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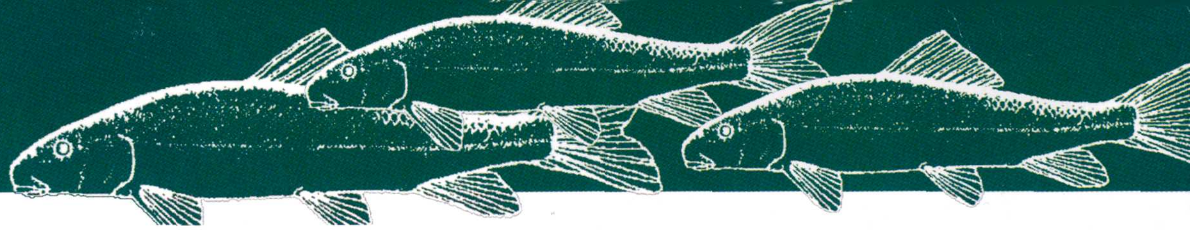

Trace Elements and Organic Compounds in Streambed Sediment and Aquatic Biota from the Sacramento River Basin, California, October and November 1995

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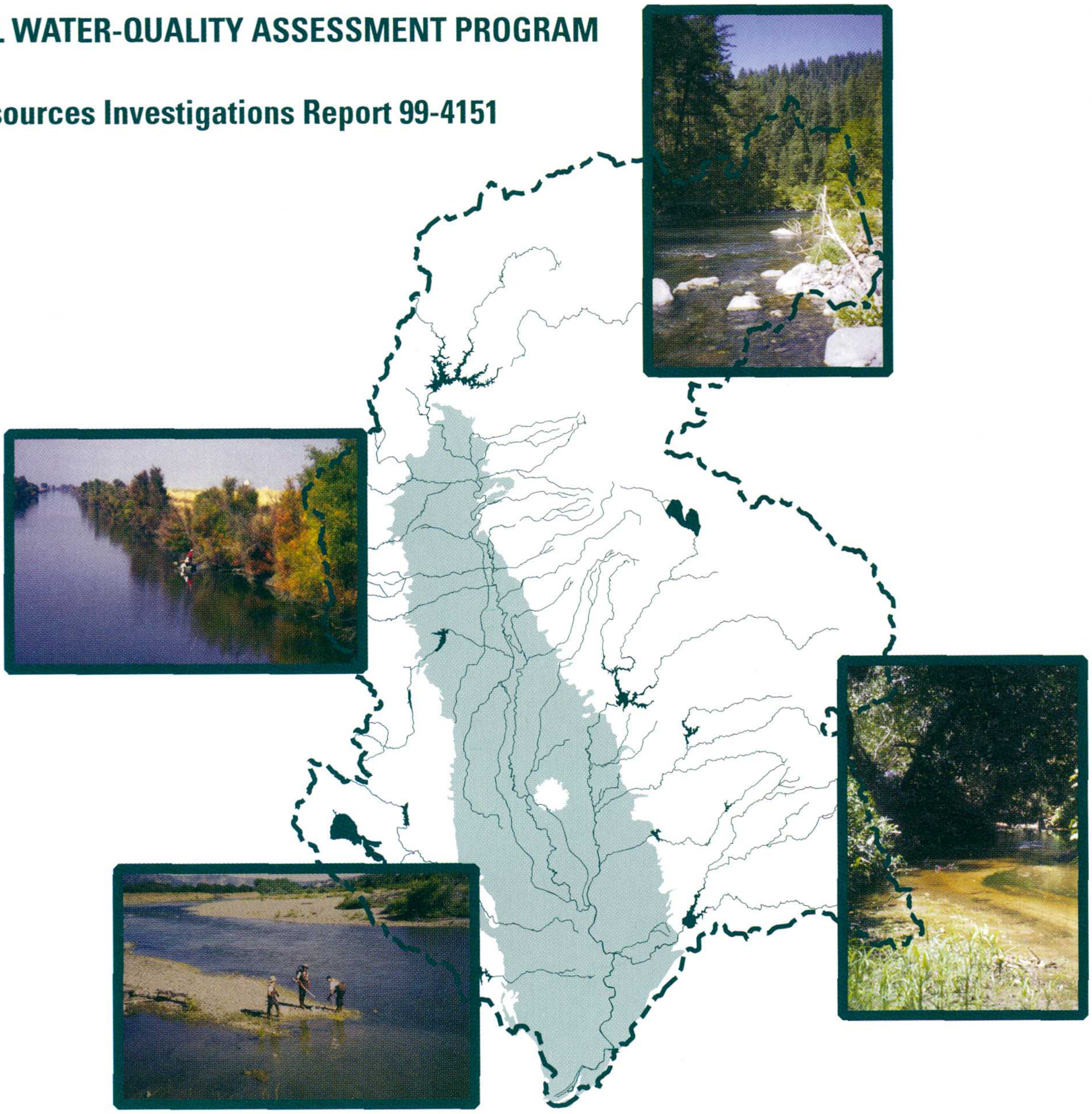
NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Water-Resources Investigations Report 99-4151



U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Trace Elements and Organic Compounds in Streambed Sediment and Aquatic Biota from the Sacramento River Basin, California, October and November 1995

By DORENE E. MACCOY *and* JOSEPH L. DOMAGALSKI

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Water-Resources Investigations Report 99-4151

Prepared in cooperation with the

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Sacramento, California
1999

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

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FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 60 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 60 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

Robert M. Hirsch

Robert M. Hirsch
Chief Hydrologist

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CONVERSION FACTORS, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
cubic meter (m^3)	0.0008107	acre-foot
gram (g)	0.03527	ounce, avoirdupois
liter (L)	1.057	quart
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile

Abbreviations

µg/g	micrograms per gram
µg/L	micrograms per liter
µg/kg	micrograms per kilogram
µm	micrometer

Acronyms

EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
NAS	National Academy of Science
NAWQA	National Water-Quality Assessment Program
NWQL	National Water-Quality Laboratory
PAH	polycyclic aromatic hydrocarbons
PCB	polychlorinated biphenyls
PEL	probable effect level (Canadian standard of measurement)
TEL	threshold effect level (Canadian standard of measurement)
USGS	U.S. Geological Survey

Trace Elements and Organic Compounds in Streambed Sediment and Aquatic Biota from the Sacramento River Basin, California, October and November 1995

By Dorene E. Maccoy *and* Joseph L. Domagalski

ABSTRACT

Elevated levels of trace elements and hydrophobic organic compounds were detected in streambed sediments and aquatic biota [Asiatic clam (*Corbicula fluminea*) or bottom-feeding fish] of the Sacramento River Basin, California, during October and November 1995. Trace elements detected included cadmium, copper, mercury, lead, and zinc. Elevated levels of cadmium, copper, and zinc in the upper Sacramento River are attributed to a mining land use, and elevated levels of zinc and lead in an urban stream, and possibly in the lower Sacramento River, are attributed to urban runoff processes. Elevated levels of mercury in streambed sediment are attributed to either past mercury mining or to the use of mercury in past gold mining operations. Mercury mining was an important land use within the Coast Ranges in the past and gold mining was an important land use of the Sierra Nevada in the past. Mercury was the only trace element found in elevated levels in the tissue of aquatic biota, and those levels also could be attributed to either mining or urban runoff. Hydrophobic organic compounds also were detected in streambed sediments and aquatic biota. The most frequently detected compounds were DDT and its breakdown products, dieldrin, oxychlordane, and toxaphene. Differences were found in the types of compounds detected at agricultural sites and the urban site. Although both types of sites had measurable concentrations of DDT or its breakdown products, the urban site also had measurable concentrations of pesticides used for household pest control. Few semivolatile compounds were detected in the streambed sediments of any site. The semivolatile compound *p*-cresol, a coal-tar derivative associated with road maintenance, was found in the highest concentration.

INTRODUCTION

The Sacramento River Basin (fig. 1) was chosen as 1 of 59 basins in the U.S. Geological Survey's (USGS) National Water-Quality Assessment Program (NAWQA). Hirsch and others (1988) provides a detailed description of the NAWQA Program. One phase of the program is the assessment of levels of trace elements and organic compounds in aquatic biota and recently deposited streambed sediment. Bottom sediments provide habitat for many benthic and epibenthic organisms and are an integral component of aquatic ecosystems. Sediments also have an influence on the environmental fate of many toxic and bioaccumulative substances in aquatic ecosystems. Therefore, the analysis of streambed sediments in the Sacramento River Basin was critical to identifying sources of contaminants that could affect the aquatic environment. Streambed sediments and biota integrate transported trace elements and hydrophobic organic contaminants with time in their natural state and, therefore, may more clearly show the distribution of these compounds in a river system than water samples alone. Seventeen sampling sites in the Sacramento River Basin were chosen for this study to represent the effects of various physiographic features and land uses on the distribution and concentration of trace elements and organic compounds in aquatic biota and streambed sediments.

Figure 1. Study area and sampling sites, Sacramento River Basin, California.

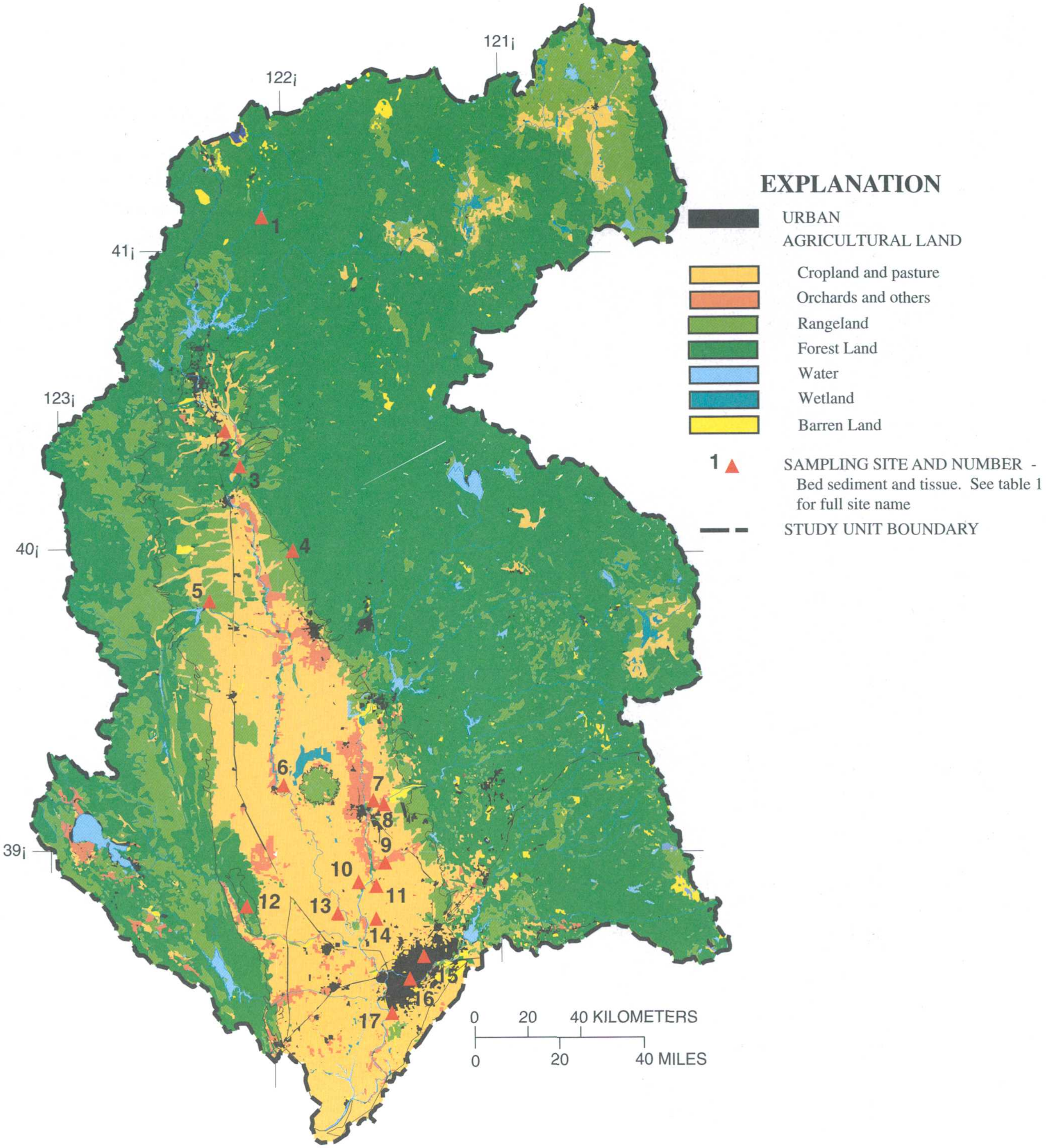

Figure 2. Study area and land use, Sacramento River Basin, California.

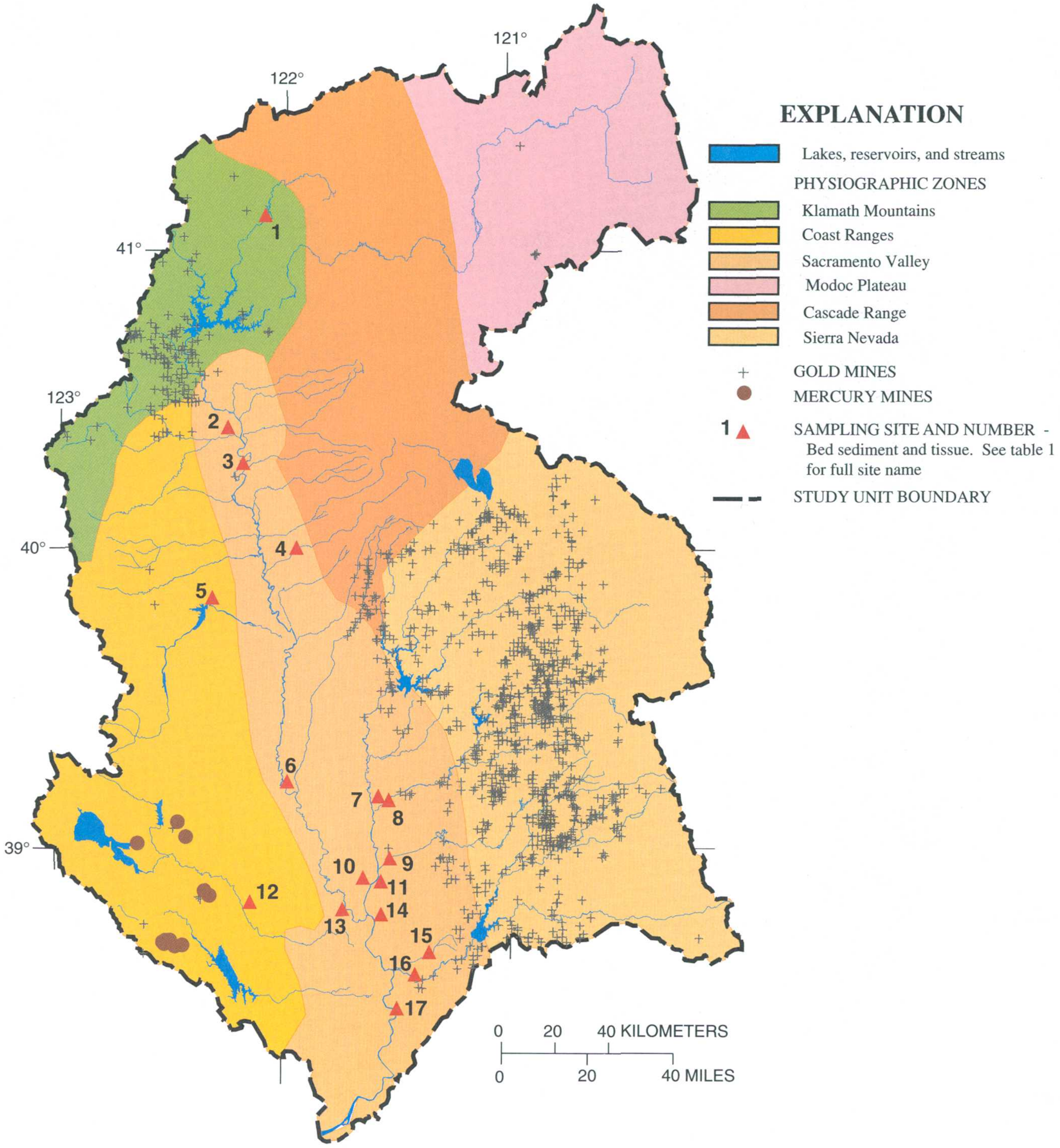

Figure 3. Study area sampling sites, gold and mercury mines, Sacramento River Basin, California.

