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REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

METAL CONCENTRATIONS, LOADS, AND TOXICITY ASSESSMENT IN THE SACRAMENTO/SAN JOAQUIN DELTA: 1993-1995

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Forward

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EXECUTIVE SUMMARY The Sierra Nevada, Klamath, Cascade, and Coast range mountains surrounding the Central Valley are rich in geological deposits of metal laden ores. Historic mining activity resulted in open mines and exposed tailings which leach metals into the Sacramento River and its tributaries. Runoff from mining operations has resulted in exceedances of water quality objectives, fish kills, and elevated metal concentrations in sediment and tissues of aquatic organisms (Nordstrom *et* al., 1977; Wilson *et* al., 1981; SWRCB, 1990; Montoya and Pan, 1992; Fujimura *et al.*, 1995; Saiki *et* al., 1995; Cain *et al.*, 1998). In addition, metals in the upper and middle regions of the watershed have been linked to impacts in aquatic life using toxicity tests (Connor *et al.*, 1993; Bailey *et al.*, 1994; Connor *et al.*, 1994). However, metal concentrations and toxicity have not been well characterized in the Sacramento-San Joaquin River Delta.

The Bay Protection and Toxic Cleanup Program (BPTCP) was created to identify toxic hot spots, develop sediment quality objectives, and remediate toxic hot spots in California. The Central Valley Regional Water Quality Control Board utilized BPTCP funds to determine if metals threatened beneficial uses in the Delta. The current study had four objectives: 1) to determine if metal concentrations (i.e., arsenic, cadmium, chromium, copper, lead, nickel, and zinc) could be measured in the Sacramento-San Joaquin Delta during low and high flow periods using ultra clean methods with detection limits low enough to evaluate compliance with water quality objectives; (2) to define the extent of water quality objective exceedances in the Delta for metals; 3) to define the extent of metal associated toxicity throughout the Delta using the EPA three species toxicity tests; and 4) to determine the metal loading patterns into the Delta from the Yolo Bypass and Sacramento River (at Greene's Landing) during low and high flow periods. To address these objectives, fixed stations were monitored over multiple seasons and storm events. However, much of the sampling effort was focused during the winter to complement ongoing monthly metals monitoring by the Sacramento County Ambient Monitoring Program. The biotoxicity project is discussed in separate reports (Deanovic *et al.*, 1996 & 1998). Because significant loads were identified entering the Delta during storm events, a study (Metals Source Pilot Study) was conducted during a single winter storm event to better characterize the source(s) of the loads.

Water samples were collected for metal analyses during the relatively normal 1993 water year (October 1992-September 1993: WY93), critically dry 1994 water year (October 1993-September 1994: WY94), and high flow 1995 water year (October 1994-September 1995: WY95). Flows in the combined discharge of the Sacramento River and Yolo Bypass peaked at 135,000 CFS on 28 March during WY93 and at 334,000 CFS on 13 March during WY95. As a result of the low rainfall during WY94, flows at Freeport did not exceed 30,000 CFS and the Yolo Bypass had measurable flows above 1000 CFS on only four days.

Were low detection limits obtained using ultra clean techniques? Yes

- Evapoconcentration prior to analysis of field collected samples resulted in the detection of arsenic, cadmium, chromium, copper, lead, nickel, and zinc down to the low to mid parts per trillion range, well below values set for water quality objectives.

● Analysis of laboratory and field blanks indicated samples could be collected relatively free of metal contamination.

Were water quality objectives exceeded for metals during the study? No

● USEPA National Ambient Water Quality Criteria and the USEPA Proposed California Toxics Rule Criteria were never exceeded in any of 549 samples collected from 15 Delta stations during critically dry, normal, and wet water years.

● The site-specific numeric water quality objectives for arsenic, copper, silver, and zinc were not exceeded in the Delta.

What trends in metal concentrations were identified?

● During the critically dry WY94, total recoverable concentrations of chromium, copper, lead, nickel, and zinc increased with increasing flow conditions and increased sediment load in the Sacramento River at Greene's Landing.

● TSS or flow could be used to predict general levels (high versus low) of total recoverable copper, chromium, lead, nickel, and zinc during the drought-like conditions in WY94. Furthermore, these metals tracked each other very closely during this period such that high total recoverable zinc concentrations coincided with high total recoverable copper, chromium, lead, and nickel concentrations.

● During the high flow WY95, total recoverable cadmium, chromium, copper, and zinc concentrations at Greene's Landing were still significantly related to TSS indicating these metals were bound to suspended sediment particles during both dry and wet years.

● During the high flow WY95, total recoverable cadmium, chromium, copper, nickel, and zinc were inter-related and lead was not associated with any other metal. Using the inter-related nature of TSS and the grouped metals (i.e., copper, zinc, chromium, and cadmium), one could begin to utilize TSS levels as a general indicator for levels of these metals (e.g., high versus low concentrations).

● The value of these relationships is in designing when to collect samples if one is interested in sampling for high metal concentrations. For some metals, high flow events would be expected to produce high total recoverable metal concentration.

Was metals related toxicity identified in the Delta? No

● Fifty eight samples exhibited toxicity during the study. Metals were never implicated in the Toxicity Identification Evaluation (TIEs) studies conducted on samples collected from the Delta which were toxic. However, TIEs could not be performed on all samples which exhibited toxicity due to budgetary constraints.

Were metal loading patterns characteristic of hydrological conditions? Yes

● Depending on the metal, Sacramento River loads increased from approximately 460%

to 5,300% from the critically dry WY94 to the wet WY95. This indicates that high flow water years can greatly increase metal inputs to the Delta when compared to dry years.

● Sediment loading patterns in the Sacramento River and Yolo Bypass were nearly identical to the load patterns for copper and zinc during the wet WY95, with greater loads in the Bypass. These metals, as well as chromium, appeared to be transported into the Delta bound to sediment particles.

Constituent	Bypass Load	River Load
Copper (kg) % of total	296,000 67	144,000 33
Zinc (kg) % of total	727,000 65	394,000 35
Chromium (kg) % of total	472,000 74	155,000 26
Lead (kg) % of total	64,700 54	54,400 46
Cadmium (kg) % of total	1,550 48	1,660 52
Nickel (kg) % of total	911,000 82	201,000 18
Arsenic (kg) % of total	22,400 52	20,800 48
Sediment (metric tons) % of total	2,500,000 66	1,300,000 34

What source(s) of metals were identified during the March 1995 high flow pilot study?

● Metal loading from historic mines in the Lake Shasta region could not be assessed because reservoir releases were maintained low to minimize downstream flooding.

● Areas of significant load contributions during the study included Cottonwood Creek in the upper Watershed and Cache Creek in the lower Watershed.

● Additional inputs of metals which resulted in high loads occurred between the Bend River bridge and Ord Ferry bridge and between County Road A-8 and Colusa. Both regions receive runoff from undammed creeks during major storm events.

Based on a lack of metals related toxicity and no exceedances of water quality objectives for metals in this study, future metals monitoring (excluding mercury) in the Delta as Regional Board special studies is not a high priority. However, staff recommend that ambient monitoring programs such as the Coordinated Monitoring Program, Regional Monitoring Program, Sacramento River Watershed Program, and CALFEDs Coordinated Monitoring and Research Program continue to include water column metals monitoring and that sediment testing and tissue analyses be included.

INTRODUCTION

BASIN DESCRIPTION

The Sacramento-San Joaquin Delta Estuary is ecologically, aesthetically, and economically significant to the State of California. The area comprises over 700 miles of interconnected waterways and encompasses 1,153 square miles (Central Valley Regional Water Quality Control Board, 1994). The Delta, together with San Francisco Bay, is the largest estuary on the west coast of North America. It is fed by three main rivers, the Sacramento, the San Joaquin, and the Mokelumne, with a combined average unimpaired flow of about twenty-two million acre-feet per year. The Sacramento-San Joaquin Delta serves California as a significant water resource. Recognized beneficial uses include fisheries and wildlife habitat, agricultural supply, recreation, navigation, industrial process and municipal and domestic supply. Two statistics are presented below to help illustrate the environmental significance of the estuary to the people of California. First, over two-hundred-eighty species of birds and over fifty species of fish inhabit the freshwater portion of the estuary (San Francisco Estuary Project, 1992; Herbold and Moyle, 1989). This is considerably more than any other water body in the State of California (San Francisco Estuary Project, 1992). Second, over half of all the drinking water for the State of California is pumped from the Delta (San Francisco Estuary Project, 1992). The Sacramento River contributes over 80% of the drinking water to the Delta, but is also a major conveyance route for contaminants from upstream sources to the Delta.

SOURCES OF METALS

The Sierra Nevada, Cascade, Klamath, and Coast range mountains surrounding the Central Valley are rich in geological deposits of metal laden ores. Historic mining activity resulted in open mines and exposed tailings which leach metals into the upper Sacramento River Watershed and its tributaries. Relatively few historic mining operations contributed the majority of metals to regional waters. Runoff from mining operations in the upper Watershed has resulted in exceedances of water quality objectives, fish kills, and elevated metal concentrations in sediment and tissues of aquatic organisms (Nordstrom *et* al., 1977; Wilson *et* al., 1981; SWRCB, 1990; Montoya and Pan, 1992; Fujimura *et al.*, 1995; Saiki *et* al., 1995; Cain *et al.*, 1998). Since the implementation of acid mine drainage controls on Iron Mountain Mine (IMM), exceedances of water quality objectives in Keswick Reservoir have been reduced (Heiman, pers. comm.). However, limited water-quality standard exceedances in Keswick Reservoir have been reported as recently as January, 1997 (Alpers, written comm.). The spatial and temporal patterns of metal dispersion from mines are variable (Alpers, written comm.). Although mine drainage is a significant contributor of metals to the system, metals also enter from other sources.

Discharges from agriculture areas are important sources of metals laden runoff to the lower Sacramento River. Agricultural drains discharged an estimated 74% of the total chromium load, 75% of total nickel load, and 17% of the total copper load in the Sacramento Valley in 1985 (Montoya *et al.*, 1988; CVRWQCB, 1989). Agricultural applications of the pesticide copper sulfate [i.e., hydroxide and sulfate (basic and pentahydrate)] reached 6,471,596 lbs. in California during 1993 (Department of Pesticide Regulation, 1995). This quantity represents a 17% increase from 1991 applications (Department of Pesticide Regulation, 1993). Of the total applied during 1993, 1,808,043 lbs. of copper were applied on rice crops (Department of Pesticide Regulation, 1995). This quantity represents a 21% increase from 1991 applications (Department of Pesticide Regulation, 1993). By far, the majority of the rice cultivation in California occurs in the Sacramento River Watershed. Copper levels measured in agricultural drainage of the Sacramento River Watershed during 1985 were significantly higher during the rice growing season (May-June) compared to January-April levels (Montoya *et al.*, 1988; CVRWQCB, 1989). Copper use on orchards is also increasing, but the potential for off site movement has not been investigated. United States Geological Survey (USGS) load estimates for the dissolved and colloidal forms of copper during July and September 1996 and May-June 1997 show increases on the Sacramento River between Colusa and Verona where water enters from the Colusa Basin Drain, Sacramento Slough, and other tributaries carrying agricultural return flows (Alpers, written comm.). Furthermore, data collected for the USGS National Water Quality Assessment (NAWQA) program on the Sacramento River indicate loads of copper into the Colusa Basin Drain during June 1997 were slightly less than that from Iron Mountain Mine via Spring Creek during the same sampling period (Alpers, written comm.). However, the transport, fate, and biotic effects of copper from the drains into the softer waters of the Sacramento River are not completely understood.

Another important source of metal input to the system is urban runoff which carries metals from transportation and homeowner uses into regional waters. Urban runoff has been estimated to contribute approximately 94% of the lead, 8-9% of the copper, cadmium, and zinc, and 14-16% of the nickel and chromium total loads in the Sacramento River Watershed (Montoya *et al.*, 1988; CVRWQCB, 1989). The American River in the lower Sacramento River Watershed receives urban runoff containing metals from several sources in the Sacramento metropolitan area. Total recoverable copper, lead, and zinc concentrations increased from upstream to downstream monitoring stations on the American River when concentrations were averaged from July 1994 to 1995 (Larry Walker Associates, 1996). Although increased concentrations were observed, they were minor and well below water quality objectives and were at least in part associated with wet weather urban inflows. Of concern to the Central Valley Regional Water Quality Control Board (CVRWQCB) are the effects metal sources may have on aquatic life throughout the Watershed, including the Delta.

METAL TOXICITY

The most sensitive beneficial use when metals are considered is the protection of aquatic life. In order to understand the scope of metal impacts in the Delta, the spatial and temporal extent of effects in the upper Watershed must first be characterized. The Basin Plan of the Central Valley Regional Water Quality Control Board contains a narrative toxicity objective which states that all waters must be maintained free of toxic substances in concentrations that cause detrimental physiological responses in aquatic organisms (Central Valley Regional Water Quality Control Board, 1994). The Basin Plan also states that compliance with this narrative objective can be evaluated in a number of ways, including the use of the US EPA three species bioassay protocols and by comparing metal concentrations with available objectives and criteria. The Regional Board uses both approaches to evaluate threats posed by elevated metal concentrations. These bioassays measure changes in growth, survival, and/or reproduction of three species from three different phyla and trophic levels. Regional Board staff have relied on the use of the three species bioassays since 1986 to assess compliance with the Basin Plan's narrative toxicity objectives. Toxicity testing results have indicated metal related toxicity in the Shasta Mining District.

Studies conducted from 1991-1992 to monitor toxicity and metal concentrations in discharges from major reservoirs identified relatively few incidents of toxicity (Goetzl and Stephenson, 1993; Connor *et al.*, 1994). Results may have been influenced by climate conditions, such as the ongoing drought, as well as mine remediation projects. Significant toxicity to the freshwater alga *Selenastrum* was detected in the Sacramento River downstream from the Keswick Dam. Toxicity was detected in 75% of the samples collected from Keswick Reservoir (Connor *et al.*, 1994). When compared to 18 other sites sampled throughout the Watershed, samples collected downstream from Keswick Dam exhibited the highest frequency of toxicity and the greatest number of exceedances of cadmium, copper, and zinc water quality objectives (Goetzl and Stephenson, 1993). There was a positive relationship between *Selenastrum* toxicity and exceedances of metal water quality objectives. Metal toxicity to *Selenastrum* was detected in a similar study conducted in 1993 (Bailey *et al.*, 1994).

In conclusion, metal analyses and toxicity testing conducted since 1988 provide some indication of metals impacting aquatic life in the Sacramento River from mining. However, no studies have been undertaken in the Delta to determine the overall importance of metals and toxicity on aquatic resources.

WATER QUALITY CRITERIA/OBJECTIVES

The CVRWQCB is not only interested in characterizing toxicity to aquatic organisms, but also in characterizing regional waters for compliance with numeric water quality objectives. However, in the past it was difficult to use monitoring data to evaluate compliance with existing metal water quality objectives because either the detection limits were too high (e.g., above actual instream concentrations) or the quality assurance and control were not rigorous. Further difficulty has been encountered because of changes in water quality objectives in California. During 1995, criteria used to protect aquatic life from inorganic constituents were promulgated in the California Inland Surface Waters Plan. These objectives were based on the US EPA National Ambient Water Quality Criteria. However, values for the Inland Surface Waters Plan were expressed as total recoverable metal, while the US EPA criteria were expressed as dissolved metal (Marshack, 1995). The Inland Surface Waters Plan was repealed in 1994 as a result of a legal challenge, leaving California without enforceable numerical water quality objectives for priority toxic pollutants in surface waters as required for each state by the Clean Water Act, except for certain site-specific numeric water quality objectives in the Water Quality Control Plan for the

CVRWQCB. The Water Quality Control Plan contains numeric water quality objectives for several metals in the Sacramento River, including arsenic, barium, cadmium, copper, cyanide, iron, manganese, silver, and zinc. In 1997, the US EPA proposed to promulgate water quality criteria for priority toxic pollutants for California's inland surface waters by developing the California Toxics Rule. In addition to the site-specific water quality objectives in the Water Quality Control Plan, criteria currently used as guidance for the CVRWQCB to protect freshwater aquatic life from inorganic constituents are the US EPA Proposed California Toxics Rule and the US EPA National Ambient Water Quality Criteria. As of 1998, both criteria are expressed as dissolved metals (Marshack, 1998). Therefore, additional metal monitoring was needed to better assess compliance.

BAY PROTECTION AND TOXIC CLEANUP PROGRAM

In 1989, the California Water Code was amended to create the Bay Protection and Toxic Cleanup Program (BPTCP). The three primary goals of the program are to: 1) identify toxic hot spots; 2) develop sediment quality objectives; and 3) remediate toxic hot spots, either through cleanup efforts, mitigation or prevention. Section 13391.5 of the Water Code defines toxic hot spots as: "....[L]ocations in enclosed bays, estuaries, or adjacent waters in the 'contiguous zone' or the 'ocean' as defined in Section 502 of the Clean Water Act (33. U.S.C. Section 1362), the pollution or contamination of which affects the interests of the State, and where hazardous substances have accumulated in the water or sediment to levels which (1) may pose a substantial present or potential hazard to aquatic life, wildlife, fisheries, or human health, or (2) may adversely affect the beneficial uses of the bay, estuary, or ocean waters as defined in the water quality control plans, or (3) exceeds adopted water quality or sediment quality objectives."

The BPTCP identifies five conditions that are used to define toxic hot spots.

1. Exceedance of water quality objectives
2. Toxicity associated with a toxic pollutant
3. Exceedance of tissue contaminant levels
4. Impairment of resident organisms
5. Degradation of populations or communities associated with toxic pollutants

Using Bay Protection Toxic Cleanup Program funds, the Central Valley Regional Water Quality Control Board conducted a study from May 1993 to December 1996 to characterize toxicity, metal concentrations, and metal loads in the Delta. The overall focus of this study was to determine if there were metal impacts in the Delta, and if so, identify whether the impacts were a result of transport or *in situ* processes. Prior to this study, there had been ongoing monitoring efforts in the Delta for many years. However, the monitoring was deficient in three general areas. First, as stated above, the monitoring focused on chemical analyses with a lack of rigorous quality assurance and high detection limits. Second, the monitoring efforts did not incorporate measurements of multiple metals and organic compounds. In addition, toxicity tests were not conducted concurrently with monitoring therefore prohibiting an assessment of the contribution metals had on aquatic life in the Delta. Furthermore, the situation of multiple metals working in an additive manner to cause toxicity is potentially important in the Delta because of the high load and diversity of inputs. Third, most of the annual metal load to the Delta is associated with major storm events. Past monitoring within the Delta had not adequately characterized metal levels and loads to the Delta during storm events.

The current study had four objectives: 1) to determine if metal concentrations (i.e., arsenic, cadmium, chromium. copper, lead, nickel, and zinc) could be measured in the Sacramento-San Joaquin Delta during low and high flow periods using ultra clean techniques with detection limits low enough to evaluate compliance with water quality objectives; 2) to define the extent of water quality objective exceedances in the Delta for metals; (3) to define the extent of metal associated toxicity throughout the Delta using the EPA three species toxicity tests; and (4) to determine the metal loading patterns into the Delta from the Yolo Bypass and Sacramento River (at Greene's Landing) during low and high flow periods. To address these objectives, fixed stations were monitored for metals and biotoxicity over multiple seasons and storm events. However, much of the sampling effort was focused during the winter to complement ongoing monthly monitoring by the Sacramento County Ambient Monitoring Program. The biotoxicity project is discussed in separate reports (Deanovic *et al.*, 1996; 1998). Because significant loads were identified entering the Delta during storm events, a pilot study was conducted ("Metals Source Pilot Study") during a single winter storm event to better characterize the source(s) of the loads (Appendix D).

MATERIALS AND METHODS

QUALITY ASSURANCE PROGRAM

The purpose of the Quality Assurance Program was to ensure the data were generated under conditions that accurately reflected the quality of the water sample. Standardized procedures were followed in all aspects of research. These methods are described in the Project Quality Assurance Plan designed for this project (Connor *et al.*, 1995). Both accuracy and precision were addressed in the quality assurance/quality control (QA/QC) document. A full description of the QA/QC methods and data can be found in Appendix C.

SAMPLE LOCATIONS

Water samples were collected for metal analyses and toxicity assessments during the 1993 (October 1992-September 1993), 1994 (October 1993-September 1994), and 1995 (October 1994-September 1995) water years. Sampling sites for metal analyses included main river inputs to the Delta, back sloughs and small upland drainages, areas receiving urban runoff, and points along the path of water movement across the Delta (Fig.1; Table 1). In addition, samples for were collected for a pilot study ("Metals Source Study") designed to identify sources of metals loads into the Delta and upstream to Shasta Dam during a single storm event (Fig. D-1; Table D-1). Additional sampling sites were selected for toxicity assessments (Deanovic *et al.*, 1996; 1998). Detailed site descriptions are provided in Appendix A and D.

SAMPLE COLLECTION AND STORAGE

Metal Analyses

Samples for total recoverable and dissolved metals analyses were collected by Regional Board staff. All samples were collected from beneath the water surface by boat, from a bridge, or from the bank in a rapidly moving section of the water course. The samples were collected by inserting cleaned bev-a-line tubing through 25 feet of PVC pipe (Goetzl and Stephenson, 1993). The use of the pipe allowed the sampling point to be about 20 feet from the shore and thus minimized edge effects. All samples were pumped from the point of collection (using a peristaltic pump) through 25 feet of acid-cleaned tubing directly into an analysis bottle containing acid. The tubing ended in a dust free sampling box which contained the sampling bottles. The bottles were handled without opening the box through gloved port holes. The tubing and the box were employed to minimize the exposure of the samples to airborne contamination. The exception to this procedure was the sampling conducted during high flow events. This sampling used an acid washed one gallon borosilicate glass composite sampler instead of a glove box for sample collection. All analysis bottles were double bagged except while being filled. All samples collected for determining the concentration of dissolved metals were filtered through a 0.45 micron polypropylene MSI cartridge filter attached to the end of the tubing. At each site water conditions, sampling conditions, water temperature, pH, and EC were recorded. After collection, all samples were triple bagged and placed in a dust free container until shipped to the Moss

Landing Mussel Watch Lab. The details of the sampling equipment and procedures are fully described in Goetzl and Stephenson (1993).

Toxicity Samples
Bioassay surveys were conducted from May 1993 to December 1996 in the Delta. Site locations, method of water collection, and sample storage are contained in Deanovic *et al.*, (1996) and (1998). Bioassays were run on all water samples collected from the Delta for metal analyses. However, additional sites were only tested for toxicity. If toxicity was detected and no samples were collected for metal analyses, then sub-samples were taken from the bioassay water and placed in a one liter polyethylene bottle (containing nitric acid) for determination of total recoverable and dissolved (filtered with a Gelman A/E glass fiber filter, nominal pore size of 0.45 μm) metal concentrations.

WERE LOW DETECTION LIMITS OBTAINED USING ULTRA CLEAN TECHNIQUES?
Total recoverable and dissolved (0.45 μm filtered) metal concentrations were analyzed by the California Department of Fish and Game Mussel Watch Laboratory and at the Moss Landing Marine Lab Trace Metals Laboratory, using ultra-clean facilities and graphite furnace atomic absorption spectrophotometry (Goetzl and Stephenson, 1993). Twenty percent of the samples were split samples analyzed by the Trace Metals Laboratory. Samples were analyzed using an evapo-concentration technique to obtain low detection limits (Goetzl and Stephenson, 1993; Goetzl *et al.*, 1994, 1995). The essence of this procedure is that a sample is concentrated twenty-five fold by evaporation followed by an acid-treatment to re-dissolve the sample. This procedure can achieve detection limits in the parts per trillion range.

Atomic Absorption Methods (Trace Metal Lab)
Samples were analyzed by flameless Atomic Absorption (AA) on a Perkin-Elmer Zeeman 5000 Atomic Absorption Spectrophotometer equipped with an HGA 500 graphite furnace at the Salinas facility of Moss Landing Marine Laboratories. Due to high concentrations, a few samples were analyzed using flame AA on a Perkin-Elmer 603 AAS. Samples and standards were prepared in a laminar-flow clean bench inside the trace metal lab. To ensure accurate results, the samples were analyzed using the stabilized-temperature platform technique. The characteristic mass for each element was computed to ensure the proper functioning of the Zeeman AA. Samples may be analyzed using a matrix modifier made up from ultra-clean chemicals. When no modifier is used, high-char temperatures allow interfering matrix components of the sample to be volatilized prior to atomization. Single spike additions to samples allow a check for recovery when standards are linear. Finally, the SLRS-2 (1993-94 samples) or SLRS-3 (1994-95 samples) river water standard reference material was evapoconcentrated and analyzed with each set of samples.

AA Methods (Mussel Watch Lab)
The Mussel Watch Lab is located at the Moss Landing Marine Laboratories in Moss Landing, California. Samples were analyzed by furnace AA on a Perkin-Elmer Zeeman 3030 Atomic

Absorption Spectrophotometer with an AS60 auto-sampler and HGA 500 graphite furnace. Samples, blanks, matrix modifiers, and standards were prepared using clean techniques inside a clean lab. Milli-Q water and ultra-clean chemicals were used for all standard preparations. To ensure accurate results the samples were analyzed using the stabilized-temperature platform technique. Matrix modifiers were used when the components of the matrix interfered with adsorption. Matrix modifiers were used for arsenic in all samples and for lead in 1993-94 samples. Blanks and a standard reference material (SLRS2 river water) were evapoconcentrated and analyzed with each set of samples.

WERE WATER QUALITY OBJECTIVES EXCEEDED?

Compliance with site-specific numeric water quality objectives described in the Water Quality Control Plan was assessed for samples collected from the Delta (CVRWQCB, 1994). In addition, the more stringent US EPA Proposed California Toxics Rule and the US EPA National Ambient Water Quality Criteria (expressed as four day average criteria) to protect freshwater aquatic life (Marshack, 1998) were compared to hardness corrected dissolved metal concentrations to determine whether exceedances occurred in the Delta during the study.

WAS METALS RELATED TOXICITY IDENTIFIED IN THE DELTA?

Standardized U.S. EPA freshwater bioassay protocols were used for this study (U.S. EPA, 1994). The three organisms used in the laboratory assays were: (1) a primary producer, the green algae *Selenastrum capricornutum*; (2) a primary consumer, the zooplankton *Ceriodaphnia dubia*; and (3) a secondary consumer, the fathead minnow, *Pimephales promelas*. A complete description of the methodologies applied in testing ambient water samples for toxicity can be found in Deanovic *et al*., (1996; 1998). When toxicity was detected in a sample, follow-up toxicity identification evaluation (TIE) procedures coupled to analytical chemistry were implemented to help determine the cause. Briefly, samples were tested for toxicity following several manipulations designed to render certain chemical/elemental constituents in the sample non-toxic. In addition, methods were applied to recover the chemical/elemental causes of the observed toxicity. A complete description of TIE procedures can be found in U.S. EPA (1991; 1992) and Bailey *et al*., (1996).

Statistical Methods and Definition of Toxicity

Toxicity was defined as a statistically significant difference ($p<0.05$) between a sample and the laboratory control. Bartlett's Test for homogeneity of variance was run on all fish growth and mortality, *Ceriodaphnia* reproduction, and algal growth data. When the data variance was homogeneous, the samples were compared to the controls using Analysis of Variance and Dunnett's mean separation tests. If the data variance was not homogeneous, then comparisons were made against the control using Kruskal-Wallis and Dunn's non-parametric multiple comparison. *Ceriodaphnia* survival was compared against the control with a Fisher's Exact Test. No statistical analyses were conducted on TIE results. Acute toxicity was defined as a statistically significant difference in mortality within 96 hours between an ambient water and laboratory control sample. *Selenastrum* toxicity was defined during the 1993-1994 monitoring as a statistically significant difference in cell counts between an ambient sample and a laboratory control. Due to the low frequency of statistically significant toxicity when ambient samples were compared to laboratory control samples, cell counts in the 1994-1995 samples were also compared to other field samples collected on the same day to determine if the relative level of cell counts differed among stations. Consult Deanovic *et al.*, (1996) and (1998) for additional information regarding the statistics applied for the toxicity test results.

WERE METAL LOADING PATTERNS CHARACTERISTIC OF HYDROLOGICAL CONDITIONS?

Water Years 1993, 1994, and 1995

Water year 1993 (October 1992-September 1993) was classified as a relatively normal water year in the Sacramento Basin. Precipitation in the region during water year 1993 was 149 percent of the long-term average while runoff was about 125 percent of the 1961-1990 median based on five representative streamflow records (Mullen *et al.*, 1994). Water year 1994 (October 1993-September 1994) was classified as critically dry and is identified in this report as a "dry year". Precipitation in the region during water year 1994 was 36 percent of the long-term average while runoff was about 69 percent of the 1961-1990 median based on five representative streamflow records (Friebel *et al.*, 1995). During such dry years, the Sacramento River serves as the primary source of water transport from the Sacramento Basin to the Delta. Conversely, water year 1995 (October 1994-September 1995) was characterized by high flows which resulted in water transport to the Delta via the Sacramento River and the Yolo Bypass. Although summary hydrologic conditions for the region are not available for water year 1995, combined flows for the Sacramento River and Yolo Bypass peaked at 334,000 CFS and 16 inches of rain fell in the City of Sacramento in January (Foe and Croyle, 1998). Therefore, water year 1995 was classified as a "wet year" for the purposes of this study.

Flow Rates

Daily water discharge rates from the Sacramento River at Greene's Landing and the Yolo Bypass at Prospect Slough were obtained from USGS flow gauges (Mullen *et al.*, 1994; Friebel *et al.*, 1995; Markham *et al.*, 1996; California Data Exchange Center, 1998).

Load Calculations

Bulk daily metal loads (kg/day) at Prospect Slough and the Sacramento River at Greene's Landing were calculated for arsenic, cadmium, chromium, copper, lead, nickel, and zinc from January through April 1994 and 1995. Mercury loads were not included in this report but can be found in Foe and Croyle (1998). Two methods were employed to calculate loads. First, regression analyses were performed to determine if significant relationships existed between flow and total recoverable concentrations of each individual metal (Steel and Torrie, 1960). When the variance appeared to greatly increase/decrease with increasing flow, the data were log transformed and a comparison of residuals was conducted. If the variance in the data was then similar with increasing flow, then a best fit line was applied to the log transformed data. When regression analyses were significant, models were developed for each metal using a linear regression with flow as the independent variable and total recoverable concentration as the dependent variable. Daily flows were entered into the linear regression equation to obtain daily predicted metal concentrations. Daily predicted concentrations (µg/l) were then multiplied by daily flow to obtain model generated estimates of metal load. This method was used to provide a rough estimate of loads when significant relationships existed between flow and metal concentrations, however transformation of the data may affect concentrations by 5-25%. Alternative methods are available which provide a more rigorous estimate of load (Cohn *et al.*, 1989; Helsel and Hirsch, 1992). These methods were not applied here since the objective was to provide a rough estimate of load fluctuations between wet and dry years and the sample collection design could not be properly applied to the models.

A second method was applied when a regression was not significant. Loads were calculated individually for Prospect Slough and Greene's Landing by multiplying daily flow readings by the average metal concentration (µg/l) measured in all field samples at each of the two sites ("Average Concentration Method"):

$$\text{Daily Load (kg)} = [\text{Avg. metal concentration } (\mu g/l)] \times (2.445 \times 10^{-3}) \times [\text{Flow (CFS)}]$$

Total load was estimated by summing the daily loads for each period. Due to the uncertainties in flow measurements (± 10%) and the uncertainty involved with the regression analyses, the number of significant figures for load calculations was set at three for the purposes of load comparisons. Loads were also calculated using data from the Sacramento Coordinated Water Quality Monitoring Program's Ambient Monitoring Program (AMP), using the Average Concentration Method and regression models. This permitted a comparison of load estimates calculated for two independent monitoring efforts on the Sacramento River at Greene's Landing and River Mile 44. However, AMP monitoring relied on different collection methods, sample frequencies, sample locations, and temporal pattern of sampling than those of this study (Larry Walker and Associates, 1996).

WHAT SOURCE(S) OF METALS WERE IDENTIFIED DURING THE METALS SOURCE PILOT STUDY?

