Water Quality in the Sacramento River Basin

California, 1994–98

U.S. Department of the Interior
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http://water.usgs.gov/nawqa/

Sacramento River Basin contact and Web site:

Joseph Domagalski
U.S. Geological Survey
Water Resources Division
Placer Hall, 6000 J Street,
Sacramento, CA 95819-6129
e-mail: joed@usgs.gov
http://water.wr.usgs.gov/sac_nawqa/index.html

National NAWQA Program:

Chief, NAWQA Program
U.S. Geological Survey
Water Resources Division
12201 Sunrise Valley Drive, MS 413
Reston, VA 20192
http://water.usgs.gov/nawqa/

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Front cover: Aerial view of the Sacramento River in the Sacramento Valley (Rand Schaal, Ph.D., pilot and photographer).

Back cover: Left, Collection of water samples during high flow conditions on the Sacramento River; right, Collection of samples of aquatic organisms and assessment of habitat conditions at a northern California headwaters stream.

Water Quality in the Sacramento River Basin, California,1994–98

By Joseph L. Domagalski,[1] Donna L. Knifong,[1] Peter D. Dileanis,[1] Larry R. Brown,[1] Jason T. May,[2] Valerie Connor,[3] *and* Charles N. Alpers[1]

[1]U.S. Geological Survey, Placer Hall, 6000 J Street, Sacramento, CA 95819-6129

[2]California State University Foundation, 6000 J Street, Sacramento, CA 95819-6063

[3]Central Valley Regional Water Quality Control Board, 3443 Routier Road, Sacramento, CA 95827-3098

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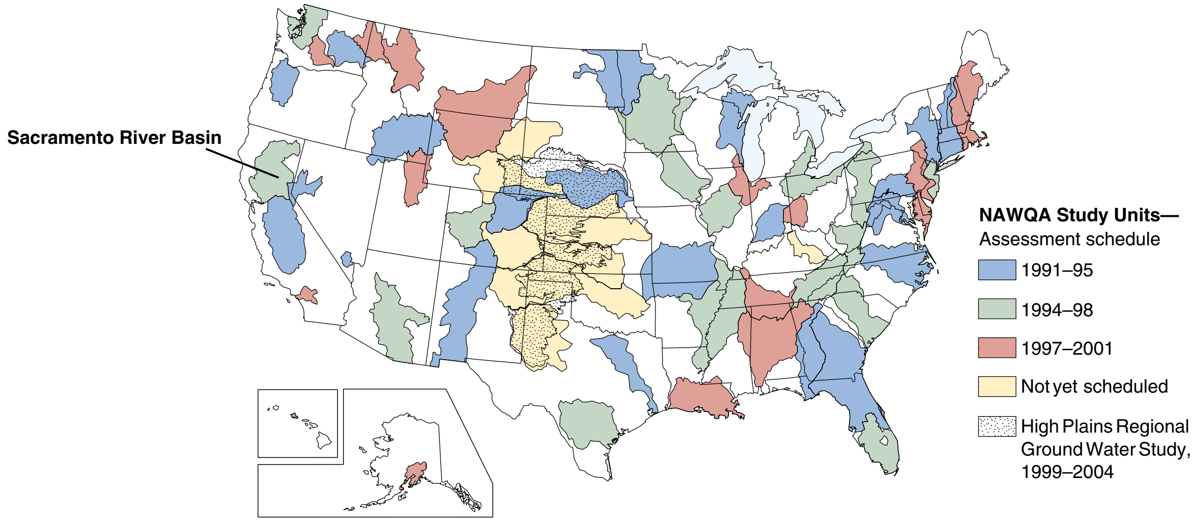
CONTENTS

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

THIS REPORT summarizes major findings about water quality in the Sacramento River Basin that emerged from an assessment conducted between 1994 and 1998 by the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Water quality is discussed in terms of local and regional issues and compared to conditions found in all 36 NAWQA study areas, called Study Units, assessed to date. Findings are also explained in the context of selected national benchmarks, such as those for drinking-water quality and the protection of aquatic organisms. The NAWQA Program was not intended to assess the quality of the Nation's drinking water, such as by monitoring water from household taps. Rather, the assessments focus on the quality of the resource itself, thereby complementing many ongoing Federal, State, and local drinking-water monitoring programs. The comparisons made in this report to drinking-water standards and guidelines are only in the context of the available untreated resource. Finally, this report includes information about the status of aquatic communities and the condition of in-stream habitats as elements of a complete water-quality assessment.

Many topics covered in this report reflect the concerns of officials of State and Federal agencies, water-resource managers, and members of stakeholder groups who provided advice and input during the Sacramento River Basin assessment. Basin residents who wish to know more about water quality in the areas where they live will find this report informative as well.



THE NAWQA PROGRAM seeks to improve scientific and public understanding of water quality in the Nation's major river basins and ground-water systems. Better understanding facilitates effective resource managment, accurate identification of water-quality priorities, and successful development of strategies that protect and restore water quality. Guided by a nationally consistent study design and shaped by ongoing communication with local, State, and Federal agencies, NAWQA assessments support the investigation of local issues and trends while providing a firm foundation for understanding water quality at regional and national scales. The ability to integrate local and national scales of data collection and analysis is a unique feature of the USGS NAWQA Program.

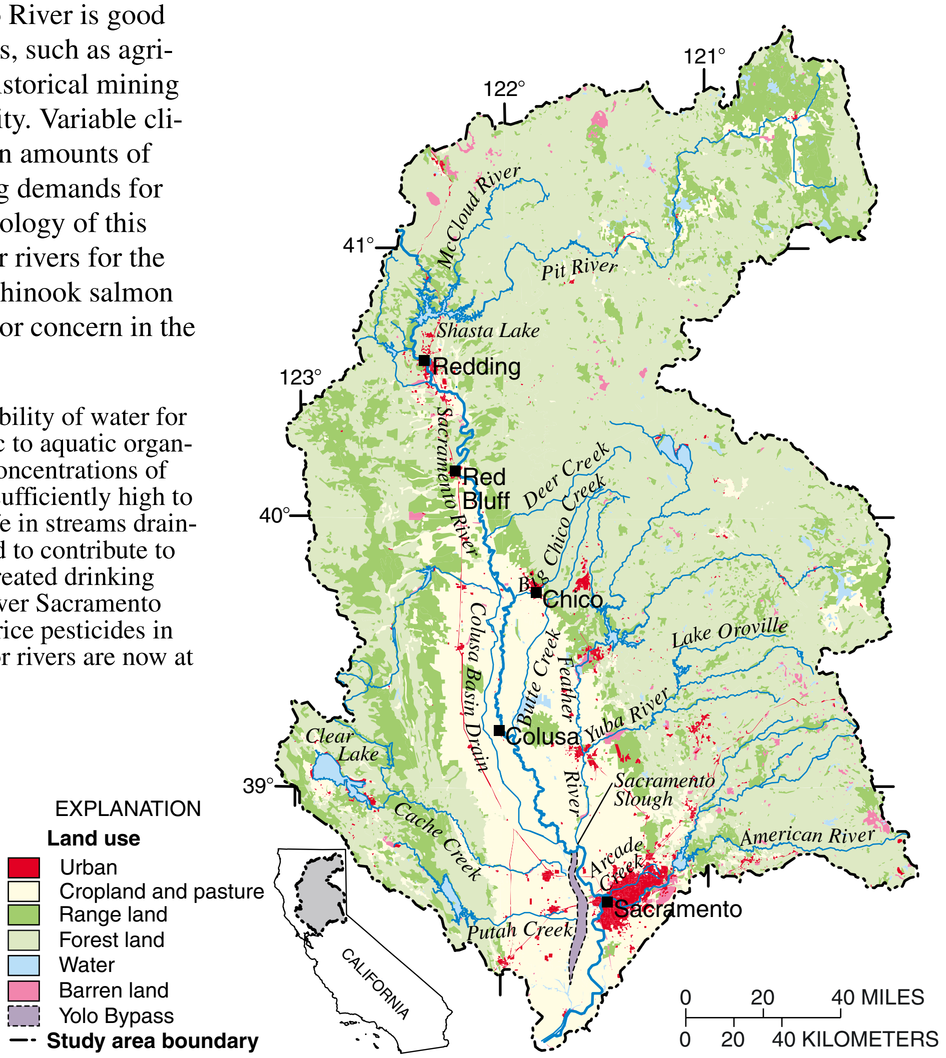
The Sacramento River Basin is one of 51 water-quality assessments initiated since 1991, when the U.S. Congress appropriated funds for the USGS to begin the NAWQA Program. As indicated on the map, 36 assessments have been completed, and 15 more assessments will conclude in 2001. Collectively, these assessments cover about one-half of the land area of the United States and include water resources that are available to more than 60 percent of the U.S. population.

SUMMARY OF MAJOR FINDINGS

Stream and River Highlights

The water quality of the Sacramento River and its major tributaries supports most beneficial uses most of the time, including drinking and irrigation water, recreation, and protection of fish and other aquatic life. Most of the water in the Sacramento River and its major tributaries, such as the Feather and American rivers, is derived from melting snow that enters the rivers by managed discharges of water from reservoirs. Because the snow is pure, much of the Sacramento River and its large tributaries have low concentrations of dissolved minerals. Although water quality of the Sacramento River is good most of the year, seasonal events, such as agricultural runoff or runoff from historical mining operations, may affect this quality. Variable climatic conditions and variation in amounts of rainfall, coupled with competing demands for water uses, affect the aquatic ecology of this basin. Management of the major rivers for the migration and reproduction of chinook salmon and other salmonid fish is a major concern in the Sacramento River Basin.

- Pesticides can affect the suitability of water for drinking and can also be toxic to aquatic organisms. In previous years, the concentrations of pesticides used on rice were sufficiently high to affect the health of aquatic life in streams draining the rice growing areas and to contribute to taste and odor problems for treated drinking water withdrawn from the lower Sacramento River. The concentrations of rice pesticides in agricultural streams and major rivers are now at acceptable levels.
- Organophosphate insecticides, a group of pesticides used in agricultural and urban areas, enter the Sacramento River from multiple sources at concentrations that exceed recommended criteria for protection of aquatic life. Although the concentrations in agricultural and urban streams sometimes exceed amounts that are toxic to zooplankton in laboratory tests, the toxicity is greatly reduced or eliminated when concentrations of these pesticides are diluted by the Sacramento River.
- Phosphorus, a plant nutrient related to algal growth, was elevated in most samples collected in agricultural and urban streams.
- Mercury from historical mining activities has been a pervasive and prevalent problem of the Sacramento River Basin and downstream locations. Mercury concentrations in water exceeded recommended guidelines for the protection of aquatic life during this study.
- Salmonid fish reproduce in mountain streams, with subsequent migration to marine waters and final migration back to the mountain streams for reproduction. Water management projects (reservoirs and dams) have blocked the normal migration routes, forcing fish to move to less desirable habitats, thus affecting their reproduction.

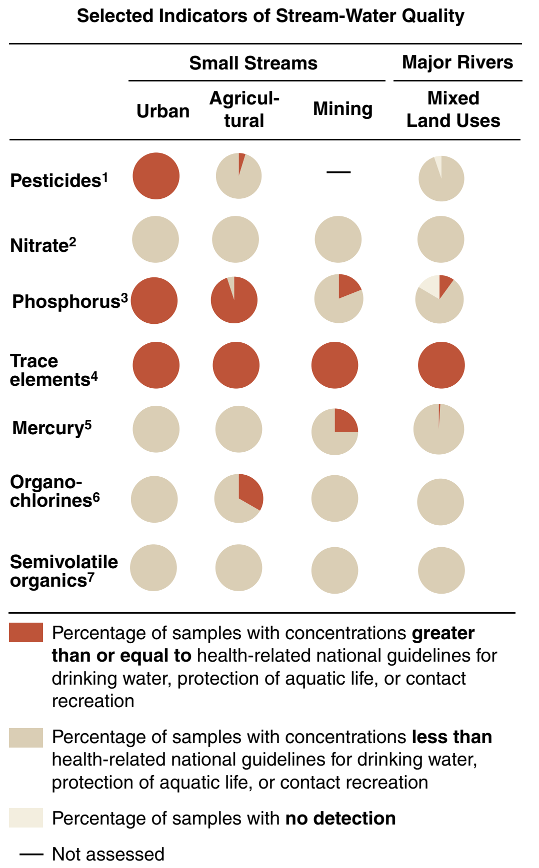


The Sacramento River Basin Study Unit has a wide range of land uses that encompass about 70,000 square kilometers in California. The large cropland and pasture area is known as the Sacramento Valley. The Sacramento River is the largest river in California and supplies drinking and irrigation water to communities and farms in both northern and southern California. In 1995, over 2.2 million people lived within the Study Unit boundary, with more than 1 million in the Sacramento metropolitan area.

- Optimal temperature of rivers for fish migration is maintained most of the time, but temperature management can be difficult during a drought.
- Reservoirs have affected habitats of bottom-dwelling aquatic insect populations downstream from the dams. This may affect the food supply for critical life stages of fish.
- Nonnative fish and other nonnative aquatic species have affected streams in the Sacramento Valley. Nonnative species may outcompete native species, resulting in new aquatic community assemblages, thus creating an imbalance in formerly stable ecosystems.

Major Influences on Streams and Rivers

- Year-to-year variation in precipitation amounts
- Runoff from agricultural, urban, and mining areas
- Existence and maintenance of water-supply and flood-control projects



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[1] Insecticides, herbicides, and pesticide metabolites, sampled in water.
[2] Nitrate (as nitrogen), sampled in water.
[3] Total phosphorus, sampled in water.
[4] Arsenic, mercury, and metals, sampled in sediment.
[5] Total mercury in unfiltered water samples.
[6] Organochlorine compounds including DDT and PCBs, sampled in fish tissue.
[7] Miscellaneous industrial chemicals and combustion by-products, sampled in sediment.

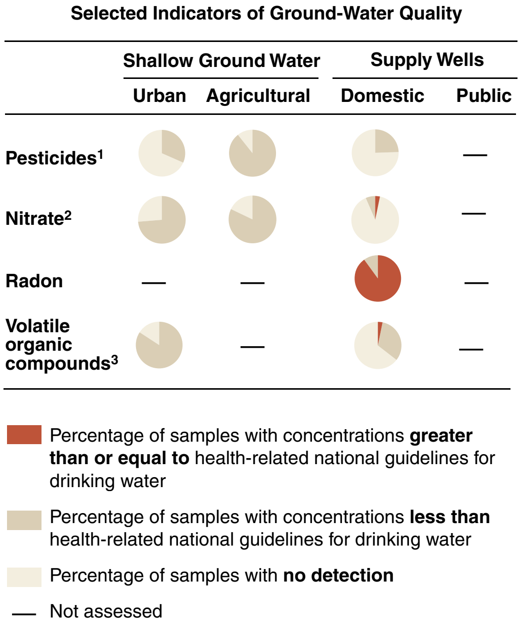
Ground-Water Highlights

Ground water of the Sacramento Valley accumulated in aquifers from precipitation in low hills surrounding the valley and from infiltration of rain, rivers, and irrigation on the valley floor. Ground water is affected by agricultural and urban land uses.

- Bentazon, a herbicide applied to rice fields, was detected in 71 percent of shallow wells sampled in the rice-growing area, despite having been suspended from use since 1989. Bentazon concentrations measured in this study did not exceed any existing drinking-water standard. To protect rivers from pesticide contamination, the rice-field water is required, by means of mechanical controls, to remain on the fields for about 1 month. During that time, pesticide levels decrease by various processes, but evaporation of the water may increase the salinity of the shallow ground water by leaving salts behind.
- Urban growth of the Sacramento metropolitan area has affected ground-water quality. Nitrate concentrations are elevated but are below drinking-water standards in most wells.
- Some of the most heavily used portion of the southeastern Sacramento Valley aquifer was shown to generally have good water quality suitable for drinking and other uses. Only about 3 percent of the ground-water samples collected had nitrate or trichloroethene concentrations that exceeded a drinking-water standard. Radon concentrations exceeded guidelines in most of the domestic wells sampled.

Major Influences on Ground Water

- Agricultural and urban land-use practices
- Soil and aquifer properties



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[1] Insecticides, herbicides, and pesticide metabolites, sampled in water.
[2] Nitrate (as nitrogen), sampled in water.
[3] Solvents, refrigerants, fumigants, and gasoline compounds, sampled in water.

INTRODUCTION TO THE SACRAMENTO RIVER BASIN

The Sacramento River Basin occupies nearly 70,000 square kilometers (km^2) in the north central part of California (fig. 1). The Sacramento River is the largest river in California, with an average annual runoff of 27 billion cubic meters (m^3) (Domagalski and Brown, 1998). The basin includes all or parts of six landforms or physiographic provinces—the Great Basin, the Middle Cascade Mountains, the Sierra Nevada, the Klamath Mountains, the Coast Ranges, and the Sacramento Valley (fig. 1). The Sacramento Valley is the low-lying province of the basin; the other provinces are mountainous. Land use in the mountainous regions of the basin is principally forest, although forest

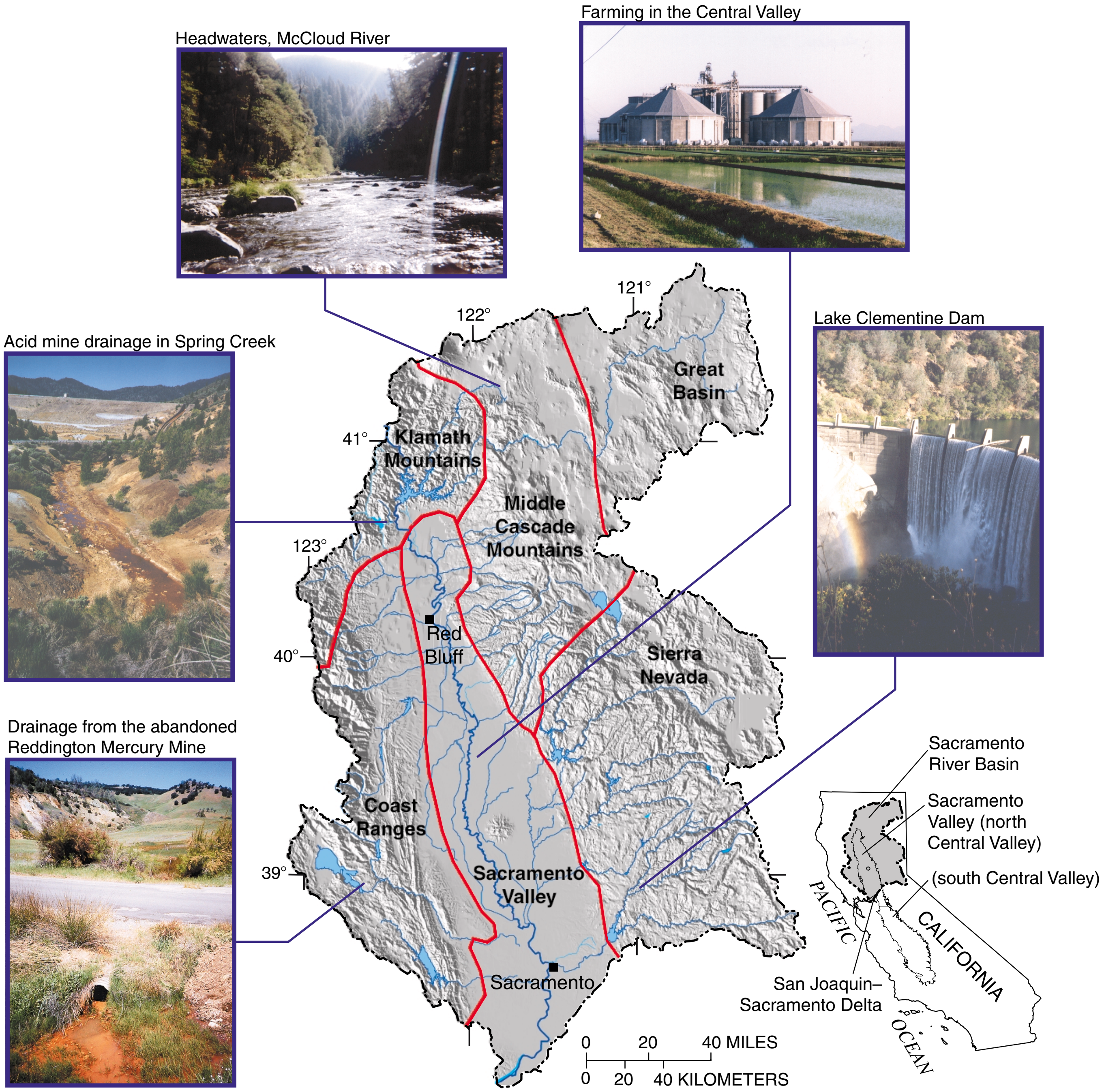


Figure 1. Physiographic provinces in the Sacramento River Basin. Physiographic provinces are regions defined principally by geologic and topographic features.

and rangeland are mixed in regions of the Coast Ranges and the Great Basin. Domagalski and others (1998) have provided more information on the physiographic provinces of the Sacramento River Basin.

The Sacramento Valley is the northern portion of the Central Valley of California and is fully contained in the Study Unit. The Sacramento Valley has the greatest population of any part of the basin, and it is there that the greatest effects or potential effects on surface and ground water are likely to occur from land-use activities. The Sacramento Valley is also the area of greatest water use in the basin.