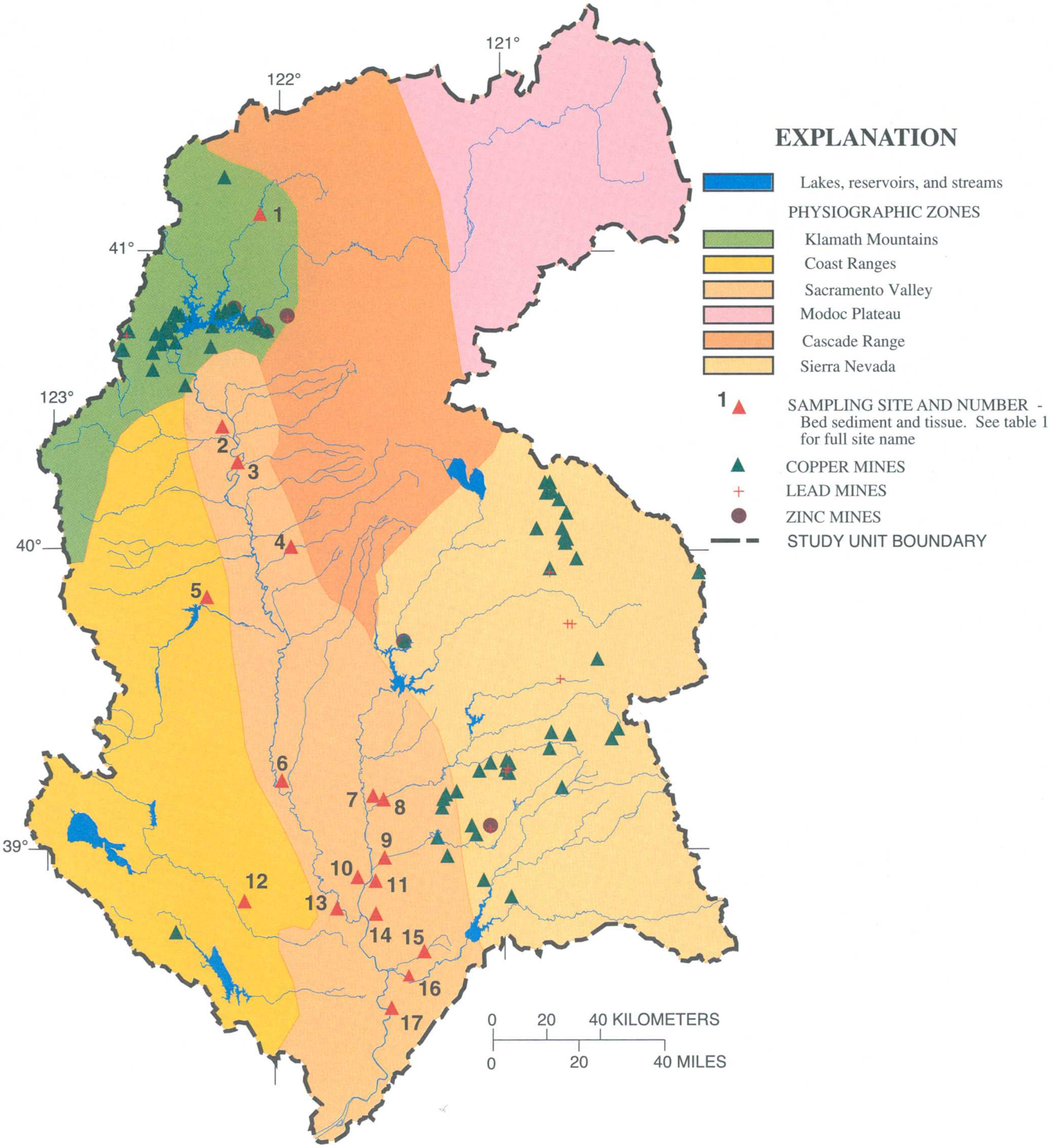

Figure 4. Study area sampling sites, copper, lead, and zinc mines, Sacramento River Basin, California.

Description of the Study Unit

The Sacramento River Basin covers nearly 69,930 square kilometers (km^2). The study unit includes all or part of six physiographic zones: the Klamath Mountains, the Sacramento Valley, the Sierra Nevada, the Coast Ranges, the Cascade Range, and the Modoc Plateau (Domagalski and others, 1998). Land cover within the Sierra Nevada and Cascade Range is principally forest. Forest and range land are mixed throughout the Coast Ranges and Modoc Plateau. The Sacramento River is the largest river in California with an average annual runoff of more than 27 billion cubic meters, which is approximately one-third of the total runoff in the State. The length of the river is 526 kilometers. The Sacramento River flows are controlled mainly by Shasta Dam and, to a lesser extent, by dams on the Feather, Yuba, and American Rivers. The Sacramento metropolitan area is home to more than 1 million people, which is nearly half of the total population in the study unit (Domagalski and others, 1998).

Land Use

The Sacramento River Basin has had a variety of land uses. The major land uses have been agriculture, urban development, and historical and current mining of mercury, gold, copper, lead, and zinc (figs. 2-4).

More than 8,094 km^2 of land are irrigated for agriculture. Major crops include rice, fruit, nuts, tomatoes, sugar beets, corn, alfalfa, and wheat (Domagalski and Brown, 1994). The Sacramento Valley is the primary agricultural zone in the study unit and is used for cropland, orchards, and pasture. The southern part of the Coast Ranges also has areas used for agriculture (fig. 2).

As of 1994, the total population in the basin was 2,208,900. The population increased by more than one-half million people between 1980 and 1990 (Domagalski and Brown, 1994). Urban land use is shown on figure 2.

Mining has been a major land use in the basin. Mercury was used in the process of gold extraction from ore and stream deposits in the mountains and foothills of California during the late 1800s to the early 1900s, and most of the mercury was not recovered (Bradley, 1918). Gold mines, as well as natural sources of mercury, are located throughout the Klamath Mountains in the upper basin (Albers, 1966). Mercury was mined in the Coast Ranges, west of the Sacramento River and in the northern Sacramento River Basin, and was used to process gold in the Sierra Nevada, east of the Sacramento River (fig. 3). Copper, lead, and zinc mines are located throughout the Klamath Mountains and the Sierra Nevada. A few copper mines are in the eastern part of the Sacramento Valley and one mine is in the southern part of the Coast Ranges (fig. 4).

Purpose and Scope

The purpose of this report is to present concentrations and possible sources of elevated levels of trace elements and synthetic organic compounds measured in aquatic biota and streambed sediment at 17 sampling sites in the Sacramento River Basin during October and November 1995. The dominant land uses (agriculture, urban development, and historical and current mining) were examined for their influence on the elevated concentration of trace elements and organic compounds or concentrations that exceeded published criteria set by the U.S. Environmental Protection Agency (EPA), the U.S. Food and Drug Administration (FDA), the National Academy of Sciences (NAS), and the Canadian Council of Ministers of the Environment.

SELECTION OF SAMPLING SITES

Sampling sites were selected to represent a wide range of environmental conditions throughout the basin for the purpose of determining spatial distribution of trace elements and organic compounds in accordance with NAWQA guidelines (Gilliom and others, 1995). Several sites were chosen as possible mercury indicators. The sampling sites and the types of biota collected are given in table 1. Two reference (minimally impacted) sites were chosen; one from the northern basin (site 1) and the other a Cascade Range tributary (site 4). Streambed sediment was collected at all sites, and biota was collected at all sites except the Sacramento River above Bend Bridge near Red Bluff (site 3) because of the swift and erratic currents that caused dangerous sampling conditions during the study. Most of the sites were in the Sacramento Valley physiographic zone, but the streambed sediments and the contaminants detected in streambed sediment and biota may be from upstream sources. Many of the sites used to indicate possible trace element contaminants

Table 1. Streambed sediment and aquatic biota sampling sites and characteristics, Sacramento River Basin, California

[USGS, U.S. Geological Survey; Indicator, sampling sites located at outlets of drainage basins with homogeneous land use; Integrator, downstream of large, complex drainage basins that often have multiple land uses; *Cottus gulosus*, riffle sculpin; *Catostomus occidentalis*, Sacramento sucker; *Corbicula fluminea*, asiatic clam; *Cyprinus carpio*, common carp]

Site No.	USGS site name	Abbreviated site name	USGS station No.	Type of sampling site	Site group	Biota tissue types
1	McCloud River below Ladybug Creek, near McCloud	McCloud River	11367808	Indicator	Reference	*Cottus gulosus*
2	Cottonwood Creek near Cottonwood	Cottonwood Creek	11376000	Indicator	Below Coast Ranges	*Catostomus occidentalis*
3	Sacramento River above Bend Bridge, near Red Bluff	Bend Bridge	11377100	Integrator	Sacramento River	none
4	Deer Creek near Vina	Deer Creek	11383500	Indicator	Reference	*Cottus gulosus*
5	Stoney Creek below Black Butte Dam, near Orland	Stoney Creek	11388000	Indicator	Below Coast Ranges	*Catostomus occidentalis*
6	Sacramento River at Colusa	Colusa	11389500	Integrator	Sacramento River	*Corbicula fluminea*
7	Jack Slough at Highway 70, near Marysville	Jack Slough	391006121352001	Indicator	Sacramento Valley	*Corbicula fluminea*
8	Yuba River near Marysville	Yuba River	11421000	Integrator	Below Sierra Nevada	*Corbicula fluminea*, *Cottus gulosus*
9	Bear River at Highway 70, near Rio Oso	Bear River	38582121323201	Indicator	Below Sierra Nevada	*Catostomus occidentalis*
10	East Canal at Kirkville Road, near Nicolaus	East Canal	385433121381601	Indicator	Sacramento Valley	*Cyprinus carpio*
11	Feather River near Nicolaus	Feather River	11425000	Integrator	Below Sierra Nevada	*Corbicula fluminea*
12	Cache Creek at Guinda	Cache Creek	384942122105601	Indicator	Below Coast Ranges	*Catostomus occidentalis* (fillet and liver for trace elements), *Corbicula fluminea*
13	Colusa Basin Drain at Road 99E, near Knights Landing	Colusa Basin Drain	11390890	Indicator	Sacramento Valley	*Cyprinus carpio*
14	Sacramento River at Verona	Verona	11425500	Integrator	Sacramento River	*Corbicula fluminea*
15	Arcade Creek near Del Paso Heights	Arcade Creek	11447360	Indicator	Urban	*Corbicula fluminea*
16	American River at Sacramento	American River	11447000	Integrator	Below Sierra Nevada	*Catostomus occidentalis* (fillet and liver for trace elements), *Corbicula fluminea*
17	Sacramento River at Freeport	Freeport	11447650	Integrator	Sacramento River	*Corbicula fluminea*

are below reservoirs that can alter the concentration and transport of metals downstream from urban and mining sources.

The names of the sites are shown in table 1 followed by the abbreviated name and site numbers in parentheses. Hereafter, the sites will be referred to by their abbreviated name and site number. The McCloud River below Ladybug Creek, near McCloud (McCloud River, site 1) was the only site in the Klamath Mountain physiographic zone. This site had no known significant anthropogenic inputs of trace elements or organic compounds and was used as a reference site. Cottonwood Creek near Cottonwood (Cottonwood Creek, site 2); Stoney Creek below Black Butte Dam, near Orland (Stoney Creek, site 5); and Cache Creek at Guinda (Cache Creek, site 12) are on the west side of the Sacramento physiographic zone and downstream from the Coast Ranges physiographic zone. The Coast Ranges may be a source of mercury from abandoned or inactive mercury mines. Deer Creek near Vina (Deer Creek, site 4) represents runoff from the Cascade Mountain physiographic zone and was chosen as a reference site because anthropogenic activity was minimal within its drainage area. Yuba River near Marysville (Yuba River, site 8); Feather River near Nicolaus (Feather River, site 11); Bear River at Highway 70, near Rio Oso (Bear River, site 9); and American River at Sacramento (American River, site 16) also are within the Sacramento Valley physiographic zone, downstream from the Sierra Nevada physiographic zone, and could be affected by mercury from historical gold mining. The sites in the Sacramento Valley physiographic zone that receive mostly agricultural runoff are Colusa Basin Drain at Road 99E, near Knights Landing (Colusa Basin Drain, site 13); East Canal at Kirkville Road, near Nicolaus (East Canal, site 10); and Jack Slough at Highway 70, near Marysville (Jack Slough, site 7). Arcade Creek near Del Paso Heights (Arcade Creek, site 15) is in the Sacramento Valley physiographic zone and receives runoff from the Sacramento metropolitan area. Four sites on the main stem Sacramento River are within the Sacramento Valley physiographic zone and are downstream from multiple physiographic zones and land uses such as mining, agriculture, and urban areas—Sacramento River above Bend Bridge, near Red Bluff (Bend Bridge, site 3); Sacramento River at Colusa (Colusa, site 6); Sacramento River at Verona (Verona, site 14); and Sacramento River at Freeport (Freeport, site 17).

METHODS OF STREAMBED SEDIMENT COLLECTION AND DATA ANALYSIS

Sample Collection

Detailed protocols used in sampling streambed sediments for organic compounds and trace elements for the NAWQA Program are described in Shelton and Capel (1994). The laboratory procedures used by the USGS National Water-Quality Laboratory (NWQL) to analyze organic compounds in streambed sediment are described in Forman and others (1995). The procedures used to analyze streambed sediment for semivolatile organic compounds are described in Furlong and others (1996). Laboratory procedures used by the NWQL to analyze trace elements in streambed sediments are described by Arbogast (1990) and Fishman (1993).

Fine streambed sediment was collected at all 17 sites. The sampling techniques used to collect streambed sediment were designed to minimize contamination of samples. Teflon spoons were used to carefully scoop a total of approximately 1.5 liters (L) of fine sediment from 5 to 10 depositional areas (such as stream banks and eddies, shallow pools and behind boulders) within a 0.1-km reach at each site. Separate sampling equipment was used for organic and trace element samples. To avoid contaminating the samples, vinyl gloves were used and the collection container was covered while the composite was collected. Replicate samples were collected for trace elements in streambed sediment for sample-collection quality assurance. Samples for trace elements were wet sieved through a 63-micrometer (µm) nylon mesh into plastic jars and samples for organic compounds were sieved through a 2-millimeter (mm) stainless steel sieve into glass jars. The samples were packed in ice and shipped to the NWQL.

Data Analysis

Certain references and guidelines were used to compare the concentrations of metals detected in streambed sediments in the Sacramento River Basin. There are no comprehensive guidelines for evaluating sediment quality in California, therefore, average crustal abundance and Canadian interim guidelines were used in the analysis for this report.

Canadian guidelines are a compilation of data gathered throughout North America to help assess Canada's sediment-quality standards. Guidelines refer to numerical limits set with the intention to protect all forms of aquatic life and all aspects of aquatic life cycles during an indefinite period of exposure to substances associated with bed sediments (Canadian Council of Ministers of the Environment, 1995b). The interim guidelines are based on the available scientific information on the biological effects of sediment-associated chemicals. Field data of sediment concentrations of contaminants and the co-occurrence of certain benthic species were used in developing interim guidelines. A detailed description of the methods used to develop these guidelines are described in Canadian Council of Ministers of the Environment (1995a). The interim guidelines define two levels of effect—the threshold effect level (TEL), the concentration below which adverse effects are expected to occur only rarely; and the probable effect level (PEL), the concentration above which adverse effects are predicted to occur frequently (Canadian Council of Ministers of the Environment, 1995a). Concentrations that fall between the TEL and PEL values are considered to be associated occasionally with adverse biological effects. These guidelines were developed for evaluating the quality of aquatic sediments in Canada. Accordingly, application of these guidelines should be done with the understanding that sediment quality may vary considerably across broad geographic scales, and will likely be influenced by local conditions.

Ideally, baseline data on trace elements in aquatic sediment would reflect the concentrations expected from the natural weathering of material upstream. Unfortunately, baseline data for metals of the Sacramento River streambed sediments have not been established and would be difficult to derive because of the variety of physiographic zones and their natural degree of metal enrichment, relative to enrichment caused by human activities. In the absence of baseline data, average crustal abundance values were compared to the Sacramento River Basin samples. These values were derived from numerous samples of trace elements in rock and soil gathered throughout the world and compiled by Emsley (1996). Data above crustal abundance values do not necessarily mean there has been anthropogenic inputs. The areas sampled in the Sacramento River Basin may be naturally metal rich.

The geochemical and biological processes that control metal bioavailability from sediments are not fully understood. Bioaccumulation of metals by plants and animals may vary considerably from one environmental setting to another, independent of concentrations in sediment or water (Luoma, 1989). Defining the processes that control the bioavailability and deleterious effects of trace elements on aquatic organisms in the Sacramento River Basin are beyond the scope of this report.

Pearson correlation coefficients were calculated to determine if the elevated levels of trace elements in bed sediment were related to elevated levels of organic carbon. The Pearson correlation coefficient gives a numeric value between two independent variables that varies between −1 and +1. A coefficient of 1 indicates a strong correlation and a coefficient of 0 indicates that neither of the two variables can be predicted from the other by using a linear model (Helsel and Hirsch, 1992). The correlation between total organic carbon and cadmium, copper, lead, mercury, and zinc, produced coefficients of −0.097, −0.125, 0.413, 0.113, and −0.087, respectively, which indicates no strong correlation between total organic carbon and the metals in the Sacramento River Basin streambed sediment. The comparatively high correlation coefficient for lead and organic carbon was due to the high values of organic carbon and lead at the urban stream site in Arcade Creek. Because of the lack of significant correlation, the streambed sediment data were not normalized to organic carbon for comparisons of trace elements. Further research is needed to conclude whether total organic carbon would be a controlling factor of the trace elements in Sacramento River Basin streambed sediments.