Water samples were collected for a one-time pilot study during a major storm event in March 1995 to assess the relative metal load contribution from sources upstream of the Delta, primarily in the Sacramento River Watershed. Sampling methods followed those described above with sampling dates reported in Table D-1. The study was designed to assess metal loads, therefore only total recoverable concentrations were quantified. No toxicity samples were collected and the lack of dissolved metals analyses prohibited an assessment of water quality objective exceedances. Although the objective of the pilot study was to track sources of metals during a high flow event, the data could not be used to quantify the load contribution from mines in the area of Lake Shasta and Keswick Reservoir because discharges from the reservoirs were maintained at low levels to minimize downstream flooding. This resulted in samples downstream of the reservoirs which were negligibly affected by runoff from mines. A full description of the results of the Metals Source Pilot Study can be found in Appendix D.

RESULTS AND DISCUSSION

QUALITY ASSURANCE/QUALITY CONTROL PROGRAM

Field blanks collected on nine occasions indicated negligible contamination with no metals detected above 1 µg/l (Table C-1). Field duplicates were collected on 64 occasions with a resulting average difference between two laboratories of 16% (Table C-2). Analysis of laboratory blanks resulted in 65% of the individual metals data quantified as below the detection limits for the methods applied in this study (Table C-3). Intra-laboratory precision results ranged from 2 to 20%, depending upon the metal (Goetzl *et al.*, 1994, 1995). A more complete description of the quality assurance and quality control results can be found in Appendix C.

HYDROLOGICAL CONDITIONS

Water samples for chemical analyses were collected and toxicity assessments were performed during the relatively normal 1993 water year (WY93), critically dry 1994 water year (WY94), and high flow 1995 water year (WY95). Flows in the combined discharge of the Sacramento River and Yolo Bypass peaked at 135,000 on 28 March during WY93 and at 334,000 CFS on 13 March during WY95 (Mullen *et al.*, 1994; Markham *et al.*, 1996). As a result of the low rainfall during WY94, flows at Freeport did not exceed 30,000 and the Yolo Bypass had measurable flows above 1,000 CFS on only four days (Fig. 2; Friebel *et al.*, 1994).

WERE LOW DETECTION LIMITS OBTAINED USING ULTRA CLEAN TECHNIQUES?

Evapoconcentration of field collected samples resulted in the detection of arsenic, cadmium, chromium, copper, lead, nickel, and zinc down to the low to mid parts per trillion range (Table 2). This method improved upon other analytical methods and resulted in detection limits which were among the lowest of four programs monitoring metals in the Sacramento River Watershed (Table 2; Larry Walker and Associates, 1996; Sacramento Regional County Sanitation District, 1996). The advantage of a lower detection limit is metals can be quantified at concentrations which are well below values set for water quality objectives. Furthermore, these lower detection limits minimize the frequency of non-detects, permit the detection of metals at and below actual instream values, and provide for a more accurate estimate of metal loads (Goetzl and Stephenson, 1993).

WERE WATER QUALITY OBJECTIVES EXCEEDED?

Site-specific numeric water quality objectives in the Water Quality Control Plan for the CVRWQCB were compared to dissolved metal concentrations (0.45 µm filtered) in samples collected from 15 Delta stations during WY94 and WY95 to determine if the exceedances occurred (CVRWQCB, 1994; Tables 3-17). The site-specific numeric water quality objectives for arsenic, copper, silver, and zinc in the Delta were not exceeded.

Dissolved metal concentrations were compared to the more stringent USEPA National Ambient Water Quality Criteria and the USEPA Proposed California Toxics Rule Criteria (Tables 3-17). With the exception of As, criteria for the metals quantified in this study are water hardness dependent. No water quality criteria were exceeded for 549 individual Delta metal analyses (Table 18).

WAS METALS RELATED TOXICITY IDENTIFIED IN THE DELTA?

Waters sampled from the Delta region were tested for toxicity during WY94 and WY95 using the EPA three species toxicity tests to determine if aquatic life was impacted. Deanovic *et al.*, (1996) and Deanovic *et al.*, (1998) contain a full description of the results. In brief, 34 and 58 (including relative reductions in algal cell counts) toxic events were detected during WY94 and WY95, respectively (Table 19 & 20).

Approximately 7% of the samples collected from the Delta region tested toxic to *Ceriodaphnia* during WY94, while samples were toxic 14% of the time during WY95. Most of the toxicity (e.g., 68%) to *Ceriodaphnia* occurred in samples collected from back-sloughs and small upland drainages. Toxicity Identification Evaluations were performed on toxic samples during both years to determine if the cause of toxicity could be determined. Typically, toxicity was related to pesticides, including organophosphates, carbamates, and unknown metabolically activated compounds. Metals were never implicated in TIE studies conducted on the samples which exhibited toxicity (Table 19 & 20). However, TIEs were not performed on all toxic samples due to budgetary limitations.

On 329 occasions *Selenastrum* toxicity tests were performed on samples collected from the Delta during WY94 to WY95. The number of toxic events remained fairly constant at about 1% for both water years (Table 19). However, nearly 30% of the ambient samples exhibited reductions in cell counts relative to other ambient samples collected on the same day in WY 95 (Table 20). As with *Ceriodaphnia*, the majority of the events with reduced cell counts occurred in the back-sloughs and small upland drainages (Table 20). TIE tests on Delta samples which exhibited toxicity implicated non-polar organics as causative toxicants and, as with the *Ceriodaphnia* TIEs, no examples of metal related toxicity were found.

Pimephales toxicity tests were conducted on 216 Delta samples, with the bulk of the testing during WY94 (Table 19). Approximately 9% of the samples were toxic in WY94 with toxicity in all water categories except urban runoff receiving waters. No TIEs were conducted on these samples so the causative agents remain unknown.

The EPA Three Species may not necessarily be the most sensitive organisms to metals. Tables were created documenting the most sensitive 10-15 literature reports for algae, invertebrates, and fish. Dissolved metal concentrations were selected as this is the form most bioavailable to aquatic organisms during water column exposure. Effect levels from the literature values were then compared to the highest dissolved concentration measured in the Delta for each metal to assess the potential for effects in species other than the three species used in the EPA toxicity tests applied in this study (Reyes, 1994; Table 21).

Dissolved lead peaked at 3.87 μg/l (at 5-mile Slough; hardness = 80 mg/l) and averaged 0.31 μg/l over the combined water years (Table 21). No algal responses would be expected at these concentrations (Table 22). Unicellular invertebrates, such as ciliates, had reduced oxygen uptake after only four minutes exposure to 0.75 μg/l lead (Table 23; Slabbert and Morgan, 1982). Three-spine stickleback, a freshwater fish, had increased mortality in response to 0.2 μg/l dissolved lead exposure after five days (Table 24; Jones, 1938). More recent work indicates carp enzyme systems are sensitive to lead down to 1.1 μg/l (Table 24; Nakagawa *et al.*, 1995).

The average dissolved concentration of arsenic was 1.28 μg/l and the highest concentration was 3.03 μg/l (Table 21; at 5-mile Slough; hardness = 80 mg/l). Phytoplankton exhibited altered photosynthetic productivity following long-term exposure to 1.5 μg/l arsenic, however exposure for 109 days at this concentration in the basin is highly unlikely (Table 25; Wangberg *et al.*, 1991). Fifty percent of *Daphnia duplex* were immobilized following exposure to 0.5 μg/l arsenic for as little as one day (Table 26; Lilius *et al.*, 1995). Fish did not respond to arsenic exposure until concentrations exceeded 27 μg/l (Table 21).

Dissolved chromium concentrations reached 5.39 μg/l (hardness = 98 mg/l) at Duck Slough and averaged 1.34 μg/l from 1993-1995 (Table 21). Algal responses occurred from 2 μg/l to 5.2 μg/l and included altered biomass and incipient growth inhibition (Table 28; Bringmann, 1975; Shabana *et al.*, 1986). *Selenastrum* responses were not reported until 20 μg/l (Table 28; Pillard *et al.*, 1987). The most sensitive response of any aquatic invertebrate in the USEPA Aquire Database was decreased survival in an euglenoid down to 1 μg/l (Table 29; Yonge *et al.*, 1979). Environment Canada (1994) reported toxicity in some zooplankton species at chromium concentrations of 0.5 μg/l. Cytogenetic alterations and changes in growth were reported in carp at 0.05 μg/l and 1.5 μg/l, respectively (Table 30; Al-Sabti *et al.*, 1994; Mao and Wang, 1990).

Greene's Landing had the highest measured dissolved nickel concentration of 26 μg/l (hardness = 44 mg/l) and the average for the study was 2.72 μg/l (Table 21). Blue-green algae exhibited mortality at concentrations down to 1.2 μg/l (Table 31; Bringmann and Kuhn, 1978). The EC_{50} for *Selenastrum capricornutum* exposed for four days to nickelous chloride was 6.3 μg/l (Table 45; Blaise *et al.*, 1986). Mortality was recorded for *Ceriodaphnia dubia* down to 3.8 μg/l (Table 32; Kszoz *et al.*, 1992). No fish responses were reported in this concentration range (Table 33).

The maximum dissolved concentration of copper measured in this study was 9.48 μg/l (at Greene's Landing; hardness = 62 mg/l) which has been shown to have effects on fish, invertebrates, and algae (Table 21). Freshwater fish responses ranged from avoidance to death (Table 34; Reyes, 1994). This concentration was lethal to several species of water flea for exposure durations down to two days (Table 35; Reyes, 1994). Algal responses ranged from altered photosynthetic output to decreased growth and altered metabolism (Table 36; Reyes, 1994).

The highest dissolved zinc concentration measured during monitoring was 70.2 µg/l (at 5-mile Slough; hardness = 80 mg/l) (Table 21). This concentration is high enough to have potential effects on aquatic life. The most sensitive fish response in the literature was avoidance of solutions containing 5.6 µg/l zinc sulfate by rainbow trout (Table 37; Sprague, 1964b). Invertebrates, such as the aquatic sowbug, experienced mortality at 10 µg/l (Table 38; Migliore & DeNicola Guidici, 1990). Algae exhibit population declines (as measured by declines in cell numbers) when exposed to concentrations down to 5 µg/l (Table 39). This concentration is slightly above the mean concentration when both water years were averaged. Exposures of *Selenastrum* for seven days at 5 µg/l, as opposed to the four day exposures in this study, resulted in inhibited cell growth.

Cadmium concentrations peaked at 0.55 µg/l (at Greene's Landing; hardness = 72 mg/l) and averaged 0.3 µg/l in this study (Table 21). Exposure of rainbow trout to comparable concentrations for 18 months resulted in reduced survival (Table 40; Birge *et al.*, 1981). Other more short term effects include albinism in catfish (Table 40; Westerman and Birge, 1978). Invertebrates, such as copepods and water fleas, are reported to respond at this concentration range with increased mortality (Table 41). Algal responses to cadmium are reported to occur in the parts per billion range (Table 42; Reyes, 1994).

Some of the potential responses of algae, invertebrates, and fish described above would obviously be affected by the duration of exposure, which is difficult to assess from the composite Delta samples. Furthermore, some of the dissolved metal could be biologically unavailable because of high organo-iron complexes present in the Delta. However, the maximum dissolved concentrations of metals reported in this report may be an underestimation of actual instream maxima. For example, total recoverable metal concentrations measured during the metals source pilot study were, by far, the highest measured during the three water years (Appendix D). No dissolved concentrations were measured during the source study. Furthermore, none of the water samples collected during the metals source study were tested for toxicity due to the project objectives. It is possible that high total recoverable concentrations in the metals source pilot study coincided with higher dissolved metal concentrations than those presented in Table 21.

WERE METAL LOADING PATTERNS CHARACTERISTIC OF HYDROLOGICAL CONDITIONS?

The objectives of the metal loads component of this study were to: (1) estimate loads on the mainstem lower Sacramento River from January to April during a critically dry and a wet year and determine how they vary with hydrological conditions and (2) determine the spatial partitioning of loads during a wet year when water enters the Delta from the Yolo Bypass and lower Sacramento River. The emphasis of this study on high flows was designed to complement ongoing monthly metals monitoring by the Sacramento County Ambient Monitoring Program. Load calculations were based on a regression relationship and/or the Average Concentration (AC) method (see methods). More rigorous load evaluation methods are available (Cohn *et al.*, 1989).

However, the intent here was to provide rough load estimates and the two methods selected were considered adequate for this purpose.

Regression models for WY94 consistently estimated lower loads at Greene's Landing during WY94 when compared to the AC method (Table 43). When significant, the regression model approach was considered to be more robust because it tested for statistical fitness whereas the AC approach lacked statistical analyses. The load estimate for cadmium during the dry WY94 was the lowest of all metals, with 698 kg contributed to the Delta over the four month time period (Table 43). Zinc load was the highest of all metals, ranging from 37,900 to 50,700 kg depending upon the method selected.

Water years were compared using the regression model for WY94 and the AC method for WY95. Increased flows and higher total recoverable metal concentrations for most metals combined to result in increases in metal loads ranging from approximately 240% to 2,400% (Table 43). This is somewhat of an invalid comparison because much of the water entering the Delta during WY95 was in the Bypass and, therefore, this load contribution would not be included in these values. When total loads into the Delta from the Sacramento River Watershed (e.g., Greene's Landing + Yolo Bypass) for WY95 are compared to WY94, percent increase in loads ranges from 460% for cadmium to 5,300% for chromium (Table 43 & 44). To put these percentages in the context of the amount of metals added to the Delta, cadmium loads increased from 698 kg in WY94 to 1,660 kg in WY95 while nickel loads increased from 13,700 kg to 1,110,000 kg. Chromium loads also increased markedly from 10,500 kg to 627,000 kg. These data indicate high flow years contribute significantly more metal loads to the Delta when compared to a critically dry year.

In an effort to determine if similar load patterns emerged with an independent data set, loads were calculated in the same manner using the Sacramento County Ambient Monitoring Program (AMP) data collected during the same water years. The same pattern emerged when WY94 and WY95 were compared but, with the exception of cadmium, the magnitude of increased loads for WY95 was lower than those estimated for this study (Table 45). A similar pattern of lower load prediction for most metals was found when estimates for each method (e.g., average concentration and model) were compared (Table 45). For example, load calculations using the Ambient Monitoring Program data ranged from 18% to 102% of estimates in this study. As with the metal concentration comparisons among these two studies, much of the difference can be attributed to the frequency of sample collection. Sampling frequency for this study was much greater than that of the AMP due to the programmatic questions each study addressed. The increased sample frequency in this study resulted in samples which were collected across a wider spectrum of flow conditions within the time period of interest, which is important for accurate predictions of loads.

Metal loads were calculated for the lower Sacramento River and Yolo Bypass during high flow to using the BPTCP data to characterize the contribution differences between these two sources of Delta water. Since the regression relationships between total recoverable metal concentrations and flows were not significant for WY95, comparisons between the two sources were based on the AC method. Bypass water carried between 48% and 82% of the total load of the measured metals whereas the Sacramento River contributed between 18% and 52% (Table 44). Combined loads for these two sources varied from 3,210 kg of cadmium to 1,120,000 kg and 1,110,000 kg of zinc and nickel, respectively. Dividing loads by the number of days from January to April provides an estimate of the average daily load entering the Delta from the Sacramento River Watershed during high flow conditions. Average daily loads of cadmium, zinc, and nickel which entered the Delta from January through April of 1995 was estimated at 31 kg, 10,700 kg, and 10,700 kg, respectively.

Interesting patterns developed when the load contributions were compared for the lower Sacramento River and Yolo Bypass. Foe and Croyle (1998) estimated the sediment load entering the Delta from the Sacramento River and the Bypass to be 1,300,000 (34%) and 2,500,000 (66%) metric tons, respectively, from January through April 1995. The percentages of copper and zinc from the two sources was nearly identical to those of sediment (Table 44). The Bypass contributed 74% of the chromium as well. These three metals were significantly related to TSS during this water year (see trends in metal concentration section below), indicating that they were either bound to sediment particles diverted into the Bypass or bound to sediment sources within the Bypass. The bulk of nickel loads entering the Delta from the Sacramento River Watershed were carried in the Bypass as well, but this contribution had no relationship to sediment loads. Nickel is common in the geological deposits of the western valley and may enter the Bypass from local sources. Arsenic, cadmium, and lead loads were generally equal in the Bypass and lower Sacramento River.

WHAT TRENDS IN METAL CONCENTRATIONS WERE IDENTIFIED?

Metal analyses conducted in this study were essential for assessing exceedances of water quality objectives, performing meaningful toxicity tests, and calculating loads. Another important use for the metals analyses data can be in the determination of relationships between metal concentrations and other water quality and hydrological parameters. The following paragraphs describe relationships which occurred during this study between metal concentrations, flow, and total suspended solids. In addition, some metals seemed to be inter-related, such that high concentrations in one usually coincided in high concentrations in others. These relationships can be useful for determining the best time to collect water quality samples. For example, if certain events (e.g., high flow storm events) can be used to predict when metal concentrations may be among the highest levels for the year in a particular area, monitoring plans can be developed to capture the data of interest by knowing when to expect peak flows. The information is not intended to be used as a predictive tool for metals concentrations in place of actual in-stream monitoring. On the contrary, the information is intended to improve our understanding of when, where, and possibly why we could expect metals concentrations to be high such that appropriate monitoring designs can be developed for future studies.

Four hundred and four water samples were collected from 37 stations for analysis of dissolved and total recoverable metal concentrations (Appendix B). When total recoverable and dissolved concentrations were independently averaged for all samples collected, a trend of increasing chromium, copper, nickel, and zinc concentrations was observed from WY93 and WY94 to WY95 (Table 46). Clearly, the data are highly variable within each year due to the large spatial and temporal scale of the sampling effort. This typically would result in data which are not significantly different. The data were not analyzed statistically due to large differences in the number of samples collected among years. However, the results indicate that extended periods of unusually high flows can result in marked increases in the average concentration of chromium, copper, nickel, and zinc. Other metals did not exhibit a consistently strong association with peak flows. For example, total recoverable and dissolved arsenic showed a trend of decreasing average concentration from WY94 to WY95. Cadmium, on the other hand, had a distinctly different profile with total recoverable concentrations increasing and dissolved concentrations essentially remaining unchanged during the three water years. Average total recoverable lead concentrations decreased slightly from the WY93 to WY94, then increased by more than three fold in WY95, while the average dissolved concentration increased from WY93 to WY95. It should be noted that averaging the metal analyses for all stations can be problematic because of different sample collection frequencies at each station and different stations monitored among water years. Ideally, statistical analyses of the data would be performed to ascertain if significant relationships existed in the data set. Again, the experimental design employed in this study resulted in great variability about the mean which prohibits the identification of significant relationships. The data should however be used for the basis of follow-up studies which should incorporate a more statistically balanced sampling design.

An analysis of average metal concentrations was performed at Greene's Landing on the lower Sacramento River to determine if the trends among water years held true within a station extensively sampled during the same period. Similar to when concentrations from all stations were averaged, the average total recoverable and dissolved chromium, lead, nickel, and zinc showed a trend of increased concentrations from WY93 to WY94, WY94 to WY95, and WY93 to WY95 (Table 47). Average dissolved concentrations of cadmium behaved in a similar fashion as the entire data set, with no changes among water years. However, average total recoverable cadmium concentrations had a different pattern with a decrease from WY94 to WY95. Average dissolved copper concentrations were also inconsistent with the combined data with no difference between WY93 and WY 94, but matched the trends for the combined data from WY94 to WY95. Arsenic was not measured at Greene's Landing during WY94 and therefore changes during water years could not be compared at this station. With the exception of dissolved cadmium concentrations, the concentration of the monitored metals appear to be closely tied to flow or other parameters related to flow when high flow conditions are compared to normal or drought conditions. However, the reverse trend (e.g., decreased concentrations with decreased flows) does not hold true when comparing drought conditions to normal hydrological conditions.

Dissolved and total recoverable metal concentrations collected from the Sacramento River at Greene's Landing were regressed against each other, flow at Freeport, and total suspended solids (TSS) for WY94, WY95, and combined the WY94 and WY95 (WY94/95) to determine if these factors were interrelated. The number of significant relationships between dissolved metals, total recoverable metals, flow, and TSS declined from 13 in the critically dry WY94 to eight in the high flow WY95 (Tables 44 and 49). When data from water year 1994 and 1995 were combined, 16 of 35 regression analyses were significant (Table 49).

During the dry WY94, total recoverable concentrations of chromium, copper, lead, nickel, and zinc at Greene's Landing were significantly associated with total suspended solids and flows (Table 48; Figs. 3-12). These significant relationships indicate these metals were bound to suspended sediments. These metal laden suspended sediments are in turn closely associated with flows during this critically dry year, such that the total recoverable metal concentrations increase with increasing flows. Conversely, dissolved chromium, copper, and nickel were also closely tied to flow conditions but did not exhibit significant relationships with total suspended solids (Table 48; Figs. 13-18). Filtration (0.45μm) of samples as done in this study would permit the passage of colloid-associated metals into the dissolved fraction. The lack of significant relationships between dissolved metals and TSS may be due to the presence of other suspended solids in the TSS measurements. Total recoverable metal concentrations could not be used to predict dissolved concentrations due to a lack of significant relationships (Table 48; Figs. 19 & 20). Both total recoverable and dissolved cadmium concentrations were unrelated to flow and TSS, which is consistent with the lack of a trend reported in Tables 46 and 47. Therefore, concentrations of several metals would be expected to increase with increasing flow conditions and/or increased sediment load in the Sacramento River during dry conditions.

These conclusions did not necessarily hold true at Greene's Landing during the wet WY95. Of particular interest is the absence of significant relationships between flows and total recoverable and dissolved metal concentrations in WY95 when compared to WY94 (Tables 48 and 49; Figs. 21-34). When compared to the dry WY94, the breakdown in the relationships in WY95 may be related to, but are not limited to: (1) an increase in tributary input of suspended sediments in the system during this exceptionally wet year; (2) contribution of suspended sediments, flow, and metals from sources further into the watershed; (3) resuspension of deeply buried sediments in the waterways; (4) transportation of larger particles which may have different affinities for metal contaminants than those which occur in the system during dry years; (5) stripping of algae from rocks and transport downstream due to scour during high flows; and (6) flushing of planktonic communities from lakes and rivers during high flow conditions. The major sources of suspended sediments in the lower watershed during a dry water year are the Sacramento, Feather, and American Rivers, whereas smaller tributaries on the western and eastern valley slopes may contribute significantly to the total suspended solids during a wet year. The different geological sources of these sediments may result in different binding affinities for the metals and could therefore disrupt the relationships between total recoverable metals, total suspended solids, and flow. However, this is conjecture at this point and would require further study to clarify the role of small tributary sediments during high flow conditions.

Although the relationships between flow and metal concentrations broke down during high flows found in WY95, total recoverable copper, zinc, and cadmium concentrations at Greene's Landing were still significantly related to TSS indicating these metals are bound to suspended sediment particles during both dry and wet years (Table 49; Figs. 35-37). The level of significance for this relationship with cadmium ($R^2 = 0.92$) is drastically different than in WY94, again possibly pointing toward further evidence that additional sources of suspended sediments enter the system during high flows (Table 49; Fig. 38). In contrast to WY94, total recoverable and dissolved concentrations for some metals (i.e., copper and lead) were related in WY95 (Table 49; Figs. 39 & 40). Therefore, as dissolved concentrations of lead increased at Greene's Landing, one could predict that total recoverable copper concentrations would increase as well.

Significant relationships between total recoverable copper, zinc, chromium, and nickel at Greene's Landing reemerged again when data from the two water years were combined (Table 50; Figs. 41-48). Consistent with WY94 and WY95, total recoverable concentrations of these metals were significantly associated with suspended sediments and flow for WY94/95 (Table 50; Figs. 41-48). One could apply the relationships between flow and total recoverable concentrations of these metals as a predictive tool. Although the relationships are significant, there is considerable variability about the regression line, especially during high flows (Fig. 46). Therefore, predicting total recoverable concentrations from flow would have a wide margin of error. Dissolved chromium, lead, and nickel also were significantly related to flow, but only dissolved lead was significantly related to TSS (Table 50; Figs. 49-54). This finding indicates the dissolved forms of chromium and nickel increased over the sampling period with increasing flow, but the metals were not significantly related to suspended sediments. Dissolved chromium and lead were associated with the total recoverable form. This relationship was also significant for copper and nickel, but the dissolved forms of these two metals were not associated with suspended sediments. Therefore, the relationships among dissolved concentration, total recoverable concentration, flow, and TSS are often metal dependent, different when extreme water years are compared and when water years are combined. Additional research would be required to determine if consistent relationships occurred during dry and wet years and blind studies may be necessary to determine the accuracy of using these relationships as a predictive tool for metal concentrations in the Sacramento River.

Relationships found between flow, TSS, and metals during this study should not be applied to times of the year other than when winter flows occur because the relationships may not apply. For example, the Sacramento County's Ambient Monitoring Program (AMP) collected similar concentration and flow data throughout the year from the Sacramento River about eight miles upstream of Greene's Landing (Larry Walker & Associates, 1996). Many of the relationships between flow, TSS, and metals were not significant during the dry WY94 (Table 51), indicating the relationships reported during winter flows do not necessarily hold true at other times of the year. However, relationships between TSS and total recoverable copper, zinc, chromium, and cadmium held true during WY95 for both sampling efforts (Table 52). When water years were combined for both data sets, little overlap in significant relationships between metals, flow, and TSS occurred (Tables 50 and 53). These contrasting data sets provide a good example of the differences which may be encountered during environmental monitoring with two different approaches: a systematic sampling effort with samples collected approximately every two weeks versus a program with samples collected many times during set events.

In comparing individual metals to flows and TSS, some associations were apparent (e.g., total recoverable copper, zinc, chromium, and nickel were associated with flow and TSS at Greene's Landing in the combined WY94 and WY95). To better understand this grouping of metals, total recoverable concentrations of each metal was plotted against other individual metals for individual and combined water years (Tables 54; Figs. 55-65, 67-75, & 80-89). During the dry WY94, significant relationships existed between total recoverable copper and chromium, lead, nickel and zinc (Tables 54; Figs. 55-58). Zinc was also significantly related to chromium, lead, and nickel (Tables 54; Figs. 59-61). When all of the combinations of metal relationships were examined, copper, chromium, lead, zinc, and nickel appeared to be inter-related (Tables 54; Figs. 62-64). Interestingly, these metals were all significantly related to flow and TSS during this water year (Table 48). Flow and TSS were also significantly related to each other during WY94 and seemed to track closely track each other (Figs. 65 & 66). Cadmium was the only metal which did not have significant relationships with the other metals or flow and TSS. It would appear that TSS or flow could be used to formulate rough predictions of copper, chromium, lead, nickel, and zinc concentrations during the drought-like conditions in WY94. Furthermore, these metals would be expected to track each other very closely such that high zinc concentrations could be used to predict high copper, chromium, lead, and nickel concentrations.

A different pattern emerged at Greene's Landing during the wet WY95: cadmium, chromium, copper, nickel, and zinc were inter-related and lead was not associated with any other metal (Table 54; Figs. 67-75). Although none of these metals had significant relationships with flow during this water year, copper, zinc, chromium, and cadmium were significantly related to TSS (Table 49). Furthermore, the relationship between flow and TSS was not significant during WY95 (Fig. 76). This could be explained by several outlier points on the plot. Three low flow and low TSS values occurred at the beginning of January 1995 (Fig. 76). This was followed by a first flush event with high flows, precipitation, and TSS (Figs. 76-78). This high TSS pulse followed a peak of almost three inches in rainfall which was then followed by peak flows of nearly 100,000 CFS (Figs. 77-78). Conditions prior to, and including the pulsed event, appeared to cause the breakdown in the relationship between flow and TSS during WY95. Therefore, the data points were removed and the data was re-plotted resulting in a significant relationship (Fig. 79). The rapid changes in flow conditions induced by heavy rainfall could explain the lack of relationships between flow and the grouped metals. Using the inter-related nature of TSS and the grouped metals (i.e., copper, zinc, chromium, cadmium, and nickel), one could begin to predict high TSS concentrations would result in high concentrations of these metals during periods of very high flows.

Copper, zinc, chromium, lead, and nickel were again inter-related when both water years were combined (Table 54; Figs. 80-89). With the exception of lead, these metals were again significantly related to flow and TSS (Table 50). In addition, flow and TSS were also significantly related (Fig. 90). As illustrated for WY94, TSS and/or flow would appear to be useful in predicting concentration of copper, zinc, chromium, and nickel. Clearly, however, further study would be required to determine how accurate such predictions would be.

Furthermore, these relationships vary with water year as is apparent for WY94 and WY95 and should only be applied to different water years for the purpose of testing the "goodness of fit" of the relationship under different hydrological conditions. A more appropriate use of these relationships is in the design of monitoring plans for metals. For example, if a study is designed to quantify metals when concentrations are high, the relationships above indicate knowledge of flow conditions in the river can be used to optimize sampling such that concentrations would be expected to be high.

WHAT SOURCE(S) OF METALS WERE IDENTIFIED DURING THE METALS SOURCE PILOT STUDY?

Given that concentrations of many metals peaked with high flow conditions, a special pilot study was undertaken to track sources of metal loads up the Sacramento River Watershed during one of the largest storms of the year in 1995. Due to the limited budget for the study and the focus on metal loads, analyses were performed for total recoverable concentrations only. Samples were not collected for the determination of toxicity or exceedances of water quality objectives (e.g., dissolved metal analyses). Although the objective of the pilot study was to track sources of metal loads during a high flow event, the data could not be used to quantify the load contribution from mines in the area of Lake Shasta and Keswick Reservoir because discharges from the reservoirs were maintained at low levels to minimize downstream flooding. This resulted in samples downstream of the reservoirs which were negligibly affected by runoff from mines. However, some previously reported and some unknown sources of metals were identified during the study. A complete description of the results from this study can be found in Appendix D.

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SUMMARY OF RECOMMENDATIONS

1. Continue to rely on the metal analysis protocols and QA/QC guidelines implemented in this project for determining metal concentrations in the surface waters of the Central Valley.

2. Continue using the US EPA Three Species Assays to identify toxicity in field samples. However, findings from a comprehensive literature search indicate other species may be more sensitive to metals. If future biomonitoring studies indicate a species is in decline in the Delta, efforts should be made to determine if the species could be affected by ambient metal concentrations.

3. Conduct a special study to determine if there is a problem with accumulation of metals in the tissues of aquatic organisms, and determine if bioaccumulation is/is not resulting in biomagnification. If accumulation is occurring, determine if the high total loads measured during wet years, such as WY95, play a role in any identifiable bioaccumulation problem.

4. Relative to other sources, determine the contribution of mines, urban runoff, and agricultural discharges on the overall metal loads entering the Delta. Included in this study should be a description of how the contribution varies seasonally and with major storm events.

5. Ambient monitoring programs such as the Coordinated Monitoring Program, Regional Monitoring Program, Sacramento River Watershed Program, and CALFEDs Coordinated Monitoring and Research Program continue to include water column metals monitoring and incorporate sediment testing and tissue analyses.

6. Additional recommendations specific to the Metals Source Pilot Study can be found in Appendix D. Several metals appear to be closely associated with suspended sediment particles. Special studies should initiated to determine if erosion controls can reduce suspended sediment and total recoverable metal concentrations in regions which were sources of high suspended sediment and metal concentrations during the study.