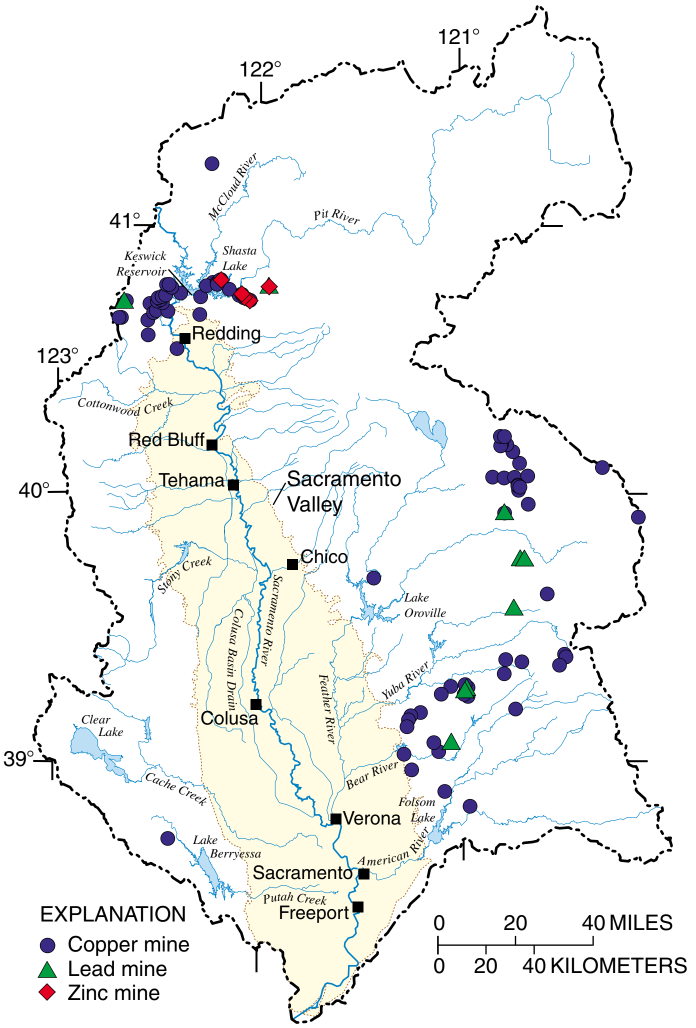
Land-Use Effects on Water Quality and Stream Habitat

The Sacramento Valley supports a diverse agricultural economy, much of which depends on the availability of irrigation water. Water is collected in reservoirs at several locations within the mountains surrounding the Sacramento Valley and is released according to allocations for agricultural, urban, and environmental needs. The reservoirs also are managed for flood control. The reservoirs provide flood protection and allow the storage of water during dry years, but the placement of dams at the reservoirs has blocked migration routes for salmonid fish.

More than 8,000 km^2 of the Sacramento Valley are irrigated. The major crops are rice, fruits, nuts, tomatoes, sugar beets, corn, alfalfa, and wheat. Dairy products also are an important agricultural commodity. The land areas adjacent to the Sacramento Valley are mostly forested (fig. 1).

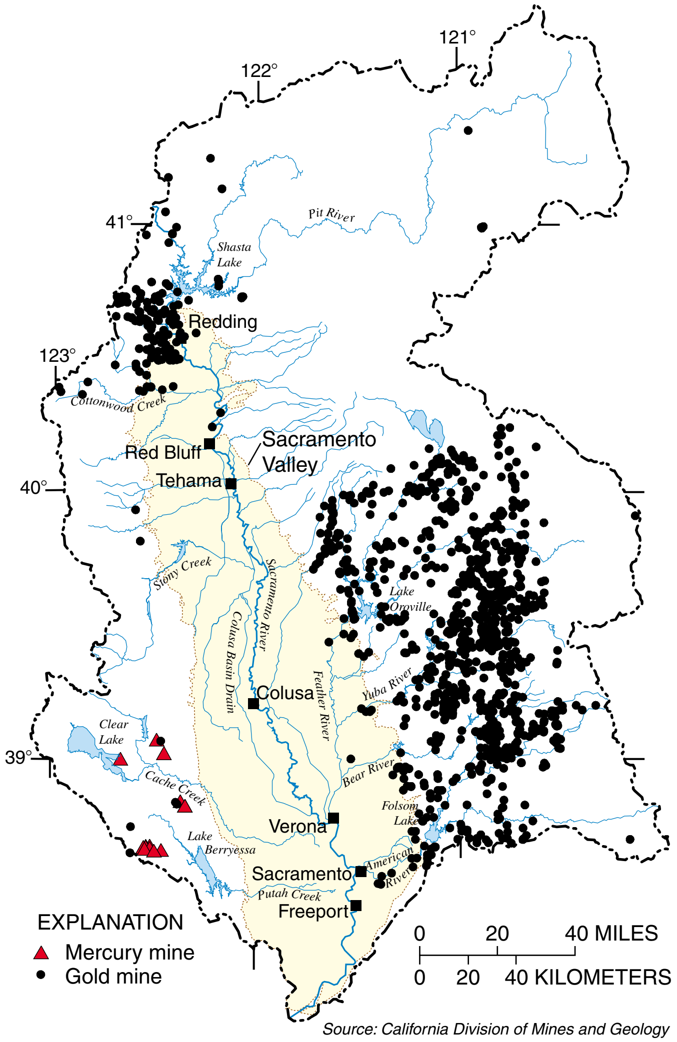
The largest cities of the basin are in the Sacramento Valley and include Chico, Red Bluff, Redding, and Sacramento. The Sacramento metropolitan area is home to more than 1 million people, which is nearly half of the total population (U.S. Department of Commerce, 1992) in the basin.

Previous mining for copper, lead, and zinc (fig. 2) in the Klamath Mountains has resulted in acid mine drainage (drainage of acidic waters from mines) into part of Keswick Reservoir, which is located immediately downstream from Shasta Lake. The drainage includes both mined metals and nonmined metals such as cadmium. Mercury that was used in previous mining within the Coast Ranges (fig. 3) enters the Sacramento Valley through Cache and Putah creeks. Although neither creek flows directly into the Sacramento River during low-flow conditions, the load of mercury can be transported to downstream receiving waters, including the San Francisco Bay, during stormwater runoff



Source: California Division of Mines and Geology

Figure 2. Locations of copper, lead, and zinc mines. The most severe case of drainage of acidic waters from mines has been in the region near Shasta Lake.



Source: California Division of Mines and Geology

Figure 3. Locations of gold and mercury mines. The era of gold mining began in 1849 after the discovery of placer deposits in the American River.

conditions. Mercury also can enter the Sacramento River from the Sierra Nevada, where it was used in historical gold mining (fig. 3).

Water Use in California

Water storage, transportation, and allocation in California are strategically managed to take into account the wide diversity of the State's geography and physiography. Water is stored in nonpopulated areas of California and then transferred by natural stream channels or man-made canals to areas of demand. Reservoirs within the Sacramento River Basin have been constructed in the mountainous areas just adjacent to the valley. All major rivers of the Sacramento River Basin have one or more reservoirs, which were constructed during the late 1940s to late 1960s mainly for flood control. Storage capacity of the reservoirs is managed to capture runoff from winter storms. However, stored water is not used solely in the Sacramento River Basin; it is transported to other locations in California and is a major source of supply for Los Angeles and other southern California communities.

Total water use in the Sacramento River Basin is about 18 billion cubic meters per year (m^3/yr). Allocations of water for agricultural, urban, and environmental uses are made according to the California water plan (California Department of Water Resources, 1998) but are modified on the basis of the yearly conditions of reservoir storage. For example, during drought years, total allocations are decreased. Pie charts in figure 4 show the percentage of allocations during average years of rainfall for 1995 and projected for 2020. Of those allocations, surface water provides 82 percent and ground water 18 percent of the total demand. During drought years, surface water drops to about 75 percent and ground water rises to about 25 percent of total demand.

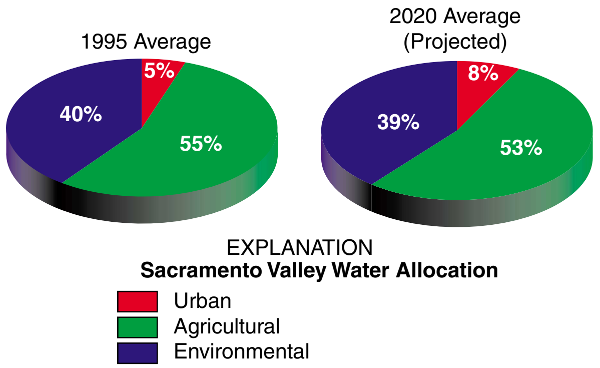


Figure 4. Water allocations for average rainfall years for 1995 and projected for 2020.

Effects of Hydrologic Conditions on Study Results

The average annual precipitation for the entire Sacramento River Basin is 914 millimeters (mm), most of which falls as rain or snow during November through March. Because little or no rain falls during the summer growing season, irrigation is required for successful agriculture. Most of the water-quality samples for the Sacramento River Basin study were collected between the fall of 1995 and the spring of

1998, which covered a series of wet winters. Precipitation amounts in northern California are variable and dependent on the location of the Pacific jet stream. The average annual rainfall at the city of Sacramento is about 460 mm. Since the 1940s, however, as little as 140 mm and as much as 915 mm have been recorded in a year.

Two major hydrological events occurred during the period of this study. The first, a major flood, occurred during the winter of 1996–97. Flooding began on January 1, 1997, and affected a major part of the Sacramento River downstream from Shasta Lake as well as tributaries to the Sacramento River, especially the Feather and Yuba rivers. Some streams, such as the Yuba River, had the highest recorded streamflow following the rainfall associated with the flood of January 1, 1997 (fig. 5). The second major hydrological event was the El Niño episode of 1997–98. The term "El Niño" refers to an "ocean–atmosphere phenomenon" during which wind and ocean current in the equatorial Pacific result in warmer-than-normal water along the North and South American Pacific coasts. El Niño winters frequently bring higher-than-normal precipitation in northern California because of a southward shift of the storm tracks and jet stream over North America.

Study Design Focuses on Land Use

Chemical and biological samples were collected from rivers and streams within, or downstream from, forested, urban, agricultural, and mining areas to assess overall quality and effects of specific land-use practices. In most cases, river or stream sampling sites were located in the Sacramento Valley—the region of both the highest water use and where many potential effects on water quality had occurred and are likely to occur. At some sites, water samples were collected monthly and during storms to assess the effects of storm runoff on contaminant transport. Other sites were sampled only monthly, usually during normal flows. Shallow ground water was sampled from three areas—the highly used part of the southeastern Sacramento Valley aquifer, downstream from rice fields, and downstream from the recently urbanized area of metropolitan Sacramento. Domestic wells (existing wells) were sampled for the southeastern Sacramento Valley aquifer study area, whereas monitoring wells (drilled for this study) were sampled for the rice and urban land-use study areas.

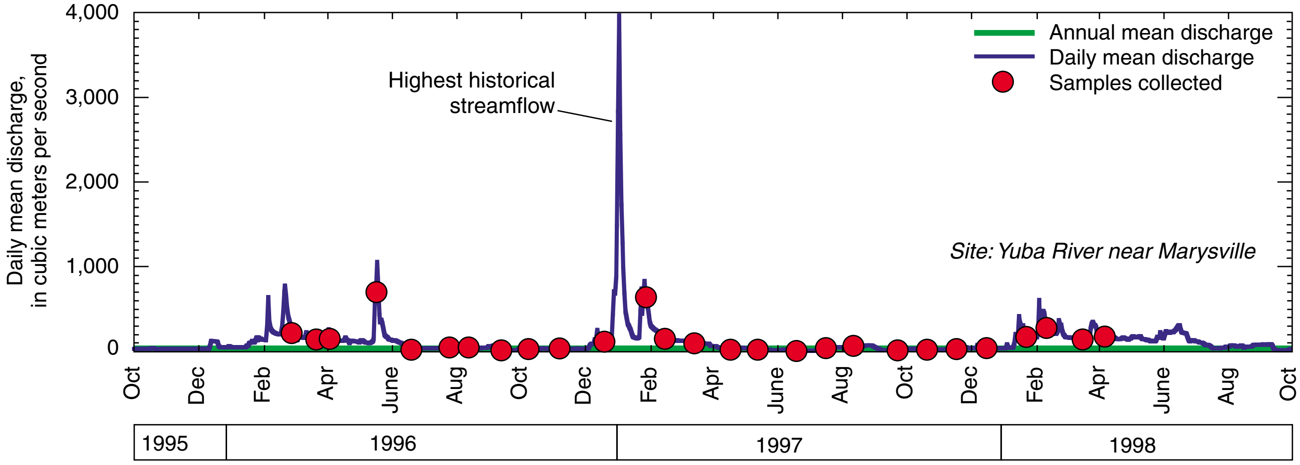


Figure 5. Yuba River hydrograph. The highest recorded discharge for the lower Yuba River occurred shortly after a large rainfall on January 1, 1997.

Surface Water

Water of the Sacramento River and its major tributaries is generally of good quality; the source is snow that melts and collects in upstream reservoirs and is released in response to water needs or flood control. The amount of dissolved solids in the Sacramento River and its major tributaries (Yuba, Feather, and American rivers) was low at all of the sampled locations (fig. 6). Higher median concentrations of dissolved solids occurred at agricultural sites such as the Sacramento Slough and Colusa Basin Drain, but those are diluted upon mixing with Sacramento River water (Domagalski and Dileanis, 2000). Nutrient concentrations such as nitrate also were low throughout the Sacramento River Basin (Domagalski and Dileanis, 2000) (fig. 7), and drinking-water standards for nitrate were not exceeded during the course of this study. At some locations, algae attached to streambed material was abundant, indicating that further investigation of nutrient dynamics and their consequences to the streams of this watershed is warranted. Excess algal growth, which is usually related to higher-than-normal nutrient inputs to streams, is a water-quality concern when the algae affect the aquatic community (because of dissolved oxygen depletion). No such effects were observed in the Sacramento River or its major tributaries. Excess algae also can contribute to taste and odor problems in drinking water.

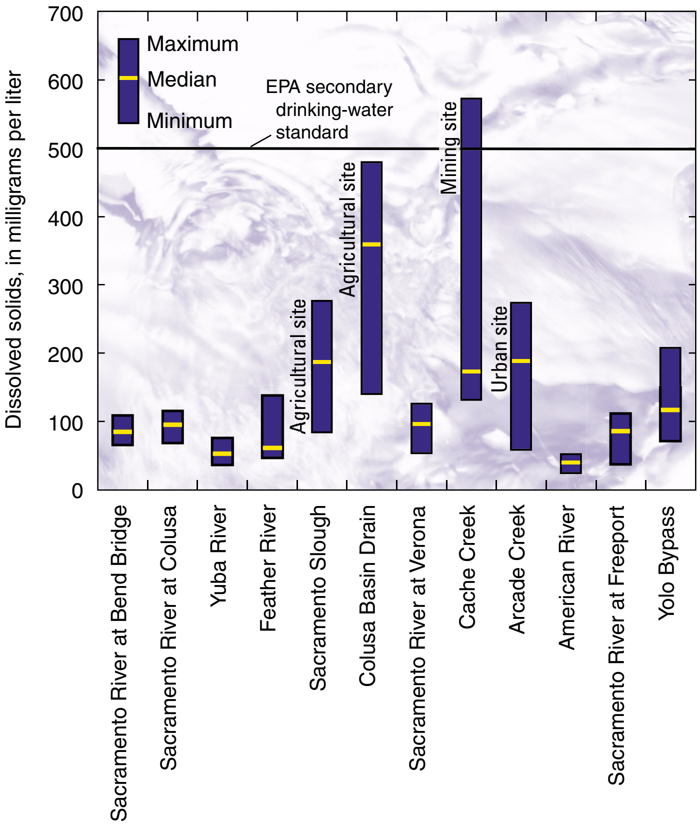


Figure 6. Concentrations of dissolved solids at the fixed sites. The highest concentrations were measured at the agricultural, mining, and urban sites. (EPA, Environmental Protection Agency)

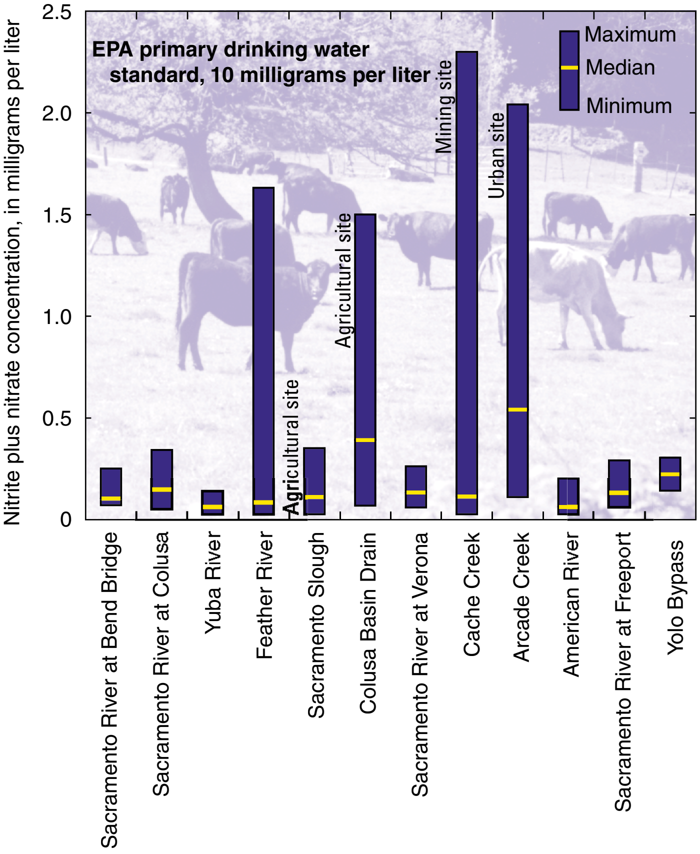
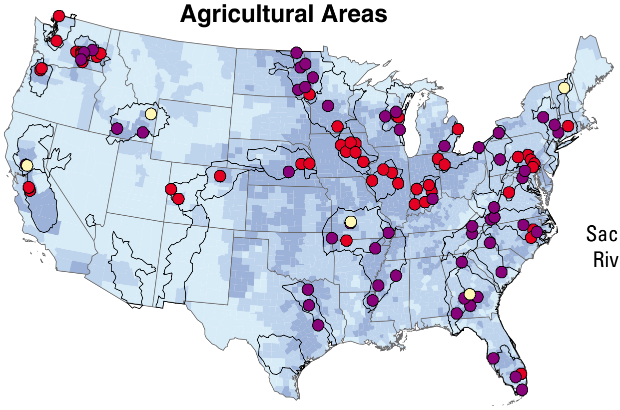


Figure 7. Concentrations of nitrite plus nitrate at the fixed sites. The highest concentrations were measured at the mining and urban sites.

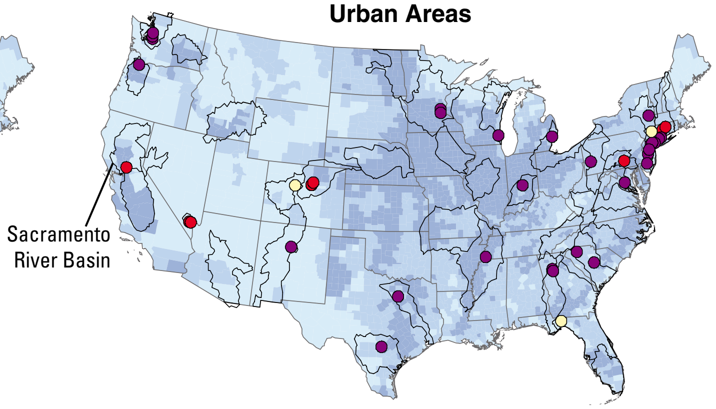
Some stream segments are listed as “impaired” by various contaminants (U.S. Environmental Protection Agency, accessed January 2, 2000). An impairment means that a standard of water quality for beneficial uses (for example, as a source of drinking water or for recreation or industrial use) is not being met. The impaired water bodies shown in figure 8 are mainly affected by nonpoint sources of contaminants from agriculture or from a combination of point and nonpoint sources from abandoned mines. Water-quality objectives are usually not met only during conditions of stormwater-driven runoff. The Clean Water Act requires States to maintain a listing of

NUTRIENTS IN A NATIONAL CONTEXT

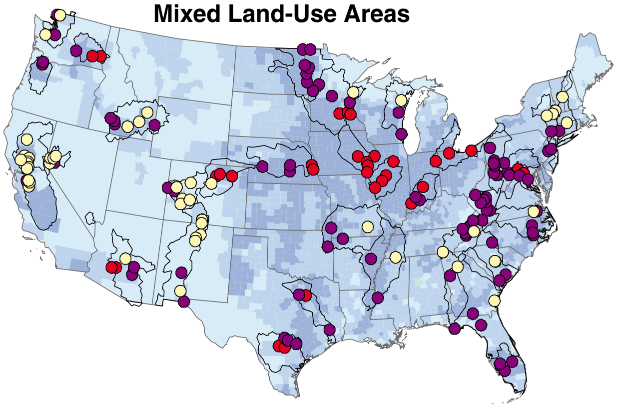
Nutrient concentrations in the streams of mixed land-use and agricultural regions of the Sacramento River Basin tend to be lower relative to those measured in other areas of the United States with similar fertilizer applications within their watersheds. The maps show nitrogen; phosphorus concentrations have a very similar pattern. Elevated concentrations of nitrogen or phosphorus can stimulate nuisance growth of algae. The nutrient concentrations tend to be less than those of adjacent areas in California, agricultural areas of the Pacific Northwest, and large areas of the midcontinent region. In contrast to mixed land-use streams, nutrient concentrations of the urban stream are among the highest of similar urban streams throughout the United States. The lower concentrations in streams of mixed land-use probably can be attributed to dilution by streamflow. The Sacramento River and its major tributaries are derived from melting snow, which has low nutrient concentrations. These rivers tend to dilute the agricultural drainage, and therefore nutrient concentrations remain low in the major rivers. In addition, some instream processes remove nutrients, such as algal growth that incorporates nutrients in algae biomass. The urban stream, Arcade Creek, is entirely within an urbanized area, and all runoff to the stream is affected by that urban land use. The only inputs of water to Arcade Creek are from impacted land. The range in nutrient concentrations for all NAWQA Study Units is shown in the Appendix.