METHODS OF AQUATIC BIOTA SAMPLE COLLECTION AND DATA ANALYSIS

Sample Collection

One bivalve and three species of fish were collected for analysis of trace elements and organic compounds in tissue. Detailed protocols for collecting aquatic biota for trace elements and organic compounds for the NAWQA Program are described in Crawford and Luoma (1994).

Corbicula fluminea (*C. fluminea*), an introduced clam species, were collected using a hand-held clam rake for the smaller stream sites and a boat-towed clam rake for the larger river sites. Collection of *C. fluminea* was done within a 100-meter reach at each site. *C. fluminea* were rinsed, measured, placed in either precleaned stainless steel containers for organic analysis or polyethylene containers for trace metal analysis, and allowed to depurate for 24 hours prior to packaging on ice and shipping to the laboratory. All biological sampling equipment was cleaned between sites to prevent cross contamination.

Common carp [*Cyprinus carpio* (*C. carpio*)], Sacramento Sucker [*Catostomus occidentalis* (*C. occidentalis*)], or riffle sculpin [*Cottus gulosus* (*C. gulosus*)] were collected, depending on the species most abundant at each site, using backpack-mounted electro shockers on smaller streams and boat electro shockers on rivers. A fish sample for organic analysis consisted of 8–10 whole fish of the same species that were rinsed with deionized water, wrapped in foil, labeled, placed on ice, and shipped to the laboratory for analysis. For trace element analysis at each site, livers were extracted from another 8–10 fish of the same species, stored in plastic bags, labeled, placed on ice, and shipped. Because of the small size of the *C. gulosus* 8–10 whole fish were collected for trace element analysis, stored in plastic bags, labeled, placed on ice, and shipped. Samples of fillets, including the belly flap, were removed from the same *C. occidentalis* whose livers were sampled at the American River site (16) and the Cache Creek site (12), in accordance with pro- cedures of the U.S. Environmental Protection Agency (1995). The filleting was done on an aluminum foil covered board using stainless steel dissecting equipment. After the skin was removed from the fillet, it was weighed and placed in a plastic bag with a composite of 8–10 others from that site and stored on ice until shipped.

Procedures used by the NWQL to analyze organic compounds in biota are described in Leiker and others (1995). Analysis of trace elements in biota was done by; inductively coupled plasma-mass spectrometry, inductively coupled plasma-atomic emission spectroscopy, and cold vapor atomic absorption.

Data Analysis

FDA action levels and NAS guidelines were used to compare the concentrations of mercury and organochlorine compounds detected in biota.

The FDA has set regulatory limits for contaminant residue in edible fish or shellfish. These action levels are listed in the FDA compliance policy guide (U.S. Food and Drug Administration, 1984, 1989) and are based on specific quantities of food consumed by humans and the frequency of consumption. The action levels are established by FDA on the basis of the EPA recommendation and were derived from FDA monitoring data. Exceeding the action levels may result in a ban on commercial harvest of fish or shellfish. When developing the FDA action levels, economic risk, in addition to risk to human health, was considered, but no effects on aquatic organisms were considered (Nowell and Resek, 1994).

NAS has established guidelines for the protection of freshwater and saltwater aquatic life. Guidelines were established to protect organisms from accumulating high concentrations of potentially toxic compounds, either from direct exposure or consumption of contaminated prey (Rasmussen, 1993). The NAS guidelines are based on whole fish concentrations, and the reader should keep this in mind when comparing fish liver and fillet data to these guidelines (National Academy of Science-National Academy of Engineering, 1973).

In order to compare NAWQA fillet data to published criteria, the NAWQA tissue concentrations were adjusted to approximate wet weight values by multiplying the dry weight concentration by the percent dry weight of the sample. For example, the dry weight mercury concentration in *C. occidentalis* fillets from the American River is 4.6 micrograms per gram (μg/g) and the percentage of water in that sample is 75.7. Accordingly, the dry weight percentage is 24.3, and 4.6 μg/g is multiplied by 0.243 to give an estimated wet weight concentration of 1.1 μg/g.

STREAMBED SEDIMENT RESULTS AND DISCUSSION

Trace Elements

Twenty-four trace elements were analyzed in streambed sediment (table 2) at sites in the Sacramento River Basin (figs. 5–9), and eight of these elements were elevated or exceeded Canadian criteria for the protection of aquatic organisms. The elevated elements were arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Cadmium, copper, lead, mercury, and zinc are discussed because of their association with possible sources for particular land uses, or their natural enrichment in specific physiographic zones.

Cadmium, copper, lead, and zinc in the Sacramento River Basin

Cadmium concentrations in streambed sediments throughout the Sacramento River Basin exceeded average crustal abundance at most sites (fig. 5). Cadmium concentration was less than average crustal abundance at four sites: Verona (site 14), Cottonwood Creek (site 2), Stoney Creek (site 5), and Deer Creek (site 4). The cadmium concentration at the Bend Bridge site (site 3) was 1.6 µg/g, which is more than double the downstream Sacramento River cadmium concentrations at the sites of Colusa (site 13; 0.5 µg/g), Verona (site 14; 0.1 µg/g), and Freeport (site 17; 0.7 µg/g), as well as at the tributary sites (table 2). This value is between the Canadian TEL (0.596 µg/g) and PEL (3.53 µg/g) values, indicating that possible adverse effects could occur on aquatic organisms. The Bend Bridge site could receive inputs of cadmium from several land uses upstream, including urban areas, agriculture, and mining.

The source of cadmium in the upper Sacramento River sediments possibly is the result of historical and current mining from the West Shasta Mining District, but this needs further investigation. The West Shasta Mining District includes the massive sulfide deposits west of Keswick Reservoir and Shasta Lake in the northern part of the Sacramento River Basin (fig. 1). The mining district occupies an area about 9 mi long and 1 mi wide that trends north 25° east (Albers, 1966).

Cadmium concentrations in streambed sediment of the Sacramento River decreased in a downstream direction from the Bend Bridge (site 3) to the Verona (site 14) sites, but then increased at the Freeport site (site 17). The increase at Freeport may be attributable to sediment inputs from the American River (site 16) and Arcade Creek (site 15) sites and other urban streams. Cadmium has many uses, such as nickel-cadmium batteries, and its presence in urban runoff is to be expected. Since the Sacramento River at Freeport is downstream of a large city, the elevated streambed concentrations may be related to the urban land use. Cadmium also was found in elevated levels at the Cache Creek site. However, that site is not near any large population centers and the elevated levels in the streambed sediments of Cache Creek may be attributable to natural sources.

Cadmium in its natural state is a sulfide mineral associated with zinc sulfides, such as sphalerite, and sometimes is mined in association with zinc, lead, and copper-bearing ores. The availability of cadmium in sediment to aquatic organisms depends upon such factors as pH, redox potential, water hardness (presence of calcium and magnesium), presence of humic material, and other complexing agents, and the strength of the bond between the metal and the sediments (Jaagumagi, 1993). Cadmium is a relatively rare heavy metal and is not biologically essential (Eisler, 1985). Some of the toxic effects associated with cadmium on freshwater biota have been mortality, reduced growth, and inhibited reproduction (Eisler, 1985).

The copper concentrations in streambed sediments exceeded average crustal abundance values at all sites except Verona (14) and Deer Creek (4) (fig. 6). The copper concentration of 170 µg/g at the Bend Bridge site (3) was more than double the downstream concentrations (table 2) and approached the Canadian PEL value of 197 µg/g (fig. 6). The adverse effects of copper bioaccumulation in aquatic organisms are not well known (Jaagumagi, 1993). Copper is an essential micronutrient readily taken in by aquatic organisms and studies have shown that some organisms can limit accumulation of copper through increases in depuration rates (Luoma, 1983). The Bend Bridge site on the Sacramento River receives input from multiple sources upstream, as indicated previously in this report, but the high concentrations of copper may be attributed to runoff from mines within the West Shasta Mining District (fig. 1).

It was expected that copper concentrations in streambed sediments may be elevated at sites downstream of areas where rice is cultivated such as the Colusa Basin Drain (site 13), the East Canal (site 10) or Jack Slough (site 7). Copper is used in rice cultivation to control algae. However, there is no apparent accumulation of copper in the streambed sediments of those sites.

Lead and zinc were at elevated concentrations in the streambed sediments of the Arcade Creek (site 15), a small urban stream (table 2). The observed lead concentration of 84 µg/g exceeded average crustal abundance (14 µg/g), as well as the concentration of

Table 2. Trace elements and organic carbon in streambed sediments, Sacramento River Basin, California

[nd, not detected or less than detection limit; nd(4.5), reporting limit different from detection limit due to analytical procedure; values given in micrograms per gram unless specified as percent (%), reported in bottom material <63 micron fraction dry weight. Abbreviated site names and corresponding site number in bold. See table 1 for full site name]

Trace element or organic carbon	Detection limit[1]	Crustal abundance[2]	McCloud River **1**	Cottonwood Creek **2**	Bend Bridge **3**	Deer Creek **4**	Stoney Creek **5**	Colusa[3] **6**			Jack Slough **7**
Aluminum	0.005%	8.2	5.4	7.5	8.3	8.6	8.7	7.6	7.8	7.8	8.6
Antimony	.1	.2	.4	.8	1	.3	.8	.7	.7	.7	.7
Arsenic	.1	1.5	3.2	7.1	18	8.8	9.2	8.2	8.3	8.9	6.6
Barium	1	500	360	640	610	360	640	510	510	520	480
Beryllium	1	2.6	nd	1	1	1	2	1	1	1	1
Bismuth	10	.048	nd	nd	nd	nd	nd	nd	nd	nd	nd
Cadmium	.1	.11	.3	.1	1.6	.1	.1	.5	.5	.6	.3
Calcium	.005%	4.1	1.1	1.2	1.7	3.5	1	1.7	1.7	1.7	1.9
Cerium	4	68	20	33	39	23	36	28	30	30	43
Chromium	1	100	32	210	230	190	220	170	170	160	160
Cobalt	1	20	14	23	29	30	30	21	22	22	35
Copper	1	50	72	56	170	51	60	59	63	67	63
Europium	2	2.1	nd	nd	nd	nd	nd	nd	nd	nd	nd
Gallium	4	18	13	18	20	17	20	17	16	16	18
Gold	8	.0011	nd	nd	nd	nd	nd	nd	nd	nd	nd
Holmium	4	1.4	nd	nd	nd	nd	nd	nd	nd	nd	nd
Iron	.005%	4.1	3.5	4.8	6.3	5.7	6.2	4.4	4.6	4.7	5.2
Lanthanum	2	32	9	16	19	13	17	15	16	15	22
Lead	4	14	7	13	18	8	16	8	10	9	13
Lithium	2	20	20	50	40	30	60	40	40	40	20
Magnesium	.005%	2.3	.94	2.1	1.6	2.4	2.2	1.7	1.7	1.7	1
Manganese	4	950	1,800	790	790	940	1,300	690	720	730	2,300
Mercury	.02	.05	.03	.05	.16	nd	.07	.06	.07	.07	.04
Molybdenum	2	1.5	nd	nd	nd	nd	nd	nd	nd	nd	nd
Neodymium	4	38	11	18	21	13	22	17	18	18	22
Nickel	2	80	14	130	91	72	160	96	98	99	78
Niobium	4	20	6	11	17	12	13	9	11	10	13
Phosphorus	.005%	1,000	.17	.11	.08	.08	.11	.08	.09	.09	.08
Potassium	.05%	2.1	.7	1.5	1	.64	1.5	1	1	1	.83
Scendium	2	16	15	20	25	26	25	19	20	20	24
Selenium	.1	.05	1	.8	1	.2	.5	.4	.5	.5	.2
Silver	.1	.07	.1	.1	1.2	.1	.1	.2	.2	.2	.1
Sodium	.005%	2.3	1.3	1.3	1.3	1.4	1	1.8	1.8	1.8	1.2
Strontium	2	370	170	150	190	270	110	180	170	170	180
Sulfur	.06%	260	.17	.09	nd	.05	.06	nd	nd	nd	nd
Tantalum	40	2	nd	nd	nd	nd	nd	nd	nd	nd	nd
Thorium	4	12	nd(4.5)	7.6	6.7	nd(3)	4.9	5.6	4.8	4.6	8.8
Tin	10	2.2	nd	nd	nd	nd	nd	nd	nd	nd	nd
Titanium	.005%	5.6	.3	.39	.58	.52	.52	.41	.43	.42	.55
Uranium	.05	2.4	1.9	2.2	4.1	2.1	2.2	1.8	2	1.9	2.3
Vanadium	2	160	120	160	260	240	200	160	160	160	180
Yttrium	2	30	15	19	24	18	23	19	21	20	22
Ytterbium	1	3.3	1	2	3	2	2	2	2	2	2
Zinc	4	75	66	99	450	90	120	140	150	150	110
Organic carbon	.01%	1.43	3.72	2.48	1.43	2.73	.94	.73	.77	.79	1.28
Organic and inorganic carbon	.01%	1.44	3.73	2.49	1.44	2.74	.97	.73	.77	.8	1.29
Inorganic carbon	.01%	.01	.01	.01	.01	.01	.03	nd	nd	.01	.01

Table 2. Trace elements and organic carbon in streambed sediments, Sacramento River Basin, California—Continued

Trace element or organic carbon	Detection limit[1]	Yuba River 8	Bear River 9	East Canal 10	Feather River 11	Cache Creek 12	Colusa Basin Drain[3]			Verona 14	Arcade Creek 15	American River 16	Freeport 17
							13						
Aluminum	0.005%	8.1	8.3	8.6	8.1	8.4	8.6	8.3	8.6	7.1	8.5	8.1	8.2
Antimony	.1	1	1	.6	.9	1	.6	0.7	0.6	0.7	1	1	0.8
Arsenic	.1	15	16	12	12	13	10	10	10	8.5	8.1	11	9.9
Barium	1	430	460	580	470	550	650	630	650	560	730	640	530
Beryllium	1	1	1	2	1	1	2	2	2	1	2	2	1
Bismuth	10	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Cadmium	.1	.3	.6	.2	.2	.7	nd	nd	nd	0.1	0.7	0.3	0.7
Calcium	.005%	2.1	1.4	1.5	2.2	1.5	1	1	1	1.2	1.3	1.8	1.8
Cerium	4	31	38	35	43	37	3.5	34	35	33	54	55	39
Chromium	1	160	160	190	250	200	190	190	190	170	110	170	200
Cobalt	1	25	28	24	30	26	26	25	26	23	22	27	25
Copper	1	80	73	65	69	84	74	65	74	45	60	60	77
Europium	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Gallium	4	17	18	18	18	18	19	18	19	16	20	17	19
Gold	8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Holmium	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Iron	.005%	6.5	5.3	5.1	5.4	5.4	5.7	5.7	5.7	4.6	4.9	5.2	5.3
Lanthanum	2	16	19	19	23	19	17	17	17	17	30	31	20
Lead	4	22	30	17	18	17	13	8	13	13	84	41	22
Lithium	2	20	20	40	20	40	80	80	80	60	30	30	40
Magnesium	.005%	1.4	1.3	1.8	2	1.8	2.4	2.3	2.4	2	.92	1.5	1.9
Manganese	4	1,000	1,000	1,100	1,100	820	1,000	1,000	1,000	900	890	1,100	790
Mercury	.02	.37	.37	.08	.21	.15	.06	.06	.06	.24	.13	.16	.14
Molybdenum	2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Neodymium	4	17	20	20	22	21	19	19	19	17	27	28	21
Nickel	2	81	100	120	140	120	170	160	170	160	57	100	110
Niobium	4	9	11	11	13	12	11	11	11	12	11	14	11
Phosphorus	.005%	.1	.09	.07	.08	.09	.07	.07	.07	.1	.12	.1	.09
Potassium	.05%	.72	.91	1.1	.86	1.1	1.4	1.4	1.4	1.2	1.3	1.3	1.1
Scendium	2	25	23	22	25	24	23	23	23	19	17	20	23
Selenium	.1	.9	.6	.2	.4	.6	.4	.3	.4	.6	.5	.5	.4
Silver	.1	.2	.3	.1	.2	.3	.2	.2	.2	.1	2.2	.2	.2
Sodium	.005%	.98	1	1.3	1.1	1.3	1.2	1.1	1.2	1.2	.87	.98	1.4
Strontium	2	160	140	170	190	150	150	150	150	130	190	210	170
Sulfur	.06%	.09	.06	nd	nd	nd	nd	nd	nd	.11	.09	nd	nd
Tantalum	40	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Thorium	4	7.6	7.4	6.7	7.9	7.9	7.6	8	7.6	6.3	15	15	6.4
Tin	10	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Titanium	.005%	.51	.48	.46	.55	.49	.44	.42	.44	.39	.44	.49	.49
Uranium	.05	2.6	1.8	2.1	2.8	2.8	2.0	2.1	2	1.8	3.2	4.7	2.7
Vanadium	2	210	170	170	190	190	180	170	180	150	140	180	190
Yttrium	2	20	20	20	22	23	19	19	19	17	18	20	22
Ytterbium	1	2	2	2	2	2	2	2	2	2	2	2	2
Zinc	4	100	110	120	98	170	120	120	120	95	260	120	160
Organic carbon	.01%	3.1	1.48	.79	1.1	1.02	.73	.74	.73	2.31	3.61	2.3	.99
Organic and inorganic carbon	.01%	3.11	1.52	.8	1.12	1.03	.78	.79	.78	2.43	3.64	2.31	1.0
Inorganic carbon	.01%	.01	.04	.01	.02	.01	.05	.05	.05	.12	.03	.01	.01

[1] Detection limit set by the National Water-Quality Laboratory.