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Table 1. Sites and Dates of Sampling in the Delta and Lower Sacramento River Basin

Site Name	Date Sampled
5 Mile Sl	10/5/94
Antioch	7/19/93
Antioch	7/19/93
Antioch	4/27/94
Antioch	4/27/94
Antioch	4/27/94
Antioch	4/27/94
Antioch	11/4/94
Antioch	11/4/94
Duck Slough	5/10/94
Duck Slough	5/10/94
Duck Slough	7/12/94
Duck Slough	7/12/94
Duck Slough	8/9/94
Duck Slough	8/9/94
Duck Slough	9/2/94
Duck Slough	9/2/94
Duck Slough	9/2/94
Duck Slough	1/9/95
French Camp Slough	3/23/94
French Camp Slough	3/23/94
French Camp Slough	9/2/94
French Camp Slough	9/2/94
Grizzly Bay	2/5/95
Grizzly Bay	2/5/95
Martinez	2/5/95
Martinez	2/5/95
Martinez	2/5/95
Middle R. @ Bullfrog	7/7/93
Middle R. @ Bullfrog	7/7/93
Middle R. @ Bullfrog	8/17/93
Middle R. @ Bullfrog	8/17/93
Middle R. @ Bullfrog	10/29/93
Middle R. @ Bullfrog	10/29/93
Middle R. @ Bullfrog	1/11/94
Middle R. @ Bullfrog	1/11/94
Middle R. @ Bullfrog	1/11/94
Middle R. @ Bullfrog	4/27/94
Middle R. @ Bullfrog	4/27/94
Mokelumne River	8/3/93
Mokelumne River	8/3/93
Mokelumne River	9/14/93
Mokelumne River	9/14/93
Mokelumne River	9/14/93
Mokelumne River	10/14/93
Mokelumne River	10/14/93
Mokelumne River	4/12/94
Mokelumne River	4/12/94
Mokelumne River	5/10/94
Mokelumne River	5/10/94

Site Name	Date Sampled
Mokelumne River	7/21/94
Mokelumne River	7/21/94
Mokelumne River	7/21/94
Mokelumne River	7/21/94
Mokelumne River	10/19/94
Mokelumne River	12/13/94
Mokelumne River	12/13/94
Mokelumne River	12/13/94
Mokelumne River	3/22/95
Mokelumne River	3/22/95
Old River @ Tracy Blvd.	5/25/94
Old River @ Tracy Blvd.	5/25/94
Old River @ Tracy Blvd.	6/3/94
Old River @ Tracy Blvd.	6/3/94
Paradise Cut	4/30/94
Paradise Cut	5/10/94
Paradise Cut	5/10/94
Paradise Cut	5/25/94
Paradise Cut	5/25/94
Paradise Cut	6/3/94
Paradise Cut	6/3/94
Paradise Cut	7/12/94
Paradise Cut	7/12/94
Prospect Slough	7/12/94
Prospect Slough	7/12/94
Prospect Slough	8/9/94
Prospect Slough	8/9/94
Prospect Slough	9/2/94
Prospect Slough	9/2/94
Prospect Slough	9/2/94
Prospect Slough	1/10/95
Prospect Slough	1/10/95
Prospect Slough	1/11/95
Prospect Slough	1/12/95
Prospect Slough	1/13/95
Prospect Slough	1/14/95
Prospect Slough	1/15/95
Prospect Slough	1/15/95
Prospect Slough	1/17/95
Prospect Slough	1/18/95
Prospect Slough	1/22/95
Prospect Slough	1/23/95
Prospect Slough	1/25/95
Prospect Slough	1/25/95
Prospect Slough	1/26/95
Prospect Slough	1/26/95
Prospect Slough	1/27/95
Prospect Slough	1/28/95
Prospect Slough	1/28/95
Prospect Slough	1/31/95

Table 1 (cont). Sites and Dates of Sampling in the Delta and Lower Sacramento River Basin

Site Name	Date Sampled
Prospect Slough	2/3/95
Prospect Slough	2/6/95
Prospect Slough	2/10/95
Prospect Slough	2/14/95
Prospect Slough	2/17/95
Prospect Slough	2/28/95
Prospect Slough	3/21/95
S.J. River @ Pt. Antioch	10/29/93
S.J. River @ Pt. Antioch	10/29/93
S.J. River @ Pt. Antioch	10/29/93
S.J. River @ Pt. Antioch	11/29/93
S.J. River @ Pt. Antioch	1/10/94
S.J. River @ Pt. Antioch	1/10/94
Sac River @ G. Landing	1/11/93
Sac River @ G. Landing	1/13/93
Sac River @ G. Landing	1/14/93
Sac River @ G. Landing	11/10/93
Sac River @ G. Landing	11/11/93
Sac River @ G. Landing	11/12/93
Sac River @ G. Landing	1/10/94
Sac River @ G. Landing	1/13/94
Sac River @ G. Landing	1/18/94
Sac River @ G. Landing	1/19/94
Sac River @ G. Landing	1/23/94
Sac River @ G. Landing	1/24/94
Sac River @ G. Landing	1/25/94
Sac River @ G. Landing	1/26/94
Sac River @ G. Landing	1/27/94
Sac River @ G. Landing	1/28/94
Sac River @ G. Landing	1/29/94
Sac River @ G. Landing	1/30/94
Sac River @ G. Landing	1/31/94
Sac River @ G. Landing	2/1/94
Sac River @ G. Landing	2/2/94
Sac River @ G. Landing	2/5/94
Sac River @ G. Landing	2/7/94
Sac River @ G. Landing	2/8/94
Sac River @ G. Landing	2/9/94
Sac River @ G. Landing	2/10/94
Sac River @ G. Landing	2/11/94
Sac River @ G. Landing	2/12/94
Sac River @ G. Landing	2/16/94
Sac River @ G. Landing	2/17/94
Sac River @ G. Landing	2/18/94
Sac River @ G. Landing	2/19/94
Sac River @ G. Landing	2/20/94
Sac River @ G. Landing	2/21/94
Sac River @ G. Landing	2/22/94
Sac River @ G. Landing	2/23/94
Sac River @ G. Landing	2/24/94
Sac River @ G. Landing	2/25/94
Sac River @ G. Landing	2/27/94

Site Name	Date Sampled
Sac River @ G. Landing	2/28/94
Sac River @ G. Landing	3/1/94
Sac River @ G. Landing	3/4/94
Sac River @ G. Landing	3/9/94
Sac River @ G. Landing	3/10/94
Sac River @ G. Landing	3/15/94
Sac River @ G. Landing	3/16/94
Sac River @ G. Landing	5/10/94
Sac River @ G. Landing	10/5/94
Sac River @ G. Landing	1/6/95
Sac River @ G. Landing	1/7/95
Sac River @ G. Landing	1/8/95
Sac River @ G. Landing	1/10/95
Sac River @ G. Landing	1/11/95
Sac River @ G. Landing	1/12/95
Sac River @ G. Landing	1/13/95
Sac River @ G. Landing	1/14/95
Sac River @ G. Landing	1/15/95
Sac River @ G. Landing	1/17/95
Sac River @ G. Landing	1/18/95
Sac River @ G. Landing	1/20/95
Sac River @ G. Landing	1/22/95
Sac River @ G. Landing	1/23/95
Sac River @ G. Landing	1/24/95
Sac River @ G. Landing	1/25/95
Sac River @ G. Landing	1/26/95
Sac River @ G. Landing	1/27/95
Sac River @ G. Landing	1/28/95
Sac River @ G. Landing	1/29/95
Sac River @ G. Landing	1/30/95
Sac River @ G. Landing	1/31/95
Sac River @ G. Landing	2/1/95
Sac River @ G. Landing	2/2/95
Sac River @ G. Landing	2/3/95
Sac River @ G. Landing	2/6/95
Sac River @ G. Landing	2/10/95
Sac River @ G. Landing	2/14/95
Sac River @ G. Landing	2/17/95
Sac River @ G. Landing	2/21/95
Sac River @ G. Landing	2/23/95
Sac River @ G. Landing	2/24/95
Sac River @ G. Landing	2/28/95
Sac River @ G. Landing	3/3/95
Sac River @ G. Landing	3/5/95
Sac River @ G. Landing	3/7/95
Sac River @ G. Landing	3/11/95
Sac River @ G. Landing	3/22/95
Sac. R. @ Hood	7/19/93
Sac. R. @ Hood	7/19/93
Sac. R. @ Hood	8/3/93
Sac. R. @ Hood	8/3/93
Sac. R. @ Hood	8/3/93

Table 1 (cont). Sites and Dates of Sampling in the Delta and Lower Sacramento River Basin

Site Name	Date Sampled
Sac. R. @ Hood	9/14/93
Sac. R. @ Hood	9/14/93
Sac. R. @ Hood	10/14/93
Sac. R. @ Hood	10/14/93
Sac. R. @ Hood	10/14/93
Sac. R. @ Hood	12/13/93
Sac. R. @ Hood	12/13/93
Sac. R. @ Hood	12/13/93
Sac. R. @ Hood	4/12/94
Sac. R. @ Hood	4/12/94
Sac. R. @ Hood	4/12/94
Sac. R. @ Hood	4/12/94
Sac. R. @ Hood	5/10/94
Sac. R. @ Hood	5/10/94
Sac. R. @ Hood	5/10/94
Sac River @ Rio Vista	7/20/93
Sac River @ Rio Vista	7/20/93
Sac River @ Rio Vista	7/20/93
Sac River @ Rio Vista	8/3/93
Sac River @ Rio Vista	8/3/93
Sac River @ Rio Vista	9/14/93
Sac River @ Rio Vista	9/14/93
Sac River @ Rio Vista	9/14/93
Sac River @ Rio Vista	10/14/93
Sac River @ Rio Vista	10/14/93
Sac River @ Rio Vista	12/13/93
Sac River @ Rio Vista	12/13/93
Sac River @ Rio Vista	4/12/94
Sac River @ Rio Vista	4/12/94
Sac River @ Rio Vista	5/10/94
Skag Slough	1/22/95
Skag Slough	1/23/95
Skag Slough	1/28/95
Skag Slough	2/14/95
S.J. River @ Stockton	10/29/93
S.J. River @ Stockton	10/29/93
S.J. River @ Stockton	10/29/93
S.J. River @ Stockton	11/29/93
S.J. River @ Stockton	1/10/94
S.J. River @ Stockton	1/10/94
S.J. River @ Stockton	1/10/94
S.J. River @ Stockton	4/27/94
S.J. River @ Stockton	4/27/94
Sycamore	3/13/95
Ulatis Creek	3/23/94
Ulatis Creek	3/23/94
Ulatis Creek	12/13/94
Ulatis Creek	12/13/94
S.J. River @ Vernalis	7/7/93
S.J. River @ Vernalis	7/7/93

Site Name	Date Sampled
S.J. River @ Vernalis	8/17/93
S.J. River @ Vernalis	8/17/93
S.J. River @ Vernalis	10/29/93
S.J. River @ Vernalis	10/29/93
S.J. River @ Vernalis	1/11/94
S.J. River @ Vernalis	1/11/94
S.J. River @ Vernalis	1/11/94
S.J. River @ Vernalis	4/27/94
S.J. River @ Vernalis	4/27/94
S.J. River @ Vernalis	4/27/94
S.J. River @ Vernalis	4/27/94
S.J. River @ Vernalis	4/27/94
S.J. River @ Vernalis	3/22/95
S.J. River @ Vernalis	
S.J. River @ Vernalis	
Victoria island	1/9/95

Table 2. Analytical information for four programs monitoring metals in the Sacramento River Watershed

	Monitoring Program				
	Ambient Monitoring Program	**SRCSD Waste Water Treatment Plant**	**Iron Mountain Mine Monitoring Program**		**BPTCP**
Metal Detection Limits (µg/l)			USBR: @ Spring Cr. Dam, Keswick Dam, and Shasta Dam	CVRWQCB	
As	1	0.05	*NS*	NS	0.03
Cd	0.03	0.01	*5-10*	0.1	0.002
Cr	1	0.05 - 0.1	*NS*	NS	0.05
Cu	0.5	0.05	*20-40*	1	0.04
Ni	1	0.05 - 0.15	*NS*	NS	0.02
Pb	0.1	0.1	*NS*	NS	0.01
Zn	4	0.2 - 0.5	*20-40*	3	0.01
Analytical Lab	ToxScan Laboratory	Frontier Geoscience	USBR Keswick Dam Lab	CH2M Hill'; Quality Analytical Labs, Inc."	Moss Landing Mussel Watch
Method	EPA methods	Variable - see reports	Graphite Furnace AA	Graphite Furnace AA	Evapo-concentration & AA Spectrophotometer

Table 2 (cont.). Analytical information for four programs monitoring metals in the Sacramento River Watershed

	Monitoring Program				
	Ambient Monitoring Program	**SRCSD Waste Water Treatment Plant**	**Iron Mountain Mine Monitoring Program**		**BPTCP**
Sample Method	pumped cross-sectional composite and 24-hour time-composite	24-hour composite	grab	grab	Acid cleaned CPE tubing and peristaltic pump
Total or total recoverable	Total recoverable	Total recoverable	Mine samples = Total Sac. River = Total and dissolved	Total	Total recoverable
Citation	1	2	3	3	4

1 = Larry Walker Associates. 1996. Sacramento Coordinated Water Quality Monitoring Program 1995 Annual Report
2 = Sacramento Regional County Sanitation District, 1996
3 = RWQCB IMM Monitoring Reports, 1985-86 through 1992-93
4 = Goetzl, J. and M. Stephenson. 1993. Metals Implementation Project: Metals Monitoring of Central Valley Reservoir Releases: 1991-1992
NS = not sampled
*= 11/95 to 6/93
= 7/93 - present

Table 3. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the San Joaquin River at Antioch During Water Years 1993 and 1994.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O˙	D	T	C*	C#	O˙	D	T	C*#	D	T	C*	C#	
7/19/93	2.22	4.65	9.2	7.2	10	2.06	9.98	85	96	100	0.78	4.09	145	0.013	0.03	0.86	1.9	78
10/29/93		2.72	37.0	29.0	10		4.99	340	380	100		1.34	550		0.014	2.90	6.2	626
10/29/93	2.73	1.72	37.0	29.0	10	3.18	1.68	340	380	100	2.62	0.19	550	0.018	0.017	2.90	6.2	626
11/29/93		2.69	37.0	29.0	10		2.3	340	380	100		1.86	550		0.02	2.90	6.2	616
1/10/94	3.82	3.68	25.9	20.4	10	2	10.5	236	267	100	0.12	3.35	392	0.04	0.02	2.10	4.6	262
4/27/94	2.71	4.72	16.4	13.0	10	1.46	7.06	151	170	100	0.81	3.27	254	0.013	0.031	1.42	3.1	154
4/27/94	2.75	4.85	16.4	13.0	10	1.23	6.48	151	170	100	0.63	2.82	254	0.016	0.029	1.42	3.1	154
11/4/94	2.19	3.69			10	2.97	7.23				0.71	2.31		0.014	0.012			no data

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C^ = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 1-hour average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O˙ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = dissolved concentrations.

Table 3 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the San Joaquin River at Antioch During Water Years 1993 and 1994.

	NICKEL				ARSENIC				SILVER				LEAD			HARDNESS
DATE	**D**	**T**	**C***	**C#**	**D**	**T**	**C†**	**O˙**	**D**	**T**	**C^**	**O˙**	**D**	**T**	**C*#**	
7/19/93	1.47	5.91	127	42						0.01	2.25	10	0.08	0.85	1.9	78
10/29/93		3.21	510	170										0.03	11	626
10/29/93	2.73	1.61	510	170									0.25		11	626
11/29/93		2.97	510	170						0.014	79	10		0.07	11	616
1/10/94	0.98	3.42	355	117						0.004	18	10	0.04	0.41	7.1	262
4/27/94	1.98	5.15	227	75									0.12	0.66	4.0	154
4/27/94	1.43	4.15	227	75									0.13	0.93	4.0	154
11/4/94	2.12	4.2			0.13	0.41	5	10	0.004	0.012		10	0.09	0.36		no data

Table 4. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Duck Slough During Water Years 1994 and 1995.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O˚	D	T	C*	C#	O˚	D	T	C*#	D	T	C*	C#	
5/10/94	4.9	12	11.2	8.8	10	7.76	26	103	116	100	5.39	18.7	175	0.012	0.069	1.02	2.2	98
7/12/94	4.41	12.6	8.6	6.8	10	7.17	32.3	79	89	100	4.78	19.6	136	0.035	0.081	0.81	1.8	72
8/9/94	4.52	12.5	8.2	6.4	10	6.75	27.5	75	85	100	5	22.4	130	0.011	0.066	0.78	1.7	68
9/2/94	-	13.5	8.4	6.6	10		29.6	77	87	100		23.1	133		0.071	0.79	1.7	70
9/2/94	3.58	14.9	8.4	6.6	10	4.56	30.7	77	87	100	4.08	21.9	133	0.021	0.064	0.79	1.7	70
1/9/95	3.39	-	23.5	18.5	10	2.75	-	215	243	100	2.41	-	357	0.021	-	1.93	4.2	234

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O˚ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = dissolved concentrations

Table 4 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Duck Slough During Water Years 1994 and 1995.

DATE	NICKEL				ARSENIC				LEAD			HARDNESS
	D	T	C*	C#	D	T	C†	O'	D	T	C*#	
5/10/94	8.52	24.1	155	51	1.09	2.06	5	10	1.05	3.3	2.5	98
7/12/94	6.85	28.8	119	39	1.32	1.58	5	10	0.88	4.28	1.8	72
8/9/94	8	31.4	113	38	2.05	2.4	5	10	1.38	8.98	1.6	68
9/2/94		35.8	116	38		2.21	5	10		8.56	1.7	70
9/2/94	5.16	34.3	116	38	2.17	3.98	5	10	1.08	7.39	1.7	70
1/9/95	6.35	-	323	107	-	-	5	10	0.37	-	6.3	234

Table 5. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from French Camp Slough During Water Year 1994.

DATE	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
	D	T	C*	C#	O˙	D	T	C*	C#	O˙	D	T	C*#	D	T	C*	C#	
3/23/94	2.83	2.72	5.6	4.4	10	3.59	9.24	52	59	100	0.81	4	91	0.011	0.044	0.56	1.2	44
9/2/94	2.94	6.17	9.6	7.6	10	2.27	13.3	88	100	100	0.99	3.64	151	0.014	0.038	0.89	1.9	82

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O˙ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 5 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from French Camp Slough During Water Year 1994.

	NICKEL				ARSENIC				LEAD			HARDNESS
DATE	**D**	**T**	**C***	**C#**	**D**	**T**	**C†**	**O˙**	**D**	**T**	**C*#**	
3/23/94	1.29	3.33	78	26	1.33	1.49	5	10	0.41	2.26	1.0	44
9/2/94	0.99	2.15	133	44	2.4	2.71	5	10	0.37	1.58	2.0	82

Table 6. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Hood During Water Years 1993 and 1994.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O˚	D	T	C*	C#	O˚	D	T	C*#	D	T	C*	C#	
7/19/93	1.42	3.6	6.1	4.8	10	1.12	6.46	56	63	100	0.32	2.85	98	nd	0.041	0.60	1.3	48
8/3/93	1.61	3.77	8.0	6.3	10	1.47	5.91	73	83	100	0.36	3.25	127	0.015	0.039	0.76	1.6	66
8/3/93		4.18	8.0	6.3	10		7.41	73	83	100		3.27	127		0.037	0.76	1.6	66
9/14/93	2	3.76	7.8	6.1	10	5.02	16	72	81	100	0.36	2.52	124	0.026	0.038	0.74	1.6	64
10/14/93	1.38	2.71	6.1	4.8	10	1.29	8.55	56	63	100	0.22	1.57	98	0.012	0.036	0.60	1.3	48
10/14/93	1.39		6.1	4.8	10	0.95		56	63	100	0.34		98	0.014		0.60	1.3	48
12/13/93		4.38	6.7	5.3	10		7.5	62	70	100		3.99	107		0.08	0.65	1.4	54
12/13/93	2.16	4.35	6.7	5.3	10	0.38	7.6	62	70	100	0.19	3.4	107	0.01	0.07	0.65	1.4	54
4/12/94	2.12	2.89	8.4	6.6	10	2.36	4.62	77	87	100	0.4	1.34	133	0.015	0.027	0.79	1.7	70
4/12/94	2.17	2.94	8.4	6.6	10	1.72	3.81	77	87	100	0.34	1.03	133	0.015	0.033	0.79	1.7	70
5/10/94		2.63	6.7	5.3	10		5.14	62	70	100		1.52	107		0.036	0.65	1.4	54
5/10/94	1.84	2.94	6.7	5.3	10	1.33	3.8	62	70	100	0.55	1.36	107	0.016	0.026	0.65	1.4	54

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C^ = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 1-hour average criteria)
O˚ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 6 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Hood During Water Years 1993 and 1994.

	NICKEL				LEAD			SILVER				HARDNESS
DATE	D	T	C*	C#	D	T	C*#	D	T	C^	O•	
7/19/93	0.7	4.19	84	28	0.06	2.85	1.1	0.003	0.009	0.98	10	48
8/3/93	0.84	4.3	111	37	0.05	0.61	1.6	0.004		1.69	10	66
8/3/93		4.81	111	37		0.53	1.6		0.011	1.69	10	66
9/14/93	0.96	3.76	108	36	0.03	0.3	1.5			1.60	10	64
10/14/93	0.63	2.3	84	28	nd	0.31	1.1			0.98	10	48
10/14/93	0.67		84	28	0.06		1.1			0.98	10	48
12/13/93		4.52	93	31		0.64	1.3	0.002	0.012	1.20	10	54
12/13/93	0.87	4.81	93	31	0.04	0.63	1.3			1.20	10	54
4/12/94	0.92	2.02	116	38	0.07	0.24	1.7			1.87	10	70
4/12/94	0.75	1.64	116	38	0.075	0.24	1.7			1.87	10	70
5/10/94		2.34	93	31		0.29	1.3			1.20	10	54
5/10/94	1	1.83	93	31	0.09	0.34	1.3			1.20	10	54

Table 7. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Middle River at Bullfrog Landing During Water Years 1993 and 1994.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O*	D	T	C*	C#	O*	D	T	C*#	D	T	C*	C#	
7/7/93	1.67	2.54	8.8	6.9	10	1.15	6.77	81	92	100	0.45	0.007	139		0.007	0.83	1.8	74
8/17/93	1.73	28.3	6.1	4.8	10	1.31	6.66	56	63	100	0.58	26.8	98		0.456	0.60	1.3	48
10/29/93	1.47	1.59	7.5	6.0	10	0.62	1.34	70	79	100	0.24	0.41	120	0.005	0.01	0.72	1.6	62
1/11/94		2.06	10.2	8.0	10		2.2	94	106	100		0.56	160		0.02	0.94	2.0	88
1/11/94	2.01	0.75	10.2	8.0	10	1.2	1.7	94	106	100	0.39	0.24	160	0.02	0.01	0.94	2.0	88
4/27/94	2.07	2.38	13.6	10.8	10	0.16	1.97	125	142	100	0.28	0.68	212	0.007	0.01	1.21	2.6	124

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C^ = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 1-hour average criteria)
O* = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Staff Report of the

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

REGIONAL WATER QUALITY CONTROL BOARD
CENTRAL VALLEY REGION

METAL CONCENTRATIONS, LOADS, AND TOXICITY ASSESSMENT IN THE SACRAMENTO/SAN JOAQUIN DELTA: 1993-1995

December 1998

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Table 7 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Middle River at Bullfrog Landing During Water Years 1993 and 1994.

	NICKEL				LEAD			SILVER				HARDNESS
DATE	D	T	C*	C#	D	T	C*#	D	T	C^	O•	
7/7/93	1.04	2.62	122	40	0.1	0.46	1.8	0.005	0.013	2.06	10.00	74
8/17/93	1.22	38.8	84	28	0.22	39.4	1.1					48
10/29/93	0.71	1.07	105	35		0.13	1.5					62
1/11/94		2.16	141	47		0.11	2.2					88
1/11/94	1.52	0.84	141	47	0.06	0.03	2.2					88
4/27/94	1.41	1.98	189	62	0.06	0.16	3.2					124

Table 8. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Mokelumne River During Water Years 1993, 1994, and 1995.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O˙	D	T	C*	C#	O˙	D	T	C*#	D	T	C*	C#	
8/3/93			4.7	3.7	10			44	50	100			77			0.48	1.1	36
8/3/93	1.62	1.98	4.7	3.7	10	2.49	6.15	44	50	100	0.09	0.66	77	0.013	0.022	0.48	1.1	36
9/14/93		3.19	4.3	3.4	10		4.84	40	45	100		1.08	70		0.031	0.44	1.0	32
9/14/93	1.6	2.8	4.3	3.4	10	3.16	4.12	40	45	100	0.09	1.51	70	0.011	0.026	0.44	1.0	32
10/14/93	1.37	1.77	3.4	2.6	10	1.24	3.37	31	35	100	0.11	0.54	55	0.01	0.017	0.36	0.8	24
4/12/94	1.29	2.21	4.3	3.4	10	0.75	4.2	40	45	100	0.2	1.49	70	0.005	0.013	0.44	1.0	32
5/10/94		2.42	4.1	3.2	10		4.51	38	43	100		0.94	66		0.012	0.42	0.9	30
5/10/94		2.05	4.1	3.2	10		2.91	38	43	100		1.06	66		0.006	0.42	0.9	30
7/21/94	1.25	2.01			10	5.65	5.32			100	0.16	0.72		0.017	0.024			no data
7/21/94	1.14	1.88			10	5.57	6.34			100	0.11	0.57		0.008	0.022			no data
10/19/94		2.15			10		7.29			100		0.73			0.019			no data
12/13/94	1.84	3.97			10	4.1	52.8			100	0.72	3.54		0.01	0.02			no data
12/13/94	1.89				10	2				100	0.77			0.01				no data
3/11/95		4.31	3.1	2.5	10		16.1	29	33	100		2.41	52		0.066	0.34	0.7	22
3/11/95		4.79	3.1	2.5	10		6.27	29	33	100		3.86	52		0.033	0.34	0.7	22
3/22/95		4.26	4.7	3.7	10		18.2	44	50	100		2.1	77		0.095	0.48	1.1	36
3/22/95		4.72	4.7	3.7	10		13.3	44	50	100		1.93	77		0.084	0.48	1.1	36

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C^ = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 1-hour average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O˙ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss.concentrations.

Table 8 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Mokelumne River During Water Years 1993, 1994, and 1995.

	NICKEL				LEAD			SILVER				ARSENIC				HARDNESS
DATE	D	T	C*	C#	D	T	C*#	D	T	C^	O•	D	T	C†	O•	
8/3/93			66	22			0.8			0.60	10					36
8/3/93	0.31	0.75	66	22	0.08	0.3	0.8	nd	0.003	0.60	10					36
9/14/93		1.23	60	20		0.45	0.7									32
9/14/93	0.39	1.11	60	20	0.1	0.5	0.7									32
10/14/93	0.31	0.92	47	16	0.07	0.26	0.5									24
4/12/94	0.55	1.73	60	20	0.1	0.34	0.7									32
5/10/94		1.48	57	19		0.32	0.7						1.27	5	10	30
5/10/94		1.19	57	19		0.38	0.7						1.22	5	10	30
7/21/94	0.44	0.68			0.08	0.3		0.008	0.008		10	0.6	0.5	5	10	no data
7/21/94	0.47	0.63			0.1	0.25						0.45	0.63	5	10	no data
10/19/94		0.83				0.28										no data
12/13/94	1.34	3.34			0.18	0.67										no data
12/13/94	1.33				0.18											no data
3/11/95		2.61	44	14		4.66	0.5									22
3/11/95		5.72	44	14		3.19	0.5									22
3/22/95		2.47	66	22		0.89	0.8									36
3/22/95		1.72	66	22		1.3	0.8									36

Table 9. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Old River at Tracy Blvd. During Water Year 1994.

DATE	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
	D	T	C*	C#	O˙	D	T	C*	C#	O˙	D	T	C*#	D	T	C*	C#	
5/25/94	1.44	2.43	16.2	12.8	10	1.99	7.18	149	168	100	0.37	2.33	251	0.014	0.02	1.40	3.0	152
6/3/94	1.74	3.84	23.8	18.8	10	1.99	9.26	218	246	100	0.25	3.2	362	0.008	0.023	1.96	4.2	238

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O˙ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 9 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Old River at Tracy Blvd. During Water Year 1994.

	NICKEL				LEAD			ARSENIC				HARDNESS
DATE	D	T	C*	C#	D	T	C*#	D	T	C†	O•	
5/25/94	3.01	2.82	224	74	0.12	3.06	4.0	1	0.98	5	10	152
6/3/94	1	3.28	327	108	0.05	1.92	6.4	1.58	0.81	5	10	238

Table 10. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Paradise Cut During Water Year 1994.

DATE	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
	D	T	C*	C#	O*	D	T	C*	C#	O*	D	T	C*#	D	T	C*	C#	
4/30/94	1.19		37	29	10	0.83		340	380	100	0.21		550	0.008		2.9	6.2	432
5/10/94	2.19	3.42	37	29	10	nd	4.86	335	379	100	0.06	2.13	549	0.008	0.018	2.8	6.2	396
5/25/94	1.01		37	29	10	2.07		337	380	100	0.25		550	0.009		2.9	6.2	398
5/25/94	1.81		37	29	10	1.43		337	380	100	0.08		550	nd		2.9	6.2	398
6/3/94	2.41	4.3	36	28	10	2.54	7.3	327	369	100	0.08	nd	536	0.008	0.019	2.8	6.0	384
7/12/94	0.2	4.88	37	29	10	3.55	8.95	338	380	100	0.2	4.72	550	0.007	0.025	2.9	6.2	400
7/12/94			37	29	10			338	380	100			550			2.9	6.2	400

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O* = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 10 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Paradise Cut During Water Year 1994.

	NICKEL				LEAD			ARSENIC				HARDNESS
DATE	D	T	C*	C#	D	T	C*#	D	T	C†	O•	
4/30/94	2.07		510	170	nd		11	1.24		5	10	432
5/10/94	1.83	3.79	504	167	nd	0.33	11	0.24	0.11	5	10	396
5/25/94	2.12		506	167	0.04		11	1.4		5	10	398
5/25/94	2.29		506	167	nd		11	1.34		5	10	398
6/3/94	2.38	4.75	491	162	0.07	0.64	10	1	1.74	5	10	384
7/12/94	2.16	8.59	508	168	0.05	0.6	11	2.27	3.15	5	10	400
7/12/94			508	168			11					400

Table 11. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Prospect Slough During Water Years 1994 and 1995.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O*	D	T	C*	C#	O*	D	T	C*#	D	T	C*	C#	
7/12/94	3.52	8.29	9.8	7.7	10	6.83	16.6	90	102	100	3.06	10.8	155	0.017	0.035	0.91	2.0	84.3
8/9/94	4.1	7.7	8.6	6.8	10	4.03	12.1	79	89	100	3.83	11	136	0.023	0.03	0.81	1.8	72
9/2/94		8.16	10.0	7.9	10		13.3	92	104	100		9.58	157		0.036	0.92	2.0	86
9/2/94	4.22	8.49	10.0	7.9	10	3.97	12.2	92	104	100	3.52	9.84	157	0.021	0.031	0.92	2.0	86
1/10/95		124	9.6	7.6	10		270	88	100	100		242	151		0.568	0.89	1.9	82
1/10/95		162	9.6	7.6	10		328	88	100	100		271	151		0.52	0.89	1.9	82
1/11/95		86.9	10.2	8.0	10		172	94	106	100		168	160		0.229	0.94	2.0	88
1/12/95		34.4	7.5	6.0	10		66.3	70	79	100		57.6	120		0.181	0.72	1.6	62
1/13/95		17.9	7.1	5.6	10		42.4	66	74	100		32.7	114		0.163	0.69	1.5	58
1/14/95		40.3	9.6	7.6	10		84	88	100	100		58	151		0.224	0.89	1.9	82
1/15/95		29.8	7.3	5.8	10		128	68	77	100		42.3	117		0.203	0.71	1.5	60
1/15/95		28.9	7.3	5.8	10		128	68	77	100		42.5	117		0.197	0.71	1.5	60
1/17/95		19	6.1	4.8	10		78.9	56	63	100		27.1	98		0.087	0.60	1.3	48
1/18/95		24.3		no data	10		103		no data	100		32.9	no data		0.17			no data
1/22/95		13.3	7.8	6.1			26.3	72	81	100		18.7	124		0.092	0.74	1.6	64

D = Dissolved concentration (μg/l) following 0.45 μm filtration
T = Total recoverable concentration (μg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O* = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 11 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Prospect Slough During Water Years 1994 and 1995.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O*	D	T	C*	C#	O*	D	T	C*#	D	T	C*	C#	
1/23/95		14.9	7.3	5.8	10		39.3	68	77	100		17.4	117		0.104	0.71	1.5	60
1/25/95	3.48	9.06	7.8	6.1	10	5.69	28.3	72	81	100	2.51	9.56	124	0.023	0.075	0.74	1.6	64
1/26/95	4.78	15	6.9	5.5	10	8.17	36.3	64	72	100	4.08	21.6	111	0.064	0.107	0.67	1.5	56
1/27/95		12.3	7.3	5.8	10		31.9	68	77	100		19.2	117		0.096	0.71	1.5	60
1/28/95	4.51	12.5	7.3	5.8	10	7.87	32.8	68	77	100	3.69	17.6	117	0.064	0.111	0.71	1.5	60
1/31/95		9.73	8.2	6.4	10		23.3	75	85	100		11.5	130		0.065	0.78	1.7	68
2/3/95		8.69	8.2	6.4	10		19.9	75	85	100		10	130		0.07	0.78	1.7	68
2/6/95		14.7	5.8	4.6	10		29.2	54	61	100		14.3	94		0.082	0.58	1.3	46
2/10/95		7.34	8.0	6.3	10			73	83	100		7.65	127		0.068	0.76	1.6	66
2/14/95		8.22	9.4	7.4	10			87	98	100		10.5	148		0.084	0.87	1.9	80
2/17/95		5.72	15.9	12.5	10			146	165	100		8.08	245		0.036	1.38	3.0	148
2/28/95		8.59	24.3	19.2	10			223	252	100		14.5	370		0.065	1.99	4.3	244
3/21/95		10	6.9	5.5	10		20.5	64	72	100		13.3	111		0.072	0.67	1.5	56

Table 11 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Prospect Slough During Water Years 1994 and 1995.