Streams Draining Agricultural Areas



Streams Draining Urban Areas



Streams Draining Mixed Land-Use Areas

EXPLANATION

Average annual concentration of total nitrogen, in milligrams per liter

- 🔴 Highest (greater than 2.9)
- 🟣 Medium (0.64 to 2.9)
- ○ Lowest (less than 0.64)

Average annual total nitrogen input, in kilograms per square kilometer by county for 1995–98. Inputs are from fertilizer, manure, and the atmosphere.

- ▨ Greater than 2,801
- ▨ 672 to 2,801
- ▨ Less than 672

— **NAWQA Study Unit boundary**

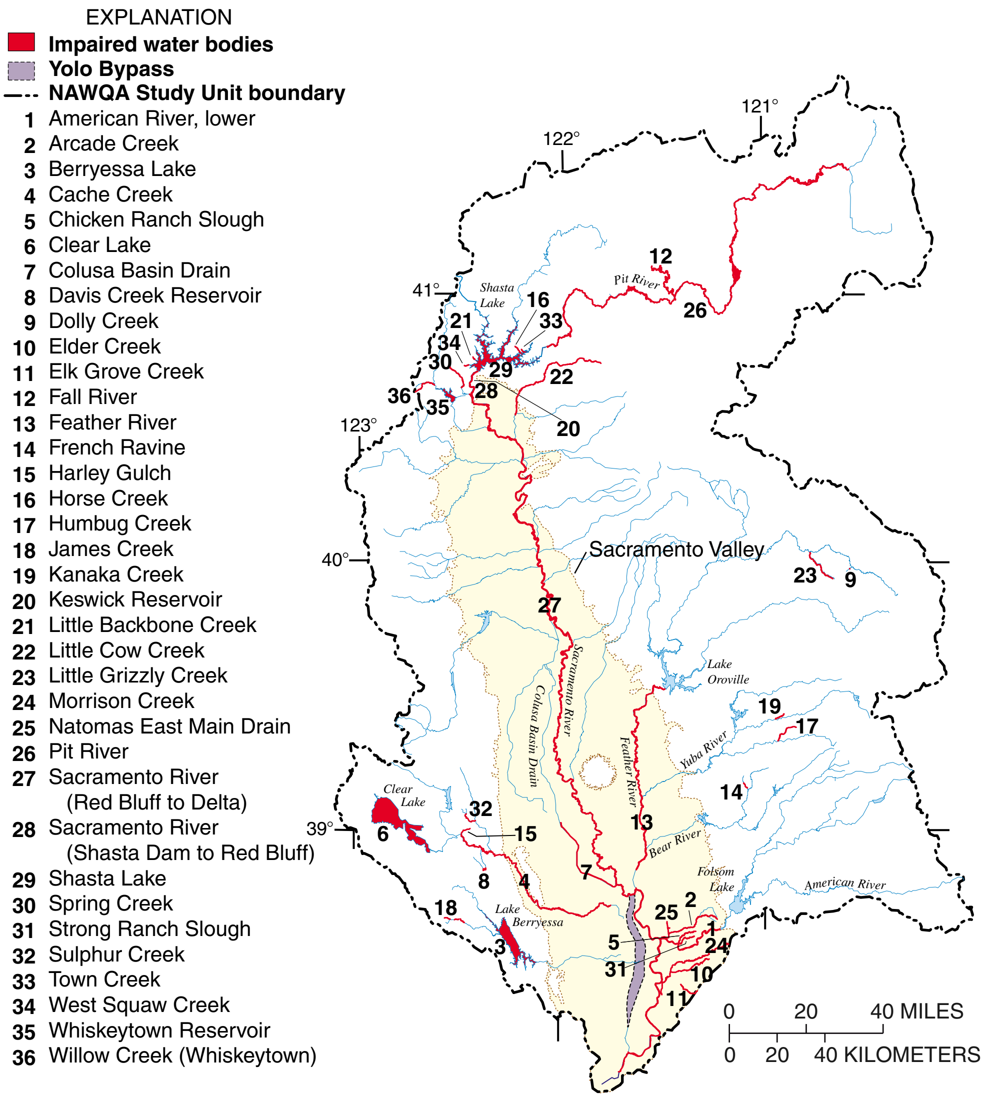


Figure 8. Impaired water bodies of the Sacramento River Basin according to the California 303(d) list (U.S. Environmental Protection Agency, accessed January 2, 2000). Impaired water bodies require the implementation of a management plan called a Total Maximum Daily Load (TMDL) to bring the water body into compliance with existing standards. Most of the impairments are the result of pesticides from agricultural or urban use, or from metals derived from historical mining operations.

impaired water bodies for the purpose of establishing a Total Maximum Daily Load (TMDL). A TMDL is a plan to restore the beneficial uses of the stream or to otherwise correct the impairment. The most prevalent listings in the Sacramento River Basin are for organophosphate pesticides and mercury, for which TMDLs currently are being considered.

Pesticides in Surface Water

The concentrations of molinate and other pesticides (used in rice farming) measured during this study in the Colusa Basin Drain or in the Sacramento River, represent a significant improvement over concentrations measured in previous years (Domagalski, 2000). The major pesticides that have been used on rice are molinate, thiobencarb, and carbofuran. Rice farming requires that fields be flooded with water throughout the growing season. Molinate and thiobencarb are applied to control aquatic grasses and weeds, whereas carbofuran is applied to control insects. During the late 1970s, the levels of rice pesticides in the Colusa Basin Drain were sometimes acutely toxic to fish such as carp (*Cyprinus carpio*) (Bennett and others, 1998). The toxicity was attributed to molinate.

In the early 1980s, consumers of drinking water in the city of Sacramento reported an objectionable taste, which was attributed to thiobencarb. A management program was enacted to reduce the levels of these pesticides in streams. The plan requires that rice-field water be retained on fields for 1 month following pesticide application to allow concentrations in water to be reduced through mechanisms such as volatilization, biological processes, or sunlight-induced degradation. Sampling of rice pesticides during this study showed that concentrations occasionally were in excess of management objectives in agricultural streams but always were very low in the Sacramento River (fig. 9). A target concentration

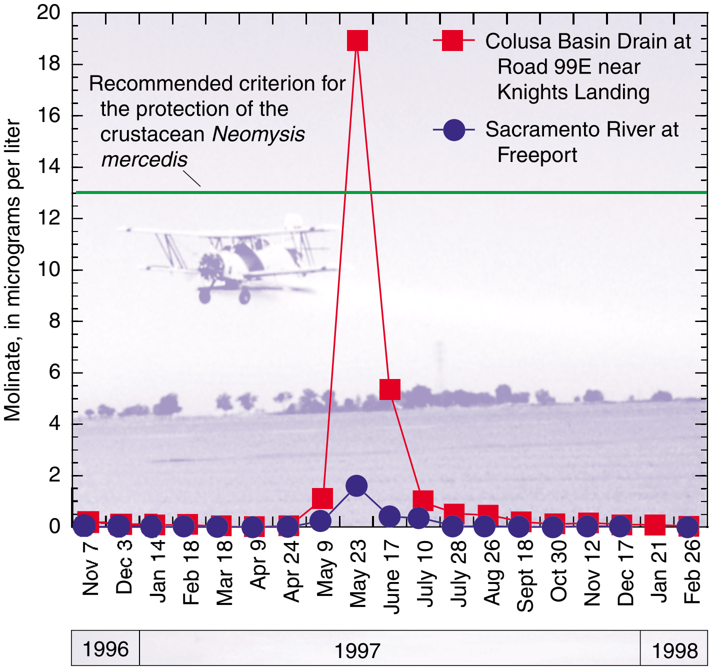


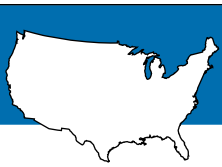
Figure 9. Concentrations of molinate at the Colusa Basin Drain at Road 99E near Knights Landing and Sacramento River at Freeport sites. The water in the Colusa Basin Drain is primarily agricultural drainage.

of 13 micrograms per liter (µg/L) of molinate in water was chosen for management of this herbicide. That level was chosen to protect the crustacean *Neomysis mercedis*, an important part of the food chain for young fish (Harrington, 1990). Concentrations in agricultural streams exceeded the target at least during 1 month of the year. Concentrations in the Sacramento River were always below those reported to be harmful to *N. mercedis* (Domagalski, 2000).

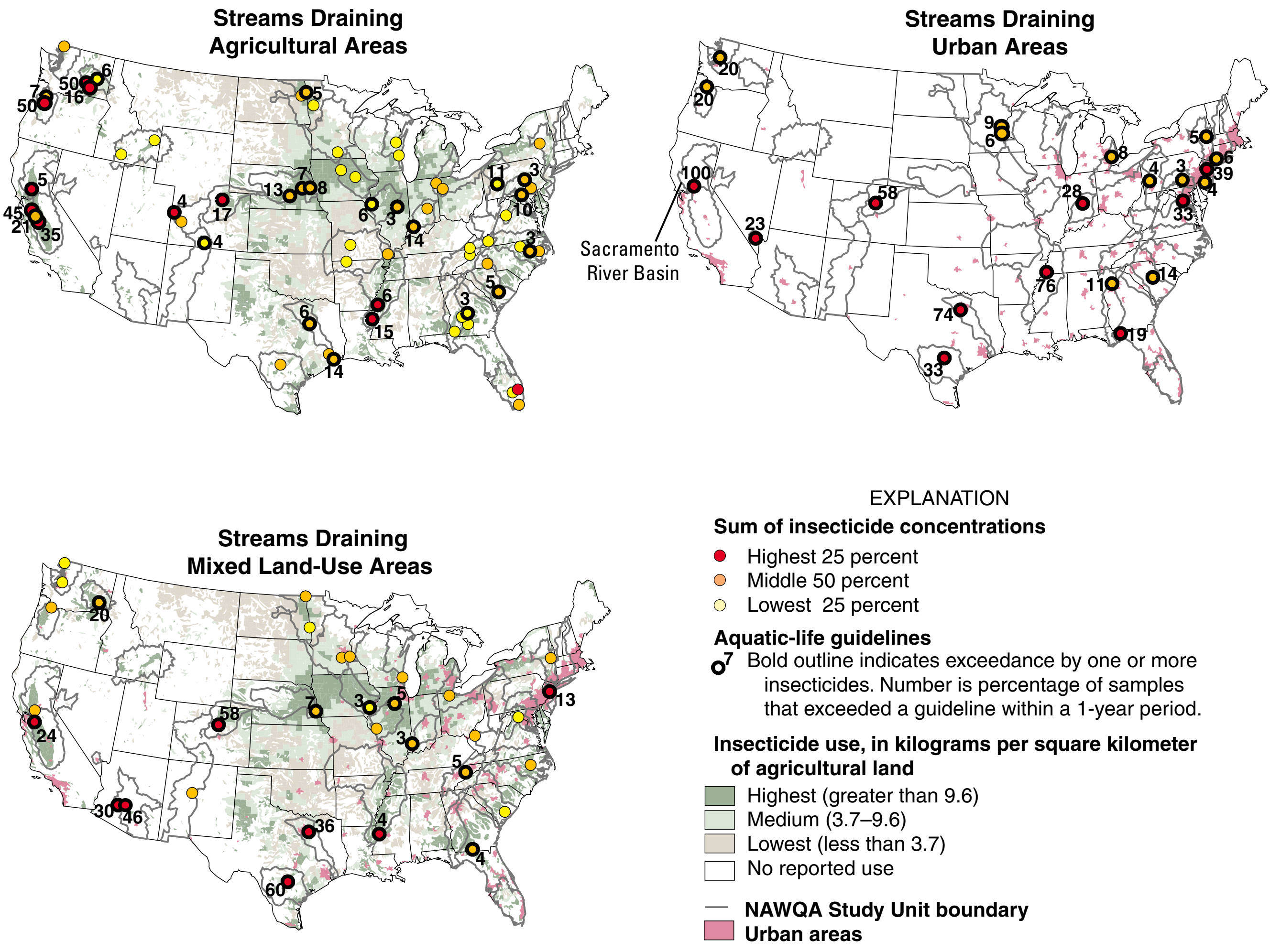
Pesticides also are transported to the Sacramento River, its tributaries, and agricultural drainage canals during winter storms (Kuivila and Foe, 1995; MacCoy and others, 1995; Domagalski, 1996). The pesticide that is considered a major problem for stormwater-driven transport is diazinon because of its toxicity to aquatic organisms and its high detection frequency. Diazinon is toxic to some species of zooplankton, such as *Ceriodaphnia dubia*, at low concentrations (0.35 µg/L) (Amato and others, 1992). The zooplankton species *C. dubia*, is used in laboratory assays to test water for toxicity (U.S. Environmental Protection Agency, 1991a,b). Diazinon is applied to orchard crops, especially almonds, prunes, and stone fruits, during December and January to protect trees from insects that lay eggs in the trees during the winter and hatch the following spring. Toxic concentrations in tributaries to the Sacramento River can occur when agricultural areas contribute storm runoff; toxic concentrations rarely occur in the Sacramento River itself (MacCoy and others, 1995). Diazinon was present in stormwater runoff at a number of sites in 1994 (Domagalski, 1996), and in nonstorm flows during 1996 through 1998. In the 1994 study, the Feather River was shown to be the greatest source of diazinon to the Sacramento River during a single storm, but other streams probably contributed to the diazinon load in the Sacramento River as well. This depended in part on the timing of diazinon applications and the location of greatest rainfall. The results of the routine samplings for diazinon during stable flow conditions at Arcade Creek near Del Paso Heights, Colusa Basin Drain at Road 99E near Knights Landing, and Sacramento River at Freeport are shown in figure 10. No stormwater runoff samples were collected. The highest concentrations during this NAWQA study occurred at Arcade Creek near Del Paso Heights, an urban site. Concentrations of diazinon in Arcade Creek that are toxic to *C. dubia* can occur in any season and result from household pesticide use and urban runoff. A standard for diazinon of 0.08 µg/L was proposed by the International Commission for the Great Lakes. As figure 10 shows, that standard was frequently exceeded at the Arcade Creek near Del Paso Heights site.

Pesticides of Historical Use

Pesticides that are no longer used, such as DDT, can still be detected in streambed sediments and the tissues of aquatic organisms because of their persistent chemical characteristics. Concentrations of pesticides such as DDT and its breakdown products tended to be low to nondetectable in the



ORGANOPHOSPHATE INSECTICIDES IN AGRICULTURAL AND URBAN STREAMS IN A NATIONAL CONTEXT



Organophosphate insecticides such as diazinon, chlorpyrifos, and malathion are toxic at low concentrations to some aquatic organisms. Some species of zooplankton are affected by diazinon concentrations as low as 0.35 µg/L. Diazinon levels at the urban stream, Arcade Creek, were elevated at various times of the year and exceeded recommended criteria for the protection of aquatic life for every measurement taken. Those levels were among the highest in the Nation. Most of the diazinon measured at the Arcade Creek site probably originated from household use throughout the watershed. Runoff from yards from either rainwater or irrigation water contributes to the loading of diazinon to stormwater drains that ultimately discharge into the creek. Diazinon enters agricultural drainage mainly in stormwater runoff because it is sprayed on orchards during the rainy winter season. Previous studies have shown that concentrations of diazinon in agricultural streams can be elevated less than a day after rainfall. Although diazinon concentrations of agricultural streams also were among the highest in the Nation, only one sample from those streams taken in this study exceeded recommended criteria. The range in diazinon concentrations for all NAWQA Study Units is shown in the Appendix.

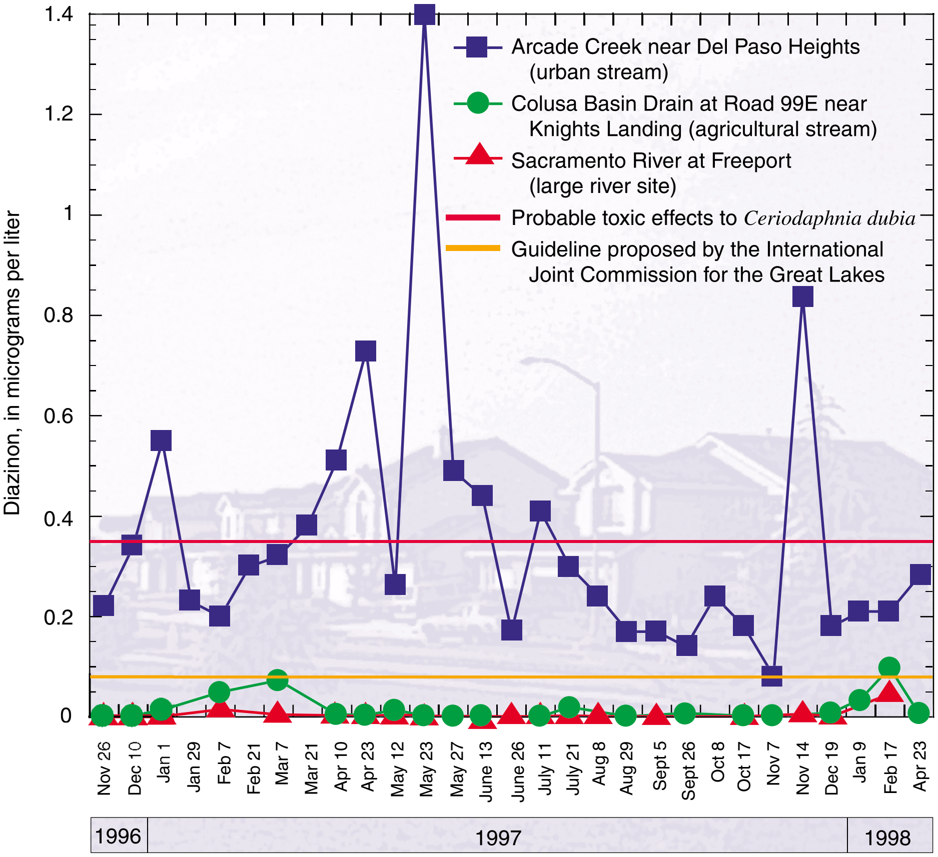


Figure 10. Concentrations of diazinon at the Colusa Basin Drain at Road 99E near Knights Landing, Arcade Creek near Del Paso Heights, and Sacramento River at Freeport sites. The highest concentrations were in the urban stream, Arcade Creek.

streambed sediments of the Sacramento River (MacCoy and Domagalski, 1999). Concentrations were higher in the streambed sediment of agricultural and urban streams. At some agricultural sites, and the urban site on Arcade Creek, the concentrations of DDT or its breakdown products in streambed sediment exceeded the Canadian sediment quality guidelines. The Canadian guidelines are designed to limit the accumulation of specific contaminants in organisms to levels below those that may adversely affect aquatic life (Canadian Council of Ministers of the Environment, 1995).

Concentrations of DDT or its breakdown products such as *p,p′*-DDE, or other organochlorine insecticide residues, were very low in the tissues of aquatic organisms collected in the Sacramento River and its large tributaries (fig. 11). Concentrations of *p,p′*-DDE in the tissues of aquatic organisms collected from agricultural drainage sites were higher (fig. 11). The levels found in tissues of aquatic organisms from the agricultural drainage sites probably do not pose a health risk for humans but are above criteria developed by the New York State Department of Environmental Conservation (Newell and others, 1987) for protection of fish-eating wildlife such as birds. No national criteria exist to protect fish-eating wildlife from organochlorine compounds such as DDT or its breakdown products; New York's are the only criteria available for comparison. The levels of *p,p′*-DDE found in the tissue of aquatic organisms tended to be relatively high when compared with other NAWQA Study Units. The range in concentrations for DDT and its breakdown products for all NAWQA Study Units is shown in the Appendix.