[2] Emsley, 1996.

[3] Samples were collected in triplicate.

lead at other sites in the basin, and fell between the TEL (35.0 µg/g) and PEL (91.3 µg/g) values for sediment quality (fig. 7). At these levels, adverse biological effects may occur. Lead concentrations in streambed sediment also were elevated at all sites downstream of the Sierra Nevada (fig. 7). The source of the lead is unknown. Although a few lead mines are present in the Sierra Nevada (fig. 4), lead mining was not extensive. Elevated levels of lead at the American River site (site 16) may be partly attributable to urban runoff. As with cadmium, elevated levels of lead in the streambed sediments of the Sacramento River at Freeport (site 17) may be partly attributable to urban runoff downstream of the city of Sacramento. There has been a decline in the lead concentration in urban streams since the reduction of lead in gasoline and the removal of lead-based paints from use on home exteriors (Smith and others, 1987). Several factors can affect the bioavailability of lead in aquatic organisms, including organic carbon concentration, phosphate concentrations, and pH (Luoma, 1986).

Lead can bioaccumulate and, in contrast to zinc, is neither essential nor beneficial to living organisms (Eisler, 1988). The processes affecting bioavailability of sediment-associated lead and zinc are not thoroughly understood (Luoma, 1986), and further study is needed to predict their possible toxic effects.

The zinc concentrations in streambed sediments in the Sacramento River Basin exceeded the average crustal abundance of 75 µg/g at all sites except McCloud River (site 1, fig. 8). The zinc concentration at Bend Bridge (site 3) was 450 µg/g, almost three

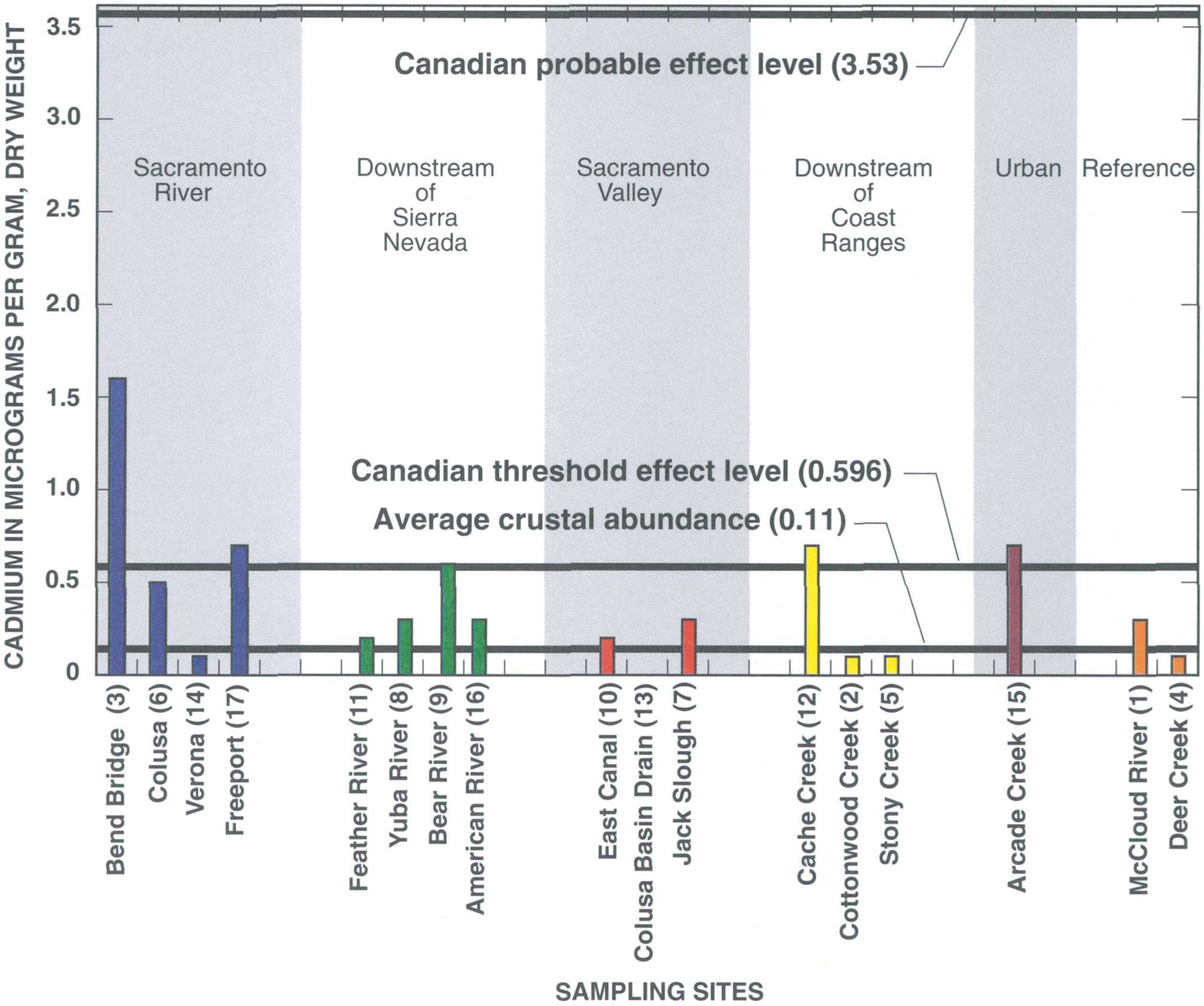

Figure 5. Cadmium concentrations in streambed sediment, Sacramento River Basin, California. See table 1 for full site name.

times the concentration of the downstream Sacramento River sites at Colusa (site 6; 140 µg/g), Verona (site 14; 95 µg/g), and Freeport (site 17; 160 µg/g), as well as most of the tributary sites (table 2). The concentration of zinc exceeds the Canadian PEL value of 315 µg/g (fig. 8), which suggests that adverse effects may occur frequently in aquatic organisms. Zinc is present in sulfide, carbonate, and silicate minerals, and is detected commonly in sulfides in combination with iron, copper, and lead (Jaagumagi, 1993). In addition, zinc often times occurs in sewage discharge and mining runoff (Leland and Kuwabara, 1985). Zinc is an essential micronutrient, and its uptake in most aquatic organisms seems to be independent of environmental concentrations (Jaagumagi, 1993). Although zinc can bioaccumulate in some organisms, there is no evidence of biomagnification (Jaagumagi, 1993). Significant adverse effects on growth, reproduction, and survival are documented for sensitive aquatic plants and animals at water concentrations of zinc between 10–25 micrograms per liter (µg/L) (Eisler, 1993), but there is little evidence documenting adverse effects from high sediment concentrations. The source of the zinc measured in streambed sediments at the Bend Bridge site may be attributed to urban runoff, or runoff from present and historical mining activities from the West Shasta Mining District (fig. 1).

A zinc concentration of 260 µg/g was detected in streambed sediments at Arcade Creek (site 15, table 2). This concentration is above average crustal abundance (75 µg/g) and is between the TEL (123 µg/g) and PEL (315 µg/g) values, indicating possible adverse effects on aquatic life (fig. 8). Zinc is used in the production of rubber products, including tires (Winter, 1997), and the

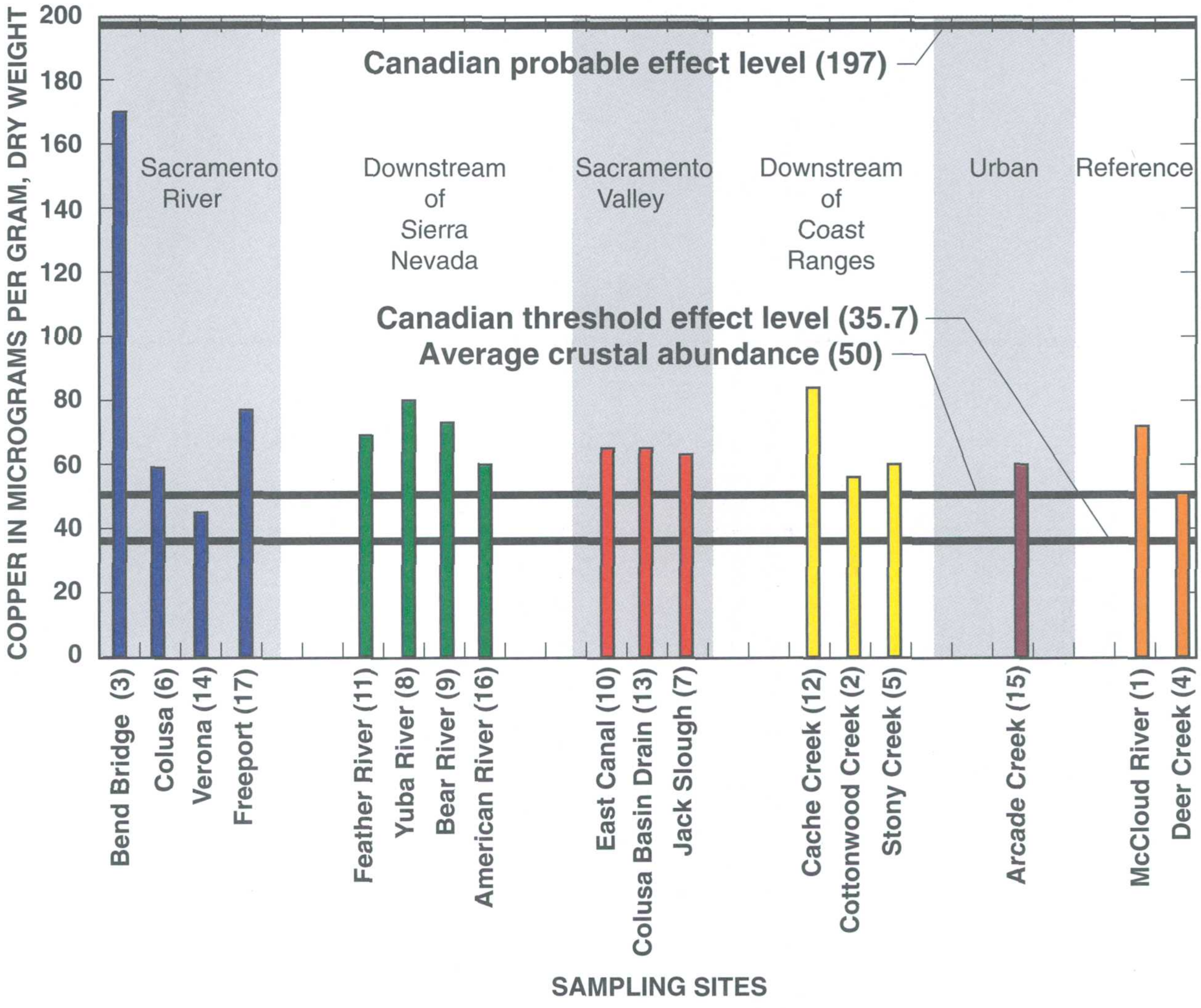

Figure 6. Copper concentrations in streambed sediment, Sacramento River Basin, California. See table 1 for full site name.

breakdown of tire rubber and other urban runoff may contribute to the elevated zinc concentrations in streambed sediments at Arcade Creek.

Cadmium, copper, and zinc concentrations can have a synergistic effect on aquatic toxicity, and the toxicity of these elements can vary among species and environments (Eisler, 1993). Further research is needed to determine the additive toxicity and bioaccumulation in aquatic organisms of cadmium, copper, and zinc detected in the streambed sediments at Bend Bridge (site 3).

Mercury in the Sacramento River Basin

Mercury concentrations exceeded average crustal abundance values in streambed sediments at several locations throughout the Sacramento River Basin (table 2). The concentrations were elevated and

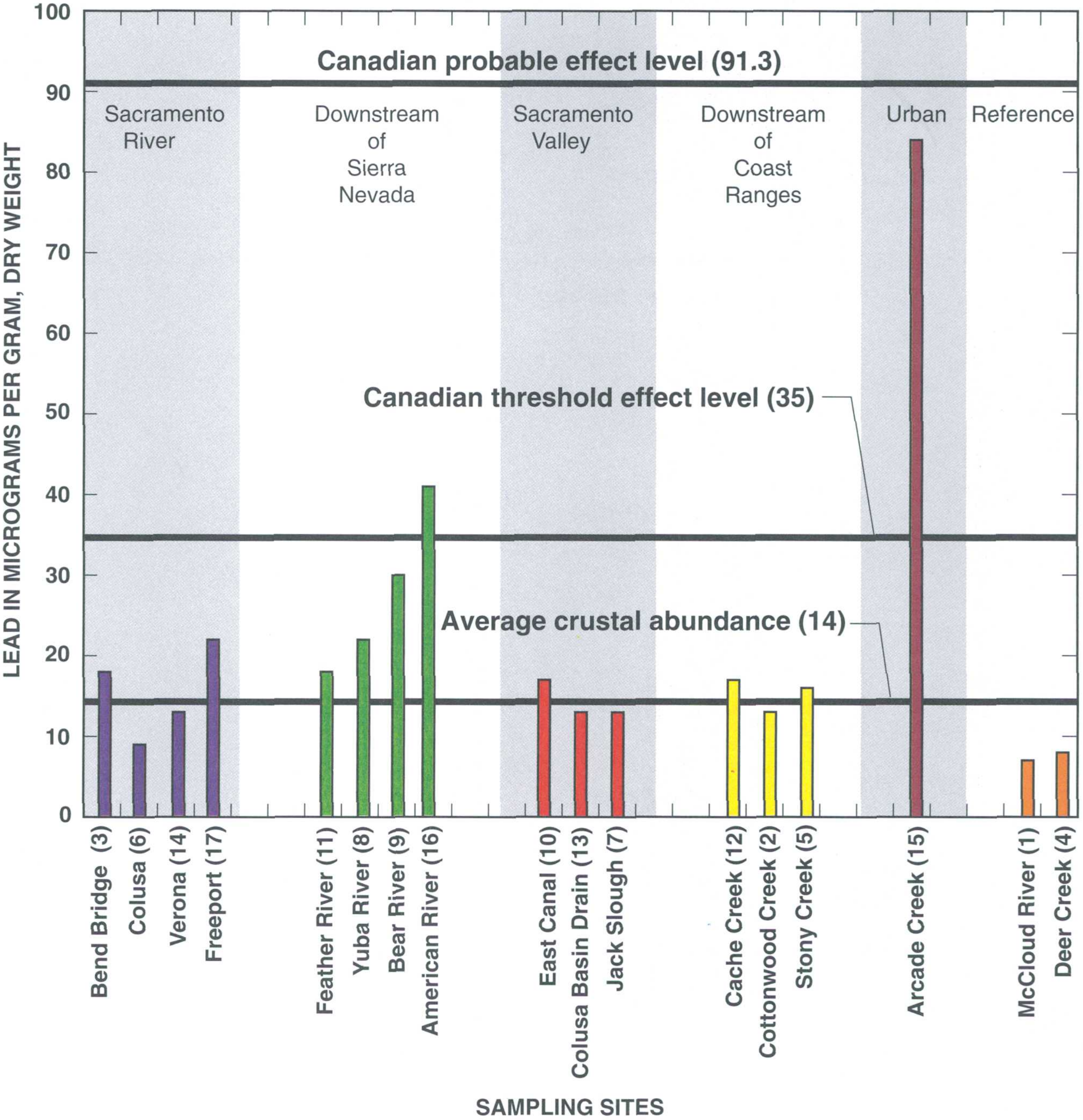

Figure 7. Lead concentrations in streambed sediment, Sacramento River Basin, California. See table 1 for full site name.

approached or exceeded sediment quality guidelines at sites downstream from the Sierra Nevada and Coast Ranges physiographic zones, which contain past and current mining operations. The concentrations of mercury in streambed sediments at Feather River (site 11; 0.21 µg/g), Yuba River (site 8; 0.37 µg/g), Bear River (site 9; 0.37 µg/g), and downstream of the confluence of the Feather and Sacramento Rivers at Verona (site 14; 0.24 µg/g) were among the highest found in the basin. These values fall between the TEL (0.174 µg/g) and PEL (0.486 µg/g) standards (fig. 9) for sediment quality and could adversely affect aquatic life. The mercury concentrations in streambed sediment at the Sacramento River sites of Bend Bridge (site 3) and Freeport (site 17), Cache Creek (site 12), Arcade Creek (site 15), and American River (site 16) did not approach or exceed Canadian sediment-quality guidelines. Anthropogenic sources of mercury to aquatic systems include mining and smelting, coal combustion, paints, fungicide application and, in the past, the chlor-alkali industry (Leland and Kuwabara, 1985). In aquatic systems, mercury generally is sorbed to