	NICKEL				LEAD			ARSENIC				HARDNESS
DATE	D	T	C*	C#	D	T	C*#	D	T	C†	O•	
7/12/94	5.36	15.3	136	45	0.4	1.24	2.1	1	1.06	5	10	84.3
8/9/94	7.04	15.7	119	39	0.41	1.24	1.8	1.93	1.67	5	10	72
9/2/94		18.3	138	46		2.24	2.1		2.1	5	10	86
9/2/94	6.12	18.5	138	46	0.73	2.06	2.1	2.04	3.24	5	10	86
1/10/95		601	133	44		28.4	2.0		0.6	5	10	82
1/10/95		587	133	44		41.2	2.0			5	10	82
1/11/95		417	141	47		16	2.2		1.46	5	10	88
1/12/95		103	105	35		7.81	1.5		1.5	5	10	62
1/13/95		38	99	33		3.65	1.4		1.63	5	10	58
1/14/95		79.2	133	44		13.5	2.0		1.2	5	10	82
1/15/95		53.7	102	34		6.54	1.4		2.48	5	10	60
1/15/95		62.8	102	34		6.15	1.4		2.27	5	10	60
1/17/95		36.6	84	28		2.95	1.1		3.32	5	10	48
1/18/95		45.1		no data		4.82			4.41	5	10	no data
1/22/95		27.3	108	36		2.49	1.5		1.07	5	10	64

Table 11 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Prospect Slough During Water Years 1994 and 1995.

	NICKEL				LEAD			ARSENIC				HARDNESS
DATE	D	T	C*	C#	D	T	C*#	D	T	C†	O•	
1/23/95		28.8	102	34		3	1.4		1.18	5	10	60
1/25/95	4.39	16.7	108	36	0.38	1.26	1.5	1.43	1.81	5	10	64
1/26/95	7.28	36.6	96	32	0.57	2.53	1.3	1.51	nd	5	10	56
1/27/95		28.3	102	34		2.07	1.4		1.48	5	10	60
1/28/95	6.75	29.3	102	34	0.57	2.11	1.4	1.45	0.99	5	10	60
1/31/95		14.8	113	38		1.45	1.6			5	10	68
2/3/95		13.5	113	38		1.12	1.6			5	10	68
2/6/95		21.3	81	27		1.95	1.1			5	10	46
2/10/95		11.4	111	37		0.76	1.6			5	10	66
2/14/95		15.8	130	43		4.2	2.0			5	10	80
2/17/95		13.8	219	72		0.75	3.8			5	10	148
2/28/95		28.3	334	111		1.93	6.5			5	10	244
3/21/95		19.3	96	32		3.45	1.3			5	10	56

Table 12 Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Rio Vista During Water Years 1993 and 1994.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O˙	D	T	C*	C#	O˙	D	T	C*#	D	T	C*	C#	
7/20/93	1.56	3.51	5.6	4.4	10	1.31	6.96	52	59	100	0.41	2.63	91	0.01	0.04	0.56	1.2	44
7/20/93	1.45		5.6	4.4	10	0.7		52	59	100	0.5		91	0.015		0.56	1.2	44
8/3/93	2.4	3.17	7.8	6.1	10	2.64	4.55	72	81	100	1.14	2.06	124	0.024	0.031	0.74	1.6	64
9/14/93	1.97	2.98	7.8	6.1	10	1.4	6.08	72	81	100	0.56	2.11	124	0.017	0.035	0.74	1.6	64
9/14/93	1.86		7.8	6.1	10	0.88		72	81	100	0.59		124	0.014		0.74	1.6	64
10/14/93	1.91	3.48	6.9	5.5	10	2.64	12.5	64	72	100	0.3	2.36	111	0.025	0.035	0.67	1.5	56
12/13/93	1.58	2.97	9.0	7.1	10	0.71	4.6	83	94	100	0.72	1.56	142	0.01	0.03	0.84	1.8	76
4/12/94	1.88	2.98	9.0	7.1	10	1.06	4.02	83	94	100	0.37	1.77	142	0.019	0.024	0.84	1.8	76
5/10/94	1.9	2.97	7.5	6.0	10	1.75	5.07	70	79	100	0.52	2.05	120	0.015	0.028	0.72	1.6	62

D = Dissolved concentration (μg/l) following 0.45 μm filtration
T = Total recoverable concentration (μg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C^ = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 1-hour average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O˙ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 12 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Rio Vista During Water Years 1993 and 1994.

	NICKEL				LEAD			ARSENIC				SILVER				HARDNESS
DATE	**D**	**T**	**C***	**C#**	**D**	**T**	**C*#**	**D**	**T**	**C†**	**O•**	**D**	**T**	**O^**	**O•**	
7/20/93	1.35	4.97	78	26	0.1	0.62	1.0					nd	0.009	0.84	10	44
7/20/93	1.02		78	26	0.08		1.0					<0.002		0.84	10	44
8/3/93	1.71	2.89	108	36	0.18	0.32	1.5					0.006	0.007	1.60	10	64
9/14/93	1.22	3.24	108	36	0.03	0.21	1.5						0.006	1.60	10	64
9/14/93	1.1		108	36	0.09		1.5					<0.002	nd	1.60	10	64
10/14/93	0.85	3.62	96	32	0.04	0.27	1.3					nd	0.008	1.27	10	56
12/13/93	0.87	2.88	125	41	0.04	0.36	1.9					0.002	0.01	2.15	10	76
4/12/94	1.21	2.99	125	41	0.08	0.26	1.9									76
5/10/94	1.43	3.45	105	35	0.09	0.29	1.5	1.9	2.2	5	10					62

Table 13. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Skag Slough During Water Year 1995.

DATE	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
	D	T	C*	C#	O•	D	T	C*	C#	O•	D	T	C*#	D	T	C*	C#	
1/22/95		11.9	12.9	10.2	10		26.3	119	134	100		22.7	201		0.068	1.15	2.5	116
1/23/95		14.6	13.6	10.8	10		45.6	125	142	100		24.3	212		0.068	1.21	2.6	124
1/28/95		13	11.7	9.3	10		30.3	108	122	100		20.1	184		0.12	1.06	2.3	104
2/14/95		3.89	19.8	15.6	10			182	205	100		5.74	304		0.026	1.67	3.6	192
3/10/95		5.22	22.3	17.6	10		15.3	204	230	100		4.82	340		0.057	1.85	4.0	220

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O• = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 13 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Skag Slough During Water Year 1995.

DATE	NICKEL				LEAD			ARSENIC				HARDNESS
	D	T	C*	C#	D	T	C*#	D	T	C†	O•	
1/22/95		33.9	178	59		2.52	3.0		2.54	5	10	116
1/23/95		41.9	189	62		3.9	3.2		3.08	5	10	124
1/28/95		37.2	162	54		2.19	2.6		1.48	5	10	104
2/14/95		11.1	273	90		0.5	5.1					192
3/10/95		14.1	306	101		4.66	5.9					220

Table 14 Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the San Joaquin River at Stockton During Water Year 1994.

DATE	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
	D	T	C*	C#	$O^{\bullet}$	D	T	C*	C#	$O^{\bullet}$	D	T	C*#	D	T	C*	C#	
10/29/93		2.85	8.8	6.9	10		5.55	81	92	100		0.83	139		0.009	0.83	1.8	74
10/29/93	1.98	2.66	8.8	6.9	10	4.5	4.96	81	92	100	0.15	1.16	139	0.006	0.014	0.83	1.8	74
11/29/93		2.66	19.5	15.4	10		8.2	178	202	100		0.98	299		0.03	1.64	3.6	188
1/10/94		2.96	20.9	16.5	10		10.3	191	216	100		0.38	319		0.02	1.75	3.8	204
1/10/94	2.67	2.76	20.9	16.5	10	10	10.8	191	216	100	0.08	0.54	319		0.02	1.75	3.8	204
4/27/94	2.99	4.25	18.0	14.2	10	6.65	13	165	187	100	0.2	0.6	278	0.01	0.021	1.54	3.3	172

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
$O^{\bullet}$ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 14 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the San Joaquin River at Stockton During Water Year 1994.

	NICKEL				LEAD			HARDNESS
DATE	D	T	C*	C#	D	T	C*#	
10/29/93		1.66	122	40		1.18	1.8	74
10/29/93	1.29	1.71	122	40	0.23	1.36	1.8	74
11/29/93		1.94	268	89		0.95	5.0	188
1/10/94		2.52	287	95		0.1	5.4	204
1/10/94	2.07	2.3	287	95		0.74	5.4	204
4/27/94	1.84	2.17	249	82	0.16	0.83	4.5	172

Table 15. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Ulatis Creek During Water Years 1994 and 1995.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O˙	D	T	C*	C#	O˙	D	T	C*#	D	T	C*	C#	
3/23/94	2.98	4.23	29.4	23.2	10	5.55	9.56	268	303	100	1.71	3.87	442	0.018	0.027	2.34	5.1	304
12/13/94	3.89	21.1			10	18.5	57.3			100	0.65	13.1		0.043	0.126			no data

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O˙ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 15 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from Ulatis Creek During Water Years 1994 and 1995.

DATE	NICKEL				LEAD			ARSENIC				HARDNESS
	D	T	C*	C#	D	T	C*#	D	T	C†	O'	
3/23/94	3.65	5.69	403	133	0.07	0.46	8.2	1.62	1.78	5	10	304
12/13/94	3.45	16.2			0.2	5.18		1.39	1.22	5	10	no data

Table 16. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the San Joaquin River at Vernalis During Water Years 1993, 1994, and 1995.

DATE	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
	D	T	C*	C#	O*	D	T	C*	C#	O*	D	T	C*#	D	T	C*	C#	
7/7/93	1.63	6.38	15.7	12.4	10	1.52	16.1	144	163	100	0.63	8.38	243		0.015	1.36	3.0	146
8/17/93	1.5	4.49	14.8	11.6	10	0.96	11.1	136	153	100	0.64	5.7	229		0.011	1.29	2.8	136
10/29/93	1.09	2.83	14.0	11.1	10	0.47	9.48	129	146	100	0.2	2.62	218	0.008	0.02	1.24	2.7	128
1/11/94	2.47		16.6	13.1	10	0.39		152	172	100	0.17		256			1.43	3.1	156
1/11/94	1.93	1.51	16.6	13.1	10	0.3	3.5	152	172	100	0.74	1.19	256	0.001	0.01	1.43	3.1	156
4/27/94			9.8	7.7	10		0.08	90	102	100			154			0.91	2.0	84
4/27/94			9.8	7.7	10		0.24	90	102	100			154			0.91	2.0	84
4/27/94	1.17	3.58	9.8	7.7	10	0.48	9.24	90	102	100	0.4	4.4	154	0.002	0.014	0.91	2.0	84
4/27/94	0.68		9.8	7.7	10	0.54		90	102	100	0.34		154			0.91	2.0	84
3/11/95		34.1	12.7	10.0	10		107	117	132	100		69.1	198		0.169	1.14	2.5	114
3/22/95		2.89	9.8	7.7	10		5.87	90	102	100		2.11	154		0.024	0.91	2.0	84

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
O* = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 16 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the San Joaquin River at Vernalis During Water Years 1993, 1994, and 1995.

DATE	NICKEL				LEAD			HARDNESS
	D	T	C*	C#	D	T	C*#	
7/7/93	2.23	11.2	217	72		1.43	3.8	146
8/17/93	1.7	8.9	204	67		1.13	3.5	136
10/29/93	1.13	4.03	194	64	0.04	0.14	3.3	128
1/11/94	0.95		229	76			4.1	156
1/11/94	1.93	2	229	76	0.15	0.06	4.1	156
4/27/94			136	45			2.1	84
4/27/94			136	45			2.1	84
4/27/94	0.97	5.53	136	45	0.07	0.79	2.1	84
4/27/94	0.88		136	45	0.09		2.1	84
3/11/95		128	176	58		17.6	2.9	114
3/22/95		3.97	136	45		5.43	2.1	84

Table 17. Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Greene's Landing During Water Year 1995.

DATE	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
	D	T	C*	C#	O*	D	T	C*	C#	O*	D	T	C*#	D	T	C*	C#	
1/6/95	2.99	5.54	10.6	8.3	10	3.2	10.2	97	110	100	1.28	3.71	166	0.028	0.063	0.97	2.1	92
1/7/95	3.39	9.02	8.0	6.3	10	3.75	17.9	73	83	100	1.98	7.2	127	0.028	0.118	0.76	1.6	66
1/8/95	4.91	10.6	7.3	5.8	10	5.59	19.7	68	77	100	2.94	11.4	117	0.038	0.108	0.71	1.5	60
1/10/95	4.9	28.4	6.5	5.1	10	5.99	62.9	60	68	100	3	29	104	0.039	0.474	0.64	1.4	52
1/12/95	3.35	17.4	5.4	4.3	10	2.86	33.1	50	57	100	3.2	19.3	87	0.034	0.184	0.54	1.2	42
1/13/95	3.67	14.2	7.1	5.6	10	6.32	32.5	66	74	100	4.78	21	114	0.035	0.166	0.69	1.5	58
1/14/95	3.94	15.2	5.2	4.1	10	11.2	71.8	48	54	100	4.42	21.3	84	0.018	0.167	0.52	1.1	40
1/15/95	3.62	10.7	5.6	4.4	10	7.93	44.8	52	59	100	3.05	12.2	91	0.031	0.114	0.56	1.2	44
1/17/95	3.6	9.39	5.6	4.4	10	9.4	18.4	52	59	100	3.4	11.6	91	0.002	0.087	0.56	1.2	44
1/18/95	3.68	10.3			10	4.68	46.9			100	3.83	13.3		0.033	0.09			no data
1/20/95	4.28	9.68	6.1	4.8	10	4.84	19.5	56	63	100	3.43	12.6	98	0.11	0.089	0.60	1.3	48
1/22/95	3.35	9.98	6.7	5.3	10	4.25	23.3	62	70	100	2.5	12	107	0.025	0.095	0.65	1.4	54
1/23/95	3.42	9.43	6.3	5.0	10	4.41	25.4	58	66	100	2.52	8.57	101	0.024	0.087	0.62	1.3	50
1/24/95	3.09	8.27	6.9	5.5	10			64	72	100	2.68	8.44	111	0.027	0.084	0.67	1.5	56
1/25/95	2.88	7.07	6.7	5.3	10	5.06	20.9	62	70	100	4.43	8.27	107	0.025	0.08	0.65	1.4	54
1/26/95	3.16	9.9	6.3	5.0	10	4.86	24.4	58	66	100	2.07	11	101	0.032	0.111	0.62	1.3	50
1/27/95	3.27	8.82	6.1	4.8	10	6.06	22.3	56	63	100	4.46	10.6	98	0.033	0.08	0.60	1.3	48

Table 17 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Greene's Landing During Water Year 1995.

DATE	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
	D	T	C*	C#	O˙	D	T	C*	C#	O˙	D	T	C*#	D	T	C*	C#	
1/28/95	2.77	8.11	6.1	4.8	10	5.9	21.7	56	63	100	2.07	9.84	98	0.073	0.082	0.60	1.3	48
1/29/95	2.89	7.34	5.6	4.4	10	4.34	17.8	52	59	100	2.13	7.75	91	0.034	0.105	0.56	1.2	44
1/30/95	2.87	6.79	6.1	4.8	10	2.47	14.4	56	63	100	1.75	7.17	98	0.021	0.054	0.60	1.3	48
1/31/95	1.89	7.02	6.1	4.8	10	3.98	14.6	56	63	100	1.59	6.77	98	0.02	0.104	0.60	1.3	48
2/1/95		3.53	6.3	5.0	10		12.2	58	66	100		5.02	101		0.07	0.62	1.3	50
2/2/95		5.9	6.3	5.0	10		13.3	58	66	100		4.88	101		0.042	0.62	1.3	50
2/3/95		6.57	6.1	4.8	10		14.3	56	63	100		6.03	98		0.062	0.60	1.3	48
2/6/95	2.37	6.45	5.8	4.6	10	3.6	14.5	54	61	100	1.68	5.78	94	0.032	0.051	0.58	1.3	46
2/10/95	2.49	4.95			10	2.41	10.6			100	1.41	4.47		0.012	0.057			no data
2/14/95		5.07			10							4.65			0.056			no data
2/17/95		7.3			10							8.79			0.11			no data
2/21/95		4.99			10							4.16			0.048			no data
2/23/95		4.78			10							3.93			0.053			no data
2/24/95		4.08			10							3.9			0.057			no data
2/28/95		4.14			10							3.97			0.045			no data
3/3/95		4.75			10							4.44			0.066			no data
3/5/95		4.94			10							5.02			0.076			no data

Table 17 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Greene's Landing During Water Year 1995.

	COPPER					ZINC					CHROMIUM			CADMIUM				HARDNESS
DATE	D	T	C*	C#	O˙	D	T	C*	C#	O˙	D	T	C*#	D	T	C*	C#	
3/7/95		5.73			10							4.94			0.052			no data

D = Dissolved concentration (µg/l) following 0.45 µm filtration
T = Total recoverable concentration (µg/l)
C* = USEPA National Ambient Water Quality Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C# = USEPA Proposed California Toxics Rule Criteria to Protect Freshwater Aquatic Life (expressed as dissolved metal 4-day average criteria)
C† = California Proposition 65 Regulatory Level as Drinking Water Level
O˙ = Site-specific numeric water quality objective (hardness corrected when applicable) for the CVRWQCB Water Quality Control Plan. Objectives = diss. concentrations.

Table 17 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Greene's Landing During Water Year 1995.

DATE	NICKEL				LEAD			ARSENIC				HARDNESS
	D	T	C*	C#	D	T	C*#	D	T	C†	O*	
1/6/95	2.19	6.02	146	48	0.45	1.2	2.3	1.41	1.52	5	10	92
1/7/95	2.97	10.5	111	37	0.78	3.48	1.6		1.2	5	10	66
1/8/95	4.51	16	102	34	0.77	3.91	1.4	0.45	0.3	5	10	60
1/10/95	4.31	3.16	90	30	0.81	11.2	1.2	1.37		5	10	52
1/12/95	8.5	27.1	75	25	0.53	3.69	1.0	1.19	1.32	5	10	42
1/13/95	4.78	23.6	99	33	0.65	4.02	1.4	1.14	1.09	5	10	58
1/14/95	6.02	26.9	72	24	0.8	2.66	0.9	0.84	2.45	5	10	40
1/15/95	19.1	13.8	78	26	0.48	2.55	1.0	0.91	0.9	5	10	44
1/17/95	26	24.8	78	26	0.49	1.57	1.0	1.12	0.72	5	10	44
1/18/95	6.21	23.7			0.52	7.42		1.06	0.61	5	10	no data
1/20/95	6.33	18	84	28	0.54	2.05	1.1	1.07	1.2	5	10	48
1/22/95	3.75	16.2	93	31	0.4	1.75	1.3	1.36	1.4	5	10	54
1/23/95	4.45	13.1	87	29	0.43	3.24	1.2	1.09	1.22	5	10	50
1/24/95	3.46	11.8	96	32	0.36	1.55	1.3	1.25	1.07	5	10	56
1/25/95	4.07	12	93	31	0.4	2.11	1.3	1.14	1.52	5	10	54
1/26/95	4.34	17.4	87	29	0.35	1.83	1.2	1.25	1.59	5	10	50
1/27/95	4.06	16.2	84	28	0.46	2.28	1.1	1.18	1.08	5	10	48

Table 17 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Greene's Landing During Water Year 1995.

DATE	NICKEL				LEAD			ARSENIC				HARDNESS
	D	T	C*	C#	D	T	C*#	D	T	C†	O*	
1/28/95	4.34	15.7	84	28	0.41	2.06	1.1	1	1.24	5	10	48
1/29/95	3.95	10.8	78	26	0.34	1.63	1.0	1.22	1.13	5	10	44
1/30/95	3.11	11.3	84	28	0.24	1.04	1.1		1.18	5	10	48
1/31/95	2.99	10.6	84	28	0.37	1.04	1.1		1.54	5	10	48
2/1/95		6.61	87	29		1.08	1.2					50
2/2/95		5.92	87	29		0.86	1.2					50
2/3/95		8.45	84	28		1.33	1.1					48
2/6/95	2.44	8.63	81	27	0.25	1.11	1.1					46
2/10/95	2.15	7.1			0.18	0.63						no data
2/14/95		6.71				0.65						no data
2/17/95		12.3				1.08						no data
2/21/95		7.04				4.48						no data
2/23/95		6.31				1.56						no data
2/24/95		4.59				6.94						no data
2/28/95		5.85				1.16						no data
3/3/95		5.79				2.86						no data
3/5/95		6.56				0.96						no data

Table 17 (cont.). Summary of Metal Concentration Data and Related Water Quality Objectives for Samples Collected from the Sacramento River at Greene's Landing During Water Year 1995.

DATE	NICKEL				LEAD			ARSENIC				HARDNESS
	D	T	C*	C#	D	T	C*#	D	T	C†	O'	
3/7/95		6.18				1						no data

Table 18. Number of Dissolved Metal Analyses and Events When Water Quality Objectives or Criteria Were Exceeded for Stations Monitored in the Sacramento/San Joaquin River Delta during Water Years 1993-1995.

STATION	NUMBER OF ANALYSES FOR DISSOLVED METALS	NUMBER OF EVENTS WHEN WATER QUALITY OBJECTIVES/CRITERIA WERE EXCEEDED
Sacramento River @ Antioch	31	0
Duck Slough	34	0
French Camp Slough	14	0
Sacramento River @ Hood	57	0
Middle River @ Bullfrog Landing	28	0
Mokelumne River	25	0
Old River @ Tracy Blvd.	14	0
Paradise Cut	42	0
Prospect Slough	42	0
Sacramento River @ Rio Vista	61	0
Skag Slough	0	N/A
San Joaquin River @ Stockton	16	0
Ulatis Creek	7	0
San Joaquin River @ Vernalis	35	0
Greene's Landing	143	0
ALL STATIONS COMBINED	**549**	**0**

Table 19. Summary of 1993-1994 Toxicity Monitoring Results for the Sacramento/San Joaquin River Delta

Waterway Category	Ceriodaphnia		Selenastrum		Pimephales	
	# Events Exhibiting Toxicity (sample size)	Toxicity Related to (number of events):	# Events Exhibiting Toxicity• (sample size)	Toxicity Related to (number of events):	# Events Exhibiting Toxicity (sample size)	Toxicity Related to:
Main River Inputs into the Delta	2 (29)	diazinon (2) and unknown (1)	0 (26)	N/A	5 (25)	*
Island Drains	1 (49)	no TIE	0 (45)	N/A	2 (41)	*
Back-sloughs and Small Upland Drainages	10 (73)	chlorpyrifos (2)†, carbofuran (2)†, and unknown (9)	1 (65)	non-polar organic(1)	7 (62)	*
Urban Runoff Receiving Water	0 (10)	N/A	0 (9)	N/A	0 (8)	N/A
Points Along the Pathways of Water Movement Across the Delta	3 (76)	no TIE	0 (68)	N/A	3 (63)	*
Total Frequency	16 (237)		1 (213)		17 (199)	

• = "toxic" defined as significantly reduced cell counts relative to a laboratory control
† = linked to toxicity in fixed-date samples and follow-up samples
* = no TIEs conducted due to the chronic nature of the observed toxicity

Table 20. Summary of 1994-1995 Toxicity Monitoring Results for the Sacramento/San Joaquin River Delta

Waterway Category	Ceriodaphnia		Selenastrum		Pimephales	
	# Events Exhibiting Toxicity (sample size)	**Toxicity Related to (number of events):**	**# Events With Reduced Cell Count• (sample size):**	**Reduced Cell Count Related to (number of events):**	**# Events Exhibiting Toxicity (sample size)**	**Toxicity Related to:**
Main River Inputs into the Delta	2 (28)	unknown	6 (20)	unknown	(0) 14	N/A
Island Drains	1 (32)	carbaryl (1)	3 (8)	non-polar organic (1) and unknown (2)	(0) 1	N/A
Back-sloughs and Small Upland Drainages	17 (104)	chlorpyrifos (14)†, diazinon (3), metabolically activated pesticides (2), and unknown (8)	20 (72)	non-polar organic (2) and unknown	(0) 2	N/A
Urban Runoff Receiving Water	4 (7)	diazinon (5)† and chlorpyrifos (4)	1 (5)	no TIE(^)	N/A	N/A
Points Along the Pathways of Water Movement Across the Delta	0 (1)	N/A	4 (11)	unknown	N/A	N/A
Total Frequency	24 (172)		29 (116)		(0) 17	

(^) = Storm water studies indicate toxicity to algae at Mosher Slough is partially caused by diuron and unknown chemicals
• : cell counts reduced relative to other ambient station sampled on same day
† -- linked to toxicity in fixed-date samples and follow-up samples

Table 21. Summary of Dissolved Metal Analyses from Samples Collected from 1993 through 1995 and Relationship to Documented Effects in the Literature

				Documented Effects in the Literature# at Highest Metal Concentrations Measured in this Study		
Metal	**Average Conc. (ppb)**	**Range (ppb)**	**Location of Highest Concentration**	**Fish**	**Invertebrates**	**Algae**
Copper	2.64	0.2-9.48	Greene's Landing	Yes	Yes	Yes
Zinc	4.39	0.16-70.2	5-mile	Yes	Yes	Yes
Chromium	1.34	0.06-5.39	Duck Slough	Yes	Yes	Yes
Lead	0.31	0.01-3.87	5-mile	Yes	Yes	No
Cadmium	0.03	0.001-0.55	Greene's Landing	Yes	Yes	No
Nickel	2.72	0.13-26	Greene's Landing	No	Yes	Yes
Arsenic	1.28	0.13-3.03	5-mile	No	Yes	Yes

= See Tables 22-42 for description of effect, species exposed, and literature reference.

Table 22. Summary of lead concentrations reported to have adverse effects on sensitive freshwater algal and diatom species

Species name	Chemical	Duration or test type	Effect/Endpoint	Concentration (µg/L) *	Reference	Where cited
Chlorella rubescens, green algae	lead	IC50	changes in abundance, growth, biochemical process	between 5 and 10	C. E. Calderon Llanten & H. Greppin, 1993. Ref. No. 16488	2
Chlorella pyrenodiosa, green algae	lead	4 d	change in cell number	10.35	J. L. Stauber & T. M. Florence, 1987. Ref. No. 12971	2
Aulosira fertilissima, blue-green algae	lead acetate	7 d	change in biochemical process	20.7	E.F. Shabana et al., 1986. Ref. No. 3385	2
Anabaena sp., blue green algae	lead nitrate	20 d	change in cell number	21	V. M. Laube et al., 1980. Ref. No. 9477	1, 2
Scenedesmus quadricauda, green algae	lead acetate	14 d	change in chlorophyll content	80	M. Pawlaczyk-Szpilowa et al., 1972. Ref. No. 2741	2
Haematococcus capensis, green algae	lead acetate	7 d	change in cell number	100	T. C. Hutchinson, 1973. Ref. No. 8864	2
Hydrodictyon reticulatum, green algae	lead	7 d	change in biomass	100	U. N. Rai & P. Chandra, 1992. Ref. No. 8987	2
Phytoplankton, mixed freshwater species	lead acetate	4 d	change in biomass	100	K. Pietilainen, 1975. Ref. No. 8184	2
Pediastrum tetras, green algae	lead		change in population size	200	M. Wettern et al., 1976. Ref. No. 10082	2
Chlamydomonas reinhardtii, green algae	lead chloride	1 d	change in chlorophyll content	207	U. Irmer, et al., 1986. Ref. No. 12272	2
Selenastrum capricornutum, green algae	lead nitrate	1 d	changes in cell number, physiology	207	S. Capelo et al., 1993. Ref. No. 4063	2
Anasystis aeruginosa, blue-green algae	lead acetate		mortality	250	G. Bringmann & R. Kuhn, 1978. Ref. No. 2463	2
Scenedesmus acuminatus, green algae	lead	6 d	EC50 for change in population size	250	P. M. Stokes, 1981. Ref. No. 9501	2
Scenedesmus obtusiusculus, green algae	lead chloride	7 d	35% growth inhibition	500	T. J. Monahan, 1976	1, 2
Micrasterias thomasiana, green algae	lead chloride	2 hr	histological alteration	621	U. Meindl & G. Roderer, 1990. Ref. No. 3151	2

1 - Cited in Lead Criteria Document 1984 (USEPA, 1985A); 2 - Cited in USEPA AQUIRE Database

* Concentration is amount of lead in solution (eg., not as lead acetate); shaded row indicates species used in US EPA Three Species toxicity test protocols

EC50 - median effective concentration; IC50 - mean inhibitory concentration (for growth or a physiological process)

Table 23. Summary of lead concentrations reported to have adverse effects on sensitive freshwater invertebrate species

Species name	Chemical	Duration or test type	Effect/Endpoint	Concentration (mg/L)	Reference	Where cited
Tetrahymena pyriformis, ciliate	lead chloride	4 min	change in oxygen uptake	0.75	J. L. Slabbert & W. S. G. Morgan, 1982. Ref. No. 11048	2
Hyalella azteca, amphipod	lead	70 d	mortality	2.6	U. Borgmann et al, 1993. Ref. No. 9248	2
Asellus aquaticus, aquatic sowbug	lead nitrate	16 d	LT50	10	L. Migliore & M. De Nicola Giudici, 1990. Ref. No. 10515	2
Lymnaea palustris, marsh snail (freshwater)	lead nitrate	133 d	mortality	12	U. Borgmann et al., 1978. Ref. No. 8314	2
Daphnia magna, water flea	lead acetate	1.7 d	change in biochemical processes	16	R. Berglind et al., 1985. Ref. No. 10906	2
Aeshna cyanea, blue-green dragonfly larvae	lead nitrate	42 d	enzyme alterations	20	W. Meyer et al., 1986. Ref. No. 12306	2
Astacus astacus, European crayfish	lead	14 d	changes in enzymes, histological damage	20	W. Meyer et al., 1991. Ref. No. 376	2
Libuella depressa, dragonfly	lead nitrate	42 d	enzyme alterations	20	W. Meyer et al., 1986. Ref. No. 12306	2
Libuella quadrimaculata, common skimmer dragonfly	lead nitrate	42 d	enzyme alterations	20	W. Meyer et al., 1986. Ref. No. 12306	2
Neanthes arenaceodentata, polychaete	lead chloride	183 d	LOEC for reproductive alterations	20	D. J. Reish & T. V. Gerlinger, 1984. Ref. No. 4007	2
Tubifex tubifex, tubificid worm	lead nitrate	4 d	EC50 for immobilization	42	B. S. Khangarot, 1991. Ref. No. 2918	2
Anodonta grandis, freshwater mussel	lead nitrate	28 d	changes in growth, DNA	50	M. C. Black et al., 1996. Ref. No. 16859	2
Anopheles stephensi, mosquito	lead acetate	1 d	genetic alteration	60	G. P. Sharma et al., 1988. Ref. No. 5315	2
Caenorhabditis elegans, nematode	lead nitrate	4 d	LC50	60	P. L. Williams & D. B. Dusenbery, 1990. Ref. No. 3437	2
Ceriodaphnia dubia, water flea	lead nitrate	2 d	LC50	248	R. L. Spehar & J. T. Fiandt, 1986. Ref. No. 12093	2

