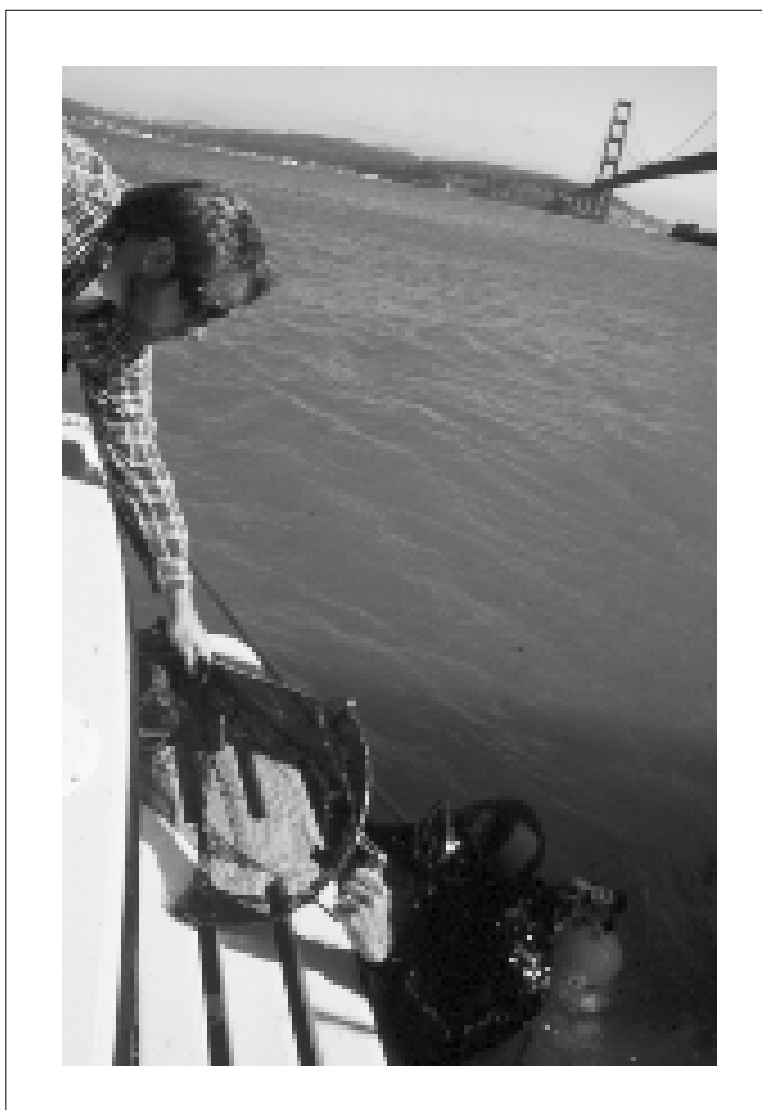
The 3 species used appeared to respond differently to exposure to Estuary water. To evaluate the influence of hydrographic conditions on PI1 and bivalve survival, salinity and chlorophyll data from the USGS Pilot Study (summarized in this report, data from Caffrey *et al.* 1994) were plotted for both bivalve deployment periods from stations representing channel locations throughout the RMP study area (Figure 70). PI1 values for mussels correspond to both salinity and chlorophyll levels. Condition of oysters did not correspond well with salinity but did correspond well with chlorophyll. Changes in PI1 and survival of clams were poorly related to salinity or chlorophyll.

The large decreases in PI1 and high mortalities for both oysters and mussels at the Napa River station did not appear to be associated with hydrographic conditions. However, evaluation of relationships and between survival and condition in these species and trace contaminant concentrations were not explored due to the limited data available. As with bioaccumulation, the effects of environmental factors such as salinity, temperature, and food availability on tissue weight and condition was not analyzed. Moreover, the effects on bivalves of being suspended above the bottom in mesh bags were not controlled. To do this would have required deployment of bivalves on moorings at the uncontaminated sites where they were collected. The natural condition of bivalves from the uncontaminated sites at the end of the dry-season deployment was not measured either. It is therefore possible that the general decreases in the condition of transplanted bivalves in the Estuary noted above was paralleled by decreases at the collection sites. The measurement of condition in bivalves from the uncontaminated

sites at the end of the dry-season deployment has been incorporated into the 1994 program.

It should also be noted that bivalve condition is closely linked to reproductive cycles. For example, *Corbicula* is known to lose up to 50% of its weight during reproduction (Foe, pers. comm.), which confounds con-

taminant body burden and condition measurements. Additional modifications to the bioaccumulation component, such as time bulking or transplanting immature clams for estimates of clam condition and contaminant uptake, may reduce these confounding factors considerably and facilitate interpretation of results.





# Pilot Studies

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## SAN FRANCISCO BAY/DELTA REGIONAL MONITORING PROGRAM PLANKTON AND WATER QUALITY PILOT STUDY, 1993

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### Introduction

The pilot program described here is motivated by a fundamental principle of the Regional Monitoring Strategy, namely "...the development of data that will provide information on status and trends in the Estuary." As pointed out in the Strategy, knowledge of status and trends serves two primary purposes: (1) to become aware of or anticipate deleterious conditions in the Estuary, and (2) to assess the effectiveness of management actions. This program addresses these two purposes by focusing on aquatic resources, one of the five key management issues identified by the Comprehensive Conservation and Management Plan and central to the Regional Monitoring Strategy. It also bears on at least two of the other management issues - pollutants and water use.

A regional monitoring program must cover many types of resources, including pelagic and benthic channel habitat, shoal habitat, wetlands, river channels, sloughs, and small bays and harbors. This particular program centers on the pelagic channel habitat. However, because of the intimate connection between channel habitat and many or most of these other habitats, channel measurements reflect to some extent the status of and trends in other resource types as well. A primary aim of this program is to provide a high-resolution description of critical aspects of habitat quality, which can be used along with other information (1) to determine the suitability of habitat for aquatic resources; (2) to monitor

responsiveness of the habitat to freshwater flow variability; and (3) to provide a context for understanding pollutant distributions. In a single transect, measurements are made throughout the water column at up to 37 stations to define physical (salinity, temperature, suspended particulate matter, and light penetration), chemical (dissolved oxygen) and biological (chlorophyll *a*) characteristics that influence both chemical and biological reactions.

A second aim of the program is to investigate planktonic indicators of ecosystem structure and function. Phytoplankton *production* is the major single source of energy for the San Francisco Bay food web. Our measurements of chlorophyll and light penetration can be used to provide an estimate of this production, and therefore the availability of food for organisms at higher trophic levels. Phytoplankton *community composition* at the species level, which can be a sensitive indicator of habitat change, is also a standard component of this program. Community composition data enable detection of species known to be responsible for harmful or nuisance algal blooms. In 1993, two other indicators were also evaluated, *photosynthetic parameters* and *water column respiration*. Photosynthetic parameters partially characterize the physiological state of the phytoplankton and may provide indirect evidence of nutrient deficiency or the effects of pollutants. Water col-

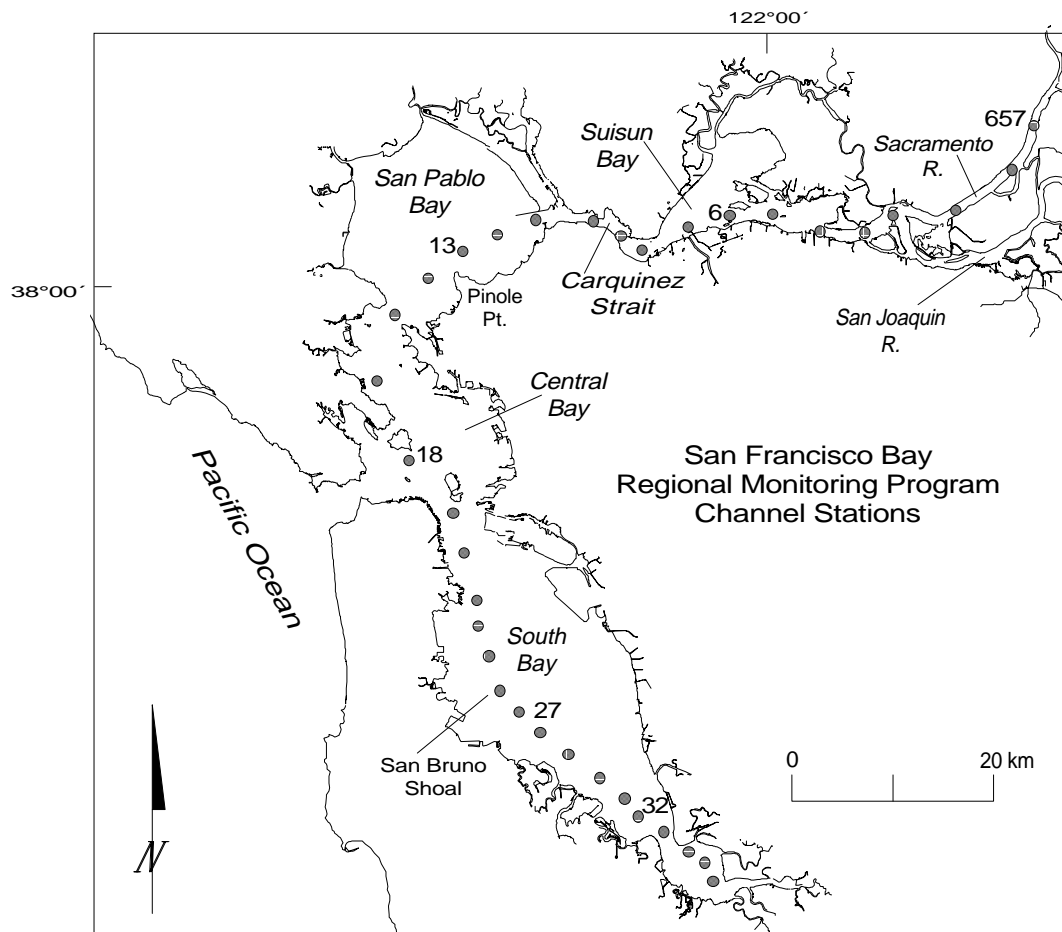
umn respiration serves as a simple integrated measure of organic matter metabolism by the plankton, including bacteria, phytoplankton, and microzooplankton. It therefore reflects the total supply of organic matter, whether from photosynthesis, tidal marsh efflux, point sources, or upstream in the Delta. These biological indicators therefore contain much information about the flow of energy into the food web.

## Sampling Methods

Samples were taken monthly near the time of neap tide. Tidal mixing has strong effects on certain properties of the estuary such as salinity distribution, creating variability that can obscure climatic, anthropogenic and

other effects. Sampling times must therefore be chosen to minimize tidal sources of variability. Not much can be done regarding the semidiurnal tidal cycle, as cruises must start from a fixed location in the early morning. Effects of the lunar cycle, on the other hand, can be removed by scheduling monthly cruises to coincide with the neap tide. This schedule also minimizes the effect of semidiurnal tides by choosing the smallest such tidal cycle every month.

Sampling stations were located along the axis of the Estuary from near the mouth of Coyote Creek to Rio Vista on the Sacramento River (Figure 1). Up to 37 stations were sampled on each cruise. The distance between stations ranged from approximately 1 to 8 km. This initial array of stations was chosen primarily to maintain continuity with the historical data set for the Bay, but the



**Figure 1. Regional Monitoring Program Sampling Stations.** Vertical profiles were done at 1-8 km intervals in the central channel. Numbered stations mark the location of supplementary measurements for several biological indicators.

**Table 1. Variables measured during the 1993 RMP pilot study.**

CTD variables:	salinity temperature depth suspended particulate matter light penetration dissolved oxygen chlorophyll a
biological indicators:	phytoplankton community composition photosynthetic parameters water column respiration

exact number and locations will shift in response to ongoing analysis of the sampling design.

At each station, a vertical profile of several habitat indicators was obtained from a variety of electronic probes mounted on a common frame and lowered through the water. The term “CTD” is usually used to describe the entire electronic data acquisition package (Table 1). As each probe has a different response time, the vertical resolution ranges from centimeters (suspended particulate matter) to meters (dissolved oxygen). The other biological indicators are much more expensive and time-consuming to perform and so they were measured less often and at fewer stations: on alternate months, they were measured in near-surface water from six stations (657, 6, 13, 18, 27, 32; Figure 1). Detailed methods and measurement values are described in U.S. Geological Survey Open-File Report 94-82.

## Habitat Characterization

### Introduction

As mentioned above, a primary purpose of this program is to provide an ongoing record of physical, chemical and biological characteristics of San Francisco Bay. This record serves three purposes. First, it gives us a current summary of habitat quality—the “status” of the Bay—which we define to be a picture of the spatial and temporal variation *within* the current year. Knowledge of this unfolding status alerts us to unusual phenomena

that may require deeper consideration. Can we observe any unusual zones of oxygen depletion? Do local build-ups of chlorophyll signal the onset of nuisance blooms? Are there temperature “hotspots” that could interfere with fish movements? Such information affords us the ability to act swiftly in response to perceived problems and short-term changes (i.e., on the scale of months or seasons) in Bay conditions. Eventually, monthly results could be provided in a timely fashion and in an easily interpretable form to interested parties, as a kind of monthly “weather report.”

A second purpose of the program is to provide a longer-term picture of “trends” in the Bay, by which we mean interannual and longer-term variability. As the monitoring results build up over several years, a picture will begin to emerge about change on the scale of years. Considerably more and more careful interpretation and planning is required to ensure the success of this goal. Measurements are affected by many sources of variability, including those arising from sample collection, processing and analysis; semidiurnal tidal cycles; time of year and spatial location; as well as the differences among years due to natural environmental variability and human activity. One of our goals is to determine the sampling design – spatial location and temporal frequency – that can isolate the latter source of variability and offer an objective picture of long-term trends in the status of the Bay.

Finally, a monitoring program should also be expected to provide clues to the mechanisms underlying

both the status and the trends. This will involve analyses of the data that provide additional descriptions of structure within and among various variables. Without an understanding of these mechanisms, it will be impossible to understand the real significance of, for example, pollutant concentrations.

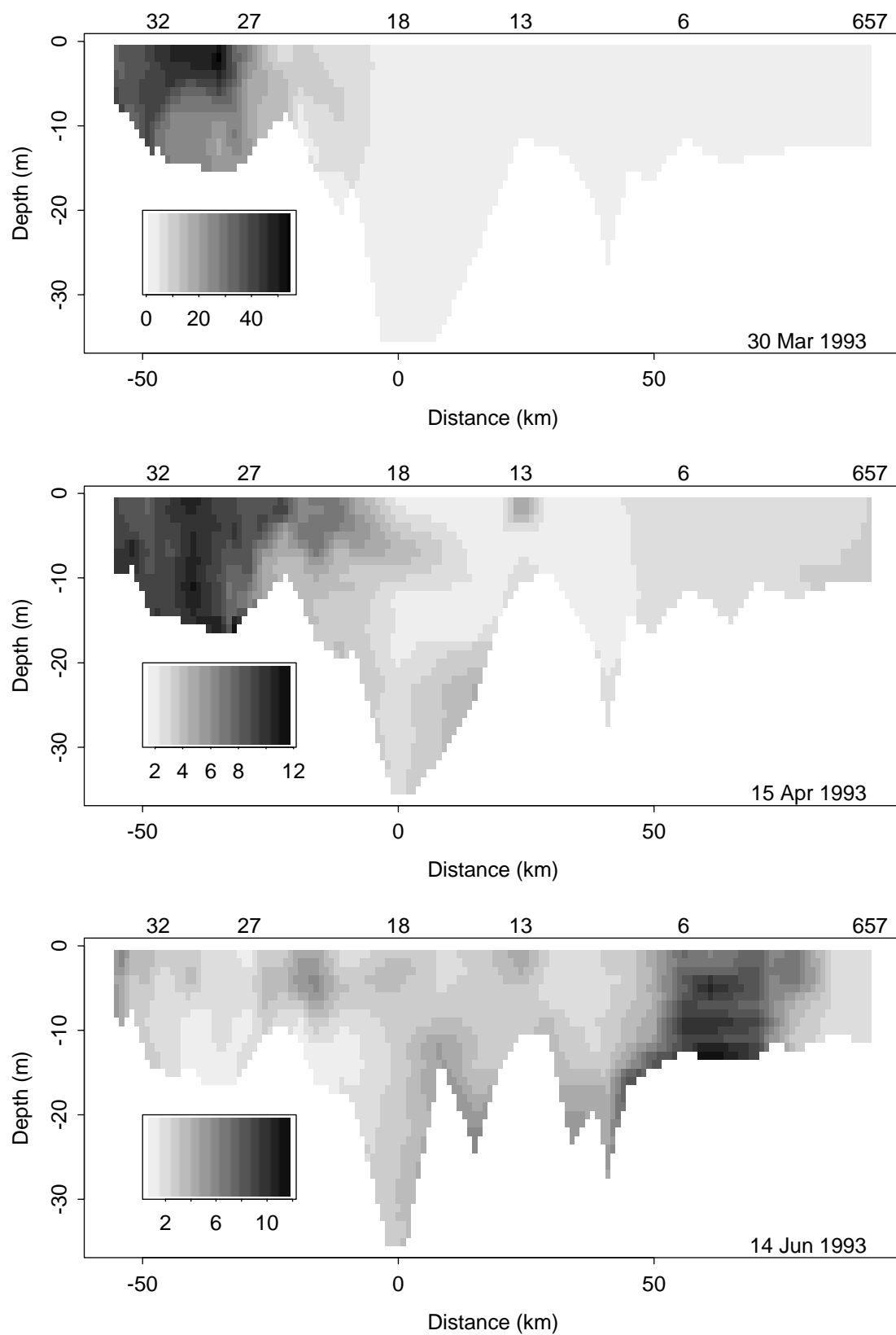
### Chlorophyll distributions during 1993

The data set for 1993, which is now undergoing analysis, permits us to give some concrete examples regarding the first purpose, namely, the “status” of the Bay for a particular year. We focus on measures of chlorophyll, an integral component of photosynthesizing phytoplankton that can be used as an indicator of the total biomass of the phytoplankton community. The distribution of chlorophyll is dependent on many physical, chemical, and biological factors. For example, the concentration of suspended particulate matter affects the supply of solar energy to the water column and therefore the growth rate of phytoplankton; inorganic nitrogen or silicate concentration limits the peak sizes of phytoplankton blooms; and benthic invertebrates such as *Potamocorbula* cause reductions in chlorophyll concentrations by grazing on phytoplankton. These multiple factors render chlorophyll distributions difficult to interpret, but they also endow chlorophyll with an ability to respond to many different dimensions of change. An analogy can be made in the case of human health with body temperature, which will respond to many different bodily malfunctions but serves as an integrative indicator of change. Of course, in the case of ecosystems, there is no standard chlorophyll distribution representing a healthy state—the equivalent of 98.6 °F—so in most cases we cannot make any immediate judgments from current chlorophyll levels alone regarding the desirability of these levels. Exceptions are when chlorophyll concentrations are too high or too low. When they are too low, then both the pelagic and benthic food webs, which are heavily dependent on phytoplankton, are at risk. When they are too high, phytoplankton can contribute to taste and odor problems (as they do at times in Delta municipal water supplies) and, when they die, create anoxic conditions accompanied by foul odors and possibly the loss of fish and invertebrate life.

Chlorophyll variability in the Bay is traditionally dominated by two main events, the spring bloom in South Bay and the summer maximum in Suisun Bay and/or the

ivers. Our monitoring during 1993 highlighted these two events in some detail (Figure 2). Note that a cross-section of the sampled water column is shown in each case, *not* a cross-section of the Bay. The data are interpolated to every kilometer between stations. As the exact number of stations and the distribution of tidal stages changes from cruise to cruise, the shape of the cross-section also changes somewhat. In the transect for March, the spring bloom in the South Bay was well-developed between Dumbarton Bridge (just south of station 32) and the San Bruno Shoal (just north of station 27). Highest chlorophyll levels were confined to the top 5 m, where they reached values of 50  $\mu\text{g L}^{-1}$ . Chlorophyll decreased abruptly from the southern side of the San Bruno Shoal toward Central Bay (station 18), north of which virtually no structure was seen. The next transect, in April, shows that the bloom in South Bay had mixed throughout the entire water column and extended north either through dispersion or growth. The maximum chlorophyll levels in South Bay had declined considerably to about 10  $\mu\text{g L}^{-1}$ . There is little structure to be found in North Bay apart from a gradual chlorophyll increase toward the Sacramento River (station 657). Note, however, the small local maximum just north of Pinole Point (station 13) in San Pablo Bay. The June transect shows that the South Bay bloom had dissipated (this could also be observed in the May transect), although an isolated portion remained just north of the San Bruno Shoal. The local maximum near Pinole Point had decreased somewhat and dispersed along the channel. Of most interest, however, was the new maximum in Suisun Bay that extended upstream from Roe Island (station 6). This marked the beginning of a summer maximum in Suisun Bay that tended to track the location of the estuarine turbidity maximum.

Several important points regarding sampling frequency can be deduced from these transects. First, chlorophyll dynamics are rapid in comparison to our sampling frequency of once per month. The frequency cannot therefore be reduced without missing major features of seasonal variability in the Bay. In fact, from supplementary cruises carried out in South Bay around the time of the spring bloom, we know that the March cruise missed the bloom peak of about 70  $\mu\text{g L}^{-1}$ . Even a monthly frequency therefore may not characterize this bloom in sufficient detail. We believe that the size and shape of the South Bay bloom is a significant aspect of “status”



**Figure 2. Chlorophyll Distributions ( $\mu\text{g L}^{-1}$ ).** Transects of chlorophyll *a* reflect the dynamic structure and spatial variability of phytoplankton biomass in the Bay. 0=Golden Gate, positive distance is up-stream (north), negative distance is south.

as it represents the single most important source of energy for the South Bay food web.

A related point involves the frequency of stations along the transect. Certain features, such as the local maximum at Pinole Point during April, are highly discrete phenomena that occur at single stations only. These maximum may nevertheless be ecologically important if they occur, as this one does, in a “desert” of low chlorophyll. It therefore seems prudent to locate stations in such a manner that such local features will be observed with some certainty. Tidal “smearing” suggests that these features should have scales of at least the tidal excursion, namely 5-10 km. A final point regards the Suisun Bay maximum in June. In this case, the phytoplankton density is low in surface waters because of the manner in which this maximum forms (see below). The traditional scheme of taking samples from 1 m below the surface only would have missed the extent of this accumulation and recorded only a minor increase in the Suisun Bay channel. It is obvious that a full vertical profile is necessary.

### Salinity distributions during 1993

The dependence of phytoplankton peaks on salinity distribution is illustrated clearly by these high-resolution transects (Figure 3). According to current understanding, prerequisites for the South Bay bloom include a stratified water column (along with low mixing by tides and winds, and low benthic invertebrate populations, which filter overlying populations of phytoplankton and other particles). The March chlorophyll transect (Figure 2) portrayed a South Bay bloom confined to the region from the Dumbarton Bridge to the southern extent of the San Bruno Shoal. The March salinity transect showed vertical stratification of the water column over this region as well. By the April cruise, stratification had broken down in this region, at least during the cruise period, and the phytoplankton community had decreased markedly and become dispersed throughout the water column. No stratification was observed during the June cruise and remnants of the bloom were difficult to find. Note, however, that a local chlorophyll maximum and stratification both persist just north of the San Bruno shoal.

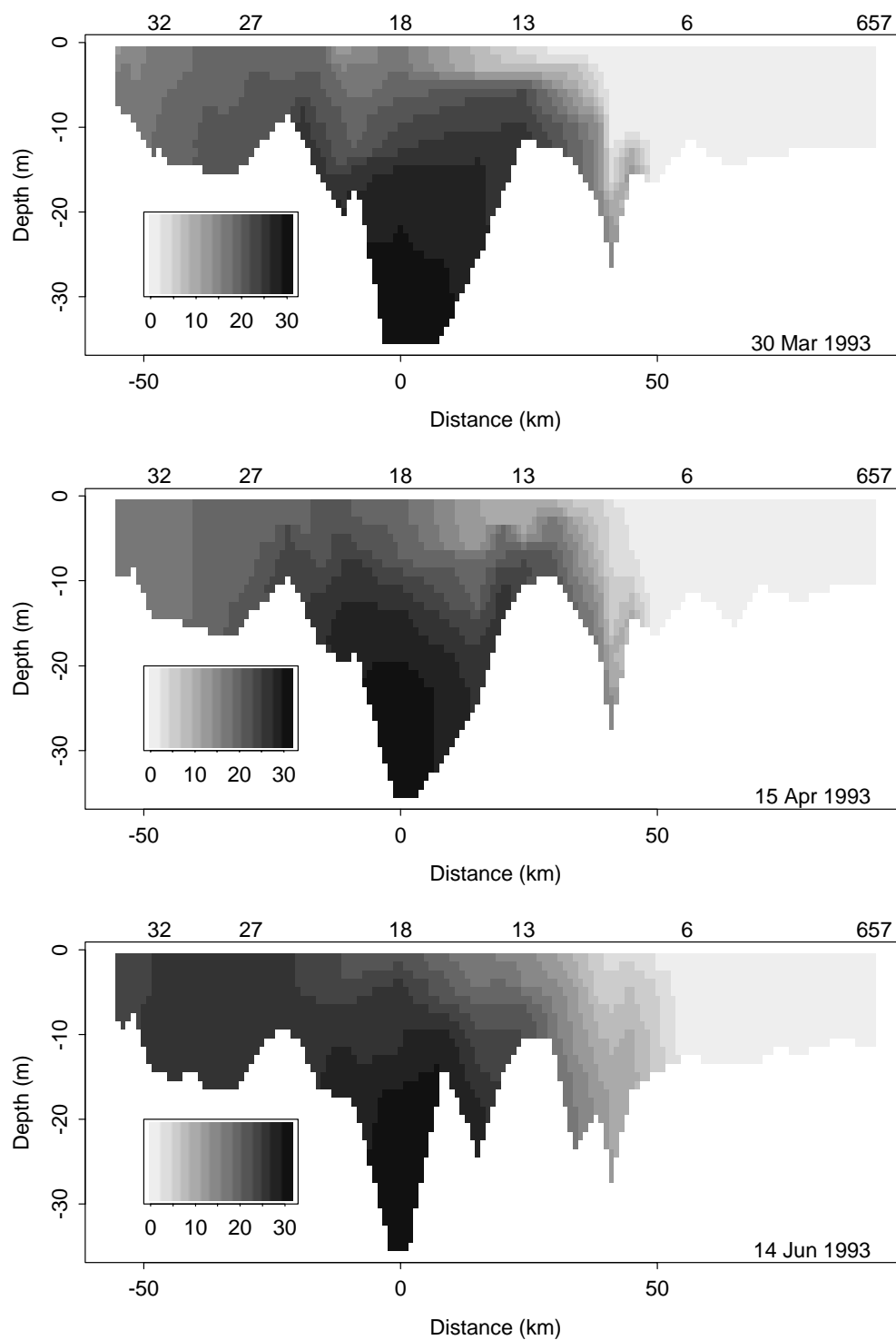
The North Bay also exhibits interesting relationships between stratification and chlorophyll. The 2‰ near-bottom salinity position is thought to mark approxi-

mately the division between a downstream stratified regime and an upstream well-mixed regime. In March, the 2‰ position was located at about 40 km upstream of station 18 (note that the scale used here is *not* distance from the Golden Gate), which coincided with a division into strongly stratified downstream and largely unstratified upstream regions. In April and June, the 2‰ isohaline was located at 45 and 50 km, respectively, again consistent with its presumed significance as a marker between two different mixing regimes. In June, a chlorophyll maximum developed in Suisun Bay just upstream of the 2‰ isohaline position. This maximum was absent during earlier transects when the transition region was situated in the deeper waters of the Carquinez Strait. Again, observations are consistent with the traditional view that a “null zone” associated with the transition from stratified to unstratified regimes must be situated in Suisun Bay for accumulation of phytoplankton cells to take place. When phytoplankton cells are relatively heavy, as in the case of certain thick-walled diatoms or when coated with clay particles, the sinking rates of cells are rapid and densities are lower in surface waters near the null zone. This may account for the subsurface maximum in Suisun Bay during 1993.

The Pinole Point local maximum has been documented in the past. Certain investigators have proposed that it represents an entrapment zone caused by estuarine circulation patterns, much like the maximum in Suisun Bay. Others have countered that it results from tidal pumping, an out-of-phase cycling of water between the northern shoals of San Pablo Bay and the main channel that causes peaks in phytoplankton and other particulate matter at certain stages in the tidal cycle. Our monitoring data do not yet clarify the differing viewpoints, but they do record the consistent presence of this feature during spring and summer.

## Variability and Sampling Frequency

One of our main concerns is to improve the existing sampling design within the context of a Regional Monitoring Program. There are many different features of the estuary that one might want to follow through the years as an indicator of change in the structure or function of the estuarine ecosystem. Each feature has its own mea-



**Figure 3. Salinity Distributions (Practical Salinity Units).** In southern South Bay, stratification was evident early in 1993 but disappeared in spring as Suisun Bay stratification began to develop. The movement of the 2 part per thousand isohaline into Suisun Bay in summer coincided with an increase in chlorophyll concentrations. 0=Golden Gate, positive distance is upstream (north), negative distance is south.

surement peculiarities and a sampling regime cannot be specified that will be optimal for all variables. All of them will, however, share certain sources of variability, including variability due to (1) measurement noise; (2) semidiurnal tides; (3) location; (4) season; and (5) year. Here, we briefly describe some of the considerations currently guiding our efforts to improve the design of the sampling program.

Measurement uncertainty is, of course, fundamental to all kinds of data, due to noise in the measurement and calibration process. We believe that this is not a major source of variability for the habitat measurements compared with other sources, but it could very well be so for the biological indicators (see below). A critical step in the selection of indicators is to characterize this source of error and eliminate indicators in which the measurement uncertainty could easily outweigh the interannual variability.

Variability induced by semidiurnal tides is a source of uncertainty that causes distortion of data collected during a single transect. Previous studies of this time scale of variability in South Bay show it to be important but difficult to characterize. Tides cause a translation along the axis of the Bay and distortion of the structure of a water column, but they also mix material from the sediments into overlying water. The translation and distortion of the data are amenable to hydrodynamic modeling, but the mixing up and sedimentation of materials (including chlorophyll) is a complex process that depends on local conditions and for which there is insufficient empirical evidence. As a result, little can be done at this time to correct for semidiurnal tidal distortions of nonconservative substances, i.e., substances that have sources or sinks within the Bay.

Spatial variability is another source of uncertainty when estimating Bay-wide statistics such as the mean value of chlorophyll. Two questions need to be answered: (1) How should stations be distributed? (2) How many stations should be selected? Our work to date suggests that the present design can be made more efficient by dropping some stations and aiming for an approximately constant inter-station distance (i.e., a *systematic* sample) among the remaining stations. In certain practical situations, estimates can be improved with a *stratified* systematic sample in which the sampling grid is augmented in areas of high concentrations. In order for stratification to be useful, however, the strata must remain fairly

stable. This may not be the case in the estuary, where major spatial features have a lifetime of at most a few months. At this early stage in the monitoring program, then, we are inclined to a layout of stations with equal spacing between stations.

A final source of uncertainty, and perhaps the largest for interannual comparisons, is seasonal variability. Even though variability from the spring-neap tidal cycle can be reduced by scheduling cruises near neap tides, the major ecological events of the year are not perfectly timed with this cycle and will be sampled at different points in their evolution in different years. In South Bay, for example, the maximum extent of the spring bloom is an important feature that would usually be missed by relying solely on a monthly sampling regime. Increasing the number of cruises, however, is much more expensive than increasing the number of stations per cruise. One solution would be to stratify the cruise times and keep the total number of cruises constant. Unfortunately, the historic record is so sparse for Central and North bays that stratification could easily misrepresent what is happening north of the Bay Bridge. As in the case of spatial frequency, we believe that we should continue to sample at monthly intervals for the next year. Perhaps the best intermediate solution is to augment the regular whole-Bay transects with smaller dedicated visits to known events such as the South Bay bloom and the Suisun Bay estuarine turbidity maximum. Without augmenting the monthly sampling in some fashion in a system as dynamic as San Francisco Bay, it is unlikely that a meaningful comparison can be made among years for events that are perhaps most illustrative of the status of the Bay.

## Phytoplankton Community Composition

Monitoring the species present in the phytoplankton community is important for two reasons: (1) to detect the presence of harmful or nuisance bloom-forming species, and (2) to serve as an indicator of long-term change. Algal blooms cause problems in several ways. If high concentrations are followed by a rapid die-off, anoxic conditions may develop with harmful consequences for higher organisms and the production of noxious odors. In recent decades the Bay has been free of such phytoplankton blooms, although occasional blooms



of macroscopic algae (seaweed) have produced local anoxia and affected benthic communities. Even at lower than anoxia-producing concentrations, phytoplankton blooms may introduce taste and odors into municipal water supplies. Such problems have been experienced upstream in the Delta for some years. Finally, certain toxic species may proliferate to very high concentrations, entering the food web and causing mortality at higher trophic levels, including in humans. Many of these species belong to a group known as dinoflagellates and form what are called “red tides” because of a coloration of the water due to the pigmentation of these organisms. Interestingly, a red tide did form last year in South Bay immediately after the spring diatom bloom, but it was due to *Mesodinium rubrum*, a nontoxic ciliate (not a dinoflagellate) that contains a small pigmented alga as an endosymbiont. Toxic dinoflagellate red tides are unknown as yet in San Francisco Bay, although species known elsewhere to form toxic red tides do occasionally occur in the Bay phytoplankton. For example, during 1993, *Prorocentrum minimum* formed a small percentage of the autumnal bloom in Central Bay. This species has been associated with Paralytic Shellfish Poisoning (PSP) incidents at other locations.

Recently, it has been found that diatoms can also produce a potent mammalian toxin, known as domoic acid (DA). In late summer and fall of 1991, a series of deaths of brown pelicans and Brandt’s cormorants in Monterey Bay was traced to the consumption of anchovies that had, in turn, been feeding on large concentrations of *Pseudonitzschia australis*, a DA-producing diatom. This organism is also found off of British Colum-

bia, suggesting a wide distribution on the west coast. We have not identified this species as such in San Francisco Bay. It is interesting to note that the very similar *Nitzschia seriata* was observed in Central Bay in spring and fall of 1993 (*Pseudonitzschia australis* is also known as *Nitzschia pseudoseriata*). Some researchers believe that *Nitzschia seriata* may be a very cold northern species and that records of it in California are suspect. If so, then we may actually have the DA-producing species entering Central Bay from the coastal ocean. We measured levels of only  $10^4$  cells  $L^{-1}$ , at least one order of magnitude less than peak concentrations occurring in Monterey Bay in 1991. This year, we need to make a definitive identification of the organism in question. Because northern anchovy constitutes much of the fish biomass in the Bay, the potential presence of DA-forming diatoms is of some concern.

The composition of the phytoplankton community also can serve as an index of trends in the estuary. The diatom community has a long history of being used in this context and many quantitative approaches have been applied to the detection of change in diatom communities due to anthropogenic forces. Phytoplankton community composition is not a current feature of the US EPA’s Environmental Monitoring and Assessment Program (EMAP), but in the case of a regional monitoring program (as opposed to the national assessment goals of EMAP) we believe that phytoplankton species information will prove to be worthwhile and fundamental to assessing change. Our 1993 data represents the first year of the program and interannual comparisons are not yet possible.

**Table 2. Phytoplankton dominants during the Regional Monitoring Program cruises of 1993.** Only the times of peak community biomass are shown. Each species contributed at least 10% of the total community biomass in the sample. Species marked with \* contributed at least 50% of the total.

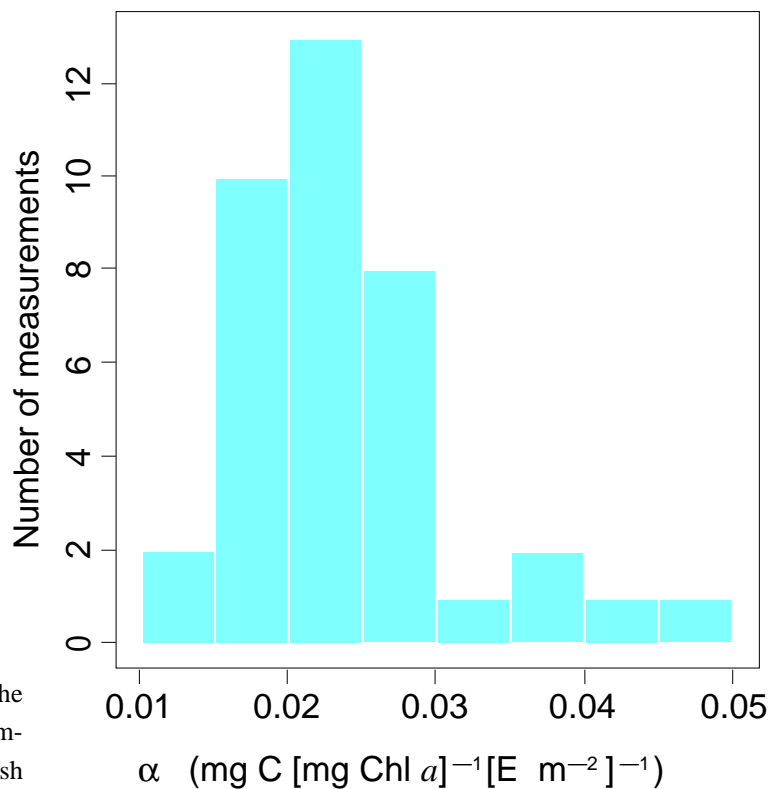
Station	Month	Species
657 (Rio Vista)	April	<i>Fragilaria crotonensis</i> , <i>Glenodinium</i> sp.
6 (Roe I.)	June	<i>Melosira lirata</i> *
13 (Pinole Pt.)	April	<i>Coscinodiscus oculus-iridis</i> *
18 (Central Bay)	April	<i>Coscinodiscus lineatus</i> (?), <i>Ditylum brightwellii</i> , <i>Thalassiosira rotula</i> , <i>Gymnodinium splendens</i>
	October	<i>Ceratium minutum</i> *, <i>Gymnodinium splendens</i>
27 (SF airport)	February	<i>Coscinodiscus oculus-iridis</i> *, <i>Rhizosolenia setigera</i>
32 (Ravenswood Pt.)	April	<i>Coscinodiscus curvulatus</i> *, <i>Ditylum brightwellii</i>

We can, however, point out the main features of the data (Table 2). Note that because of the bimonthly sampling, the actual peaks may have occurred as much as a month later or earlier and different species may have been involved. In any case, these data suggest that peaks were attained between February and April at all stations, except for a summer peak in Suisun Bay and a secondary autumnal maximum in Central Bay. The times of maximum biomass were dominated by diatoms in all cases, except for the autumnal bloom in Central Bay, which was composed mainly of dinoflagellates. These dinoflagellate species are of particular interest, as they are capable of feeding on other particles, in addition to their ability to photosynthesize. They are also common to the coastal ocean and probably reflect the intrusion of more oceanic water as the river influence receded upstream. At other times during the year, small cryptophytes were common at all stations except Rio Vista. In many other water bodies, cryptophytes are common between bloom periods and are an important component of the system over an annual period.