Metals in Water and Streambed Sediment

Acid mine drainage has been a serious environmental problem in the northern portion of the Sacramento River Basin (Alpers and others, 2000a,b). Several streams are listed as impaired (fig. 8) because of high concentrations of metals such as cadmium, copper, lead, and zinc. Metals concentrations in previous years have been toxic to fish in the upper Sacramento River near and downstream from Redding (Alpers and others, 2000a,b). Recent mitigation efforts at one of the more contaminated sites in the Spring Creek drainage near Shasta Lake have significantly lowered concentrations of metals in the Sacramento River, and no toxic effects to fish were observed during the course of this investigation (Alpers and others, 2000a,b). However, elevated levels of metals such as copper in streambed sediment can still be measured in the upper Sacramento River Basin downstream from Redding (MacCoy and Domagalski, 1999). Copper and other metals may still affect aquatic organisms.

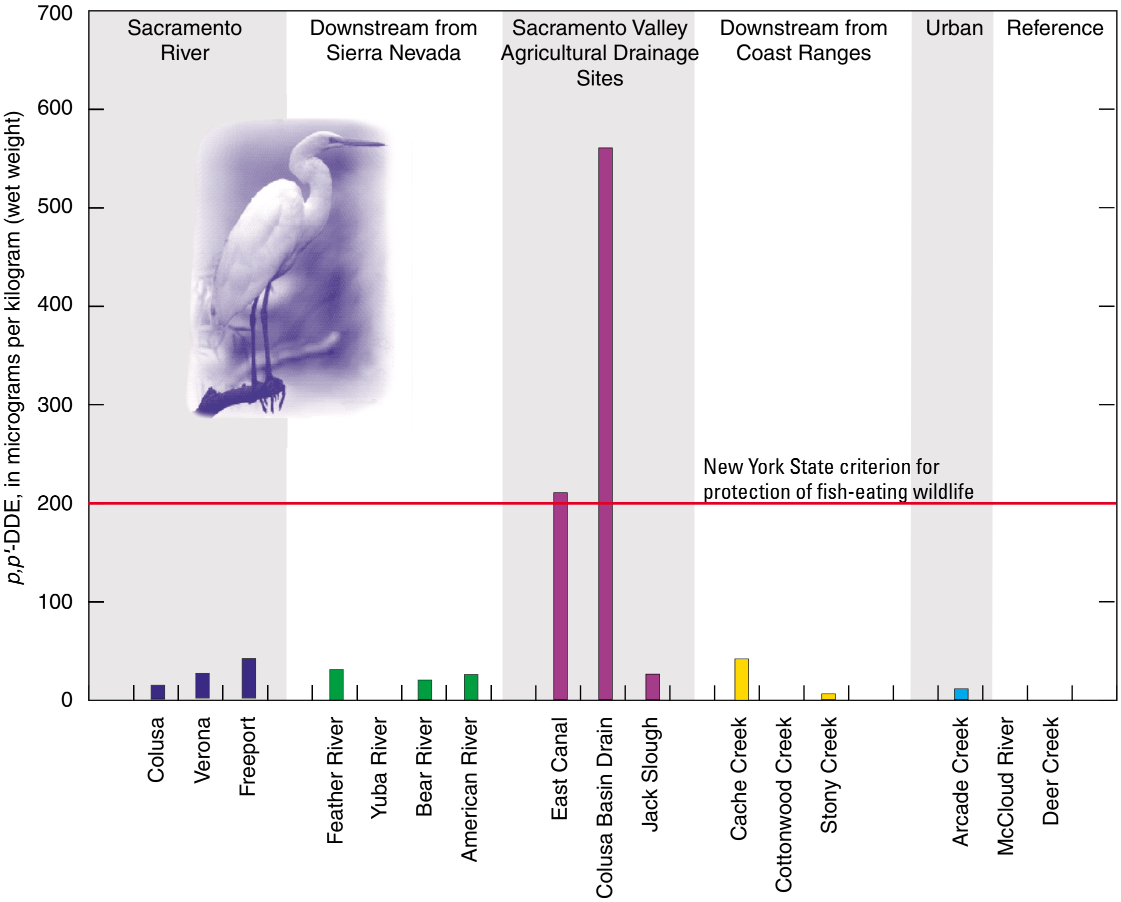


Figure 11. Conentrations of *p,p'*-DDE (a DDT breakdown product) in biota from the Sacramento River Basin. The use of DDT in the United States was terminated in 1972.

Trace Metals in Aquatic Organisms

For the NAWQA Program, looking for trace metals includes sampling streambed sediment and tissues of aquatic organisms. In theory, the transfer of metals from the streambed sediment into aquatic organisms can be understood by knowing the concentrations and geochemical forms of the trace metals in both the sediment and biota, as long as the feeding behaviors of the organisms are also understood. A predictive model of metals in tissue that is based on the amounts in streambed sediment could be developed from these studies. In practice, this becomes difficult because the actual bioavailability of metals in sediment can vary from site to site. For example, the concentrations measured in aquatic organisms may not be fully assimilated into the cellular material of the organism but rather may be present as undigested material or even attached to external body parts. Because metals contamination from acid mine drainage is an important water-quality issue for the upper Sacramento River Basin, and knowledge of the actual bioavailability of metals in the mine drainage is essential for current and future management of the mine waste, a collaborative study was completed by the Sacramento River Basin NAWQA Program and the National Research Program of the USGS (Cain and others, 2000). In that study, biologists examined streambed sediment and the cytosol from the caddisfly, an aquatic insect widely distributed in the upper Sacramento River and part of the food chain for a variety of fishes, including salmonid species. Cytosol is cellular material that can be isolated from aquatic insects. Biologists analyzed both whole body samples and cytosol samples for metals. Metal concentrations in cytosol provide a good indication of the potential effects on aquatic organisms from acid mine drainage. Aquatic insects also were sampled in a nearby reference stream that was unaffected by acid mine drainage. Elevated levels of cadmium, copper, lead, and zinc, derived from acid mine drainage, could clearly be distinguished in the cytosol samples, and it was shown that metals from the acid mine drainage were transported at least 120 kilometers downstream from the mine sources.

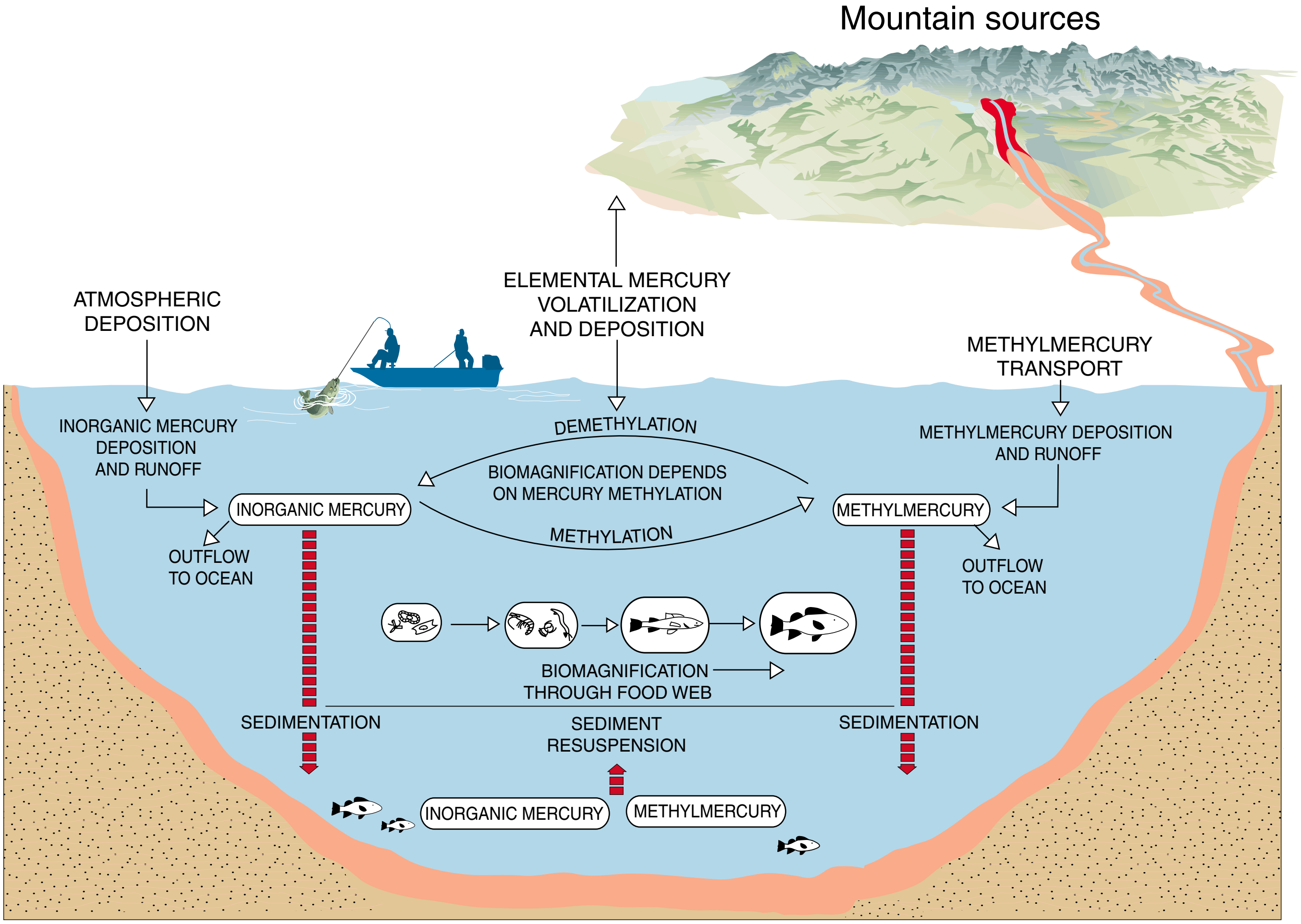


Figure 12. Mercury pathways in aquatic systems.

Mercury in Water and Streambed Sediment

Mercury is currently considered the most serious water-quality problem in the Sacramento River, some tributaries of the Sacramento River, and downstream locations including the San Francisco Bay (Domagalski, 1998). Mercury can enter streams or aquatic systems through either atmospheric deposition or transport from geological or man-made sources (fig. 12). Several processes contribute to the subsequent bioaccumulation of mercury in fish tissue. Because of the presence of mercury in the tissue of certain fish species, advisories have been posted for several water bodies, and more advisories are planned, both within the Sacramento River Basin and in the San Francisco Bay. Specific advisories for fish species and locations are listed on the California Office of Environmental Health Hazards Assessment Web site at http://www.oehha.org/fish.html. A recent study (Davis and others, 2000) documented mercury levels of concern to human health in sport fish collected in the lower Sacramento and Feather rivers.

Although atmospheric mercury is the principal cause of mercury contamination of water bodies in other parts of the United States, especially the midwestern and eastern United States, the cause is different in California. Geologic and anthropogenic sources, especially from historical mining for both mercury and gold, are the main reasons for mercury problems in the Sacramento River Basin (Domagalski, 1998). Mercury was mined in the Coast Ranges near Clear Lake and at locations east and south of Clear Lake (fig. 3), and it was used in the recovery of gold from ore and stream deposits during the late 19th century (fig. 3).

Decades of gold mining in the Sierra Nevada have resulted in the deposition of mercury in the streambed sediments of the gold mining region. The release of mercury from ore to streambed sediments in the mercury mining regions of the Coast Ranges also

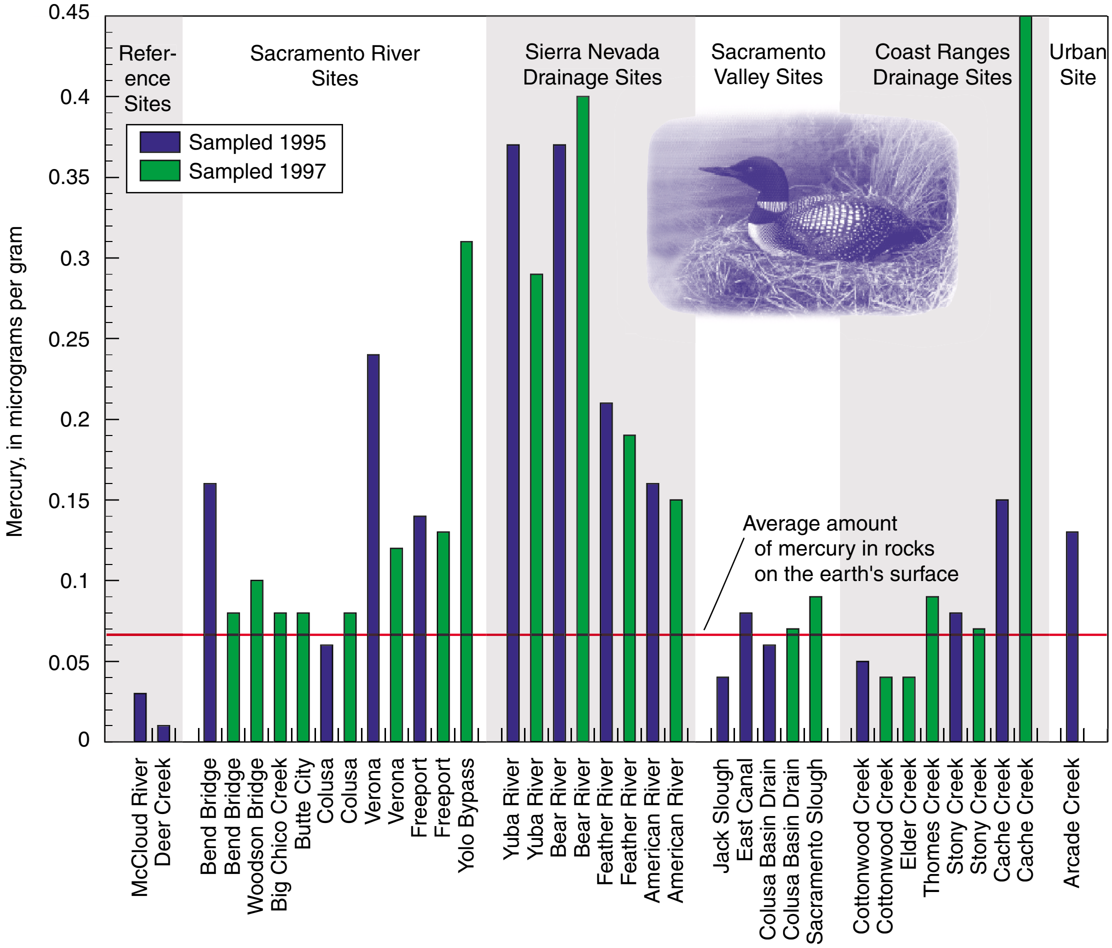


Figure 13. Concentrations of mercury in streambed sediment at select locations of the Sacramento River Basin.

has occurred (Hunerlach and others, 1999). The construction of reservoirs in the lower Sierra Nevada between 1948 and 1968 has had the positive effect of reducing the amount of mercury transported downstream (Slotton and others, 1997). Reservoirs trap mercury because suspended sediment, the principal means by which it is transported, tends to settle to the bottom. This trapping of mercury will have future implications on the management of these reservoirs, including potential dam removal. Some dams are being considered for removal in order to restore habitat for fish. Residual mercury from mining operations is present in the streambed sediments downstream from the Sierra Nevada reservoirs, as indicated by the NAWQA Program for the Sacramento River Basin. Concentrations of mercury in the streambed sediments of 24 sites sampled during the NAWQA Program are shown in figure 13. The highest concentrations of mercury in streambed sediment were measured in samples collected from sites downstream from the Sierra Nevada and the Coast Ranges. Sites on the Sacramento River downstream from the Feather River tended to have higher mercury concentrations relative to sites sampled upstream from the confluence of these two rivers because of historical gold mining.

The U.S. Environmental Protection Agency (EPA) has recommended water-quality criteria for mercury to protect aquatic life and human health. A recommended criterion of 12 nanograms per liter (ng/L) of total mercury in water was proposed by the EPA in 1985 (Marshack, 1995). That criterion is supposed to limit the amount of mercury accumulation in fish tissue and thereby protect human health. The 12-ng/L criterion was exceeded mainly during runoff conditions at all fixed sites during the timeframe of this investigation. In 1999, the recommended level was revised to 50 ng/L (U.S. Environmental Protection Agency,

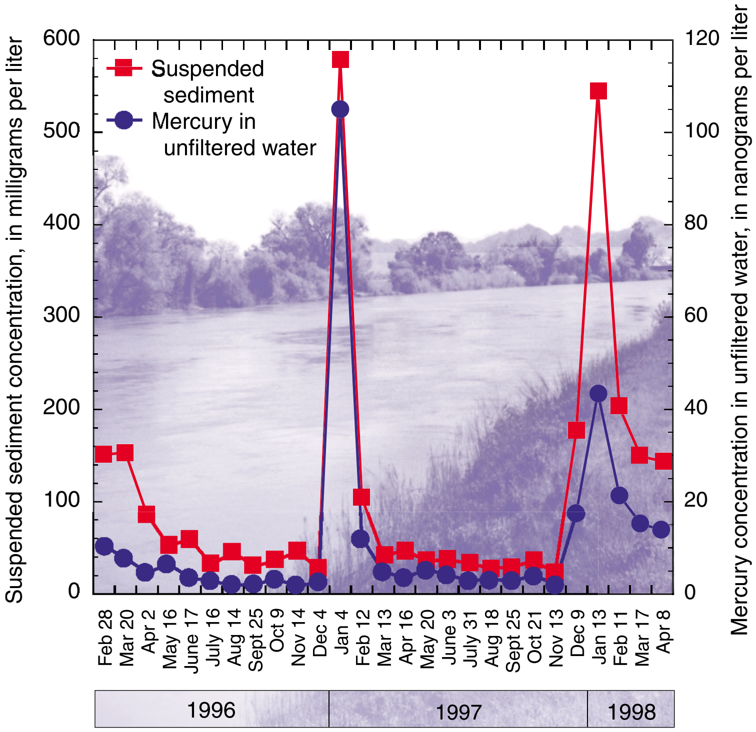


Figure 14. Mercury and suspended sediment concentrations for the Sacramento River at Colusa site. Mercury concentrations increase with sediment concentrations because mercury is attached to sediment particles.

1999). The 50-ng/L level was exceeded only at Cache Creek at Rumsey, Sacramento River at Colusa, and the Yolo Bypass at Interstate 80. Continued monitoring of mercury levels in fish tissue will be required to determine if the 50-ng/L criteria is effective. Time series plots of mercury and suspended sediment for the Sacramento River at Colusa are shown in figure 14. The higher concentrations of mercury correlate well with suspended sediment because much of the load of total mercury is transported with the suspended material (Alpers and others, 2000b).

Methylmercury is the most bioaccumulative form of mercury in the environment because it builds up in organisms more readily than other forms of mercury. It is a toxic form of mercury that can bioaccumulate in the tissues of aquatic organisms and cause human health problems if fish with high levels are consumed. Methylmercury usually is formed by bacterially mediated reactions in sediments. Concentrations in water were measured at selected sites on the Sacramento River and at sites receiving agricultural drainage to assess the effects of agricultural activities on the production or the levels of methylmercury.

Concentrations of methylmercury in unfiltered water are shown in figure 15. The highest median concentration was 0.19 ng/L, which represents the samples collected at the Colusa Basin Drain at Road 99E near Knights Landing site. There is no water-quality standard in California or in any other State that is based on methylmercury concentrations in water. However, a concentration at or below 0.1 ng/L of methylmercury has been suggested as being representative of pristine water (Rudd, 1995). That concentration is typical of rivers upstream from wetland environments and away from mercury sources (Rudd, 1995). The median methylmercury concentrations for the Sacramento River sites were slightly above 0.1 ng/L and maximum concentrations approach 2 ng/L. It is not known how or if those levels of methylmercury in water contribute to elevated levels of mercury in fish tissue.

There was a seasonal component to methylmercury concentrations for the sites at which they were measured for this study. The lowest concentrations were measured during middle to late summer (fig. 16). Higher concentrations tended to be measured during the autumn to winter months. The magnitude of the concentrations may also have been related to precipitation and runoff conditions. The highest concentrations for the period of this study were measured during January and February of 1997 and were attributed to the January 1997 flood. During the subsequent El Niño winter of 1997–98, higher-than-normal amounts of rain were recorded for much of the Sacramento River Basin, although there was no single storm of the magnitude of the January 1997 flood. Methylmercury concentrations increased during the El Niño winter, but not to the extent of the flood of the previous year. The effect of these methylmercury concentrations on downstream water bodies, such as the San Francisco Bay, has not been determined.