2 - Cited in USEPA AQUIRE database

* Concentration is amount of lead in solution (eg., not as lead acetate); shaded row indicates species used in US EPA Three Species toxicity test protocols

EC50 - median effective concentration; LC50 - median lethal concentration; LOEC - Lowest observable effect concentration; LT50 - median survival time

Table 24. Summary of lead concentrations reported to have adverse effects on sensitive freshwater fish species

Species name	Chemical	Duration or test type	Effect/Endpoint	Concentration (µg/L)	Reference	Where cited
Gasterosteus aculeatus , three-spine stickleback	lead nitrate	4.75	LT50	0.2	J. R. E. Jones, 1938. Ref. No. 2657	2
Phoxinus phoxinus, minnow	lead nitrate	21 d	mortality	0.5	J. R. E. Jones, 1938. Ref. No. 2657	2
Cyprinus carpio, common carp	lead nitrate	20 d	enzyme alterations	1.1	H. Nakagawa et al., 1995. Ref. No. 16750	2
Heteropneustes fossilis, Indian catfish	lead nitrate	60 d	changes in enzymes, biochemical processes	6	K. C. Singhal, 1994. Ref. no 4448	2
Salmo gairdneri, rainbow trout	lead nitrate	18 min.	physical abnormality	7.2	P. H. Davies et al., 1976. Ref. No. 2103	2
Carassius auratus, goldfish	lead nitrate	4.75 d	physiological change	8	J. R. E. Jones, 1938. Ref. No. 2657	2
Pimephales promelas, fathead minnow	lead nitrate	2.94 d	LT50	10	E. K. Biegert & V. Valkovic. Ref. No. 5302	2
Salvelinus fontinalis, brook trout	lead	21 d	impaired locomotion	14.3	E. S. Adams, 1975. Ref. No. 15675	2
Salmo salar, Atlantic salmon	lead nitrate	15.8 d	change in hatching success	17.2	M. Grande & S. Andersen, 1983. Ref. No. 10982	2
Brachydanio rerio, zebrafish	lead acetate	16 d	no observable effect on hatching	20	G. Dave & R. Xiu, 1991. Ref. No. 3680	2
Barbus conchonius, rosy barb	lead nitrate	30 d	change in biochemical process	47.4	H. Tewari et al., 1987. Ref. No. 12599	2
Salvelinus namaycush , lake trout	lead nitrate	115 d	mortality	48	S. Sauter, et al., 1976. Ref. No. 8439	2
Lepomis macrochirus, bluegill	lead nitrate	62 d	mortality	70	S. Sauter, et al., 1976. Ref. No. 8439	2
Tilapia aurea, tilapia	lead chloride	1 d	changes in biochemical, blood parameters	100	P. Allen, 1993. Ref. No. 16833	2
Ictalurus punctatus, channel catfish	lead nitrate	68 d	mortality	75	S. Sauter, et al., 1976. Ref. No. 8439	2

1 - Cited in Lead Criteria Document 1984 (USEPA, 1985); 2 - Cited in USEPA AQUIRE Database

* Concentration is amount of lead in solution (eg., not as lead acetate); shaded row indicates species used in US EPA Three Species toxicity test protocols

LC50 - median lethal concentration; LT50 - median time for 50% survival

Table 25. Summary of arsenic concentrations reported to have adverse effects on sensitive species of freshwater algae

Species name	Chemical	Duration or test type	Effect/Endpoint	Concentration (mg/L)	Reference	Where cited
Phytoplankton, freshwater species	arsenic acid, sodium salt	109 d	EC50 for change in photosynthetic productivity	1.5	S. A. Wangberg et al., 1991. Ref. No. 9419	2
Scenedesmus obliquus, green algae	arsenic acid, disodium salt	1 hr	change in photosynthetic productivity	48	O. Hofslagare et al., 1994. Ref. No. 16290	2
Clorella vulgaris, green algae	arsenic acid, disodium salt	91 d	LOEC for population growth	60	L. E. Den Dooren de Jong, 1965. Ref. No. 2849	2
Chlamydomonas sp ., green algae	arsenic acid, disodium salt	28 d	change in population growth	75	E. R. Christensen & P. A. Zielski, Ref. No. 9773	2
Melosira granulata, diatom	arsenic acid, trisodium salt	20 d	change in population growth	75	D. Planas & F. P. Healey, 1978. Ref. No. 7146	1, 2
Ochromonas vallesiaca, phytoplankton	sodium arsenate		decreased growth	75	D. Planas & F. P. Healey, 1978.	1
Ankistrodesmus falcatus, green algae	arsenic acid, disodium salt	14 d	EC50 for growth	256	Vocke et al., 1980. Ref. No. 5342	1, 2
Spirogyra sp ., green algae	arsenic oxide	1.83 d	physiological change	300	E. W. Surber & O. L. Meehan, 1931. Ref. No. 10297	2
Selenastrum capricornutum, green algae	arsenic acid, trisodium salt	4 d	EC50 for population growth	690	J. E. Richter, 1982	1, 2
Gloetaenium loitesbergeri, green algae	arsenic acid, sodium salt	1.54 d	physiological change	800	P. V. D. Prasad & Y. B. K. Chowdary, 1981. Ref. No. 15634	2
Nostoc sp ., blue-green algae	arsenic acid, disodium salt	32 d	change in biomass	1000	S. Maeda et al., 1987. Ref. No. 13296	2
Scenesemus quadricauda, green algae	arsenic acid, disodium salt	7 d	change in population growth	2100	G. Bringmann & R. Kuhn, 1980. Ref. No. 5303	2
Chlamydomonas reinhardtii, green algae	arsenic acid, trisodium salt	20 d	change in population growth	2300	D. Planas & F. P. Healey, 1978. Ref. No. 7146	1, 2
Cladophora sp ., green algae	arsenous acid, sodium salt	14 d	100% mortality	2320	B. C. Cowell, 1965.	1
Zygnema sp ., green algae	arsenous acid, sodium salt	14 d	100% mortality	2320	B. C. Cowell, 1965.	1

1 - Cited in Arsenic Criteria Document 1984 (USEPA, 1985B); 2 - Cited in USEPA AQUIRE Database

* Concentration is amount of arsenic in solution (eg., not as arsenic acid salt); shaded row indicates species used in US EPA Three Species toxicity test protocols

EC50 - median effective concentration; LOEC - lowest observable effect concentration

Table 26. Summary of arsenic concentrations reported to have adverse effects on sensitive species of freshwater invertebrates

Species name	Chemical	Duration or test type	Effect/Endpoint	Concentration (mg/L)	Reference	Where cited
Daphnia pulex, water flea	arsenic oxide	1 d	EC50 for immobilization	0.5	H. Lilius et al., 1995. Ref. No. 16385	2
Chironomidae, midge species	arsenic oxide	2 d	mortality	8	E. W. Surber & O. L. Meehan, 1931. Ref. No. 10297	2
Bosmina longirostris, water flea	arsenic acid, sodium salt	4 d	EC50 for immobilization	10	A. Novak et al., 1980. Ref. No. 2210	2
Caenis diminuta, mayfly larvae	arsenic oxide	2 d	mortality	16	E. W. Surber & O. L. Meehan, 1931. Ref. No. 10297	2
Tetrahymena pyriformis, ciliate	arsenic oxide	4.3 min.	change in oxygen uptake	25	J. L. Slabbert & J. P. Maree, 1986. Ref. No. 12836	2
Paramecium sp ., ciliate	arsenic oxide	2.5 d	change in rate of growth	80	E. W. Surber & O. L. Meehan, 1931. Ref. No. 10297	2
Gammarus pseudolimnaeus, amphipod	arsenic oxide	14 d	mortality	88	R. L. Spehar et al., 1980. Ref. No. 9783	2
Moina macropa, water flea	arsenic acid, disodium salt	7 d	mortality, changes in growth, reproduction	100	S. Maeda et al., 1990. Ref. No. 3118	2
Belestoma elegans, water bug	arsenic oxide	1 d	mortality	100	M. E. Lanzer-DeSouza & N. M. M. DaSilva, 1988. Ref. No. 13488	2
Hyalella knickerbockeri, amphipod	arsenic oxide	2 d	mortality	800	E. W. Surber & O. L. Meehan, 1931. Ref. No. 10297	2
Simodephalus serrulatus, water flea	arsenous acid, sodium salt	acute test	LC50	812	H. O. Sanders & O. B. Cope, 1966.	1
Daphnia magna, water flea	arsenic pentoxide	14 d	mortality, altered reproduction	932	R. L. Spehar et al., 1980. Ref. No. 9783	2
Helisoma campanulatum, ramshorn snail	arsenic oxide	28 d	mortality	961	R. L. Spehar et al., 1980. Ref. No. 9783	2
Lymnaea emarginata, pond snail	arsenic oxide	28 d	mortality	961	R. L. Spehar et al., 1980. Ref. No. 9783	2
***Ceriodaphnia dubia*, water flea**	**arsenic acid, sodium salt**	**8 d**	**altered reproduction**	**1020 ***	**R. B. Naddy et al., 1995. Ref. No. 13729**	**2**

1 - Cited in Arsenic Criteria Document 1984 (USEPA, 1985B); 2 - Cited in USEPA AQUIRE Database

EC50 - median effective concentration

* Concentration is amount of arsenic in solution (eg., not as arsenic acid salt); shaded row indicates species used in US EPA Three Species toxicity test protocols

Table 27. Summary of arsenic concentrations reported to have adverse effects on sensitive freshwater fishes

Species name	Chemical	Duration or test type	Effect/Endpoint	Concentration (µg/L)	Reference	Where cited
Oncorhynchus mykiss, rainbow trout	arsenic acid	1 d	physiological change	25	A. A. Oladimeji, 1984. Ref. No. 10888	2
Morone saxatilis, striped bass larvae	arsenic acid, sodium salt	21 d	mortality	80	R. J. Klauda, 1985. Ref. No. 4233	2
Carassius aratus, goldfish	arsenic acid, monosodium salt	2 d	behavioral change	100	P. A. Weir & C. H. Hine, 1970. Ref. No. 908	2
Lepomis cyanellus, green sunfish	arsenic acid, disodium salt	2 d	LC50	150	E. M. B. Sorensen, 1976. Ref. No. 5549	2
Oncorhynchus kisutch, coho salmon parr	arsenic oxide	183 d	mortality, change in growth & physiology	300	J. W. Nichols et al., 1984. Ref. No. 10236	2
Anabas testudineus, climbing perch	arsenic acid, disodium salt	12 hr	mortality	488	S. Jana & S. S. Sahana, 1989. Ref. No. 2618	2
Clarias batrachus, walking catfish	arsenic acid, disodium salt	13 hr	mortality	488	S. Jana & S. S. Sahana, 1989. Ref. No. 2618	2
Pimephales promelas, fathead minnow	arsenic pentoxide	30 d	change in growth	530	D. L. DeFoe, 1982. Ref. No. 3687	2
Oncorhynchus mykiss, rainbow trout	arsenic acid, disodium salt	77 d	mortality	1400	S. M. McGreachy & D. G. Dixon, 1990. Ref. No. 273	2
Channa punctatus, snake-head catfish	arsenic acid, disodium salt	28 d	physiological change	1000	K. Ghosh & S. Jana, 1968. Ref. No. 814	2
Colisa fasciata, giant gourami	arsenic oxide	30 d	change in biological process	1500	J. P. Shukla & K. Pandey, 1985. Ref. No. 11412	2
Heteropneustes fossilis, Indian catfish	arsenic oxide	30 d	change in biological process	1500	J. P. Shukla et al., 1985. Ref. No. 11345	2
Jordanella floridae, flagfish ELS	arsenous acid, sodium salt		chronic test	2962	Call et al., 1983; Lima et al., 1984	1
Phoxinus phoxinus, minnow	arsenic acid, disodium salt	65 d	change in biomass of organism	2500	R. Reuther, 1992. Ref. No. 6229	2
Thymallus arcticus, arctic grayling	arsenic acid, disodium salt	4 d	LC50	4760	K. J. Buhl & S. J. Hamilton, 1990. Ref. No. 334	2
Lepomis macrochirus, bluegill larvae	arsenic oxide	1 d	obvious stress on physiology or behavior	5000	V. C. Applegate et al., 1957. Ref No. 638	2

1 - Cited in Arsenic Criteria Document 1984 (USEPA, 1985B); 2 - Cited in USEPA AQUIRE Database

ELS - early life stage; LC50 - median lethal concentration

* Concentration is amount of arsenic in solution (eg., not as arsenic acid salt); shaded row indicates species used in US EPA Three Species toxicity test protocols

Table 28. Summary of chromium concentrations reported to have adverse effects on sensitive freshwater algal and diatom species

Species Name	Chemical	Duration (days) or test type	Effect/ Endpoint	Concentration (ug/L)	Reference	Where Cited
Microcystis aeroginosa, blue algae	Sodium dichromate (Cr VI)	NR	incipient inhibition	2	Bringmann, 1975. Ref. no. 15144	2
Anabaena orzae, blue green algae	Chromic chloride (Cr III)	7	change in biomass	5.2	Shabana et al., 1986. Ref. no. 3385	2
Aulosira fertilissama, blue green algae	Chromium	7	change in population growth	5.2	Shabana at al., 1986. Ref. no. 3046	2
Chlamydomonis reinhardi, green algae	Potassium dichromate (Cr VI)	NR	reduction in growth	10	Zarafonetis & Hampton, 1974.	1
Selenastrum capricornutum, green algae	Chromium	0.17	change in photosynthesis	20	Pillard et al., 1987. Ref. no. 12639	2
Thalassiosira guillardi, diatom	Chromium	2	change in population growth	20	Wilson & Freeburg, 1980. Ref. no. 5557	2
Hydrodictyon reticulatum, green algae	Chromium	0.5	change in biomass	100	Rai & Chandra, 1989. Ref. no. 3348	2
Scenedesmus quadricauda, green algae	Chromium oxide (Cr III)	30	change in biochemical processes	100	Angadi & Mathad, 1994. Ref. no. 17433	2
Nitzschia palea, diatom	Chromium	4	change in population growth	150	Wium-Anderson, 1974. Ref. no. 15144	2
Navicula seminuium, diatom	Potassium dichromate (Cr VI)	NR	50% growth reduction	187	Academy of Natural Sciences, 1960	1
Nitzschia linearis, diatom	Potassium dichromate (Cr VI)	5	LC50	208	Patrick et. al., 1968	1
Cyclotella meneghiniana, diatom	Potassium dichromate (Cr VI)	NR	growth inhibition	500	Cairns and Sheier, 1968	1
Ditylum brightwelli, diatom	Chromium chloride (Cr III)	5	change in population size	2000	Canterford & Canterford, 1980. Ref. No. 6405	2
Synechocyotis aquatilis, blue-green algae	Chromium	NR	change in population growth	3000	Shavrina & Gapochka, 1984. Ref. No. 11620	2
Chlorella pyrenoidosa, green algae	Chromium	0.17	change in photosynthesis	5000	Wium-Andersen, 1974. Ref. No.15144	2

1 - Cited in Chromium Criteria Document 1984 (USEPA, 1985C); 2 - Cited in USEPA AQUIRE Database; NR = not reported in AQUIRE database

* Concentration is amount of chromium in solution; shaded row indicates species used in US EPA Three Species toxicity test protocols

Table 29. Summary of chromium concentrations reported to have adverse effects on sensitive species of freshwater invertebrates

Species Name	Chemical	Duration (days) or test type	Effect/ Endpoint	Concentration (ug/L)	Reference	Where Cited
Euglena gracilis, flagellate euglenoid	Chromium oxide (Cr III)	0.13	mortality	1	Yonge, Berrent, & Cairns, 1979. Ref. no. 15029	2
Daphnia magna, water flea	Chromium (3+) salt	1	LC50	13	Dowden & Bennett, 1965. Ref. no. 915	2
Glenodium halli, dinoflagellate	Chromium	2	change in population growth	20	Wilson & Freeburg, 1980. Ref. no. 5557	2
Tetrahymena pyriformis, ciliate	Chromium nitrate (Cr III)	0.003	change in oxygen consumption	25	Slabbert & Maree, 1986. Ref. no. 12836	2
Simocephalus vetulas, water flea	Sodium dichromate (Cr VI)	NR	LC50	32.3	Mount, 1982	1
Daphnia pulex, water flea	Sodium dichromate (Cr VI)	NR	LC50	36.3	Mount, 1982	11
Anodonta imbeccillis, mussel	Chromium	4	LC50	39	Keller & Zam, 1991. Ref. no. 108	2
Simocephalus serrulatus, cladoceran	Sodium dichromate (Cr VI)	NR	LC50	40.9	Mount, 1982	1
Ceriodaphnia reticulata, water flea	Chromium	2	LC50	45	Mount & Norberg, 1984. Ref. no. 11181	2
Dugesia dorotocephala, turbellarian	Chromium	0.042	change in behavior	50	Kapu & Schaeffer, 1991. Ref. no. 10582	2
Gymnodium splendons, dinoflagellate	Chromium	2	change in population growth	50	Wilson & Freeburg, 1980. REf. no. 5557	2
Grammararus pseuolimnaeus, amphipod	Potassium dichromate (Cr VI)	NR	LC50	67.1	Call et al., 1983	1
Austropotamobius pallipes, crayfish	Chromium chloride (Cr III)	4	LC50	390	Vareille-Morel & Chaisemartin, 1982. Ref. no. 15732	2
Hyallella azteca, amphipod	Potassium chromate (Cr VI)	NR	LC50	650	Pardue & Wood, 1980. Ref. No. 6703	2
Plumatella emarginata, bryozoan	Chromium	4	LC50	650	Pardue & Wood, 1980. Ref. No. 6703	2

1 - Cited in Chromium Criteria Document 1984 (USEPA, 1985C); 2 - Cited in USEPA AQUIRE Database; NR = not reported in AQUIRE database
* Concentration is amount of chromium in solution; shaded row indicates species used in US EPA Three Species toxicity test protocols

Table 30. Summary of chromium concentrations reported to have adverse effects on sensitive freshwater fish species

Species Name	Chemical	Duration (days) or test type	Effect/ Endpoint	Concentration (ug/L)	Reference	Where Cited
Carassius aurates giblio, carp	Chromic chloride (Cr III)	9	cytogenetic changes	0.05	Al-Sabti et al., 1994. Ref. no. 2851	2
Ctenopharyngodon idella, grass carp	Chromium	NR	change in rate of growth	1.5	Mao and Wang, 1990. Ref. no. 9540	2
Heteropneustes fossilis, Indian catfish	Chromium	20	change in rate of growth	10	Pandey and Nisha, 1984. Ref. no 2388	2
Pimephales promeles, fathead minnow	Chromic chloride (Cr III)	30	mortality	43	Gendusa, 1990. Ref. no. 4087	2
Salmo gairdner, rainbow trout	Cromic nitrate (Cr III)	NR	Chronic value	68.63	Stevens and Chapman, 1984	1
Ictalurus punctatus, Channel catfish	Chromic chloride (Cr III)	30	mortality	154	Gendusa, 1991. Ref. no. 4087	2
Oncorhynchus tshawtscha, Chinook salmon	Chromium potassium salt (Cr IV)	84	mortality	200	Olson, 1958. Ref. no. 14123	2
Salvelinus fontinalis, brook trout	Sodium dichromate (CrVI)	NR	LC50	364.6	Benoit, 1976. Ref. no. 4943	2
Oncorhynchus kisutch, Coho Salmon	Sodium dichromate (CrVI)	14	Immuno-suppression	470	Sugatt, 1980.	1
Carassius auratus, goldfish	Chromium	7	LC50	660	Birge, Black and Westerman, 1979. Ref.no. 4943	2
Micropterus salmoides, largemouth bass	Chromic oxide (Cr III)	8	LC50	1170	Birge et al., 1978. Ref. no. 6199	2
Gasterosteus aculeatus, three spine stickleback	Chromium (3+) salt	10	mortality	1200	Jones, 1939. Ref. no. 2851	2
Tilapia sp., tilapia	Chromic chloride (Cr III)	56	change in rate of growth	1760	Shiau and Lin, 1993. Ref. no. 14617	2
Channa punctatus, snake-head catfish	Chromium	7	LC50	2000	Jana & Bandyopandhyaya, 1988. Ref. no. 13211	2
Poecilia reticulata, guppy	Chromic potassium sulfate (Cr III)	4	LC50	3330	Pickering and Henderson, 1964. Ref. no. 2033	2

1 - Cited in Chromium Criteria Document 1984 (USEPA, 1985C); 2 - Cited in USEPA AQUIRE Database; NR = not reported in AQUIRE database
* Concentration is amount of chromium in solution; shaded row indicates species used in US EPA Three Species toxicity test protocols

Table 31. Summary of nickel concentrations reported to have adverse effects on sensitive freshwater algal and diatom species

Species Name	Chemical	Duration (days) or test type	Effect/ Endpoint	Concentration (ug/L)	Reference	Where Cited
Anancystis aeruginosa, blue-green algae	Nickelous chloride	8	unreported mortality	1.2	Bringmann & Kuhn, 1978. Ref. no. 2463	2
Microcystis aeruginosa, blue-green algae	Nickel chloride	8	incipient inhibition	5	Bringmann & Kuhn, 1978	1
Selenastrum capricornutum, green algae	Nickelous chloride	4	EC50, change in growth	6.3	Bermingham, Van Coillie & Vasseur, 1986. Ref. no. 12748	2
Clamydomonas reinhardtii, green algae	Nickelous chloride	7	EC30, change in abundance	6.7	Welbourn, 1994. Ref. no. 13711	2
Chlorella vulgaris, green algae	Nickelous nitrate	91.3	NOEC, population growth	6.9	Den Dooren Jong, 1965. Ref. no. 2849	2
Anacystis nidulans, blue-green algae	Nickel (2+) salt	0.25	change in photosynthesis	10	Azeez & Banerjee, 1987. Ref. no. 12558	2
Chlorella pyrenoidosa, green algae	Nickel	4	change in population growth	10	Stauber & Florence, 1987. Ref. no. 12971	2
Spirulina platensis, blue-green algae	Nickel (2+) salt	0.25	change in photosynthesis	10	Azeez & Banerjee, 1987. Ref. no. 12558	2
Anabaena cylindrica, blue-green algae	Nickel sulfate	5	13% reduction in doubling time	15.1	Daday et al., 1985	1
Thalassioria guillardii, diatom	Nickel	2	change in population growth	50	Wilson & Freeburg, 1980. Ref. no. 5557	2
Nostoc linckia, blue-green algae	Nickelous chloride	1	change in biochemical processes	50	Kumar & Kumar, 1985. Ref. no. 11511	2
Scenedesmus acuminata, green algae	Nickel nitrate	12	54% reduction in growth	50	Hutchinson & Stokes, 1975.	1
Navicula pelliculosa, diatom	Nickelous nitrate	7	change in population growth	100	Fezy , Spencer & Greene, 1979. Ref. no. 8347	2
Ankistrodesmus falcatus, green algae	Nickelous nitrate	14	change in biomass	100	Spencer & Greene, 1981. Ref. no. 15439	2
Pediastrum tetras, green algae	Nickelous nitrate	14	change in biomass	100	Spencer & Greene, 1981. Ref. no. 15439	2

1 - Cited in Nickel Criteria Document 1986; 2 - Cited in USEPA AQUIRE Database

* Concentration is amount of nickel in solution; shaded row indicates species used in US EPA Three Species toxicity test protocols

Table 32. Summary of nickel concentrations reported to have adverse effects on sensitive species of freshwater invertebrates

Species Name	Chemical	Duration (days) or test type	Effect/ Endpoint	Concentration (ug/L)	Reference	Where Cited
Ceriodaphnia dubia, water flea	Nickelous nitrate	7	unspecified mortality	3.8	Kszos, Stewart & Taylor, 1992. Ref. no. 5920	2
Culex pipiens, mosquito	Nickelous chloride	7.29	ET50 , emergence from larvae to adult	4.5	Suzuki, 1959. Ref. no. 2701	2
Tubifex tubifex, tubificid worm	Nickel sulfate	2	LC50	7	Brkovic-Popovic and Popovic, 1977	1
Asellus aquaticus, aquatic sowbug	Nickelous chloride	27	LC50	10	Migliore & Guidici, 1990. Ref. no. 10515	2
Moina macrocopa, water flea	Nickelous chloride	8.5	LC50	10	Wong, 1993. REf. no. 6973	2
Daphnia magna, water flea	Nickelous chloride	42	mortality	40	Munziger, 1990. Ref. no. 3063	2
Uronema pardnez, protozoan	Nickel chloride	0.833	incipient inhibition	42	Bringmann and Kuhn, 1981	1
Microregma heterostoma, paramecium	Nickel chloride	1.16	incipient inhibition	50	Bringmann & Kuhn, 1959b	1
Biophalaria glabrata, snail	Nickel (2+) salt	1	physiological stress observed	100	Harry & Aldrich, 1963. Ref. no. 2853	2
Entosiphon sulcatum, flagellate euglenoid	Nickelous chloride	3	change in population growth	140	Bringmann and Kuhn, 1980. Ref. no. 5303	2
Anocystis imbecillis, mussel	Nickel (2+) salt	4	LC50	190	Keller & Zam, 1991. Ref. no. 108	2
Chilomas paramecium, cryptomonad	Nickelous chloride	2	change in population growth	200	Bringham, Kuhn & Winter, 1980. Ref. no. 5719	2
Juga plicifera, snail	Nickelous chloride	21	LC50	204	Chapmen, 1986. Ref. no. 11982	2
Orconectes limosus, crayfish	Nickelous chloride	30	LC50	450	Boutet & Chaisemartin, 1973. Ref. no. 5421	2
Daphnia pulicaria, water flea	Nickel	2	LC50	697	Lind, Alto & Chatterton, 1978. Ref. no. 5081	2

1 - Cited in Nickel Criteria Document 1986; 2 - Cited in USEPA AQUIRE Database

* Concentration is amount of nickel in solution; shaded row indicates species used in US EPA Three Species toxicity test protocols

Table 33. Summary of nickel concentrations reported to have adverse effects on sensitive freshwater fishes

Species Name	Chemical	Duration (days) or test type	Effect/ Endpoint	Concentration (ug/L)	Reference	Where Cited
Salmo gairdner, rainbow trout	Nickel chloride	early life stage	Chronic value	<35	Nebeker et al. 1985	1
Lepomis macrochirus, bluegill	Tetracyanonickel	>0.42	acute mortality	75	Broderius, T.C. 1973. Ref. no. 8778	2
Salmo salar, atlantic salmon	Nickelous nitrate	<100	unspecified mortality	104	Grande & Anderson, 1983. Ref. no. 10982	2
Pimephales promeles, fathead minnow	Nickel	30	unspecified mortality	433.5	Lind, Alto & Chatterton, 1978. Ref. no. 5081	2
Ictalurus punctatus, Channel catfish	Nickel chloride	7	EC50	710	Birge et al., 1981	1
Cyprinus carpio, common carp	Nickel sulfate	10.7	LC50	750	Blaylock & Frank, 1979	1
Gasterosteus aculeatus, three spine stickleback	Nickelous nitrate	10	100% mortality	800	Jones, 1939. Ref. no. 2851	2
Oncorhynchus mykiss, rainbow trout	Nickel (2+) salt	0.021	impaired reproduction	1000	Shaw & Brown, 1971. Ref. no. 9428	2
Tilapia nilotica, Nile tilapia	Nickelous chloride	4	change in behavior	1500	Alkahem, 1994. Ref. no. 16861	2
Micropterus salmoides, largemouth bass	Nickelous chloride	8	LC50	2020	Birge et al., 1978. Ref. no. 6199	2
Carassius auratus, goldfish	Nickelous chloride	7	LC50	2140	Birge, 1978. Ref. no. 5305	2
Ambloplites rupestris, rock bass	Nickel	4	LC50	2480	Lind, Alto, & Chatterton, 1978. Ref. no. 5081	2
Morone saxatilis, stripped bass	Nickelous chloride	4	LC50	3900	Palawski, Hunn & Dwyer, 1985. Ref. no. 11334	2
Poecilia reticulata, guppy	Nickelous chloride	4	LC50	4450	Pickering & Henderson, 1960. Ref. no. 2033	2
Oncorynchus kisutch, Coho salmon	Nickel (2+) salt	14	unspecified mortality	4500	Becker & Wolford, 1980. Ref. no. 478	2

1 - Cited in Nickel Criteria Document 1986; 2 - Cited in USEPA AQUIRE Database

* Concentration is amount of nickel in solution; shaded row indicates species used in US EPA Three Species toxicity test protocols

Table 34. Summary of copper concentrations reported to have adverse effects on 15 freshwater fish species

Species Name	Chemical	Duration or test type[1]	Effect/ Endpoint	Concentration (µg/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Salmo gairdneri * (fry) rainbow trout		1 hr	avoidance	0.1		Folmar, 1976	3
Ictalurus fontinalis channel catfish			Increased albinism	0.5		Westerman & Birge, 1978	3
Oncorhynchus Mykiss steelhead trout		4	Increased susceptibility to *Yersinia ruckeri* infection	2	30-60	Knittel, 1980	
Thymallus arcticus arctic grayling	copper sulfate	4	LC 50-MOR	2.58	41.3	Buhl & Hamilton, 1990	1
Salvelinus fontinalis brook trout	copper sulfate	ELS	Chronic value	3.873	37.5	Sauter *et al.*, 1976	3
Salmo gairdneri * (fry) rainbow trout	copper spiked ambeint water (pH = 6.0)	168 hr	LC 50	5.1	38 +/- 3	Welsh *et al.*, 1998	
Pimephales promelas fathead minnow	copper nitrate	32	MATC	6.2	43.9	Spehar & Fiandt, 1986	2
Oncorhynchus tshawytscha chinook salmon	copper chloride	ELS	Chronic value	<7.4		Chapman, 1975, 1982	3
Pimephales notatus bluntnose minnow	copper sulfate	LC	Chronic value	8.793	194	Horning & Neiheisel, 1979	3
Oncorhynchus tshawytscha chinook salmon	ambient mixed waste (including Cu)	96 hr	LC 50	13 +/- 3	39-40	Finlayson & Wilson, 1989	
Oncorhynchus Mykiss steelhead trout	ambient mixed waste (including Cu)	96 hr	LC 50	14 +/- 4	39-40	Finlayson & Wilson, 1989	
Oncorhynchus kisutch coho salmon	copper sulfate	4	LC50 MOR	15.1	41.3	Buhl. & Hamilton, 1990	2
Salmo clarki cutthroat trout	copper chloride		LC50 or EC50	15.7	26	Chakoumakos *et al.*, 1979	3
Salmo gairdneri * (fry) rainbow trout	copper spiked ambeint water (pH = 8.0)	168 hr	LC 50	15.9	37 +/- 2	Welsh *et al.*, 1998	
Ptychocheilus oregonensis northern squawfish	copper chloride		LC50 or EC50	18.	52-56	Andros & Garton, 1980	3
Catostomus commersoni white sucker	copper sulfate	ELS	Chronic value	20.88	45.4	McKim *et al.*, 1978	3

1. Duration given in days unless otherwise noted.
   Test Types: LC-Life Cycle, ELS-Early Life Stage.
2. Cited in AQUIRE database.
3. Cited in Copper Criteria document, (USEPA, 1984a).