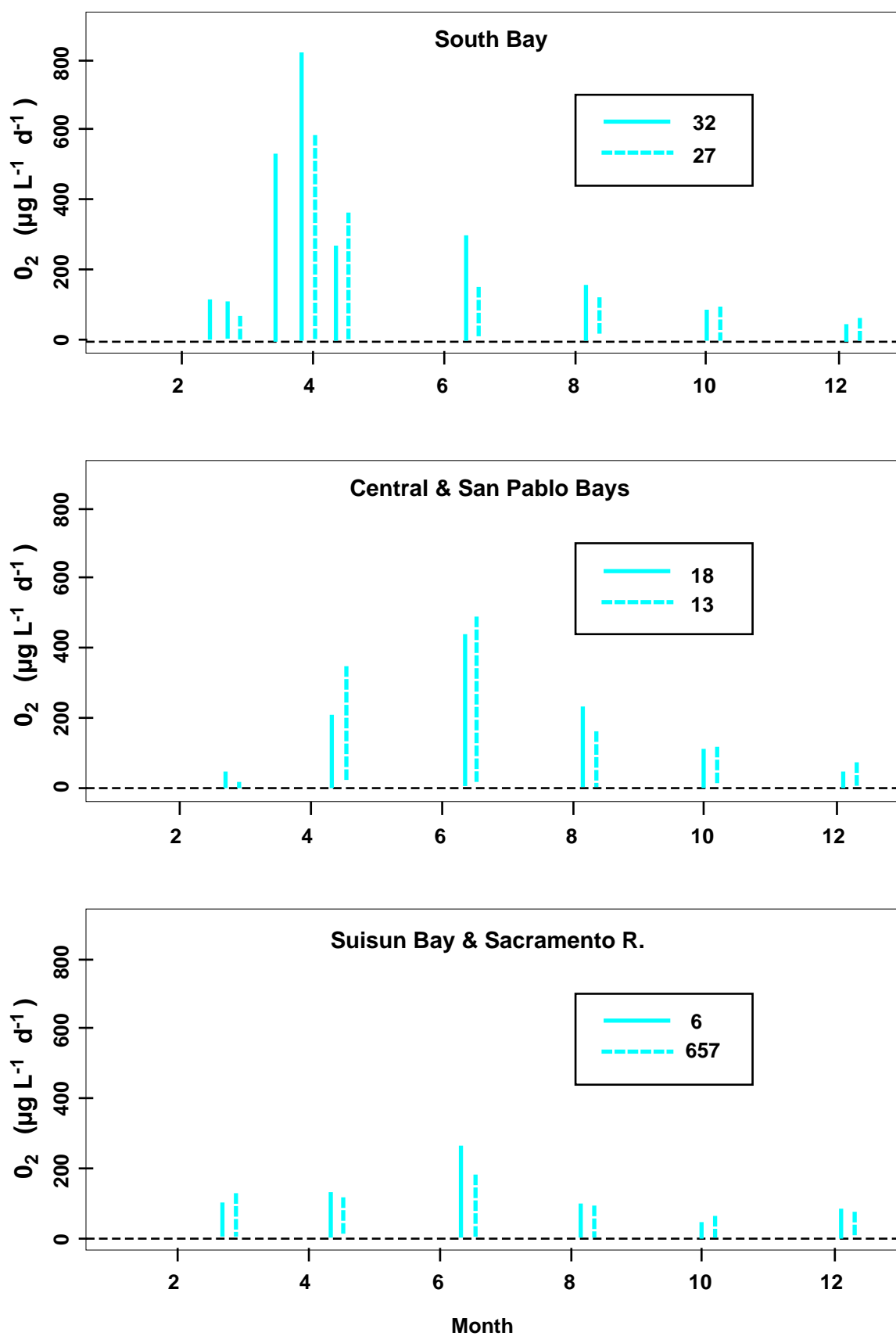
## Photosynthetic Parameters

The response of the phytoplankton community to different light intensities is often characterized by two parameters:  $\alpha$ , which measures how efficiently the phytoplankton community can convert absorbed light energy into cell biomass; and  $P_{max}$ , which measures the capacity of cells to photosynthesize in conditions of optimal light. These two photosynthetic parameters are not constant, but exhibit variability in response to many factors, such as changing solar radiation and temperature. Although it is often difficult to sort out the many factors behind their variability, they do serve as an index of the physiological state of the phytoplankton community and can therefore be used to distinguish differences among communities and environmental conditions.

Beyond indexing the physiological state of the phytoplankton community,  $\alpha$  is as an important calibration parameter in estimating estuary-wide primary production by phytoplankton. Several investigators have shown, both for San Francisco Bay and elsewhere, that primary productivity is proportional to surface chlorophyll concentrations, light penetration, and solar radiation, enabling us to make an estimate of phytoplankton production from the transect data. The proportionality constant in this relationship is  $\alpha$ , which clearly was not constant throughout the estuary and year (Figure 4). Rather than using a representative  $\alpha$  value for all cases, knowledge of the photosynthetic parameters may enable us to tailor the estimates by station and season. As photosynthetic parameters also have a daily rhythm, however, we first need to understand how much of the variability summarized in Figure 4 is attributable to time of day, as opposed to spatial location or season.



**Figure 4. Variability of Phytoplankton Photosynthetic Efficiency.** Photosynthetic efficiency of the phytoplankton varied widely due to station location, season, and time of day.



**Figure 5. Respiration by the Plankton Community.** Adjacent stations had similar rates of oxygen respiration and the pattern of change over the year was consistent for all sites.

## Community Respiration

Respiration of a water sample is an integrative measure of plankton community activity. It includes respiration by phytoplankton, bacteria, and microzooplankton and represents the metabolism of organic matter arising from photosynthesis *and* imported from rivers, tidal marsh, and point source discharges. It is sensitive both to the total supply rate of these sources, as well as to loss of organic material to bottom communities and to dispersion. Because it reflects so many activities, respiration by the plankton community is potentially a sensitive indicator of change. On the negative side, the measurement method is relatively imprecise and therefore requires large numbers of replicates and associated labor. During 1993, we were primarily interested in determining the number of replicated measurements necessary for resolving spatial and temporal change, and whether bimonthly cruises exhibited enough continuity to provide at least a coarse picture of the annual respiration pattern (Figure 5). Community respiration was consistently low throughout the Bay in fall and winter (Oct-Feb). In South Bay, respiration was highest in spring, in contrast to the rest of the Bay, which had peak respiration in early summer. During these peak periods of respiration, rates were highest in South Bay, intermediate in Central and San Pablo Bays, and the lowest in Suisun Bay and the Sacramento River. The data appear to be reliable in that adjacent stations behave in a similar manner and seasonal changes are smooth.

The supplementary data collected in the South Bay during early 1993 enabled us to evaluate the utility of bimonthly sampling. Bimonthly data may provide a qualitative picture of the annual pattern, but the pattern is distorted and we are unable to determine the timing and magnitude of the actual peaks. As one might expect, the peak respiration is closely related to the spring bloom, as bacteria and other organisms respond to the enhanced organic matter supply from phytoplankton. In 1993, the bloom reached a maximum in March, but the timing changes from year to year and one cannot be assured that a bimonthly program will capture this event. Thus, although the method appears to be reliable, the sampling frequency would have to be increased in order to ensure valid comparisons among years.

## Concluding Remarks

The recent addition of some new equipment to the *Polaris* gives us an enhanced capability to deduce appropriate station locations from the 1994 data. The system, known as MIDAS (Multiple Instrument Data Acquisition System), permits essentially continuous measurements of salinity, temperature, turbidity, and fluorescence (chlorophyll) in surface waters along with associated weather and geographic positioning information. MIDAS data provide a description of surface conditions with very high resolution (on the order of 10-100 m), permitting the use of geostatistical methods that require many more than the existing number of stations. The MIDAS data will be most useful when surface values are of primary interest. For example, in estimating primary production from chlorophyll measurements, only near-surface areas exposed to solar radiation are of interest. The MIDAS data will also be invaluable for calibrating remote sensing data, which we hope to use for Bay-wide primary production estimates that include shallow as well as deep waters.

The 1993 program was an intensive sampling effort and analysis to date has only scratched the surface of the dataset. As a result, we have not tried in this brief summary to offer any definitive conclusions. Rather, we have focused on giving a broad view of the different components of the program. A forthcoming report will make specific recommendations regarding both the CTD and biological indicator variables measured during 1993 (Table 1), additional variables that should be considered, station configuration, and sampling frequency.

## Acknowledgments

This pilot study was supported principally by the U.S. Geological Survey and a substantial contribution by a number of Program participants, including municipal and industrial dischargers, cooling water and storm water dischargers, and dredgers. Additional funding was provided by the California Department of Water Resources and the U.S. Geological Survey Toxic Substances Hydrology Program. We are also grateful to the Regional Water Quality Control Board for their oversight and coordination of the Regional Monitoring Program, and to the San Francisco Estuary Institute for their essential role in management of the Program.

# CENTRAL SAN FRANCISCO BAY SUSPENDED-SEDIMENT TRANSPORT PROCESSES STUDY 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. The sediments on the bottom of the Bay provide the habitat for benthic communities which can ingest these substances and introduce them into the food web. The bottom sediments are also a reservoir of nutrients. The transport and fate of suspended sediment is an important factor in determining the transport and fate of the constituents adsorbed on the sediment. Suspended sediments also limit light availability in the bay, which limits photosynthesis and primary production, and deposit in ports and shipping channels, which require dredging. Dredged materials are disposed in Central San Francisco Bay.

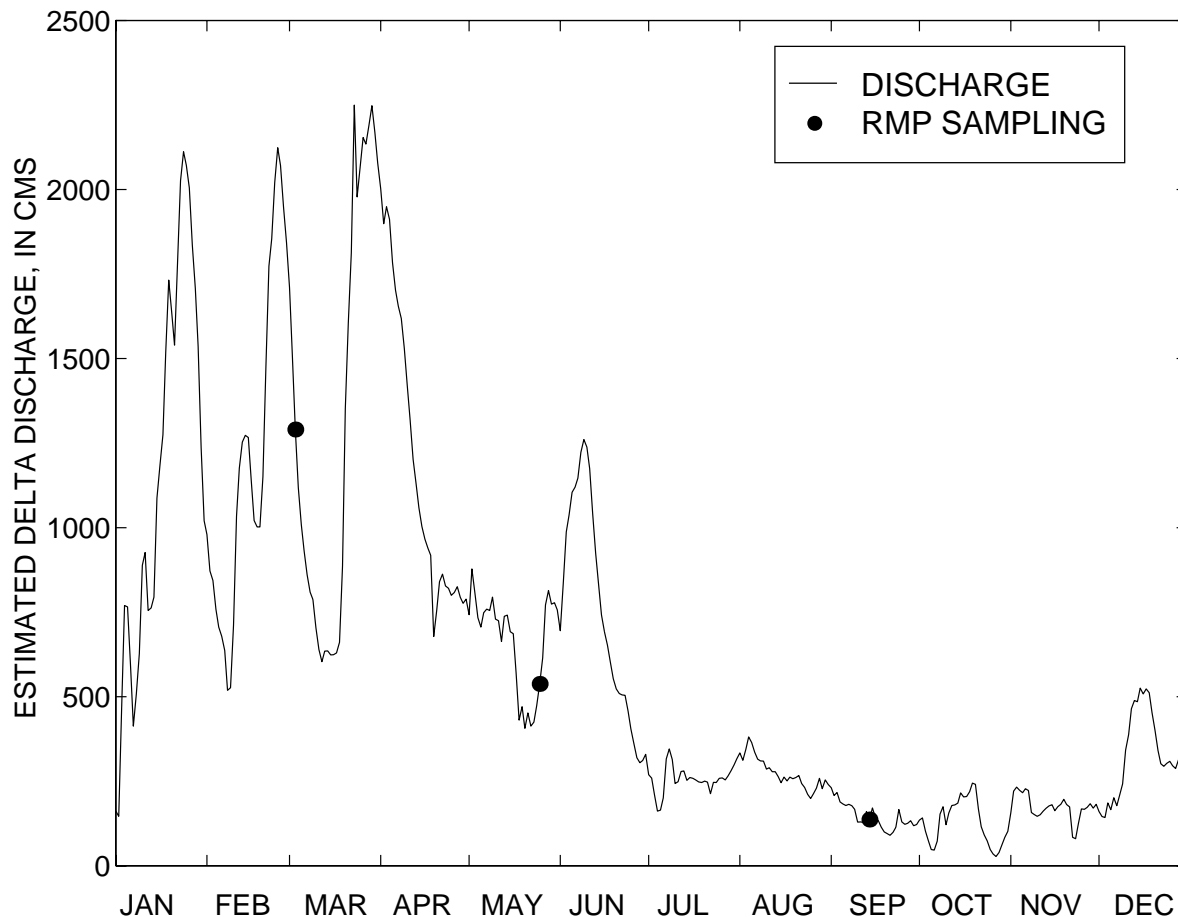
The objectives of the Central San Francisco Bay suspended-sediment transport processes study are to estimate which factors determine suspended-solids concentrations in Central Bay and to collect time series of suspended-solids concentrations that are appropriate for 1) continuous monitoring of suspended-solids concentrations and 2) calibration and validation of numerical models. Potentially important factors include semi-diurnal and diurnal tides, the spring/neap cycle, delta discharge, dredging and dredged material disposal, and wind waves.

Suspended-solids concentration monitoring sites were established at Point San Pablo in December 1992 and at the Bay Bridge in May 1993. 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 suspended-solids concentrations with calibration curves developed from analysis of water samples. The sites are serviced every 1 to 4 weeks to clean the sensors, which are susceptible to biological fouling, and to collect water samples for sensor calibration.

Initial results indicate that the spring/neap cycle was the factor with the greatest effect on the suspended-solids concentration at Point San Pablo during the winter of 1993, not runoff from the Sacramento-San Joaquin Delta or semidiurnal and diurnal tides. A singular spectrum analysis indicates that the spring/neap cycle, which accounted for 40 to 50 percent of the signal variation, was the factor with the greatest effect on the data. During the same period, however, the spring/neap cycle accounted for approximately 2 percent of the water level variation. Suspended-solids concentrations respond to lower tidal frequencies probably because of an accumulation of response caused by slow settling of the fine material compared to higher (diurnal and semidiurnal) tidal frequencies. The spring/neap component of the suspended-solids concentration lags the spring/neap tidal component by one or two days. This lag indicates that net resuspension continues after the spring tide and net deposition continues after the neap tide. Runoff from the Sacramento-San Joaquin Delta with relatively high suspended-solids concentration had a smaller effect than the spring/neap cycle because Point San Pablo was seaward of the freshwater/saltwater mixing zone where flocculation and deposition occurs.

The continuous suspended-solids concentration data can also be used to help place the discrete data collected by the RMP into a proper context. Discrete samples were collected at 16 sites in the Bay 3 times in 1993 — early March, late May, and mid September. Discrete samples were collected one meter below the water surface.

The March discrete data were collected during a high, but diminishing, delta discharge (figure 1). Sites closest to the Central Valley had the greatest suspended-solids concentrations and the least salinity. As the salinity increased in the seaward direction, suspended-solids concentrations decreased. Data collected by Cloern and Cole from USGS R/V *Polaris* during winter 1993 had a



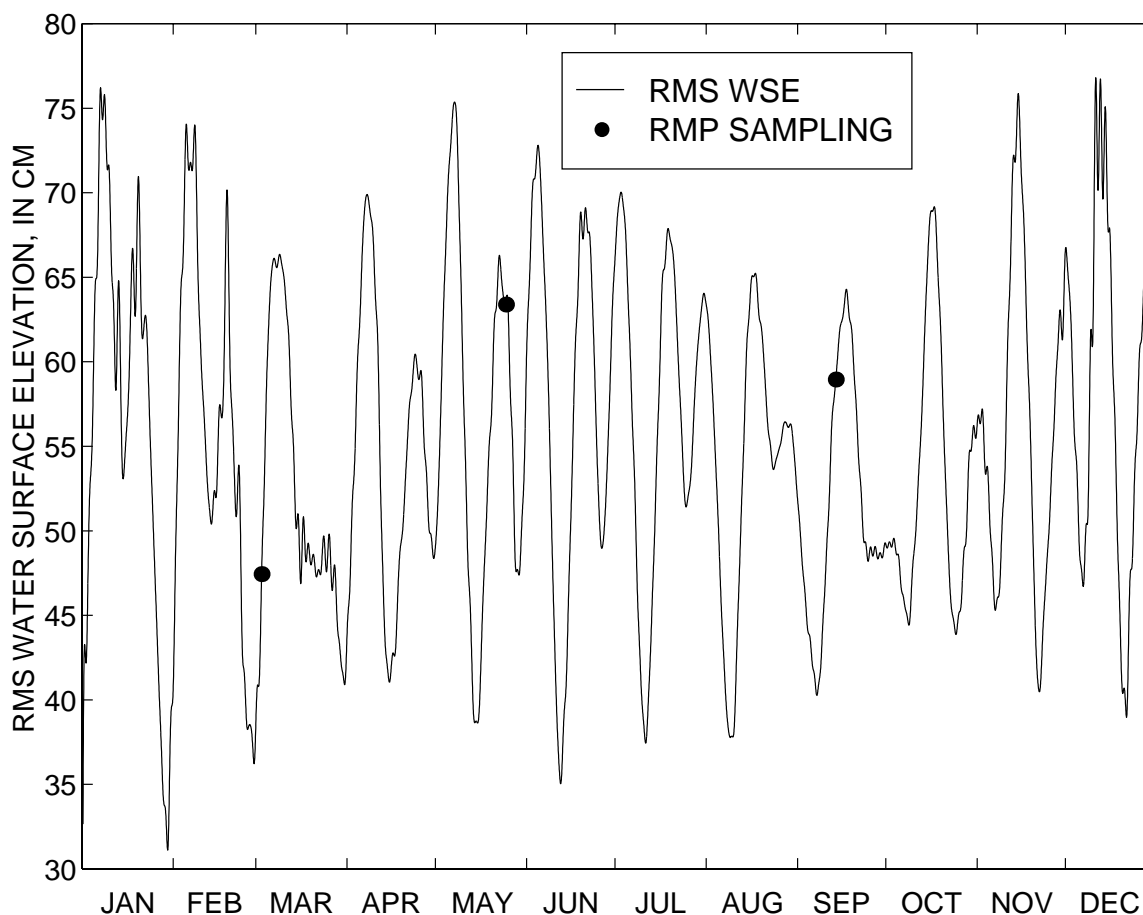
**Figure 1. Estimated Delta discharge and times of discrete sample collection in 1993.**

similar trend. When the fresh water, which contains relatively high concentrations of clay minerals, mixes with salt water, the clays flocculate and settle. The March discrete data indicate that a similar but less obvious trend may also be present in South Bay. The March discrete data were collected between a neap and spring tide (figure 2). As mentioned earlier, spring/neap variations in suspended-solids concentrations are significant and suspended-solids concentrations lag the spring/neap cycle by 1 to 2 days.

The May discrete data were collected during a moderate but increasing delta discharge (figure 1). An inverse salinity and suspended-solids concentration relation in north bay was also present. The May discrete data was collected during a weak spring tide (figure 2).

The September discrete data were collected during a low delta discharge (figure 1) and near a spring tide (figure 2). The inverse salinity/suspended-solids concentrations relation was not present. For the September and the other discrete data, the Central Bay sites have the lowest suspended-solids concentrations and the more landward sites have the highest concentrations. This is consistent with the usual gradient of suspended-solids concentration that decreases from shallow to deep water and in the seaward direction.

Only one of the discrete sampling sites is located at a continuous USGS suspended-solids concentration monitoring site — the Dumbarton Bridge in South Bay. Only the March 2 discrete sample was collected at a time when the optical OBS sensors at the Dumbarton Bridge were not fouled. Figure 3 shows the continuous data from

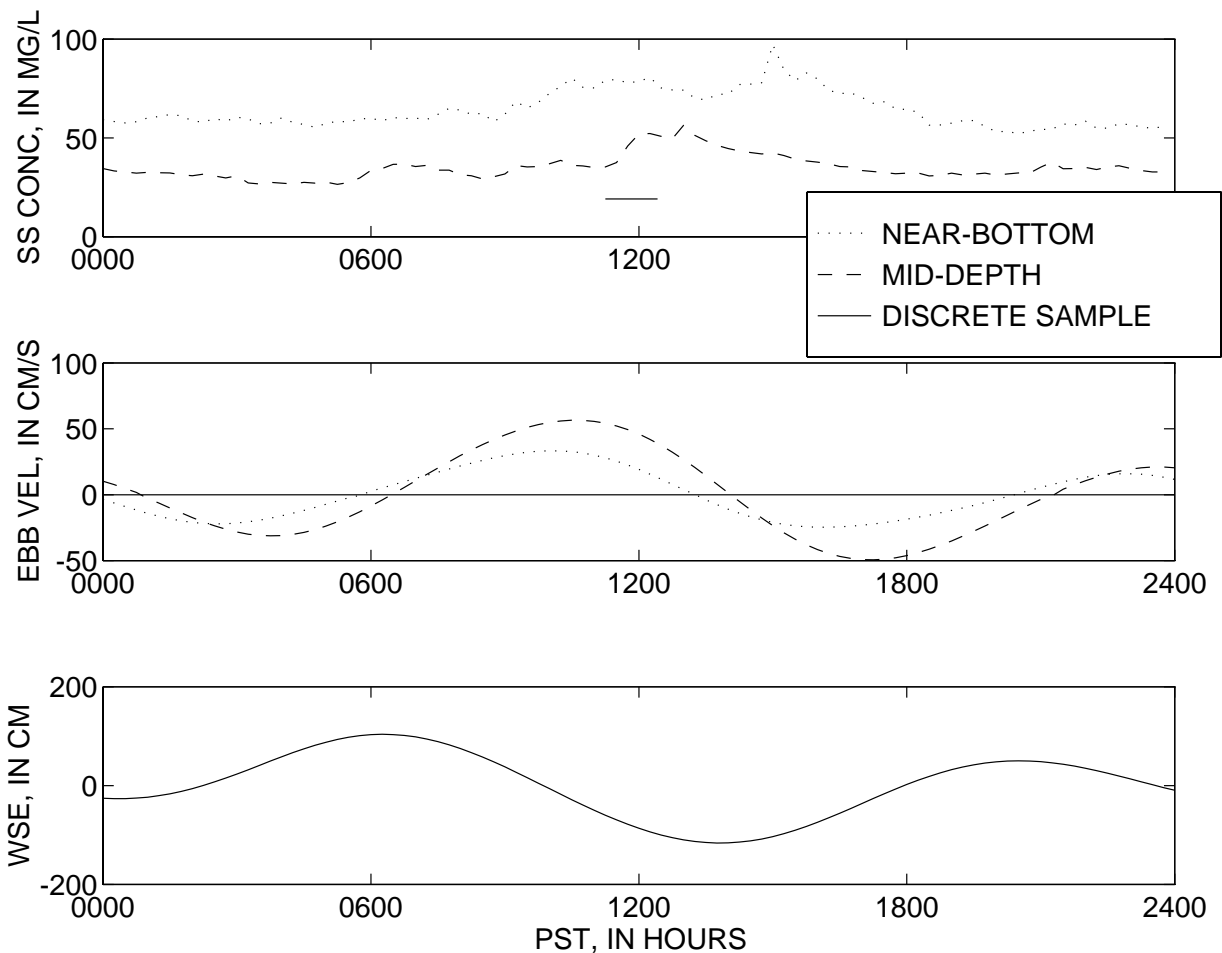


**Figure 2. Root-mean-squared water surface elevation (RMS WSE) and times of discrete sample collection in 1993.** Larger values of RMS WSE indicate spring tides and smaller values indicate neap tides.

mid-depth and near-bottom OBS sensors and the discrete sample collected one meter below the water surface between 1115 and 1225 hours. A vertical gradient of suspended-solids was present in the water column with greater concentrations near the bed. Predicted ebb velocities and tidal stage for the Dumbarton Bridge are also shown on figure 3. The near-bottom suspended-solids concentration increases with the large near-bottom velocities at 1000 hours and decreases several hours later. Settling from above may have maintained high near-bottom suspended-solids concentrations at the 1400 hour low tide. The additional suspended solids at the mid-depth sensor arrived shortly before low tide — this is a common feature of South Bay data and indicates a landward gradient of suspended-solids concentration with larger values to the south and in shallower water. The discrete

sample was collected about the time the increased suspended-solids concentration was detected by the mid-depth OBS sensor.

One of the interesting features of the discrete data was the large suspended-solids concentration at the San Pablo Bay site on May 26, 1993. The closest continuous site is at Point San Pablo, and the mid-depth suspended-solids concentration is shown on figure 4. The Point San Pablo suspended-solids concentration was greatest in the late morning soon after low tide as the concentration increased from 50 to 150 mg/L. The San Pablo Bay discrete sample had a high suspended-solids concentration of 190 mg/L and a fairly high salinity (16.3 ppt). Thus, the high suspended-solids concentration was probably not associated with a large discharge from the nearby Petaluma River but the normal tidal fluctuation



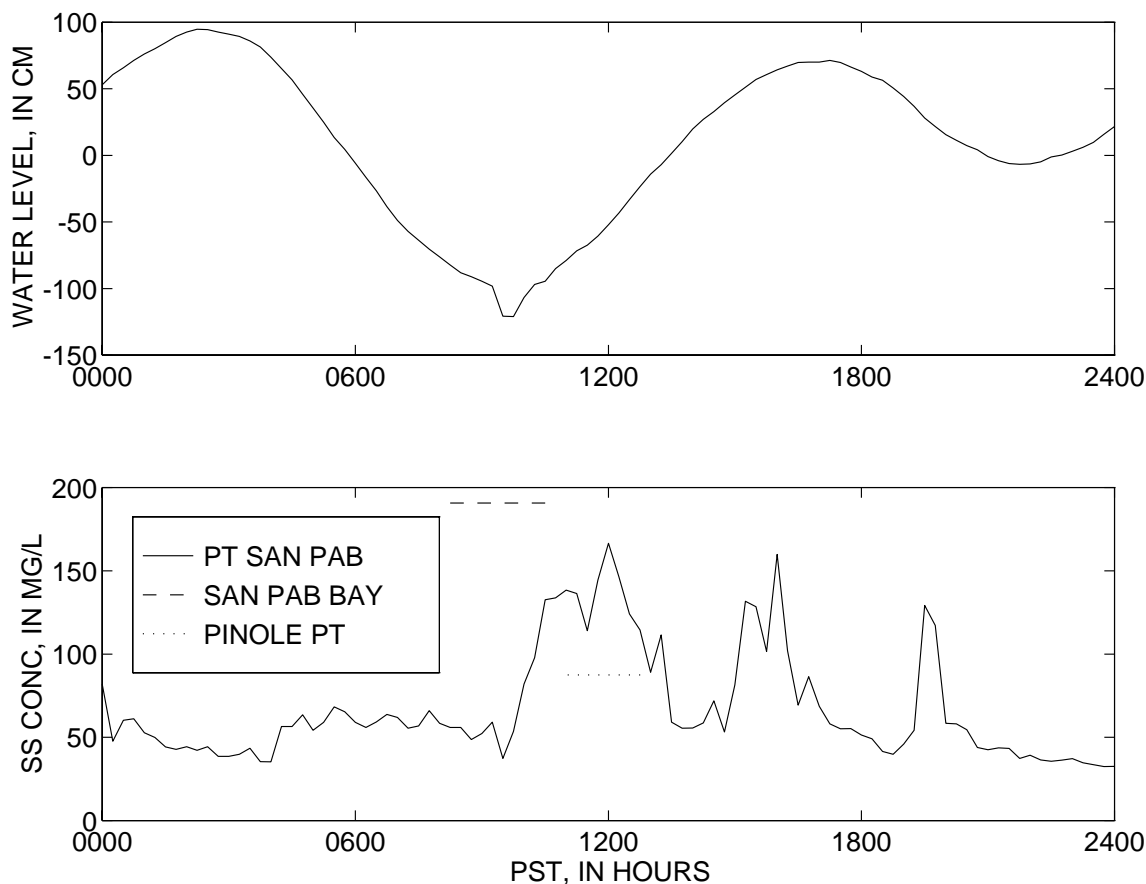
**Figure 3. Suspended-solids concentrations, predicted ebb tidal velocities, and predicted water surface elevation at the Dumbarton Bridge on March 2, 1993.**

of suspended-solids concentration. At Pinole Point at mid-day the discrete suspended-solids concentration was 87.5 mg/L, which is high compared to other discrete samples collected that day but is consistent with the magnitude of the tidal variation of suspended-solids concentration at Point San Pablo.

These two examples show that, while the discrete data are useful, they are limited in their spatial and temporal coverage and these limitations must be recognized in any analysis of the synoptic data. Both examples show how suspended-solids concentration can vary during the tidal cycle. Spring/neap variations in suspended-solids concentration are also significant. Differences in suspended-solids concentrations during discrete sampling

trips and at discrete sampling sites may largely be caused by collection of samples at different phases of the tidal and spring/neap cycles. Diurnal wind-wave resuspension will also make suspended-solids concentrations dependent on the time of day the sample was collected, especially in or near shallow water (perhaps less than 4 m). Horizontal and vertical gradients of suspended solids also exist in the Bay, so where a sample is collected will also affect its concentration. For example, at the time of sampling at the Dumbarton Bridge on March 2, the suspended-solids concentration varied from 19 to 75 mg/L in the water column. Thus, tidal variations introduce significant uncertainty to the analysis of the discrete data,





**Figure 4. Water surface elevation and suspended-solids concentrations in San Pablo Bay on May 26, 1993.**

which is really best viewed as a set of point samples in space and time, nothing more.

Water quality monitoring provides a data base to help better manage the bay and to improve the quality of specific scientific studies, especially as a data base covering several years is developed. Based upon this analysis, possible improvements to the RMP discrete sampling program are:

1. A statement regarding the temporal and spatial limits of the data and information on the time of day, wind, tidal phase, spring/neap cycle, precipitation, and delta discharge should be included with the data.
2. If resources are available, sampling frequency should be increased. It is difficult to analyze vari-

ability at a site with a sampling frequency of three samples in one year. Perhaps automatic pumping samplers could be deployed at some sites and collect a single composite sample over a tidal day and these samplers could be serviced monthly. This, however, may not be feasible due to the need to preserve samples.

3. If resources are available, the sampling should be synoptic. Because of the tidal variations, even if samples could be collected in half a day, the sampling would not be synoptic. Perhaps water samples could be collected from several shore sites and vessels simultaneously, preserved, and transported to a laboratory for analysis. Volunteer groups are often willing to loan vessels and captains to such efforts. Although fewer and less

desirable sites probably would be sampled, this scheme would give a true snapshot of water quality in the bay. Samples could be collected at a consistent tidal phase, like a low spring tide at the sampling sites, or at the same time, like when a low spring tide occurs at the Golden Gate. This would significantly reduce the uncertainty caused by tidal variations.

4. If resources are available, collection of data at more than one point in the vertical would reduce uncertainty regarding vertical variability. Additional samples one meter above the bed and at mid-depth help identify vertical gradients.

5. Sampling at sites where continuous water level, salinity, and suspended-solids are being operated would permit data comparisons that would benefit analysis of both discrete and continuous data.

In 1994, the Central Bay suspended-sediment transport processes study will continue operation of the existing sites, install an additional site at the Golden Gate Bridge, monitor suspended-sediment transport processes in shallow water, prepare a report summarizing data collected during water year 1993, further analyze the data, and prepare an interpretive report.



# Other Monitoring Activities

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## SACRAMENTO COORDINATED WATER QUALITY MONITORING PROGRAM

### Introduction

The Sacramento Coordinated Water Quality Monitoring Program (CMP) is a joint effort by the Sacramento Regional County Sanitation District (SRCSD), the City of Sacramento (City) and the Sacramento County Water Agency (SCWA) to monitor water quality in the Sacramento River and American River in the Sacramento metropolitan area. 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 fundamental purpose of the CMP is to develop a sound database of water quality information on the major surface waters in the vicinity of Sacramento. Key features of the CMP include:

- 1. The long term Ambient Water Quality Monitoring Program (AMP) for the Sacramento River and American River.**
- 2. Coordination of ongoing water quality monitoring programs within the Sacramento area to the extent feasible.**
- 3. Centralized water quality database management system for the Sacramento and American Rivers and monitored discharges to these rivers.**
- 4. Special studies to address specific monitoring needs and to evaluate and complement new regulatory initiatives.**

The primary data collection element of the CMP is the Ambient Monitoring Program (AMP). Sampling under the AMP began in December, 1992. The 1993 Annual Report for the Sacramento CMP assesses the

results of AMP monitoring completed through September, 1993. The monitoring design, preliminary results and conclusions from the first nine months of sampling (December, 1992 through September, 1993) under the AMP are provided below.

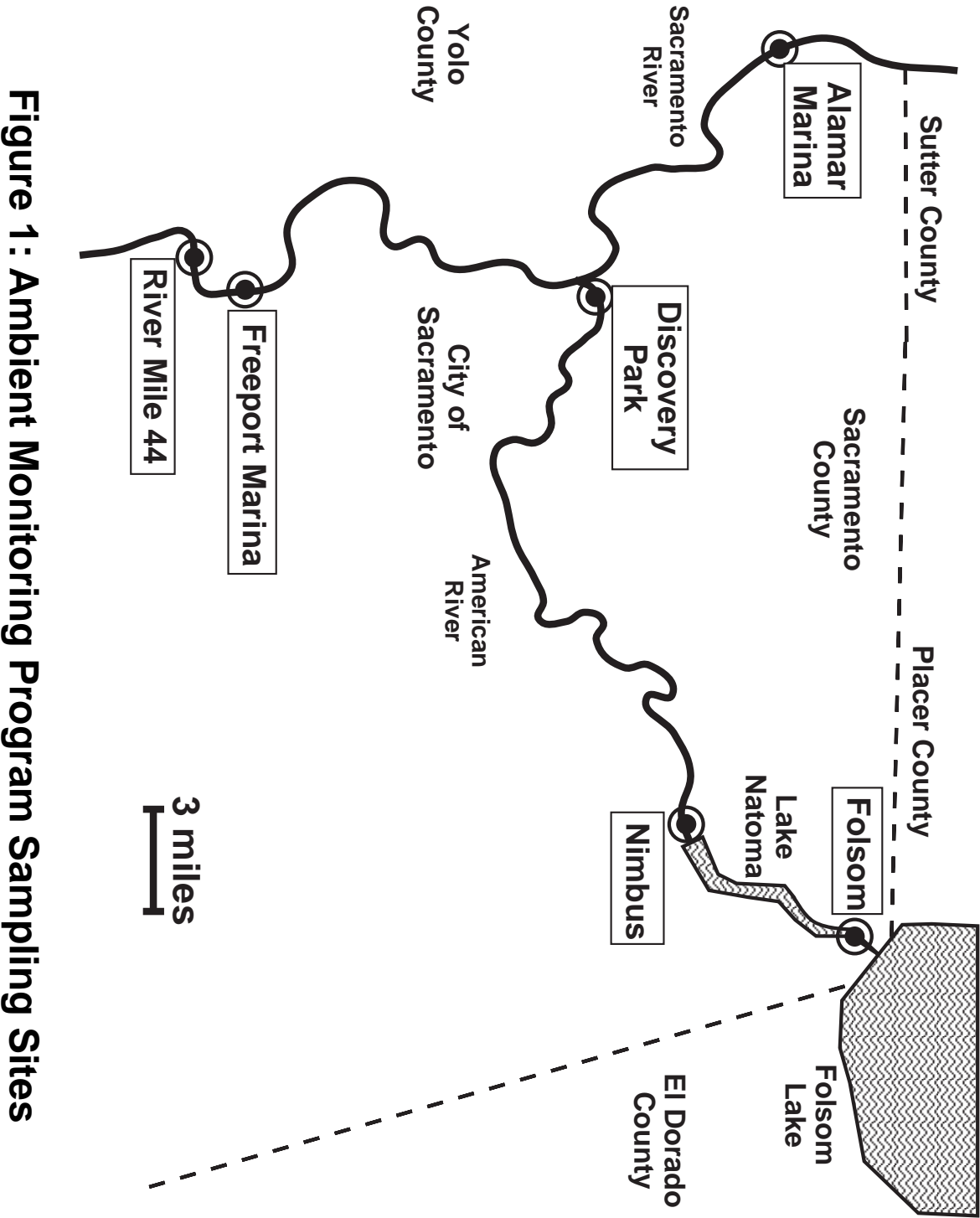
### Monitoring Design (AMP)

Six river sites are monitored under the AMP, 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 equipment consists of ISCO samplers. Methods for sample collection vary by site, depending on the availability of a platform for placement of a sampler. Twenty-four hour composite samples are taken at two locations (Alamar and Freeport) using platform-mounted samplers. Midstream, middepth grabs are taken at Nimbus. Spatially integrated samples (composited grabs taken at three depths along three or five sampling verticals) are taken by boat at the other three sampling locations.

Samples are taken twice per month at each site, typically at two week intervals.

Parameters monitored include trace elements, cyanide, and conventional parameters. Sampling frequency varies by constituent, with sampling frequency either twice monthly, monthly, or quarterly. Twice monthly sampling is performed for total recoverable and dissolved arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc; total suspended solids, total organic carbon, and dissolved organic carbon. Monthly sampling is performed for total recoverable and dissolved nickel, total cyanide and hardness. Quarterly sampling is performed for total recoverable antimony, selenium and thallium.



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 were 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 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.