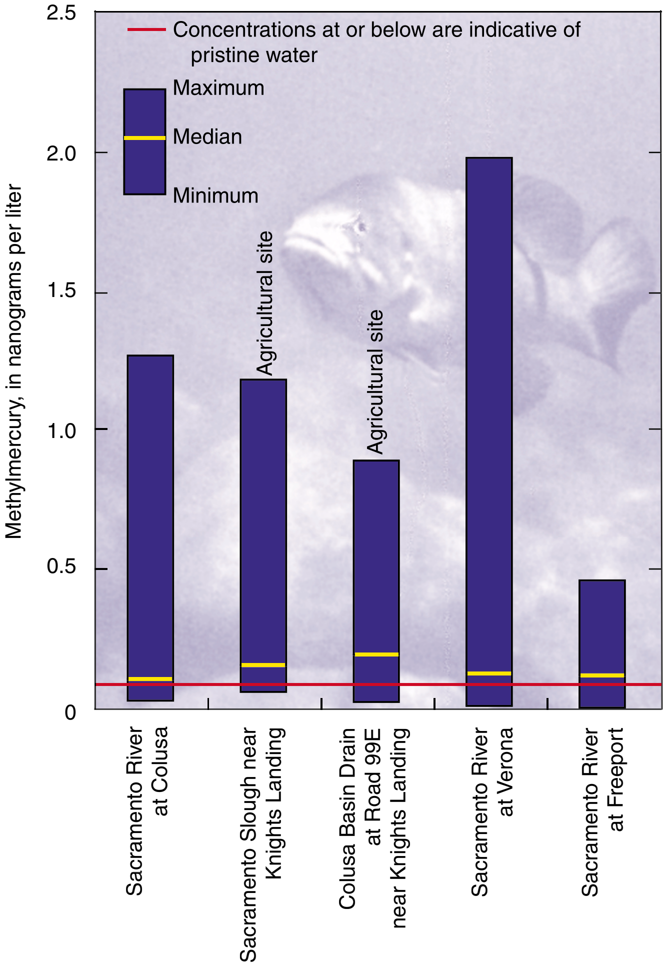


Figure 15. Concentrations of methylmercury at select locations in the Sacramento River Basin. Methylmercury is the form of mercury most likely to accumulate in aquatic species such as fish.

Ambient Toxicity Monitoring by California State Agencies

Ambient toxicity testing uses laboratory bioassays to assess the effect of contaminants on aquatic life. Essentially, the tests answer the question: Can specific types of fish, invertebrates, and algae species continue to live, grow, and reproduce in water samples collected from water bodies? The EPA protocols (U.S. Environmental Protection Agency, 1991a,b) for conducting chronic toxicity tests on freshwater species include representatives from three phyla and trophic levels. The three species are the fathead minnow, a small planktonic crustacean (*C. dubia*), and a planktonic green alga (*Selenastrum capricornutum*). These three species have been used to evaluate ambient water quality in the Sacramento River Basin since 1986. California regulatory agencies rely on the tests for evaluating compliance with narrative toxicity objectives, which state that “all waters shall be maintained free of toxic substances in concentrations that produce detrimental physiological responses in aquatic life” (Marshack, 1995). Testing has changed from conducting broad watershed surveys that determine the spatial and temporal distribution of toxicity to conducting detailed follow-up studies that couple toxicity testing with a Toxicity Identification Evaluation (TIE) to identify specific chemicals and land uses responsible for toxicity. Water-quality data from the NAWQA Program are useful in determining the exposure of aquatic organisms to specific groups of contaminants such as organophosphate pesticides. Results from 13 years of monitoring suggest that the EPA toxicity tests are powerful tools for assessing water quality.

The toxicity testing program in the Sacramento River watershed was the first indicator of the potential water-quality problems currently associated with pesticide runoff from urban areas and orchards. Using *C. dubia* tests, pulses of toxicity have been detected over a 10-year period throughout the Sacramento Valley in waters that receive drainage from orchards (de Vlaming and others, 2000). The toxicity has been linked to diazinon applied to dormant orchards and chlorpyrifos applied to nondormant orchards. *C. dubia* also was effective in identifying toxicity attributed to drainage from rice fields. Rice-field drainage also was toxic to two important local species, larval striped bass and an invertebrate, *N. mercedis*. The invertebrate toxicity was caused by methyl parathion and carbofuran. As mentioned previously, a rice management program has eliminated the toxicity to all three species. *C. dubia* toxicity is detected throughout the year in waters that receive drainage from urban areas (fig. 10). This toxicity is attributed to diazinon and chlorpyrifos. Although most toxicity has been detected with *C. dubia* and linked to insecticides, other examples of ambient water toxicity have been identified. In areas of the Sacramento Valley that receive acid mine drainage, toxicity to *S. capricornutum* and *C. dubia* has been linked to copper and zinc. Mine remediation projects have reduced both metal concentrations and toxicity. Concentrations of copper and zinc measured in this NAWQA Program confirm that metal concentrations are below toxic levels (Alpers and others, 2000b). *S. capricornutum* toxicity has been documented in

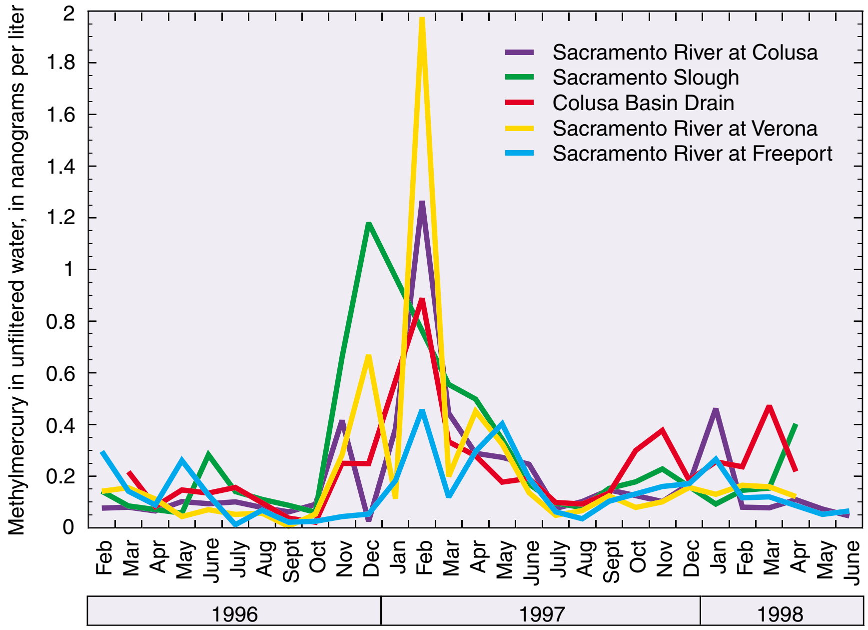


Figure 16. Seasonal changes of methylmercury concentrations. The highest concentrations were measured during high streamflow and following rainfall.

waters that receive agricultural or urban runoff. Some of the toxicity can be attributed to the herbicide diuron, also detected in samples collected by the NAWQA Program; however, additional unidentified toxicants are present. Fathead minnow toxicity has been traced to ammonia originating from dairies and wastewater treatment plants. Taken together, the results of the last decade reveal that all three testing procedures, in association with TIEs and chemical analyses, have been effective for the identification of an array of toxicants originating from various sources. In several cases, alternative land-use practices or management strategies have improved water quality, as demonstrated by toxicity test monitoring. Because resources are not available for monitoring the complete array of potential contaminants, toxicity testing is a useful tool for focusing on chemicals present in a water body at toxic levels.

NAWQA Participation with Local Water-Quality Programs

All NAWQA Study Units maintain communication and program coordination with a liaison committee of outside parties interested in water quality within the respective basins. During the early part of this NAWQA study, two significant programs were taking shape that involved new approaches to understanding and promoting the better management of water quality in the Sacramento River Basin.

In 1994, Congress recognized the need to develop a coordinated, technically sound, adequately funded program that would focus on establishing toxic pollutant standards for the Sacramento River Basin. Congress then appropriated funds for the Sacramento River Toxic Pollutant Control Program (SRTPCP) and has continued to support the program.

The long-term objective of the SRTPCP is to develop and implement a program that will bring the Sacramento River and its tributaries into compliance with water-quality standards for toxic pollutants and thereby protect beneficial uses. A second objective of the SRTPCP is to help form a viable organization of watershed stakeholders. The stakeholder organization is intended to address not only the related toxic-pollutant issues of the watershed, but also the broader water-quality and watershed issues that must be resolved to protect and enhance surface and ground water throughout the basin.

The broader program to be conducted by this stakeholder organization has been named the Sacramento River Watershed Program (SRWP). The SRWP, although initiated with funding provided under the SRTPCP, is much broader in scope than the SRTPCP. The SRWP is intended to provide a forum to address a broad array of water-quality-related issues within the watershed, not just issues on toxic pollutants. Other issues that may be addressed under the broader watershed program include, but are not limited to, conventional water quality (including sediment, temperature, and dissolved solids), habitat, endangered species, streamflow, and ground-water issues.

The NAWQA Program participates in various committees of the SRWP, including the monitoring committee, to share data. Data from the NAWQA Program are shared with the SRWP and are used to help interpret the current water-quality conditions and to help guide the continued management of the water resources of the Sacramento River Basin.

Aquatic Biology

Changes in land use in the Sacramento River Basin have had major effects on the streams in the basin and on the aquatic communities dependent on them. Riparian forests and wetlands have been removed or degraded. Water development activities, particularly construction of dams and reservoirs, have altered natural flow and water temperature. The seasonal nature of higher temperatures along a stretch of the Sacramento River downstream from Shasta Lake is shown in figure 17. Water diversions for irrigation result in less water in the Sacramento River and rapidly increasing temperatures that are potentially harmful to certain fish in the spring and summer, especially downstream from the site on the Sacramento River above Bend Bridge near Red Bluff.

Collectively, these changes in streams have resulted in corresponding changes in native ecological communities, including species extirpation and population declines in remaining native species (Moyle and Nichols, 1974; Brown and Moyle, 1993; Brown, 2000). These declines have resulted in the listing of a number of animal and plant species as threatened or endangered under State or Federal law.

Native fish species are still common in Sacramento River Basin streams

Thirty-five species of fish were collected, including 12 species native to California. Statistical techniques were used to categorize sites on the basis of similar fish groupings. Four species of fish were collected at mountain streams—rainbow trout, brown trout, riffle sculpin, and chinook salmon. These species are generally associated with cold, clear water and are considered intolerant of other environmental conditions such as warm water. Only brown trout is an introduced species. Rainbow trout were collected at all sites and were the most abundant species, representing 74 percent of the fish collected.

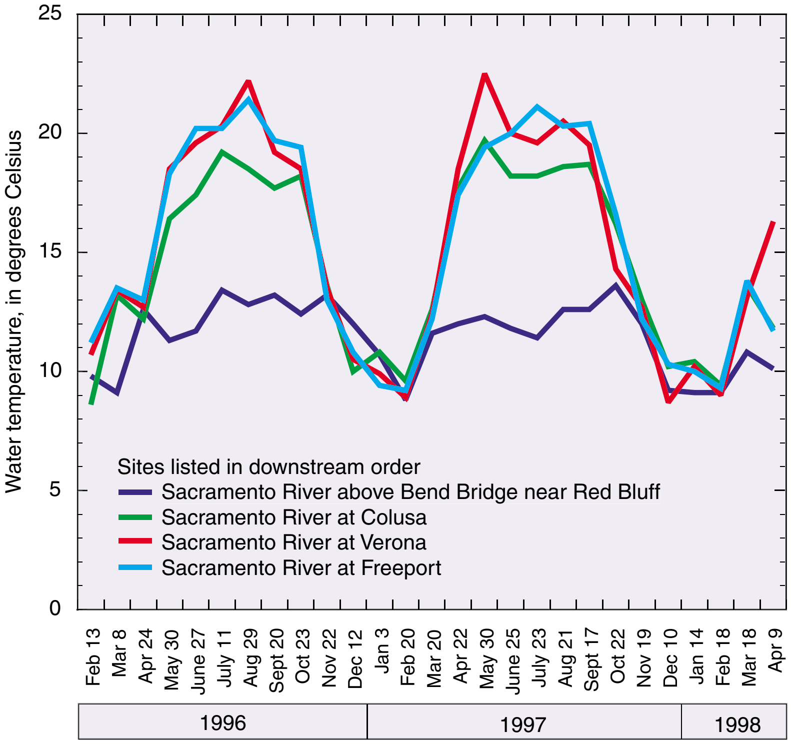


Figure 17. Temperature of the Sacramento River at select locations. Seasonal increases are caused by diversion of river water for irrigation.

Fish were also sampled at sites below the mountains but above the valley floor. Those sites are referred to as the foothill sites. Twenty-one species of fish, including 13 native species, were collected at the nine sites in the foothill group. None of the introduced species was abundant, and no introduced species represented more than 3 percent of the fish collected. Native minnows, hardhead, Sacramento pikeminnow, speckled dace, California roach, and Sacramento sucker dominated sites in this group.

Twenty-four species of fish, including nine native species, were collected at the three large river sites, which are located at low elevations on the larger rivers. Native species tended to be more abundant. The most abundant native species were Sacramento pikeminnow, Sacramento sucker, tule perch, and prickly sculpin. No introduced species exceeded 7 percent of the catch.

Agricultural land sites within the Sacramento Valley were dominated by introduced species and included sites on natural and artificial waterways that were heavily influenced by agricultural land uses or water management activities. Twenty species were collected at these sites, including only three native species.

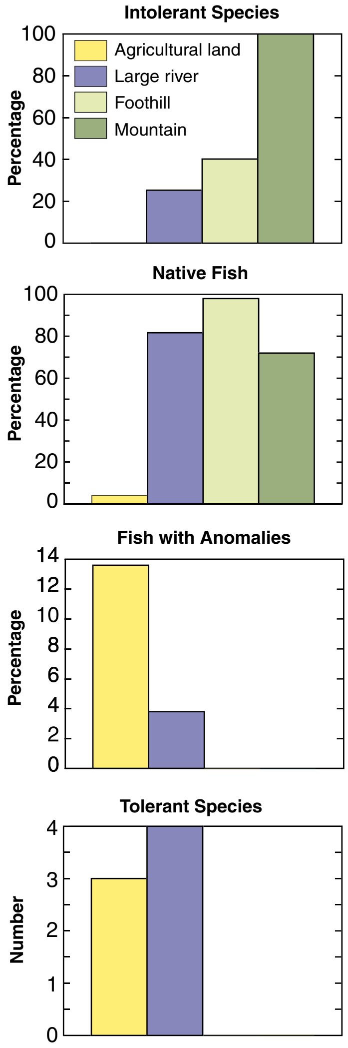


Figure 18. Characteristics of fish from ecological studies.

The group of fish at the agricultural land sites had the lowest percentage of native fish, the lowest percentage of intolerant fish, and the highest percentage of fish with external anomalies (fig. 18), indicating degraded environmental conditions. Intolerant fish are defined as those that are not adaptable to human alterations to the environment and thus decline in numbers when these alterations occur. The agricultural land site group also had a low number of native species compared with the large river and foothill site groups. In summary, the fish site data indicate that the agricultural land site group had the most degraded environmental conditions, the foothill and mountain site groups had the best conditions, and the large river site group had somewhat intermediate conditions.

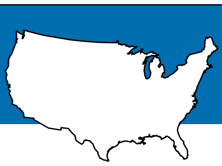
Previous studies of fish community structure in California have established correlations between the increasing numbers of introduced fish species in Central Valley streams and the disturbances caused by human activities (Moyle and Nichols, 1974; Brown and Moyle, 1993; Brown, 2000). Environmental disturbances associated with human activities include changes in water quality, streamflow, and habitat. Changes in streamflow, in particular changes in quantity and timing, have been identified as very important determinants of the structure of California fish communities (Baltz and Moyle, 1993; Moyle and Light, 1996a,b; Brown, 2000).

Differences in water quantity and water management have subsequent effects on water quality and habitat. Although these observations do not provide definitive support for the primary importance of streamflow in maintaining populations of native fish species, such relations and their effects on native fishes warrant consideration whenever changes in water management are being considered. Assessments of resident fish communities may be useful in determining the effectiveness of such changes in restoring natural ecological functions.

Streams without large reservoirs supported higher abundance of aquatic insects than streams with large reservoirs

Aquatic insect communities were compared at 23 locations including sites on two streams, Big Chico and Deer creeks, which have no major dams. Most streams sampled as part of this NAWQA Program have at least one major water project that affects a portion of the natural channels. Big Chico and Deer creeks are, therefore, unique in this study in that their flows are largely unregulated. Statistical analyses of the aquatic insect communities show that some sites on Deer and Big Chico creeks have more species and greater abundances of benthic macroinvertebrates compared with sites downstream from dams on the other streams sampled. Further research is needed to verify and evaluate these relations.

Populations of anadromous salmonids, including steelhead, rainbow trout, and chinook salmon, have declined throughout the Central Valley, resulting in protection of the remaining populations under Federal and State endangered species legislation (Yoshiyama and others, 1998). The reasons for the declines are complex and interactive; however, the construction of dams and reservoirs on California streams and rivers is widely recognized as one of the important factors (Yoshiyama and others, 1998). Dams and reservoirs block established migration routes, causing fish to reproduce in less desirable habitats. Another ecological effect from dams and reservoirs can be



AQUATIC BIOLOGY IN A NATIONAL CONTEXT

Biological indicators of water and habitat quality for 6 sites in the Sacramento River Basin were compared with similar data from 140 sites from NAWQA Study Units throughout the Nation. Because the rankings have not been calibrated for Sacramento River Basin streams, they should not be interpreted as designating “good” and “bad” water quality in streams. The sites simply score higher or lower in relation to other NAWQA sites, which represent a wide range of environmental settings.

The Yuba River site ranked among the least degraded sites nationally for all three indicators. The consistently low scores for this site can be attributed to abundant native fishes and the presence of healthy invertebrate and algal communities associated with cool water and abundant riffle habitats. The Arcade Creek and Colusa Basin Drain sites ranked among the most degraded sites nationally for all three indicators. This score may have to do more with the harsh nature of the physical environment than with water quality. Flow at these sites fluctuates widely because of storm runoff and variation in urban runoff. Biological communities in such streams tend to have few species, resulting in low indicator scores. Local determination of habitat and water quality is better accomplished using locally derived data, as has been demonstrated for Central Valley fish (Brown, 2000; May and Brown, 2000) and invertebrate communities (Brown and May, 2000a,b).

Comparisons of biological indicators of water quality from Sacramento River Basin sites with other sites with biological data from the NAWQA Program[1]

Site Name	National Land Use Category [1]	Fish Status	Invertebrate Status	Algal Status
Colusa Basin Drain at Road 99E near Knights Landing	Agriculture	🟥	🟥	🟥
Sacramento River at Colusa	Mixed	🟩	🟥	🟥
Yuba River near Marysville	Mixed	🟦	🟦	🟦
Feather River near Nicolaus	Mixed	🟩	🟩	🟩
American River at Sacramento	Mixed	🟦	🟩	🟦
Arcade Creek near Del Paso Heights	Urban	🟥	🟥	🟥

[1] Represents 140 sites from NAWQA Study Units throughout the United States with algal, invertebrate (primarily insects, worms, crayfish, clams), and fish data. “Mixed” indicates a combination of agricultural, urban, and other use.

🟥 Highest 25 percent nationally (comparatively more degraded)
🟩 Middle 50 percent nationally
🟦 Lowest 25 percent nationally (comparatively less degraded)

changes in downstream populations of aquatic insects. This is potentially important to anadromous and resident fish populations because aquatic insects are a critical food source for nearly all species of fish at some life stage.

The implication of this study is that construction of dams and reservoirs in the foothills has either submerged the productive habitat in Central Valley streams or altered them indirectly through downstream effects on ecological conditions. The importance of other downstream effects, such as disruption of sediment transport, has been recognized for anadromous salmonids. As a result of this recognition, a variety of projects are underway or are being proposed to improve conditions for anadromous fishes and to restore ecological processes in general.

Ground Water

Ground-water quality was investigated in the portion of the aquifer of the southeastern Sacramento Valley used for domestic purposes or irrigation and in the shallow portion of the aquifer below the valley's two major land uses—rice cultivation and land that had been urbanized from 5 to 25 years ago. The southeastern Sacramento Valley was chosen for investigation because it is in that region that domestic and irrigation usage of ground water is highest. Although ground water is used in other parts of the valley, its usage is not as great as in the southeastern Sacramento Valley.

The ground-water quality of some areas of the Sacramento Valley, such as the southwestern portion, is not entirely suitable for human or agricultural use because of the presence of elevated concentrations of boron, fluoride, chloride, nitrate, and sulfate (Hull, 1984; Davisson and Criss, 1993). The study conducted in the southeastern Sacramento Valley aquifer was designed to address the suitability of a portion of the aquifer. Specifically, only existing domestic wells were sampled.

Out of 31 wells sampled, only one sample exceeded the drinking water standard for nitrate. The median concentration of nitrate was 1.3 mg/L. Previous NAWQA investigations have found a median nitrate concentration of 0.48 mg/L in major aquifers throughout the United States (Nolan and Stoner, 2000). Therefore, the wells sampled in this study have nitrate values above the national median.

One or more pesticides were detected in 9 of 31, or 29 percent, of the wells of the southeastern Sacramento Valley (fig. 19). Simazine was detected in three wells, but the concentrations were very low and were not close to any drinking-water standard. Bentazon was one of the more frequently detected pesticides. Bentazon is a herbicide that was used on rice, but its use was suspended in 1989 pending a review; then, in 1992, it was formally banned by the California Department of Pesticide Regulation (Miller-Maes and others, 1993). All bentazon concentrations were below drinking-water standards.

Volatile organic chemicals (VOCs) are not causing any apparent water-quality problems in the shallow aquifer of the southeastern Sacramento Valley. In one of the wells sampled, which is downgradient from a known point source, eight different VOCs were detected. One of those VOCs (trichloroethene, measured at 5.5 µg/L) exceeded current drinking-water standards (primary MCL is 5 µg/L).