* *Salmo gairdneri* = *Oncorhynchus mykiss*
Shading *Pimephales promelas*

Table 35. Summary of copper concentrations reported to have adverse effects on 15 freshwater invertebrate species

Species Name	Chemical	Duration or test type[1]	Effect/ Endpoint	Concentration (µg/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Daphnia magna water flea		21	LC50	1.4		Dave, 1984	3
Daphnia similis water flea	copper sulfate	4	LC50 MOR	4.1		Soundrapandian & Venkataraman, 1990	2
Asellus aquaticus aquatic sowbug	copper sulfate	1530	REP, MOR	5	300	DeNicola Guidici *et al.*, 1988	2
Daphnia pulex water flea		2	LC50	5.6		Cairns, 1978	3
Moina macrocopa water flea	copper sulfate	2	LC50 MOR	5.9		Hatakeyama & Sugaya, 1989	2
Insect community	copper	14	POP	6	88g/m³	Clementes *et al.*, 1989	2
Gammarus pseudolimnaeus amphipod	copper sulfate	LC	Chronic Value	6.066	45	Arthur & Leonard, 1970	3
Ceriodaphnia dubia water flea	copper	7	NOEL REP	6.3	94.1	Belanger *et al.*, 1989	2
Daphnia pulicaria water flea			LC50 or EC50	7.24	48	Lind *et al.*, manuscript	3
Daphnia lumholzi water flea	copper	4	LC50 MOR	9.4	200	Vardia *et al.*, 1988	2
Corbicula manilensis Asiatic clam		70	ILC	<10		Harrison *et al.*, 1981, 1984	3
Proasselus coxalis isopod	copper sulfate	21.3	LT50 MOR	10		DeNicola Guidici *et al.*, 1987	2
Clistornia magnifica caddisfly	copper chloride	LC	Chronic Value	10.39	26	Nebeker *et al.*, 1984b	3
Compeloma decisum snail	copper sulfate	LC	Chronic Value	10.88	35-55	Arthur & Leonard, 1970	3
Physa integra snail	copper sulfate	LC	Chronic Value	10.88	35-55	Arthur & Leonard, 1970	3

1. Duration given in days unless otherwise noted.
Test Types: LC-Life Cycle, ELS-Early Life Stage.
2 Cited in AQUIRE database.
3 Cited in Copper Criteria document, (USEPA, 1984a).

Shading *Ceriodaphnia dubia*

Table 36. Summary of copper concentrations reported to have adverse effects on 15 freshwater algal species

Species Name	Chemical	Duration or test type[1]	Effect/ Endpoint	Concentration (µ/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Chlorella pyrenoidosa green algae			lag in growth	1		Steeman-Nielsen & Wium-Andersen, 1970	3
Mixed periphyton algae		2.5	photosynthesis	2.5		Leland & Carter, 1984	4
Algae mixed culture			significant reduction in photosynthesis	5		Elder & Horne, 1978	3
Nitzchia palea diatom			complete growth inhibition	5		Steeman-Nielsen & Wium-Anderse, 1970	3
Scenedesmus quadricuada green algae			metabolism	5		Peterson et al., 1984	4
Chlamydomonas reinhardtii green algae	copper sulfate	3	NOEC-LOEC	5.9	76	Garvey et al., 1991	2
Chlorella sp green algae			photosynthesis inhibited	6.3		Gachter et al., 1973	3
Phytoplankton mixed species		5.2	reduced rate of primary production	10		Cote, 1983	3
Selenastrum capricornutum green algae	copper sulfate	3	EC50 GRO	10		Vasseur et al., 1988	1
Uroglena sp crysophyte	copper sulfate	14.35	PGR	19.7	102	Moore & Winner, 1989	2
Chlorella regularis green algae			lag in growth	20		Sakaguchi et al., 1977	3
Haematococcus sp green algae		4	inhibited growth	50		Pearlmutter & Buchheim, 1983	3
Chlorella vulgaris green algae		4	IC50	62		Ferard et al., 1983	2
Anabeana strain 7120 algae			lag in growth	64		Laube et al., 1980	2
Anabeana nidulans algae			growth inhibition	100		Young & Lisk, 1972	2

1. Duration given in days unless otherwise noted.
Test Types: LC-Life Cycle, ELS-Early Life Stage.
2. Cited in AQUIRE database.
3. Cited in Copper Criteria document (USEPA, 1984a).
4. Cited in Table II-10 (Lillebo *et al.*, 1988).

Shading *Selenastrum capricornutum*

Table 37. Summary of zinc concentrations reported to have adverse effects on 14 freshwater fish species

Species Name	Chemical	Duration or test type[1]	Effect/ Endpoint	Concentration (µg/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Salmo gairdneri rainbow trout	zinc sulfate	10 minutes	Avoidance	5.6	13-15	Sprague, 1964b	2
Jordanella floridea flagfish	zinc sulfate	LC	Chronic Value	36.41	44	Spehar, 1976a,b	2
Salmo salar Atlantic salmon (parr)	zinc sulfate	4 hours	EC50 avoidance	49.88	18	Sprague, 1964b	2
Oncorhynchus tshawytscha chinook salmon	zinc sulfate		acute toxicity	84	21	Finlayson & Verrue, 1982	2
Salmo clarki cutthroat trout (fingerling)	zinc sulfate		acute toxicity	90		Rabe & Sappington, 1970	2
Morone saxatilis striped bass (larvae)			acute mortality	100	38	Hughes, 1973	4
Pimephales promelas fathead minnow	zinc sulfate	LC	Chronic value	106.3	46	Benoit & Holcombe, 1978	2
Thymallus arcticus arctic grayling		4	LC50 MOR	112	41.3	Buhl & Hamilton, 1990	3
Salmo trutta brown trout	zinc chloride	48 hr	LC 50	164	102	Marr *et al.*, 1995	
Oncorhynchus mykiss steelhead trout	acid mine waste	96 hr	LC 50	167	52	Finlayson and Wilson, 1989	
Poecilia reticulata guppy	zinc sulfate	LC	Chronic value	<173	30	Pierson, 1981	2
Oncorhynchus tshawytscha chinook salmon	acid mine waste	96 hr	LC 50	178	52	Finlayson and Wilson, 1989	
Salmo trutta brown trout	zinc chloride	48 hr	LC 50	164	102	Marr *et al.*, 1995	
Lepomis macrochirus bluegill (fry)	zinc sulfate	3	lethal	235	51	Cairns & Sparks, 1971; Sparks *et al.*, 1972b	2
Oncorhynchus kisutch coho salmon (fry)	zinc sulfate	1	decreased white blood cells	500	3-10	McLeay, 1975	2

1. Duration given in days unless otherwise noted.
Test Types: LC-Life Cycle, ELS-Early Life Stage.
2. Cited in Zinc Criteria document, (USEPA, 1987).
3. Cited in AQUIRE database.
4. Cited in Table II-12 (Lillebo *et al.*, 1988).

Salmo gairdneri = *Oncorhynchus mykiss*; Shading = *Pimephales promelas*

Table 38. Summary of zinc concentrations reported to have adverse effects on 15 freshwater invertebrate species

Species Name	Chemical	Duration or Test Type[1]	Effect/ Endpoint	Concentration (µg/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Asellus aquaticus aquatic sowbug	zinc sulfate	18	LT50 MOR	10	240	Migliore & DeNicola Guidici, 1990	3
Daphnia magna water flea	zinc sulfate	50	REP	25	51.9	Paulauskis & Winner, 1988	3
Ceriodaphnia reticulata water flea	zinc chloride		acute toxicity	32	45	Carlson & Roush, 1985	2
Tanytarsus dissimilis midge (embryo-3rd instar)	zinc chloride	10	LC50	36.8	46.8	Anderson *et al.*, 1980	2
Corbicula sp. clam	zinc sulfate	5-30	GRO, ENZ	34-1130		Farris *et al.*, 1989	3
Ceriodaphnia dubia water flea	zinc	7	NOEC/LOEC	<25-25	46	UCD Aquatic Toxicology Lab(unpublished results)	
Tropocyclops prasinus copepod	zinc chloride	2	EC50 motility	52	10	Lalande & Pinel-Alloul, 1986	2
Ancylus fluviatilis river limpet	zinc sulfate	100	LC50 MOR	80		Willis, 1988	3
Zooplankton (mixed species)	zinc chloride	3 weeks	reduced crustacean density and diversity	100		Marshall *et al.*, 1981	2
Daphnia pulex water flea			acute toxicity	117	45	Mount & Norberg, 1984	2
Anodonta imbecilis mussel	zinc sulfate	4	LC50 MOR	268		Keller & Zam, 1991	3
Physa heterostropha snail (young)	zinc sulfate		acute toxicity	303	20	Wurtz, 1962	2
Daphnia lumholzi water flea	zinc	4	LC50 MOR	437.5		Vardia et al., 1988	3
Aedes aegypti mosquito (pupa)	zinc sulfate	3	20% mortality	500	4	Abbasi et al.,1985	2
Biomphalaria glabrata snail	zinc chloride	33	REP	500	61-61.8	Munzinger & Guarducci, 1988	3

1. Duration given in days unless otherwise noted.
2. Cited in Zinc Criteria document SEPA, 1987).
3. Cited in AQUIRE database.

Shading *Ceriodaphnia dubia*

Table 39. Summary of zinc concentrations reported to have adverse effects on 10 freshwater algal species

Species Name	Chemical	Duration or Test Type[1]	Effect/ Endpoint	Concentration (µg/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Ankistrodesmus falcatus green algae	zinc chloride	1	PGR	5-30		Wong & Chau, 1990	3
Navicula pelliculosa diatom	zinc chloride	1	PGR	5-30		Wong & Chau, 1990	3
Scenedesmus quadricauda green algae	zinc chloride	1	PGR	5-30		Wong & Chau, 1990	3
Selenastrum capricornutum green algae	zinc chloride	7	incipient growth inhibition	30		Bartlett *et al.*, 1974	2
Chlamydomonas variabilis green algae		6	30% reduction in division rate	503		Bales *et al.*, 1983	2
Algae mixed species	zinc sulfate	5-30	BMS	540		Genter *et al.*, 1988	3
Navicula seminulum diatom	zinc chloride	5	EC50 growth	1320		Acad. of Nat. Sci., 1960	2
Chlorella vulgaris green algae	zinc sulfate	4	EC50 growth	2400		Rachlin & Farran, 1974	2
Chlorella saccarophila green algae	zinc chloride	4	EC50	7100		Rachlin *et al.*, 1982	2
Navicula incerta diatom	zinc chloride	4	EC50	10000		Rachlin *et al.*, 1983	2

1. Duration given in days unless otherwise noted.
2. Cited in Zinc Criteria document (USEPA, 1987).
3. Cited in AQUIRE database.

Shading *Selenastrum capricornutum*

Table 40. Summary of cadmium concentrations reported to have adverse effects on 15 freshwater fish species

Species Name	Chemical	Duration or test type[1]	Effect/ Endpoint	Concentration (μg/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Salmo gairdneri rainbow trout		18 months	reduced survival	0.2	112	Birge *et al.*, 1981	2
Ictalurus punctatus catfish	cadmium chloride		increased albinism	0.5		Westerman & Birge, 1978	2
Morone saxatilis striped bass	cadmium chloride		LC50 or EC50	1	34.5	Hughes, 1973	2
Oncorhynchus tshawytscha Chinook salmon (juvenile)			acute mortality	1.1	20-22	Finlayson & Verrue, 1982	3
Salmo trutta brown trout			acute mortality	1.4	39.48	Spehar & Carlson, 1984	3
Salvelinus fontinalis brook trout			acute mortality	<1.5	42	Carrol *et al.*, 1979	3
Oncorhynchus mykiss steelhead trout (fry)	acid mine waste	96 hr	LC 50	1.6	52	Finlayson and Wilson, 1989	
Oncorhynchus tshawytscha Chinook salmon (fry)	acid mine waste	96 hr	LC 50	1.9	52	Finlayson and Wilson, 1989	
Oncorhynchus kisutch coho salmon (juvenile)	cadmium chloride	9	LC50	2.0	22	Chapman & Stevens, 1978	2
Salmo salar Atlantic salmon	cadmium chloride	70	reduced growth	2.0	13	Peterson, 1983	2
Jordanella floridea flagfish	cadmium chloride	LC	Chronic value	4.4161	44-51	Carlson *et al.*, 1982	2
Catostomus commersoni white sucker	cadmium chloride	ELS	Chronic value	7.099	44	Eaton *et al.*, 1978	2
Salvelinus namaycush lake trout	cadmium chloride	ELS	Chronic value	7.357	44	Eaton *et al.*, 1978	2
Esox lucius nothern pike	cadmium chloride	ELS	Chronic value	7.361	44	Eaton *et al.*, 1978	2
Micropterus dolomieui smallmouth bass	cadmium chloride	ELS	Chronic value	7.390	44	Eaton *et al.*, 1978	2

1. Duration given in days unless otherwise noted.
   Test Types: LC-Life Cycle, ELS-Early Life Stage.
2. Cited in Cadmium Criteria document, (USEPA, 1984b).
3. Cited in Table II-7 (Lillebo *et al.*, 1988).

• *Salmo gairdneri* = *Oncorhynchus mykiss*
Shading *Pimephales promelas*

Table 41. Summary of cadmium concentrations reported to have adverse effects on 15 freshwater invertebrate species

Species Name	Chemical	Duration or test type[1]	Effect/ Endpoint	Concentration (µg/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Daphnia magna water flea	cadmium chloride	LC	Chronic value	0.1523	53	Chapman *et al.*, manuscript	3
Ceriodaphnia reticulata water flea	cadmium chloride	7	LOEC REP	0.2	240	Elnabarawy *et al.*, 1986	2
Moina macrocopa water flea	cadmium chloride	20	reduced survival	0.2	80-84	Hatakeyama & Yasuno, 1981b	3
Acanthocyclops viridis copepod	cadmium chloride	3	LC50	0.5		Braginsky & Scherban, 1978	3
Hyalella azteca scud	cadmium	42	LC50*MOR	0.53	130	Borgmann *et al.*, 1991	2
Ceriodaphnia dubia water flea	cadmium sulfate	7	GRO, REP	1	90	Winner, 1988	2
Daphnia pulex water flea	cadmium chloride	140	reduced reproduction	1	57	Bertram & Hart, 1979	3
Polypedilum nubifer midge	cadmium chloride	8	DVP	1		Hatakeyama, 1987	2
Gammarus fasciatus scud	cadmium	42	MOR	1.49		Borgmann *et al.*, 1989	2
Astacus astacus European crayfish	cadmium	14-70	ENZ, HIS	2		Meyer *et al.*, 1991	2
Ephemerella sp mayfly	cadmium chloride	28	LC50	<3	44-48	Spehar *et al.*, 1978	3
Aplexa hypnorum snail	cadmium chloride	LC	Chronic value	3.460	45.3	Holcombe *et al.*, 1984	3
Tanytarsus dissimilis midge	cadmium chloride	10	LC50	3.8	47	Anderson *et al.*, 1980	3
Daphnia galeata mendotae cladoceran	cadmium chloride	22 weeks	reduced biomass	4.0		Marshall, 1978a	3
Cambarus latimus crayfish	cadmium chloride	5 months	significant mortality	5	11.1	Thorp *et al.*, 1979	3

1. Duration given in days unless otherwise noted.
Test Types: LC-Life Cycle, ELS-Early Life Stage.
2. Cited in AQUIRE database.
3. Cited in Cadmium Criteria document (USEPA, 1984b).

Shading *Ceriodaphnia dubia*

Table 42. Summary of cadmium concentrations reported to have adverse effects on 15 freshwater algal species

Species Name	Chemical	Duration or test type[1]	Effect/ Endpoint	Concentration (µg/L)	Hardness (mg/L as $CaCO_3$)	Reference	Where Cited
Asterionella formosa diatom			factor of 10 growth rate decrease	2		Conway, 1978	3
Algae mixed species	cadmium chloride		significant reduction in population	5		Giesy *et al.*, 1979	2
Scenedesmus quadricauda green algae	cadmium chloride		reduction in cell count	6.1		Klass *et al.*, 1974	3
Chlamydomonas reinhardtii green algae	cadmium chloride	6.7	PGR	7.5-40		Lawrence *et al.*, 1989	2
Selenastrum capricornutum green algae	cadmium chloride	4.0	PGR	8		Thompson *et al.*, 1987	2
Chara vulgaris	cadmium sulfate	14	IC50 GRO	9.5		Heumann, 1987	2
Scenedesmus bijugatus	cadmium sulfate	1-12	physiological	10		Sathya & Balakrishnan, 1987	2
Chlorella vulgaris green algae			reduction in growth	50		Hutchinson & Stokes, 1975	3
Scenedesmus dimorphus green algae	cadmium nitrate	2	EC50*IMM	63		Ghosh *et al.*, 1990	2
Scenedesmus subspicatus green algae	cadmium chloride	3	EC50 BMS	100		Kuhn & Pattard, 1990	2
Algae	cadmium	14	BMS	100		Kerrison *et al.*, 1988	2
Chlorella saccharophila green algae	cadmium chloride	4	EC50	105		Rachlin *et al.*, 1984	3
Anabeana flos-aquae	cadmium chloride	4	EC50	120		Rachlin *et al.*, 1984	3
Chlorella pyrenoidosa	cadmium chloride		reduction in growth	250		Hart & Scaife, 1977	3
Navicula incerta diatom	cadmium chloride		EC50	310		Rachlin *et al.*, 1982	3

1. Duration given in days unless otherwise noted.
   Test Types: LC-Life Cycle, ELS-Early Life Stage.
2. Cited in AQUIRE database.
3. Cited in Cadmium Criteria document (USEPA, 1984b).

Shading *Selenastrum capricornutum*

Table 43. Comparison of Metal Load Estimates in the Sacramento River at Greene's Landing from January Through April During a Dry Year (1994) and Wet Year (1995).

Year and Method	Copper		Zinc		Chromium		Lead		Cadmium		Nickel		Arsenic	
	Total (kg)	Daily Avg.	Total (kg)	Daily Avg.	Total (kg)	Daily Avg.	Total (kg)	Daily Avg.	Total (kg)	Daily Avg.	Total (kg)	Daily Avg.	Total (kg)	Daily Avg.
1994														
Average Concentration Method	20,900	174	50,700	423	14,700	123	3,240	27	698	6	19,800	165		
Model	16,500	141†	37,900	323†	10,500	89†	2,290	20†	*	*	13,700	117†		
1995														
Average Concentration Method	144,000	1360^	394,000	3720^	155,000	1,460^	54,400	513^	1,660	16^	#######	1,900^	20,800	196^
Model	*	*	*	*	*	*	*	*	*	*	*	*	*	*
% Increase	**872 (1)**		**1040 (1)**		**1476 (1)**		**2,376 (1)**		**237 (2)**		**1,467 (1)**		**N/A**	

(1) = % increase from 1994 model calculation to 1995 average concentration method
(2) = % increase from 1994 average concentration method to 1995 average concentration method
* = Model could not be applied due to insignificant relationship between total metal concentrations and flow
† = Daily average based on 117 days when flows were recorded
^ = Daily average based on 106 days when flows were recorded
The number of significant figures for load estimates was set at three due to uncertainties in flow measurements and regression analyses.

Table 44. Comparison of Metal Loads to the Delta Contributed by Sources Which Drain Into the Yolo Bypass and Sacramento River During High Flows From January Through April 1995

METAL	CONTRIBUTION	BYPASS	RIVER	TOTAL
Copper	Total (kg)	296,000	144,000	440,000
	Daily Average	2,850*	1,360†	4,210
	Percent	67	33	100
Zinc	Total (kg)	727,000	394,000	1,120,000
	Daily Average	6,990*	3,720†	10,700
	Percent	65	35	100
Chromium	Total (kg)	472,000	155,000	627,000
	Daily Average	4,540*	1,460†	6,000
	Percent	74	26	100
Lead	Total (kg)	64,700	54,400	119,000
	Daily Average	622*	513†	1,140
	Percent	54	46	100
Cadmium	Total (kg)	1,550	1,660	3,210
	Daily Average	15*	16†	31
	Percent	48	52	100
Nickel	Total (kg)	911,000	201,000	1,110,000
	Daily Average	8,760*	1,900†	10,700
	Percent	82	18	100
Arsenic	Total (kg)	22,400	20,800	43,200
	Daily Average	215*	196†	410
	Percent	52	48	100

* = Yolo Bypass daily average based on 104 days when USGS gage station #11453000 was functional
† = Sacramento River daily average based on 106 days when flows were recorded
The number of significant figures for load estimates was set at three due to uncertainties in flow measurements and regression analyses.

Table 45. Comparison of Metal Load Estimates in the Sacramento River at River Mile 44 from January Through April of a Dry Year (1994) and Wet Year (1995) Based on Metal Analyses Conducted for the Sacramento Coordinated Water Quality Monitoring Program's Ambient Monitoring Program

Year and Method	Copper Total (kg)	Copper Daily Avg.	Zinc Total (kg)	Zinc Daily Avg.	Chromium Total (kg)	Chromium Daily Avg.	Lead Total (kg)	Lead Daily Avg.	Cadmium Total (kg)	Cadmium Daily Avg.	Nickel Total (kg)	Nickel Daily Avg.	Arsenic Total (kg)	Arsenic Daily Avg.
1994														
Average Concentration Method**	12,000	100	28,800	241	5,580	47	1,640	14	123	1	9,440	79	7,800	65
% of BPTCP estimates (same method)	57		57		38		51		18		48		N/A	
Model (estimated by regression)	12,600	108†	30,700	262†	7,020	60†	1,680	14†	193	2†	10,300	88†	6,680	57†
% of BPTCP estimates (same method)	76		81		67		73		N/A		75		N/A	
1995														
Average Concentration Method**	95,100	897	198,000	1,860	46,700	441	19,300	182	998	9	102,000	966	21,300	201
% of BPTCP estimates (same method)	66		50		30		36		60		51		102	
Model (estimated by regression)	116,000	1090^	190,000	1790^	58,800	555^	20,600	194^	1,830	17^	149,000	1400^	28,100	265^
% of BPTCP estimates (same method)	N/A		N/A		N/A		N/A		N/A		N/A		N/A	
Minimum % Increase in load from WY94 to WY95	**792**		**619**		**837**		**1,180**		**811**		**1,080**		**420**	

† = Daily average based on 117 days when flows were recorded

^ = Daily average based on 106 days when flows were recorded

The number of significant figures for load estimates was set at three due to uncertainties in flow measurements and regression analyses.

** = values reported as non-detectable were set at zero for the purposes of obtaining an average concentration.

Note: AMP model estimates were provided by Klauss Suverkropp of Larry Walker Associates

Table 46. Total Recoverable and Dissolved (0.45 μm) Metal Concentrations (μg/l) in Samples Collected from All Stations Monitored during water years 1993, 1994, and 1995.

	Total Cu (μg/l)	Dis. Cu (μg/l)	Total Zn (μg/l)	Dis. Zn (μg/l)	Total Cr (μg/l)	Dis. Cr (μg/l)	Total Pb (μg/l)	Dis. Pb (μg/l)	Total Cd (μg/l)	Dis. Cd μg/l)	Total Ni (μg/l)	Dis. Ni (μg/l)	Total As (μg/l)	Dis. As (μg/l)
1993 (normal)														
Mean	5.56	1.83	9.61	1.94	4.65	0.60	2.81	0.11	0.06	0.02	6.90	1.37		
SD	5.85	0.58	6.56	1.10	6.07	0.36	8.88	0.07	0.10	0.01	8.83	0.85		
Max.	28.3	2.91	26.8	5.02	26.8	1.42	39.4	0.26	0.456	0.03	38.8	4.15		
Min.	1.98	0.32	4.12	0.7	0.007	0.09	0.2	0.03	0.007	0.009	0.75	0.31		
n =	19	19	19	19	19	19	19	16	19	14	19	19		
1994 (critically dry)														
Mean	4.54	2.45	10.03	3.40	3.71	1.00	0.97	0.24	0.09	0.04	5.39	1.97	1.72	1.38
SD	3.11	1.32	8.21	2.79	4.79	1.20	1.42	0.26	0.14	0.08	6.94	1.71	0.91	0.61
Max.	14.9	9.48	39	18.5	23.1	5.39	8.98	1.38	0.74	0.55	35.8	8.52	3.98	2.4
Min.	0.75	0.2	0.08	0.16	0.19	0.06	0.01	0.01	0.006	0.001	0.52	0.13	0.11	0.24
n =	111	86	116	85	110	86	112	78	113	79	111	86	25	24
1995 (wet)														
Mean	21.20	3.48	57.61	7.74	33.76	2.45	5.82	0.55	0.13	0.03	63.50	5.02	1.49	1.19
SD	31.77	0.95	75.23	11.20	63.37	1.18	8.03	0.59	0.13	0.02	141.17	4.50	0.83	0.49
Max.	162	5.4	333	70.2	312	4.78	41.2	3.87	0.568	0.11	653	26	4.41	3.03
Min.	1.15	1.84	3.2	1.98	0.73	0.39	0.28	0.09	0.012	0.002	0.83	1.33	0.3	0.13
n =	113	39	97	39	113	39	113	38	113	38	113	39	43	26

Table 47. Total Recoverable and Dissolved (0.45 µm) Metal Concentrations (µg/l) in Samples Collected at Greene's Landing from January Through March of 1993, 1994, and 1995.

		Total Cu (µg/l)	Dis. Cu (µg/l)	Total Zn (µg/l)	Dis. Zn (µg/l)	Total Cr (µg/l)	Dis. Cr (µg/l)	Total Pb (µg/l)	Dis. Pb (µg/l)	Total Cd (µg/l)	Dis. Cd µg/l)	Total Ni (µg/l)	Dis. Ni (µg/l)	Total As (µg/l)	Dis. As (µg/l)
1993															
	Mean	3.92	2.91	6.20	2.10	1.54	0.29	0.29	0.08	0.05	0.03	1.85	0.75		
	SD	0.41		0.14		0.88		0.12		0.01		0.36			
	Max.	4.21	2.91	6.3	2.1	2.16	0.29	0.37	0.08	0.05	0.03	2.1	0.75		
	Min.	3.63	2.91	6.1	2.1	0.92	0.29	0.2	0.08	0.04	0.03	1.59	0.75		
	n=	2	1	2	1	2	1	2	1	2	1	2	1		
1994															
	Mean	5.08	2.93	12.35	4.53	3.57	1.15	0.79	0.25	0.17	0.05	4.83	1.87		
	SD	3.05	1.70	9.01	3.29	3.30	0.81	0.50	0.15	0.19	0.12	4.36	1.05		
	Max.	14.29	9.48	39	18.5	14.9	3.78	2.15	0.53	0.74	0.55	19.5	4.62		
	Min.	1.29	1.32	0.11	1.4	0.26	0.31	0.01	0.01	0.01	0.01	0.52	0.64		
	n=	46	30	49	30	46	30	48	29	48	27	46	30		
1995															
	Mean	8.64	3.44	23.68	5.63	9.34	2.76	3.27	0.51	0.10	0.03	12.10	5.51	1.25	1.09
	SD	5.40	0.82	17.16	3.93	6.17	1.03	4.39	0.22	0.08	0.02	6.95	5.20	0.58	0.22
	Max.	28.4	5.05	71.8	22.4	29	4.78	28.7	0.99	0.474	0.11	28.3	26	2.97	1.41
	Min.	2.76	1.89	3.98	1.98	1.67	1.28	0.39	0.18	0.027	0.002	2.71	2.15	0.3	0.45
	n=	47	27	37	27	47	27	47	27	47	27	47	27	24	20

Table 48. Bay Protection Toxic Cleanup Program: Summary of regression coefficients for total recoverable and dissolved (0.45 μm) metals, flow, and TSS for the Sacramento River at Greene's Landing during water year 1994.

	Cu	Zn	Cr	Pb	Cd	Ni	As
Total vs. Diss.	n=36 r2 = 0.24	n=36 r2 = 0.19	n=31 r2 = 0.22	n=33 r2 = 0.15	n=38 r2 = 0.13	n=37 r2 = 0.26	n=1
Total vs. Flow	n=56 r2 = 0.56* P<.001	n=63 r2 = 0.52* P<.001	n=54 r2 = 0.64* P<.001	n=58 r2 = 0.58* P<.001	n=58 r2 = 0.027	n=56 r2 = 0.6* P<.001	
Diss. vs. Flow	n=47 r2 = 0.3* P<.05	n=46 r2 = 0.24	n=41 r2 = 0.34* P<.05	n=43 r2 = 0.12	n=45 r2 = 0.11	n=46 r2 = 0.37* P<.02	
Total vs. TSS	n=30 r2 = 0.7* P<.001	n=32 r2 = 0.64* P<.001	n=29 r2 = 0.72* P<.001	n=29 r2 = 0.61* P<.001	n=30 r2 = 0.023	n=29 r2 = 0.72* P<.001	
Diss. vs TSS	n=31 r2 = 0.1	n=32 r2 = 0.065	n=27 r2 = 0.047	n=27 r2 = 0.25	n=30 r2 = 0.015	n=29 r2 = 0.14	

* = significant relationship

Table 49. Bay Protection Toxic Cleanup Program: Summary of regression coefficients for total recoverable and dissolved (0.45 µm) metals, flow, and TSS for the Sacramento River at Greene's Landing during water year 1995.

	Cu	Zn	Cr	Pb	Cd	Ni	As
Total vs. Diss.	n= 26 r2 = 0.59* P<.002	n= 26 r2 =0.022	n=26 r2 = 0.37	n=26 r2 = 0.41* P<.05	n= 31 r2 = 0.029	n=29 r2 = 0.099	n=17 r2 =0.004
Total vs. Flow	n=51 r2 = 0.12	n= 39 r2 = 0.06	n= 51 r2 = 0.18	n=49 r2 = 0.0054	n= 50 r2 = 0.077	n=52 r2 =0.23	n= 24 r2 = 0.042
Diss. vs. Flow	n= 28 r2 = 0.0026	n= 27 r2 = 0.011	n=27 r2 =0.14	n=26 r2 = 0.0000069	n= 33 r2 =0.016	n= 29 r2 = 0.051	n= 19 r2 =0.00082
Total vs. TSS	n=31 r2 =0.85* P<.001	n= 30 r2 =0.52* P<.005	n=31 r2 =0.78* P<.001	n= 29 r2 =0.16	n= 30 r2 =0.92* P<.001	n=31 r2 =0.081	n=21 r2 = 0.0013
Diss. vs TSS	n=23 r2 = 0.43* P<.05	n= 22 r2 = 0.000051	n=22 r2 = 0.12	n=21 r2 =0.47* P<.05	n= 28 r2 = 0.0087	n=23 r2 = 0.0042	n= 16 r2 =0.012

* = significant relationship

Table 50. Bay Protection Toxic Cleanup Program: Summary of regression coefficients for total recoverable and dissolved (0.45 µm) metals, flow, and TSS for the Sacramento River at Greene's Landing for the combined water years 1994 and 1995.

	Cu	Zn	Cr	Pb	Cd	Ni	As
Total vs. Diss.	n= 62 r2 = 0.32* P<.02	n=60 r2 =0.11	n=56 r2 = 0.55* P<.001	n=59 r2 = 0.46* P<.001	n=67 r2 =0.12	n=69 r2 = 0.29* P<.02	n=18 r2 = 0.014
Total vs. Flow	n= 107 r2 = 0.26* P<.01	n= 102 r2 = 0.24* P<.02	n=105 r2 =0.38* P<.001	n= 107 r2 = 0.15	n=108 r2 =0.018	n=108 r2 = 0.45* P<.001	n=25 r2 =0.063
Diss. vs. Flow	n=75 r2 = 0.11	n= 73 r2 = 0.078	n= 68 r2 = 0.58* P<.001	n=69 r2 =0.32* P<.01	n= 78 r2 = 0.039	n= 75 r2 =0.28* P<.02	n=20 r2 = 0.14
Total vs. TSS	n= 61 r2 =0.83* P<.001	n=62 r2 =0.6* P<.001	n=60 r2 =0.81* P<.001	n=58 r2 =0.22	n=60 r2 =0.039	n=60 r2 = 0.3* P<.02	n=21 r2 = 0.0013
Diss. vs TSS	n=54 r2 =0.17	n=54 r2 =0.023	n= 49 r2 =0.28	n=48 r2 =0.56* P<.001	n= 58 r2 =0.069	n=52 r2 =0.087	n=16 r2 =0.012

* = significant relationship

Table 51. Ambient Monitoring Program: Summary of regression coefficients for total recoverable and dissolved metals, flow, and TSS for the Sacramento River at River Mile 44 for WY94. Sampling dates ranged from 10/4/93 - 9/13/94.