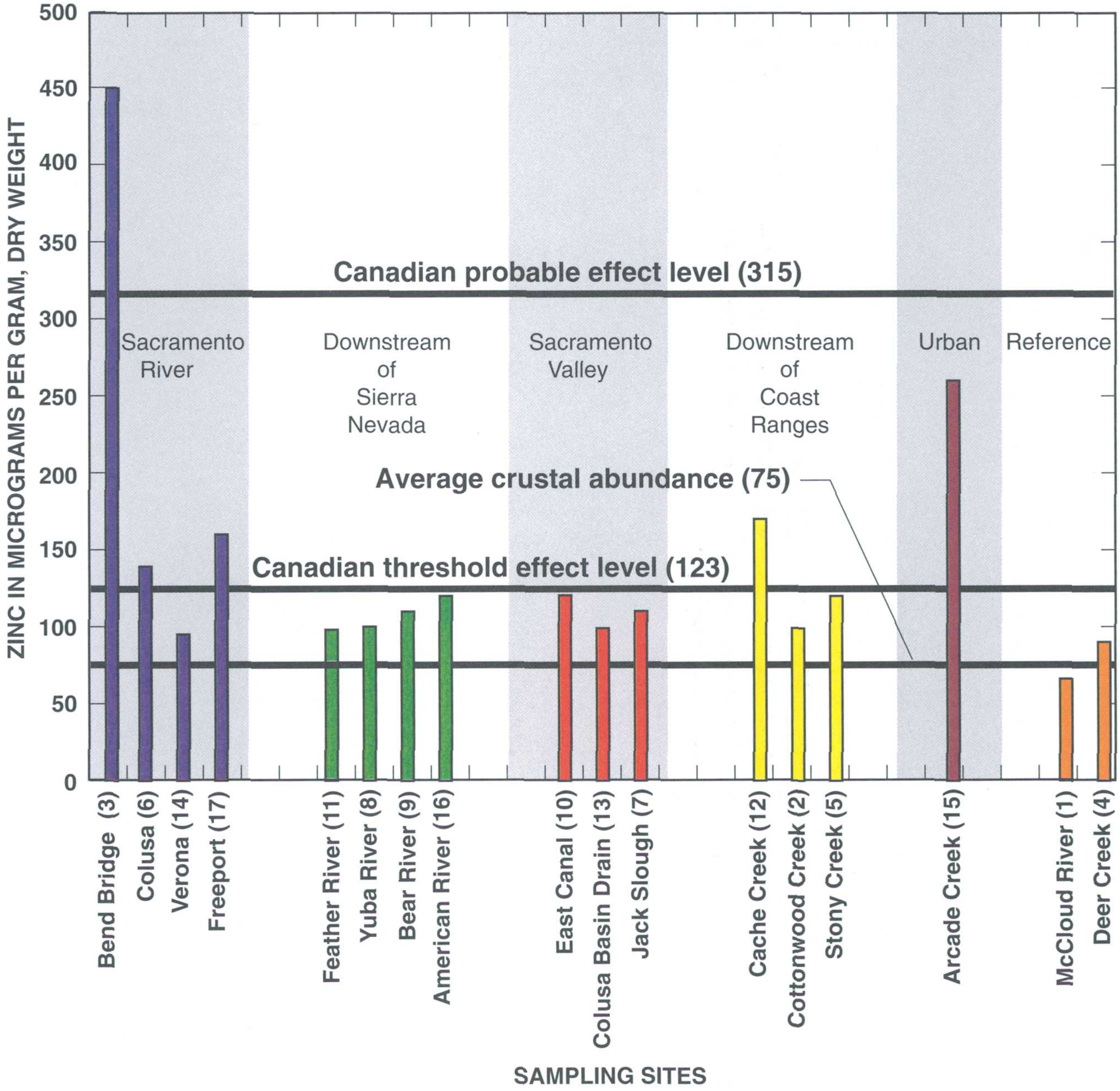

Figure 8. Zinc concentrations in streambed sediment, Sacramento River Basin, California. See table 1 for full site name.

particulate matter and tends to combine with organic matter, but it also can be found as the mercury sulfide mineral, cinnabar. Mercury also can be converted by bacteria in sediments to methyl mercury (Harte and others, 1991). The methylated forms of mercury are generally more bioavailable. Bioaccumulation and bioconcentration of the organic form is high, and methyl mercury can be biomagnified (Canadian Council of Ministers of the Environment, 1987). Because of the areas where mercury was detected, the origin of mercury in the streambed sediments of the lower Sacramento River Basin probably is from historical gold mining in the Sierra Nevada, east of the Sacramento River, and from mercury mining in the Coast Ranges, west of the Sacramento River.

Organic Compounds

Of the 31 organochlorine compounds analyzed in streambed sediment in the Sacramento River Basin, 9 were detected. Of the 67 semivolatile compounds analyzed in streambed sediment, 17 were present at

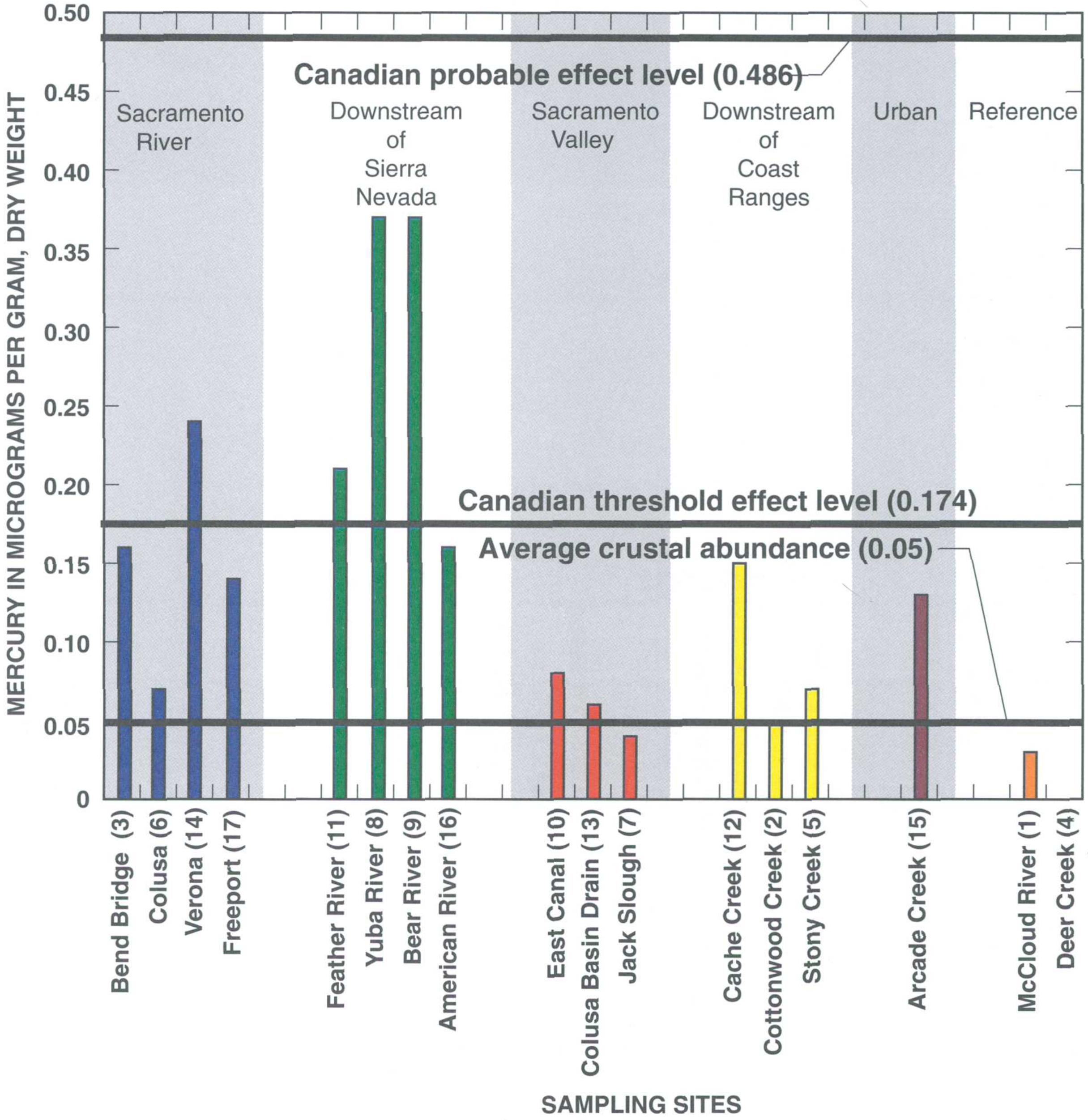

Figure 9. Mercury concentrations in streambed sediment, Sacramento River Basin, California. See table 1 for full site name.

concentrations at or above detection levels. Most of the semivolatile compounds were detected at low contrations and were either polychlorinated biphenyls (PCB) or polycyclic aromatic hydrocarbons (PAH). These types of compounds are not discussed in detail in this report.

Organochlorine compounds in agricultural drains and the Sacramento River

Concentrations of DDD, DDE, and DDT were detected in streambed sediments at agricultural indicator sites (Sacramento Valley sites 7, 10, and 13), and DDE was detected at three Sacramento River sites (sites 6, 14, and 17; fig. 10). Concentrations of *o,p′*-DDD [2.6 micrograms per kilogram (μg/kg)] and *p,p′*-DDD (8.2 μg/kg) were detected at Jack Slough (site 7). *p,p′*-DDD fell between the TEL (3.54 μg/kg) and PEL (8.51 μg/kg) and may have adverse effects on aquatic life (table 3). *p,p′*-DDE values at the sites on the Sacramento River at Colusa (site 6; 3.5 μg/kg) and Freeport (site 17; 1.8 μg/kg), East Canal (site 10; 1.5 μg/kg), and Colusa Basin Drain (site 13; 5.4 μg/kg) also were between the TEL (1.42 μg/kg) and PEL (6.75 μg/kg) values. At Jack Slough, *p,p′*-DDE

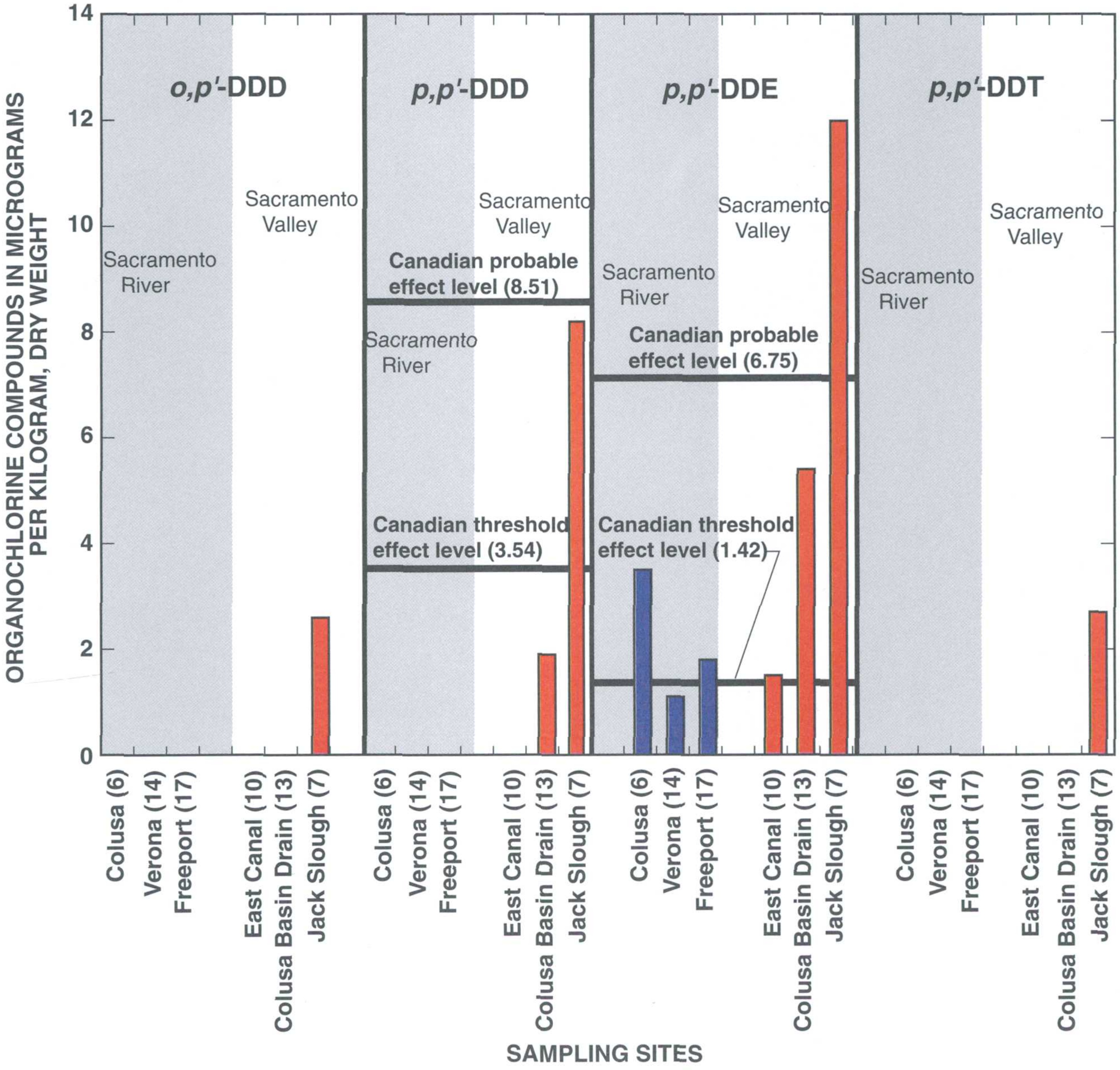

Figure 10. DDD, DDE, and DDT concentrations in streambed sediment, Sacramento River Basin, California. See table 1 for full site name.

(12 µg/kg) exceeded the PEL guideline of 6.75 µg/kg, the level at which adverse effects are predicted to occur frequently in aquatic organisms. The concentration of *p,p′*-DDT detected at Jack Slough (2.7 µg/kg) was at a level that did not exceed the published Canadian guidelines.

The detections of DDD, DDE, and DDT at these sites can be attributed to past agricultural use. These compounds were not detected at sites with little or no upstream agriculture.

Organochlorine compounds in an urban stream, Arcade Creek near Del Paso Heights

Organochlorine compounds were detected in streambed sediments at Arcade Creek (site 15; fig. 11).

Table 3. Organochlorine compounds in streambed sediments, Sacramento River Basin, California

[nd, not detected or less than detection limit; nd(5), reporting limit different from detection limit due to analytical procedure; values given in micrograms per kilogram unless specified as grams per kilogram (g/kg). Abbreviated site names and corresponding site number in bold. See table 1 for full site name]

Compound	Detection limit[1]	McCloud River **1**	Cottonwood Creek **2**	Bend Bridge **3**	Deer Creek **4**	Stoney Creek **5**	Colusa **6**	Jack Slough **7**	Yuba River **8**
Aldrin	1	nd	nd	nd	nd	nd	nd	nd	nd
Benzene hexachloro	50	nd	nd	nd	nd	nd	nd	nd	nd
α-BHC	1	nd	nd	nd	nd	nd	nd	nd	nd
β-BHC	1	nd	nd	nd	nd	nd	nd	nd	nd
cis-Chlordane	1	nd	nd	nd	nd	nd	nd	nd	nd
trans-Chlordane	1	nd	nd	nd	nd	nd	nd	nd	nd
Chloroneb	10	nd	nd(5)	nd(5)	nd(5)	nd	nd(5)	nd	nd(5)
Dacthal (DCPA)	5	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-DDD	1	nd	nd	nd	nd	nd	nd	2.6	nd
o,p′-DDE	1	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-DDT	2	nd	nd	nd	nd	nd	nd	nd	nd
p,p′-DDD	1	nd	nd	nd	nd	nd	nd	8.2	nd
p,p′-DDE	1	nd	nd	nd	nd	nd	3.5	12	nd
p,p′-DDT	2	nd	nd	nd	nd	nd	nd	2.7	nd
Dieldrin	1	nd	nd	nd	nd	nd	nd	nd	nd
Endosulfan	1	nd	nd	nd	nd	nd	nd	nd	nd
Endrin	2	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor	1	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor epoxide	1	nd	nd	nd	nd	nd	nd	nd	nd
Isodrin	1	nd	nd	nd	nd	nd	nd	nd	nd
γ-HCH (lindane)	1	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-Methoxychlor	5	nd	nd	nd	nd	nd	nd	nd	nd
p,p′-Methoxychlor	5	nd	nd	nd	nd	nd	nd	nd	nd
Mirex	1	nd	nd	nd	nd	nd	nd	nd	nd
cis-Nonachlor	1	nd	nd	nd	nd	nd	nd	nd	nd
trans-Nonachlor	1	nd	nd	nd	nd	nd	nd	nd	nd
Oxychlordane	1	nd	nd	nd	nd	nd	nd	nd	nd
PCBs	50	nd	nd	nd	nd	nd	nd	nd	nd
cis-Permethrin	5	nd	nd	nd	nd	nd	nd	nd	nd
trans-Permethrin	5	nd	nd	nd	nd	nd	nd	nd	nd
Toxaphene	200	nd	nd	nd	nd	nd	nd	nd	nd
Carbon inorganic (g/kg)	.1	nd	nd	nd	nd	nd	nd	nd	nd
Carbon organic (g/kg)	.1	24	9.6	1.4	9.9	2.4	6.1	16	22
Carbon organic/ inorganic (g/kg)	.1	24	9.6	1.4	9.9	2.4	6.1	16	22
Sample weight		17.1	25.1	26.8	25.2	25.4	25.1	25.1	25.2

p,p′-DDD (4.9 µg/kg) fell between the TEL (3.54 µg/kg) and PEL (8.54 µg/kg) of the Canadian guidelines, and *p,p′*-DDE (2.1 µg/kg) also fell between the TEL (1.42 µg/kg) and PEL (6.75 µg/kg) (table 3). Concentrations of DDT compounds at these levels may cause adverse effects on aquatic life. The detections of DDD and DDE in the sediments of Arcade Creek can be attributed to past agricultural land use in that basin.