The effects of rice cultivation—one of the most prevalent agricultural practices in the Sacramento Valley—on ground water were examined by drilling and sampling 28 new wells (fig. 20). The wells were drilled to completion near the water table so that the agricultural effects on the most

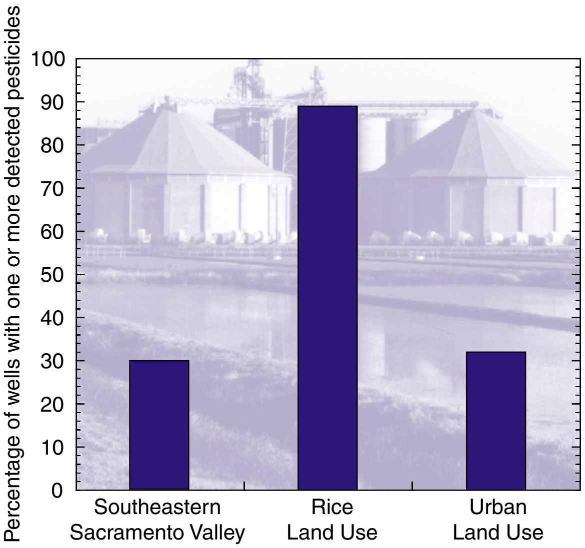


Figure 19. Percentage of wells having one or more detected pesticides for the three ground-water studies.

recent water that entered the ground could be assessed. Rice cultivation requires that fields be flooded for the duration of the growing season, which lasts from May through September.

Pesticides were more frequently detected in the wells of the rice land-use study area compared with other regions outside the rice study area. One or more pesticides were detected in 25 of 28 (89 percent) of the wells sampled (fig. 19). The most frequently detected pesticide of the rice study was bentazon, a herbicide used in rice fields until suspension in 1989 and a formal ban in 1992. Although no observed concentrations exceeded drinking-water standards, the high detection frequency, almost 10 years since the last known use, suggests that bentazon is easily transported to ground water and does not readily degrade in ground water. Molinate, another herbicide used on rice, was detected in 7 out of 28 wells. Thiobencarb, also a herbicide, was found in three wells; carbofuran, an insecticide used on rice, was detected in four. Herbicides and insecticides are applied to rice at the same time, shortly after planting in May. The most heavily used pesticides on rice are molinate, thiobencarb, and carbofuran. Therefore, it is not surprising to see these compounds in the ground water under the rice land-use region. None of the pesticide concentrations that were measured exceeded any known water-quality standard.

Nutrient concentrations tended to be low in the ground water under the rice fields. The median nitrate concentration was 2 mg/L, and no concentrations exceeded a drinking-water standard. The median nitrate concentration measured in previous NAWQA investigations in agricultural land use settings was 3.4 mg/L (Nolan and Stoner, 2000).

Dissolved solids were elevated in rice fields relative to the other ground water sampled in this study. The elevated concentrations are most likely related to evaporation of irrigation water, which leaves behind salt. The effects of these increases in dissolved solids on deeper portions of the aquifer are unknown.

The effects of recent urbanization on the quality of shallow ground water were investigated as part of this NAWQA study (fig. 21). The chosen metropolitan area was that of the city and surrounding counties of Sacramento. The part of the metropolitan area developed between 5 and 25 years ago was chosen for the investigation because it was assumed that the water quality of older urban land might have degraded water quality because it was developed prior to the passage of the Clean Water Act and the period of more recent environmental awareness.

Trichloromethane was the most frequently detected volatile organic chemical (16 of 19 wells). The concentrations were always very low and did not exceed any drinking-water standards. The presence of trichloromethane can be attributed to lawn irrigation using water treated by chlorination. One or more pesticides were detected in 6 of 19 (32 percent) of the wells sampled in the urban land-use study (fig. 19). Atrazine, or its degradation product, was the most frequently detected pesticide in the shallow ground water under the recently urbanized area. The

Figure 20. Drilling and installing a new monitoring well in the rice-growing region of the Sacramento Valley.

Figure 21. Drilling and installation of a new monitoring well in the Sacramento metropolitan area. This study of shallow ground water was the first of its kind within the Sacramento metropolitan area.

occurrence of atrazine in ground water could not be attributed to either current urban land use or past agricultural production. All atrazine concentrations were below drinking-water standards.

An examination of the nitrate data revealed the highest potential contamination of ground water from recent urban development. Although no wells had concentrations of nitrate above the drinking-water standard, one well had a concentration of 8 mg/L, and 5 of the 19 (26 percent) of the sampled wells had concentrations that exceeded 5 mg/L. The median concentration of nitrate was 2.4 mg/L. The median concentration of nitrate in ground water under urban areas measured in previous NAWQA investigations was 1.6 mg/L (Nolan and Stoner, 2000).

With the exception of arsenic, trace elements generally were not found to be a problem from the perspective of human toxicity. Some wells did have high concentrations of iron and manganese. The primary drinking-water standard for cadmium (5 µg/L) was exceeded in three wells of the rice land-use study. The source of that cadmium is unknown. Arsenic exceeded the current drinking-water standard of 50 µg/L in one urban well and approached the drinking-water standard in three other wells. Arsenic would be more problematic if the drinking-water standard were lowered to 5 µg/L, as proposed by the EPA (U.S. Environmental Protection Agency, 2000). At that level, the standard would be exceeded in 53 percent of the urban wells, 39 percent of the rice land-use wells, and 48 percent of the domestic wells sampled in the southeastern Sacramento Valley. Iron and manganese dissolve when oxygen is absent in the ground water. Although generally nontoxic, these two metals can limit the beneficial uses of the ground water because they may precipitate when the ground water is exposed to air. The precipitation can be severe enough to adversely affect household uses of water as well as plumbing.

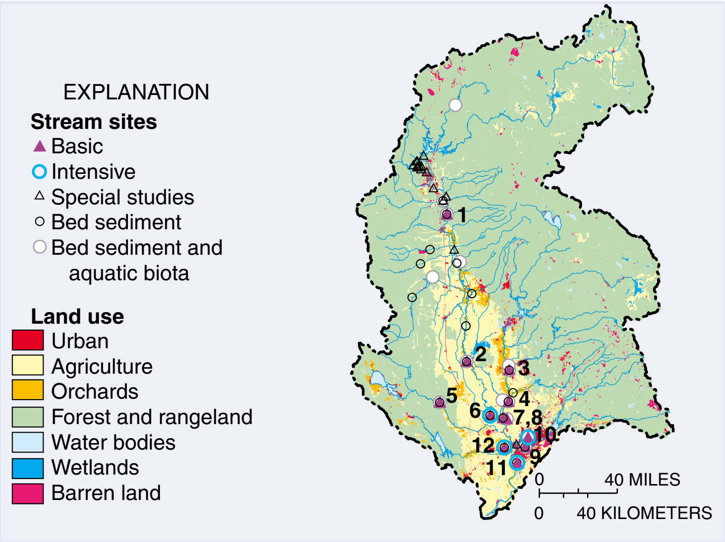
Radon concentrations exceeded the EPA proposed drinking-water standard of 300 picocuries per liter in 90 percent of the domestic wells sampled. The median concentration from wells sampled in the southeastern Sacramento Valley was 495 picocuries per liter. Radon is a colorless gas formed from the radioactive decay of radium. Radium is produced by the radioactive decay of uranium, which has a half-life of 4.4 billion years, whereas the half-life of solid radium is 1,620 years. Radon, on the other hand, has a half-life of only 3.8 days. Because radon is a gas, it moves easily in underground geologic environments and readily enters ground water. Regions of the country with geologic formations containing granite, volcanic rocks, certain types of shale known as dark shale, and some sedimentary and metamorphic rocks are more likely to have soil or ground water enriched in radon. Those conditions exist in the Sacramento River Basin. The health effects of consuming water containing radon at levels determined in this study have not been identified.

Stream Chemistry

Basic and Intensive Fixed Sites (see Glossary) were selected to assess the occurrence of dissolved compounds and select compounds associated with solid materials in stream water or streambed sediment. Basic Fixed Sites were sampled less frequently and for fewer compounds than Intensive Fixed Sites.

Basic and Intensive Fixed Sites

1. Sacramento River above Bend Bridge near Red Bluff
2. Sacramento River at Colusa
3. Yuba River at Marysville
4. Feather River near Nicolaus
5. Cache Creek at Rumsey
6. Colusa Basin Drain at Road 99E near Knights Landing
7. Sacramento Slough near Knights Landing
8. Sacramento River at Verona
9. Arcade Creek near Del Paso Heights
10. American River at Sacramento
11. Sacramento River at Freeport
12. Yolo Bypass at Interstate 80 near West Sacramento

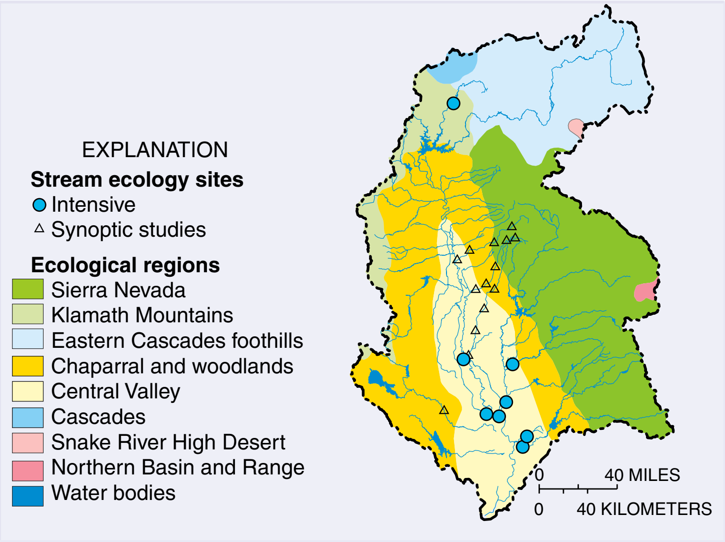


Special Studies

A study of metals transport from an acid mine drainage site and a generalized study of mercury transport along a reach of the Sacramento River downstream from Shasta Lake were completed.

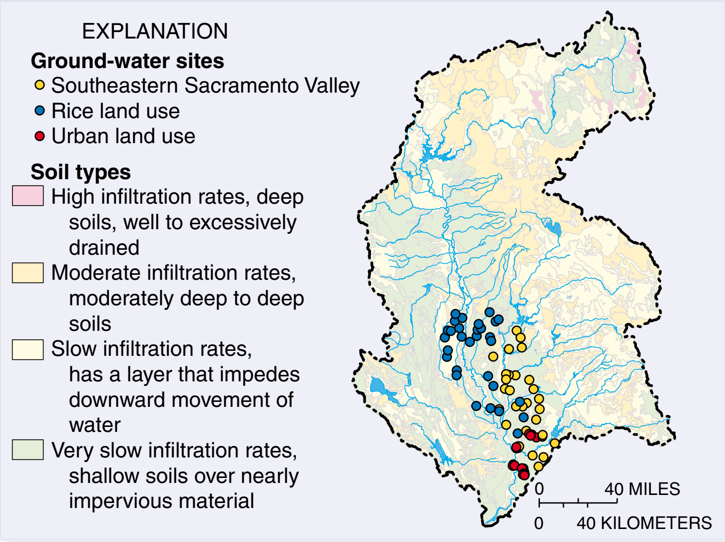
Stream Ecology

Ecological assessments were completed along mountain to valley reaches (synoptic studies) of 3 streams, at 7 of the 12 Basic Fixed Sites, and at 1 reference site to determine variations in the community structure of aquatic biota.



Ground-Water Chemistry

Surveys of water quality in a used portion of the Sacramento Valley aquifer and the effects of agricultural and urban land uses on water quality were completed.



SUMMARY OF DATA COLLECTION IN THE SACRAMENTO RIVER BASIN, 1994–98

Study component	What data were collected and why	Types of sites sampled	Number of sites	Sampling frequency and period
Stream Chemistry				
Basic Fixed Sites—General water chemistry	Streamflow, nutrients, major ions, suspended sediment, water temperature, specific conductance, organic carbon, trace metals, mercury, dissolved oxygen, alkalinity and pH; to describe concentrations, loads, and seasonal variations.	Large rivers, most with continuous streamflow measurements available; streams with continuous streamflow measurements that drain forested, agricultural, and mining areas.	8	Monthly, 02/97–04/98
Intensive Fixed Sites—Agricultural and large river	In addition to the above constituents, 84 pesticides; to describe concentrations and seasonal variations.	One agricultural stream that drains primarily agricultural areas; one large river site near the mouth of the basin.	3	Monthly, 02/96–04/98; Monthly for pesticides, 11/96–03/97 and 08/97–04/98; twice per month for pesticides 04/97–07/97
Intensive Fixed Sites—Urban	The same constituents as Basic Fixed Sites and Intensive Fixed Sites and, in addition, 85 volatile organic compounds; to describe concentrations and seasonal variations.	One stream that drains a primarily urbanized area.	1	Monthly for pesticides and volatile organic chemicals, 11/96–12/96 and 01/98–04/98; twice monthly for pesticides, 01/97–11/97. Storm sampling for volatile organic chemicals, 04/96 and 10/96
Contaminants in streambed sediments	Trace elements and organic compounds; to determine presence of potentially toxic compounds attached to streambed sediments.	Depositional zones of large rivers and select tributaries, including fixed sites.	17 in 1996; 19 in 1997	One sampling for trace elements and organic compounds in 1995; one sampling for trace elements in 1997
Contaminants in tissues of aquatic organisms	Asiatic clams and bottom-feeding fish were collected to determine the presence of contaminants that can accumulate in tissues of aquatic organisms. The tissue samples were analyzed for trace elements and organic compounds.	Fixed sites and other select sites of large rivers and select tributaries.	17	One sampling in 1997
Stream Ecology				
Intensive Assessments	Fish, macroinvertebrates, and algae; to assess biological communities and habitat in streams representing primary ecological regions.	Sites at or near a fixed site or at a pristine or reference location.	9	Three samplings, 1996–98
Synoptic Studies	Fish, macroinvertebrates, and algae; to determine spatial distribution and communnity structure of aquatic species and habitat.	Sites along an elevation gradient from the Sierra Nevada to the Sacramento Valley.	14	Two samplings, 1997–98
Ground-Water Chemistry				
Aquifer Survey	Major ions, nutrients, pesticides, trace elements, volatile organic compounds, and radon; to describe the overall water quality and natural chemistry in a surficial aquifer.	Domestic wells in the southeastern Sacramento Valley.	31 wells	Once in 1996
Land-Use Effects—Agriculture (rice)	Major ions, nutrients, trace elements, and pesticides; to describe the water quality and natural chemistry in a surficial aquifer in an agricultural setting.	Newly drilled monitoring wells completed near the water table in a surficial aquifer beneath or near rice fields.	28 wells	Once in 1997
Land-Use Effects—Urban	Major ions, nutrients, pesticides, trace elements, volatile organic compounds, and radon; to describe the overall water quality and natural chemistry in a surficial aquifer.	Newly drilled monitoring wells completed near the water table in a surficial aquifer beneath a recently urbanized area.	19 wells	Once in 1998
Special Studies				
Sacramento River Trace Metals Study	Trace elements measured in whole water, filtered water, ultrafiltered water, and on colloids.	Sacramento River and select tributaries including an acid mine drainage site.	19	During selected high flow and low-flow stream conditions, 07/96–06/97

GLOSSARY

Amalgamation—The dissolving or blending of a metal (commonly gold and silver) in mercury to separate it from its parent material.

Aquatic guidelines—Specific levels of water quality which, if reached, may adversely affect aquatic life. These are nonenforceable guidelines issued by a governmental agency or other institution.

Aquatic-life criteria—Water-quality guidelines for protection of aquatic life. Often refers to U.S. Environmental Protection Agency water-quality criteria for protection of aquatic organisms. See also Water-quality guidelines and Water-quality standards.

Aquifer—A water-bearing layer of soil, sand, gravel, or rock that will yield usable quantities of water to a well.

Basic Fixed Sites—Sites on streams at which streamflow is measured and samples are collected for temperature, salinity, suspended sediment, major ions and metals, nutrients, and organic carbon to assess the broad-scale spatial and temporal character and transport of inorganic constituents of stream water in relation to hydrologic conditions and environmental settings.

Bed sediment—The material at the bottom of a stream or other watercourse.

Benthic invertebrates—Insects, mollusks, crustaceans, worms, and other organisms without a backbone that live in, on, or near the bottom of lakes, streams, or oceans.

Bioaccumulation—The biological sequestering of a substance at a higher concentration than that at which it occurs in the surrounding environment or medium. Also, the process whereby a substance enters organisms through the gills, epithelial tissues, dietary, or other sources.

Bioavailability—The capacity of a chemical constituent to be taken up by living organisms either through physical contact or by ingestion.

Criterion—A standard rule or test on which a judgment or decision can be based.

Dissolved solids—Amount of minerals, such as salt, that are dissolved in water; amount of dissolved solids is an indicator of salinity or hardness.

Drainage basin—The portion of the surface of the earth that contributes water to a stream through overland runoff, including tributaries and impoundments.

Drinking-water standard or guideline—A threshold concentration in a public drinking-water supply, designed to protect human health. As defined here, standards are U.S. Environmental Protection Agency regulations that specify the maximum contamination levels for public water systems required to protect the public welfare; guidelines have no regulatory status and are issued in an advisory capacity.

Ecological studies—Studies of biological communities and habitat characteristics to evaluate the effects of physical and chemical characteristics of water and hydrologic conditions on aquatic biota and to determine how biological and habitat characteristics differ among environmental settings in NAWQA Study Units.

Ecoregion—An area of similar climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.

Ecosystem—The interacting populations of plants, animals, and microorganisms occupying an area, plus their physical environment.

Ground water—In general, any water that exists beneath the land surface, but more commonly applied to water in fully saturated soils and geologic formations.

Habitat—The part of the physical environment where plants and animals live.

Hydrograph—Graph showing variation of water elevation, velocity, streamflow, or other property of water with respect to time.

Intensive Fixed Sites—Basic Fixed Sites with increased sampling frequency during selected seasonal periods and analysis of dissolved pesticides for 1 year.

Maximum contaminant level (MCL)—Maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLs are enforceable standards established by the U.S. Environmental Protection Agency.

Median—The middle or central value in a distribution of data ranked in order of magnitude. The median is also known as the 50th percentile.

Micrograms per liter (µg/L)—A unit expressing the concentration of constituents in solution as weight (micrograms) of solute per unit volume (liter) of water; equivalent to one part per billion in most stream water and ground water. One thousand micrograms per liter equals 1 milligram per liter (mg/L).

Nitrate—An ion consisting of nitrogen and oxygen (NO_3^-). Nitrate is a plant nutrient and is very mobile in soils.

Nonpoint source—A pollution source that cannot be defined as originating from discrete points such as pipe discharge. Areas of fertilizer and pesticide applications, atmospheric deposition, manure, and natural inputs from plants and trees are types of nonpoint source pollution.

Nutrient—An element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Organochlorine compound—Synthetic organic compounds containing chlorine. As generally used, the term refers to compounds containing mostly or exclusively carbon, hydrogen, and chlorine. Examples include organochlorine insecticides, polychlorinated biphenyls, and some solvents containing chlorine.

Organophosphate insecticides—A class of insecticides derived from phosphoric acid. They tend to have high acute toxicity to vertebrates. Although readily metabolized by vertebrates, some metabolic products are more toxic than the parent compound.

Phosphorus—A nutrient essential for growth that can play a key role in stimulating aquatic growth in lakes and streams.

Plankton—Floating or weakly swimming organisms whose migration is controlled by waves and currents. Animals of the group are called zooplankton and the plants are called phytoplankton.

Point source—A source at a discrete location such as a discharge pipe, drainage ditch, tunnel, well, concentrated livestock operation, or floating craft.

Polychlorinated biphenyls (PCBs)—A mixture of chlorinated derivatives of biphenyl, marketed under the trade name Aroclor with a number designating the chlorine content (such as Aroclor 1260). PCBs were used in transformers and capacitors for insulating purposes and in gas pipeline systems as a lubricant. Further sale for new use was banned by law in 1979.

Radon—A naturally occurring, colorless, odorless, radioactive gas formed by the disintegration of the element radium; damaging to human lungs when inhaled.

Recharge—Water that infiltrates the ground and reaches the saturated zone.

Runoff—Excess rainwater or snowmelt that is transported to streams by overland flow, tile drains, or ground water.

Semivolatile organic compound (SVOC)—Operationally defined as a group of synthetic organic compounds that are solvent-extractable and that can be determined by gas chromatography/mass spectrometry. SVOCs include phenols, phthalates, and polycyclic aromatic hydrocarbons (PAHs).

Suspended sediment—Particles of rock, sand, soil, and organic detritus carried in suspension in the water column, in contrast to sediment that moves on or near the streambed.

Tolerant species—Those species that are adaptable to (tolerant of) human alterations to the environment and often increase in number when human alterations occur.

Trace element—An element found in only minor amounts (concentrations less than 1.0 milligram per liter) in water or sediment; includes arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc.

Volatile organic compounds (VOCs)—Organic chemicals that have a high vapor pressure relative to their water solubility. VOCs include components of gasoline, fuel oils, and lubricants, as well as organic solvents, fumigants, some inert ingredients in pesticides, and some by-products of chlorine disinfection.