	Cu	Zn	Cr	Pb	Cd	Ni	As
Total vs. Diss.	n=22 r2 =0.19	n= 22 r2 =0.0012	n= 31 N/A: all values < detection limit	n=22 r2 =0.0053	n= 22 r2 = 0.036	n= 14 r2 =0.62* .01<P<.02	n=22 r2 =0.70* P<.001
Total vs. Flow	n=22 r2 = 0.35	n=22 r2 = 0.2072	n=22 r2 = 0.011	n=22 r2 =0.12	n=22 r2 = 0.076	n=14 r2 =0.68* .005< P<.01	n=22 r2 = 0.14
Diss. vs. Flow	n=22 r2 =0.024	n=22 r2 =0.15	n=22 N/A: all values < detection limit	n=22 r2 =0.056	n=22 r2 =0.10	n=14 r2 =0.51	n=22 r2 = 0.23
Total vs. TSS	n=22 r2 =0.84 P<.001	n=22 r2 =0.323	n=22 r2 =0.17	n=22 r2 =0.20	n=22 r2 =.46 .02< P<.05	n= 14 r2 = 0.74 .002< P<.005	n=22 r2 =0.0132
Diss. vs TSS	n=22 r2 =.096	n=22 r2 =0.015	n=22 N/A: all values < detection limit	n=22 r2 =0.012	n=22 r2 =0.056	n=14 r2 =0.45	n=22 r2 =0.075

* = significant relationship

Table 52. Ambient Monitoring Program: Summary of regression coefficients for total recoverable and dissolved metals, flow, and TSS for the Sacramento River at River Mile 44 for WY95. Sampling dates ranged from 10/25/94 - 9/25/95.

	Cu	Zn	Cr	Pb	Cd	Ni	As
Total vs. Diss.	n=24 r2 =0.20	n=24 r2 =0.33	n=24 r2 =0.00013	n= 24 r2 =0.0085	n= 24 N/A: all values < detection limit	n = 12 r2 =0.053	n=22 r2 =0.32
Total vs. Flow	n=21 r2 =0.13	n=21 r2 =0.080	n=21 r2 = 0.069	n=21 r2 = 0.22	n=21 r2 = 0.071	n=10 r2 = 0.00034	n=19 r2 = 0.16
Diss. vs. Flow	n=21 r2 = 0.059	n=21 r2 = 0.0002	n=21 r2 = 0.0032	n=21 r2 = 0.021	n=21 N/A: all values < detection limit	n=10 r2 = 0.0035	n=21 r2 = 0.51* .01< P<.02
Total vs. TSS	n=24 r2 = 0.72* P<.001	n=24 r2 = 0.54* .005< P<.01	n=24 r2 = 0.47* .01< P<.05	n=24 r2 = 0.69* P<.001	n=24 r2 = 0.74* P<.001	n=12 r2 = 0.431	n=22 r2 = 0.001032
Diss. vs TSS	n=24 r2 = 0.096	n=24 r2 = 0.628	n=24 r2 = 0.019	n=24 r2 = 0.0003005	n=24 r2 = 5X10(-16)	n=12 r2 =0.067	n=24 r2 =0.085

* = significant relationship

Table 53. Ambient Monitoring Program: Summary of regression coefficients for total recoverable and dissolved metals, flow, and TSS for the Sacramento River at River Mile 44 fof WY94-WY95. Sampling dates ranged from 10/4/93 - 9/25/95.

	Cu	Zn	Cr	Pb	Cd	Ni	As
Total vs. Diss.	n=46 r2 = 0.088	n=46 r2 =0.060	n=46 r2 = 0.010	n=46 r2 = 0.042	n=46 r2 = 0.0034	n= 26 r2 = 0.20	n= 44 r2 = 0.52* P<.001
Total vs. Flow	n=43 r2 =0.27	n=43 r2 = 0.015	n=43 r2 = 0.27	n=43 r2 =0.31* .02<P<.05	n=43 r2 =0.072	n=24 r2 =0.24	n=41 r2 =0.36 .02<P<.05
Diss. vs. Flow	n=43 r2 =0.0053	n=43 r2 =0.024	n=43 r2 =0.032	n=43 r2 =0.0048	n=43 r2 =0.031	n=24 r2 =0.11	n=43 r2 =0.56* P<.001
Total vs. TSS	n= 46 r2 =0.75* P<.001	n= 46 r2 =0.15	n= 46 r2 =0.50* P<.001	n= 46 r2 =0.66* P<.001	n= 46 r2 =0.61 P<.001	n= 26 r2 =0.46 .001<P<.002	n=44 r2 =0.062
Diss. vs TSS	n= 46 r2 =0.024	n= 46 r2 =0.39 .005<P<.01	n= 46 r2 =0.000031	n= 46 r2 =0.024	n= 46 r2 =0.018	n= 26 r2 =0.15	n= 46 r2 =0.19

* = significant relationship

Table 54. Bay Protection Toxic Cleanup Program: Summary of total recoverable metals regressed against other metals for samples collected from the Sacramento River at Greene's Landing during the critically dry Water Year 1994 (upper right) and wet Water Year 1995 (lower left).

	Total Cu	Total Zn	Total Cr	Total Pb	Total Cd	Total Ni
Total Cu		n=54 r2 =0.38* P<.005	n=54 r2 = 0.38* P<.005	n=54 r2 = 0.78* P<.001	n=54 r2 =0.048 P>0.50	n=54 r2 = 0.84* P<.001
Total Zn	n=37 r2 =0.69* P<.001		n=54 r2 =0.84* P<.001	n= 56 r2 = 0.80* P<.001	n=56 r2 =0.10 0.50>P>0.20	n=54 r2 = 0.84 * P<.001
Total Cr	n=48 r2 =0.83* P<.001	n=37 r2 =0.78* P<.001		n=54 r2 =0.51* P<.001	n= 43 r2 = 0.06 P>0.50	n= 54 r2 =0.97* P<.001
Total Pb	n=48 r2 =0.14 0.50>P>0.20	n=37 r2 =0.28 0.10>P>0.05	n=48 r2 =0.14 0.50>P>0.20		n=56 r2 =0.027 P>0.50	n=54 r2 = 0.83* P<.001
Total Cd	n=48 r2 =0.82* P<.001	n=37 r2 =0.61* P<.001	n=48 r2 =0.54* P<.001	n=48 r2 =0.12 0.50>P>0.20		n=54 r2 =0.072 P>0.50
Total Ni	n=48 r2 =0.45* P<.002	n=37 r2= 0.41* P<.02	n=48 r2 =0.51* P<.001	n=48 r2 =.026 P>0.50	n=48 r2 =0.18 0.50>P>0.20	

* = significant relationship

Table 54 (cont). Bay Protection Toxic Cleanup Program: Summary of total recoverable metals regressed against other metals for samples collected from the Sacramento River at Greene's Landing during the combined 1994 and 1995 Water Years.

	Total Cu	Total Zn	Total Cr	Total Pb	Total Cd	Total Ni
Total Cu		n=94 r2 =0.77* P<.001	n=102 r2 = 0.85* P<.001	n=102 r2 = 0.22* P<.05	n=102 r2 =0.012 P>0.50	n=102 r2 = 0.59* P<.001
Total Zn			n=94 r2 =0.79* P<.001	n= 94 r2 = 0.34* P<.001	n=94 r2 =0.00002 P>0.50	n=94 r2 = 0.57 * P<.001
Total Cr				n=102 r2 =0.25* P<.02	n= 102 r2 = 0.00058 P>0.50	n= 102 r2 =0.69* P<.001
Total Pb					n=104 r2 =0.00079 P>0.50	n=102 r2 = 0.80* P<.001
Total Cd						n=102 r2 =0.01 P>0.50
Total Ni						

* = significant relationship

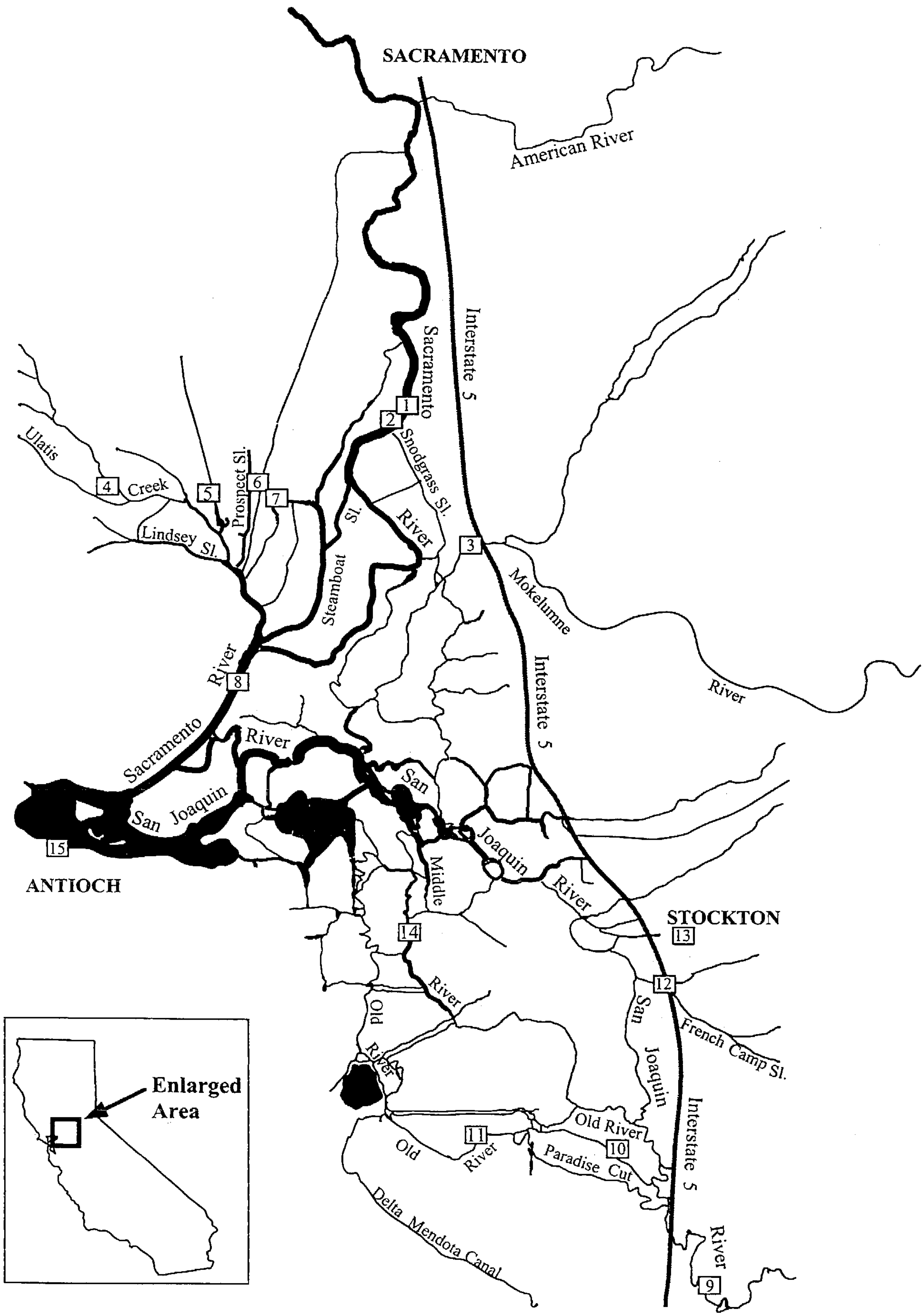

Figure 1. Map of the Sacramento-San Joaquin River Delta and its major tributaries. Numbers refer to stations sampled during the Delta studies and are described in Appendix A. Sample dates are identified in Table 1.

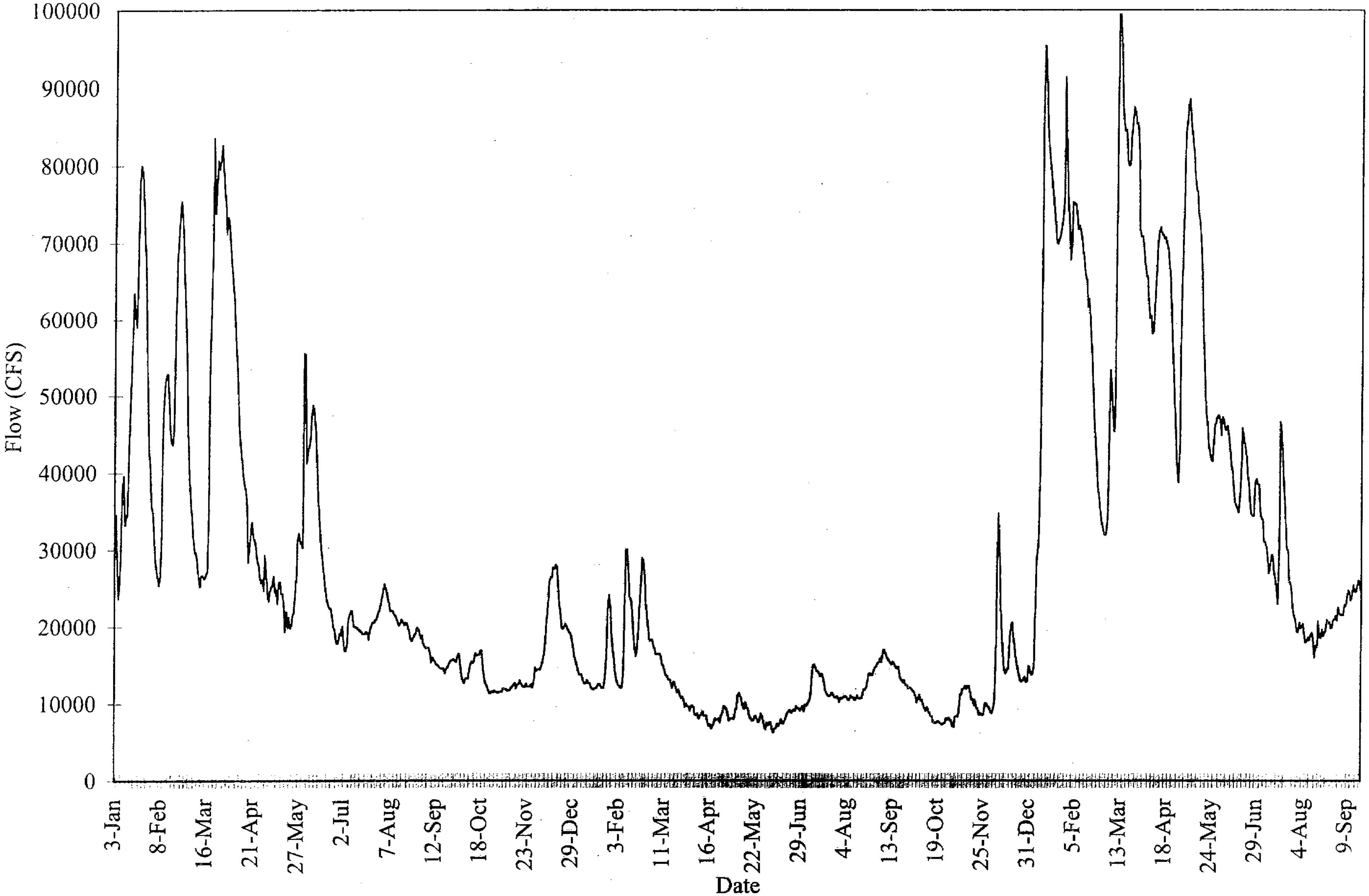

Figure 2. Sacramento River Flow at Freeport from January 1993 to September 1995

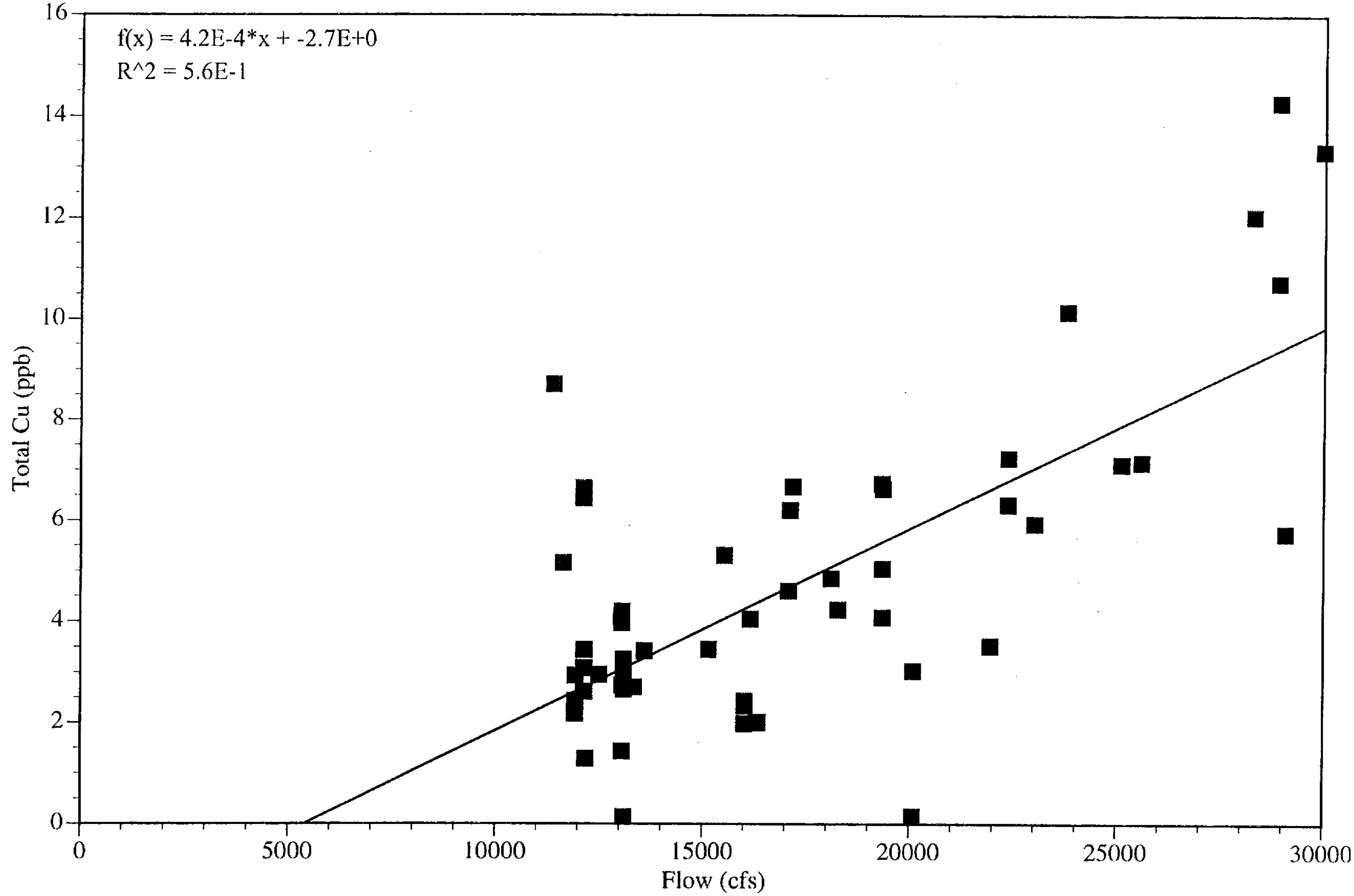

Figure 3. Regression of flow versus total copper concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

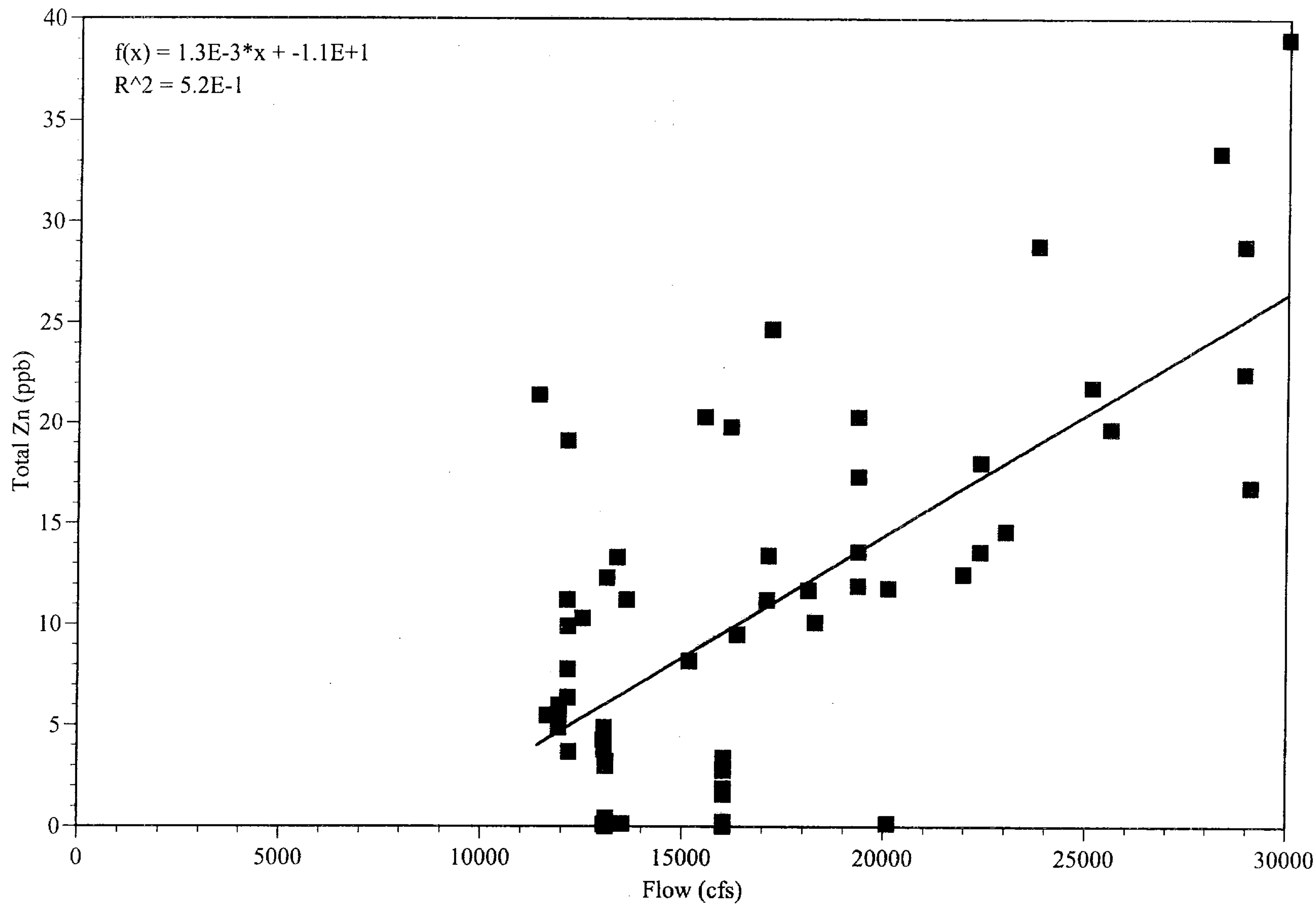

Figure 4. Regression of flow versus total recoverable zinc concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

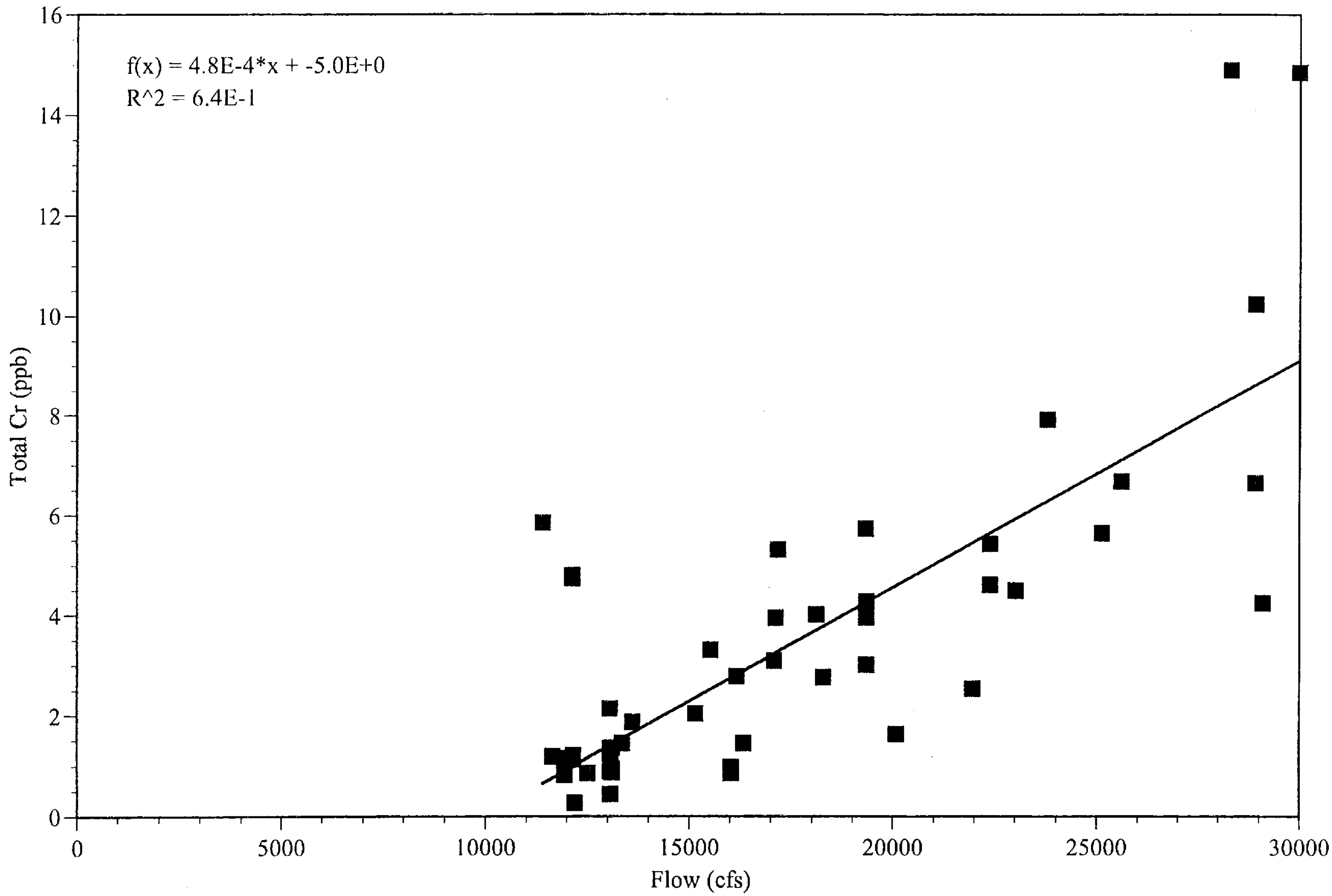

Figure 5. Regression of flow versus total recoverable chromium concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

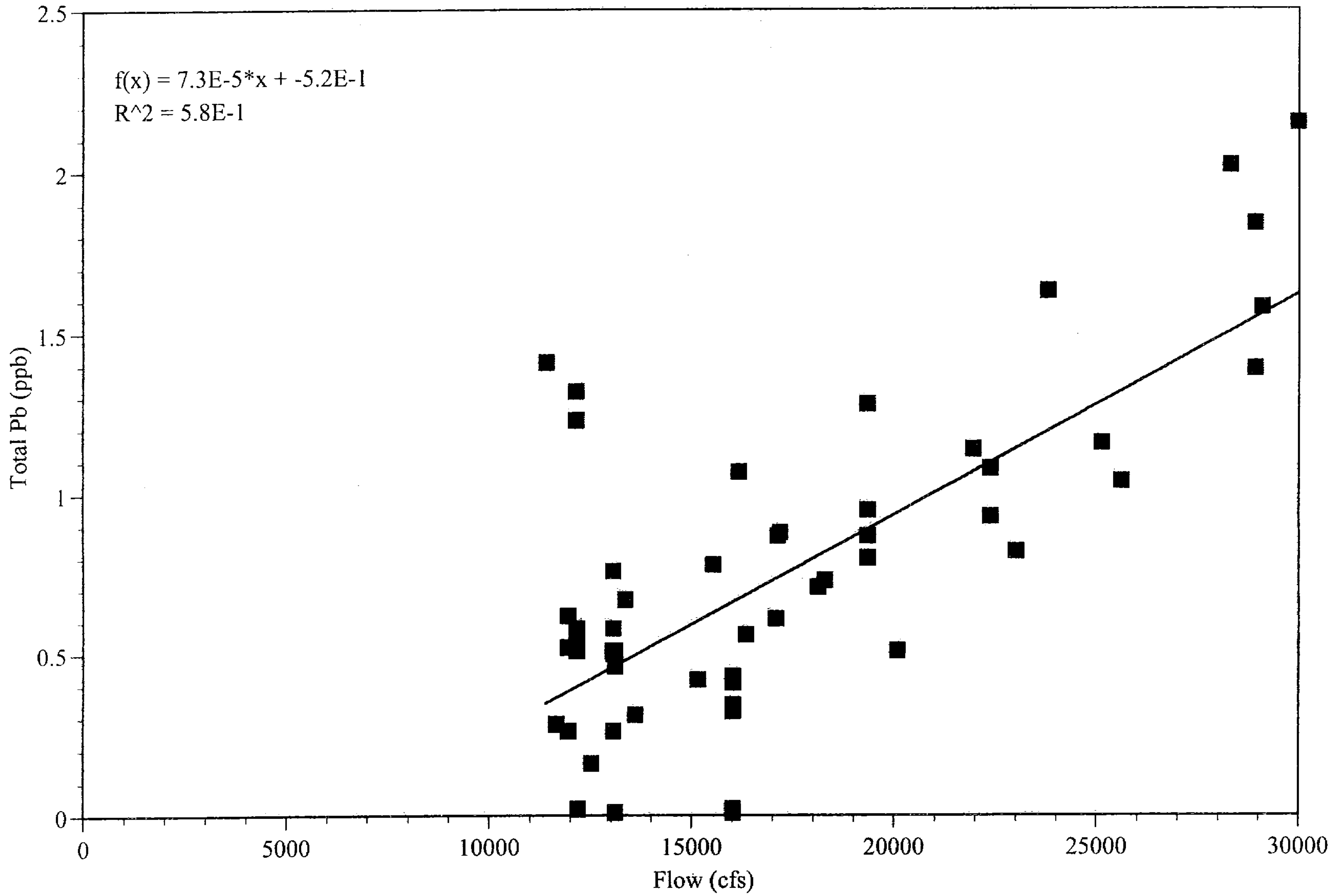

Figure 6. Regression of flow versus total recoverable lead concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

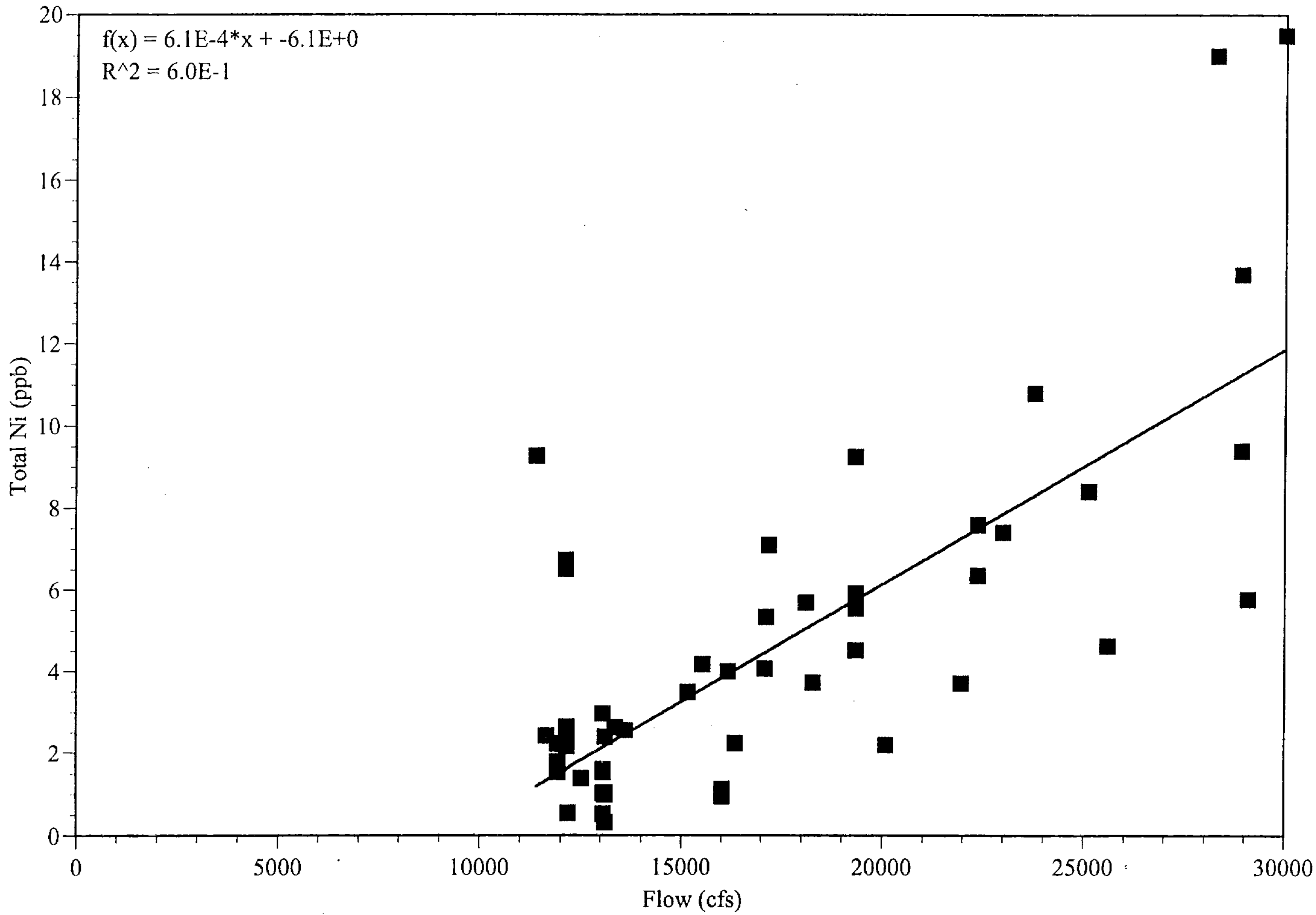

Figure 7. Regression of flow versus total recoverable nickel concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