## **Preliminary Results (AMP)**

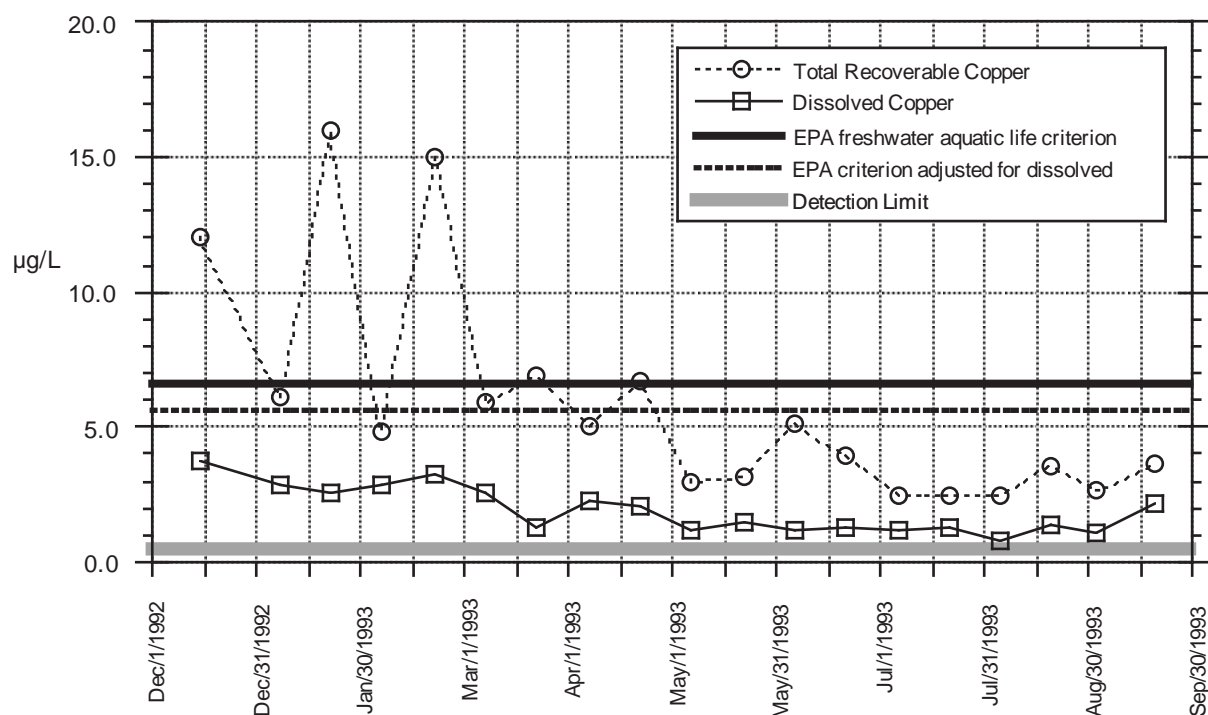
Data collected over the first nine months of the Ambient Program are not adequate to provide conclusive evidence of ambient conditions. Preliminary results have indicated the following:

- 1. Total recoverable levels of trace metals generally appear to exhibit a seasonal pattern in the Sacramento River, with higher concentrations occurring during the wet season when river flows and suspended solids levels are highest.**
- 2. The quality of the American River is typically better than the quality of the Sacramento River. Median values of suspended solids, temperature, hardness, organic carbon and trace metals were typically lower in the American River.**
- 3. For most parameters tested, no differences were observed between spatially integrated cross sectional samples and samples at middepth from fixed locations at Alamar Marina and Freeport.**
- 4. Potential compliance problems with EPA aquatic life and/or human health criteria for lead, mercury and copper apparently exist in both rivers.**
- 5. No significant differences were observed between weekend and weekday samples.**

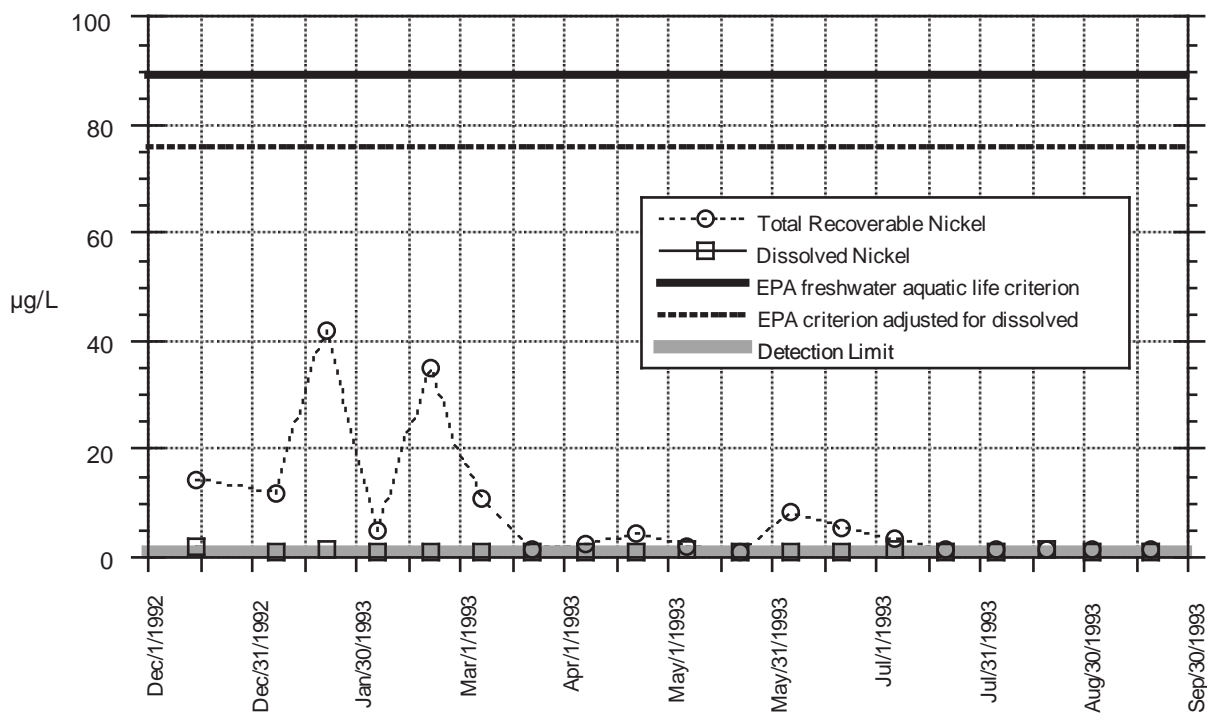
Time series plots for total recoverable and dissolved copper and nickel during the first nine months of the Ambient Program are shown in Figures 2 and 3.

## **Conclusions (AMP)**

The Ambient Program is generating reliable data and is fulfilling the monitoring objectives. Adjustments to the program will be made to ensure that this continues in the future. Use of automated composite samplers at Alamar Marina and Freeport will continue. Sampling will be performed during weekdays to facilitate activities of the sampling crew.



**Figure 2: Total Recoverable and Dissolved Copper  
in the Sacramento River at River Mile 44  
(Preliminary Results - December 1992 to September 1993)**



**Figure 3: Total Recoverable and Dissolved Nickel  
in the Sacramento River at River Mile 44  
(Preliminary Results - December 1992 to September 1993)**

## BAY PROTECTION AND TOXIC CLEANUP PROGRAM

The San Francisco Bay Regional Water Quality Control Board is continuing to conduct studies relevant to Regional monitoring. In 1993-94 two new studies are being conducted.

### Reference Site Study

This study has four goals: 1) to identify a fine grain sediment reference site in San Francisco Bay, 2) to identify protocols for sediment toxicity tests that can be successfully used in San Francisco Bay, 3) to determine the reasons for effects in toxicity tests in samples from uncontaminated areas, and 4) to develop and test the use of estuarine sediment Toxicity Identification Evaluation (TIE) methods in identifying the causes of toxicity in sediment toxicity tests.

In general, the study design is to sample five sites that fit our criteria for reference sites: uncontaminated sites with fine grain sediment. These sites include two sites (Bollinas Lagoon and Tomales Bay) where effects in toxicity tests have been found that may be from natural causes. The five sites are Tomales Bay, Bollinas Lagoon, Paradise Cove, and two sites in San Pablo Bay. Three field replicates are being collected at each site. The following toxicity tests are being performed on all field replicates: the 10-day solid phase amphipod tests using *Eohaustorius* and *Ampelisca*, the 10-day pore water test using *Eohaustorius*, and the urchin and bivalve development test in pore water. In addition, sampling cores are being used to measure *Eohaustorius* survival in undisturbed sediment in a 10-day test. A 10-day survival test using amphipod protocols is also being performed using *Nubelia* on one field replicate at each site. *Nubelia* lives in mudflats and is resistant to fine grain size and sulfides, yet is sensitive to contaminants. The *Neanthes* test may be added to the battery of tests at some point. Ammonia and hydrogen sulfide is being measured at the beginning and end of all toxicity tests. Samples are being archived for chemistry.

If significant toxicity is found in any of the pore water tests from any site, a TIE will be performed to

determine the cause of toxicity. This site will then be eliminated from subsequent sampling runs. Chemical analysis will be performed on the site that is chosen as the reference site and to back up TIE results.

Samples will be collected at three times of year: in the spring, summer and winter. During the last sampling run, contaminated sites will be sampled with the remaining reference site(s) to determine if the toxicity tests and TIE methods produce interpretable results for contaminated sites compared to reference. This study may also include small experiments to answer questions that develop in the course of the study.

### Study to Measure Contaminant Levels in San Francisco Bay Fish

A study is currently in progress to measure the levels of contaminants in fish caught in San Francisco Bay. Except for striped bass, there is very little data on the concentrations of contaminants in fish caught in San Francisco Bay. Subsistence fishers, who are mainly made up of ethnic minorities, use Bay-caught fish to make up a large part of their diet. Although, in general, fish constitute a good source of protein, these people may be exposed to higher concentrations of contaminants than the general population by eating large amounts of fish of certain species from areas that have elevated levels of contaminants. This study will measure the concentrations of a full range of contaminants in several species of fish at 13 pier or shoreline locations that are frequently fished and/or are near areas with elevated levels of contaminants. These sampling locations are Fremont Forebay, Dumbarton Bridge, San Mateo Bridge, Richmond Inner Harbor, Berkeley Pier, Fruitvale Pier (Oakland Inner Harbor), Oakland Middle Harbor Pier, Double Rock (Candlestick), Islais Creek, 7th St Pier (San Francisco), Point Molate, Rodeo Pier and Vallejo Pier. In addition, striped bass, sturgeon and sharks will be sampled from several other areas in the Bay.

All fish have been collected. Chemical analysis is now in progress. In addition to the white croaker, perch,

and striped bass that were collected at the 13 sites, striped bass, sturgeon, and sharks were sampled from several other areas in the Bay.

The Regional Board established a committee composed of staff from State agencies, environmental groups and groups working for environmental justice to design the study. Agencies and groups that contributed to the design of the study included the Dept. of Health Services, Office of Environmental Health Hazard Assessment, Dept. of Fish and Game, Dept. of Toxic Substances Control, San Francisco Estuary Institute, Save San Francisco Bay, SAFER!, Citizens for a Better Environment and Baykeeper. The Department of Fish and Game has been contracted to conduct this study. In addition, SAFER! is coordinating fishers to fish at one of the 13

sites. The cooperation between state agencies and public interest groups in developing and conducting this study has provided a successful model for addressing environmental issues in the future.

The final report, which will be available in November, will report the level of contaminants found in different fish species at different locations, determine which species are more contaminated than others, determine which fishing locations are the most contaminated and determine the chemicals of concern. The Office of Environmental Health Hazard Assessment will then evaluate the data to determine if health warnings should be issued for any of these areas. It is possible that a larger scale study will be needed to conduct a thorough health risk assessment.

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## REGIONAL WETLANDS MONITORING PLAN

### Overview

The CCMP calls for a comprehensive Regional Monitoring Plan (RMP) to assess changes in environmental conditions throughout the San Francisco Estuary and its attending watersheds and wetlands. Planning is underway to expand the existing RMP to include wetlands. As part of this planning effort, the Region IX EPA has sponsored SFEI to produce Regional Wetlands Monitoring Guidelines. A pilot project to test the Wetlands Monitoring Guidelines as part of the RMP is currently under consideration for multi-agency funding.

The Wetlands Guidelines will integrate among various existing or anticipated regional wetlands planning efforts of government. It will acknowledge the Tidal Marsh Ecosystem Recovery Plan of the Region 1 USFWS, the LTMS Index of Tidal Marsh Restoration Potential, the LTMS Tidal Marsh Restoration Monitoring Guidelines, the SF National Estuarine Research Reserve (SF NERR), the narrative guidelines of the proposed salinity standards of Region IX EPA to protect tidal marshlands, and the concept of watershed monitoring that is emerging through programs of the EPA, Region 2 Water Quality Control Board (RWQCB), and the

Council of Bay Area Resource Conservation Districts. The Wetlands Guidelines will be a key element of the Regional Wetlands Management Plan of the RWQCB.

The Wetlands Guidelines will consist of three main parts:

1. **Scientific rationale for regional wetlands habitat goals;**
2. **Analytical frame work for regional wetlands monitoring; and**
3. **A blue print or administrative plan for a citizen-based wetlands health monitoring organization. Descriptions of these three elements are provided below.**

### Part 1: Scientific Rationale for Regional Wetland Habitat Goals

Goals for the conservation of wetlands in the San Francisco Bay Area are required to implement the Cali-



California State Wetlands Policy and the regional Comprehensive Conservation and Management Plan (CCMP). The process to establish goals will be informed by the best available information about natural history and human operations that affect the form and function of wetlands in the Bay Area. The purpose of this scientific effort is to begin to answer the following basic question: how much of what kinds of wetlands do we want where, and why?

At this time, the effort to establish regional wetland habitat goals pertains to the baylands and watersheds that drain directly to the SF Estuary between the Golden Gate and the confluence of the Sacramento and San Joaquin Rivers.

The critical assumption is that wetland habitat goals must be scientifically valid, practical, and comprehensive. The goals might be developed for categories of wetlands, but only if the categories demonstrate geomorphic and ecological integrity, are consistent with management practices, help to implement the regional goals, and include the whole worth of wetlands in the Region. Based upon these criteria, the general categories of habitat are: eel grass beds, tidal mud flats, tidal marsh ponds, tidal marshlands, upland-tidal ecotone, perennial non-tidal wetlands, seasonal non-tidal wetlands, and riparian zones. No assumption is made about the relative importance of these habitat categories.

#### **Section A of Part 1: Descriptions of Past and Present Wetland Conditions**

This section involves the collection and cartographic display of information about the natural and human history of wetlands in the Region. To the extent possible, information will be captured on geographic information systems ArcInfo and GRASS. Five aspects of wetlands will be described: (1) Climatic Controls; (2) Historical Distribution and Abundance of Wetlands; (3) Modern Distribution and Abundance of Wetlands; (4) Modern Distribution and Abundance of Wetland Flora and Fauna; and (5) Landscape Resistance to Wetlands Restoration, which is indicated by the existing infrastructure of facilities and land use policies for wetlands.

#### **Section B of Part 1: Expert Scientific Conclusions and Recommendations**

This section is designed to meet two objectives: (1) integrate among the wetlands descriptions from Part A above and among expert scientific opinions to develop a consensus of understanding about the forms and functions of wetlands in the Region; and (2) develop a set of scientific recommendations for the continued conservation and recovery of the Regional wetlands resources.

#### **Section C of Part 1: Summary Science Report**

This effort to establish scientific rationale for regional wetlands habitat goals will conclude with a Summary Science Report. The report will feature (1) an Account of the Scientific Process undertaken; and (2) a Prescription for Future Wetlands in the Region. The Science Report will be produced by SFEI, based upon the information collected in Section A and the expert advice received in Section B.

The Account of Scientific Process will explain the scientific qualifications of the information used, and will present the conclusions and recommendations of the scientists involved. Dissenting scientific opinions will be fully represented.

The Prescription for Future Wetlands will consist of a series of wetland maps that show approximately how much of what kinds of wetlands and related habitats would be required within each major watershed of the Region to support target increases in population size for priority species of wildlife. A number of maps will be produced for each major watershed in the Region to suggest variations of a wetlands mosaic that could achieve the same ecological objectives. The maps *will not* dictate land use or ecological objectives for real estate parcels, but they *will* indicate the required amounts and relative spatial relationship of wetland habitats. The wetlands maps will be stored in hardcopy and on geographic information systems ArcInfo and GRASS at SFEI.

## Part 2: Analytical Framework for Regional Wetlands Monitoring

The analytical frame work for the RWMP consists of six main sections: (A) a conceptual model of estuarine wetlands functions; (B) the diagnostic approach; (C) the selected health indicators; (D) the sampling strategy for data collection; (E) the statistical procedures for data analysis; and (F) the procedures for data management and reporting.

### Section A of Part 2: Regional Estuarine Wetlands Conceptual Model

A conceptual model of estuarine marshlands has been developed for the Region (Figure 1), based primarily upon research within the San Francisco Estuary and the Tijuana Estuary. The model may pertain more to fully tidal marshlands than to marshlands that are diked or subject to damped tidal regimes. Scientific review of the model is ongoing.

The model is robust because it illustrates both the hydro-geomorphology and ecology of estuarine marshlands regardless of aqueous salinity or tidal regime. It also suggests the relative geomorphic importance of ecological components in relation to tidal elevation, which is a proxy measure for marshland age and position within estuarine marsh drainage systems. The model therefore transcends broad scales of time and space for processes that operate within or among marshlands of estuaries large or small.

The model could benefit the RMP in at least four ways. First, the model indicates the major components of the estuarine marsh ecosystem that should be targeted to monitor marshland conditions. Second, the model suggests major geomorphic and ecological classes of estuarine marshland that might be regarded as monitoring strata. Third, the model suggests how data might be compiled as virtual transects along important gradients. Fourth, the model suggests how the RWMP might be linked to the existing RMP through monitoring of natural processes. The living resources of estuarine marshlands are separated into functional components based

upon trophic level, higher taxonomy, and intertidal distribution.

### Section B of Part 2: Diagnostic Approach

Two categories of wetlands health indicators are recognized. Response Indicators are factors selected as primary measures of wetland condition. Stressor Indicators are factors expected to strongly influence the Response Indicators. Any factor might be either a Response Indicator or a Stressor Indicator, depending upon the condition of interest.

Reference Conditions are target levels of Response Indicators. Health status is measured relative to Reference Conditions. They may be conditions of historical times, the least impacted existing conditions, current compliance standards, or unprecedented future goals.

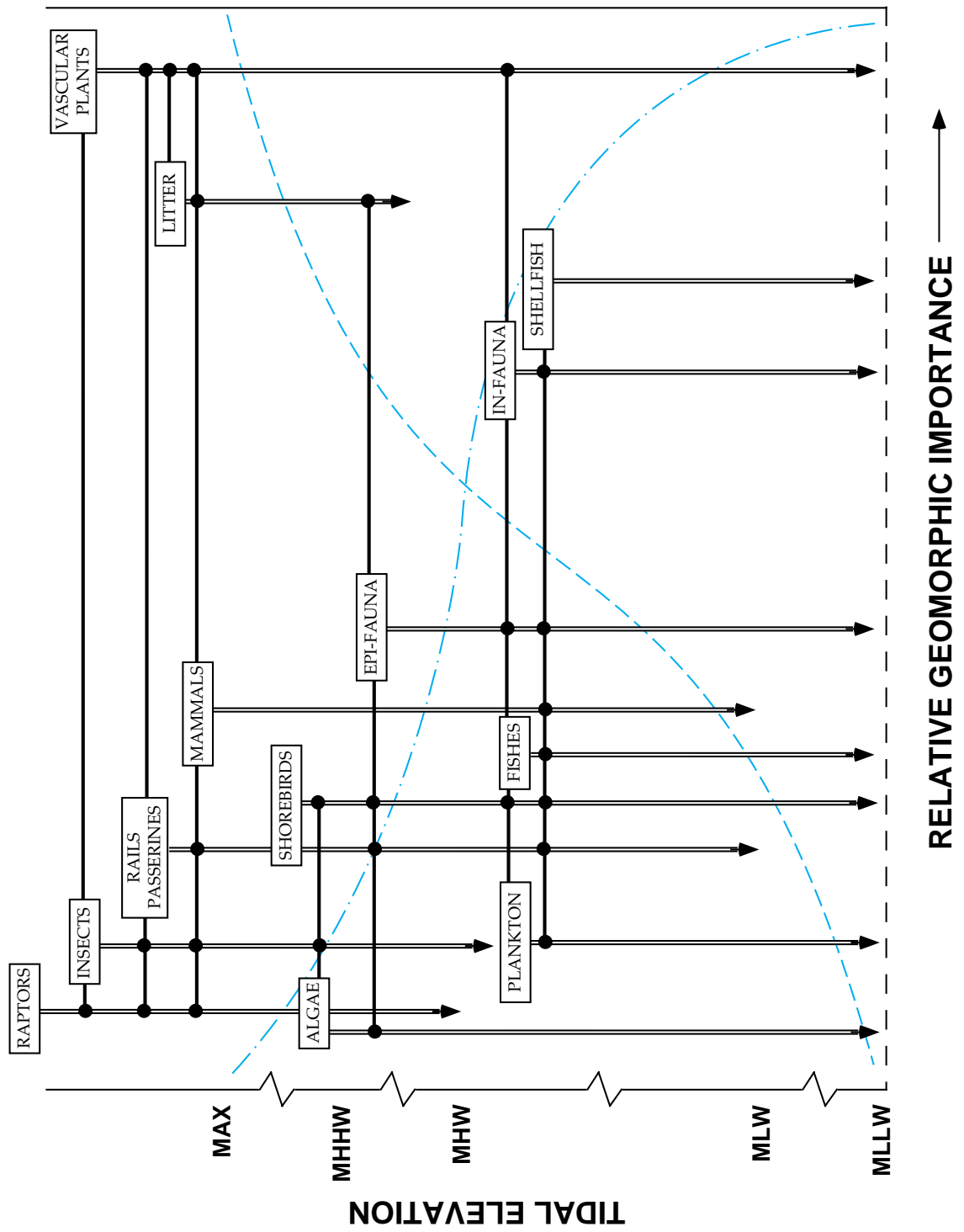
Reference Sites are places of least disturbance or negative impact, where background patterns of Response Indicators can be monitored. Reference Sites support some Reference Conditions. Different sites might be chosen for different Response Indicators. Most tidal marsh Reference Sites will be located within the component marshlands of the SF NERR. Reference Sites for diked baylands have not been identified, but might represent farmed baylands, grazed baylands, and duck clubs. Reference Sites are discussed further as sampling strata in the text about analytical frame work below.

Adaptive Management in health assessment accommodates the uncertainty about forecasts for Response Indicators. Expected amounts of variability are revealed by conditions within and among Reference Sites. A suite of Stressor Indicators are selected to monitor changes in the level of risk that the Reference Conditions will not be achieved. Progress toward a Reference Condition is quantified as a Response Curve, which should show increased similarity between existing conditions and the Reference Condition over time. The Reference Conditions and health indicators can be changed as new information and understanding is gained.

### Section C of Part 2: Health Indicators

A list of candidate Response and Stressor Indicators has been created and protocols for the indicators are being drafted at this time. The indicators have been selected to represent the major elements of the draft

Figure 1. Conceptual Wetlands Model



conceptual model of regional tidal marsh functions described above, and to address the regional wetlands assessment issues identified in the CCMP.

The major assessment issues for the estuarine wetlands of the San Francisco Estuary are indicated by the CCMP, representing the past five years of intensive effort in the Region to identify the concerns of the public, the gaps in knowledge, and the failures and successes of government. Each of these assessment issues can be addressed by the Wetlands Guidelines, depending upon the selection of Response and Stressor Indicators. The assessment issues have been classified based upon the ecological scale to which they pertain. Most issues pertain to the Region as a whole, which reflects the regional scope of the CCMP.

### **Section D of Part 2: Sampling Strategy**

For the first generation of the Wetlands Guidelines, the sampling universe will be the Regional tidal marshlands and diked baylands. These will be classified among a number of primary, secondary, and tertiary strata, based in large part upon the conceptual model described above, and in part upon other generalized understanding of wetland form and function in the Region.

The two primary strata will be tidal marshlands and diked baylands. Each of these are further classified among secondary strata, and the tidal marshlands will also be classified among tertiary strata, according to the scheme described below.

For tidal marshland, the two secondary strata are defined by age or stage of development, and are termed youthful and mature. The physical nature of youthful marshland is directly controlled by tidal action, whereas the physical nature of mature marshland is controlled by vegetation. Youthful marshland is mostly inorganic and below MHW, whereas mature marshland is mostly organic and above MHW.

Tidal marshlands can also be classified according to their aqueous salinity regimes. The convention has been to use salinity regime as a proxy criterion for ecological classification of estuarine wetlands. Robust correlations between ecological community structure and

salinity regime persist, although the distributions of many species of plants and animals vary continuously along the salinity gradient, and recent research challenges the assumption that salinity actually controls the ecological structure of estuarine marshlands in arid climates. Conventional ecological thinking thus defines three strata of tidal marshlands for estuaries: haline, brackish, and freshwater. These will be adopted as tertiary strata for tidal marshlands in the Region. It is expected that these tertiary strata are more distinct among marshlands arrayed along the main axis of the Estuary as a whole, where topographic controls and zoogeography reinforce the classification scheme, than within individual marshland settings, where correlations between community structure and salinity seem to be weak due to codominance and interannual variability among small scale ecological and geomorphic processes.

Diked marshlands must be assigned to a separate primary stratum. Where tidal action is damped or eliminated, the dynamic natural processes of marshland maintenance and development are replaced by static conditions or processes of degradation. Diked marshlands typically subside due to oxidation of organic sediments and compaction. Spatial variations in subsidence cause the formation of isolated depressions with seasonal hydroperiods controlled by precipitation, tides, and watertable fluctuations. Some depressions are filled by storm water runoff, some by pumping from tidal sloughs, and some by direct precipitation. But most are filled and drained over short time periods by a rising and falling watertable, as controlled by the tides and on-site water management.

The diked baylands will be classified among three secondary strata, based upon management practices. The proposed strata are termed diked-farmed, diked-grazed, and diked-ponded. The latter term refers to diked baylands that are dedicated to waterfowl management or other wetland resource conservation. These strata are justified because the associated land management practices result in very different hydroperiod, which in turn result in different ecological and hydrological functions.

Restored marshlands can be classified according to the stratification scheme described above. Each tidal marsh restoration project may be somewhat distinct in terms of its suite of specific ecological objectives and

engineering design, but standard protocols should be used to assess restoration progress. In this regard, the RWMP will acknowledge the guidelines already developed in the Region for the LTMS, Tidal Marsh Ecosystem Recovery Plan, and existing or proposed wetlands restoration projects.

Based upon the above discussion of geomorphology and aqueous salinity regime, a total of fifteen strata of Regional baylands are defined, as shown immediately below. Major differences in ecological community structure are expected to correspond to these classes, which therefore should be considered as sampling strata for assessments of estuarine wetlands condition.

### **Section E of Part 2: Statistical Procedures**

The Wetlands Guidelines are designed to describe wetland conditions, not to explain them. Hypotheses suggested by correlative relationships discovered through the Wetlands Guidelines should be tested through controlled experimentation. Wetlands processes and functions will be described as changes in condition along spatial gradients and over time.

### **Section F of Part 2: Data Management and Reporting**

Data management will involve the storage, retrieval, and transfer of monitoring data. A Data and Information Management Systems (DIMS) is being developed at SFEI to facilitate vertical integration of information through the regional citizenship and all levels of government. The details about DIMS are described in the Regional Monitoring Strategy of the Estuary Project.

A draft method to assess regional wetlands health status has been developed at SFEI. The method requires that each Response Indicator level is standardized as percent of the Reference Condition. Levels for all Response Indicators are plotted together on a bar chart. Overall health status would be measured as the area bounded by the tops of the bars and the 100% health status line (representing the Reference Conditions). Increasing health would be indicated by a decrease in this area of the graph over time or space. In an analogous way, spatial or temporal variations in health status for

individual Response Indicators could also be assessed graphically. Bar width could be varied among Response Indicators to reflect difference in their importance.

## **Part 3: Citizen Volunteer Monitoring Organization**

The Wetlands Guidelines will include a plan to use citizen volunteers to the extent possible for data collection for some Response and Stressor Indicators. Volunteer citizen monitoring can be justified in operational and ethical terms. Three major reasons to develop volunteer citizen monitoring have been identified. The first reason is practical. The Wetlands Guidelines will require more measurements of more factors than have ever been measured for wetlands in the Region, and that existing programs will not be able to provide sufficient staff or funding to implement the Wetlands Guidelines without volunteer citizen support. The second reason is pragmatic. Citizens are collecting data now, but the utility of the information is greatly diminished without the standardization, quality control, and quality assurance provided by regional organization with government sponsors. The third reason is ethical. Volunteer monitoring connects people to government through land care, and thus improves government, citizenship, and land health.

A draft conceptual plan to train and use citizen volunteer monitors has been developed by SFEI in cooperation with the Coyote Creek Riparian Station, the RWQCB, and Region IX EPA. The draft plan has been submitted to the Region 2 Water Quality Control Board for review and revision as part of the Regional Wetlands Management Plan and the Regional Watershed Management Plan. As envisioned at this time, the citizen monitoring plan will address science development, data collection and management, information exchange, and public reporting about watersheds entirely, including natural processes and human operations affecting conditions of resources in wetlands, streams, riparian zones, and terrestrial settings. It is expected that the Wetlands Guidelines and citizen monitoring plan will eventually merge with the existing aquatic estuarine monitoring plan to create a more comprehensive RMP for the Region as a whole.

## Discussion and Conclusions

This first report from the San Francisco Estuary Regional Monitoring Program has presented a large amount of information on trace contaminants in water, sediment, and tissues, and their possible ecological effects. This is the first time that such information collected from stations throughout the Estuary has been reported and interpreted comprehensively. Consistent with the objectives of the RMP, the status of trace contamination in the Estuary in 1993 was well documented, and the data are available for comparison and evaluations in other programs, model verification, etc.

The Regional Monitoring Program results presented in this report represents sampling at 16 stations and three times in 1993. Due to this limited coverage in space and time, the trends and relationships presented may not reflect conditions at all Estuary locations, or trends over longer time periods. The determination of accurate trends in space and time can be determined after several years of RMP data collection and analysis.

Throughout this report trace metal and organic concentrations measured in the Estuary have been presented in the context of their relationships with other environmental factors measured at the same time. Dissolved contaminant concentrations were usually closely related to salinity and/or DOC. Deviations from conservative mixing gradients identified stations with higher concentrations than expected and suggested sources for various contaminants under differing conditions of local runoff and Delta outflow. Total contaminant concentrations in water were variably related to dissolved concentrations, but were often closely related to TSS. For sediments, most of the variation in sediment concentrations was directly related to sediment grain-size and organic content. Again, deviations from these relationships help identify stations where local sources may explain elevated concentrations. Distinguishing between natural and anthropogenic sources of variability is essential to interpreting data collected in the RMP.

The upstream river sampling produced data of limited use due to the confounding effect of tidal influence at the Rio Vista station. That station should be moved farther up-river past tidal influence.

Although some of the trace contaminant concentra-

tions in water at several stations were above the water quality guidelines used for evaluation, there was no indication of acute aquatic toxicity. The sediment toxicity tests exhibited the opposite trend: only nickel was above the ERM guideline, but widespread sediment toxicity was indicated. Potential causes of this observed toxicity were not investigated. However, it is difficult to extrapolate the results of laboratory toxicity tests using nonresident species to potential ecological effects in the Estuary. The use and application of toxicity testing in the RMP will continue to be reviewed and modified annually, moving towards toxicity tests that can be used as meaningful indicators of actual ecological effects in the Estuary.

Bioaccumulation of contaminants by transplanted bivalves demonstrated that most metals and all organic contaminants were bioavailable and accumulated in their tissues. However, the use of different species and uncontrolled environmental factors such as salinity, suspended sediment, and food supply confound the ability to clearly interpret differences in bioaccumulation of contaminants in between locations or seasons.

The RMP Pilot Studies provided information important to the developing RMP. The information from these studies will help put RMP measurements into the perspective of Estuary processes and mechanisms at other time scales. The studies showed differences in the spatial scales of Estuary processes (stratification), and in time scales (spring bloom, suspended sediment concentrations) important in interpretation of the RMP measurements.

The Hydrography and Phytoplankton Study water profiles showed stratification of the Estuary. As shown for the RMP data, trace contaminant concentrations vary with salinity. Therefore, differences in salinity over water depth may indicate different contaminant concentrations at different depths. It will be important to refine our knowledge of these relationships to provide better indications of trace contaminant distributions in the water column. Additionally, the appropriate sampling frequency in time and space necessary to monitor the major environmental events in the Estuary, such as the spring bloom and Delta outflows, can be evaluated. Questions remaining to be addressed by these studies relate to the

**Table 30. Summary of monitoring measurements that were above various guidelines for environmental quality (see text) at each RMP location.**  
 This table only includes information from analyses completed on 1993 RMP data.  
 Number in parentheses indicates number of observations greater than applicable guideline concentrations. For sediment toxicity, the number of times and endpoints (5 possible) with significant toxicity is used.

Location Name	Water			Sediment			Tissue	
	Metals	Organics	Toxicity	Metals	Organics	Toxicity	Metals†	Organics*
Extreme South Bay	—		—	Ni(2)	—	2		
Dumbarton Bridge	—	PCB, D, C	—	Ni(2)	—		Se(2), Cr, Cd(2), Cu, Zn	—
Redwood Creek	Ni	PCB, C		Ni	—	3	Se, As, Cd	—
Oyster Point	—			Ni(2)	—		—	
Yerba Buena Isl.	—	PCB, D, C	—	Ni	—	2	Cr, Se(2)	—
Golden Gate/ Horseshoe Bay	—	PCB, C		Ni(2)	—		Cr, Se(2), As, Cd	—
Richardson Bay	—			Ni(2)	—		—	
Point Isabel	—			Ni(2)	—		—	
San Pablo Bay	Pb, Hg, Cu(2), Cr, Ni	PCB, C		Ni(2)	—		Se(2), Cr, Cu(2), Zn(3), As, Cd(2)	—
Pinole Point	Cr, Cu, Hg, Ni	PCB, D	I	Ni(2)	—	3	Cr, Se(2), As	—
Davis Point	—	PCB, D, C		Ni(2)	—		Zn(3), Cd(3), As(2), Cu(2), Se(2)	—
Napa River	Cu, Hg(2)	PCB, C	I	Ni(2)	—	3	Zn(2), Cd(3), Cu(2), Se, As	—
Pacheco Creek	Pb, Cu, Hg(2), Ni			Ni(2)	—		—	
Grizzly Bay	Hg, Cu, Ni	PCB, D, C DDT	—	Ni(2)	—	5	As(2), Cr, Se(2)	—
Sacramento River	—	PCB, D, C DDT	—	Ni(2)	—	4	As(2), Cr, Se	—
San Joaquin River	—	PCB, D	—	Ni(2)	—	4	As(2), Cr, Se(2)	—

Chromium VI standard was used for water and tissue.  
 For copper, proposed standard of 4.9 ppb was used.

I inconclusive results  
 — values below guidelines  
 blank not measured  
 † based on Median International Standards for shellfish  
 \* based on USFDA Action Levels for shellfish and NAS guidelines  
 D = Dieldrin  
 C = Chlordanes

utility of the phytoplankton measurements as indicators of ecological health of the Estuary, and how to use the RMP and USGS data together to understand their relationships better.

Information produced by the Sediment Transport Study is important because, as shown by the RMP data, total contaminant concentrations in water was largely dependent on the TSS concentrations. This implies that the RMP measurements collected at one water depth, three times a year cannot determine accurately the range of contaminant concentrations without better characterizing the dynamics of TSS.

In this report, results for trace contaminant concentrations, toxicity, and bioaccumulation were each presented separately. In order to assess the overall condition of the Estuary in terms of contaminants and their possible effects, the results of the individual sections of the report must be collectively evaluated. For this assessment, contaminant concentration objectives, criteria, guidelines, or standards are used as indicators of estuarine health. Regional Basin Plan Objectives or EPA criteria were used for water, ERM guidelines (Long *et al.* 1993) were used for sediment, significant differences from controls were used for toxicity tests, and Median International Standards (metals) or USFDA action levels (organics) were used for tissue contaminant levels (see respective sections for details of objectives and guidelines used).

Because toxicity testing or bioaccumulation monitoring was not conducted at all locations, comparisons among all RMP stations are limited. For this summary, these criteria and guidelines are only used as a comparative guide to the result of monitoring at each station. Considered all together they provide a qualitative summary of the condition of the Estuary in terms of trace contamination.

RMP stations above guidelines and with significant toxicity are listed in Table 30. All RMP stations had total PCB concentrations in water, and nickel concentrations in sediments, above the guidelines. None of the RMP stations sampled indicated water toxicity, but all of the sediment stations tested had significant sediment toxicity.

Trace metals were most often above water quality objectives at the northern estuary stations in San Pablo

Bay, Napa River, Grizzly, and Suisun Bays. Additionally, tissue metals concentrations were more often above the MIS at those stations. Grizzly Bay (BF20) had the most sediment toxicity and trace organics levels above guidelines, along with the Sacramento River station (BG20). The South and Central Bays had fewer concentrations above guidelines, although concentrations of some metals, PCBs, and PAHs in water and sediment were highest there.

There was very little continuity in guideline exceedances between water, sediment, and tissue. Although water trace organic concentrations were often above guidelines, concentrations in sediment or tissues were always below guidelines. Similarly, of the trace metals above guidelines in water, only sediment nickel concentrations were above guidelines Estuary-wide. However, many trace metals that were below water quality guidelines were above tissue guidelines at the same locations.

These results indicate that there is room for improvement in the Estuary's water and sediment quality. These improvements can be accomplished through continued enhancement of public awareness, source control, and improved treatment technology. The RMP's role is to provide feedback to the public, their discharge agencies, and the regulatory community on the success of their programs and policies.





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*The M/V Rincon Point*

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## Regional Monitoring Program

### STATEMENT OF INCOME AND EXPENSES

July 1, 1992 through December 31, 1993

INCOME	Cash	In-kind	Total
Municipal Dischargers	\$710,100		\$710,100
Industrial Dischargers	204,914		204,914
Cooling Water Dischargers	50,000		50,000
Stormwater Dischargers	90,000		90,000
Dredged Material Dischargers		100,000	100,000
Interest 7/1/92 - 12/31/93	14,431		14,431
<b>TOTAL INCOME</b>	<b>\$1,069,445</b>	<b>\$100,000</b>	<b>\$1,169,445</b>

EXPENSES	Cash Payments
Applied Marine Sciences, Inc.	\$612,272
EcoAnalysis, Inc.	9,014
San Francisco Estuary Institute (AHI)	166,248
U.S. Geological Survey	25,000
Miscellaneous (printing, postage, software)	3,278
	<b>\$815,812</b>

RMP ACCOUNT BALANCE as of 12/31/93	\$253,633
Approximate outstanding contractual amounts	\$155,381
Approximate fund balance as of 12/31/93	\$98,252

NOTES: THIS STATEMENT IS UNAUDITED AND APPROXIMATE.

SFEI's audited financial statement is available upon request.