Cis-chlordane, *trans*-chlordane, *cis*-nonachlor, *trans*-nonachlor and dieldrin also were detected, but at levels below published Canadian guidelines. The source of these agricultural compounds in Arcade

Table 3. Organochlorine compounds in streambed sediments, Sacramento River Basin, California—Continued

Compound	Detection limit[1]	Bear River 9	East Canal 10	Feather River 11	Cache Creek 12	Colusa Basin Drain 13	Verona 14	Arcade Creek 15	American River 16	Freeport 17
Aldrin	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzene hexachloro	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
α-BHC	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
β-BHC	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
cis-Chlordane	1	nd	nd	nd	nd	nd	nd	3.2	nd	nd
trans-Chlordane	1	nd	nd	nd	nd	nd	nd	3.4	nd	nd
Chloroneb	10	nd	nd	nd	nd	nd	nd(5)	nd	nd	nd
Dacthal (DCPA)	5	nd	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-DDD	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-DDE	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-DDT	2	nd	nd	nd	nd	nd	nd	nd	nd	nd
p,p′-DDD	1	nd	nd	nd	nd	1.9	nd	4.9	nd	nd
p,p′-DDE	1	nd	1.5	nd	nd	5.4	1.1	2.1	nd	1.8
p,p′-DDT	2	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dieldrin	1	nd	nd	nd	nd	nd	nd	2.6	nd	nd
Endosulfan	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
Endrin	2	nd	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor epoxide	1	nd	nd	nd	nd	nd	nd	nd(2.0)	nd	nd
Isodrin	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
γ-HCH (lindane)	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-Methoxychlor	5	nd	nd	nd	nd	nd	nd	nd	nd	nd
p,p′-Methoxychlor	5	nd	nd	nd	nd	nd	nd	nd	nd	nd
Mirex	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
cis-Nonachlor	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
trans-Nonachlor	1	nd	nd	nd	nd	nd	nd	4.2	nd	nd
Oxychlordane	1	nd	nd	nd	nd	nd	nd	nd	nd	nd
PCBs	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
cis-Permethrin	5	nd	nd	nd	nd	nd	nd	nd	nd	nd
trans-Permethrin	5	nd	nd	nd	nd	nd	nd	nd	nd	nd
Toxaphene	200	nd	nd	nd	nd	nd	nd	nd	nd	nd
Carbon inorganic (g/kg)	.1	.4	.5	nd	1	1.8	nd	nd	nd	nd
Carbon organic (g/kg)	.1	7.3	5.1	3.6	7.9	9.2	3.3	14	3.7	7.7
Carbon organic/ inorganic (g/kg)	.1	7.7	5.6	3.6	8.9	11	3.3	14	3.7	7.7
Sample weight		25.2	25.1	25.2	25.2	25.3	25.1	25	25.2	25.1

[1] Detection limit set by the National Water-Quality Laboratory.

Creek is most likely residential runoff, and the effects on aquatic organisms at that site need further investigation.

The Arcade Creek Basin has been urbanized rapidly in the last 20 years. Detections of organochlorine compounds other than DDD, DDE, and DDT at Arcade Creek can be attributed to household pest control.

Semivolatile compounds in the upper Sacramento River Basin

As listed in table 4, *p*-cresol, the coal tar derivative, was detected at McCloud River (site 1; 820 µg/kg) and Deer Creek (site 4; 110 µg/kg), as well as at Cottonwood Creek (site 2; 160 µg/kg), Cache Creek (site 12; 300 µg/kg), Bear River (site 9; 360 µg/kg), and Colusa (site 13; 430 µg/kg). *p*-cresol is used as a disinfectant and is released into the environment from the production of coal tar and metal refining, as well as in the manufacturing of chemicals, wood pulp, and glass fiber. Also, it is present in emissions from automobile gas and diesel engines (Merck Index, 1983; Smith and others, 1988). It has been shown that *p*-cresol can be degraded to other compounds by bacteria (Howard, 1989). The time required for bacteria to use 95 percent of the parent compound in river systems is 1–2 days (Smith and others, 1988). The

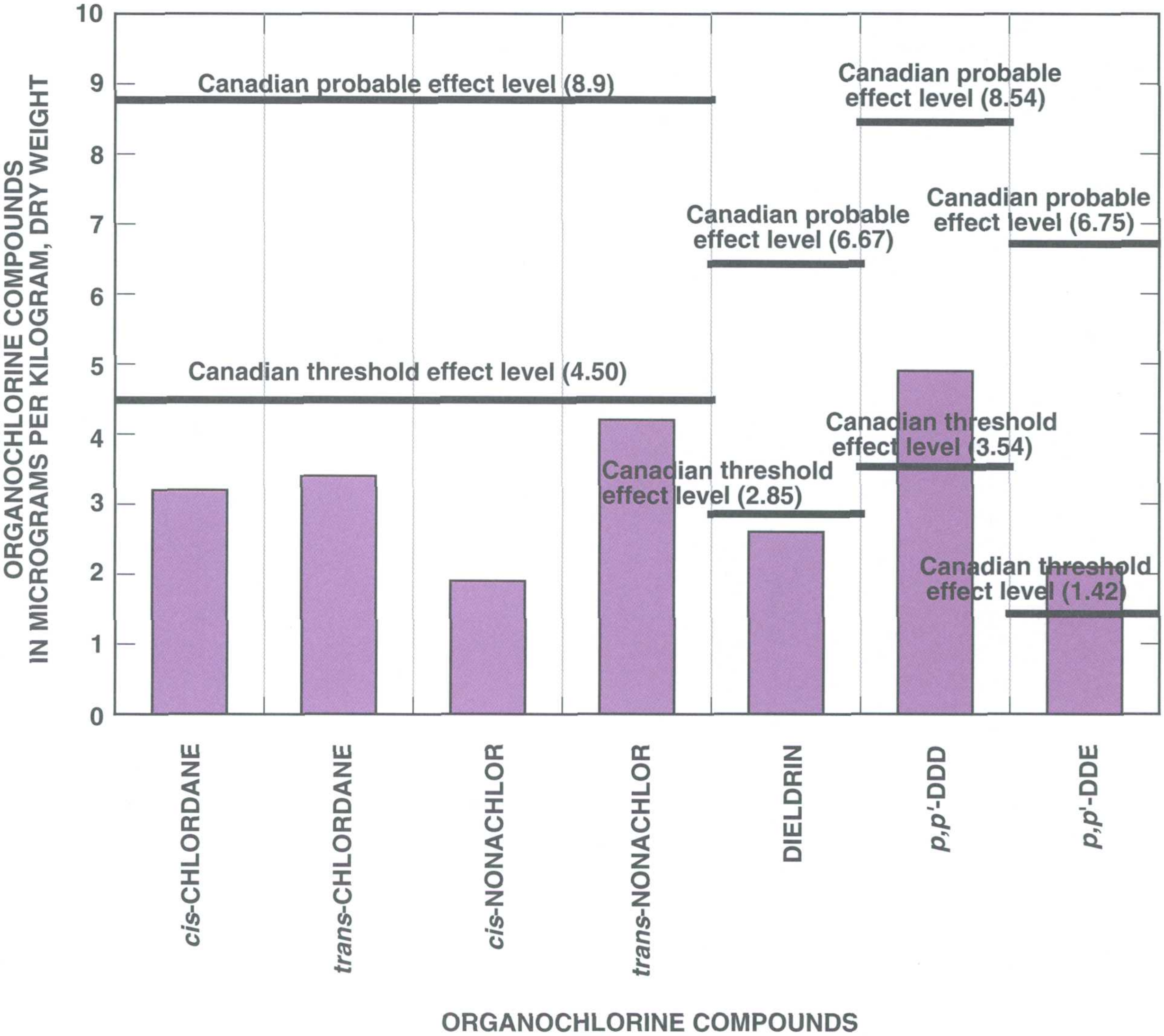

Figure 11. Organochlorine compounds in streambed sediment from Arcade Creek, Sacramento River Basin, California.

Table 4. Semivolatile compounds in streambed sediments, Sacramento River Basin, California

[nd, not detected or less than detection limit; g, grams; values given in micrograms per kilogram; dry weight in less than 2-millimeter fractions. Abbreviated site names and corresponding site number in bold. See table 1 for full site name]

Compound	Detection limit[1]	McCloud River **1**	Cottonwood Creek **2**	Bend Bridge **3**	Deer Creek **4**	Stoney Creek **5**	Colusa **6**	Jack Slough **7**	Yuba River **8**
Acenaphthene	50	nd	nd	nd	nd	nd	nd	nd	nd
Acenaphthylene	50	nd	nd	nd	nd	nd	nd	nd	nd
Acridine	50	nd	nd	nd	nd	nd	nd	nd	nd
C8-Alkylphenol	50	nd	nd	nd	nd	nd	nd	nd	nd
Anthracene	50	nd	nd	nd	nd	nd	nd	nd	nd
Anthraquinone	50	nd	nd	nd	nd	nd	nd	nd	nd
Azobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd
Benz[a]anthracene	50	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[c]cinnoline	50	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[b]fluoranthene	50	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[k]fluoranthene	50	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[ghi]perylene	50	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[a]pyrene	50	nd	nd	nd	nd	nd	nd	nd	nd
2,2'-Biquinoline	50	nd	nd	nd	nd	nd	nd	nd	nd
bis(2-Chloroethoxy)methane	50	nd	nd	nd	nd	nd	nd	nd	nd
bis(2-Ethylhexyl)phthalate	50	nd	52	nd	52	nd	63	68	81
4-Bromophenyl-phenylether	50	nd	nd	nd	nd	nd	nd	nd	nd
Butylbenzylphthalate	50	nd	nd	nd	nd	nd	57	nd	66
9H-Carbozole	50	nd	nd	nd	nd	nd	nd	nd	nd
4-Chloro-3-methylphenol	50	nd	nd	nd	nd	nd	nd	nd	nd
2-Chloronaphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd
2-Chlorophenol	50	nd	nd	nd	nd	nd	nd	nd	nd
4-Chlorophenyl-phenylether	50	nd	nd	nd	nd	nd	nd	nd	nd
Chrysene	50	nd	nd	nd	nd	nd	nd	nd	nd
p-Cresol	50	820	160	nd	110	nd	430	nd	nd
Dibenz[a,h]anthracene	50	nd	nd	nd	nd	nd	nd	nd	nd
Dibenzothiophene	50	nd	nd	nd	nd	nd	nd	nd	nd
Di-n-butylphalate	50	58	60	nd	80	58	nd	82	85
1,2-Dichlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd
1,3-Dichlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd
1,4-Dichlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd
Diethylphthalate	50	nd	nd	nd	51	nd	nd	nd	nd
1,2-Dimethylnaphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd

Table 4. Semivolatile compounds in streambed sediments, Sacramento River Basin, California—Continued

Compound	Detection limit[1]	McCloud River 1	Cottonwood Creek 2	Bend Bridge 3	Deer Creek 4	Stoney Creek 5	Colusa 6	Jack Slough 7	Yuba River 8
1,6-Dimethylnaphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd
2,6-Dimethylnaphthalene	50	140	51	nd	nd	nd	nd	nd	nd
3,5-Dimethylphenol	50	nd	nd	nd	nd	nd	nd	nd	nd
Dimethylphthalate	50	nd	nd	nd	nd	nd	nd	nd	nd
4,6-Dinitro-2-methylphenol	50	nd	nd	nd	nd	nd	nd	nd	nd
2,4-Dinitrotoluene	50	nd	nd	nd	nd	nd	nd	nd	nd
2,6-Dinitrotoluene	50	nd	nd	nd	nd	nd	nd	nd	nd
Di-n-oxtylphthalate	50	nd	nd	nd	nd	57	nd	nd	nd
Fluoranthene	50	nd	nd	nd	nd	nd	nd	nd	nd
9H-Fluorene	50	nd	nd	nd	nd	nd	nd	nd	nd
Hexachlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd
Indeno[1,2,3-cd]pyrene	50	nd	nd	nd	nd	nd	nd	nd	nd
Isophorone	50	nd	nd	nd	nd	nd	nd	nd	nd
Isoquinoline	50	nd	nd	nd	nd	nd	nd	nd	nd
2-Methylanthracene	50	nd	nd	nd	nd	nd	nd	nd	nd
1-Methyl-9H-fluorene	50	nd	nd	nd	nd	nd	nd	nd	nd
1-Methylphenanthrene	50	nd	nd	nd	nd	nd	nd	nd	nd
1-Methylpyrene	50	nd	nd	nd	nd	nd	nd	nd	nd
4,5-Methylenephenanthrene	50	nd	nd	nd	nd	nd	nd	nd	nd
Naphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd
Nitrobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd
4-Nitrophenol	50	nd	nd	nd	nd	nd	nd	nd	nd
N-Nitrosodi-n-propylamine	50	nd	nd	nd	nd	nd	nd	nd	nd
N-Nitrosodiphenylamine	50	nd	nd	nd	nd	nd	nd	nd	nd
Pentachloroanisole	50	nd	nd	nd	nd	nd	nd	nd	nd
Pentachloronitrobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd
Pentachlorophenol	50	nd	nd	nd	nd	nd	nd	nd	nd
Phenanthrene	50	nd	nd	nd	nd	nd	nd	nd	nd
Phenanthridine	50	nd	nd	nd	nd	nd	nd	nd	nd
Phenol	50	140	51	nd	nd	nd	nd	nd	nd
Pyrene	50	nd	nd	nd	nd	nd	nd	nd	nd
Quinoline	50	nd	nd	nd	nd	nd	nd	nd	nd
1,2,4-Trichlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd
2,3,6-Trimethylnaphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd
Sample weight (g)		17.1	25.1	26.8	25.2	25.4	25.1	25.1	25.2

Table 4. Semivolatile compounds in streambed sediments, Sacramento River Basin, California—Continued

Compound	Detection limit[1]	Bear River 9	East Canal 10	Feather River 11	Cache Creek 12	Colusa Basin Drain 13	Verona 14	Arcade Creek 15	American River 16	Freeport 17
Acenaphthene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acenaphthylene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Acridine	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
C8-Alkylphenol	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Anthracene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Anthraquinone	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Azobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benz[a]anthracene	50	nd	nd	nd	nd	nd	nd	63	nd	nd
Benzo[c]cinnoline	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Benzo[b]fluoranthene	50	nd	nd	nd	nd	nd	nd	78	nd	nd
Benzo[k]fluoranthene	50	nd	nd	nd	nd	nd	nd	76	nd	nd
Benzo[ghi]perylene	50	68	nd	nd	nd	nd	nd	75	nd	65
Benzo[a]pyrene	50	nd	nd	nd	nd	nd	nd	79	nd	nd
2,2'-Biquinoline	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
bis(2-Chloroethoxy)methane	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
bis(2-Ethylhexyl)phthalate	50	85	70	85	57	100	53	770	86	65
4-Bromophenyl-phenylether	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Butylbenzylphthalate	50	59	60	69	49	66	51	nd	nd	51
9H-Carbozole	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
4-Chloro-3-methylphenol	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Chloronaphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Chlorophenol	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
4-Chlorophenyl-phenylether	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Chrysene	50	nd	nd	nd	nd	nd	nd	70	nd	nd
p-Cresol	50	360	nd	nd	300	nd	nd	nd	nd	nd
Dibenz[a,h]anthracene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dibenzothiophene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Di-n-butylphalate	50	63	88	120	56	91	57	140	81	52
1,2-Dichlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
1,3-Dichlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
1,4-Dichlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Diethylphthalate	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
1,2-Dimethylnaphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd

Table 4. Semivolatile compounds in streambed sediments, Sacramento River Basin, California—Continued

Compound	Detection limit[1]	Bear River 9	East Canal 10	Feather River 11	Cache Creek 12	Colusa Basin Drain 13	Verona 14	Arcade Creek 15	American River 16	Freeport 17
1,6-Dimethylnaphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
2,6-Dimethylnaphthalene	50	nd	nd	nd	nd	nd	nd	120	nd	nd
3,5-Dimethylphenol	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dimethylphthalate	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
4,6-Dinitro-2-methylphenol	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
2,4-Dinitrotoluene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
2,6-Dinitrotoluene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Di-n-oxtylphthalate	50	nd	nd	nd	nd	nd	nd	nd	60	nd
Fluoranthene	50	nd	nd	nd	nd	nd	nd	97	nd	nd
9H-Fluorene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Hexachlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Indeno[1,2,3-cd]pyrene	50	nd	nd	nd	nd	nd	nd	89	nd	nd
Isophorone	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Isoquinoline	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
2-Methylanthracene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
1-Methyl-9H-fluorene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
1-Methylphenanthrene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
1-Methylpyrene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
4,5-Methylenephenanthrene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Naphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Nitrobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
4-Nitrophenol	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
N-Nitrosodi-n-propylamine	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
N-Nitrosodiphenylamine	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Pentachloroanisole	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Pentachloronitrobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Pentachlorophenol	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Phenanthrene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Phenanthridine	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Phenol	50	nd	nd	nd	50	nd	nd	100	nd	nd
Pyrene	50	53	nd	nd	nd	nd	nd	94	nd	nd
Quinoline	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
1,2,4-Trichlorobenzene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
2,3,6-Trimethylnaphthalene	50	nd	nd	nd	nd	nd	nd	nd	nd	nd
Sample weight, in grams		25.2	25.1	25.2	25.2	25.3	25.1	25	25.2	25.1

[1] Detection limit set by the National Water-Quality Laboratory.

p-cresol detected in the Sacramento River Basin sites could be attributed to nearby road maintenance. Little is known of the toxicity of *p*-cresol to aquatic biota, and further investigation is needed to determine its source and biological significance.