Water-quality guidelines—Specific levels of water quality which, if reached, may adversely affect human health or aquatic life. These are nonenforceable guidelines issued by a governmental agency or other institution.

Water-quality standards—State-adopted and U.S. Environmental Protection Agency-approved ambient standards for water bodies. Standards include the use of the water body and the water-quality criteria that must be met to protect the designated use or uses.

Watershed—See Drainage basin.

Water table—The point below the land surface where ground water is first encountered and below which the earth is saturated. Depth to the water table varies widely across the country.

Wetlands—Ecosystems whose soil is saturated for long periods seasonally or continuously, including marshes, swamps, and ephemeral ponds.

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APPENDIX—WATER-QUALITY DATA FROM THE SACRAMENTO RIVER BASIN IN A NATIONAL CONTEXT

For a complete view of Sacramento River Basin data and for additional information about specific benchmarks used, visit our Web site at http://water.usgs.gov/nawqa/. Also visit the NAWQA Data Warehouse for access to NAWQA data sets at http://water.usgs.gov/nawqa/data.

This appendix is a summary of chemical concentrations and biological indicators assessed in the Sacramento River Basin. Selected results for this basin are graphically compared to results from as many as 36 NAWQA Study Units investigated from 1991 to 1998 and to national water-quality benchmarks for human health, aquatic life, or fish-eating wildlife. The chemical and biological indicators shown were selected on the basis of frequent detection, detection at concentrations above a national benchmark, or regulatory or scientific importance. The graphs illustrate how conditions associated with each land use sampled in the Sacramento River Basin compare to results from across the Nation, and how conditions compare among the several land uses. Graphs for chemicals show only detected concentrations and, thus, care must be taken to evaluate detection frequencies in addition to concentrations when comparing study-unit and national results. For example, molinate concentrations in Sacramento River Basin agricultural streams were similar to the national distribution, but the detection frequency was much higher (100 percent compared to 7 percent).

CHEMICALS IN WATER

Concentrations and detection frequencies, Sacramento River Basin, 1994–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals

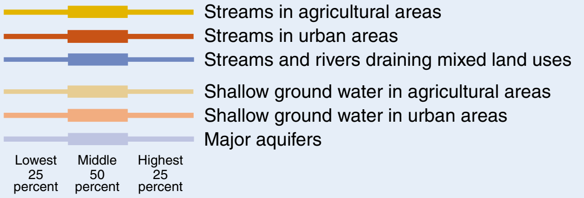
◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

-- Not measured or sample size less than two

12 Study-unit sample size. For ground water, the number of samples is equal to the number of wells sampled

National ranges of detected concentrations, by land use, in 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected



National water-quality benchmarks

National benchmarks include standards and guidelines related to drinking-water quality, criteria for protecting the health of aquatic life, and a goal for preventing stream eutrophication due to phosphorus. Sources include the U.S. Environmental Protection Agency and the Canadian Council of Ministers of the Environment.

| Drinking-water quality (applies to ground water and surface water)

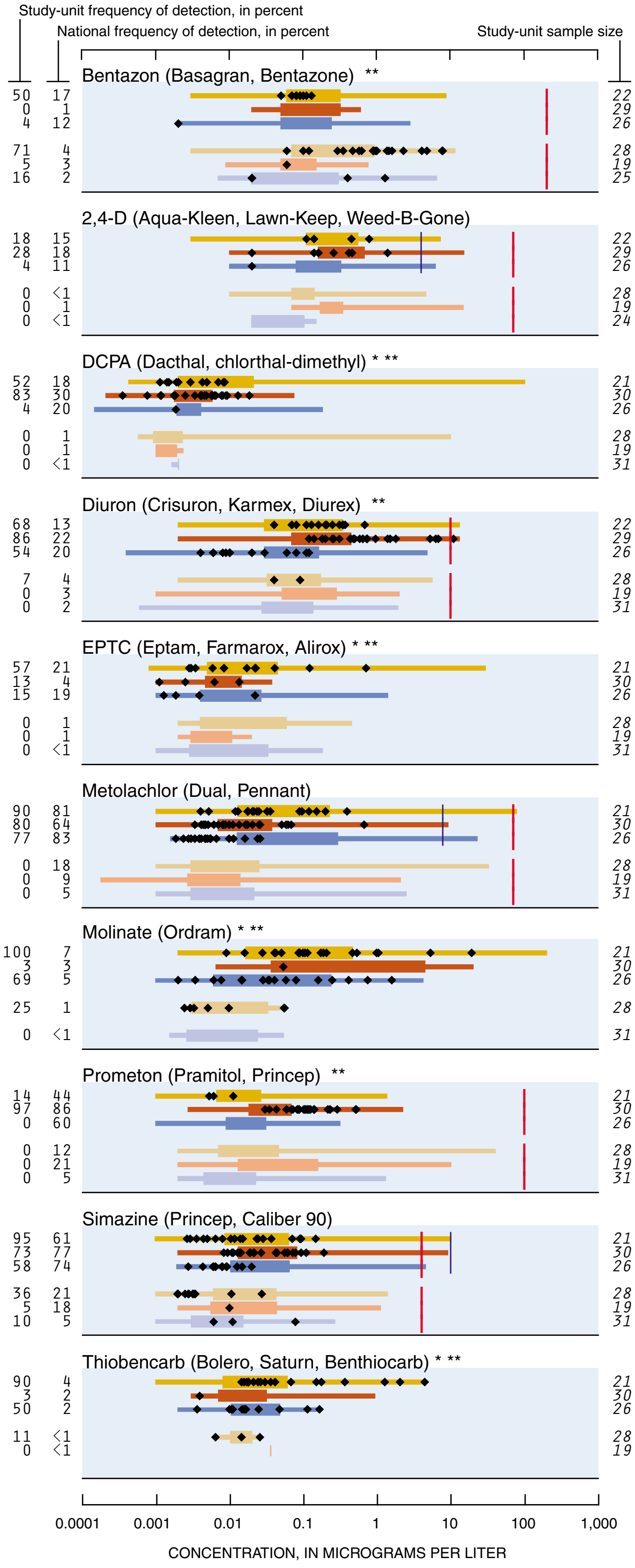
| Protection of aquatic life (applies to surface water only)

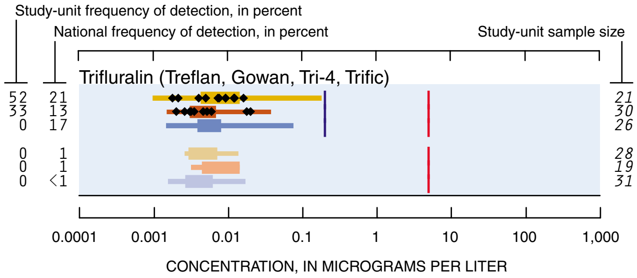
| Prevention of eutrophication in streams not flowing directly into lakes or impoundments

* No benchmark for drinking-water quality

** No benchmark for protection of aquatic life

Pesticides in water—Herbicides

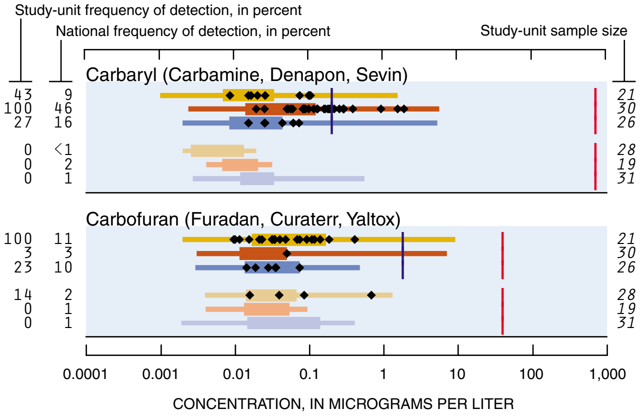


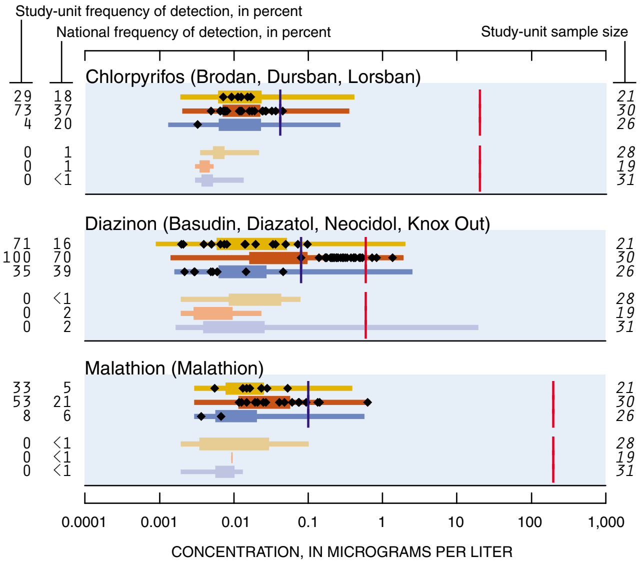


Other herbicides detected
Alachlor (Lasso, Bronco, Lariat, Bullet) **
Atrazine (AAtrex, Atrex, Atred, Gesaprim)
Benfluralin (Balan, Benefin, Bonalan) * **
Bromacil (Hyvar X, Urox B, Bromax)
Bromoxynil (Buctril, Brominal) *
Cyanazine (Bladex, Fortrol)
Deethylatrazine (Atrazine breakdown product) * **
Dichlorprop (2,4-DP, Seritox 50, Lentemul) * **
2,6-Diethylaniline (Alachlor breakdown product) * **
MCPA (Rhomene, Rhonox, Chiptox)
Metribuzin (Lexone, Sencor)
Napropamide (Devrinol) * **
Norflurazon (Evital, Predict, Solicam, Zorial) * **
Oryzalin (Surflan, Dirimal) * **
Pebulate (Tillam, PEBC) * **
Pendimethalin (Pre-M, Prowl, Stomp) * **
Pronamide (Kerb, Propyzamid) **
Propanil (Stam, Stampede, Wham) * **
Tebuthiuron (Spike, Tebusan)
Triclopyr (Garlon, Grandstand, Redeem, Remedy) * **

Herbicides not detected
Acetochlor (Harness Plus, Surpass) * **
Acifluorfen (Blazer, Tackle 2S) **
Butylate (Sutan +, Genate Plus, Butilate) **
Chloramben (Amiben, Amilon-WP, Vegiben) **
Clopyralid (Stinger, Lontrel, Transline) * **
2,4-DB (Butyrac, Butoxone, Embutox Plus, Embutone) * **
Dacthal mono-acid (Dacthal breakdown product) * **
Dicamba (Banvel, Dianat, Scotts Proturf)
Dinoseb (Dinosebe)
Ethalfluralin (Sonalan, Curbit) * **
Fenuron (Fenulon, Fenidim) * **
Fluometuron (Flo-Met, Cotoran) **
Linuron (Lorox, Linex, Sarclex, Linurex, Afalon) *
MCPB (Thistrol) * **
Neburon (Neburea, Neburyl, Noruben) * **
Picloram (Grazon, Tordon)
Propachlor (Ramrod, Satecid) **
Propham (Tuberite) **
2,4,5-T **
2,4,5-TP (Silvex, Fenoprop) **
Terbacil (Sinbar) **
Triallate (Far-Go, Avadex BW, Tri-allate) *

Pesticides in water—Insecticides



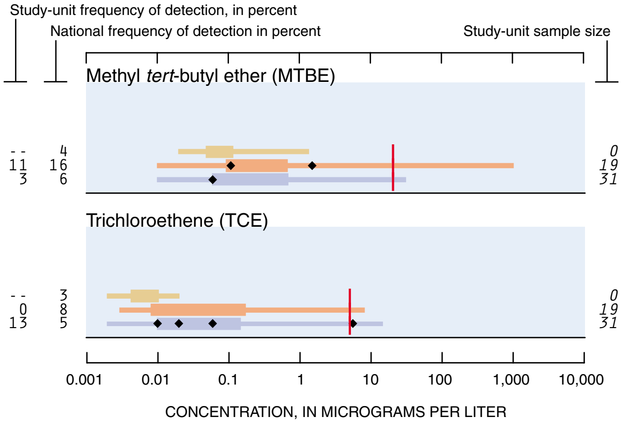


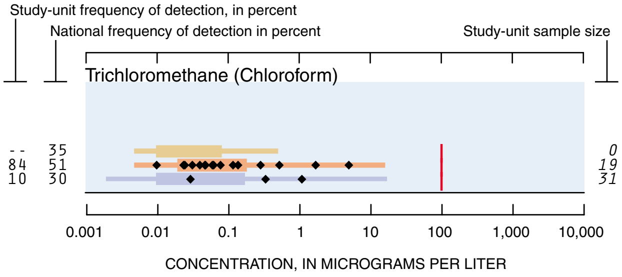
Other insecticides detected
Azinphos-methyl (Guthion, Gusathion M) *
p,p'-DDE
Propargite (Comite, Omite, Ornamite) * **

Insecticides not detected
Aldicarb (Temik, Ambush, Pounce)
Aldicarb sulfone (Standak, aldoxycarb)
Aldicarb sulfoxide (Aldicarb breakdown product)
Dieldrin (Panoram D-31, Octalox, Compound 497)
Disulfoton (Disyston, Di-Syston) **
Ethoprop (Mocap, Ethoprophos) * **
Fonofos (Dyfonate, Capfos, Cudgel, Tycap) **
alpha-HCH (alpha-BHC, alpha-lindane) **
gamma-HCH (Lindane, gamma-BHC)
3-Hydroxycarbofuran (Carbofuran breakdown product) * **
Methiocarb (Slug-Geta, Grandslam, Mesurol) * **
Methomyl (Lanox, Lannate, Acinate) **
Methyl parathion (Penncap-M, Folidol-M) **
Oxamyl (Vydate L, Pratt) **
Parathion (Roethyl-P, Alkron, Panthion, Phoskil) *
cis-Permethrin (Ambush, Astro, Pounce) * **
Phorate (Thimet, Granutox, Geomet, Rampart) * **
Propoxur (Baygon, Blattanex, Unden, Proprotox) * **
Terbufos (Contraven, Counter, Pilarfox) **

Volatile organic compounds (VOCs) in ground water

These graphs represent data from 16 Study Units, sampled from 1996 to 1998





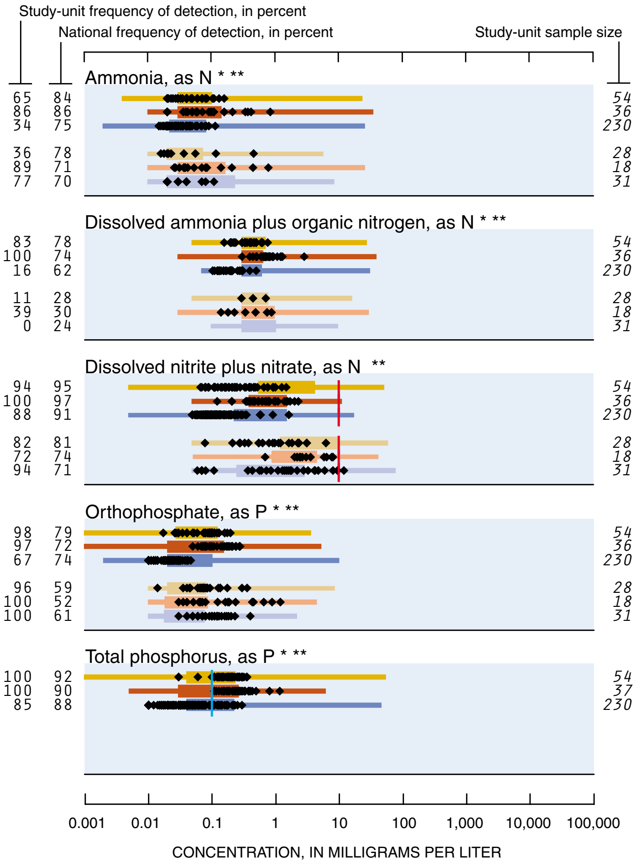
Other VOCs detected

Bromodichloromethane (Dichlorobromomethane)
Carbon disulfide *
Chloromethane (Methyl chloride)
Dichlorodifluoromethane (CFC 12, Freon 12)
1,2-Dichloroethane (Ethylene dichloride)
1,1-Dichloroethane (Ethylidene dichloride) *
cis-1,2-Dichloroethene ((Z)-1,2-Dichloroethene)
Ethenylbenzene (Styrene)
Iodomethane (Methyl iodide) *
Tetrachloroethene (Perchloroethene)
Tetrachloromethane (Carbon tetrachloride)
1,1,1-Trichloroethane (Methylchloroform)
Trichlorofluoromethane (CFC 11, Freon 11)
1,2,4-Trimethylbenzene (Pseudocumene) *

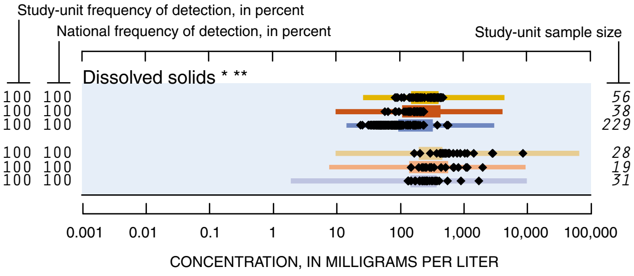
VOCs not detected

tert-Amylmethylether (*tert*-amyl methyl ether (TAME)) *
Benzene
Bromobenzene (Phenyl bromide) *
Bromochloromethane (Methylene chlorobromide)
Bromoethene (Vinyl bromide) *
Bromomethane (Methyl bromide)
2-Butanone (Methyl ethyl ketone (MEK)) *
n-Butylbenzene (1-Phenylbutane) *
sec-Butylbenzene *
tert-Butylbenzene *
3-Chloro-1-propene (3-Chloropropene) *
1-Chloro-2-methylbenzene (*o*-Chlorotoluene)
1-Chloro-4-methylbenzene (*p*-Chlorotoluene)
Chlorobenzene (Monochlorobenzene)
Chlorodibromomethane (Dibromochloromethane)
Chloroethane (Ethyl chloride) *
Chloroethene (Vinyl chloride)
1,2-Dibromo-3-chloropropane (DBCP, Nemagon)
1,2-Dibromoethane (Ethylene dibromide, EDB)
Dibromomethane (Methylene dibromide) *
trans-1,4-Dichloro-2-butene ((Z)-1,4-Dichloro-2-butene) *
1,2-Dichlorobenzene (*o*-Dichlorobenzene)
1,3-Dichlorobenzene (*m*-Dichlorobenzene)
1,4-Dichlorobenzene (*p*-Dichlorobenzene)
1,1-Dichloroethene (Vinylidene chloride)
trans-1,2-Dichloroethene ((E)-1,2-Dichlorothene)
Dichloromethane (Methylene chloride)
1,2-Dichloropropane (Propylene dichloride)
2,2-Dichloropropane *
1,3-Dichloropropane (Trimethylene dichloride) *
trans-1,3-Dichloropropene ((E)-1,3-Dichloropropene)
cis-1,3-Dichloropropene ((Z)-1,3-Dichloropropene)
1,1-Dichloropropene *
Diethyl ether (Ethyl ether) *
Diisopropyl ether (Diisopropylether (DIPE)) *
1,2-Dimethylbenzene (*o*-Xylene)
1,3 & 1,4-Dimethylbenzene (*m*-&*p*-Xylene)
1-4-Epoxy butane (Tetrahydrofuran, Diethylene oxide) *
Ethyl methacrylate *
Ethyl *tert*-butyl ether (Ethyl-*t*-butyl ether (ETBE)) *
1-Ethyl-2-methylbenzene (2-Ethyltoluene) *
Ethylbenzene (Phenylethane)
Hexachlorobutadiene
1,1,1,2,2,2-Hexachloroethane (Hexachloroethane)
2-Hexanone (Methyl butyl ketone (MBK)) *
Isopropylbenzene (Cumene) *
p-Isopropyltoluene (*p*-Cymene) *
Methyl acrylonitrile *
Methyl-2-methacrylate (Methyl methacrylate) *
4-Methyl-2-pentanone (Methyl isobutyl ketone (MIBK)) *
Methyl-2-propenoate (Methyl acrylate) *
Methylbenzene (Toluene)
Naphthalene
2-Propanone (Acetone) *
2-Propenenitrile (Acrylonitrile)
n-Propylbenzene (Isocumene) *
1,1,2,2-Tetrachloroethane *
1,1,1,2-Tetrachloroethane
1,2,3,4-Tetramethylbenzene (Prehnitene) *
1,2,3,5-Tetramethylbenzene (Isodurene) *
Tribromomethane (Bromoform)
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon 113) *
1,2,4-Trichlorobenzene
1,2,3-Trichlorobenzene *
1,1,2-Trichloroethane (Vinyl trichloride)
1,2,3-Trichloropropane (Allyl trichloride)
1,2,3-Trimethylbenzene (Hemimellitene) *