SFEI has a July 1 - June 30 fiscal year, and amounts in the official audit will not correspond directly to the amounts shown here.

Much of the SFEI (AHI) work on the Annual Report was done during calendar year 1994, and therefore the final cost of the Annual Report is not reflected in these figures.



## Appendices



## Appendix 1—Sponsoring Agencies

### Regional Monitoring Program Sponsoring Agencies

#### Municipal Dischargers:

City of Benicia  
Burlingame WWTP\*  
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 WWTP\*  
Mountain View Sanitary District  
Napa Sanitation District  
Novato Sanitation District  
City of Palo Alto  
City of Petaluma  
City of Pinole  
Rodeo Sanitary District  
City of San Francisco  
City of San Jose/Santa Clara  
City of San Mateo  
Sausalito-Marín 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 County  
CALTRANS\*  
Contra Costa County Flood Control\*  
Fairfield-Suisun Sewer District\*  
Marin County Stormwater\*  
City and County of San Francisco\*  
San Mateo County Stormwater\*  
Santa Clara Valley Water District  
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\*

\* indicates sponsors added for 1994



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*Downloading data from the CTD (conductivity, temperature, depth) instrument.*

**Table 1. Concentrations of conventional water quality parameters for water samples.**

. means data not collected.

For conversion of  $\mu\text{M}$  to  $\mu\text{g/L}$  use the following *atomic weight multipliers*; P = 31; C = 12; N = 14; Si = 28.

Station Code	Station Name	date	ammonia $\mu\text{M}$	chlorophyll-a $\text{mg/m}^3$	conductivity $\mu\text{mho}$	DOC $\mu\text{M}$	DO $\text{mg/l}$	nitrate $\mu\text{M}$	nitrite $\mu\text{M}$	pH	phaeophytin $\text{mg/m}^3$	phosphate $\mu\text{M}$	salinity o/oo	silicates $\mu\text{M}$	temp C	TSS $\text{mg/l}$
BA20	Extreme South Bay	3/2/93	16.76	1.23	.	289	10.00	142.64	31.47	7.8	.	6.42	6.78	137.57	11.0	14.4
BA30	Dumbarton Bridge	3/2/93	12.18	1.85	.	284	9.80	101.39	19.41	8.0	.	8.11	13.77	183.56	12.0	19.1
BA40	Redwood Creek	3/2/93	6.12	3.47	.	244	.	49.64	16.18	8.2	.	4.67	17.95	100.14	14.5	5.1
BB30	Oyster Point	3/2/93	8.28	2.97	.	205	10.50	27.50	12.35	8.1	.	3.26	16.43	92.44	14.0	4.4
BC10	Yerba Buena Is.	3/3/93	7.10	2.75	.	236	9.00	32.86	9.41	7.9	.	16.07	16.07	89.07	15.0	4.2
BC20	Golden Gate	3/3/93	7.74	0.99	.	122	8.90	18.14	9.99	7.9	.	1.94	24.00	70.66	14.0	3.1
BC30	Richardson Bay	3/3/93	1.84	1.33	.	201	9.60	15.00	5.29	8.0	.	1.96	16.48	109.13	15.0	3.8
BC41	Point Isabel	3/2/93	6.83	1.52	.	248	10.70	24.50	9.70	8.1	.	2.78	13.86	126.77	13.0	11.1
BD20	San Pablo Bay	3/4/93	7.29	2.96	.	319	10.00	31.96	8.53	7.8	.	2.75	6.08	154.10	12.5	7.2
BD30	Pinole Point	3/4/93	6.43	3.24	.	290	9.90	26.77	8.23	7.9	.	2.60	9.11	151.15	12.5	7.0
BD40	Davis Point	3/4/93	6.89	3.19	.	260	9.70	26.18	8.53	7.9	.	2.71	8.43	126.25	12.0	13.2
BD50	Napa River	3/4/93	11.00	1.03	.	290	9.90	42.18	10.29	7.8	.	3.11	4.88	164.86	14.5	29.7
BF10	Pacheco Creek	3/4/93	8.20	0.76	.	282	11.10	32.77	12.94	8.2	.	2.72	0.00	118.67	15.0	81.8
BF20	Grizzly Bay	3/5/93	9.49	0.78	.	295	10.50	30.77	9.70	7.8	.	2.83	0.00	109.22	11.5	46.9
BG20	Sacramento River	3/5/93	7.44	0.99	.	295	10.00	35.41	11.18	7.8	.	2.81	0.00	152.52	11.0	38.5
BG30	San Joaquin River	3/5/93	7.44	0.78	.	516	9.40	37.27	13.82	7.7	.	3.02	0.00	136.93	14.0	42.5
BA20	Extreme South Bay	5/24/93	1.93	2.70	.	237	7.30	47.90	2.65	7.8	.	13.27	21.51	113.80	21.0	15.3
BA30	Dumbarton Bridge	5/24/93	4.87	2.38	.	233	7.20	35.60	2.23	7.9	.	11.11	22.17	91.30	21.0	6.0
BA40	Redwood Creek	5/24/93	5.62	1.98	.	179	7.50	17.60	1.47	7.9	.	5.72	24.17	68.00	20.0	2.0
BB30	Oyster Point	5/24/93	4.95	1.48	.	161	8.00	14.20	1.16	7.3	.	4.18	24.99	74.50	19.0	7.8
BC10	Yerba Buena Is.	5/24/93	5.12	1.42	.	.	.	10.30	0.66	7.9	.	2.64	26.86	57.00	17.0	3.8
BC20	Golden Gate	5/25/93	2.68	1.27	.	113	8.30	9.80	0.58	7.9	.	1.54	24.00	41.00	15.0	0.0
BC30	Richardson Bay	5/25/93	2.18	1.21	.	155.5	7.10	9.20	0.47	7.9	.	1.88	28.20	59.60	17.0	3.8
BC41	Point Isabel	5/25/93	3.44	2.26	.	173	8.30	15.00	0.75	8.0	.	2.31	24.69	77.20	17.0	6.0
BD20	San Pablo Bay	5/26/93	4.03	3.52	.	209.5	8.30	23.30	0.87	7.6	.	3.51	16.27	72.00	18.0	190.7
BD30	Pinole Point	5/26/93	5.29	1.76	.	199	8.10	18.00	0.97	8.0	.	2.88	17.60	123.90	18.0	87.5
BD40	Davis Point	5/26/93	4.53	1.48	.	223.5	8.20	18.10	0.90	8.0	.	2.69	8.85	40.10	19.0	26.5
BD50	Napa River	5/26/93	4.45	1.74	.	228	8.40	17.50	0.62	8.0	.	2.74	7.79	34.00	19.0	40.5
BF10	Pacheco Creek	5/26/93	3.94	4.95	.	231	8.50	13.70	0.87	8.0	.	2.55	7.47	61.80	19.0	85.2
BF20	Grizzly Bay	5/27/93	0.07	33.69	.	235	9.40	9.40	0.48	8.0	.	2.02	0.67	56.20	20.0	23.1
BG20	Sacramento River	5/27/93	5.45	20.26	.	203	9.40	9.70	0.58	8.0	.	1.44	0.00	229.60	20.0	19.9
BG30	San Joaquin River	5/27/93	0.07	76.19	.	.	9.90	0.10	0.17	7.9	.	0.19	0.00	19.10	20.0	43.9
BA20	Extreme South Bay	9/13/93	2.14	1.75	39000	177	6.20	28.23	1.22	7.9	119	11.67	28.50	158.54	21.0	9.1
BA30	Dumbarton Bridge	9/13/93	2.75	1.62	39000	182	6.85	25.65	0.93	7.9	113	11.41	28.66	179.13	21.0	11.2
BA40	Redwood Creek	9/13/93	4.10	1.88	36500	152	6.95	18.11	1.38	7.8	119	8.96	28.94	135.99	21.0	11.7
BB30	Oyster Point	9/13/93	2.50	2.12	39000	121	7.45	20.45	1.40	7.9	179	6.36	29.31	101.38	21.0	9.6
BC10	Yerba Buena Is.	9/13/93	4.65	2.89	39000	104	7.45	11.91	0.92	7.8	153	2.82	29.62	59.62	19.0	5.4
BC20	Golden Gate	9/14/93	0.08	5.37	39000	64	8.15	8.53	0.51	8.0	211	1.26	33.00	17.75	14.5	1.7
BC30	Richardson Bay	9/14/93	2.10	3.76	38000	79	7.40	12.71	0.91	7.8	202	2.33	30.38	50.60	17.0	9.7
BC41	Point Isabel	9/14/93	0.56	3.89	37500	102	8.95	13.38	0.79	7.9	271	2.52	29.40	62.36	18.0	15.5
BD20	San Pablo Bay	9/15/93	1.06	2.35	33000	115	7.20	14.63	0.87	7.8	360	3.25	25.73	87.36	20.5	58.9
BD30	Pinole Point	9/15/93	0.90	1.71	32500	121	8.20	16.50	0.86	7.8	154	3.42	24.44	96.28	20.0	13.2
BD40	Davis Point	9/15/93	2.43	1.43	28000	117	8.45	15.64	1.01	7.7	210	3.83	19.98	129.03	20.0	40.7
BD50	Napa River	9/15/93	3.06	1.27	23000	136	8.15	19.43	1.09	7.9	216	3.03	16.04	156.19	20.0	58.2
BF10	Pacheco Creek	9/15/93	3.28	0.97	17000	140	9.25	24.72	1.04	7.9	134	3.67	11.39	197.26	20.0	45.9
BF20	Grizzly Bay	9/16/93	0.94	2.48	8500	151	9.20	24.79	0.79	8.0	317	3.69	5.93	226.69	18.0	100.6
BG20	Sacramento River	9/16/93	2.17	2.82	250	139	8.40	15.98	1.46	7.8	201	2.34	0.01	284.14	20.5	31.2
BG30	San Joaquin River	9/16/93	2.04	2.42	850	141	8.75	17.00	0.99	7.6	259	2.49	0.02	139.91	21.5	37.5

**Table 2. Total or near-total\* concentrations of trace elements in water samples.**  
 \* means not measured.

Station Code	Station Name	Date	Ag* ng/kg	As µg/L	Cl* ng/kg	Cr ug/kg	CN µg/L	Cu* ug/kg	Hg ng/L	Ni* ug/kg	Pb* ng/kg	Se µg/L	Zn* ug/kg
BA20	Extreme South Bay	3/2/93	6.44	2.42	57.40	3.04	< 1.0	3.41	10.02	5.17	620	0.373	6.65
BA30	Dumbarton Bridge	3/2/93	7.98	1.96	56.81	2.34	< 1.0	3.25	8.74	4.64	480	0.281	4.13
BA40	Redwood Creek	3/2/93	6.37	2.07	133.34	1.01	< 1.0	2.99	4.42	10.37	330	0.177	4.37
BB30	Oyster Point	3/2/93	4.25	1.49	42.75	0.70	< 1.0	2.35	3.30	2.62	160	0.131	1.43
BC10	Yerba Buena Is.	3/3/93	3.66	1.82	33.32	0.86	< 1.0	2.45	3.98	2.74	240	0.132	1.86
BC20	Golden Gate	3/3/93	2.12	1.65	16.37	0.43	< 1.0	0.71	1.71	1.30	90	0.128	0.77
BC30	Richardson Bay	3/3/93	2.40	1.46	26.28	0.76	< 1.0	2.41	3.75	2.00	230	0.130	1.61
BC41	Point Isabel	3/2/93	5.36	2.29	31.47	1.90	< 1.0	1.86	5.99	3.59	470	0.187	2.56
BD20	San Pablo Bay	3/4/93	3.06	1.53	26.09	2.58	< 1.0	3.18	6.44	5.17	330	0.113	2.33
BD30	Pinole Point	3/4/93	2.81	1.42	30.43	1.67	< 1.0	2.92	6.07	4.18	220	0.159	1.99
BD40	Davis Point	3/4/93	3.26	1.35	30.12	2.57	< 1.0	3.09	5.51	4.50	300	0.133	2.48
BD50	Napa River	3/4/93	7.61	1.61	30.80	3.51	< 1.0	4.40	13.57	9.77	1130	0.157	7.43
BF10	Pacheco Creek	3/4/93	6.26	1.95	30.56	15.11	< 1.0	4.27	18.30	4.84	2340	0.171	5.41
BF20	Grizzly Bay	3/5/93	9.71	1.69	25.94	12.24	< 1.0	6.21	14.61	8.70	1260	0.121	10.41
BG20	Sacramento River	3/5/93	7.44	1.68	21.16	8.40	< 1.0	5.23	10.26	6.66	920	0.197	8.40
BG30	San Joaquin River	3/5/93	8.00	1.85	21.97	8.83	< 1.0	5.31	10.59	6.52	910	0.159	7.49
BA20	Extreme South Bay	5/24/93	141.78	3.61	97.41	3.66	< 1.0	4.45	13.69	5.65	848	0.406	4.82
BA30	Dumbarton Bridge	5/24/93	119.29	2.81	68.86	2.28	< 1.0	3.58	7.17	4.30	585	0.259	3.26
BA40	Redwood Creek	5/24/93	81.20	2.40	69.02	1.03	< 1.0	2.16	3.88	2.50	273	0.282	1.91
BB30	Oyster Point	5/24/93	71.86	2.14	75.56	1.22	< 1.0	2.15	4.64	2.40	304	0.165	1.87
BC10	Yerba Buena Is.	5/24/93	51.58	1.78	68.47	1.42	< 1.0	1.61	3.46	1.79	237	0.234	1.87
BC20	Golden Gate	5/25/93	36.66	1.58	62.30	0.50	< 1.0	0.74	1.93	0.98	87	0.318	0.74
BC30	Richardson Bay	5/25/93	68.28	1.72	66.88	1.27	< 1.0	2.02	4.40	1.80	353	0.220	2.89
BC41	Point Isabel	5/25/93	71.51	2.10	67.53	1.37	< 1.0	1.62	4.20	2.26	388	0.184	2.13
BD20	San Pablo Bay	5/26/93	25.47	3.65	92.28	38.21	< 1.0	10.29	63.51	15.98	6459	0.205	30.37
BD30	Pinole Point	5/26/93	14.45	2.69	80.17	18.31	< 1.0	6.47	27.11	9.60	3104	0.233	18.94
BD40	Davis Point	5/26/93	100.07	2.25	50.84	6.43	< 1.0	4.00	11.18	5.37	1045	0.180	9.41
BD50	Napa River	5/26/93	126.30	2.15	48.28	5.29	< 1.0	4.39	12.66	5.93	1288	0.190	11.59
BF10	Pacheco Creek	5/26/93	15.50	2.59	61.15	15.92	< 1.0	7.66	26.20	10.87	3853	0.190	22.00
BF20	Grizzly Bay	5/27/93	119.29	2.06	29.55	8.01	< 1.0	4.49	12.40	4.98	1213	0.205	11.01
BG20	Sacramento River	5/27/93	56.62	1.37	30.87	3.68	< 1.0	3.35	5.95	3.20	528	0.153	5.00
BG30	San Joaquin River	5/27/93	43.99	1.71	26.93	4.81	< 1.0	3.90	8.13	3.38	788	0.204	5.41
BA20	Extreme South Bay	9/13/93	17.62	3.96	145.22	1.42	< 1.0	3.51	5.36	4.25	406	0.300	2.17
BA30	Dumbarton Bridge	9/13/93	18.86	4.37	140.59	2.19	< 1.0	3.48	7.99	4.52	573	0.259	2.76
BA40	Redwood Creek	9/13/93	19.37	3.58	121.88	1.87	< 1.0	3.02	4.88	3.87	445	0.252	2.23
BB30	Oyster Point	9/13/93	18.04	2.87	113.81	2.16	< 1.0	2.45	7.70	3.38	529	0.224	2.57
BC10	Yerba Buena Is.	9/13/93	9.34	2.30	64.06	0.90	< 1.0	1.66	3.90	1.46	269	0.275	1.76
BC20	Golden Gate	9/14/93	0.65	1.70	43.05	0.21	< 1.0	1.48	0.83	0.33	77	0.264	0.26
BC30	Richardson Bay	9/14/93	9.03	2.00	65.79	1.46	< 1.0	1.74	4.82	1.74	388	0.214	2.06
BC41	Point Isabel	9/14/93	15.11	2.20	72.84	3.41	< 1.0	2.34	10.05	3.19	888	0.233	3.52
BD20	San Pablo Bay	9/15/93	29.97	2.38	111.51	7.13	< 1.0	6.42	19.85	7.55	2217	0.273	14.24
BD30	Pinole Point	9/15/93	9.91	2.31	71.69	2.64	< 1.0	3.08	6.44	2.80	446	0.353	2.52
BD40	Davis Point	9/15/93	18.59	2.74	78.68	7.27	< 1.0	4.41	11.01	5.84	1420	0.324	10.51
BD50	Napa River	9/15/93	22.01	2.93	107.91	8.21	< 1.0	7.37	32.55	7.71	2134	0.271	14.74
BF10	Pacheco Creek	9/15/93	13.01	2.89	65.18	5.40	< 1.0	5.47	14.99	5.21	1167	0.260	9.56
BF20	Grizzly Bay	9/16/93	31.15	2.95	40.60	16.14	< 1.0	11.54	35.01	9.89	688	0.250	18.76
BG20	Sacramento River	9/16/93	9.00	2.02	26.34	4.44	< 1.0	3.74	9.98	3.45	688	0.241	8.43
BG30	San Joaquin River	9/16/93	10.32	1.99	24.25	4.94	< 1.0	4.12	11.36	4.03	1070	0.265	9.39

**Table 3. Dissolved concentrations of trace elements in water samples.** Please note that the mercury and selenium data for March exceeded quality assurance limits and should be used with caution.

Station Code	Station Name	Date	Ag ng/kg	As μg/kg	Cd ng/kg	Cr μg/kg	CN ng/kg	Cu μg/kg	Hg ng/kg	Ni μg/kg	Pb ng/kg	Se μg/kg	Zn μg/kg
BA20	Extreme South Bay	3/2/93	2.08	1.75	57.20	0.45	<1.0	2.42	3.80	3.56	87.38	0.51	3.08
BA30	Dumbarton Bridge	3/2/93	1.04	2.05	56.27	0.23	<1.0	2.52	2.82	3.42	69.26	0.28	2.61
BA40	Redwood Creek	3/2/93	1.12	2.24	65.08	0.17	<1.0	2.33	8.66	3.20	27.50	0.16	1.74
BB30	Oyster Point	3/2/93	1.32	1.79	42.40	0.15	<1.0	1.95	6.28	2.38	9.09	0.15	0.90
BC10	Yerba Buena Is.	3/3/93	1.61	1.60	38.58	0.15	<1.0	1.94	1.87	2.41	6.80	0.15	0.92
BC20	Golden Gate	3/3/93	1.16	1.50	26.57	0.14	<1.0	0.99	1.91	1.30	5.16	0.10	0.50
BC30	Richardson Bay	3/3/93	0.68	1.57	33.63	0.13	<1.0	1.91	1.64	1.99	7.92	0.14	1.22
BC41	Point Isabel	3/2/93	1.04	1.40	34.78	0.20	<1.0	1.99	2.12	2.49	13.17	0.09	0.77
BD20	San Pablo Bay	3/4/93	1.34	1.57	29.23	0.22	<1.0	2.54	2.43	3.73	21.31	0.15	0.78
BD30	Pinole Point	3/4/93	1.38	1.33	28.69	0.21	<1.0	2.30	2.01	3.60	15.63	0.15	0.74
BD40	Davis Point	3/4/93	1.62	1.48	33.04	0.36	<1.0	2.36	2.45	3.75	62.88	0.17	0.98
BD50	Napa River	3/4/93	2.00	1.42	30.90	0.67	<1.0	2.33	3.85	6.19	143.58	0.15	1.67
BF10	Pacheco Creek	3/4/93	2.91	1.53	8.85	0.41	<1.0	2.65	2.09	2.64	216.09	0.18	1.35
BF20	Grizzly Bay	3/5/93	3.44	1.37	11.73	0.36	<1.0	2.76	4.83	3.03	259.31	0.16	1.52
BG20	Sacramento River	3/5/93	3.63	1.60	10.74	0.08	<1.0	2.69	3.81	2.79	212.40	0.19	1.39
BG30	San Joaquin River	3/5/93	4.51	1.53	11.87	0.44	<1.0	2.94	5.34	2.76	288.78	0.17	1.79
BA20	Extreme South Bay	5/24/93	5.24	3.19	130.34	0.08	<1.0	3.25	1.71	2.94	51.22	0.21	1.12
BA30	Dumbarton Bridge	5/24/93	4.97	2.91	122.09	0.08	<1.0	3.08	2.34	2.81	46.72	0.22	0.94
BA40	Redwood Creek	5/24/93	3.59	2.30	73.80	0.09	<1.0	1.98	1.17	2.10	29.29	0.17	0.62
BB30	Oyster Point	5/24/93	2.79	1.86	71.60	0.08	<1.0	1.64	1.39	1.75	20.19	0.16	0.59
BC10	Yerba Buena Is.	5/24/93	1.67	1.97	62.64	0.10	<1.0	1.23	0.83	1.18	9.64	0.21	0.77
BC20	Golden Gate	5/25/93	1.63	1.77	59.72	0.10	<1.0	0.69	0.66	0.79	9.71	0.12	0.32
BC30	Richardson Bay	5/25/93	1.59	1.63	63.85	0.09	<1.0	1.02	1.21	1.02	9.50	0.19	0.58
BC41	Point Isabel	5/25/93	3.09	1.94	64.04	0.10	<1.0	1.32	0.76	1.29	6.89	0.25	0.48
BD20	San Pablo Bay	5/26/93	4.76	2.33	68.10	0.19	<1.0	1.90	1.21	1.92	6.26	0.22	0.41
BD30	Pinole Point	5/26/93	3.36	1.92	67.26	0.16	<1.0	1.64	0.91	1.62	11.12	0.24	0.58
BD40	Davis Point	5/26/93	1.09	1.81	44.52	0.16	<1.0	1.83	1.04	1.43	12.70	0.14	0.60
BD50	Napa River	5/26/93	0.59	1.79	40.84	0.13	<1.0	1.89	1.01	1.44	5.81	0.17	0.54
BF10	Pacheco Creek	5/26/93	0.59	1.98	40.81	0.20	<1.0	1.89	0.91	1.38	8.50	0.15	0.47
BF20	Grizzly Bay	5/27/93	0.36	1.67	15.30	0.22	<1.0	1.95	1.28	1.02	23.99	0.15	0.38
BG20	Sacramento River	5/27/93	0.89	1.39	12.68	0.23	<1.0	1.38	1.17	0.72	48.35	0.12	0.49
BG30	San Joaquin River	5/27/93	1.27	1.41	7.22	0.28	<1.0	1.71	1.31	0.68	62.27	0.15	0.31
BA20	Extreme South Bay	9/13/93	8.44	3.73	131.32	0.13	<1.0	2.89	1.93	2.79	24.66	0.25	0.56
BA30	Dumbarton Bridge	9/13/93	8.28	3.80	125.60	0.11	<1.0	2.82	1.36	2.73	29.99	0.22	0.55
BA40	Redwood Creek	9/13/93	8.74	3.70	131.26	0.13	<1.0	2.32	1.83	2.37	5.85	0.26	0.52
BB30	Oyster Point	9/13/93	8.58	3.23	117.68	0.13	<1.0	1.79	1.24	1.76	12.23	0.24	0.62
BC10	Yerba Buena Is.	9/13/93	3.80	2.18	87.89	0.11	<1.0	1.18	1.09	1.01	16.19	0.18	0.76
BC20	Golden Gate	9/14/93	0.59	1.73	39.60	0.13	<1.0	0.20	0.35	0.31	3.17	0.23	0.08
BC30	Richardson Bay	9/14/93	1.95	2.08	66.07	0.13	<1.0	0.87	0.79	0.84	10.69	0.16	0.49
BC41	Point Isabel	9/14/93	1.95	1.95	85.74	0.12	<1.0	1.15	0.98	1.08	10.56	0.22	0.56
BD20	San Pablo Bay	9/15/93	2.86	2.34	91.63	0.14	<1.0	1.30	3.34	1.35	10.27	0.22	0.46
BD30	Pinole Point	9/15/93	3.57	2.42	93.31	0.13	<1.0	1.55	1.75	1.46	6.75	0.28	0.46
BD40	Davis Point	9/15/93	4.00	2.41	97.03	0.14	<1.0	1.82	0.82	1.58	8.49	0.27	0.51
BD50	Napa River	9/15/93	2.30	2.55	90.76	0.15	<1.0	2.02	1.10	1.68	5.59	0.23	0.66
BF10	Pacheco Creek	9/15/93	1.80	2.38	57.95	0.19	<1.0	1.96	3.85	1.40	8.76	0.28	0.51
BF20	Grizzly Bay	9/16/93	1.38	2.40	38.78	0.37	<1.0	2.01	3.27	1.20	56.86	0.23	0.55
BG20	Sacramento River	9/16/93	0.62	1.95	13.17	0.22	<1.0	1.62	3.51	0.73	66.17	0.26	0.57
BG30	San Joaquin River	9/16/93	0.10	1.91	11.94	0.12	<1.0	1.70	3.01	0.75	47.62	0.19	0.30

**Table 4. (page 1 of 2). Dissolved and total PAH concentrations in water from March, 1993.** Units in pg/L. (parts per quadrillion).  
 \* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Sum PAHs dissolved	total	1-me phenanthrene		2-me phenanthrene		Anthracene dissolved	total	B[a]anthracene dissolved	total	B[a]pyrene dissolved	total	B[b]fluoranthene dissolved	total
					dissolved	total	dissolved	total								
BA30	Dumbarton Bridge	3/3/97	2145	27775	122	346	120	567	* 5	123	11	467	* 6	* 89	22	3563
BA40	Redwood Creek	3/3/97	5351	22373	213	339	361	593	47	100	22	306	* 10	* 116	35	3092
BC10	Yerba Buena	3/4/97	6687	12815	318	406	474	627	* 23	31	16	107	* 9	* 31	38	1088
BC20	Golden Gate	3/4/97	2926	5742	149	227	248	382	* 12	* 20	17	56	* 9	* 17	* 9	330
BD20	San Pablo Bay	3/5/97	2783	9110	154	265	171	349	9	36	27	138	* 11	* 23	35	1044
BD30	Point Pinole	3/5/97	6640	9204	471	547	974	1137	* 5	* 16	28	93	* 6	* 17	34	436
BD40	Davis Point	3/5/97	6269	11729	259	393	402	562	32	63	35	155	* 10	* 36	54	860
BD50	Napa River	3/5/97	7128	19613	82	420	249	856	7	106	118	401	* 32	* 38	7	1472
BF20	Grizzly Bay	3/6/97	1828	7113	80	262	102	436	15	25	26	151	* 5	* 11	* 10	570
BG20	Sacramento River	3/6/97	1968	5548	27	173	89	273	* 22	* 38	8	43	* 18	* 37	* 17	192
BG30	San Joaquin River	3/6/97	1085	4352	62	201	115	241	18	24	18	58	* 9	* 23	* 9	415

Station Code	Station Name	Collection Date	B[el]pyrene dissolved	total	B[ghi]perylene dissolved	total	B[k]fluoranthene dissolved	total	Chrysene dissolved	total	Dibenz[a,h]anthracene		Fluoranthene dissolved	total	Indeno [1,2,3-cd]pyrene	
											dissolved	total			dissolved	total
BA30	Dumbarton Bridge	3/3/97	* 12	2609	* 6	* 87	* 11	1464	67	1907	* 6	* 90	622	5322	* 3	2785
BA40	Redwood Creek	3/3/97	* 5	2039	* 10	* 21	* 8	1062	92	1199	* 10	* 31	1598	4866	* 5	1902
BC10	Yerba Buena	3/4/97	* 9	660	* 17	* 24	* 8	339	129	590	* 9	* 49	2572	4033	* 9	218
BC20	Golden Gate	3/4/97	* 4	295	* 9	* 17	* 4	156	60	343	* 9	* 17	1019	1740	* 9	18
BD20	San Pablo Bay	3/5/97	* 6	656	* 11	* 23	* 16	334	137	696	* 11	* 23	886	2286	* 11	24
BD30	Point Pinole	3/5/97	* 6	17	* 6	* 17	* 14	220	180	517	* 6	* 17	1034	1609	* 6	17
BD40	Davis Point	3/5/97	* 10	36	* 10	* 36	* 17	397	89	577	* 10	* 36	1504	2883	* 10	36
BD50	Napa River	3/5/97	* 178	981	* 4	* 15	* 4	201	232	1087	* 4	* 15	1946	4333	* 2	606
BF20	Grizzly Bay	3/6/97	* 5	499	* 10	* 10	* 5	196	79	643	* 5	* 36	352	1312	* 5	26
BG20	Sacramento River	3/6/97	* 18	37	* 18	* 36	* 16	181	18	366	* 19	* 38	414	1230	* 20	40
BG30	San Joaquin River	3/6/97	* 4	150	9	* 23	* 4	132	35	427	* 9	* 24	127	812	* 9	24

**Table 4. (page 2 of 2). Dissolved and total PAH concentrations in water from March, 1993.** Units in pg/L, (parts per quadrillion).  
 \* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Kv1911		Phenanthrene		Pyrene		X-me		Y-me	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/3/97	* 9	* 21	558	2395	329	5111	104	442	129	385
BA40	Redwood Creek	3/3/97	* 10	* 21	1456	2468	967	3391	249	428	232	380
BC10	Yerba Buena	3/4/97	* 40	* 47	2293	2857	53	838	262	369	348	441
BC20	Golden Gate	3/4/97	* 12	* 25	966	1326	50	272	161	246	173	247
BD20	San Pablo Bay	3/5/97	* 11	* 29	879	1592	113	1046	142	280	147	260
BD30	Point Pinole	3/5/97	* 9	* 20	1732	1949	770	1009	767	875	594	692
BD40	Davis Point	3/5/97	* 10	* 42	1964	2728	1222	2038	325	405	305	448
BD50	Napa River	3/5/97	* 4	* 20	1939	3798	1932	4085	239	661	150	512
BF20	Grizzly Bay	3/6/97	* 10	* 21	510	1146	423	996	90	424	70	310
BG20	Sacramento River	3/6/97	* 38	* 66	648	1245	461	1217	72	181	37	149
BG30	San Joaquin River	3/6/97	* 9	* 31	309	847	190	471	71	229	71	205

**Table 5. (Page 1 of 6). Dissolved and total PCB concentrations in water from March, 1993. Units pg/L, (parts per quadrillion).**  
PCT=Polychlorinated Terphenyls; 0 means not present or rounding error.

Station Code	Station Name	Collection Date	Total PCBs		Total PCTs		PCB005/8		PCB015		PCB018	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	361.32	847.33	19.57	109.35	15.36	17.95	0.00	0.00	0.00	0.00
BA40	Redwood Creek	3/2/93	137.31	381.77	12.61	20.45	0.00	0.00	0.00	0.00	0.00	0.00
BC10	Yerba Buena	3/3/93	347.84	498.58	21.30	32.495	0.00	0.00	0.00	0.00	0.00	0.00
BC20	Golden Gate	3/3/93	2885.59	2935.42	9.74	17.46	3.20	3.20	0.00	0.00	2.48	2.48
BD20	San Pablo Bay	3/4/93	171.78	311.20	10.25	35.25	0.00	0.00	0.00	0.00	0.00	0.00
BD30	Point Pinole	3/4/93	203.51	253.79	15.99	26.93	12.07	12.07	91.20	91.20	0.00	0.00
BD40	Davis Point	3/4/93	100.44	239.19	12.82	21.9	0.00	0.00	0.00	0.00	0.00	0.00
BD50	Napa River	3/4/93	492.10	751.87	14.90	23.27	10.35	10.35	0.00	0.00	0.00	0.00
BF20	Grizzly Bay	3/5/93	25.58	265.03	4.01	15.09	0.00	0.00	0.00	0.00	0.00	0.00
BG20	Sacramento River	3/5/93	146.03	246.85	14.73	39.63	12.46	12.46	0.00	0.00	0.00	0.00
BG30	San Joaquin River	3/5/93	150.82	240.97	13.38	25.29	0.00	0.00	0.00	0.00	0.00	0.00

Station Code	Station Name	Collection Date	PCB027/24		PCB028		PCB028/31		PCB029		PCB031	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	0.00	0.00	5.85	10.84	0.00	0.00	0.00	0.00	11.10	14.62
BA40	Redwood Creek	3/2/93	5.79	9.06	11.47	13.31	0.00	0.00	0.00	0.00	25.14	28.63
BC10	Yerba Buena	3/3/93	0.00	0.00	0.00	2.70	0.00	0.00	0.00	0.00	0.00	2.36
BC20	Golden Gate	3/3/93	0.00	0.00	1.68	1.68	0.00	0.00	0.00	0.00	2.05	2.05
BD20	San Pablo Bay	3/4/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BD30	Point Pinole	3/4/93	4.91	4.91	4.88	4.88	0.00	0.00	0.00	0.00	0.00	0.00
BD40	Davis Point	3/4/93	0.00	0.00	5.00	5.00	0.00	0.00	0.00	0.00	4.19	4.19
BD50	Napa River	3/4/93	0.00	0.00	19.91	19.91	0.00	0.00	0.00	0.00	27.69	27.69
BF20	Grizzly Bay	3/5/93	0.00	0.00	0.94	0.94	0.00	0.00	0.00	0.00	0.85	0.85
BG20	Sacramento River	3/5/93	0.00	0.00	1.20	1.20	0.00	0.00	0.00	0.00	1.47	1.47
BG30	San Joaquin River	3/5/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00



**Table 5. (Page 2 of 6). Dissolved and total PCB concentrations in water from March, 1993. Units pg/L, (parts per quadrillion).**

0 means not present or rounding error.

Station Code	Station Name	Collection Date	PCB040		PCB044		PCB049		PCB052		PCB060/56	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	0.00	0.00	18.99	24.06	0.00	0.00	0.00	0.00	0.00	0.00
BA40	Redwood Creek	3/2/93	0.00	0.00	5.22	7.78	0.00	0.00	0.00	4.24	0.00	0.00
BC10	Yerba Buena	3/3/93	0.00	0.00	4.17	5.80	0.00	0.00	0.00	0.00	0.00	2.26
BC20	Golden Gate	3/3/93	0.00	0.00	58.30	58.30	25.65	25.65	56.45	56.45	0.00	0.00
BD20	San Pablo Bay	3/4/93	0.00	0.00	2.12	4.24	0.00	0.00	0.00	0.00	2.97	2.97
BD30	Point Pinole	3/4/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BD40	Davis Point	3/4/93	0.00	0.00	4.17	4.17	0.00	0.00	5.08	5.08	0.00	0.00
BD50	Napa River	3/4/93	5.64	5.64	18.76	18.76	12.24	12.24	70.91	70.91	nm	0.00
BF20	Grizzly Bay	3/5/93	0.00	0.00	0.62	10.33	0.00	0.00	0.00	0.00	0.99	0.99
BG20	Sacramento River	3/5/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BG30	San Joaquin River	3/5/93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Station Code	Station Name	Collection Date	PCB066/95		PCB070		PCB074		PCB087/115		PCB097	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	32.93	58.89	11.84	22.56	5.54	10.91	0.00	0.00	8.42	15.99
BA40	Redwood Creek	3/2/93	12.70	25.23	6.50	10.95	4.06	6.28	0.00	0.00	0.00	3.92
BC10	Yerba Buena	3/3/93	19.54	26.93	8.31	8.31	3.63	4.65	12.03	12.03	35.21	35.21
BC20	Golden Gate	3/3/93	183.15	185.28	82.76	82.76	20.57	20.57	130.20	130.20	100.90	100.90
BD20	San Pablo Bay	3/4/93	12.59	12.59	5.97	8.97	3.30	5.25	0.00	0.00	4.02	4.02
BD30	Point Pinole	3/4/93	5.84	9.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BD40	Davis Point	3/4/93	10.10	23.08	4.73	10.35	0.00	2.57	0.00	0.00	0.00	0.00
BD50	Napa River	3/4/93	33.52	50.02	19.17	26.52	5.60	9.01	3.98	3.98	6.64	15.00
BF20	Grizzly Bay	3/5/93	2.24	17.35	1.19	11.71	0.83	5.09	0.00	0.00	0.00	10.09
BG20	Sacramento River	3/5/93	9.38	13.50	5.75	5.75	2.51	2.51	0.00	0.00	0.00	0.00
BG30	San Joaquin River	3/5/93	8.52	14.79	0.00	4.82	0.00	3.37	0.00	0.00	3.65	3.65

**Table 5. (Page 3 of 6). Dissolved and total PCB concentrations in water from March, 1993. Units pg/L, (parts per quadrillion).**  
0 means not present or rounding error.

Station Code	Station Name	Collection Date	PCB099		PCB101/90		PCB105		PCB105/132		PCB110/77	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	0.00	7.28	28.52	50.94	0.00	0.00	15.84	35.51	23.25	49.51
BA40	Redwood Creek	3/2/93	0.77	5.92	11.34	23.55	0.00	0.00	4.22	11.79	6.41	17.89
BC10	Yerba Buena	3/3/93	14.31	20.09	17.92	25.75	0.00	0.00	22.01	27.70	30.21	38.34
BC20	Golden Gate	3/3/93	96.06	96.06	182.94	187.39	0.00	0.00	245.34	247.56	350.47	353.12
BD20	San Pablo Bay	3/4/93	5.36	9.95	10.79	15.73	0.00	0.00	7.25	14.35	11.14	20.95
BD30	Point Pinole	3/4/93	0.00	0.00	0.00	4.11	0.00	0.00	4.01	6.35	5.12	8.19
BD40	Davis Point	3/4/93	0.00	0.00	6.10	13.39	0.00	0.00	4.50	12.11	6.59	17.09
BD50	Napa River	3/4/93	4.89	8.48	22.16	32.69	0.00	0.00	18.08	28.28	38.82	58.21
BF20	Grizzly Bay	3/5/93	1.35	5.86	0.00	9.75	0.00	0.00	1.17	12.05	1.66	18.46
BG20	Sacramento River	3/5/93	0.00	0.00	8.23	13.18	0.00	0.00	12.68	20.89	10.78	22.40
BG30	San Joaquin River	3/5/93	2.08	2.08	5.87	9.81	0.00	0.00	7.83	14.47	8.90	17.33

Station Code	Station Name	Collection Date	PCB114/131/122		PCB118		PCB128		PCB129/178		PCB132	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	10.60	20.06	nm	20.62	3.64	12.26	0.00	0.00	0.00	0.00
BA40	Redwood Creek	3/2/93	1.25	1.25	2.94	13.33	1.11	4.50	0.00	0.00	0.00	0.00
BC10	Yerba Buena	3/3/93	6.92	8.03	20.68	27.69	5.53	7.17	0.00	0.00	0.00	0.00
BC20	Golden Gate	3/3/93	5.67	5.67	188.82	191.11	97.67	98.95	0.00	0.00	0.00	0.00
BD20	San Pablo Bay	3/4/93	0.00	7.81	12.11	21.26	1.50	3.87	0.00	0.00	0.00	0.00
BD30	Point Pinole	3/4/93	7.37	10.42	12.64	12.64	0.00	1.17	0.00	0.00	0.00	0.00
BD40	Davis Point	3/4/93	5.37	14.91	6.31	6.31	0.42	2.66	0.00	0.00	0.00	0.00
BD50	Napa River	3/4/93	4.84	14.70	11.88	27.50	2.48	6.59	5.21	5.21	0.00	0.00
BF20	Grizzly Bay	3/5/93	0.51	0.51	0.93	13.65	0.28	4.69	0.00	0.00	0.00	0.00
BG20	Sacramento River	3/5/93	0.00	0.00	15.33	22.71	1.30	3.49	0.00	0.00	0.00	0.00
BG30	San Joaquin River	3/5/93	3.57	3.57	12.99	12.99	0.00	1.98	0.00	0.00	0.00	0.00

**Table 5. (Page 4 of 6). Dissolved and total PCB concentrations in water from March, 1993. Units pg/L, (parts per quadrillion).**  
0 means not present or rounding error.