Few other semivolatile compounds were detected in streambed sediments. Two other classes of semivolatile compounds detected were phthalates and polynuclear aromatic hydrocarbons. Phthalates are components of plastic materials, and polynuclear aromatic hydrocarbons are by-products of combustion. The higher concentrations or more frequent detections of those compounds occurred in the streambed sediment of Arcade Creek near Del Paso Heights (site 15). Urban runoff is a likely source of these compounds.

AQUATIC BIOTA RESULTS AND DISCUSSION

Trace Elements

Of the 22 trace elements analyzed for in aquatic biota, 19 were detected at varying concentrations in tissue sampled from the Sacramento River Basin (table 5). Several of the detected trace elements occur naturally in aquatic organisms and further investigation is needed to determine if the observed metal concentrations could be detrimental to the organisms. As mentioned previously, no samples of aquatic tissue could be collected from Bend Bridge because fish samples could not be collected. Therefore, it is not known if the elevated concentrations of trace metals in streambed sediment at that site are affecting tissue concentrations in aquatic biota. Of the trace metals sampled in aquatic tissue, mercury has the greatest propensity to bioaccumulate. Unfortunately, the sampling procedures for trace elements in tissue precluded a thorough assessment of the extent and range of concentrations at these sites. The biota targeted for trace element analysis were either *C. fluminea* or bottom-feeding fish. Mercury bioaccumulation in *C. fluminea* is not well documented. Liver is the preferred tissue for trace element analysis in bottom-feeding fish; however, mercury does not necessarily concentrate to high levels in fish liver, but may concentrate in other organs, such as muscle (Goldstein and others, 1996). There was a variety of species collected at the sites of this study, and only at a relatively few sites were samples collected in multiple tissue types. Therefore, only limited statements can be made about mercury in aquatic tissue from this study. The possible sources of mercury and adverse effects on aquatic organisms in the Sacramento River Basin are discussed later in this report.

Mercury in the tissue of aquatic organisms

Total mercury was detected in the fillets of *C. occidentalis* collected from American River (1.1 µg/g, estimated wet weight) (site 16; fig. 12). This level exceeds the FDA action level of 1.0 µg/g (human health criteria) and NAS guideline of 0.5 µg/g for the protection of aquatic life. Elevated levels of mercury also were detected in *C. occidentalis* fillets at Cache Creek (site 12; 0.28 µg/g, estimated wet weight) but were well below the FDA action level and NAS guideline. Trace element concentrations were reported by the NWQL as µg/g, dry weight. However, regulatory guidelines of the FDA and NAS are expressed as wet weight. Since the percentage of water content of the tissue was measured, an estimate of the wet weight metal concentration could be calculated.

Mercury is a naturally occurring element in the environment, but it has no known essential function in vertebrate organisms (Wiener and Spry, 1994). Mercury can enter the air and water from natural sources such as volcanoes and weathering of rock. It can enter the environment as a result of human activities such as the burning of coal for heat and electricity, discharges of wastewater from mines, metal smelter operations, and discharge from wastewater treatment plants. Under certain conditions, microbial processes can change inorganic mercury forms into organic forms, such as methyl mercury. Methyl mercury is considered more toxic to humans and aquatic organisms than inorganic mercury, and is the form most likely to be detected in fish tissue (U.S. Environmental Protection Agency, 1992). Research has shown that methyl mercury is bioaccumulated readily by aquatic organisms and can biomagnify as it progresses through the food chain (Wiener and Spry, 1994).

Fillets and livers from *C. occidentalis*, and whole body tissue from *C. fluminea* collected from the American River (site 16) and Cache Creek (site 12) were analyzed for total mercury. The concentrations of total mercury in the fish livers and *C. fluminea* were at or below detection level and significantly below the concentrations in fillets (fig. 12). Methyl mercury has

Table 5. Trace elements in aquatic biota, Sacramento River Basin, California

[nd, not detected or less than detection limit; nd(.5), reporting limit different from detection limit due to analytical procedure; values given in micrograms per gram, dry weight. Abbreviated site names and corresponding site number in bold. See table 1 for full site name]

Trace element	Detection limit[1]	McCloud River **1**	Cotton-wood Creek **2**	Deer Creek **4**	Stoney Creek **5**	Sacramento River[2] **6**			Jack Slough **7**	Yuba River **8**		Bear River **9**	East Canal **10**
		Whole *Cottus gulosus*	Whole *Catastomus occidentalis*	Whole *Cottus gulosus*	*Catastomus occidentalis* livers	*Corbicula fluminea*					Whole *Cottus gulosus*	*Catastomus occidentalis* livers	*Corbicula fluminea*
Aluminum	1	23.9	95.1	43.2	1.4	972	371	229	391	387	191	4.7	19
Antimony	.2	nd	nd	nd	nd	nd(.5)	nd	nd	nd(1)	nd(.7)	nd	nd	nd
Arsenic	.2	nd	.4	.6	.8	8.2	10.9	7	6	10.2	.4	.3	.6
Barium	.1	5.8	12	9.8	.3	18.3	13.5	13.6	30.7	17.5	8.1	.2	.2
Beryllium	.2	nd	nd	nd	nd	nd(.5)	nd	nd	nd(1)	nd(.7)	nd	nd	nd
Boron	.2	.7	.6	.8	.7	1.5	1.4	1.3	1.4	1.8	.5	2.1	.9
Cadmium	.2	nd	nd	nd	1.9	3.5	4.4	3.3	1.9	2.5	nd	nd	3.9
Chromium	.5	1.3	1.7	1.8	nd	21.7	21	21	9.2	15.9	1.6	.9	.5
Cobalt	.2	nd	.5	.5	.7	1.6	1.9	1.3	5.3	1.5	.6	nd	nd
Copper	.5	1.9	3.6	3.1	37.1	96.7	92.7	88.2	111	65.9	2.6	48.8	136
Iron	1	57.1	142	94.2	302	1,080.0	427	362	831	638	264	370	580
Lead	.2	nd	nd	nd	nd	nd(.5)	.5	nd	nd(1)	nd(.7)	nd	nd	nd
Manganese	.1	8.4	52.7	8.2	6.7	45.8	26.5	24.1	269	41	13.4	14.1	7.3
Mercury	.1	nd	.1	.1	nd	.1	.1	.2	nd	.64	.46	.1	.2
Molybdenum	.2	nd	nd	nd	.9	.6	.8	.5	1.2	.8	nd	1.4	.8
Nickel	.2	.4	1.7	1.5	.2	6.4	7	3.8	6.3	5.5	1.5	nd	nd
Selenium	.1	1.8	1.2	.9	2.8	3.4	4.3	3.2	4.2	3.6	2.9	2.5	5
Silver	.2	nd	.2	nd	.2	nd(.5)	nd	nd	nd(1)	nd(.7)	nd	.3	.4
Strontium	.1	43.1	77.3	87.5	.7	15.4	14	11.8	19.6	12.9	48.4	.3	.8
Uranium	.2	nd	nd	nd	nd	nd(.5)	nd	nd	nd(1)	nd(.7)	nd	nd	nd
Vanadium	.1	.2	.5	.7	.8	2.3	1.5	.9	1.7	1.6	1.3	.2	1.1
Zinc	.5	39.6	53.4	60.1	64.1	198	202	207	166	121	42.1	86.6	811
Percent water		75.2	73.0	74.7	69.7	90.8	89.9	88.3	93.8	91.9	77.3	73.8	76.6

Table 5. Trace elements ia aquatic biota, Sacramento River Basin, California—Continued

Trace element	Detection limit[1]	Feather River 11	Feather River[2] 11			Cache Creek 12		Colusa Basin Drain 13	Verona 14	Arcade Creek 15		American River 16		Freeport 17
		Corbicula fluminea				*Catastomus occidentalis* livers	*Catastomus occidentalis* fillets	*Cyprinus carpio* livers	*Corbicula fluminea*			*Catastomus occidentalis* livers	*Catastomus occidentalis* fillets	*Corbicula fluminea*
Aluminum	1	144	92.8	56.7	214	nd	nd	103	828	50.1	305	5	nd	394
Antimony	.2	nd(.5)	nd(.5)	nd(.5)	nd	nd	nd	nd	nd(.7)	nd(.4)	nd(.5)	nd	nd	nd(.5)
Arsenic	.2	6.3	6.2	6	3.4	.4	.4	.5	11	4.2	8.8	.3	.4	10.2
Barium	.1	8.9	7.9	8.7	26.2	.1	4.3	1.1	18.6	36.1	10.2	.1	4.6	15.2
Beryllium	.2	nd(.5)	nd(.5)	nd(.5)	nd	nd	nd	nd	nd(.7)	nd(.4)	nd(.5)	nd	nd	nd(.5)
Boron	.2	1.7	1.3	2.1	5.5	.6	.7	.8	1.8	1.9	1	.6	.6	2
Cadmium	.2	1.2	1.2	1.2	nd	.3	nd	1.8	3	.8	1.3	1	nd	3.4
Chromium	.5	10.2	9.2	9.9	2.4	nd	.8	.9	15.9	5.9	11.4	nd	1.4	17.1
Cobalt	.2	1.3	1.2	1.3	1	.1	nd	.6	2	.9	1.3	.2	nd	1.2
Copper	.5	55.1	52.3	56.1	20.8	60.7	.6	157	68.7	65.5	74.8	75.8	.8	87
Iron	1	324	283	261	325	402	8.4	1,220	950	267	421	1,400	12.3	502
Lead	.2	nd(.5)	nd(.5)	nd(.5)	nd	nd	nd	.4	nd(.7)	1.1	.8	.4	nd	nd(.5)
Manganese	.1	20	21	19.3	31.2	4.5	8.1	9.2	45.3	21.6	34.5	4.9	26.5	38.6
Mercury	.1	.16	.16	.16	nd	.3	1.1	.24	.11	.38	.35	.11	4.6	.2
Molybdenum	.2	.7	.6	.6	.4	.9	nd	1.2	1	1.4	.8	1.1	nd	.8
Nickel	.2	4.8	4.4	5.2	11.9	.1	.4	.4	7.5	1.3	3	.2	.7	4
Selenium	.1	2.7	3.2	3.3	2.2	2.2	.7	6.8	3.7	3.4	3	4.5	1.4	4.8
Silver	.2	nd(.5)	nd(.5)	nd(.5)	nd	.2	nd	.9	nd(.7)	nd(.4)	nd(.5)	.3	nd	nd(.5)
Strontium	.1	9.2	8	8.4	21.7	.4	40.2	2	15.3	24.7	11.4	.2	50.9	22.5
Uranium	.2	nd(.5)	nd(.5)	nd(.5)	nd	nd	nd	nd	nd(.7)	nd(.4)	nd(.5)	nd(.2)	nd	nd(.5)
Vanadium	.1	.8	.5	nd(.5)	.8	.4	nd	1.6	2.7	.9	1.1	2	nd	1.6
Zinc	.5	123	116	127	95.2	70.3	11.6	1,090	194	403	133	129	18.8	178
Percent water		89.3	88.1	88.5	83.9	64.7	74.8	79	91.3	90.2	89	74.2	75.7	88.9

[1] Detection limit set by the National Water-Quality Laboratory.

[2] Samples were collected in triplicate.

been shown to have a high affinity to sulfhydryl groups on membranes of proteins associated with muscle tissue (Leland and Kuwabara, 1985), and may be the cause of higher concentrations of total mercury in the fillets.

Mercury also was detected in the tissue of *C. fluminea* and in whole *C. gulosus* at some sites. The highest concentrations in *C. fluminea* were from samples collected from the Yuba River site (site 8). This is not surprising because the site is downstream of historic gold mining operations where mercury was used in the processing of gold ore. Although the Bear River site also is downstream of historic gold mining, the tissue concentrations are relatively low, probably because the tissue analyzed consisted of liver from *C. occidentalis*, and mercury typically does not bioconcentrate in liver. Mercury in *C. fluminea* also was slightly elevated relative to other sites at the Arcade Creek site (site 15). The sediments of Arcade Creek had mercury concentrations in excess of average crustal abundance and may be a source of mercury to aquatic organisms.

The bioaccumulation of mercury in *C. fluminea* is unknown. *Catostomus occidentalis* is an omnivorous species and individuals spend a considerable amount of time in the benthic portion of streams where the potential for contact with sedimentary contaminants, such as mercury, is high.

The form of mercury in the environment also influences bioaccumulation. Mercury transported from the Coast Ranges to the site on Cache Creek (site 12) is in the mercury sulfide form, but the form or forms in the sediments of the American River is unknown. Elemental mercury was used in the upper American

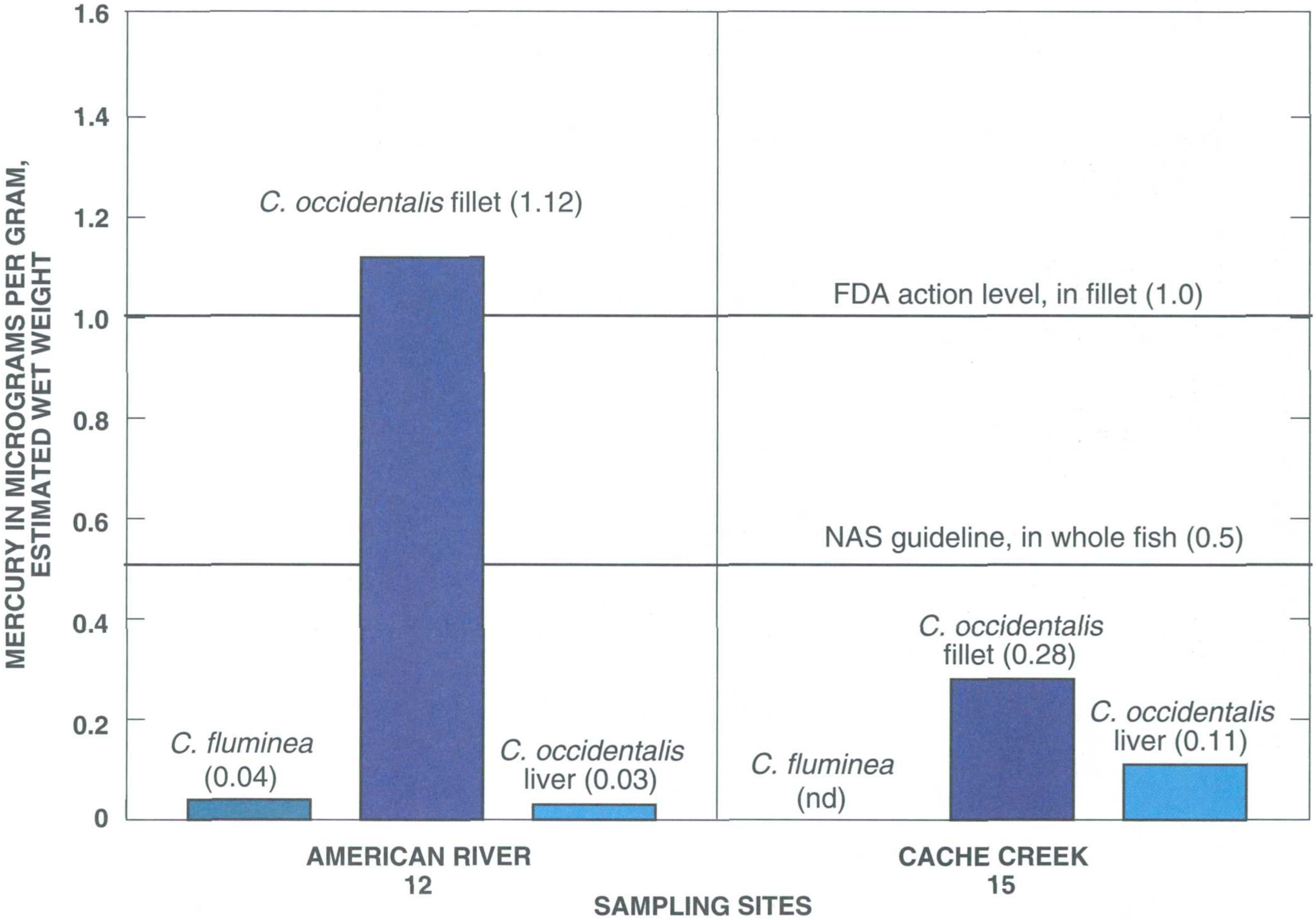

Figure 12. Mercury in biota from the American River and Cache Creek, Sacramento River Basin, California. FDA, U.S. Food and Drug Administration; NAS, National Academy of Science. See table 1 for full site name.