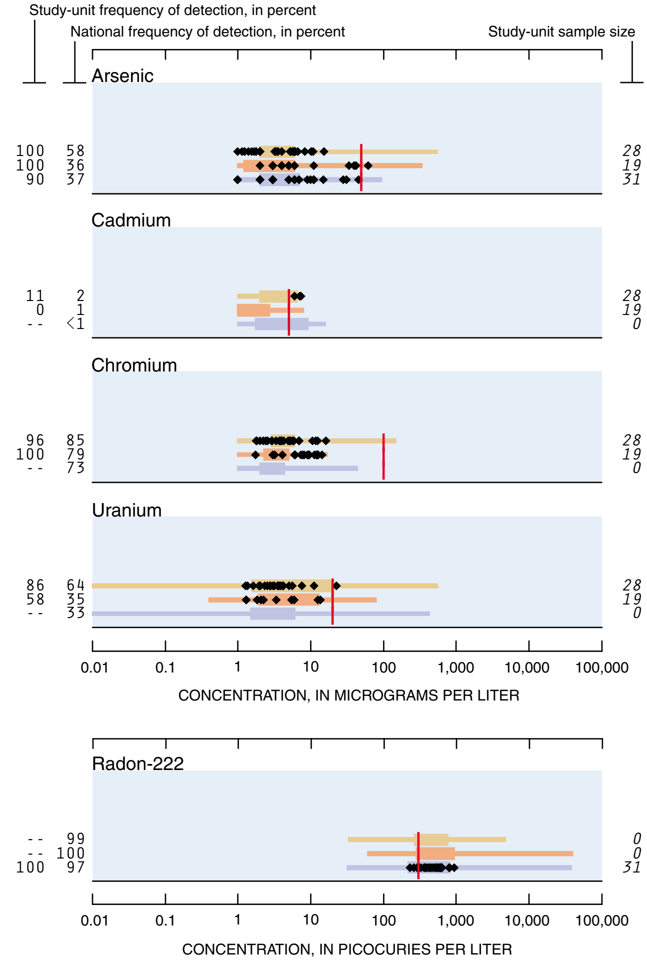
Nutrients in water



Dissolved solids in water



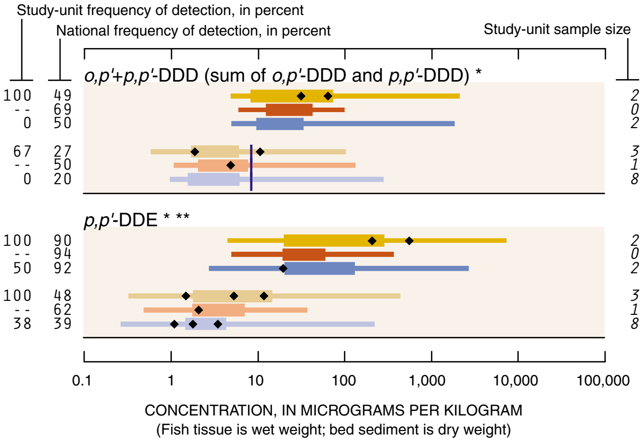
Trace elements in ground water



Other trace elements detected
Selenium
Zinc

Trace elements not detected
Lead

Organochlorines in fish tissue (whole body) and bed sediment



CHEMICALS IN FISH TISSUE AND BED SEDIMENT

Concentrations and detection frequencies, Sacramento River Basin, 1994–98—Detection sensitivity varies among chemicals and, thus, frequencies are not directly comparable among chemicals. Study-unit frequencies of detection are based on small sample sizes; the applicable sample size is specified in each graph

◆ Detected concentration in Study Unit

66 38 Frequencies of detection, in percent. Detection frequencies were not censored at any common reporting limit. The left-hand column is the study-unit frequency and the right-hand column is the national frequency

-- Not measured or sample size less than two

12 Study-unit sample size

National ranges of concentrations detected, by land use, in 36 NAWQA Study Units, 1991–98—Ranges include only samples in which a chemical was detected

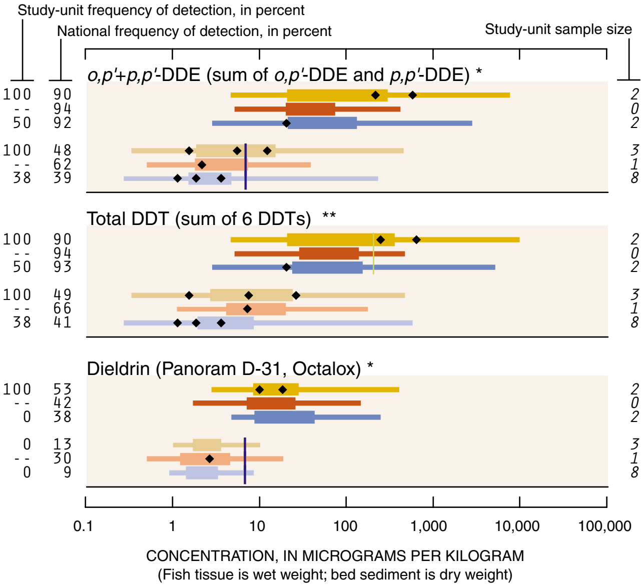
Fish tissue from streams in agricultural areas
Fish tissue from streams in urban areas
Fish tissue from streams draining mixed land uses
Sediment from streams in agricultural areas
Sediment from streams in urban areas
Sediment from streams draining mixed land uses

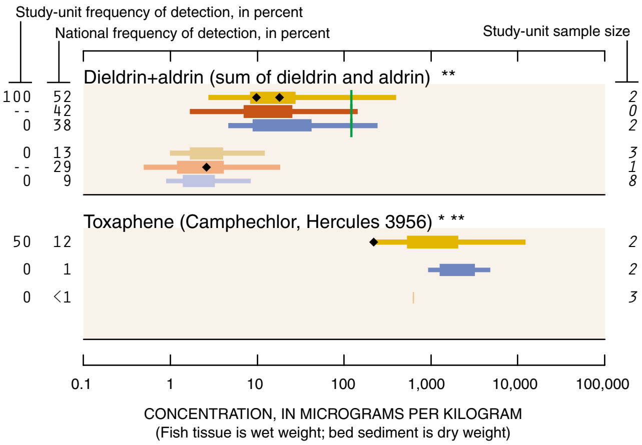
Lowest 25 percent | Middle 50 percent | Highest 25 percent

National benchmarks for fish tissue and bed sediment

National benchmarks include standards and guidelines related to criteria for protection of the health of fish-eating wildlife and aquatic organisms. Sources include the U.S. Environmental Protection Agency, other Federal and State agencies, and the Canadian Council of Ministers of the Environment

| Protection of fish-eating wildlife (applies to fish tissue)
| Protection of aquatic life (applies to bed sediment)
* No benchmark for protection of fish-eating wildlife
** No benchmark for protection of aquatic life





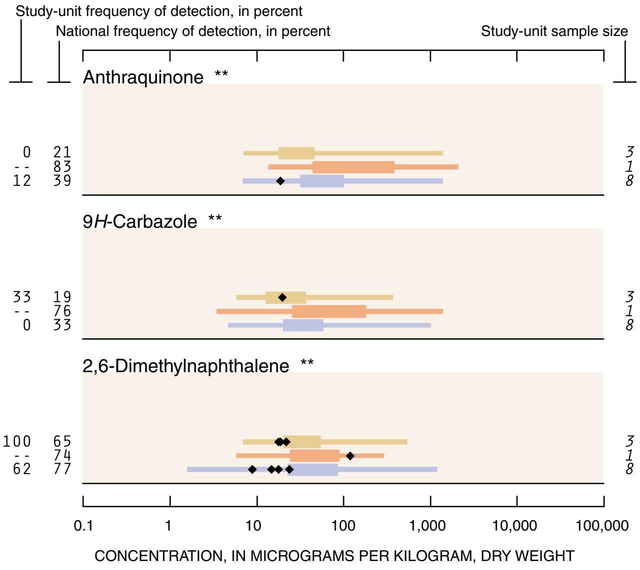
Other organochlorines detected

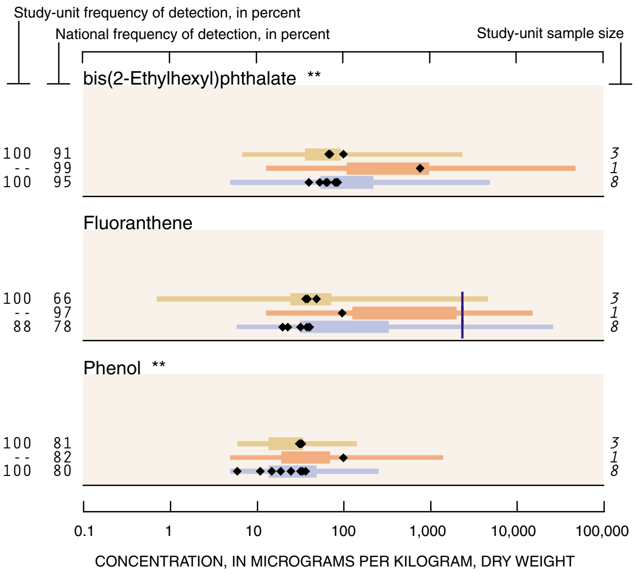
o,p'+*p,p'*-DDT (sum of *o,p'*-DDT and *p,p'*-DDT) *

Organochlorines not detected

Chloroneb (Chloronebe, Demosan) * **
DCPA (Dacthal, chlorthal-dimethyl) * **
Endosulfan I (alpha-Endosulfan, Thiodan) * **
Endrin (Endrine)
gamma-HCH (Lindane, gamma-BHC, Gammexane) *
Total-HCH (sum of alpha-HCH, beta-HCH, gamma-HCH, and delta-HCH) **
Heptachlor epoxide (Heptachlor breakdown product) *
Heptachlor+heptachlor epoxide (sum of heptachlor and heptachlor epoxide) **
Hexachlorobenzene (HCB) **
Isodrin (Isodrine, Compound 711) * **
p,p'-Methoxychlor (Marlate, methoxychlore) * **
o,p'-Methoxychlor * **
Mirex (Dechlorane) **
PCB, total
Pentachloroanisole (PCA) * **
cis-Permethrin (Ambush, Astro, Pounce) * **
trans-Permethrin (Ambush, Astro, Pounce) * **

Semivolatile organic compounds (SVOCs) in bed sediment





Other SVOCs detected

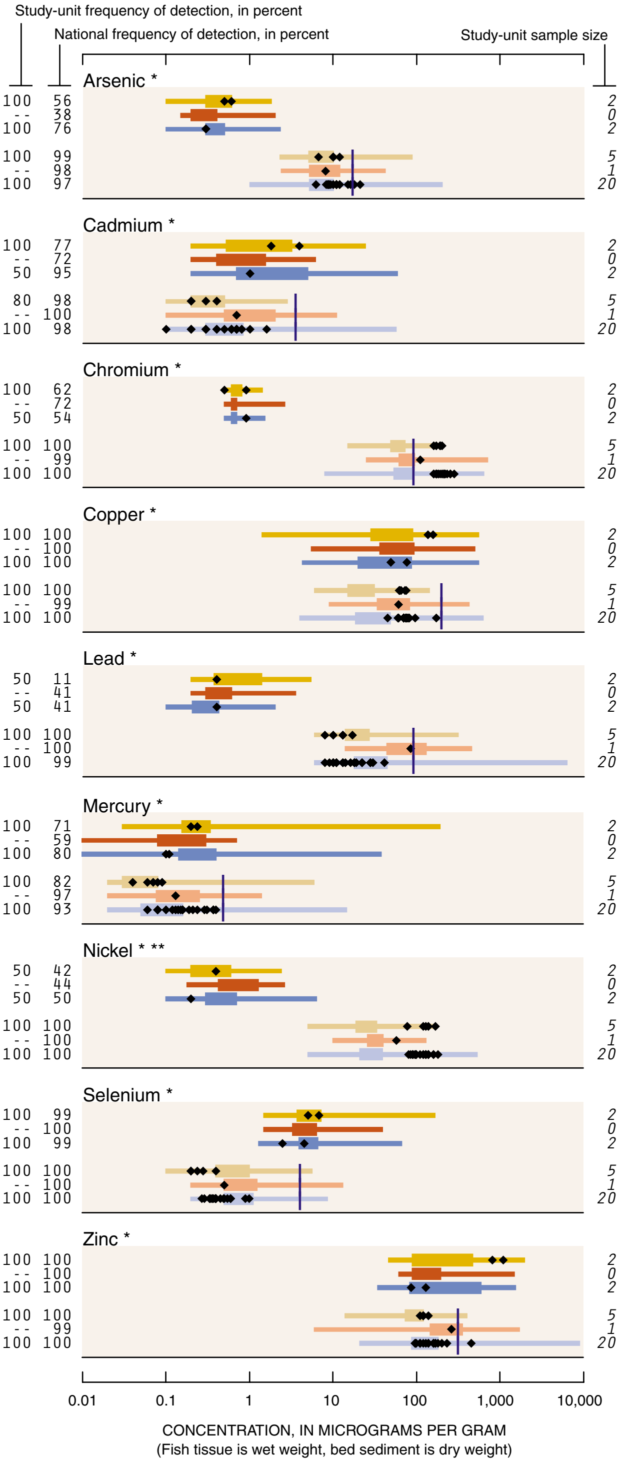
Acenaphthene
Acenaphthylene
Anthracene
Benz[*a*]anthracene
Benzo[*a*]pyrene
Benzo[*b*]fluoranthene **
Benzo[*ghi*]perylene **
Benzo[*k*]fluoranthene **
Butylbenzylphthalate **
Chrysene
p-Cresol **
Di-*n*-butylphthalate **
Di-*n*-octylphthalate **
Diethylphthalate **
1,6-Dimethylnaphthalene **
Dimethylphthalate **
9*H*-Fluorene (Fluorene)
Indeno[1,2,3-*cd*]pyrene **
2-Methylanthracene **
4,5-Methylenephenanthrene **
1-Methylphenanthrene **
Naphthalene
Phenanthrene
Pyrene

SVOCs not detected

Acridine **
C8-Alkylphenol **
Azobenzene **
Benzo[*c*]cinnoline **
2,2-Biquinoline **
4-Bromophenyl-phenylether **
4-Chloro-3-methylphenol **
bis(2-Chloroethoxy)methane **
2-Chloronaphthalene **
2-Chlorophenol **
4-Chlorophenyl-phenylether **
Dibenz[*a,h*]anthracene
Dibenzothiophene **
1,2-Dichlorobenzene (*o*-Dichlorobenzene) **
1,3-Dichlorobenzene (*m*-Dichlorobenzene) **
1,4-Dichlorobenzene (*p*-Dichlorobenzene) **
1,2-Dimethylnaphthalene **
3,5-Dimethylphenol **
2,4-Dinitrotoluene **
2-Ethylnaphthalene **
Isophorone **
Isoquinoline **
1-Methyl-9*H*-fluorene **
1-Methylpyrene **
Nitrobenzene **
N-Nitrosodi-*n*-propylamine **

N-Nitrosodiphenylamine **
Pentachloronitrobenzene **
Phenanthridine **
Quinoline **
1,2,4-Trichlorobenzene **
2,3,6-Trimethylnaphthalene **

Trace elements in fish tissue (livers) and bed sediment



BIOLOGICAL INDICATORS

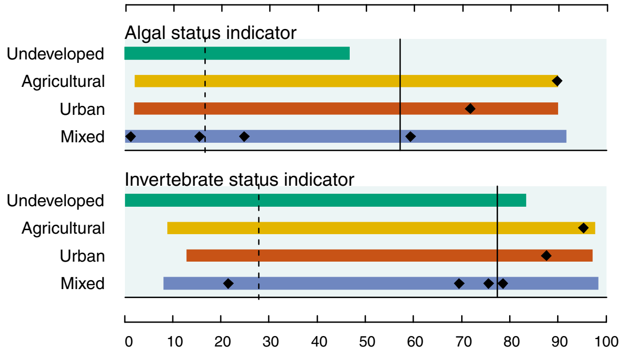
Higher national scores suggest habitat disturbance, water-quality degradation, or naturally harsh conditions. The status of algae, invertebrates (insects, worms, and clams), and fish provide a record of water-quality and stream conditions that water-chemistry indicators may not reveal. **Algal status** focuses on the changes in the percentage of certain algae in response to increasing siltation, and it often correlates with higher nutrient concentrations in some regions. **Invertebrate status** averages 11 metrics that summarize changes in richness, tolerance, trophic conditions, and dominance associated with water-quality degradation. **Fish status** sums the scores of four fish metrics (percent tolerant, omnivorous, non-native individuals, and percent individuals with external anomalies) that increase in association with water-quality degradation

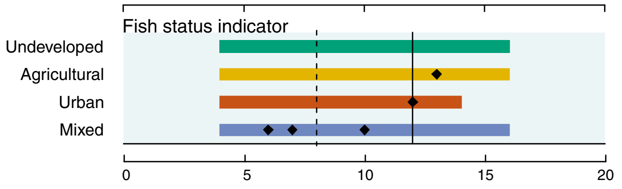
Biological indicator value, Sacramento River Basin, by land use, 1994–98

◆ Biological status assessed at a site

National ranges of biological indicators, in 16 NAWQA Study Units, 1994–98

🟩 Streams in undeveloped areas
🟨 Streams in agricultural areas
🟧 Streams in urban areas
🟦 Streams in mixed-land-use areas
— 75th percentile
- - 25th percentile





A COORDINATED EFFORT

Coordination with agencies and organizations in the Sacramento River Basin was integral to the success of this water-quality assessment. We thank those who served as members of our liaison committee.

Federal Agencies
U.S. Environmental Protection Agency
U.S. Fish and Wildlife Service
Bureau of Reclamation
National Marine Fisheries Service

State Agencies
California Regional Water Quality Control Board
California Department of Water Resources
California Department of Fish and Game
California Division of Mines and Geology
California State Water Resources Control Board

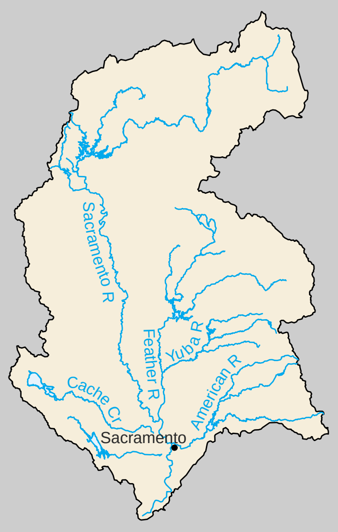
Other
University of California, Davis

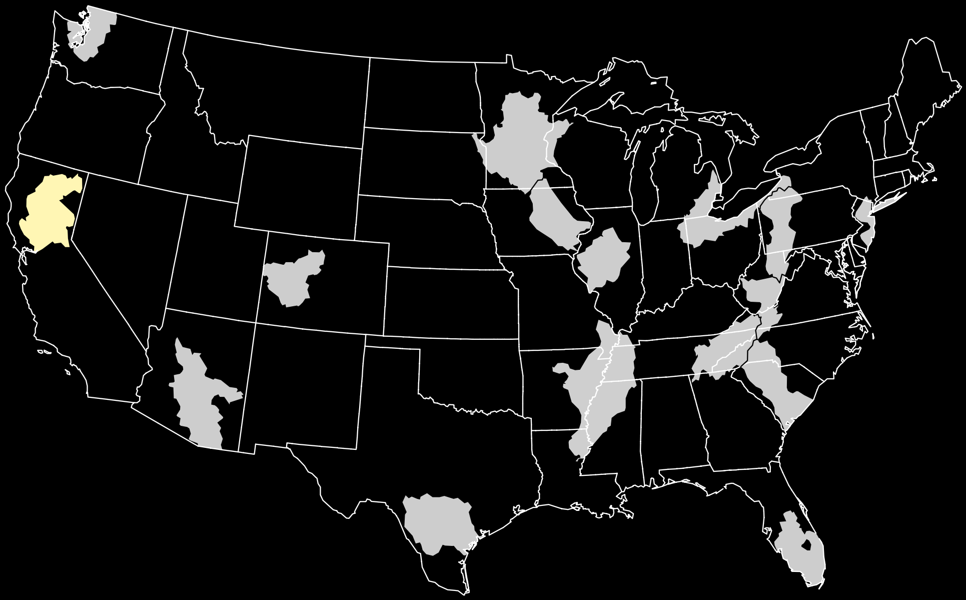
We also thank the following organizations for contributing to this effort.

We are grateful to the Sacramento River Watershed Program (SRWP) and the Sacramento Regional County Sanitation District (SRCSD). The SRWP was initiated in 1995, just as the NAWQA Program initiated most of the water-quality sample collection activities in the basin. The SRWP has the following mission statement: "To ensure that current and potential uses of the watershed's resources are sustained, restored, and where possible, enhanced, while promoting the long-term social and economic vitality of the region." The current SRWP membership includes a diverse group of stakeholders interested in water quality of the Sacramento River Basin. The infrastructure of the SRWP provides a unique means of achieving the NAWQA goals of coordination. The SRCSD anticipated the need for a more comprehensive approach to water-quality management of the Sacramento River Basin. As a result, the SRCSD was instrumental in developing the Sacramento River Toxic Pollutant Control Program and was a partner with the Sacramento River Basin NAWQA Program in a detailed study of trace metals in the Sacramento River system. Other agencies contributing to or helping to facilitate funding for that study include the California State Water Resources Control Board, the U.S. Environmental Protection Agency, and the National Marine Fisheries Service.

NAWQA

National Water-Quality Assessment (NAWQA) Program
Sacramento River Basin





Domagalski and others—Water Quality in the Sacramento River Basin
U.S. Geological Survey Circular 1215

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