Station Code	Station Name	Collection Date	PCB137/176		PCB138		PCB141/179		PCB146		PCB149	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	0.00	0.00	27.29	76.43	0.00	0.00	0.00	0.00	nm	30.42
BA40	Redwood Creek	3/2/93	0.00	0.00	6.65	31.28	0.00	0.00	0.00	0.00	4.04	22.23
BC10	Yerba Buena	3/3/93	0.00	0.00	32.72	47.87	0.00	0.00	0.00	0.00	23.37	35.12
BC20	Golden Gate	3/3/93	10.44	10.44	323.07	330.16	43.93	43.93	0.00	0.00	190.45	194.28
BD20	San Pablo Bay	3/4/93	0.00	0.00	14.17	28.49	0.00	0.00	0.00	0.00	16.66	29.25
BD30	Point Pinole	3/4/93	0.00	0.00	6.18	13.39	0.00	0.00	0.00	0.00	17.39	17.39
BD40	Davis Point	3/4/93	0.00	0.00	6.55	21.46	0.00	0.00	0.00	0.00	4.11	4.11
BD50	Napa River	3/4/93	7.39	7.39	1.54	27.92	5.43	5.43	4.23	4.23	21.34	44.96
BF20	Grizzly Bay	3/5/93	0.00	0.00	1.81	22.88	0.00	0.00	0.00	0.00	3.09	20.58
BG20	Sacramento River	3/5/93	0.00	0.00	13.70	29.16	0.00	0.00	0.00	0.00	nm	12.37
BG30	San Joaquin River	3/5/93	0.00	0.00	10.63	23.14	0.00	0.00	0.00	0.00	40.79	40.79

Station Code	Station Name	Collection Date	PCB151/82		PCB153		PCB156/171/202		PCB157/173/201		PCB158	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	6.49	16.12	54.87	102.37	3.24	13.19	1.66	4.43	1.66	4.64
BA40	Redwood Creek	3/2/93	3.29	9.09	8.03	35.08	0.99	5.16	0.00	0.00	0.00	1.40
BC10	Yerba Buena	3/3/93	6.31	10.10	26.28	41.90	6.65	9.68	0.00	0.95	1.80	2.16
BC20	Golden Gate	3/3/93	0.00	0.00	176.19	181.75	77.26	78.02	11.71	11.71	18.61	18.61
BD20	San Pablo Bay	3/4/93	4.14	5.94	14.96	30.41	6.46	7.85	0.87	0.87	1.44	1.44
BD30	Point Pinole	3/4/93	0.00	0.00	12.77	18.91	2.29	2.29	0.00	0.00	0.00	0.00
BD40	Davis Point	3/4/93	0.00	0.00	10.44	25.84	0.74	3.40	0.00	0.00	0.00	0.60
BD50	Napa River	3/4/93	9.77	9.77	35.96	61.13	8.37	14.02	0.73	0.73	0.73	0.73
BF20	Grizzly Bay	3/5/93	0.00	0.00	2.22	19.76	0.31	3.93	0.00	0.00	0.00	0.00
BG20	Sacramento River	3/5/93	0.00	0.00	17.82	30.10	1.79	1.79	0.46	0.46	0.00	0.00
BG30	San Joaquin River	3/5/93	4.54	4.54	13.10	24.01	1.62	1.62	0.00	0.00	0.00	0.00

**Table 5. (Page 5 of 6). Dissolved and total PCB concentrations in water from March, 1993. Units pg/L, (parts per quadrillion).**  
 () means not present or rounding error; nm means not measured.

Station Code	Station Name	Collection Date	PCB170/190		PCB174		PCB177		PCB180		PCB183	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	8.60	25.68	5.90	20.78	3.74	14.41	8.25	35.21	9.15	20.01
BA40	Redwood Creek	3/2/93	0.97	7.48	1.40	9.19	1.14	6.18	2.70	15.87	1.91	7.19
BC10	Yerba Buena	3/3/93	8.56	13.49	4.46	8.54	2.45	5.58	8.33	17.37	2.66	6.31
BC20	Golden Gate	3/3/93	46.69	48.29	26.84	28.45	14.39	15.86	51.52	55.01	17.01	18.82
BD20	San Pablo Bay	3/4/93	2.54	8.63	3.62	7.73	2.87	16.13	7.19	15.56	2.12	5.34
BD30	Point Pinole	3/4/93	1.23	3.15	2.55	4.03	2.64	4.17	0.00	3.47	2.87	4.83
BD40	Davis Point	3/4/93	0.77	5.00	1.42	5.64	0.85	3.48	3.24	10.95	1.26	5.28
BD50	Napa River	3/4/93	5.16	13.37	7.87	14.77	5.28	10.37	11.00	26.07	6.35	12.33
BF20	Grizzly Bay	3/5/93	0.37	6.68	0.54	6.46	0.56	4.14	0.86	12.36	0.61	4.75
BG20	Sacramento River	3/5/93	2.44	5.18	4.82	6.99	2.06	4.31	6.54	11.35	3.46	6.57
BG30	San Joaquin River	3/5/93	1.70	5.43	2.47	6.31	1.87	4.45	5.00	12.54	0.00	2.80

Station Code	Station Name	Collection Date	PCB185		PCB187		PCB189		PCB191		PCB194	
			dissolved	total	dissolved	total	dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	0.00	0.00	11.05	34.54	0.00	0.00	0.00	0.00	3.69	13.80
BA40	Redwood Creek	3/2/93	0.00	0.00	2.07	14.87	0.73	0.73	0.00	0.00	0.00	6.58
BC10	Yerba Buena	3/3/93	0.00	0.00	4.78	13.98	0.00	0.00	0.00	0.00	5.37	7.51
BC20	Golden Gate	3/3/93	0.00	0.00	16.98	19.86	1.99	1.99	2.33	2.33	5.58	6.44
BD20	San Pablo Bay	3/4/93	0.00	0.00	4.66	4.66	0.00	0.00	0.00	0.00	1.61	5.81
BD30	Point Pinole	3/4/93	0.00	0.00	3.59	6.38	0.00	0.00	3.96	3.96	0.00	1.96
BD40	Davis Point	3/4/93	0.00	0.00	4.06	11.27	0.00	0.00	0.00	0.00	0.68	5.57
BD50	Napa River	3/4/93	0.40	0.40	8.90	13.19	0.87	0.87	nm	0.00	0.00	4.74
BF20	Grizzly Bay	3/5/93	0.00	0.00	0.78	13.86	0.00	0.00	0.26	0.26	0.00	6.89
BG20	Sacramento River	3/5/93	0.00	0.00	7.18	10.54	0.00	0.00	0.00	0.00	nm	0.00
BG30	San Joaquin River	3/5/93	0.00	0.00	4.15	9.80	0.00	0.00	0.00	0.00	1.49	1.49

**Table 5. (Page 6 of 6). Dissolved and total PCB concentrations in water from March, 1993. Units pg/L, (parts per quadrillion).**  
0 means not present or rounding error; nm means not measured.

Station Code	Station Name	Collection Date	PCB195/208		PCB196/203		PCB199	
			dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	1.81	9.00	2.60	12.54	0.00	11.24
BA40	Redwood Creek	3/2/93	0.75	3.76	0.79	5.01	1.12	6.34
BC10	Yerba Buena	3/3/93	1.61	3.06	1.70	1.70	2.41	5.43
BC20	Golden Gate	3/3/93	2.98	3.57	4.97	6.13	4.87	6.12
BD20	San Pablo Bay	3/4/93	1.47	1.47	1.55	1.55	2.19	6.07
BD30	Point Pinole	3/4/93	0.00	0.00	0.00	1.45	0.00	2.06
BD40	Davis Point	3/4/93	0.76	0.76	0.81	3.35	1.14	4.16
BD50	Napa River	3/4/93	0.65	0.65	3.51	8.88	3.87	9.48
BF20	Grizzly Bay	3/5/93	0.00	2.63	0.25	4.69	0.36	4.52
BG20	Sacramento River	3/5/93	0.00	0.00	1.43	3.00	2.03	4.24
BG30	San Joaquin River	3/5/93	1.24	1.24	1.30	3.89	1.84	4.38

Station Code	Station Name	Collection Date	PCB205		PCB206		PCB207	
			dissolved	total	dissolved	total	dissolved	total
BA30	Dumbarton Bridge	3/2/93	0.00	0.00	6.36	17.43	2.50	2.50
BA40	Redwood Creek	3/2/93	0.00	0.00	nm	4.90	1.04	1.04
BC10	Yerba Buena	3/3/93	0.00	0.00	5.67	9.61	2.23	3.15
BC20	Golden Gate	3/3/93	0.00	0.00	3.45	3.45	0.00	0.81
BD20	San Pablo Bay	3/4/93	0.00	0.00	0.00	0.00	2.03	2.03
BD30	Point Pinole	3/4/93	0.00	0.00	nm	0.00	0.00	1.15
BD40	Davis Point	3/4/93	0.00	0.00	nm	6.33	1.06	1.06
BD50	Napa River	3/4/93	0.00	0.00	nm	8.76	0.00	0.00
BF20	Grizzly Bay	3/5/93	0.00	0.00	nm	8.31	0.00	0.00
BG20	Sacramento River	3/5/93	0.00	0.00	nm	0.00	1.21	1.21
BG30	San Joaquin River	3/5/93	0.00	0.00	3.96	3.96	1.71	1.71

nm means not measured; \* means value below method detection limit (MDL).

Station		Collectio	Sum	Alpha-chlor	Cis-nonachlor	Gamma-chlor	Heptachlor	Epoxide + Ox	Heptachlor	Trans-nonachlor				
Code	Name	Date	dissolved	total	dissolved	total	dissolved	total	dissolved	total				
BA30	Dumbarton Bridge	3/2/93	571	681	974	1005	621	622	15	30	4	6	nm	nm
BA40	Redwood Creek	3/2/93	165	214	86	92	848	848	6	9	0	0	nm	nm
BC10	Yerba Buena	3/3/93	143	165	1187	1210	1161	1162	13	18	0	0	nm	1
BC20	Golden Gate	3/3/93	84	93	435	440	371	371	5	7	0	0	nm	1
BD20	San Pablo Bay	3/4/93	260	291	83	116	*1	11	22	37	2	6	nm	6
BD30	Point Pinole	3/4/93	55	69	82	89	21	22	*743	*747	0	2	nm	nm
BD40	Davis Point	3/4/93	105	153	377	410	1672	1686	23	34	2	6	nm	nm
BD50	Napa River	3/4/93	117	201	42	70	1985	1995	3	23	5	10	nm	14
BF20	Grizzly Bay	3/5/93	64	169	50	197	1034	1152	18	78	1	15	nm	nm
BG20	Sacramento River	3/5/93	183	214	419	457	5419	5484	53	104	13	29	nm	nm
BG30	San Joaquin River	3/5/93	69	69	114	114	2443	2496	22	38	6	14	nm	nm

**Table 6. (Page 2 of 3). Dissolved and total pesticide concentrations in water from March, 1993.** Units in pg/l, (parts per quadrillion).  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	p,p'-DDD dissolved	p,p'-DDD total	p,p'-DDE dissolved	p,p'-DDE total	p,p'-DDMU dissolved	p,p'-DDMU total	p,p'-DDT dissolved	p,p'-DDT total	Dieldrin dissolved	Dieldrin total	Endol dissolved	Endol total
BA30	Dumbarton Bridge	3/2/93	86	144	92	223	*35	*61	47	107	281	292	*25	*27
BA40	Redwood Creek	3/2/93	23	41	10	33	*9	*12	6	16	64	70	*6	*7
BC10	Yerba Buena	3/3/93	79	100	17	50	0	3	14	28	257	264	23	24
BC20	Golden Gate	3/3/93	14	21	16	26	0	0	14	21	49	51	*3	*5
BD20	San Pablo Bay	3/4/93	45	92	45	165	*6	*26	18	90	124	139	8	9
BD30	Point Pinole	3/4/93	7	17	44	85	0	5	5	22	333	337	3	4
BD40	Davis Point	3/4/93	47	93	45	172	*9	*30	23	96	190	205	8	9
BD50	Napa River	3/4/93	17	93	190	427	*26	*53	8	162	107	122	5	6
BF20	Grizzly Bay	3/5/93	23	167	21	542	*1	*59	9	148	111	167	8	10
BG20	Sacramento River	3/5/93	54	106	155	769	*36	91	21	52	201	224	26	27
BG30	San Joaquin River	3/5/93	24	68	87	399	*18	61	6	72	175	193	4	4

Station Code	Station Name	Collection Date	EndolII,f2 dissolved	EndolII,f2 total	EndolII,f3 dissolved	EndolII,f3 total	Endoso4,f3 dissolved	Endoso4,f3 total	Endoso4,f2 dissolved	Endoso4,f2 total	HCB dissolved	HCB total
BA30	Dumbarton Bridge	3/2/93	*90	*92	138	*140	*32	*51	*8	*9	161	164
BA40	Redwood Creek	3/2/93	*55	*57	113	113	13	13	*3	*5	565	566
BC10	Yerba Buena	3/3/93	*19	*21	3	*4	*70	*72	*2	*4	15	16
BC20	Golden Gate	3/3/93	*9	*10	3	4	24	28	*1	*3	23	24
BD20	San Pablo Bay	3/4/93	*7	9	16	*20	*102	*140	*2	*4	66	71
BD30	Point Pinole	3/4/93	*2	*4	2	*3	*12	*26	*2	*4	50	52
BD40	Davis Point	3/4/93	*2	*5	13	*18	*70	*115	*6	*10	30	36
BD50	Napa River	3/4/93	*3	5	8	11	65	107	2	3	54	59
BF20	Grizzly Bay	3/5/93	*2	*15	1	3	*5	15	*7	*50	12	18
BG20	Sacramento River	3/5/93	*15	*16	15	*15	*14	*15	*32	*484	50	53
BG30	San Joaquin River	3/5/93	*14	18	2	*8	*5	*48	*11	45	21	26

**Table 6. (Page 3 of 3). Dissolved and total pesticide concentrations in water from March, 1993.**

Units in pg/l, (parts per quadrillion).

\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Alpha-HCH dissolved	Alpha-HCH total	Beta-HCH dissolved	Beta-HCH total	Gamma-HCH dissolved	Gamma-HCH total	Oxadiazon dissolved	Oxadiazon total
BA30	Dumbarton Bridge	3/2/93	90	91	nm	1	100	103	2985	3000
BA40	Redwood Creek	3/2/93	62	62	56	57	71	72	2100	2100
BC10	Yerba Buena	3/3/93	147	148	93	94	106	107	1313	1317
BC20	Golden Gate	3/3/93	115	116	*58	*58	49	49	373	375
BD20	San Pablo Bay	3/4/93	229	231	28	30	177	180	158	179
BD30	Point Pinole	3/4/93	8	9	*4	*7	8	11	45	46
BD40	Davis Point	3/4/93	64	65	38	39	66	68	804	837
BD50	Napa River	3/4/93	170	172	86	88	189	191	2160	2181
BF20	Grizzly Bay	3/5/93	2	3	10	13	53	54	116	146
BG20	Sacramento River	3/5/93	5	6	13	*17	113	123	315	331
BG30	San Joaquin River	3/5/93	2	2	13	14	69	70	2066	2081



Table 7. Water toxicity data for 1993 RMP cruises.

SD means standard deviation; no mark means oysters; \* means mussels.

Station Code	Station Name	Date	Bivalve larvae % normal	<i>Thalassiosira</i>		<i>Thalassiosira</i>		Ambient mean cells/ml	Ambient SD	salinity o/oo
				control mean cells/ml	control SD	control mean cells/ml	control SD			
BA20	South Bay	2-Mar-93	91.70*	1.85E+06	3.51E+04	2.50E+06	7.55E+04	15.0		
BA40	Redwood Creek	2-Mar-93	92.00*	1.91E+06	6.66E+04	2.12E+06	1.01E+05	16.0		
BC10	Yerba Buena Is.	3-Mar-93	92.30*	1.72E+06	7.57E+04	2.58E+06	1.65E+05	17.0		
BD30	Pinole Point	4-Mar-93	70.70*	2.13E+06	1.01E+05	5.20E+06	1.07E+05	15.0		
BD50	Napa River	4-Mar-93	74.30*	2.42E+06	2.65E+04	5.06E+06	2.08E+05	15.0		
BF20	Grizzly Bay	5-Mar-93	91.00*	1.93E+06	1.04E+05	4.03E+06	2.23E+05	15.0		
BG20	Sacramento River	5-Mar-93	92.00*	1.71E+06	9.45E+04	3.99E+06	7.47E+05	15.0		
BG30	San Joaquin River	5-Mar-93	87.00*	2.49E+06	4.51E+04	5.25E+06	1.32E+05	15.0		
BA20	South Bay	24-May-93	87.25	2.02E+06	1.13E+05	2.79E+06	1.24E+05	25.0		
BA40	Redwood Creek	24-May-93	94.50	1.70E+06	1.71E+05	2.81E+06	1.48E+05	25.0		
BC10	Yerba Buena Is.	24-May-93	97.75	1.08E+06	1.90E+05	1.95E+06	7.32E+04	25.0		
BD30	Pinole Point	26-May-93	92.25	1.38E+06	1.35E+05	2.89E+06	8.26E+04	25.0		
BD50	Napa River	26-May-93	76.75	1.23E+06	1.49E+05	3.16E+06	1.00E+05	25.0		
BF20	Grizzly Bay	27-May-93	95.00	1.76E+06	9.60E+04	2.32E+06	2.53E+05	25.0		
BG20	Sacramento River	27-May-93	93.50	1.33E+06	8.37E+04	3.15E+06	1.84E+05	25.0		
BG30	San Joaquin River	27-May-93	94.50	1.04E+06	7.81E+04	1.43E+06	3.73E+05	25.0		
BA20	South Bay	13-Sep-93	94.00*	1.54E+06	9.47E+04	2.76E+06	1.94E+05	25.5		
BA40	Redwood Creek	13-Sep-93	94.00*	1.32E+06	9.93E+04	3.15E+06	5.06E+04	27.0		
BC10	Yerba Buena Is.	13-Sep-93	92.00*	1.73E+06	1.13E+05	2.34E+06	2.16E+05	27.0		
BD30	Pinole Point	15-Sep-93	94.00*	2.09E+06	3.77E+04	3.58E+06	1.16E+05	23.0		
BD50	Napa River	15-Sep-93	90.00*	2.21E+06	9.71E+04	3.10E+06	7.23E+04	15.6		
BF20	Grizzly Bay	16-Sep-93	97.00*	1.06E+06	9.95E+04	1.78E+06	3.61E+05	15.0		
BG20	Sacramento River	16-Sep-93	91.00*	1.22E+06	5.91E+04	1.45E+06	3.16E+05	15.0		
BG30	San Joaquin River	16-Sep-93	93.00*	1.27E+06	6.81E+04	1.66E+06	3.02E+05	15.0		

**Table 8. Concentrations of conventional water quality parameters for river station samples.**

. means data not collected.

For conversion of  $\mu\text{M}$  to  $\mu\text{g/L}$  use the following *atomic* weight multipliers; P = 31; C = 12; N = 14; Si = 28.

River	Station	Date	ammo- nia μM	nitrate μM	nitrite μM	phos- phate μM	salinity o/oo	silicate μM	DOC μM	temp C	DO mg/L	pH	conduc- tivity μmho	TSS mg/L	chloro- phylla mg/m³	phaeo- pythin mg/m³
Sacramento	Freeport	4/30/93	0.07	10.66	0.45	0.67	0.00	188.16	144	17.0	10.27	6.90	105	25.1	2.78	1.33
Sacramento	Freeport	5/13/93	0.07	.	0.32	0.48	0.00	191.12	138	16.0	10.08	7.50	40	18.5	1.76	0.66
Sacramento	Freeport	5/5/93	0.07	7.12	0.32	0.72	0.00	167.82	150	16.5	9.00	8.60	6.5	30.7	3.14	1.94
San Joaquin	Manteca	6/10/93	0.07	112.40	2.48	3.99	0.01	273.05	296	.	.	.	.	72.7	19.38	7.30
San Joaquin	Manteca	6/3/93	0.07	66.82	1.70	2.64	0.01	234.25	.	18.0	8.53	8.08	400	46.4	14.09	5.43
Sacramento	Rio Vista	5/20/93	7.80	12.69	0.66	1.54	0.00	129.22	.	19.0	.	.	11	20.0	3.14	1.16
Sacramento	Rio Vista	6/10/93	2.10	9.43	0.37	1.30	0.00	202.57	191	.	.	.	.	15.4	6.08	5.75
Sacramento	Rio Vista	6/3/93	7.38	11.69	0.71	0.96	0.00	154.39	178	22.5	7.64	.	102	28.8	1.73	1.53
San Joaquin	Stockton	4/30/93	4.70	90.23	1.99	5.67	0.01	197.83	334	19.9	10.00	.	50	23.1	5.89	6.19
San Joaquin	Stockton	5/13/93	0.07	73.05	1.47	3.75	0.01	191.51	289	22.0	11.15	7.20	370	35.2	8.04	8.11
San Joaquin	Stockton	5/5/93	4.45	74.32	1.39	4.28	0.01	228.63	295	.	9.60	7.83	395	21.0	4.18	4.37
San Joaquin	Vernalis	5/20/93	13.09	112.80	3.46	3.41	0.01	252.32	280	.	.	.	.	68.3	11.67	5.54

Table 9. Total or near-total\* concentrations of trace elements for river station samples.

River	Station	Date	Ag* ng/kg	As μg/kg	Cd* ng/kg	CN μg/kg	Cr μg/kg	Cu* μg/kg	Hg ng/kg	Ni* μg/kg	Pb* ng/kg	Se μg/kg	Zn* μg/kg
Sacramento	Freeport	4/30/93	0.41	1.60	29.13	< 1.0	3.26	3.39	6.00	3.53	493.40	0.17	8.55
Sacramento	Freeport	5/5/93	1.45	1.60	25.83	< 1.0	2.82	3.09	5.56	3.17	563.27	0.22	4.21
Sacramento	Freeport	5/13/93	1.85	1.37	18.63	< 1.0	2.74	2.45	4.62	1.37	377.31	0.16	2.95
Sacramento	Rio Vista	5/20/93	0.77	1.31	19.38	< 1.0	2.52	2.35	4.73	2.85	344.54	0.19	2.90
Sacramento	Rio Vista	6/3/93	5.24	1.43	26.75	< 1.0	2.51	3.26	5.34	3.71	529.21	0.12	4.06
Sacramento	Rio Vista	6/10/93	3.10	1.52	29.62	< 1.0	2.87	3.75	6.65	3.07	624.22	0.34	9.45
San Joaquin	Stockton	4/30/93	2.71	2.31	5.63	< 1.0	1.62	2.74	5.22	3.09	739.41	0.59	3.38
San Joaquin	Stockton	5/5/93	1.25	1.85	2.99	< 1.0	1.40	2.63	3.68	2.62	634.04	0.64	2.56
San Joaquin	Stockton	5/13/93	3.18	1.83	6.43	< 1.0	2.42	2.99	3.77	2.99	861.71	0.60	3.59
San Joaquin	Vernalis	5/20/93	7.66	2.22	15.16	< 1.0	7.34	3.80	11.25	5.15	1086.70	0.74	9.91
San Joaquin	Manteca	6/3/93	1.95	2.12	11.15	< 1.0	3.85	3.29	8.87	3.81	889.02	0.35	4.31
San Joaquin	Manteca	6/10/93	6.64	2.32	14.96	< 1.0	5.54	3.81	10.62	5.64	1102.07	0.24	10.35

Table 10. Dissolved concentrations of trace elements for river station samples.

. means not measured.

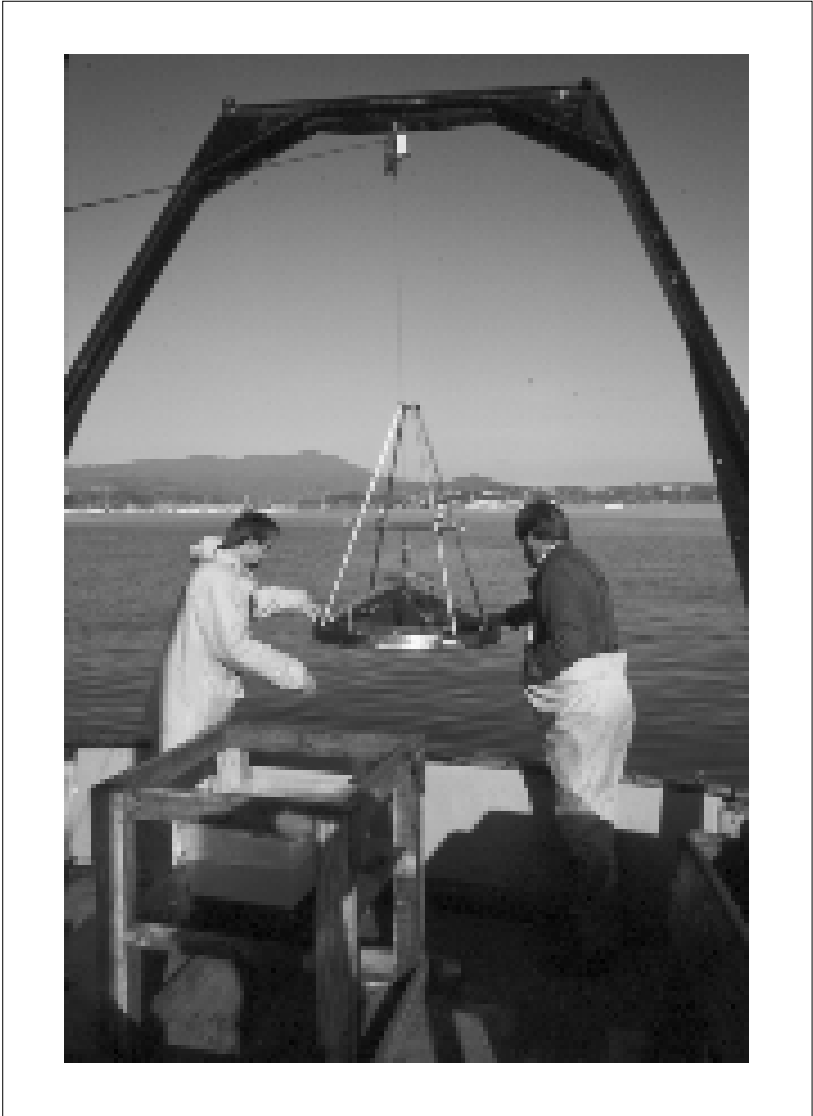
River	Station	Date	Ag ng/kg	As μg/kg	Cd ng/kg	CN μg/kg	Cr μg/kg	Cu μg/kg	Hg ng/kg	Ni μg/kg	Pb μg/kg	Se μg/kg	Zn μg/kg
Sacramento	Freeport	4/30/93	0.23	1.44	8.33	< 1.0	0.17	1.13	1.79	0.48	26.00	0.20	0.35
Sacramento	Freeport	5/5/93	0.09	1.32	5.99	< 1.0	0.17	1.00	0.90	0.43	26.08	0.16	0.29
Sacramento	Freeport	5/13/93	0.24	1.05	4.99	< 1.0	0.17	0.94	0.75	0.40	18.84	0.14	0.26
Sacramento	Rio Vista	5/20/93	0.27	1.14	13.66	< 1.0	0.20	1.15	1.51	0.71	47.22	0.23	0.62
Sacramento	Rio Vista	6/3/93	.	1.33	.	< 1.0	.	.	1.22	.	.	0.11	.
Sacramento	Rio Vista	6/10/93	1.13	1.20	11.22	< 1.0	0.43	1.57	1.51	0.71	46.38	0.27	0.72
San Joaquin	Stockton	4/30/93	0.32	1.98	6.17	< 1.0	0.09	1.65	1.33	1.26	21.82	0.66	0.47
San Joaquin	Stockton	5/5/93	0.20	1.92	4.07	< 1.0	0.13	1.63	1.51	1.06	85.70	0.63	0.47
San Joaquin	Stockton	5/13/93	0.87	1.66	3.68	< 1.0	0.15	1.60	1.50	0.98	82.53	0.53	0.43
San Joaquin	Vernalis	5/20/93	0.09	1.70	4.74	< 1.0	0.19	1.01	1.76	1.17	9.72	0.77	0.22
San Joaquin	Manteca	6/3/93	0.31	1.43	2.99	< 1.0	0.10	1.04	1.47	0.89	27.89	0.31	0.19
San Joaquin	Manteca	6/10/93	0.36	1.71	4.26	< 1.0	0.30	1.42	1.47	1.04	53.23	.	0.34

**Table 11. General characteristics of sediment samples.**  
 . means not measured, depths same in September as in March.

Station Code	Station Name	Date	Eh @2.5 cm mV	% fines < 0.062 mm	pH	salinity o/oo	temp C	TOC % dry	TN % dry	Depth meters
BA21	Extreme South Bay	3/12/93	-55	71.80	7.52	6.78	12.5	1.46	0.155	5.5
BA30	Dumbarton Bridge	3/12/93	-47	77.30	7.80	13.77	11.2	1.41	0.158	7.0
BA41	Redwood Creek	3/12/93	-51	48.90	7.53	17.95	14.3	1.62	0.148	2.5
BB30	Oyster Point	3/11/93	-53	34.50	7.81	16.43	11.5	1.38	0.090	9.0
BC11	Yerba Buena Is.	3/11/93	-37	42.40	7.51	16.07	11.2	1.62	0.148	6.0
BC21	Horseshoe Bay	3/11/93	-16	78.20	7.00	24.00	9.9	1.54	0.181	39.0
BC32	Richardson Bay	3/11/93	-28	59.40	7.03	16.48	13.6	0.94	0.101	1.0
BC41	Point Isabel	3/11/93	-28	67.60	7.28	13.86	13.4	0.97	0.112	1.5
BD22	San Pablo Bay	3/10/93	-45	29.50	7.36	6.08	11.4	1.32	0.125	3.0
BD31	Pinole Point	3/10/93	-37	65.90	7.26	9.11	11.7	1.86	0.132	6.5
BD41	Davis Point	3/10/93	-47	16.20	7.46	8.43	8.6	0.51	0.054	6.5
BD50	Napa River	3/10/93	-38	77.70	.	4.88	11.0	1.55	0.162	4.0
BF10	Pacheco Creek	3/10/93	-60	3.60	.	0.00	11.8	0.16	0.018	4.0
BF21	Grizzly Bay	3/9/93	-33	90.80	.	0.00	11.3	1.49	0.148	3.0
BG20	Sacramento River	3/9/93	-18	17.20	.	0.00	10.0	2.14	0.118	8.0
BG30	San Joaquin River	3/9/93	-15	18.00	.	0.00	10.0	1.12	0.074	5.0
BA21	Extreme South Bay	9/23/93	-32	75.69	.	28.50	18.6	1.50	0.209	.
BA30	Dumbarton Bridge	9/23/93	-35	74.52	.	28.66	18.3	1.43	0.188	.
BA41	Redwood Creek	9/23/93	-38	55.92	.	28.94	18.6	1.29	0.180	.
BB30	Oyster Point	9/22/93	-38	36.31	.	29.31	17.9	1.02	0.140	.
BC11	Yerba Buena Is.	9/22/93	-41	52.15	.	29.62	15.5	1.22	0.143	.
BC21	Horseshoe Bay	9/22/93	-20	27.38	.	33.00	14.0	0.50	0.104	.
BC32	Richardson Bay	9/22/93	-36	55.70	.	30.38	15.2	0.50	0.086	.
BC41	Point Isabel	9/21/93	-37	36.72	.	29.40	17.1	1.02	0.126	.
BD20	San Pablo Bay	9/21/93	-42	61.02	.	25.73	17.1	1.29	0.148	.
BD31	Pinole Point	9/21/93	-28	65.35	.	24.44	16.6	1.51	0.167	.
BD41	Davis Point	9/21/93	-36	20.25	.	19.98	16.1	0.50	0.076	.
BD50	Napa River	9/21/93	-32	87.42	.	16.04	17.7	1.55	0.170	.
BF10	Pacheco Creek	9/20/93	-35	5.00	.	11.39	18.8	0.50	0.038	.
BF21	Grizzly Bay	9/20/93	-4	72.33	.	5.93	18.6	1.39	0.137	.
BG20	Sacramento River	9/20/93	-55	5.00	.	0.01	20.6	0.50	0.051	.
BG30	San Joaquin River	9/20/93	-27	5.00	.	0.02	20.3	0.50	0.058	.

**Table 12. Concentrations of trace elements for sediment samples.**  
 . means not measured. \* means near-total concentrations were measured instead of total.

Station Code	Station Name	Date	Ag* mg/kg	Al* mg/kg	As mg/kg	Cd* mg/kg	Co* mg/kg	Cr* mg/kg	Cu* mg/kg	Fe* mg/kg	Hg µg/kg	Mn* mg/kg	Ni* mg/kg	Pb* mg/kg	Se mg/kg	V* mg/kg	Zn* mg/kg
BA21	Extreme South Bay	3/12/93	0.47	29500	9.81	0.04	18.80	93.3	46.90	46900	320.61	11730	95.80	41.20	0.28	61.00	143.60
BA30	Dumbarton Bridge	3/12/93	0.46	32000	13.14	0.04	17.30	94.6	45.50	46700	402.30	12750	91.60	35.00	0.23	61.70	136.70
BA41	Redwood Creek	3/12/93	1.18	26200	8.56	0.20	13.90	77.6	41.80	39500	337.20	10540	74.50	39.60	0.34	49.50	116.90
BB30	Oyster Point	3/11/93	0.28	16300	14.15	0.05	11.70	61.0	28.90	28300	265.51	6620	61.20	21.60	0.27	39.20	85.00
BC11	Yerba Buena Is.	3/11/93	0.28	18400	10.43	0.09	8.80	47.5	25.40	27000	216.85	7450	48.20	22.30	0.32	36.10	75.90
BC21	Horseshoe Bay	3/11/93	0.20	29600	13.24	0.11	0.00	75.0	32.70	41600	127.22	11960	72.30	26.00	0.43	56.30	96.00
BC32	Richardson Bay	3/11/93	0.23	25200	11.37	0.13	13.50	69.0	32.20	36500	408.88	9870	63.30	24.30	0.14	56.00	94.30
BC41	Point Isabel	3/11/93	0.26	29700	29.41	0.07	13.20	83.2	37.70	39900	302.39	11800	71.90	29.70	0.27	54.30	109.80
BD22	San Pablo Bay	3/10/93	0.29	28500	19.35	0.26	14.90	76.7	49.70	42400	391.46	11550	77.10	29.20	0.42	59.30	121.50
BD31	Pinole Point	3/10/93	0.28	29100	15.36	0.28	15.90	82.8	49.00	44900	236.14	11520	80.30	35.80	0.20	66.20	120.10
BD41	Davis Point	3/10/93	0.08	23500	7.37	0.11	14.70	67.3	25.10	36600	110.88	9320	68.90	15.70	0.14	55.40	85.70
BD50	Napa River	3/10/93	0.34	33600	10.11	0.29	18.20	86.4	59.20	51500	189.53	13720	92.30	33.40	0.30	72.30	144.00
BF10	Pacheco Creek	3/10/93	0.03	15200	5.93	0.07	14.40	58.4	14.10	29600	30.65	5980	61.70	6.61	0.07	55.20	61.90
BF21	Grizzly Bay	3/9/93	0.29	45500	16.11	0.28	20.70	105.3	63.20	55800	236.03	18240	104.50	27.10	0.21	86.00	151.50
BG20	Sacramento River	3/9/93	0.09	25100	8.53	0.13	16.10	65.6	26.70	34200	79.89	10040	82.50	10.20	0.16	40.10	84.50
BG30	San Joaquin River	3/9/93	0.11	21900	8.90	0.15	14.70	75.9	29.00	33000	298.79	8650	72.90	11.30	0.17	66.00	78.60
BA21	Extreme South Bay	9/23/93	0.50	23139.6	10.13	0.15	.	78.5	39.83	37491.3	468.00	.	79.20	25.33	1.27	.	119.74
BA30	Dumbarton Bridge	9/23/93	0.31	19244.3	9.73	0.15	.	77.3	32.26	34478.9	472.00	.	74.30	18.24	0.54	.	96.36
BA41	Redwood Creek	9/23/93	0.44	16759.5	7.93	0.10	.	50.9	27.08	27768.5	355.00	.	51.45	17.31	0.44	.	81.39
BB30	Oyster Point	9/22/93	0.40	18224.3	10.20	0.12	.	57.3	29.44	31936.5	250.00	.	59.44	15.52	0.56	.	83.71
BC11	Yerba Buena Is.	9/22/93	0.41	19566.0	8.49	0.18	.	69.2	35.03	32253.8	346.00	.	64.71	21.94	0.86	.	100.04
BC21	Horseshoe Bay	9/22/93	0.14	16042.6	7.99	0.12	.	58.9	21.22	29529.7	116.00	.	58.12	12.66	0.59	.	69.89
BC32	Richardson Bay	9/22/93	0.25	21925.8	9.38	0.20	.	66.9	28.04	31182.6	242.00	.	59.02	20.86	0.39	.	84.07
BC41	Point Isabel	9/21/93	0.28	31365.7	12.40	0.12	.	81.8	35.12	44021.3	330.00	.	72.82	23.41	0.38	.	105.45
BD20	San Pablo Bay	9/21/93	0.30	29413.6	13.34	0.20	.	76.7	43.24	40089.3	394.00	.	76.88	22.47	1.51	.	110.57
BD31	Pinole Point	9/21/93	0.33	24918.7	12.35	0.31	.	79.7	51.36	38332.1	343.00	.	89.61	25.02	1.27	.	120.31
BD41	Davis Point	9/21/93	0.13	23448.8	7.35	0.14	.	71.0	28.92	32441.8	168.00	.	72.40	14.16	0.70	.	87.51
BD50	Napa River	9/21/93	0.34	30547.1	14.24	0.25	.	86.9	59.51	48793.6	404.00	.	93.41	23.58	2.24	.	137.31
BF10	Pacheco Creek	9/20/93	0.04	12133.9	4.15	0.08	.	51.3	14.82	26986.9	41.90	.	59.00	5.57	0.46	.	54.38
BF21	Grizzly Bay	9/20/93	0.27	26209.0	20.62	0.25	.	81.5	52.79	41522.2	415.00	.	85.09	20.71	3.30	.	124.42
BG20	Sacramento River	9/20/93	0.08	17057.6	6.08	0.17	.	59.1	22.47	29736.3	76.70	.	67.75	9.05	0.61	.	72.62
BG30	San Joaquin River	9/20/93	0.07	16697.2	5.87	0.16	.	70.8	24.43	29762.2	87.30	.	70.48	10.19	0.58	.	71.56



**Table 13. (Page 1 of 3). Petroleum hydrocarbons and PAH concentrations in sediment from September, 1993.** Units  $\mu\text{g/kg}$ , dry weight (ppb).  
 \* means value below method detection limit (MDL); †total PAHs does not include perylene or methylated PAHs.