River basin for gold mining processes, but that mercury is subject to oxidation and adsorption onto sedimentary particles after its release to the environment.

Organochlorine Compounds

Of the 28 organochlorine compounds analyzed in aquatic biota, 10 were detected at 11 of the 17 sites. Of the compounds detected, isomers or metabolites of DDT were the most frequently detected in aquatic biota. The higher concentrations of organochlorine compounds were detected in organisms from agricultural drains but the broader range of compounds were detected in organisms from the urban stream. All of the organochlorine pesticides detected in aquatic biota have been banned from commercial and private use.

Organochlorine compounds in agricultural drains

At Colusa Basin Drain (site 13), the anaerobic breakdown products of DDT, *o,p′*-DDD (8.9 µg/kg) and *p,p′*-DDD (56 µg/kg) were detected in whole *C. carpio* tissue (table 6). *o,p′*-DDD (6.5 µg/kg) and *p,p′*-DDD (11 µg/kg) also were detected at another agricultural drain site on Jack Slough (site 7).

The aerobic breakdown product of DDT, *p,p′*-DDE, was detected in biota at 12 sites (table 6; fig. 13). The highest concentrations of *p,p′*-DDE were detected in whole *C. carpio* tissue from the agricultural drain sites at East Canal (site 10; 210 µg/kg) and Colusa Basin Drain (site 13, 560 µg/kg) (fig. 13). None of the DDT or metabolite concentrations in aquatic biota exceeded the FDA action level of 5,000 µg/kg for DDT.

Other organochlorine compounds detected at the Colusa Basin Drain site were dieldrin (18 µg/kg) and toxaphene (220 µg/kg). The toxaphene level exceeds the NAS guideline of 100 µg/kg for organochlorine compounds, which is set for the protection of fish-eating wildlife.

DDD, DDE, or DDT were not detected at the McCloud River or Deer Creek sites. These sites were chosen to represent locations relatively unimpacted by anthropogenic activities.

The aquatic tissue sampled at the McCloud River and Deer Creek sites was from *C. gulosus*, an insectivorous species. Because of the differences of feeding behavior of that organism and those sampled at the agricultural drains (*C. carpio*, *C. fluminea*) direct comparisons are limited. *C. carpio* is a bottom-feeding omnivore and *C. fluminea* is a filter feeder. Both *C. carpio* and *C. fluminea* would be expected to have a higher potential to bioaccumulate organic contaminants relative to *C. gulosus*.

The levels of DDT and its isomers or metabolites measured in the agricultural drains of the Sacramento River system tended to be less than those previously reported by Brown (1998) for the San Joaquin River system. The San Joaquin River system drains the southern part of the Central Valley while the Sacramento River drains the northern part. Differences in land use between the Sacramento and San Joaquin Valleys may account for the lower amounts of organochlorine insecticides measured in the Sacramento River system. Organochlorine insecticides also were detected in biota samples collected from the San Joaquin River (Brown, 1998), but were not detected in biota collected from the Sacramento River.

Organochlorine compounds in Arcade Creek, the urban stream site

Of the 10 organochlorine compounds detected in aquatic biota from the Sacramento River Basin, 8 were found in the tissues of *C. fluminea* from Arcade Creek.

The DDT breakdown products, *p,p′*-DDD (13 µg/kg), *o,p′*-DDD (3.9 µg/kg) and *p,p′*-DDE (11 µg/kg) were detected in *C. fluminea* from Arcade Creek. Additional organochlorine compounds detected in *C. fluminea* for this site were *cis*-chlordane (14 µg/kg), *cis*-nonachlor (4.9 µg/kg), dieldrin (11 µg/kg), *trans*-chlordane (8.4 µg/kg) and *trans*-nonachlor (15 µg/kg). None of the compounds detected exceeded published criteria.

As mentioned previously, organochlorine compounds other than DDD, DDE, and DDT were detected in streambed sediment at the Arcade Creek site. Those compounds were not detected at agricultural sites and their occurrence was attributed to their use for household pest control. The same compounds detected in sediment of Arcade Creek also were detected in the tissue of aquatic organisms.

Organochlorine Compounds at Other River Sites

p,p′-DDD and *p,p′*-DDE were detected in whole *C. fluminea* collected from Freeport (site 17; 5.9 and 40 µg/kg, respectively). *p,p′*-DDE also was detected in *C. fluminea* from Colusa (site 13; 14 µg/kg) and Verona

Table 6. Organochlorine compounds in aquatic biota, Sacramento River Basin, California

[Values given in micrograms per gram, wet weight; nd, not detected or less than detection limit; nd(14), reporting limit different from detection limit due to analytical procedure. Abbreviated site names and corresponding site number in bold. See table 1 for full site name]

Compound	Detection limit[1]	McCloud River **1**	Cottonwood Creek **2**	Deer Creek **4**	Stoney Creek **5**	Sacramento River **6**	Jack Slough **7**	Yuba River **8**		Bear River **9**
		Whole *Cottus gulosus*	Whole *Catastomus occidentalis*	Whole *Cottus gulosus*	Whole *Catastomus occidentalis*	*Corbicula fluminea*		Whole *Cottus gulosus*	*Corbicula fluminea*	Whole *Catastomus occidentalis*
Aldrin	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
cis-Chlordane	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
trans-Chlordane	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dacthal (DCPA)	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Dieldrin	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-DDD	5.0	nd	nd	nd	nd	nd	6.5	nd	nd	nd
o,p′-DDE	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-DDT	5.0	nd	nd	nd(10)	nd	nd(10)	nd(10)	nd	nd	nd
p,p′-DDD	5.0	nd	nd	nd	nd	nd	11	nd	nd	nd
p,p′-DDE	5.0	nd	nd	nd	5.9	14	26	nd	nd	20
p,p′-DDT	5.0	nd	nd	nd(10)	nd	nd(10)	nd(10)	nd	nd	nd
Endrin	5.0	nd(14)	nd(7)	nd	nd	nd	nd	nd	nd	nd
α-HCH	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
β-HCH	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
δ-HCH	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd(6.8)
γ-HCH (lindane)	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor epoxide	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Hexachlorobenzene	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-Methoxychlor	5.0	nd	nd	nd(10)	nd(5.3)	nd(10)	nd	nd	nd	nd(7.4)
p,p′-Methoxychlor	5.0	nd	nd	nd(10)	nd	nd(15)	nd	nd	nd	nd
Mirex	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
cis-Nonachlor	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
trans-Nonachlor	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Oxychlordane	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
PCBs	50.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Pentachloroanisole	5.0	nd	nd	nd	nd	nd	nd	nd	nd	nd
Toxaphene	200	nd	nd	nd	nd	nd	nd	nd	nd	nd
Percent lipids		4.3	6	2	8.1	1.3	1.3	25	2	4.4

Table 6. Organochlorine compounds in aquatic biota, Sacramento River Basin, California—Continued

Compound	Detection limit[1]	East Canal 10	Feather River 11	Cache Creek 12	Colusa Basin Drain 13	Verona 14	Arcade Creek 15	American River 16	Freeport 17
		Whole *Cottus gulosus*	Whole *Catastomus occidentalis*	Whole *Cottus gulosus*	Whole *Catastomus occidentalis*	*Corbicula fluminea*		Whole *Cottus gulosus*	*Corbicula fluminea*
Aldrin	5.0	nd	nd	nd	nd	nd	nd	nd	nd
cis-Chlordane	5.0	nd	nd	nd	nd	nd	14	nd	nd
trans-Chlordane	5.0	nd	nd	nd	nd	nd	8.4	nd	nd
Dacthal (DCPA)	5.0	nd	nd	nd	nd	nd	nd	nd	nd
Dieldrin	5.0	9.8	nd	nd	18	nd	11	nd	nd
o,p′-DDD	5.0	nd(9.4)	nd	nd(8.7)	8.9	nd	3.9	nd	nd
o,p′-DDE	5.0	nd	nd	nd	nd(7.0)	nd	nd	nd	nd
o,p′-DDT	5.0	nd(10)	nd	nd(10)	nd	nd(10)	nd(10)	nd	nd(10)
p,p′-DDD	5.0	32	nd	15	56	nd	13	nd	5.9
p,p′-DDE	5.0	210	31	42	560	25	11	26	40
p,p′-DDT	5.0	nd(10)	nd	nd(10)	nd	nd(10)	nd(10)	nd	nd
Endrin	5.0	nd	nd	nd	nd	nd	nd	nd	nd
α-HCH	5.0	nd	nd	nd	nd	nd	nd	nd	nd
β-HCH	5.0	nd	nd	nd	nd	nd	nd	nd	nd
δ-HCH	5.0	nd(8.7)	nd	nd	nd	nd	nd	nd	nd
γ-HCH (lindane)	5.0	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor	5.0	nd	nd	nd	nd	nd	nd	nd	nd
Heptachlor epoxide	5.0	nd	nd	nd	nd	nd	nd	nd	nd
Hexachlorobenzene	5.0	nd	nd	nd	nd	nd	nd	nd	nd
o,p′-Methoxychlor	5.0	nd(10)	nd	nd(10)	nd	nd(10)	nd	nd	nd(10)
p,p′-Methoxychlor	5.0	nd(10)	nd	nd(10)	nd	nd(10)	nd	nd	nd(10)
Mirex	5.0	nd	nd	nd	nd	nd	nd	nd	nd
cis-Nonachlor	5.0	nd	nd	nd	nd	nd	4.9	nd	nd
trans-Nonachlor	5.0	nd	nd	nd	nd	nd	15	nd	nd
Oxychlordane	5.0	nd	nd	8.8	nd	nd	nd	nd	nd
PCBs	50.0	nd	nd	nd	nd	nd	nd	nd	nd
Pentachloroanisole	5.0	nd	nd	nd	nd	nd	nd	nd	nd
Toxaphene	200	nd	nd	nd	220	nd	nd	nd	nd
Percent lipids		6.5	4	12.7	3.3	1.8	1.4	3.1	2

[1] Detection limit set by the National Water-Quality Laboratory.

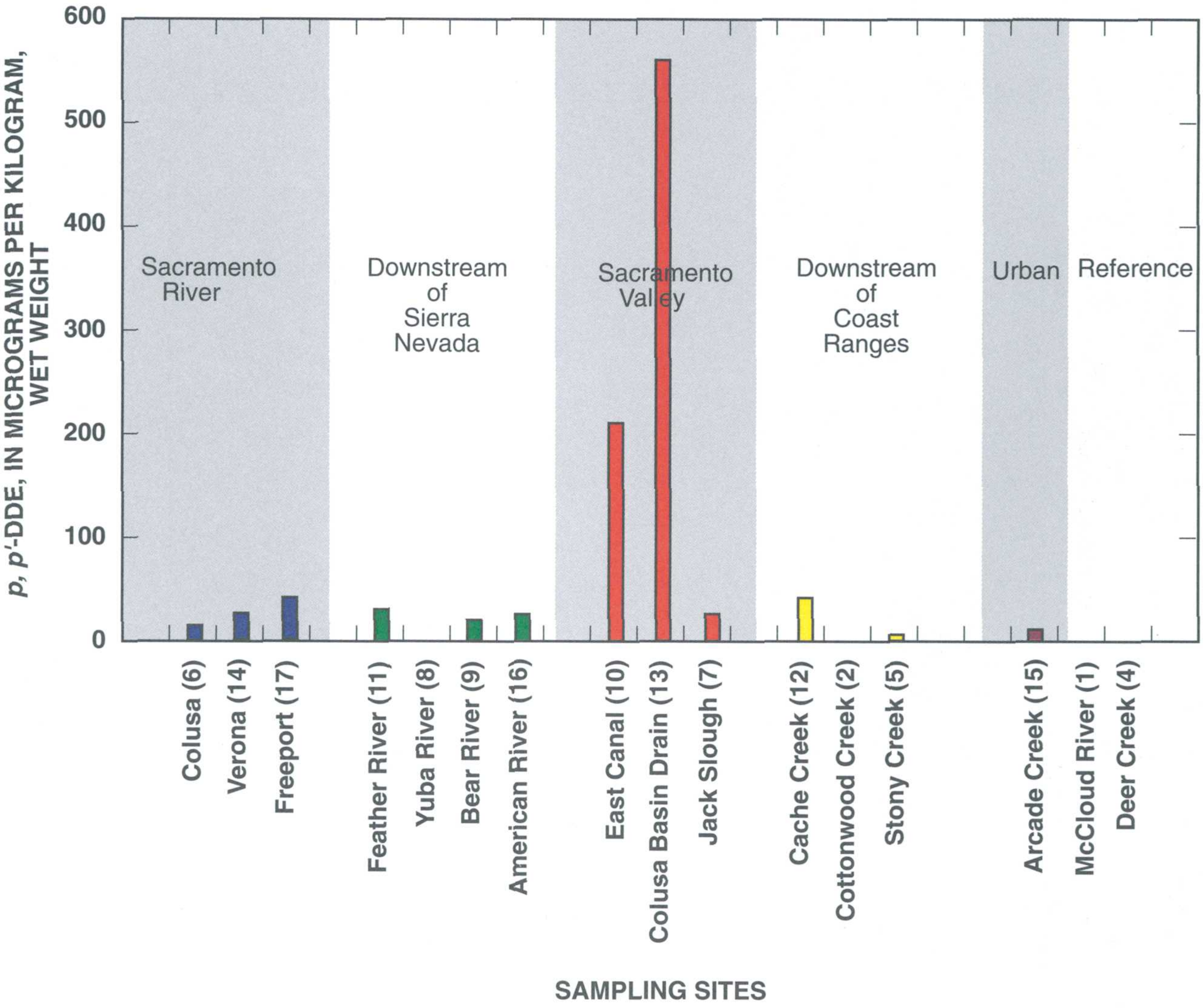

Figure 13. DDE in biota from the Sacramento River Basin, California. See table 1 for full site name.

(site 14; 25 µg/kg). *p,p′*-DDE was detected in biota from Stoney Creek (site 5; 5.9 µg/kg), Bear River (site 9; 20 µg/kg), and American River (site 16; 26 µg/kg). Whole *C. occidentalis* from Cache Creek (site 12) contained oxychlordane (8.8 µg/kg), *p,p′*-DDD (15 µg/kg) and *p,p′*-DDE (42 µg/kg). Most sites with detections of organochlorine compounds were in the Sacramento River Basin agricultural areas.

CONCLUSIONS

Cadmium, copper, and zinc were detected in streambed sediments at the Bend Bridge site (site 3) at levels that could have adverse effects on aquatic organisms. The source of these metals probably is urban runoff from Red Bluff metropolitan area and mining runoff from the West Shasta Mining District. Further study of streambed sediment and aquatic biota from the upper Sacramento River Basin is needed to determine the exact source of these metals.

Lead and zinc were detected in streambed sediments at Arcade Creek (site 15) at levels that may have adverse effects on aquatic organisms. Lead was elevated in *Corbicula fluminea* (*C. fluminea*) taken from this site, as well. The likely source of these trace elements is urban runoff from the Sacramento metropolitan area, but the effects of these trace elements to the aquatic community at this site is not known and requires further study.

Elevated levels of mercury in streambed sediment from the Feather, Yuba, and Bear Rivers (sites 11, 8, and 9, respectively) were detected at levels that may have adverse effects on aquatic organisms. Mercury also was detected in the tissues of aquatic organisms at those sites. Total mercury was detected at levels exceeding U.S. Food and Drug Administration (FDA) action levels in *Catostomus occidentalis* (*C. occidentalis*) fillets sampled from the American River (site 16). Elevated levels of mercury at this site are probably the result of transport from historic mining operations located upstream. Total mercury was detected in *C. occidentalis* fillets from the Cache Creek site (site 12) as well, but at levels that do not exceed FDA action levels. The possible sources of mercury in Cache Creek are upstream geologic formations and historical mercury mines. The exact source and significance of the elevated mercury levels in the *C. occidentalis* fillets needs further investigation. It was concluded by this study that fish fillet data were the best sources for determining the bioavailability and distribution of total mercury in Cache Creek and the American River. Further information is needed on the forms of mercury at these locations to better understand bioavailability or the potential for bioaccumulation

Few semivolatile organic compounds were detected in streambed sediments throughout the Sacramento River Basin. The semivolatile compound with the highest concentration was the coal tar derivative, *p*-cresol which was detected in the streambed sediments of Deer Creek (site 4), Cottonwood Creek (site 2), McCloud River (site 1), Cache Creek (site 12), Bear River (site 9), and Colusa (site 13). The possible source of this compound could be the maintenance of dirt roads in the area, but further investigation is required to determine the actual source. Of all the sites sampled, Arcade Creek (site 5) had the most detections of semivolatile organic compounds.

Residues of DDT and its isomers or metabolites were detected in sediment or biota at agricultural drainage sites. In most cases, the levels were below regulatory levels. Organochlorine compounds were generally not detected in the Sacramento River samples.

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