Station Code	Station Name	Collection Date	Total Alkanes	Total Petroleum Hydrocarbons	Total PAHs†	Total						
						1-Methyl-Naph	1-Methyl-Phen	2,3,5,-TRI-Methnaph	2,6-DI-Methnaph	2-Methyl-Naph	Acenaph-thene	
BA21	South Bay	9/23/93	616000	41300	1707.1	*5.49	*6.93	*3.58	*4.84	*7.3	*6.59	
BA30	Dumbarton Bridge	9/23/93	791000	46000	2545.3	*5.23	*11.59	*2.51	*6.34	*10.15	*9.92	
BA41	Redwood Creek	9/23/93	467000	43500	1683.3	*4.15	*9.36	*2.7	*6.75	*6.37	*6.49	
BB30	Oyster Point	9/22/93	672000	43200	2680.7	*5.4	15.45	*4.33	*8.15	*7.41	*11.75	
BC11	Yerba Buena Is.	9/22/93	708000	58300	2629.2	*14.95	24.91	*6.78	*13.49	*15.74	*10.59	
BC21	Horseshoe Bay	9/22/93	1047000	50800	1928.6	*7.01	13.63	*3.18	*7.44	*9.42	*10.67	
BC32	Richardson Bay	9/22/93	644000	40500	3269.8	*6.82	19.33	*4.9	*6.88	*10.62	13.25	
BC41	Point Isabel	9/21/93	626000	47400	2231.4	*4.34	*10.4	*3.59	*5.56	*7.34	*9.24	
BD22	San Pablo Bay	9/21/93	858000	52300	3100.4	*4.99	15.8	*4.88	*5.13	*8.01	*8.59	
BD31	Pinole Point	9/21/93	1127000	40200	646.4	*2.9	*3.07	*2.5	*3.7	*4.54	*1.99	
BD41	Davis Point	9/21/93	711000	29500	389.5	*2.23	*2.32	*1.45	*2.44	*3.74	*2.13	
BD50	Napa River	9/21/93	1533000	63400	767.4	*4.07	*3.78	*1.89	*4.78	*6.79	*2.73	
BF10	Pacheco Creek	9/20/93	*335000	13200	187.6	*1.39	*1.42	*0.62	*1.25	*1.91	*5.42	
BF21	Grizzly Bay	9/20/93	2167000	43000	545.1	*3.16	*3.19	*2.25	*3.47	*5.64	*2.15	
BG20	Sacramento River	9/20/93	1111000	25500	155.3	*1.28	*0.63	*0.97	*1.24	*1.6	*0.44	
BG30	San Joaquin River	9/20/93	1749000	23700	245.2	*1.33	*0.85	*0.67	*1.42	*1.96	*0.68	

Station Code	Station Name	Collection Date	Acenaph-thylene	Anthracene	BenA-anthracene	BenA-benApyrene	BenB-fluoran	BenE-pyrene	BenK-fluoran	Bghi-erylene	Biphenyl	
BA21	South Bay	9/23/93	*10.5	16.29	75.11	155.3	88.86	95.18	94.27	164.22	*6.86	
BA30	Dumbarton Bridge	9/23/93	12.88	30.35	117.96	224.06	108.26	148.38	114.85	218.43	*7.62	
BA41	Redwood Creek	9/23/93	10.21	21.98	68.97	145.16	78.58	93.97	83.36	150.73	*5.36	
BB30	Oyster Point	9/22/93	18.34	47.34	128.42	223.76	120.56	129.09	127.91	180.99	*7.37	
BC11	Yerba Buena Is.	9/22/93	32.49	68.1	125.16	176.65	95.81	99.7	101.65	130.18	*10.3	
BC21	Horseshoe Bay	9/22/93	16.97	36.43	85.29	125.26	70.58	75.03	74.88	88.23	*8.93	
BC32	Richardson Bay	9/22/93	20.39	61.77	148.36	257.41	146.14	152.31	155.04	180.08	*8.81	
BC41	Point Isabel	9/21/93	14.84	41.84	124.9	198.22	103.39	111.6	109.69	164.2	*6.38	
BD22	San Pablo Bay	9/21/93	19.92	45.37	154.28	278.78	158.38	158.34	168.02	215.4	*6.65	
BD31	Pinole Point	9/21/93	*2.9	*6.91	22.95	43.02	27.72	30.02	29.42	48.72	*3.35	
BD41	Davis Point	9/21/93	*1.84	*5.34	14.42	23.01	14.27	16.62	15.14	26.98	*2.55	
BD50	Napa River	9/21/93	*3.56	*7.88	31.75	51.71	33.01	37.67	35.03	59.31	*4.78	
BF10	Pacheco Creek	9/20/93	*0.47	*2.66	5.06	*6.38	*4.54	*4.67	*4.81	7.72	*1.41	
BF21	Grizzly Bay	9/20/93	*1.88	*5.36	19.72	32.86	*21.48	25.2	*22.78	41.73	*4.08	
BG20	Sacramento River	9/20/93	*0.6	*1.24	3.87	*7.33	*4.83	6.37	*5.13	10.25	*1.41	
BG30	San Joaquin River	9/20/93	*0.55	*1.63	5.54	*8.72	*5.54	7.15	*5.88	11.5	*1.9	

**Table 13. (Page 2 of 3), Petroleum hydrocarbons and PAH concentrations in sediment from September, 1993.** Units µg/kg, dry weight (ppb).  
\* means value below method detection limit (MDL)

Station Code	Station Name	Collection Date	C1- chrysenes	C1-diben	C1-fluoran- pyr	C1- fluorenes	C1-naph- thalenes	C1-phen- anthr	C2- chrysenes	C2-diben	C2
BA21	South Bay	9/23/93	*29.72	*2.87	65.21	*6.01	*12.79	*31.84	*15.65	*5.73	*10.52
BA30	Dumbarton Bridge	9/23/93	44.79	*6.24	110.44	*9.75	*15.38	59.98	*22.9	*8.74	*12.3
BA41	Redwood Creek	9/23/93	33.97	*3.98	72.53	*6.27	*10.52	41.15	*15.08	*5.49	*11.82
BB30	Oyster Point	9/22/93	54.79	*6.95	131.95	*13.18	*12.81	66.71	*25.13	*9.21	*14.26
BC11	Yerba Buena Is.	9/22/93	58.89	*10.21	134.56	*22.04	*30.69	108	*25.53	*11.5	*15.06
BC21	Horseshoe Bay	9/22/93	39.42	*6.1	90.33	*11.71	*16.43	55.97	*26.33	*8.81	*11.46
BC32	Richardson Bay	9/22/93	46.95	*7.45	170.1	*10.69	*17.44	76.17	*26.28	*7.33	*15.06
BC41	Point Isabel	9/21/93	*31.05	*3.22	82.28	*6.37	*11.68	39.92	*14.07	*4.58	*8.11
BD22	San Pablo Bay	9/21/93	57.99	*6.04	136.65	*11.7	*13	71.44	*23.95	*9.08	*11.39
BD31	Pinole Point	9/21/93	*13.44	*2.05	27.04	*3.17	*7.44	*12.05	*10.2	*3.47	*3.73
BD41	Davis Point	9/21/93	*10.57	*1.35	18.61	*2.34	*5.97	*9.99	*10.3	*1.6	*4.8
BD50	Napa River	9/21/93	*19.97	*2.37	37.37	*5.18	*10.86	*16.6	*15.16	*5.36	*5.38
BF10	Pacheco Creek	9/20/93	*3.96	*0.9	*7.28	*2.22	*3.3	*5.98	*3.97	*1.49	*1.94
BF21	Grizzly Bay	9/20/93	*13.16	*2.42	*21.46	*4.49	*8.8	*12.82	*13.59	*3.99	*3.28
BG20	Sacramento River	9/20/93	*3.91	*0.74	*5.84	*1.59	*2.88	*2.89	*3.2	*1.5	*4.35
BG30	San Joaquin River	9/20/93	*8.4	*7.71	13.79	*3.49	*3.29	*7.46	*12.49	*4.24	*7.43
Station Code	Station Name	Collection Date	C2-naph- thalenes	C2-phen- anthr	chrysenes	C3-diben	C3- fluorenes	C3-naph- thalenes	C3-phen- anthr	C4- chrysenes	C4-naph thalenes
BA21	South Bay	9/23/93	*11.18	*26.12	*1.8	*2.67	*13.72	*7.8	*15.54	*7.62	*17.47
BA30	Dumbarton Bridge	9/23/93	*14.09	*36.39	*2.11	*6.82	*12.69	*18.78	*27.47	*11.04	*12.78
BA41	Redwood Creek	9/23/93	*8.39	*23.29	*1.19	*3.29	*7.75	*8.41	*13.91	*6.69	*10.74
BB30	Oyster Point	9/22/93	*16.53	50.39	*2.64	*6.45	*20.94	*17.2	*23.62	*12.42	*18.07
BC11	Yerba Buena Is.	9/22/93	*27.49	49.35	*2.29	*6.88	*10.26	*19.91	*26.55	*7.49	*18.81
BC21	Horseshoe Bay	9/22/93	*18.7	42.77	*3.85	*5.66	*14.51	21.67	27.16	*5.79	*16.26
BC32	Richardson Bay	9/22/93	*15.6	52.58	*1.92	*6.25	*10.87	*18.09	31.71	*8.68	*15.06
BC41	Point Isabel	9/21/93	*11.19	*27.52	*1.23	*3.08	*8.74	*14.27	*17.73	*6.28	*11.7
BD22	San Pablo Bay	9/21/93	*13.02	45.38	*2.06	*6.33	*15.31	*20.48	*26.23	*9.48	*15.22
BD31	Pinole Point	9/21/93	*8.27	*12.91	*2.08	*3.77	*10.72	*13.26	*12.41	*2.97	*15.08
BD41	Davis Point	9/21/93	*5.06	*11.29	*1.39	*1.77	*5.19	*4.89	*7.66	*2.28	*7.62
BD50	Napa River	9/21/93	*10.29	*20.7	*2.22	*6.39	*7.92	*8.16	*11.65	*4.13	*8.44
BF10	Pacheco Creek	9/20/93	*4.04	*5.5	*1.12	*1.74	*5.47	*5.89	*4.58	*1.41	*6.4
BF21	Grizzly Bay	9/20/93	*8.44	*15.77	*1.54	*4.29	*5.88	*8.23	*15.25	*2.66	*16.37
BG20	Sacramento River	9/20/93	*3.8	*4.71	*0.4	*1.04	*2.99	*5.83	*4.73	*1.07	*7.49
BG30	San Joaquin River	9/20/93	*8.12	*8.27	*2.58	*3.69	*7.58	*12.84	*8.55	OND	*11.32



**Table 13. (Page 3 of 3). Petroleum hydrocarbons and PAH concentrations in sediment from September, 1993.**  
Units µg/kg, dry weight (ppb). \* means value below method detection limit (MDL)

Station Code	Station Name	Collection Date	C4-phen-anthr	Chrysene	DBah-anthra	Dibenzo-thio	Fluor-anthene	Fluorene	I123cd pyrene
BA21	South Bay	9/23/93	*13.85	79.57	*12.1	*3.03	163.04	*7.14	134.08
BA30	Dumbarton Bridge	9/23/93	*14.65	149.37	*14.28	*4.75	276.41	*9.95	153.03
BA41	Redwood Creek	9/23/93	*7.74	94.99	*9.6	*3.59	172.15	*6.91	109.73
BB30	Oyster Point	9/22/93	*11.77	135.87	15.84	*7.07	293.82	12.52	154.8
BC11	Yerba Buena Is.	9/22/93	*18.69	125.88	*10.95	*11.66	283.53	36.86	111.19
BC21	Horseshoe Bay	9/22/93	*20.38	97.48	*7.08	*7.13	254.32	15.55	76.43
BC32	Richardson Bay	9/22/93	*16.95	182.92	12.56	*7.96	422.77	14.15	163.03
BC41	Point Isabel	9/21/93	*9.62	113.35	11.72	*4.99	269.48	*9.36	139.04
BD22	San Pablo Bay	9/21/93	*20.31	155.28	15.8	*5.78	343.6	13.65	186.31
BD31	Pinole Point	9/21/93	*12.42	41.8	*3.37	*1.35	57.5	*3.37	38.75
BD41	Davis Point	9/21/93	*6.77	20.67	*2.04	*1.04	37.75	*2.73	19.3
BD50	Napa River	9/21/93	*12.85	42.3	*4.45	*1.85	64.43	*5.65	44.61
BF10	Pacheco Creek	9/20/93	*4.5	*5.74	*1.01	*0.92	16.58	*5.27	5.97
BF21	Grizzly Bay	9/20/93	*11.08	25.59	*2.99	*1.34	45.51	*3.15	30.3
BG20	Sacramento River	9/20/93	*6.07	*8.67	*0.73	*0.44	10.13	*0.93	7.18
BG30	San Joaquin River	9/20/93	*10.78	*8.64	*0.47	*0.43	12.6	*1.25	6.56

Station Code	Station Name	Collection Date	Naph-thalene	Perylene	Phen anthrene	Phytane	Pristane	Pyrene
BA21	South Bay	9/23/93	*21.55	*37.42	57.79	*12.7	*9.3	217.55
BA30	Dumbarton Bridge	9/23/93	*25.05	*53.79	106.88	*16.5	*11.9	365.55
BA41	Redwood Creek	9/23/93	*17.73	*39.92	70.86	*12	*8.8	240.74
BB30	Oyster Point	9/22/93	25.47	*59.9	129.54	*17.4	*21.4	395.24
BC11	Yerba Buena Is.	9/22/93	*24.71	*47.97	220.96	*27.8	*25.1	348.59
BC21	Horseshoe Bay	9/22/93	21.84	*43.78	132.95	57.3	50.7	280.22
BC32	Richardson Bay	9/22/93	31.85	77.42	174.07	*26.9	*24.7	561.71
BC41	Point Isabel	9/21/93	*21.42	*51.91	114.25	*20.2	*28.6	350.87
BD22	San Pablo Bay	9/21/93	28.15	77.93	144.34	*18.2	*16.8	478.66
BD31	Pinole Point	9/21/93	*8.15	*19.74	21.29	*13.7	*13.1	77.34
BD41	Davis Point	9/21/93	*5.81	*12.02	14.78	*8.9	*8.9	43.63
BD50	Napa River	9/21/93	*10.11	*26.2	*23.85	*21.4	*24.5	91.71
BF10	Pacheco Creek	9/20/93	*2.76	*4.81	17.95	*2.2	*1.8	16.54
BF21	Grizzly Bay	9/20/93	*8.57	*27.86	*17.58	*19.1	*21.6	59.33
BG20	Sacramento River	9/20/93	*2.65	*9.98	*4.12	*6.6	*7.8	13.98
BG30	San Joaquin River	9/20/93	*3.11	*13.09	*4.3	*5.4	*6.7	16.69

**Table 14. (Page 1 of 5). PCB concentrations in sediment from September, 1993.** Units µg/kg, dry weight (ppb).  
 \* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Total Terphenyls	Total PCB's	7(CL2)	8(CL2)	15(CL2)	16/32(CL3)	18(CL3)	22(CL3)	24(CL3)
BA20	South Bay	9/23/93	157.561	16.753	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63
BA30	Dumbarton Br	9/23/93	146.939	2.574	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Cree	9/23/93	100.389	13.579	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44
BB30	Oyster Point	9/22/93	98.048	9.945	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43
BC10	Yerba Buena I	9/22/93	137.613	19.181	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53
BC21	Horseshoe Bay	9/22/93	117.884	7.340	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BC30	Richardson Ba	9/22/93	138.399	30.253	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37
BC41	Point Isabel	9/21/93	183.981	59.572	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42
BD20	San Pablo Bay	9/21/93	189.226	5.885	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47
BD30	Pinole Point	9/21/93	60.660	11.250	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50
BD40	Davis Point	9/21/93	22.393	1.444	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BD50	Napa River	9/21/93	75.210	8.892	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68
BF10	Pacheco Creek	9/20/93	34.347	2.729	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29
BF20	Grizzly Bay	9/20/93	34.898	2.988	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66
BG20	Sacramento R	9/20/93	22.977	10.858	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30
BG30	San Joaquin R	9/20/93	59.030	2.707	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34
Station Code	Station Name	Collection Date	25(CL3)	26(CL3)	28(CL3)	29(CL3)	31(CL3)	33(CL3)	37/42(CL4)	40(CL4)	41/64(CL4)
BA20	South Bay	9/23/93	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63
BA30	Dumbarton Bridge	9/23/93	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Creek	9/23/93	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44
BB30	Oyster Point	9/22/93	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43
BC10	Yerba Buena I.	9/22/93	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53
BC21	Horseshoe Bay	9/22/93	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	0.40	* 0.33	1.26
BC30	Richardson Bay	9/22/93	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	1.22
BC41	Point Isabel	9/21/93	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	0.65
BD20	San Pablo Bay	9/21/93	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47
BD30	Pinole Point	9/21/93	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50
BD40	Davis Point	9/21/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BD50	Napa River	9/21/93	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68
BF10	Pacheco Creek	9/20/93	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29
BF20	Grizzly Bay	9/20/93	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66
BG20	Sacramento River	9/20/93	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30
BG30	San Joaquin River	9/20/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	257.59

**Table 14. (Page 2 of 5). PCB concentrations in sediment from September, 1993.** Units µg/kg, dry weight (ppb).  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	44(CL4)	45(CL4)	46(CL4)	47/48(CL4)	49(CL4)	50(CL4)	52(CL4)	60/56(CL5)	66(CL4)
BA20	South Bay	9/23/93	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	0.67	* 0.63
BA30	Dumbarton Bridge	9/23/93	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Creek	9/23/93	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44
BB30	Oyster Point	9/22/93	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43
BC10	Yerba Buena I.	9/22/93	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	0.70
BC21	Horseshoe Bay	9/22/93	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	0.51	* 0.33	0.49
BC30	Richardson Bay	9/22/93	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	0.43	0.39
BC41	Point Isabel	9/21/93	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42
BD20	San Pablo Bay	9/21/93	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47
BD30	Pinole Point	9/21/93	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50
BD40	Davis Point	9/21/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	0.37	* 0.32
BD50	Napa River	9/21/93	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68
BF10	Pacheco Creek	9/20/93	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29
BF20	Grizzly Bay	9/20/93	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66
BG20	Sacramento River	9/20/93	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	0.39
BG30	San Joaquin Rive	9/20/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34

Station Code	Station Name	Collection Date	70(CL4)	74(CL4)	82(CL5)	83(CL5)	84?(CL5)	85(CL5)	87(CL5)	88(CL5)	92?(CL5)
BA20	South Bay	9/23/93	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63
BA30	Dumbarton Bridge	9/23/93	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Creek	9/23/93	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44
BB30	Oyster Point	9/22/93	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43
BC10	Yerba Buena I.	9/22/93	0.60	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53
BC21	Horseshoe Bay	9/22/93	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BC30	Richardson Bay	9/22/93	* 0.37	* 0.37	0.39	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37
BC41	Point Isabel	9/21/93	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42
BD20	San Pablo Bay	9/21/93	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47
BD30	Pinole Point	9/21/93	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50
BD40	Davis Point	9/21/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BD50	Napa River	9/21/93	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68
BF10	Pacheco Creek	9/20/93	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29
BF20	Grizzly Bay	9/20/93	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66
BG20	Sacramento River	9/20/93	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30
BG30	San Joaquin Rive	9/20/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34

**Table 14. (Page 3 of 5). PCB concentrations in sediment from September, 1993.** Units µg/Kg, dry weight (ppb).  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	97(CL5)	99(CL5)	100(CL5)	101(CL5)	105(CL5)	107/108/144 (CL5/5/6)	110/77 (CL5/4)	118/108/149 (CL5/5/6)
BA20	South Bay	9/23/93	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	0.92	0.83
BA30	Dumbarton Bridge	9/23/93	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Creek	9/23/93	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	0.46	0.50
BB30	Oyster Point	9/22/93	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	0.57	0.53
BC10	Yerba Buena I.	9/22/93	* 0.53	* 0.53	* 0.53	0.67	* 0.53	* 0.53	1.22	1.02
BC21	Horseshoe Bay	9/22/93	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BC30	Richardson Bay	9/22/93	* 0.37	* 0.37	* 0.37	0.40	0.38	* 0.37	0.79	0.98
BC41	Point Isabel	9/21/93	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	0.55	0.55
BD20	San Pablo Bay	9/21/93	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	0.99	0.61
BD30	Pinole Point	9/21/93	* 0.50	* 0.50	* 0.50	0.53	* 0.50	* 0.50	* 0.32	* 0.32
BD40	Davis Point	9/21/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.68	* 0.68
BD50	Napa River	9/21/93	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.29	* 0.29
BF10	Pacheco Creek	9/20/93	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.66	* 0.66
BF20	Grizzly Bay	9/20/93	* 0.66	* 0.66	* 0.66	0.38	* 0.66	* 0.66	0.69	0.58
BG20	Sacramento River	9/20/93	* 0.30	* 0.30	* 0.30	* 0.34	* 0.30	* 0.30	* 0.34	* 0.34
BG30	San Joaquin River	9/20/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34		

Station Code	Station Name	Collection Date	126(CL5)	128(CL6)	129(CL6)	136(CL6)	137(CL6)	138(CL6)	141(CL6)	146(CL6)	149(CL6)
BA20	South Bay	9/23/93	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	1.34	* 0.63	* 0.63	* 0.63
BA30	Dumbarton Bridge	9/23/93	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Creek	9/23/93	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	0.83	* 0.44	* 0.44	* 0.44
BB30	Oyster Point	9/22/93	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	1.11	* 0.43	* 0.43	* 0.43
BC10	Yerba Buena I.	9/22/93	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	2.18	* 0.53	* 0.53	0.69
BC21	Horseshoe Bay	9/22/93	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BC30	Richardson Bay	9/22/93	* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	1.88	0.56	* 0.37	0.69
BC41	Point Isabel	9/21/93	* 0.42	* 0.42	* 0.42	* 0.42	* 0.42	1.50	* 0.42	* 0.42	1.02
BD20	San Pablo Bay	9/21/93	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	0.50	* 0.47	* 0.47	* 0.47
BD30	Pinole Point	9/21/93	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	1.07	* 0.50	* 0.50	* 0.50
BD40	Davis Point	9/21/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BD50	Napa River	9/21/93	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	0.74	* 0.68	* 0.68	* 0.68
BF10	Pacheco Creek	9/20/93	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29
BF20	Grizzly Bay	9/20/93	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	0.66	* 0.66	* 0.66	* 0.66
BG20	Sacramento River	9/20/93	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	1.23	* 0.30	* 0.30	0.39
BG30	San Joaquin River	9/20/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34

**Table 14. (Page 4 of 5). PCB concentrations in sediment from September, 1993.** Units µg/kg, dry weight (ppb).  
 \* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	156/171/202														
			151(CL6)	153(CL6)	158(CL7)	167(CL6)	170(CL7)	172(CL7)	174(CL7)	177(CL7)	187/182/159	183(CL7)	185(CL7)	188(CL7)	189(CL7)	191(CL7)	194(CL8)
BA20	South Bay	9/23/93	* 0.63	1.48	* 0.63	* 0.63	3.91	* 0.63	* 0.63	* 0.63	187/182/159	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63
BA30	Dumbarton Bridge	9/23/93	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57		* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Creek	9/23/93	* 0.44	1.00	* 0.44	* 0.44	3.40	1.64	* 0.44	* 0.44		* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44
BB30	Oyster Point	9/22/93	* 0.43	1.23	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43		* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43
BC10	Yerba Buena I.	9/22/93	* 0.53	2.34	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53		* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53
BC21	Horseshoe Bay	9/22/93	* 0.33	0.80	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33		* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BC30	Richardson Bay	9/22/93	* 0.37	2.24	* 0.37	* 0.37	7.78	1.88	* 0.37	* 0.37		* 0.37	* 0.37	* 0.37	* 0.37	0.56	* 0.37
BC41	Point Isabel	9/21/93	0.62	3.01	2.19	* 0.42	4.07	2.53	* 0.42	* 0.42		* 0.47	* 0.47	* 0.47	* 0.47	1.98	0.68
BD20	San Pablo Bay	9/21/93	* 0.47	0.54	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47		* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50
BD30	Pinole Point	9/21/93	* 0.50	1.17	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50		* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BD40	Davis Point	9/21/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32		* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68
BD50	Napa River	9/21/93	* 0.68	0.84	* 0.68	* 0.68	0.99	0.99	* 0.68	* 0.68		* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29
BF10	Pacheco Creek	9/20/93	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29		* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66
BF20	Grizzly Bay	9/20/93	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66		* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30
BG20	Sacramento River	9/20/93	* 0.30	1.33	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30		* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34
BG30	San Joaquin Rive	9/20/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34							

Station Code	Station Name	Collection Date	187/182/159														
			178(CL7)	180(CL7)	183(CL7)	185(CL7)	188(CL7)	189(CL7)	191(CL7)	194(CL8)	187/182/159	183(CL7)	185(CL7)	188(CL7)	189(CL7)	191(CL7)	194(CL8)
BA20	South Bay	9/23/93	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63		* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63
BA30	Dumbarton Bridge	9/23/93	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57		* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Creek	9/23/93	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44		* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44
BB30	Oyster Point	9/22/93	* 0.43	0.45	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43		* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43
BC10	Yerba Buena I.	9/22/93	* 0.53	1.03	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53		* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53
BC21	Horseshoe Bay	9/22/93	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33		* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BC30	Richardson Bay	9/22/93	0.58	1.90	* 0.37	* 0.37	0.81	* 0.37	* 0.37	* 0.37		* 0.37	* 0.37	* 0.37	* 0.37	* 0.37	0.54
BC41	Point Isabel	9/21/93	0.76	7.71	1.46	0.54	4.36	* 0.42	* 0.42	* 0.42		* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	4.54
BD20	San Pablo Bay	9/21/93	0.60	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47		* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50
BD30	Pinole Point	9/21/93	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50		* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BD40	Davis Point	9/21/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32		* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68
BD50	Napa River	9/21/93	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68		* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29
BF10	Pacheco Creek	9/20/93	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29		* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66
BF20	Grizzly Bay	9/20/93	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66		* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30
BG20	Sacramento River	9/20/93	* 0.30	0.58	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30		* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34
BG30	San Joaquin Rive	9/20/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34							

**Table 14. (Page 5 of 5). PCB concentrations in sediment from September, 1993. Units µg/kg, dry weight (ppb).**  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	195(CL8)	196(CL8)	200(CL8)	201(CL8)	205(CL9)	206(CL9)	209(CL10)	UNK(CL6)
BA20	South Bay	9/23/93	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63
BA30	Dumbarton Bridge	9/23/93	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57	* 0.57
BA40	Redwood Creek	9/23/93	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44	* 0.44
BB30	Oyster Point	9/22/93	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43	* 0.43
BC10	Yerba Buena I.	9/22/93	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53	* 0.53
BC21	Horseshoe Bay	9/22/93	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BC30	Richardson Bay	9/22/93	* 0.37	0.74	* 0.37	0.83	* 0.37	* 0.37	* 0.37	* 0.37
BC41	Point Isabel	9/21/93	1.87	6.80	0.61	5.68	* 0.42	1.51	* 0.42	* 0.42
BD20	San Pablo Bay	9/21/93	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47	* 0.47
BD30	Pinole Point	9/21/93	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50	* 0.50
BD40	Davis Point	9/21/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BD50	Napa River	9/21/93	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68
BF10	Pacheco Creek	9/20/93	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29	* 0.29
BF20	Grizzly Bay	9/20/93	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66	* 0.66
BG20	Sacramento River	9/20/93	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30	* 0.30
BG30	San Joaquin Rive	9/20/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34

**Table 15. (Page 1 of 2) Pesticide concentrations in sediment from September, 1993.** Units  $\mu\text{g/kg}$ , dry weight (ppb).  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Total Pesticides	Alpha-BHC	HCB	Beta-BHC	Gamma-BHC	Delta-BHC	Hepta-chlor	Hepta-epoxide	Oxy-chlordane
BA20	South Bay	9/23/93	4.4254	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BA30	Dumbarton Bridge	9/23/93	2.288	* 0.28	0.29	* 0.28	* 0.28	* 0.28	* 0.28	* 0.28	* 0.28
BA40	Redwood Creek	9/23/93	1.5582	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22
BB30	Oyster Point	9/22/93	2.21	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22
BC10	Yerba Buena I.	9/22/93	3.4632	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26
BC21	Horseshoe Bay	9/22/93	3.414	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17
BC30	Richardson Bay	9/22/93	2.0416	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18
BC41	Point Isabel	9/21/93	2.968	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21
BD20	San Pablo Bay	9/21/93	2.825	* 0.23	* 0.23	* 0.23	* 0.23	* 0.23	* 0.23	* 0.23	* 0.23
BD30	Pinole Point	9/21/93	5.75	* 0.25	0.83	* 0.25	* 0.25	* 0.25	* 0.25	* 0.25	* 0.25
BD40	Davis Point	9/21/93	1.1228	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16
BD50	Napa River	9/21/93	4.446	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34
BF10	Pacheco Creek	9/20/93	0.4371	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14
BF20	Grizzly Bay	9/20/93	2.656	* 0.33	0.34	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BG20	Sacramento River	9/20/93	1.9604	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15
BG30	San Joaquin River	9/20/93	1.5288	0.20	0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17

Station Code	Station Name	Collection Date	Gamma-chlordane	Alpha-chlordane	Trans-nonachlor	cis-nonachlor	Aldrin	Di-eldrin	Endrin	Mirex	2,4'-(O,P'DDE)
BA20	South Bay	9/23/93	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32	* 0.32
BA30	Dumbarton Bridge	9/23/93	* 0.28	* 0.28	* 0.28	* 0.28	* 0.28	* 0.28	* 0.28	* 0.28	* 0.28
BA40	Redwood Creek	9/23/93	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22
BB30	Oyster Point	9/22/93	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22	* 0.22
BC10	Yerba Buena I.	9/22/93	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26	* 0.26
BC21	Horseshoe Bay	9/22/93	0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	0.34	* 0.17	* 0.17
BC30	Richardson Bay	9/22/93	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18	* 0.18
BC41	Point Isabel	9/21/93	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21	* 0.21
BD20	San Pablo Bay	9/21/93	* 0.23	* 0.23	* 0.23	* 0.23	* 0.23	* 0.23	0.34	* 0.23	* 0.23
BD30	Pinole Point	9/21/93	0.28	* 0.25	* 0.25	* 0.25	* 0.25	* 0.25	* 0.25	* 0.25	* 0.25
BD40	Davis Point	9/21/93	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16	* 0.16
BD50	Napa River	9/21/93	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34	* 0.34
BF10	Pacheco Creek	9/20/93	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14	* 0.14
BF20	Grizzly Bay	9/20/93	* 0.33	* 0.33	0.34	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33	* 0.33
BG20	Sacramento River	9/20/93	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15	* 0.15
BG30	San Joaquin River	9/20/93	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17	* 0.17

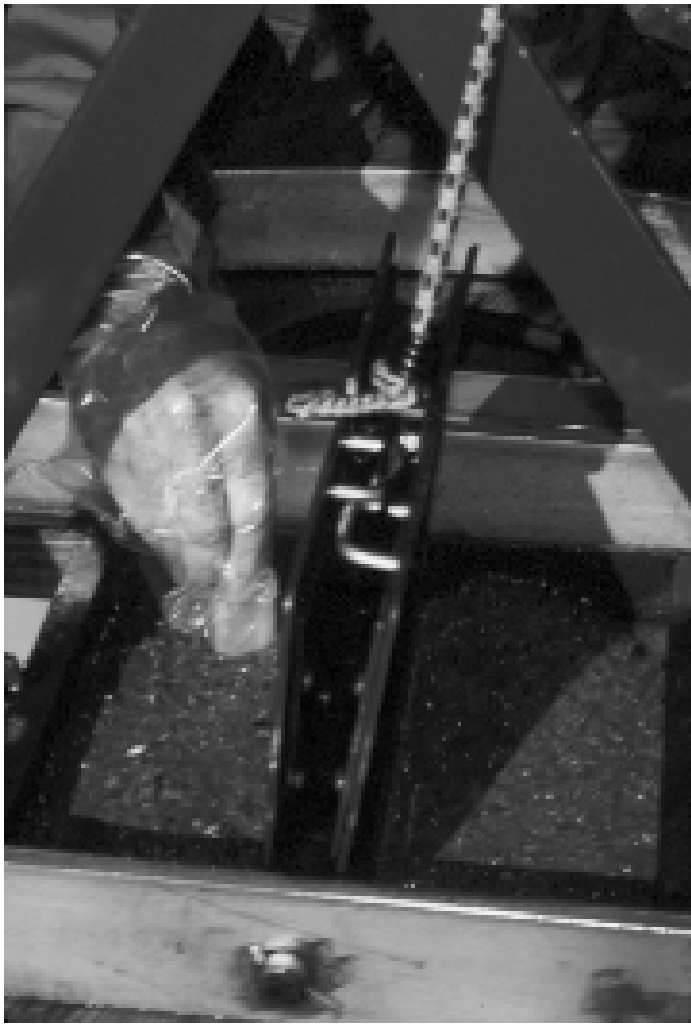
**Table 15. (Page 2 of 2) Pesticide concentrations in sediment from September, 1993.** Units µg/kg, dry weight (ppb). \* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	4,4' (P,P'DDE)	2,4' (O,P'DDD)	4,4' (P,P'DDD)	2,4' (O,P'DDT)	4,4' (P,P'DDT)
BA20	South Bay	9/23/93	1.04	* 0.32	1.41	* 0.32	* 0.32
BA30	Dumbarton Bridge	9/23/93	0.93	* 0.28	1.06	* 0.28	* 0.28
BA40	Redwood Creek	9/23/93	0.47	* 0.22	0.72	* 0.22	* 0.22
BB30	Oyster Point	9/22/93	0.48	* 0.22	1.05	* 0.22	* 0.22
BC10	Yerba Buena I.	9/22/93	0.77	* 0.26	1.75	* 0.26	* 0.26
BC21	Horseshoe Bay	9/22/93	0.92	* 0.17	1.15	* 0.17	* 0.17
BC30	Richardson Bay	9/22/93	0.45	* 0.18	1.02	* 0.18	* 0.18
BC41	Point Isabel	9/21/93	0.70	* 0.21	1.58	* 0.21	* 0.21
BD20	San Pablo Bay	9/21/93	0.86	* 0.23	1.20	* 0.23	* 0.23
BD30	Pinole Point	9/21/93	1.99	* 0.25	2.28	* 0.25	* 0.25
BD40	Davis Point	9/21/93	0.31	* 0.16	0.46	* 0.16	* 0.16
BD50	Napa River	9/21/93	1.74	* 0.34	2.22	* 0.34	* 0.34
BF10	Pacheco Creek	9/20/93	0.17	* 0.14	0.18	* 0.14	* 0.14
BF20	Grizzly Bay	9/20/93	1.08	* 0.33	1.23	* 0.33	* 0.33
BG20	Sacramento River	9/20/93	0.43	* 0.15	0.99	* 0.15	* 0.15
BG30	San Joaquin River	9/20/93	0.39	* 0.17	0.35	* 0.17	* 0.17



**Table 16. Means and Standard deviations of percent amphipod survival, mussel survival, mussel normal larva development, oyster survival, and oyster normal larva development for RMP sediment cruises. Home Sediment for *Eohaustorius* is Yaquina Bay sediment. Granite Canyon sea water was used as a control for mussel elutriate tests.**

Station Code	Station Name	Collection Date	mean % survival <i>Eohaustorius</i> ± sd	mean % survival <i>Mytilus</i> ± sd	mean % normal <i>Mytilus</i> ± sd	mean % normal <i>Crassostrea</i> ± sd
<b>Home sediment</b>						
control	na	na	97 ± 2.7	85.2 ± 9.7	96.0 ± 2.0	
BA21	South Bay	3/12/93	67 ± 5.7	88.1 ± 6.7	94.5 ± 2.8	
BA41	Redwood Ck	3/12/93	51 ± 11.4	87.6 ± 11.0	92.2 ± 2.6	
BC11	Yerba Buena	3/11/93	78 ± 8.4	88.4 ± 5.5	93.5 ± 2.6	
BD31	Pinole Point	3/10/93	62 ± 16.0	78.7 ± 13.3	89.7 ± 4.5	
BD50	Napa River	3/10/93	61 ± 18.5	74.6 ± 10.8	65.0 ± 10.3	
BF21	Grizzly Bay	3/9/93	57 ± 13.5	0.1 ± 0.1	0.0 ± 0	
BG20	Sacramento R	3/9/93	74 ± 10.8	0.3 ± 0.6	0.0 ± 0	
BG30	San Joaquin R	3/9/93	89 ± 11.4	0.7 ± 1.4	0.0 ± 0	
<b>Home sediment</b>						
control	na	na	100.0 ± 0			75.5 ± 6.8
BA21	South Bay	9/13/93	82.0 ± 13.5			90.0 ± 6.8
BA41	Redwood Ck	9/13/93	76.0 ± 8.2			89.3 ± 9.2
BC11	Yerba Buena	9/13/93	89.0 ± 7.4			92.2 ± 11.8
BD31	Pinole Point	9/15/93	89.0 ± 5.5			82.5 ± 9.0
BD50	Napa River	9/15/93	83.0 ± 11.0			75.8 ± 15.0
BF21	Grizzly Bay	9/16/93	84.0 ± 9.6			39.1 ± 16.2
BG20	Sacramento R	9/16/93	97.0 ± 4.5			0.3 ± 0.7
BG30	San Joaquin R	9/16/93	93.0 ± 6.7			0.2 ± 0.3



*Collecting a sediment sample*

Table 17. Trace metal concentrations in bivalve tissues.

. means data not collected; units expressed as dry weight.

Species	Station Code	Station Name	Collection Date	Ag μg/g	As μg/g	Cd μg/g	Cr μg/g	Cu μg/g	Hg-methyl ng/g	Hg-total μg/g	Ni μg/g	Pb μg/g	Se μg/g	Zn μg/g	TBT ng Sn/g	DBT ng Sn/g	MBT ng Sn/g
Mussel	T=0	Bodega Head	2/25/93	0.225	9.50	2.316	3.46	1.79	101.639	0.282	1.84	0.452	2.89	120.55	75	20	1.5
Oyster	T=0	Tonales Bay	2/28/93	1.008	4.77	3.232	0.84	29.03	91.198	0.234	1.22	0.065	4.02	274.41	32	6	1.5
Clam	T=0	Lake Isabella	2/27/93	0.045	12.60	0.153	5.54	22.67	22.452	0.187	4.48	0.294	2.70	64.20	0.5	0.5	1.5
Mussel	BA30	Dumbarton Bridge	6/2/93	0.407	7.19	3.995	40.91	5.73	26.931	0.261	28.85	0.922	2.41	180.06	62	21	16
Mussel	BA40	Redwood Ck.	6/2/93	0.310	7.36	3.101	6.81	7.16	48.916	0.215	5.84	2.158	2.97	169.16	86	30	21
Mussel	BC10	Yerba Buena	6/2/93	0.189	8.38	1.357	38.97	8.53	72.532	0.242	27.59	0.943	4.20	191.36	233	48	6
Mussel	BC21	Horseshoe Bay	6/2/93	0.372	9.02	1.538	7.41	6.94	72.374	0.262	6.28	0.511	3.37	160.84	100	13	7
Oyster	BD20	San Pablo Bay	6/2/93	1.966	7.01	5.128	1.83	183.47	96.410	0.203	1.03	0.202	4.16	621.12	101	14	7
Mussel	BD30	Pinole Point	6/2/93	0.014	8.45	2.268	7.89	3.93	84.495	0.300	6.11	0.020	3.34	135.77	149	35	15
Oyster	BD40	Davis Point	6/3/93	1.569	6.15	14.032	4.03	242.79	126.745	0.190	3.21	0.261	4.47	762.30	200	29	28
Oyster	BD50	Napa River	6/3/93	0.718	7.36	10.582	2.19	154.90	184.014	0.273	0.76	0.211	5.96	554.57	167	21	16
Clam	BF20	Grizzly Bay	6/3/93	0.109	16.06	0.521	8.18	36.87	45.683	0.218	7.44	0.913	4.21	90.13	53	23	1.5
Clam	BG20	Sacramento River	6/3/93	0.069	10.60	0.120	7.45	37.09	29.562	0.203	7.75	0.640	2.66	82.76	27	11	7
Clam	BG30	San Joaquin River	6/3/93	0.055	14.39	0.440	10.16	29.11	44.470	0.219	7.49	0.489	3.15	61.95	32	21	10
Mussel	T=0	Bodega Head	6/25/93	0.329	11.10	8.887	2.13	5.30	.	0.335	3.23	1.878	1.35	263.00	30	2	1
Oyster	T=0	Tonales Bay	6/28/93	1.503	14.30	7.361	2.33	99.91	.	0.718	1.47	0.220	1.89	644.00	9	2	1
Clam	T=0	Lake Isabella	6/28/93	0.055	12.30	0.530	0.52	27.70	.	0.190	0.47	0.383	3.46	99.00	1	2	23.5
Mussel	BA30	Dumbarton Bridge	10/6/93	0.462	9.42	13.461	2.55	2.66	.	0.226	4.59	3.385	1.22	481.91	15	6	1
Oyster	BA30	Dumbarton Bridge	10/6/93	1.355	8.23	15.698	6.41	374.96	.	0.332	4.23	1.496	2.49	1436.72	32	7	5
Mussel	BA40	Redwood Ck.	10/6/93	1.047	12.40	13.097	4.17	5.35	.	0.362	4.43	2.885	0.99	404.28	22	11	1
Mussel	BC10	Yerba Buena	10/6/93	0.867	8.79	6.913	5.46	7.55	.	0.351	4.06	2.304	2.37	337.10	189	51	19
Mussel	BC21	Horseshoe Bay	10/6/93	0.555	13.10	8.378	3.88	7.25	.	0.300	2.98	1.779	3.39	240.84	83	21	9
Mussel	BD20	San Pablo Bay	10/6/93	1.111	18.20	19.499	8.03	8.59	.	0.434	8.70	4.159	1.34	588.09	50	26	16
Oyster	BD20	San Pablo Bay	10/6/93	1.989	8.39	10.376	1.22	321.74	.	0.305	1.90	0.677	7.88	1286.76	71	24	11
Mussel	BD30	Pinole Point	10/6/93	.	15.40	.	.	.	.	0.276	.	.	2.25	.	57	32	18
Mussel	BD40	Davis Point.	10/7/93	0.568	18.60	16.277	3.63	3.74	.	0.503	5.77	4.174	1.62	503.28	73	36	23
Oyster	BD40	Davis Point.	10/7/93	2.140	10.70	14.922	4.41	430.27	.	0.334	3.22	0.974	8.25	1402.75	121	18	13
Mussel	BD50	Napa River	10/6/93	0.199	14.00	13.590	3.41	2.79	.	0.358	5.83	2.582	0.79	307.82	61	53	20
Oyster	BD50	Napa River	10/6/93	2.980	8.65	25.337	4.09	634.19	.	0.315	4.45	1.203	1.99	2646.54	113	19	8
Clam	BF20	Grizzly Bay	10/7/93	0.348	18.10	0.565	1.42	32.50	.	0.289	2.33	0.360	3.44	119.62	101	61	21
Clam	BG30	San Joaquin River	10/7/93	0.145	18.60	0.955	3.62	55.46	.	0.288	3.08	0.845	2.85	125.91	43	14	8
Clam	BG20	Sacramento River	10/7/93	0.051	15.90	1.041	3.13	42.68	.	0.196	3.17	1.054	1.70	126.56	47	22	10

**Table 18. (Page 1 of 4). PAH concentrations in bivalve tissue from September, 1993.** Units µg/kg, dry weight (ppb). Time=0 indicated the time of the deployment of the bivalve species from the source indicated under station name heading. \* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	Total PAHs	1-Methyl-Naph	1-Methyl-Phen	2,3,5-Tri-Methnaph	2,6-Di-Methnaph	2-Methyl-Naph	Acenaph-thene	
BA30	Dumbarton Bridge	10/5/89	Mussel	*15.7	.58	*0.4	*0.09	*0.41	*0.66	*0.21	
BA40	Redwood Creek	10/5/89	Mussel	*30.1	*0.39	*0.34	*0.05	*0.27	.88	*0.17	
BC10	Yerba Buena Is	10/5/89	Mussel	*38.7	*0.45	*0.29	*0.28	*0.32	.80	*0.43	
BC21	Horseshoe Bay	10/5/89	Mussel	*45.6	.62	*0.23	*0.22	*0.39	1.39	.61	
BD20	San Pablo Bay	10/5/89	Oyster	*43.7	*0.4	*0.27	*0.15	*0.3	*0.58	*0.1	
BD20	San Pablo Bay	10/5/89	Mussel	*15.2	1.28	*0.51	*0.29	.67	1.04	*0.56	
BD30	Pinole Point	10/5/89	Mussel	*19.8	.57	*0.16	*0.23	*0.25	.74	*0.06	
BD40	Davis Point	10/6/89	Oyster	*87.6	.65	*0.33	*0.26	*0.32	.81	*0.22	
BD40	Davis Point	10/6/89	Mussel	*13.9	*0.45	*0.09	*0.1	*0.27	.70	*0.1	
BD50	Napa River	10/6/89	Mussel	*44.2	*2.16	*2.77	*1.22	*2.03	*3.8	*1.35	
BD50	Napa River	10/6/89	Oyster	*203.9	*0.41	.80	*0.48	*0.48	*0.59	*0.27	
BF20	Grizzly Bay	10/6/89	Clam	*102.9	.63	.67	*0.5	*0.51	.91	*0.3	
BG20	Sacramento River	10/6/89	Clam	*93	.81	*0.54	*0.27	*0.52	*0.92	*0.06	
BG30	San Joaquin River	10/6/89	Clam	*78.4	*0.45	.58	*0.28	*0.33	*0.64	*0.09	
TIME=0 BH	Bodega	6/24/89	Mussel	*5.5	.49	*0.13	*0.11	*0.31	*0.61	*0.05	
TIME=0 TB	Tomales	6/27/89	Oyster	*35	.55	*0.25	*0.55	*0.42	.74	*0.25	
TIME=0 LI	Isabella	6/27/89	Clam	*64.8	.78	.84	*0.26	*0.38	.87	*0.11	
Station Code	Station Name	Collection Date	Species	Acenaph-thylene	Anthracene	BenA-anthracene	BenA-benzopyrene	BenB-fluoranthene	BenE-pyrene	BenK-fluoranthene	Bghi-perylene
BA30	Dumbarton Bridge	10/5/89	Mussel	*0.09	*0.27	.69	.45	*0.28	.40	*0.3	.62
BA40	Redwood Creek	10/5/89	Mussel	*0.17	.73	2.28	1.07	.75	1.04	.78	1.30
BC10	Yerba Buena Is	10/5/89	Mussel	*0.26	1.01	1.49	.79	.64	.77	.67	.95
BC21	Horseshoe Bay	10/5/89	Mussel	*0.35	1.40	1.77	.90	.64	.70	.67	.88
BD20	San Pablo Bay	10/5/89	Oyster	*0.15	*0.27	.78	.60	1.30	1.90	1.35	.75
BD20	San Pablo Bay	10/5/89	Mussel	*0.18	*0.45	.95	*0.31	*0.32	.38	*0.33	.49
BD30	Pinole Point	10/5/89	Mussel	*0.09	*0.36	.74	*0.27	*0.26	.29	*0.27	.35
BD40	Davis Point	10/6/89	Oyster	*0.22	*0.5	2.13	.94	1.99	3.13	2.07	1.08
BD40	Davis Point	10/6/89	Mussel	*0.09	*0.38	1.05	*0.17	*0.17	.17	*0.18	*0.17
BD50	Napa River	10/6/89	Mussel	*1.03	*2.19	1.78	*1.78	*1.18	1.98	*1.22	*0.98
BD50	Napa River	10/6/89	Oyster	*0.4	1.02	5.72	2.35	4.91	6.62	5.10	2.37
BF20	Grizzly Bay	10/6/89	Clam	*0.37	1.09	2.26	.44	.69	1.80	.72	.61
BG20	Sacramento River	10/6/89	Clam	*0.4	.85	1.45	*0.38	*0.51	1.29	*0.53	.56
BG30	San Joaquin River	10/6/89	Clam	*0.22	.68	1.54	*0.34	*0.42	1.06	.44	.44
TIME=0 BH	Bodega	6/24/89	Mussel	*0.11	*0.18	.41	*0.06	*0.08	0.09	*0.09	*0.08
TIME=0 TB	Tomales	6/27/89	Oyster	*0.08	*0.18	0.11	*0.05	*0.11	.19	*0.12	*0.05
TIME=0 LI	Isabella	6/27/89	Clam	*0.06	*0.22	.29	*0.12	*0.07	0.17	*0.08	*0.13

**Table 18. (Page 2 of 4). PAH concentrations in bivalve tissue from September, 1993.** Units µg/kg, dry weight (ppb). Time=0 indicated the time of the deployment of the bivalve species from the source indicated under station name heading. \* means value below method detection limit (MDL). ND means not detected.

Station Code	Station Name	Collection Date	Species	Biphenyl	C1-chrysenes	C1-diben	C1-fluoranthene	C1-fluorenes	C1-naphthalenes	C1-phenanthrene
BA30	Dumbarton Bridge	10/5/89	Mussel	*0.37	ND	ND	.63	ND	1.24	ND
BA40	Redwood Creek	10/5/89	Mussel	*0.53	1.07	ND	1.57	ND	1.27	1.29
BC10	Yerba Buena Is	10/5/89	Mussel	*0.55	*0.56	ND	2.08	*0.75	1.25	1.35
BC21	Horseshoe Bay	10/5/89	Mussel	*0.56	*0.65	ND	1.65	*0.82	2.01	1.99
BD20	San Pablo Bay	10/5/89	Oyster	*0.34	1.17	ND	2.61	*0.49	*0.98	*0.94
BD20	San Pablo Bay	10/5/89	Mussel	*0.93	ND	ND	ND	ND	2.32	ND
BD30	Pinole Point	10/5/89	Mussel	*0.47	*0.4	ND	.65	*0.46	1.31	*0.65
BD40	Davis Point	10/6/89	Oyster	*0.52	2.97	.52	5.98	*0.58	1.46	1.67
BD40	Davis Point	10/6/89	Mussel	*0.31	*0.59	ND	.80	ND	1.15	*0.77
BD50	Napa River	10/6/89	Mussel	*2.5	ND	ND	ND	ND	*5.96	ND
BD50	Napa River	10/6/89	Oyster	*0.5	5.63	1.18	14.48	1.59	*1	3.33
BF20	Grizzly Bay	10/6/89	Clam	*0.74	3.26	ND	9.32	ND	1.54	3.74
BG20	Sacramento River	10/6/89	Clam	*0.78	1.92	ND	6.48	*0.88	1.73	3.81
BG30	San Joaquin River	10/6/89	Clam	*0.43	2.93	ND	5.23	*0.9	*1.09	2.23
TIME=0 BH	Bodega	6/24/89	Mussel	*0.38	ND	ND	ND	ND	*1.1	ND
TIME=0 TB	Tomales	6/27/89	Oyster	*0.33	*0.53	.55	1.31	*0.67	1.29	1.90
TIME=0 LI	Isabella	6/27/89	Clam	*0.58	ND	ND	4.19	*0.93	1.65	4.79

Station Code	Station Name	Collection Date	Species	C2-chrysenes	C2-diben	C2-fluorenes	C2-naphthalenes	C2-phenanthrene	chrysenes	C3-diben
BA30	Dumbarton Bridge	10/5/89	Mussel		ND	ND	*1.12	ND	ND	ND
BA40	Redwood Creek	10/5/89	Mussel	*0.62	ND	ND	1.18	1.22	ND	ND
BC10	Yerba Buena Is	10/5/89	Mussel	*0.4	ND	*0.97	*0.97	1.64	ND	ND
BC21	Horseshoe Bay	10/5/89	Mussel	*0.49	ND	*1.33	1.79	1.37	ND	ND
BD20	San Pablo Bay	10/5/89	Oyster	1.41	1.34	1.64	1.14	2.37	ND	1.38
BD20	San Pablo Bay	10/5/89	Mussel	ND	ND	ND	ND	ND	ND	ND
BD30	Pinole Point	10/5/89	Mussel	*0.18	.57	*0.67	*0.89	*0.65	ND	.63
BD40	Davis Point	10/6/89	Oyster	2.15	2.28	1.73	*1.02	4.46	ND	2.66
BD40	Davis Point	10/6/89	Mussel	ND	ND	ND	*0.49	*0.76	ND	ND
BD50	Napa River	10/6/89	Mussel	ND	ND	ND	ND	ND	ND	ND
BD50	Napa River	10/6/89	Oyster	5.07	4.65	5.39	*0.79	11.90	*0.67	7.13
BF20	Grizzly Bay	10/6/89	Clam	1.71	3.15	ND	1.72	8.14	ND	3.74
BG20	Sacramento River	10/6/89	Clam	1.51	3.00	4.53	*1.38	5.57	ND	2.89
BG30	San Joaquin River	10/6/89	Clam	*1.01	1.40	4.15	*1.03	3.84	ND	2.43
TIME=0 BH	Bodega	6/24/89	Mussel		ND	ND	ND	ND	ND	ND
TIME=0 TB	Tomales	6/27/89	Oyster	*0.37	1.16	2.01	1.70	2.10	ND	1.24
TIME=0 LI	Isabella	6/27/89	Clam	ND	2.57	7.47	*1.29	5.06	ND	2.08

**Table 18. (Page 3 of 4). PAH concentrations in bivalve tissue from September, 1993.** Units µg/kg, dry weight (ppb). Time=0 indicated the time of the deployment of the bivalve species from the source indicated under station name heading. \* means value below method detection limit (MDL). ND means not detected.

Station Code	Station Name	Collection Date	Species	C3-fluorenes	C3-naph-thalenes	C3-phen-anthr	C4-chrysenes	C4-naph-thalenes	C4-phen-anthr	Chrysene
BA30	Dumbarton Bridge	10/5/89	Mussel	ND	1.77	ND	ND	1.56	ND	*0.38
BA40	Redwood Creek	10/5/89	Mussel	ND	ND	1.16	ND	ND	ND	1.43
BC10	Yerba Buena Is	10/5/89	Mussel	1.93	*1.05	1.41	ND	*0.73	ND	1.84
BC21	Horseshoe Bay	10/5/89	Mussel	2.00	1.61	ND	ND	2.02	ND	1.88
BD20	San Pablo Bay	10/5/89	Oyster	ND	*1.27	2.94	ND	ND	1.17	1.94
BD20	San Pablo Bay	10/5/89	Mussel	ND	ND	ND	ND	ND	ND	.83
BD30	Pinole Point	10/5/89	Mussel	*1.11	*1.29	ND	ND	*1.02	ND	.72
BD40	Davis Point	10/6/89	Oyster	3.29	1.97	4.58	ND	3.08	4.76	3.72
BD40	Davis Point	10/6/89	Mussel	ND	*0.75	ND	ND	ND	ND	.66
BD50	Napa River	10/6/89	Mussel	ND	ND	ND	ND	ND	ND	*1.91
BD50	Napa River	10/6/89	Oyster	11.93	2.86	14.49	*0.57	6.28	13.82	8.87
BF20	Grizzly Bay	10/6/89	Clam	ND	2.55	6.95	ND	5.22	4.76	3.94
BG20	Sacramento River	10/6/89	Clam	12.72	2.48	6.79	ND	5.01	4.93	2.70
BG30	San Joaquin River	10/6/89	Clam	12.41	2.84	5.50	ND	3.56	4.89	2.28
TIME=0 BH	Bodega	6/24/89	Mussel	ND	ND	ND	ND	ND	ND	*0.26
TIME=0 TB	Tomales	6/27/89	Oyster	3.43	4.21	3.13	ND	*1.12	*0.96	.54
TIME=0 LI	Isabella	6/27/89	Clam	8.70	2.60	6.04	ND	4.02	4.57	.67
Station Code	Station Name	Collection Date	Species	DBah-anthra	Dibenzo-thio	Fluor-anthene	Fluorene	I123cd-pyrene	Naph-thalene	
BA30	Dumbarton Bridge	10/5/89	Mussel	*0.06	*0.16	.86	*0.26	.37	1.53	
BA40	Redwood Creek	10/5/89	Mussel	*0.11	*0.17	2.32	*0.31	.80	1.57	
BC10	Yerba Buena Is	10/5/89	Mussel	*0.07	.26	4.10	*0.69	.64	1.62	
BC21	Horseshoe Bay	10/5/89	Mussel	*0.08	.42	4.82	.90	.55	2.16	
BD20	San Pablo Bay	10/5/89	Oyster	*0.09	*0.2	5.42	*0.2	.40	1.26	
BD20	San Pablo Bay	10/5/89	Mussel	*0.26	.38	1.40	*0.69	.30	1.37	
BD30	Pinole Point	10/5/89	Mussel	*0.05	*0.1	1.04	*0.23	.25	1.73	
BD40	Davis Point	10/6/89	Oyster	*0.13	*0.23	10.89	*0.36	.57	2.20	
BD40	Davis Point	10/6/89	Mussel	*0.02	*0.13	1.00	*0.22	*0.09	1.52	
BD50	Napa River	10/6/89	Mussel	*1.01	*1.09	*2.02	*1.03	*0.94	7.97	
BD50	Napa River	10/6/89	Oyster	.41	.35	22.82	*0.52	1.22	1.35	
BF20	Grizzly Bay	10/6/89	Clam	*0.16	.31	13.09	*0.34	.25	1.89	
BG20	Sacramento River	10/6/89	Clam	*0.09	*0.32	2.85	*0.43	.29	1.95	
BG30	San Joaquin River	10/6/89	Clam	*0.04	*0.19	2.28	*0.29	.20	1.47	
TIME=0 BH	Bodega	6/24/89	Mussel	*0.07	*0.1	*0.26	*0.19	*0.07	1.09	
TIME=0 TB	Tomales	6/27/89	Oyster	*0.07	*0.13	1.39	*0.25	*0.04	1.48	
TIME=0 LI	Isabella	6/27/89	Clam	*0.11	*0.11	1.48	*0.27	*0.07	1.80	

**Table 18. (Page 4 of 4). PAH concentrations in bivalve tissue from September, 1993.** Units µg/kg, dry weight (ppb). Time=0 indicated the time of the deployment of the bivalve species from the source indicated under station name heading. \* means value below the method detection limit (MDL). ND means not detected.

Station Code	Station Name	Collection Date	Species	Perylene	Phenanthrene	Phytane	Pristane	Pyrene
BA30	Dumbarton Bridge	10/5/89	Mussel	*0.27	.99	ND	*1.2	1.13
BA40	Redwood Creek	10/5/89	Mussel	.50	2.17	ND	*1.2	2.99
BC10	Yerba Buena Is	10/5/89	Mussel	.40	2.92	*1.2	*7.9	3.89
BC21	Horseshoe Bay	10/5/89	Mussel	.46	4.58	*4.2	54.60	4.00
BD20	San Pablo Bay	10/5/89	Oyster	1.23	.67	ND	*2.4	5.16
BD20	San Pablo Bay	10/5/89	Mussel	.59	1.10	ND	*2.7	1.63
BD30	Pinole Point	10/5/89	Mussel	*0.19	1.08	ND	*2.7	.97
BD40	Davis Point	10/6/89	Oyster	1.57	1.49	*4.7	40.10	10.00
BD40	Davis Point	10/6/89	Mussel	*0.2	1.34	ND	*2.8	.84
BD50	Napa River	10/6/89	Mussel	*1.68	3.24	ND	*2.1	3.03
BD50	Napa River	10/6/89	Oyster	3.87	3.10	ND	*7.6	23.22
BF20	Grizzly Bay	10/6/89	Clam	1.01	1.75	ND	*7.6	16.39
BG20	Sacramento River	10/6/89	Clam	.64	1.07	*1.2	*7.7	10.85
BG30	San Joaquin River	10/6/89	Clam	.47	.79	*2.9	*6.3	9.75
TIME=0 BH	Bodega	6/24/89	Mussel	*0.09	.67	ND	*1.4	.20
TIME=0 TB	Tomales	6/27/89	Oyster	.43	.84	*1.5	27.10	1.14
TIME=0 LI	Isabella	6/27/89	Clam	.61	.78	*3.2	*6	1.74

**Table 19. (Page 1 of 6). PCB congeners and total PCB's in bivalve tissue from September, 1993. Units µg/kg, dry weight (ppb).**  
 \* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	Total Terphenyls	Total PCB's	7(CL2)	8(CL2)	15(CL2)	16/32(CL3)	18(CL3)
BA30	Dumbarton Bridge	10/6/93	Mussel	674.61	246.41	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50
BA40	Redwood Creek	10/6/93	Mussel	* 250.40	451.44	* 1.09	* 1.09	* 1.09	* 1.09	* 1.09
BC10	Yerba Buena Is.	10/6/93	Mussel	259.50	246.25	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12
BC21	Horseshoe Bay	10/6/93	Mussel	294.48	170.24	* 0.78	* 0.78	* 0.78	* 0.78	* 0.78
BD20	Petaluma River	10/6/93	Oyster	475.05	218.64	* 1.86	* 1.86	* 1.86	* 1.86	* 1.86
BD20	Petaluma River	10/6/93	Mussel	379.66	86.80	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66
BD30	Pinole Point	10/6/93	Mussel	317.19	117.83	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90
BD40	Davis Point	10/7/93	Oyster	* 41.39	229.90	* 1.39	* 1.39	* 1.39	* 1.39	* 1.39
BD40	Davis Point	10/7/93	Mussel	187.15	210.35	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51
BD50	Napa River	10/6/93	Mussel	122.20	302.72	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	355.03	234.06	2.21	* 1.17	* 1.17	* 1.17	* 1.17
BF20	Grizzly Bay	10/7/93	Clam	58.29	306.79	* 1.85	* 1.85	* 1.85	* 1.85	* 1.85
BG20	Sacramento River	10/7/93	Clam	156.28	219.50	* 1.96	* 1.96	* 1.96	* 1.96	* 1.96
BG30	San Joaquin River	10/7/93	Clam	132.90	278.52	* 1.75	* 1.75	* 1.75	* 1.75	* 1.75
TIME=0 BH	Bodega Head	6/25/93	Mussel	326.70	36.89	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37
TIME=0 TB	Tomales Bay	6/28/93	Oyster	240.71	48.25	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	164.44	78.43	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50
BA40	Redwood Creek	10/6/93	Mussel	* 1.09	* 1.09	* 1.09	* 1.09	* 1.09	* 1.09	* 1.09
BC10	Yerba Buena Is.	10/6/93	Mussel	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12
BC21	Horseshoe Bay	10/6/93	Mussel	* 0.78	* 0.78	* 0.78	* 0.78	* 0.78	* 0.78	* 0.78
BD20	Petaluma River	10/6/93	Oyster	* 1.86	* 1.86	* 1.86	* 1.86	* 1.86	* 1.86	* 1.86
BD20	Petaluma River	10/6/93	Mussel	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66	2.07	* 1.66
BD30	Pinole Point	10/6/93	Mussel	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90
BD40	Davis Point	10/7/93	Oyster	* 1.39	* 1.39	* 1.39	* 1.39	* 1.39	* 1.39	* 1.39
BD40	Davis Point	10/7/93	Mussel	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	* 1.17	* 1.17	* 1.17	* 1.17	* 1.17	* 1.17	* 1.17
BF20	Grizzly Bay	10/7/93	Clam	* 1.85	2.17	* 1.85	* 1.85	* 1.85	* 1.85	* 1.85
BG20	Sacramento River	10/7/93	Clam	* 1.96	* 1.96	* 1.96	* 1.96	* 1.96	* 1.96	* 1.96
BG30	San Joaquin River	10/7/93	Clam	* 1.75	2.59	* 1.75	* 1.75	* 1.75	* 1.75	* 1.75
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37
TIME=0 TB	Tomales Bay	6/28/93	Oyster	* 1.27	2.93	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12



**Table 19. (Page 2 of 6). PCB congeners and total PCB's in bivalve tissue from September, 1993. Units µg/kg, dry weight (ppb).**  
 \* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	33(CL3)	37/42(CL4)	40(CL4)	41/64(CL4)	44(CL4)	45(CL4)	46(CL4)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	* 2.50	* 2.50	129.64	* 2.50	* 2.50	* 2.50
BA40	Redwood Creek	10/6/93	Mussel	* 1.09	1.61	* 1.09	207.97	1.33	* 1.09	* 1.09
BC10	Yerba Buena Is.	10/6/93	Mussel	* 1.12	* 1.12	* 1.12	20.89	1.80	* 1.12	* 1.12
BC21	Horseshoe Bay	10/6/93	Mussel	* 0.78	* 0.78	* 0.78	12.58	1.59	* 0.78	* 0.78
BD20	Petaluma River	10/6/93	Oyster	* 1.86	* 1.86	* 1.86	2.28	* 1.86	* 1.86	* 1.86
BD20	Petaluma River	10/6/93	Mussel	* 1.66	* 1.66	* 1.66	3.78	* 1.66	* 1.66	* 1.66
BD30	Pinole Point	10/6/93	Mussel	* 1.90	* 1.90	* 1.90	26.48	* 1.90	* 1.90	* 1.90
BD40	Davis Point	10/7/93	Oyster	* 1.39	* 1.39	* 1.39	5.15	1.65	* 1.39	* 1.39
BD40	Davis Point	10/7/93	Mussel	* 1.51	* 1.51	* 1.51	124.57	* 1.51	* 1.51	* 1.51
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	151.70	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	* 1.17	* 1.17	* 1.17	1.97	1.84	* 1.17	* 1.17
BF20	Grizzly Bay	10/7/93	Clam	* 1.85	5.37	* 1.85	6.92	7.93	* 1.85	* 1.85
BG20	Sacramento River	10/7/93	Clam	* 1.96	6.52	* 1.96	4.55	7.72	* 1.96	* 1.96
BG30	San Joaquin River	10/7/93	Clam	* 1.75	5.33	* 1.75	5.65	8.89	* 1.75	* 1.75
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	* 1.37	17.14	* 1.37	1.39	2.67
TIME=0 TB	Tomaes Bay	6/28/93	Oyster	* 1.27	* 1.27	* 1.27	2.14	* 1.27	* 1.27	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	* 1.12	* 1.12	8.25	2.95	* 1.12	* 1.12

Station Code	Station Name	Collection Date	Species	47/48(CL4)	49(CL4)	50(CL4)	52(CL4)	60/56(CL5)	66(CL4)	70(CL4)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50
BA40	Redwood Creek	10/6/93	Mussel	3.13	1.46	* 1.09	3.00	2.09	1.98	2.47
BC10	Yerba Buena Is.	10/6/93	Mussel	1.24	2.15	4.55	3.33	1.19	* 1.12	1.75
BC21	Horseshoe Bay	10/6/93	Mussel	1.26	1.79	2.04	2.76	0.81	1.06	1.83
BD20	Petaluma River	10/6/93	Oyster	* 1.86	* 1.86	* 1.86	* 1.86	2.17	* 1.86	* 1.86
BD20	Petaluma River	10/6/93	Mussel	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66
BD30	Pinole Point	10/6/93	Mussel	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90
BD40	Davis Point	10/7/93	Oyster	* 1.39	1.77	2.24	2.62	1.69	* 1.39	1.47
BD40	Davis Point	10/7/93	Mussel	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	1.48	1.89	3.30	3.05	1.71	* 1.17	1.61
BF20	Grizzly Bay	10/7/93	Clam	2.25	3.48	12.27	9.21	* 1.85	* 1.85	2.68
BG20	Sacramento River	10/7/93	Clam	* 1.96	2.75	* 1.96	7.41	* 1.96	* 1.96	* 1.96
BG30	San Joaquin River	10/7/93	Clam	3.16	7.29	15.53	11.81	2.95	* 1.75	2.78
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37
TIME=0 TB	Tomaes Bay	6/28/93	Oyster	* 1.27	* 1.27	* 1.27	* 1.27	* 1.39	* 1.27	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	* 1.12	* 1.12	1.91	* 1.12	* 1.12	* 1.12

**Table 19. (Page 3 of 6), PCB congeners and total PCB's in bivalve tissue from September, 1993. Units µg/kg, dry weight (ppb).**  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	74(CL4)	82(CL5)	83(CL5)	84?(CL5)	85(CL5)	87(CL5)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50
BA40	Redwood Creek	10/6/93	Mussel	1.86	1.32	1.10	* 1.09	* 1.09	2.73
BC10	Yerba Buena Is.	10/6/93	Mussel	1.25	* 1.12	1.93	2.43	* 1.12	3.10
BC21	Horseshoe Bay	10/6/93	Mussel	1.32	1.26	1.73	2.54	* 0.78	2.33
BD20	Petaluma River	10/6/93	Oyster	* 1.86	* 1.86	* 1.86	2.38	* 1.86	* 1.86
BD20	Petaluma River	10/6/93	Mussel	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66
BD30	Pinole Point	10/6/93	Mussel	* 1.90	* 1.90	* 1.90	2.47	* 1.90	* 1.90
BD40	Davis Point	10/7/93	Oyster	* 1.39	* 1.39	1.52	3.57	* 1.39	1.90
BD40	Davis Point	10/7/93	Mussel	* 1.51	* 1.51	* 1.51	1.60	* 1.51	* 1.51
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	* 1.17	* 1.17	1.47	4.44	* 1.17	2.41
BF20	Grizzly Bay	10/7/93	Clam	* 1.85	1.85	* 1.85	7.09	* 1.85	2.04
BG20	Sacramento River	10/7/93	Clam	* 1.96	* 1.96	* 1.96	5.27	* 1.96	1.96
BG30	San Joaquin River	10/7/93	Clam	* 1.75	2.00	* 1.75	6.79	2.10	1.99
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	* 1.37	5.48	* 1.37	* 1.37
TIME=0 TB	Tomales Bay	6/28/93	Oyster	* 1.27	* 1.27	* 1.27	8.37	* 1.27	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	1.18	* 1.12	4.85	* 1.12	* 1.12

Station Code	Station Name	Collection Date	Species	88(CL5)	92?(CL5)	97(CL5)	99(CL5)	100(CL5)	101(CL5)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	* 2.50	* 2.50	5.35	* 2.50	5.90
BA40	Redwood Creek	10/6/93	Mussel	2.15	4.20	3.28	9.54	* 1.09	10.80
BC10	Yerba Buena Is.	10/6/93	Mussel	2.33	2.26	3.03	7.14	* 1.12	13.06
BC21	Horseshoe Bay	10/6/93	Mussel	1.97	1.28	2.54	5.45	* 0.78	8.42
BD20	Petaluma River	10/6/93	Oyster	2.01	* 1.86	2.84	5.22	* 1.86	7.94
BD20	Petaluma River	10/6/93	Mussel	* 1.66	* 1.66	2.23	1.82	* 1.66	4.22
BD30	Pinole Point	10/6/93	Mussel	* 1.90	* 1.90	* 1.90	2.68	* 1.90	4.37
BD40	Davis Point	10/7/93	Oyster	2.58	1.64	3.13	7.67	* 1.39	11.28
BD40	Davis Point	10/7/93	Mussel	* 1.51	* 1.51	* 1.51	2.17	* 1.51	2.96
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	3.10	2.35	3.61	9.43	* 1.17	13.81
BF20	Grizzly Bay	10/7/93	Clam	4.70	3.90	7.53	9.20	* 1.85	9.36
BG20	Sacramento River	10/7/93	Clam	2.29	2.25	5.91	7.20	* 1.96	4.77
BG30	San Joaquin River	10/7/93	Clam	2.99	2.73	7.06	7.72	* 1.75	6.11
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37
TIME=0 TB	Tomales Bay	6/28/93	Oyster	1.69	* 1.27	* 1.27	* 1.27	* 1.27	6.03
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	* 1.12	2.23	* 1.12	* 1.12	3.52

**Table 19. (Page 4 of 6). PCB congeners and total PCB's in bivalve tissue from September, 1993.** Units µg/kg, dry weight (ppb).  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	105(CL5)	107/108/144 (CL5/5/6)	110/77 (CL5/4)	118/108/149 (CL5/5/6)	126(CL5)	128(CL6)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	* 2.50	* 2.50	4.05	* 2.50	* 2.50
BA40	Redwood Creek	10/6/93	Mussel	2.69	4.63	* 1.09	12.95	* 1.09	3.16
BC10	Yerba Buena Is.	10/6/93	Mussel	1.93	3.55	9.61	7.46	* 1.12	2.34
BC21	Horseshoe Bay	10/6/93	Mussel	1.89	2.31	* 0.78	5.22	* 0.78	1.72
BD20	Petaluma River	10/6/93	Oyster	* 1.86	3.90	* 1.86	5.65	* 1.86	* 1.86
BD20	Petaluma River	10/6/93	Mussel	1.89	* 1.66	4.19	2.27	* 1.66	* 1.66
BD30	Pinole Point	10/6/93	Mussel	* 1.90	* 1.90	* 1.90	2.45	* 1.90	* 1.90
BD40	Davis Point	10/7/93	Oyster	2.67	3.51	* 1.39	6.05	* 1.39	2.58
BD40	Davis Point	10/7/93	Mussel	* 1.51	* 1.51	* 1.51	2.34	* 1.51	* 1.51
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	3.91	4.53	* 1.17	10.36	* 1.17	2.44
BF20	Grizzly Bay	10/7/93	Clam	3.85	2.77	11.24	10.33	* 1.85	3.12
BG20	Sacramento River	10/7/93	Clam	* 1.96	2.35	* 1.96	8.15	* 1.96	2.25
BG30	San Joaquin River	10/7/93	Clam	* 1.75	2.36	* 1.75	9.33	* 1.75	2.63
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37
TIME=0 TB	Tomaes Bay	6/28/93	Oyster	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	* 1.12	* 1.12	2.86	* 1.12	* 1.12

Station Code	Station Name	Collection Date	Species	129(CL6)	136(CL6)	137(CL6)	138(CL6)	141(CL6)	146(CL6)	149(CL6)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	2.50	* 2.50	17.60	* 2.50	* 2.50	8.65
BA40	Redwood Creek	10/6/93	Mussel	* 1.09	2.14	* 1.09	30.29	1.17	7.39	17.82
BC10	Yerba Buena Is.	10/6/93	Mussel	* 1.12	2.37	* 1.12	24.35	2.73	4.99	17.63
BC21	Horseshoe Bay	10/6/93	Mussel	* 0.78	2.09	* 0.78	18.28	1.18	* 0.78	11.81
BD20	Petaluma River	10/6/93	Oyster	* 1.86	2.75	* 1.86	20.20	* 1.86	* 1.86	20.60
BD20	Petaluma River	10/6/93	Mussel	* 1.66	1.66	* 1.66	10.91	* 1.66	8.11	5.10
BD30	Pinole Point	10/6/93	Mussel	* 1.90	1.90	* 1.90	9.31	3.58	5.69	6.99
BD40	Davis Point	10/7/93	Oyster	* 1.39	2.68	* 1.39	21.26	* 1.39	10.08	21.98
BD40	Davis Point	10/7/93	Mussel	* 1.51	1.51	* 1.51	8.39	* 1.51	4.36	5.88
BD50	Napa River	10/6/93	Mussel	* 10.02	10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	* 1.17	2.15	* 1.17	28.64	3.81	* 1.17	27.96
BF20	Grizzly Bay	10/7/93	Clam	* 1.85	2.58	1.88	22.84	3.43	2.72	17.64
BG20	Sacramento River	10/7/93	Clam	* 1.96	2.52	* 1.96	16.54	* 1.96	* 1.96	10.91
BG30	San Joaquin River	10/7/93	Clam	* 1.75	3.79	* 1.75	19.07	4.28	4.78	12.88
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	1.37	* 1.37	* 1.37	* 1.37	5.99	* 1.37
TIME=0 TB	Tomaes Bay	6/28/93	Oyster	* 1.27	1.27	* 1.27	1.56	* 1.27	1.49	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	1.12	* 1.12	4.41	* 1.12	* 1.12	2.19

**Table 19. (Page 5 of 6), PCB congeners and total PCB's in bivalve tissue from September, 1993. Units µg/kg, dry weight (ppb).**  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	156/171/202									
				151(CL6)	153(CL6)	(CL6/7/8)	158(CL7)	167(CL6)	170(CL7)	172(CL7)			
BA30	Dumbarton Bridge	10/6/93	Mussel	3.22	22.49	* 2.50	* 2.50	* 2.50	3.67	* 2.50			
BA40	Redwood Creek	10/6/93	Mussel	7.10	45.98	4.92	1.87	1.36	2.61	* 1.09			
BC10	Yerba Buena Is.	10/6/93	Mussel	6.94	39.79	2.69	2.12	* 1.12	2.39	* 1.12			
BC21	Horseshoe Bay	10/6/93	Mussel	4.37	28.37	3.81	* 0.78	* 0.78	1.18	* 0.78			
BD20	Petaluma River	10/6/93	Oyster	7.29	43.43	* 1.86	* 1.86	* 1.86	3.60	* 1.86			
BD20	Petaluma River	10/6/93	Mussel	* 1.66	11.44	3.74	3.51	1.74	2.13	* 1.66			
BD30	Pinole Point	10/6/93	Mussel	2.42	13.36	7.10	* 1.90	2.59	3.98	* 1.90			
BD40	Davis Point	10/7/93	Oyster	7.90	44.13	5.30	3.29	* 1.39	1.57	* 1.39			
BD40	Davis Point	10/7/93	Mussel	1.75	13.21	2.42	* 1.51	* 1.51	2.58	* 1.51			
BD50	Napa River	10/6/93	Mussel	* 10.02	13.71	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02			
BD50	Napa River	10/6/93	Oyster	9.85	55.64	* 1.17	* 1.17	* 1.17	3.66	* 1.17			
BF20	Grizzly Bay	10/7/93	Clam	5.19	43.54	7.58	* 1.85	2.19	* 1.85	2.54			
BG20	Sacramento River	10/7/93	Clam	3.61	30.50	* 1.96	* 1.96	* 1.96	2.29	* 1.96			
BG30	San Joaquin River	10/7/93	Clam	3.75	39.04	6.43	* 1.75	2.58	* 1.75	2.11			
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	3.49	* 1.37	1.77	1.58	* 1.37			
TIME=0 TB	Tomales Bay	6/28/93	Oyster	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27	2.97	* 1.27			
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	8.68	* 1.12	* 1.12	* 1.12	1.80	* 1.12			
Station Code	Station Name	Collection Date	Species	174(CL7)	177(CL7)	178(CL7)	180(CL7)	183(CL7)	185(CL7)	187/182/159 (CL7/7/6)			
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	* 2.50	* 2.50	4.37	3.39	* 2.50	6.86			
BA40	Redwood Creek	10/6/93	Mussel	* 1.09	6.72	3.75	9.78	4.59	* 1.09	15.16			
BC10	Yerba Buena Is.	10/6/93	Mussel	* 1.12	3.97	2.20	11.50	5.89	* 1.12	11.83			
BC21	Horseshoe Bay	10/6/93	Mussel	* 0.78	* 0.78	* 0.78	7.20	1.23	* 0.78	8.61			
BD20	Petaluma River	10/6/93	Oyster	* 1.86	* 1.86	* 1.86	25.14	* 1.86	* 1.86	17.70			
BD20	Petaluma River	10/6/93	Mussel	* 1.66	5.19	2.96	9.76	7.20	* 1.66	2.87			
BD30	Pinole Point	10/6/93	Mussel	* 1.90	3.08	2.37	4.05	4.16	* 1.90	4.65			
BD40	Davis Point	10/7/93	Oyster	* 1.39	5.86	3.14	11.86	5.95	* 1.39	19.30			
BD40	Davis Point	10/7/93	Mussel	* 1.51	4.13	2.43	14.49	2.29	* 1.51	4.23			
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02			
BD50	Napa River	10/6/93	Oyster	* 1.17	* 1.17	* 1.17	23.04	* 1.17	* 1.17	24.31			
BF20	Grizzly Bay	10/7/93	Clam	* 1.85	2.93	* 1.85	17.72	4.31	* 1.85	10.14			
BG20	Sacramento River	10/7/93	Clam	* 1.96	* 1.96	* 1.96	17.77	* 1.96	* 1.96	6.57			
BG30	San Joaquin River	10/7/93	Clam	* 1.75	4.03	2.11	20.79	5.23	* 1.75	8.17			
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	4.72	3.29	* 1.37	4.11	* 1.37	* 1.37			
TIME=0 TB	Tomales Bay	6/28/93	Oyster	* 1.27	* 1.27	* 1.27	6.27	1.83	* 1.27	* 1.27			
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	* 1.12	* 1.12	2.32	* 1.12	* 1.12	* 1.12			

**Table 19. (Page 6 of 6). PCB congeners and total PCB's in bivalve tissue from September, 1993.** Units µg/kg, dry weight (ppb).  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	188(CL7)	189(CL7)	191(CL7)	194(CL8)	195(CL8)	196(CL8)	200(CL8)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50	* 2.50
BA40	Redwood Creek	10/6/93	Mussel	* 1.09	* 1.09	* 1.09	* 1.09	* 1.09	* 1.09	* 1.09
BC10	Yerba Buena Is.	10/6/93	Mussel	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12
BC21	Horseshoe Bay	10/6/93	Mussel	* 0.78	* 0.78	* 0.78	* 0.78	* 0.78	* 0.78	2.16
BD20	Petaluma River	10/6/93	Oyster	* 1.86	* 1.86	* 1.86	* 1.86	* 1.86	* 1.86	* 1.86
BD20	Petaluma River	10/6/93	Mussel	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66
BD30	Pinole Point	10/6/93	Mussel	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90
BD40	Davis Point	10/7/93	Oyster	* 1.39	* 1.39	* 1.39	* 1.39	* 1.39	* 1.39	* 1.39
BD40	Davis Point	10/7/93	Mussel	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	* 1.17	* 1.17	* 1.17	* 1.17	* 1.17	* 1.17	* 1.17
BF20	Grizzly Bay	10/7/93	Clam	* 1.85	* 1.85	* 1.85	* 1.85	* 1.85	* 1.85	5.42
BG20	Sacramento River	10/7/93	Clam	* 1.96	* 1.96	* 1.96	* 1.96	* 1.96	* 1.96	* 1.96
BG30	San Joaquin River	10/7/93	Clam	* 1.75	* 1.75	* 1.75	* 1.75	* 1.75	* 1.75	2.83
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37
TIME=0 TB	Tomales Bay	6/28/93	Oyster	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12

Station Code	Station Name	Collection Date	Species	201(CL8)	205(CL9)	206(CL9)	209(CL10)	UNK(CL6)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 2.50	9.20	* 2.50	* 2.50	* 2.50
BA40	Redwood Creek	10/6/93	Mussel	* 1.09	* 1.09	* 1.09	* 1.09	* 1.09
BC10	Yerba Buena Is.	10/6/93	Mussel	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12
BC21	Horseshoe Bay	10/6/93	Mussel	* 0.78	* 0.78	* 0.78	* 0.78	* 0.78
BD20	Petaluma River	10/6/93	Oyster	* 1.86	* 1.86	* 1.86	* 1.86	* 1.86
BD20	Petaluma River	10/6/93	Mussel	* 1.66	* 1.66	* 1.66	* 1.66	* 1.66
BD30	Pinole Point	10/6/93	Mussel	* 1.90	* 1.90	* 1.90	* 1.90	* 1.90
BD40	Davis Point	10/7/93	Oyster	* 1.39	* 1.39	* 1.39	* 1.39	1.69
BD40	Davis Point	10/7/93	Mussel	* 1.51	* 1.51	* 1.51	* 1.51	* 1.51
BD50	Napa River	10/6/93	Mussel	* 10.02	* 10.02	* 10.02	* 10.02	* 10.02
BD50	Napa River	10/6/93	Oyster	* 1.17	* 1.17	* 1.17	* 1.17	* 1.17
BF20	Grizzly Bay	10/7/93	Clam	* 1.85	* 1.85	* 1.85	* 1.85	* 1.85
BG20	Sacramento River	10/7/93	Clam	* 1.96	* 1.96	* 1.96	* 1.96	* 1.96
BG30	San Joaquin River	10/7/93	Clam	* 1.75	* 1.75	* 1.75	* 1.75	* 1.75
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 1.37	* 1.37	* 1.37	* 1.37	* 1.37
TIME=0 TB	Tomales Bay	6/28/93	Oyster	* 1.27	* 1.27	* 1.27	* 1.27	* 1.27
TIME=0 LI	Lake Isabella	6/28/93	Clam	* 1.12	* 1.12	* 1.12	* 1.12	* 1.12

**Table 20. (Page 1 of 2). Pesticides in bivalve tissue from September, 1993.** Units µg/kg, dry weight (ppb).  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	Total Pesticides	Alpha-BHC	HCB	Beta-BHC	Gamma-BHC	Delta-BHC	Hepta-chlor	Hepta-epoxide	Oxy-chlordane
BA30	Dumbarton Bridge	10/6/93	Mussel	54.55	2.32	* 1.25	* 1.25	* 1.25	* 1.25	* 1.25	* 1.25	* 1.25
BA40	Redwood Creek	10/6/93	Mussel	66.88	0.89	0.74	* 0.54	0.73	* 0.54	* 0.54	0.76	1.35
BC10	Yerba Buena Is.	10/6/93	Mussel	59.40	1.46	* 0.56	* 0.56	0.62	* 0.56	* 0.56	* 0.56	0.59
BC21	Horseshoe Bay	10/6/93	Mussel	54.22	1.83	* 0.39	0.49	0.82	* 0.39	* 0.39	0.54	0.67
BD20	Petaluma River	10/6/93	Oyster	72.88	1.54	* 0.93	* 0.93	* 0.93	* 0.93	* 0.93	* 0.93	* 0.93
BD20	Petaluma River	10/6/93	Mussel	50.32	0.89	* 0.83	* 0.83	* 0.83	* 0.83	* 0.83	* 0.83	* 0.83
BD30	Pinole Point	10/6/93	Mussel	57.48	2.06	* 0.95	* 0.95	* 0.95	* 0.95	* 0.95	* 0.95	* 0.95
BD40	Davis Point	10/7/93	Oyster	103.40	1.20	* 0.69	* 0.69	* 0.69	* 0.69	* 0.69	* 0.69	* 0.69
BD40	Davis Point	10/7/93	Mussel	61.39	1.17	* 0.76	* 0.76	* 0.76	* 0.76	* 0.76	* 0.76	* 0.76
BD50	Napa River	10/6/93	Mussel	160.16	5.93	* 5.01	* 5.01	* 5.01	11.40	* 5.01	* 5.01	* 5.01
BD50	Napa River	10/6/93	Oyster	98.70	0.90	* 0.58	* 0.58	1.01	* 0.58	* 0.58	* 0.58	0.65
BF20	Grizzly Bay	10/7/93	Clam	246.96	2.52	1.07	* 0.93	3.82	* 0.93	* 0.93	* 0.93	1.77
BG20	Sacramento River	10/7/93	Clam	221.55	1.50	2.19	* 0.98	3.63	* 0.98	* 0.98	* 0.98	1.28
BG30	San Joaquin River	10/7/93	Clam	215.95	1.34	4.23	* 0.88	3.52	* 0.88	* 0.88	* 0.88	1.24
TIME=0 BH	Bodega Head	6/25/93	Mussel	13.70	1.12	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68	* 0.68
TIME=0 TB	Tomales Bay	6/28/93	Oyster	40.53	1.26	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63	* 0.63
TIME=0 LI	Lake Isabella	6/28/93	Clam	86.99	1.76	0.59	* 0.56	* 0.56	2.41	* 0.56	* 0.56	1.16

Station Code	Station Name	Collection Date	Species	Gamma-chlordane	Alpha-chlordane	Trans-nonachlor	Cis-nonachlor	Aldrin	Di-eldrin	Endrin	Mirex
BA30	Dumbarton Bridge	10/6/93	Mussel	4.14	5.37	2.89	3.24	* 1.25	10.67	* 1.25	* 1.25
BA40	Redwood Creek	10/6/93	Mussel	5.34	4.99	3.49	4.84	* 0.54	9.09	* 0.54	* 0.54
BC10	Yerba Buena Is.	10/6/93	Mussel	3.57	3.42	2.19	1.90	* 0.56	6.89	0.62	* 0.56
BC21	Horseshoe Bay	10/6/93	Mussel	2.89	3.26	1.77	1.59	* 0.39	7.13	0.92	* 0.39
BD20	Petaluma River	10/6/93	Oyster	2.79	2.56	2.71	2.91	* 0.93	2.08	* 0.93	* 0.93
BD20	Petaluma River	10/6/93	Mussel	3.98	4.32	1.63	2.08	* 0.83	9.78	* 0.83	* 0.83
BD30	Pinole Point	10/6/93	Mussel	3.49	4.07	2.21	1.71	* 0.95	8.08	* 0.95	* 0.95
BD40	Davis Point	10/7/93	Oyster	4.54	4.08	4.78	3.61	* 0.69	2.51	* 0.69	* 0.69
BD40	Davis Point	10/7/93	Mussel	4.17	4.81	2.11	1.66	* 0.76	9.31	* 0.76	* 0.76
BD50	Napa River	10/6/93	Mussel	8.96	7.01	* 5.01	* 5.01	* 5.01	15.09	* 5.01	* 5.01
BD50	Napa River	10/6/93	Oyster	6.20	5.02	6.22	4.50	* 0.58	7.69	0.78	* 0.58
BF20	Grizzly Bay	10/7/93	Clam	10.05	9.13	10.02	6.07	4.02	7.46	1.15	* 0.93
BG20	Sacramento River	10/7/93	Clam	9.49	8.67	10.57	4.86	3.74	7.79	1.50	* 0.98
BG30	San Joaquin River	10/7/93	Clam	10.23	9.56	10.83	5.21	5.11	7.23	* 0.88	* 0.88
TIME=0 BH	Bodega Head	6/25/93	Mussel	1.10	2.11	* 0.68	* 0.68	* 0.68	3.71	* 0.68	* 0.68
TIME=0 TB	Tomales Bay	6/28/93	Oyster	7.60	5.13	4.49	2.67	* 0.63	* 0.63	* 0.63	* 0.63
TIME=0 LI	Lake Isabella	6/28/93	Clam	2.96	3.78	4.47	1.68	* 0.56	0.95	* 0.56	* 0.56

**Table 20. (Page 2 of 2). Pesticides in bivalve tissue from September, 1993.** Units µg/kg, dry weight (ppb).  
\* means value below method detection limit (MDL).

Station Code	Station Name	Collection Date	Species	2,4' (O,P'DDE)	4,4' (P,P'DDE)	2,4' (O,P'DDD)	4,4' (P,P'DDD)	2,4' (O,P'DDT)	4,4' (P,P'DDT)
BA30	Dumbarton Bridge	10/6/93	Mussel	* 1.25	13.45	* 1.25	7.05	* 1.25	* 1.25
BA40	Redwood Creek	10/6/93	Mussel	1.48	19.39	1.26	10.57	1.38	* 0.54
BC10	Yerba Buena Is.	10/6/93	Mussel	0.66	16.68	1.31	15.62	0.87	2.16
BC21	Horseshoe Bay	10/6/93	Mussel	* 0.39	15.75	1.40	13.36	0.80	1.09
BD20	Petaluma River	10/6/93	Oyster	* 0.93	32.87	1.80	21.31	* 0.93	* 0.93
BD20	Petaluma River	10/6/93	Mussel	* 0.83	12.69	* 0.83	10.11	* 0.83	* 0.83
BD30	Pinole Point	10/6/93	Mussel	1.16	19.11	1.20	10.86	* 0.95	* 0.95
BD40	Davis Point	10/7/93	Oyster	1.64	46.66	2.51	26.99	0.92	2.91
BD40	Davis Point	10/7/93	Mussel	* 0.76	18.60	0.91	12.42	2.21	2.49
BD50	Napa River	10/6/93	Mussel	* 5.01	22.36	* 5.01	16.32	* 5.01	* 5.01
BD50	Napa River	10/6/93	Oyster	2.07	77.94	2.97	38.46	1.40	3.17
BF20	Grizzly Bay	10/7/93	Clam	2.94	109.32	4.20	64.96	1.89	7.10
BG20	Sacramento River	10/7/93	Clam	* 0.98	108.98	3.23	42.76	2.09	10.78
BG30	San Joaquin River	10/7/93	Clam	* 0.88	105.22	3.43	41.58	2.22	8.90
TIME=0 BH	Bodega Head	6/25/93	Mussel	* 0.68	2.67	* 0.68	0.81	* 0.68	* 0.68
TIME=0 TB	Tomales Bay	6/28/93	Oyster	* 0.63	9.17	* 0.63	2.44	0.95	2.51
TIME=0 LI	Lake Isabella	6/28/93	Clam	3.28	53.52	* 0.56	6.57	1.28	2.09

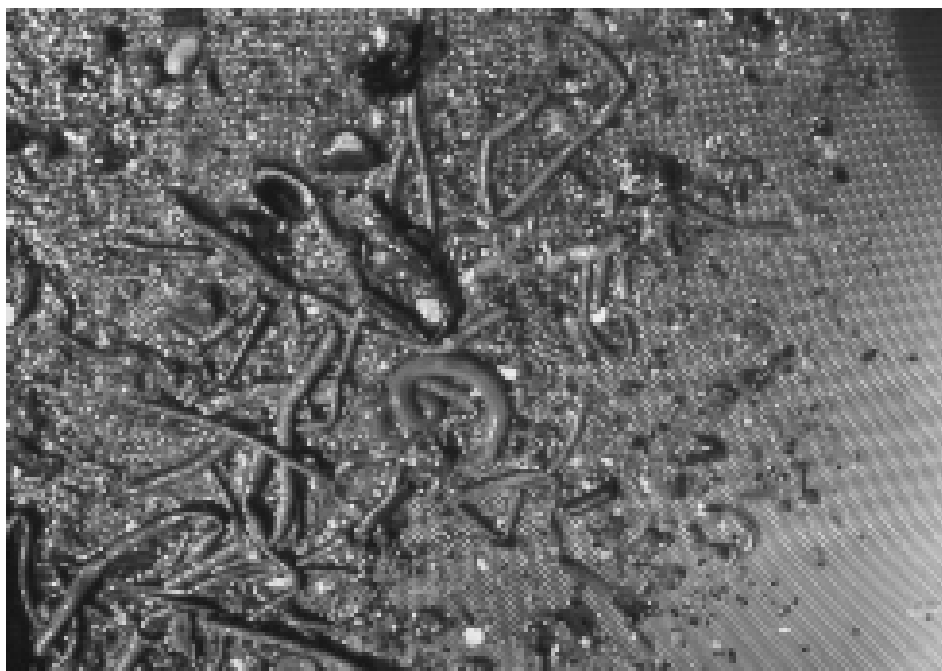
**Table 21. Bivalve condition and survival results.** SD = standard deviation. Station listings for species with zero survival are omitted.

Station Code	Cruise	Species	n	Dry Tissue Wt (g)		Condition (PII)		% survival
				Mean	SD	Mean	SD	
T=0	1	Mussel	20	0.811	.293	.172	.067	-
T=0	1	Clam	20	0.292	.104	.193	.089	-
T=0	1	Oyster	20	2.636	.733	.149	.044	-
BA30	1	Mussel	25	1.044	.374	.196	.055	88.2
BA40	1	Mussel	25	1.714	.466	.240	.092	96.3
BC10	1	Mussel	25	1.660	.508	.237	.097	94.4
BC21	1	Mussel	28	1.584	.429	.222	.112	97.5
BD20	1	Oyster	5	5.332	1.132	.161	.024	100
BD30	1	Mussel	18	0.623	.149	.147	.107	62.7
BD40	1	Oyster	20	3.707	.921	.152	.040	94.7
BD50	1	Oyster	5	2.022	.302	.125	.048	18.0
BF20	1	Clam	20	0.294	.079	.151	.060	96.2
BG20	1	Clam	20	0.261	.085	.090	.031	96.2
BG30	1	Clam	21	0.268	.072	.133	.038	85.1
T=0	3	Mussel	30	0.563	.122	.142	.051	-
T=0	3	Clam	38	0.470	.122	.169	.059	-
T=0	3	Oyster	30	2.011	.847	.225	.187	-
BA30	3	Oyster	4	0.498	.039	.059	.014	36.7
BA30	3	Mussel	24	0.325	.109	.087	.080	97.5
BA40	3	Mussel	29	0.318	.116	.084	.024	98.7
BC10	3	Mussel	30	0.817	.203	.176	.064	98.0
BC21	3	Mussel	16	1.440	.521	.188	.033	95.2
BD20	3	Mussel	27	0.343	.108	.097	.089	98.1
BD20	3	Oyster	19	1.041	.448	.087	.037	61.2
BD30	3	Mussel	27	0.386	.124	.079	.022	96.9
BD40	3	Mussel	26	0.264	.088	.085	.038	96.9
BD40	3	Oyster	10	1.240	.368	.102	.032	45.5
BD50	3	Mussel	6	0.170	.054	.059	.030	15.6
BD50	3	Oyster	11	0.903	.241	.074	.039	32.4
BF20	3	Clam	10	0.242	.098	.092	.023	83.7
BG20	3	Clam	14	0.206	.144	.077	.050	52.5
BG30	3	Clam	19	0.211	.056	.097	.033	68.7



## Appendix 3—Quality Assurance Information

1. QA/QC Summary for Laboratory Analyses of Water .....	207
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3. QA/QC Summary for Laboratory Analyses of Tissues .....	212
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5. Sediment Toxicity .....	214



*Benthic biota*

**Table 1. Page 1 of 3. Quality Assurance and Control Summary for Laboratory Analyses of Water (March 1993)**

Tables 1 - 3 are based on information requested from the various subcontractors. Quality control data for trace organics in water were not available at the time of printing, and those for sediment and tissue were incomplete.

Parameter	Method		Detection	Limit	Quantitation Limit	Precision (+/-%)		Accuracy (+1%) Spike Recovery		SRMs	Blank	Frequency
	Target		Measured			Target	Measured (RSD)	Target	%			
Ag total/dissolved <sup>1</sup>	1.16/0.25		0.31/0.04		1.03/0.13	15	7.2-10.2/2.3-7.9	25	NA	NA		1 per 3 samples
Cd total/dissolved <sup>1</sup>	0.38/0.34		0.15/0.15		0.50/0.50	15	10.5-32/2.8-12.5	25	NA	18/36 (2 per batch)		1 per 3 samples
Cr total/dissolved <sup>1</sup>	42/2.5		23/2.4		76.66/8.00	15	2-34/0.3-16	25	NA	9/15 (2 per batch)		1 per 3 samples
Cu total/dissolved <sup>2</sup>	0.007/0.006		0.006/0.001		0.02/0.003	15	0.9-2.8/0.5-2	25	NA	10/12 (2 per batch)		1 per 3 samples
Ni total/dissolved <sup>2</sup>	0.009/0.005		0.007/0.005		0.023/0.17	15	1.9-36/0.6-7.8	25	NA	8/5 (2 per batch)		1 per 3 samples
Pb total/dissolved <sup>2</sup>	0.003/2.79		0.003/0.460		0.01/1.53	15	1.5-34/0.7-9.2	25	NA	5/9 (2 per batch)		1 per 3 samples
Zn total dissolved <sup>2</sup>	0.005/0.0008		0.006/0.0007		0.02/0.002	15	1.9-38/1.2-3.8	25	NA	12/11 (2 per batch)		1 per 3 samples
As <sup>1</sup>	2		197		NA	25	3-11	25	NA	0-8 (6 per batch)		1 per 10 samples
Hg <sup>1</sup>	0.1		0.43		NA	20	2-8	25	1-6 (6-per batch)	0-4 (6 per batch)		1 per 10 samples
Se <sup>1</sup>	5		19.9		NA	35	8-20	35	NA	4-25(6 per batch)		1 per 7 samples
PAHs, Alkanes, other hydrocarbons <sup>3</sup>	50		NA		NA	20	NA	95%C.I.	NA	NA		1 per batch
PCBs, Biocides <sup>3</sup>	50		NA		NA	20	NA	95%C.I.	NA	NA		1 per batch

RSD = relative standard deviation  
 Batch Size = 16-20 samples  
 NA = not available

<sup>1</sup>units in ng/l

<sup>2</sup>units in µg/l

<sup>3</sup>units in pg/l

Table 1. Page 2 of 3. Quality Assurance and Control Summary for Laboratory Analyses of Water (May 1993)

Parameter	Method	Detection Limit	Quantitation Limit	Precision (+/-%)	Accuracy (+1%)	SRMs	Blank Frequency
	Target	Measured	Limit	Measured (RSD)	Target Spike Recovery		
Ag total/dissolved <sup>1</sup>	1.16/0.25	0.216/0.216	0.72/0.72	15 (2 per batch)	25 NA	NA	6-12 per batch
Cd total/dissolved <sup>1</sup>	0.38/0.34	0.112/0.045	0.37/0.15	15 (2 per batch)	25 NA	8/2 (2 per batch)	6-12 per batch
Cr total/dissolved <sup>1</sup>	42/25	NA/NA	NA/NA	15 NA	25 NA	NA	6-12 per batch
Cu total/dissolved <sup>2</sup>	0.007/0.006	0.007/0.001	0.02/0.003	15 (2 per batch)	25 NA	7/7 (2 per batch)	6-12 per batch
Ni total/dissolved <sup>2</sup>	0.009/0.005	0.005/0.001	0.017/0.003	15 (2 per batch)	25 NA	14/11 (2 per batch)	6-12 per batch
Pb total/dissolved <sup>2</sup>	0.003/2.79	0.003/0.001	0.001/0.003	15 (2 per batch)	25 NA	14/5 (2 per batch)	6-12 per batch
Zn total/dissolved <sup>2</sup>	0.005/0.0008	0.003/0.0007	0.010/0.002	15 (2 per batch)	25 NA	41/5 (2 per batch)	6-12 per batch
As <sup>1</sup>	2.0	91	NA	25 1-10	25 NA	1-5 (1 per 10 samples)	1 per 10 samples
Hg <sup>1</sup>	0.1	0.26	NA	20 1-8	25 1-23	NA	1 per 10 samples
Se <sup>1</sup>	5.0	31.4	NA	35 1-13	35 NA	1-15 (1 per 10 samples)	1 per 7 samples
PAHs, Alkanes, other hydrocarbons <sup>3</sup>	50	NA	NA	20 NA	95% C.I. NA	NA	1 per batch
PCBs, Biocides <sup>3</sup>	50	NA	NA	20 NA	95% C.I. NA	NA	1 per batch

RSD = relative standard deviation  
Batch Size = 16-20 samples

<sup>1</sup>units in ng/l  
<sup>2</sup>units in µg/l  
<sup>3</sup>units in pg/l

Table 1. Page 3 of 3. Quality Assurance and Control Summary for Laboratory Analyses of Water (September 1993)

Parameter	Method		Detection Limit	Precision (+/-%)		Accuracy (+/1%) Spike		SRMs	Blank	Frequency
	Target	Measured		Target	Measured (RSD)	Target	% Recovery			
Ag total/dissolved <sup>1</sup>	1.16/0.25	0.82/0.201	15	15	9.05/10.75 (2 per batch)	25	NA	NA	1	per sample
Cd total/dissolved <sup>1</sup>	0.38/0.34	0.18/0.03	15	15	1.70/1.8 (2 per batch)	25	NA	21/1 (2 per batch)	1	per sample
Cr total/dissolved <sup>1</sup>	42/25	45/3.5	15	15	0.4-18/1-20 (16 per batch)	25	NA	33/15 (2 per batch)	1	per sample
Cu total/dissolved <sup>2</sup>	0.007/5.8	0.006/0.29	15	15	1.4/3.6 (2 per batch)	25	NA	7/12 (2 per batch)	1	per sample
Ni total/dissolved <sup>2</sup>	0.009/5.4	0.002/2.13	15	15	9.65/3.7 (2 per batch)	25	NA	9/8 (2 per batch)	1	per sample
Pb total/dissolved <sup>2</sup>	0.003/2.79	0.003/0.90	15	15	3.5/4.15 (2 per batch)	25	NA	11/12 (2 per batch)	1	per sample
Zn total/dissolved <sup>2</sup>	0.005/0.82	0.004/1.9	15	15	2.05/3.9 (2 per batch)	25	NA	7/1 (2 per batch)	1	per sample
As <sup>1</sup>	2.0	62	25	25	4 (4 per batch)	25	NA	2-9 (4 per batch)	1	per 10 samples
Hg <sup>1</sup>	0.1	0.13	20	20	9 (5 per batch)	25	0-12 (2 per batch)	0-12 (4 per batch)	1	per 10 samples
Se <sup>1</sup>	5.0	4.1	35	35	10 (4 per batch)	35	NA	16-27 (5 per batch)	1	per 10 samples
PAH's, Alkanes, other Hydrocarbons <sup>3</sup>	NA	NA	20	20	NA	95% C.I.	NA	NA	1	per batch
PCB's, pesticides <sup>3</sup>	NA	NA	20	20	NA	95% C.I.	NA	NA	1	per batch

RSD = relative standard deviation

Batch Size = 16-20 samples

NA = not available

<sup>1</sup>units in ng/l<sup>2</sup>units in µg/l<sup>3</sup>units in pg/l

Table 2. Page 1 of 2. Quality Assurance and Control Summary for Laboratory Analyses of Sediment (Wet Season)

Parameter	Method Detection Limit		Precision (+/-%)		Accuracy (+/-%)		SRMs <sup>3</sup>	Blank Frequency
	Target	Measured	Target	Measured (RSD) <sup>3</sup>	Target	% Recovery		
Ag <sup>1</sup>	0.0012	0.0012	15	NA	25	NA	NA	>1 per batch
Al <sup>1</sup>	70	30	25	6.7	25	NA	97	>1 per batch
Cd <sup>1</sup>	2E-05	2.29E-05	15	NA	25	NA	NA	>1 per batch
Cr <sup>1</sup>	9.44	1	15	3.9	60	NA	66	>1 per batch
Cu <sup>1</sup>	4.57	0.6	15	14	25	NA	21.5	>1 per batch
Fe <sup>1</sup>	140	10	25	0.5	25	NA	70	>1 per batch
Mn <sup>1</sup>	27	1.5	25	9	25	NA	159	>1 per batch
Ni <sup>1</sup>	4.26	1.8	15	2	25	NA	20	>1 per batch
Pb <sup>1</sup>	0.1	0.05	15	3	25	NA	8	>1 per batch
Zn <sup>1</sup>	18.9	1.2	15	0.8	25	NA	24	>1 per batch
Ag <sup>1</sup>	1.6	0.02	25	3	25	NA	NA	1 per 10 samples
Hg <sup>1</sup>	0.005	0.0029	35	4	25	NA	5	1 per 10 samples
Se <sup>1</sup>	2.2	0.01	35	7	35	NA	NA	1 per 10 samples
PAHs, Alkanes								
Other Hydrocarbons <sup>2,4</sup>	5	NA	20	NA	20	11-43	NA	>1 per batch
PCBs/Biocides <sup>2,4</sup>	1/1	0.2/0.1	20	NA	20	0.8-10 (75% of samples)	NA	>1 per batch

RSD = relative standard deviation

Batch Size = 16 samples

NA = not available

<sup>1</sup> units in mg/kg<sup>2</sup> units in µg/kg<sup>3</sup> all QA samples >1 per batch<sup>4</sup> values are means or ranges for both wet and dry seasons

Table 2. Page 2 of 2. Quality Assurance and Control Summary for Laboratory Analyses of Sediment (Dry Season)

Parameter	Method	Detection Limit	Precision (+/-%)		Accuracy (+/-%)	SRMs <sup>3</sup>	Blank	Frequency
			Target	Measured		Target		
Ag <sup>1</sup>	0.0012	5.61E-05	15	5.6	25	NA	>1 per batch	
Al <sup>1</sup>	70	1452	25	5.9	25	89	>1 per batch	
Cd <sup>1</sup>	2E-05	1.28E-05	15	3.7	25	9	>1 per batch	
Cr <sup>1</sup>	9.44	27	15	12	60	35	>1 per batch	
Cu <sup>1</sup>	4.57	10.4	15	1.2	25	1	>1 per batch	
Fe <sup>1</sup>	140	3700	25	1.8	25	75	>1 per batch	
Mn <sup>1</sup>	27	8.8	25	4.5	25	37	>1 per batch	
Ni <sup>1</sup>	4.26	16.6	15	14.7	25	55	>1 per batch	
Pb <sup>1</sup>	0.1	0.001	15	6	25	9	>1 per batch	
Zn <sup>1</sup>	18.9	21	15	2.6	25	8	>1 per batch	
As <sup>1</sup>	1.6	0.05	25	1	25	6	1 per 10 samples	
Hg <sup>1</sup>	0.005	0.0001	35	5	25	4	1 per 10 samples	
Se <sup>1</sup>	2.2	0.15	35	6	35	5	1 per 10 samples	

RSD = relative standard deviation

Batch Size = 16 samples

NA = not available

<sup>1</sup>units in mg/kg

<sup>2</sup>units in µg/kg

<sup>3</sup>all QA samples >1 per batch

Table 3. Page 1 of 2. Quality Assurance and Control Summary for Laboratory Analyses of Tissue (Wet Season)

Parameter	Method	Detection Limit	Precision (+/-%)		Accuracy (+/-%)		SRMs <sup>3</sup>	Blank Frequency
	Target	Measured	Target	Measured (RSD) <sup>3</sup>	Target	% Recovery		
Ag <sup>1</sup>	0.0012	1.46E-05	35	8.1	35	NA	28	>1 per batch
Cd <sup>1</sup>	2E-05	5.01E-05	25	1.8	25	NA	5	>1 per batch
Cr <sup>1</sup>	9.44	0.7	25	0.9	25	NA	12	>1 per batch
Cu <sup>1</sup>	4.57	3.99	25	10.3	25	NA	16	>1 per batch
Ni <sup>1</sup>	4.26	0.6	25	3.5	25	NA	20	>1 per batch
Pb <sup>1</sup>	0.1	0.0008	25	22	25	NA	5	>1 per batch
Zn <sup>1</sup>	18.9	24.9	25	1.8	25	NA	6	>1 per batch
As <sup>1</sup>	1.6	0.21	25	2	25	NA	3	1 per 8 samples
Hg <sup>1</sup>	0.001	0.0001	35	9	35	NA	2	1 per 8 samples
Se <sup>1</sup>	2.2	0.05	35	4	35	NA	2	1 per 8 samples
PAHs, Alkanes, Other Hydrocarbons <sup>2,4</sup>	5	NA	20	NA	20	45-67/3-27	NA	>1 per batch
PCBs/Biocides <sup>2,4</sup>	1	0.2/0.1	20	NA	20	22-90	NA	>1 per batch

RSD = relative standard deviation

Batch Size = 14 samples

NA = not available

<sup>1</sup> units in mg/kg<sup>2</sup> units in µg/kg<sup>3</sup> all QA samples >1 per batch<sup>4</sup> values are means or ranges for both wet and dry seasons



Table 3. Page 2 of 2. Quality Assurance and Control Summary for Laboratory Analyses of Tissue (Dry Season)

Parameter	Method	Detection Limit	Precision (+/-%)		Accuracy (+/-%)		SRMs <sup>3</sup>	Blank	Frequency
			Target	Measured	Target	% Recovery			
Ag <sup>1</sup>	0.0012	0.00011	35	13	35	NA	30	>1	per batch
Cd <sup>1</sup>	2E-05	0.004	25	3	25	NA	16	>1	per batch
Cr <sup>1</sup>	9.44	1.2	25	11	25	NA	8	>1	per batch
Cu <sup>1</sup>	4.57	2.44	25	18	25	NA	49	>1	per batch
Ni <sup>1</sup>	4.26	0.9	25	6	25	NA	11	>1	per batch
Pb <sup>1</sup>	0.1	0.0012	25	3	25	NA	3	>1	per batch
Zn <sup>1</sup>	18.9	28	25	9	25	NA	16	>1	per batch
As <sup>1</sup>	1.6	0.064	25	5	25	NA	4	1	per 8 samples
Hg <sup>1</sup>	0.001	0.0001	35	1	35	NA	3	1	per 8 samples
Se <sup>1</sup>	2.2	0.01	35	3	35	NA	1	1	per 8 samples

RSD = relative standard deviation

Batch Size = 14 samples

<sup>1</sup> units in mg/kg<sup>2</sup> all sample concentrations higher than MDL<sup>3</sup> all QA samples >1 per batch

**Table 4. EC<sub>50</sub>s, EC<sub>25</sub>s, and coefficients of variation for copper reference toxicant tests conducted with three test species.** Results of reference toxicity tests with *M. edulis* (3/5/93) and *T. pseudonana* (5/27/93) were not included in the calculation of the control limits, because the EC<sub>25</sub> and EC<sub>50</sub> values were abnormally high, indicating lack of sensitivity in the test organisms.

Species	Endpoint	n	Mean	S.D.	CV
<i>M. edulis</i>	EC <sub>50</sub>	7	12.1	2.1	0.18
	EC <sub>25</sub>		10.2	2.0	0.19
<i>C. gigas</i>	EC <sub>50</sub>	3	23.7	7.4	0.31
	EC <sub>25</sub>		19.1	6.5	0.34
<i>T. pseudonana</i>	EC <sub>50</sub>	13	89.3	63.8	0.71
	EC <sub>25</sub>		31.3	17.9	0.57

**Table 5. Reference toxicant and QA information from the sediment toxicity tests.**

	EC or LC <sub>50</sub>			S%	QA notes
	$\bar{x}$	CI	CV		
<b>March</b>					
Mussel	>2.61 ppm	>.70	27%	26-28	Elevated DO (BD30, BD50, BF20)
Amphipods	733 ppb	82	11	14-16	Elevated pH (BC30)
<b>September</b>					
Oyster	670 ppb	±78.5	26-27		Elevated DO levels
Amphipods	5.13 ppm	±.63	12-17		Elevated DO levels

No sulfide measured in March.