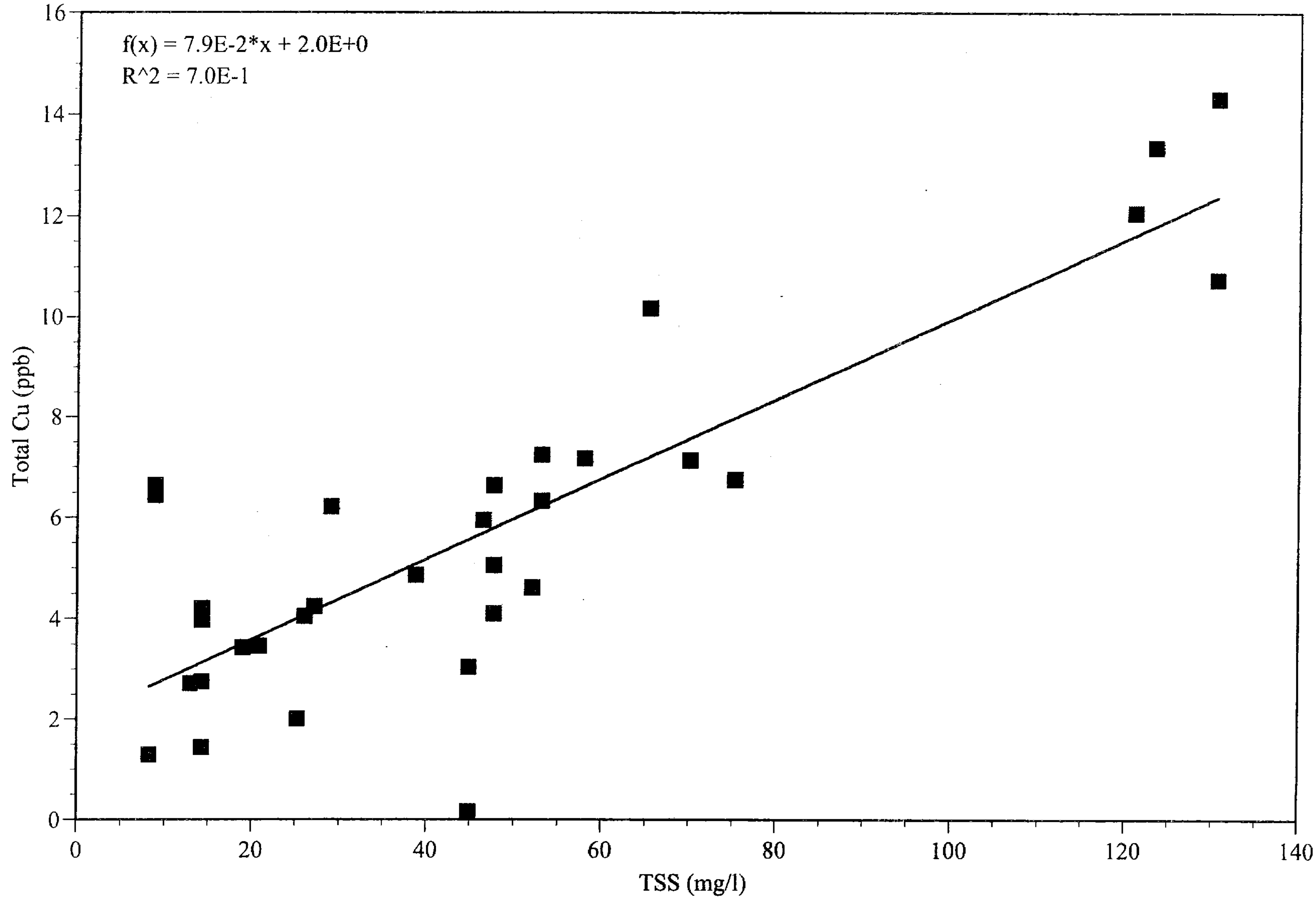

Figure 8. Regression of TSS versus total recoverable copper concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

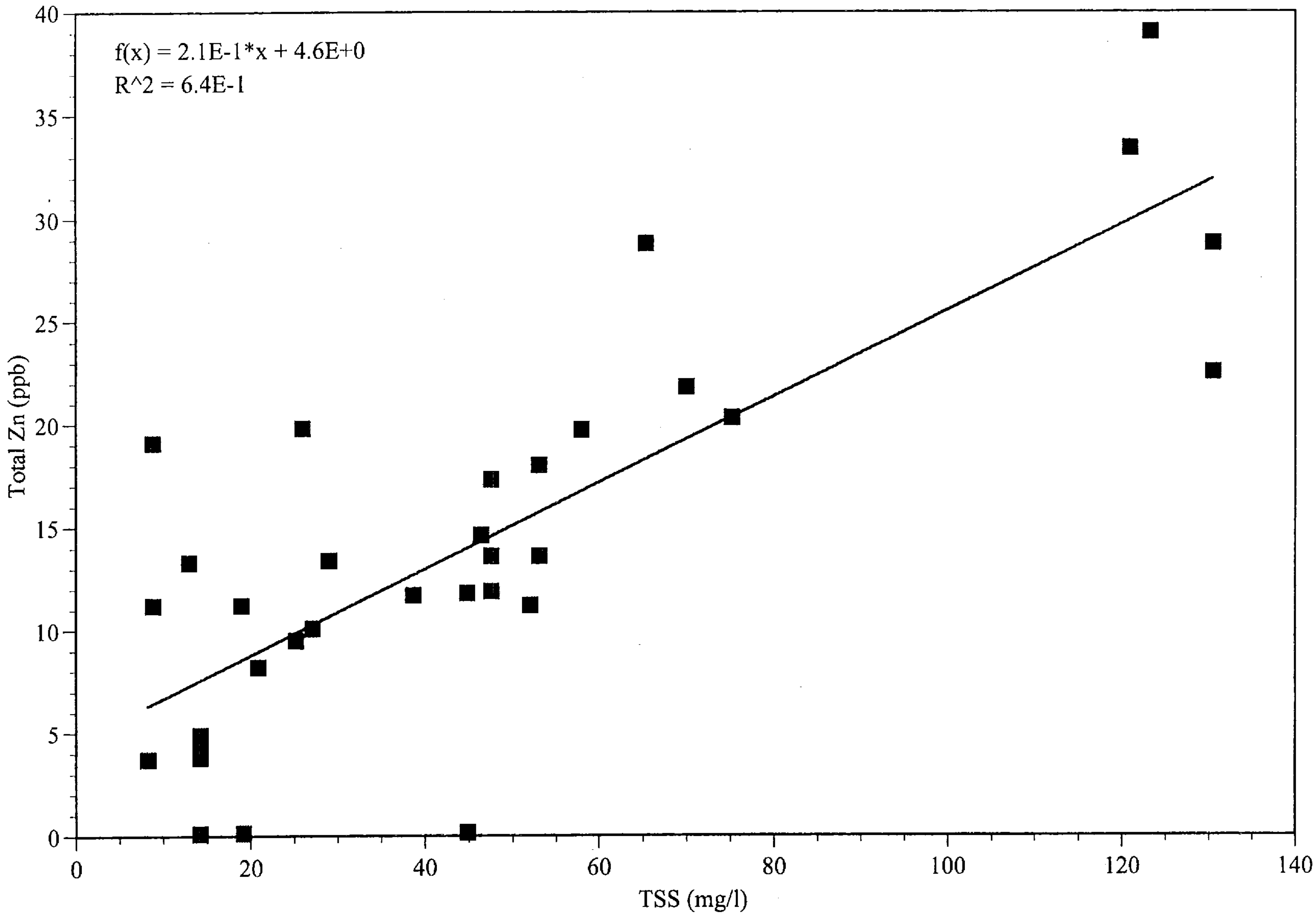

Figure 9. Regression of TSS versus total recoverable zinc concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

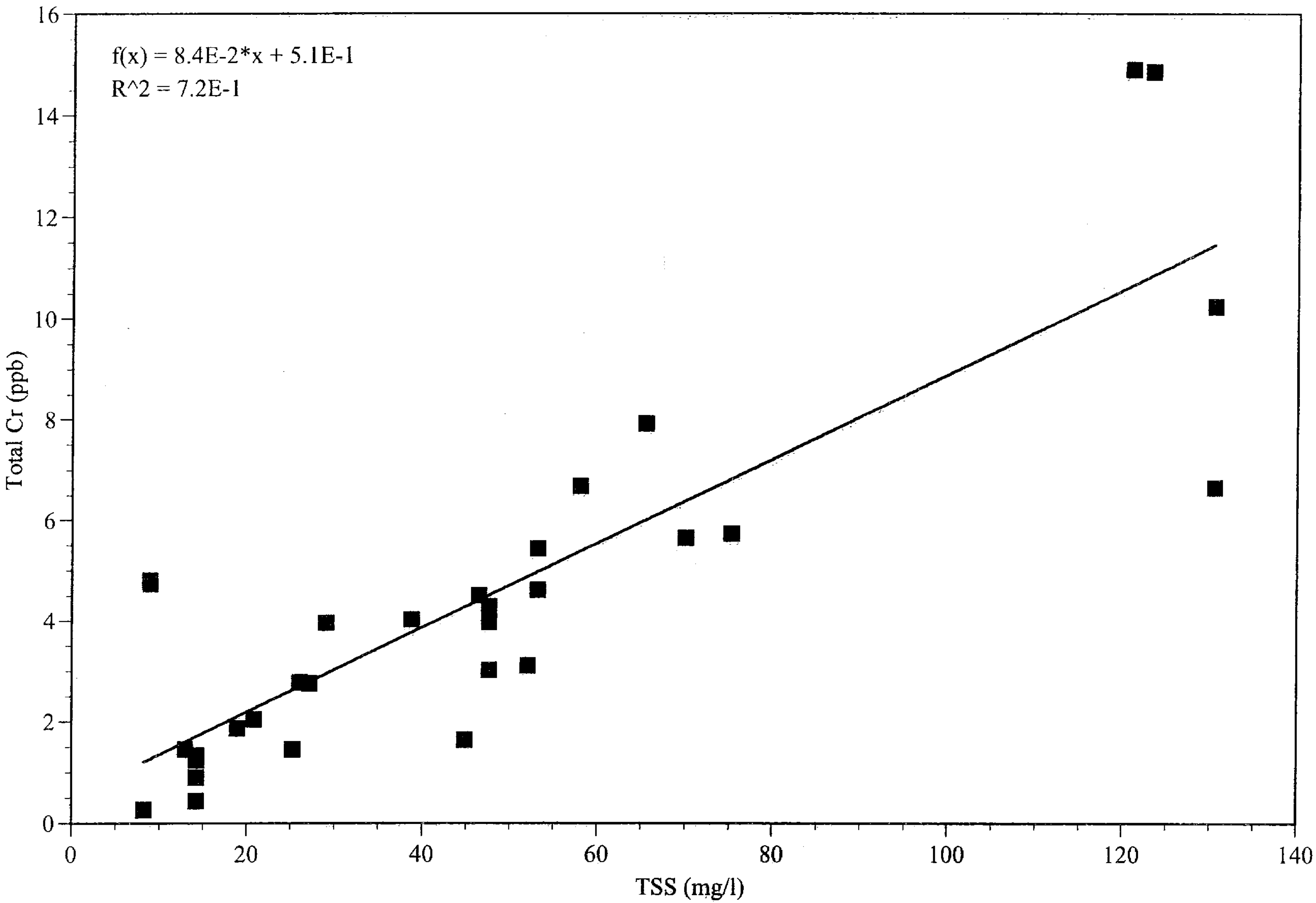

Figure 10. Regression of TSS versus total recoverable chromium concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

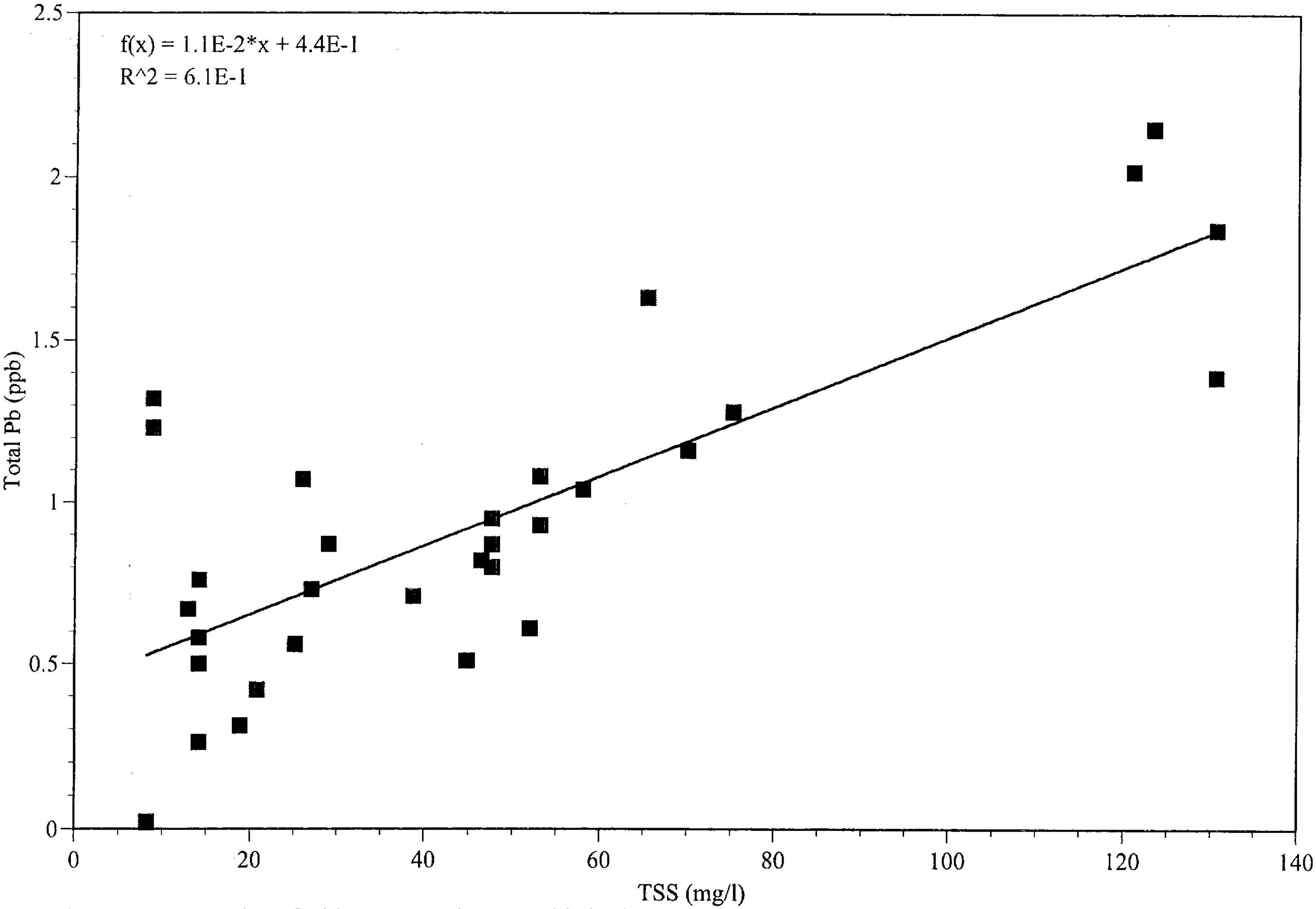

Figure 11. Regression of TSS versus total recoverable lead concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

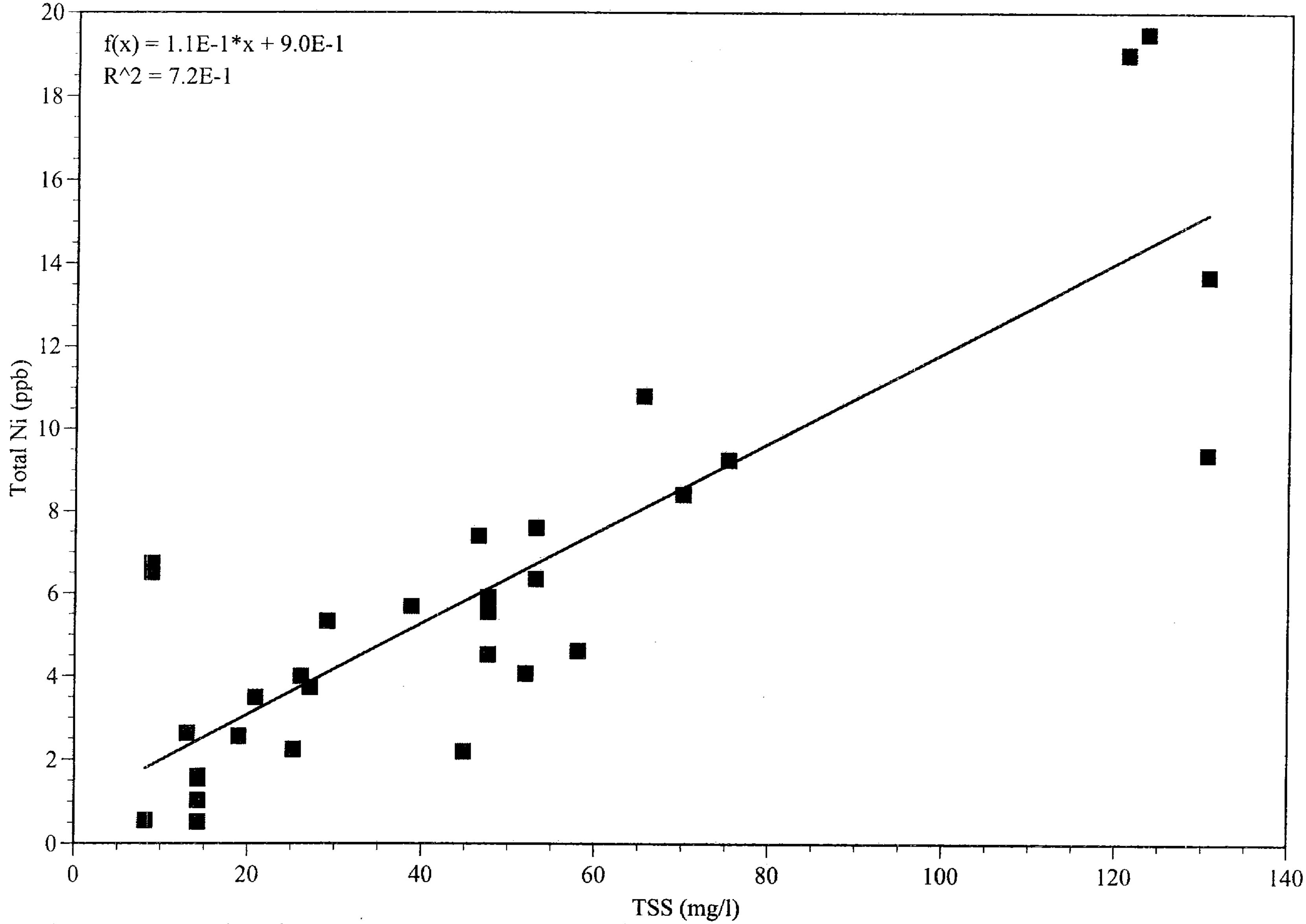

Figure 12. Regression of TSS versus total recoverable nickel concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

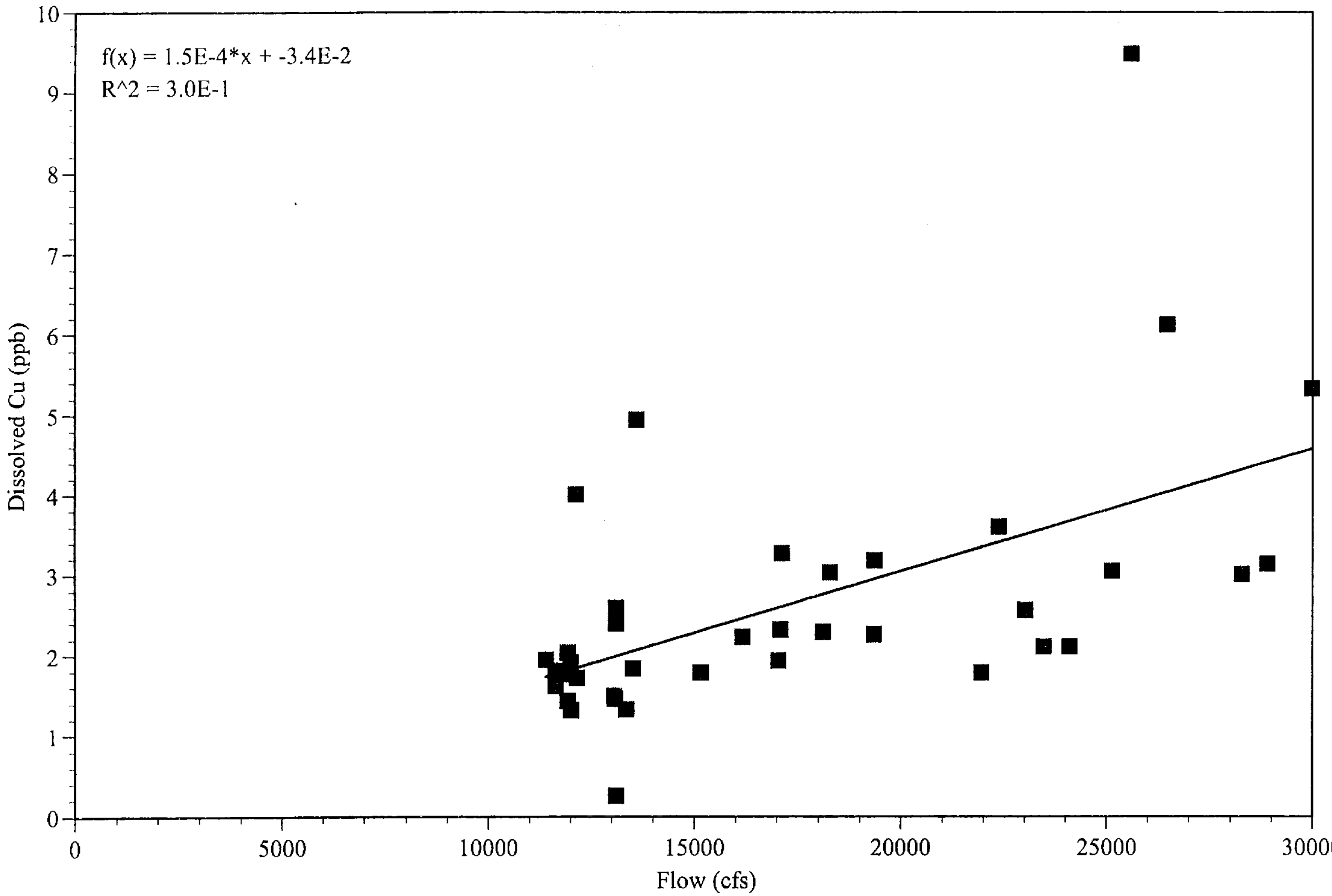

Figure 13. Regression of flow versus dissolved (0.45 µm) copper concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

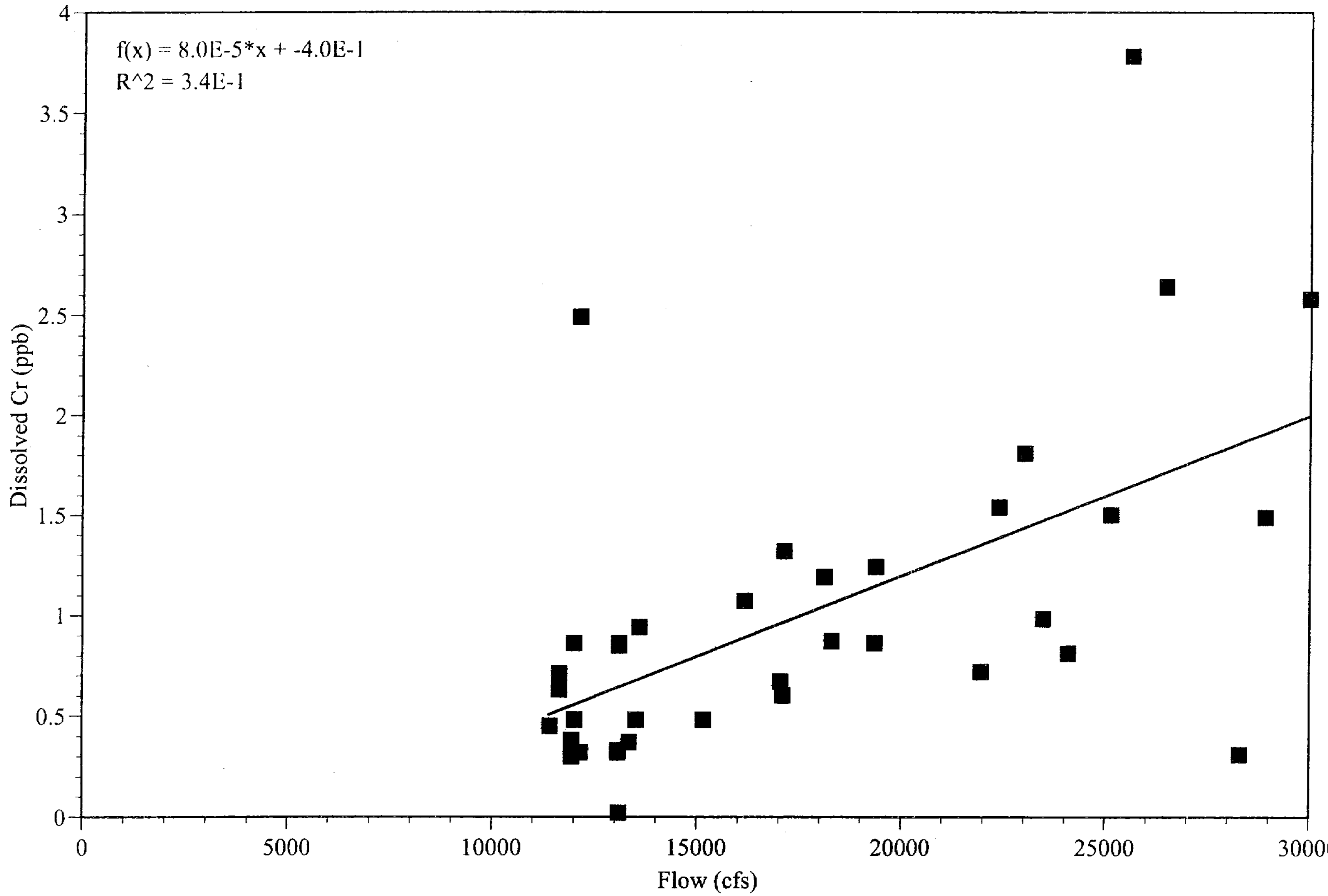

Figure 14. Regression of flow versus dissolved (0.45 µm) chromium concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

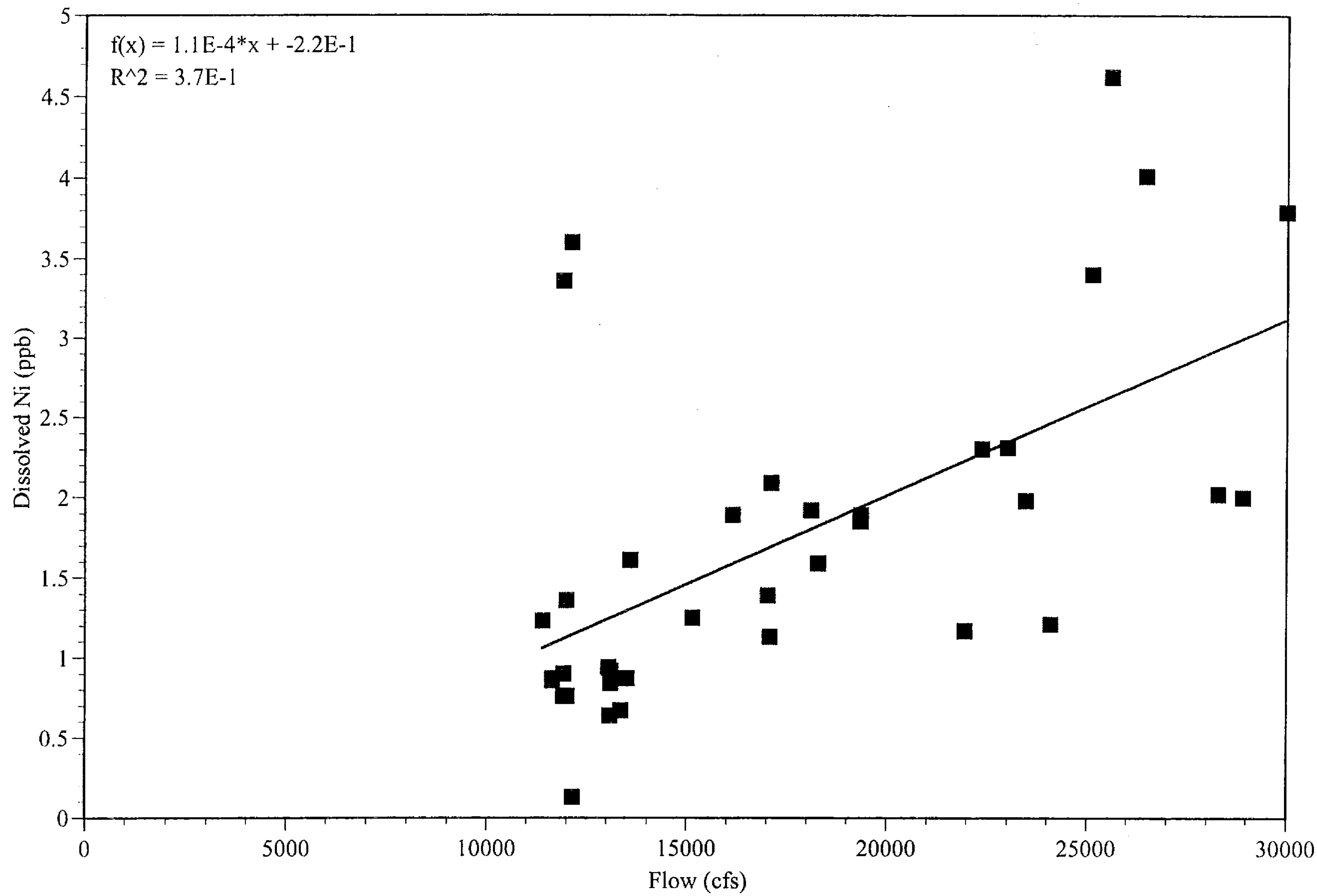

Figure 15. Regression of flow versus dissolved (0.45 µm) nickel concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

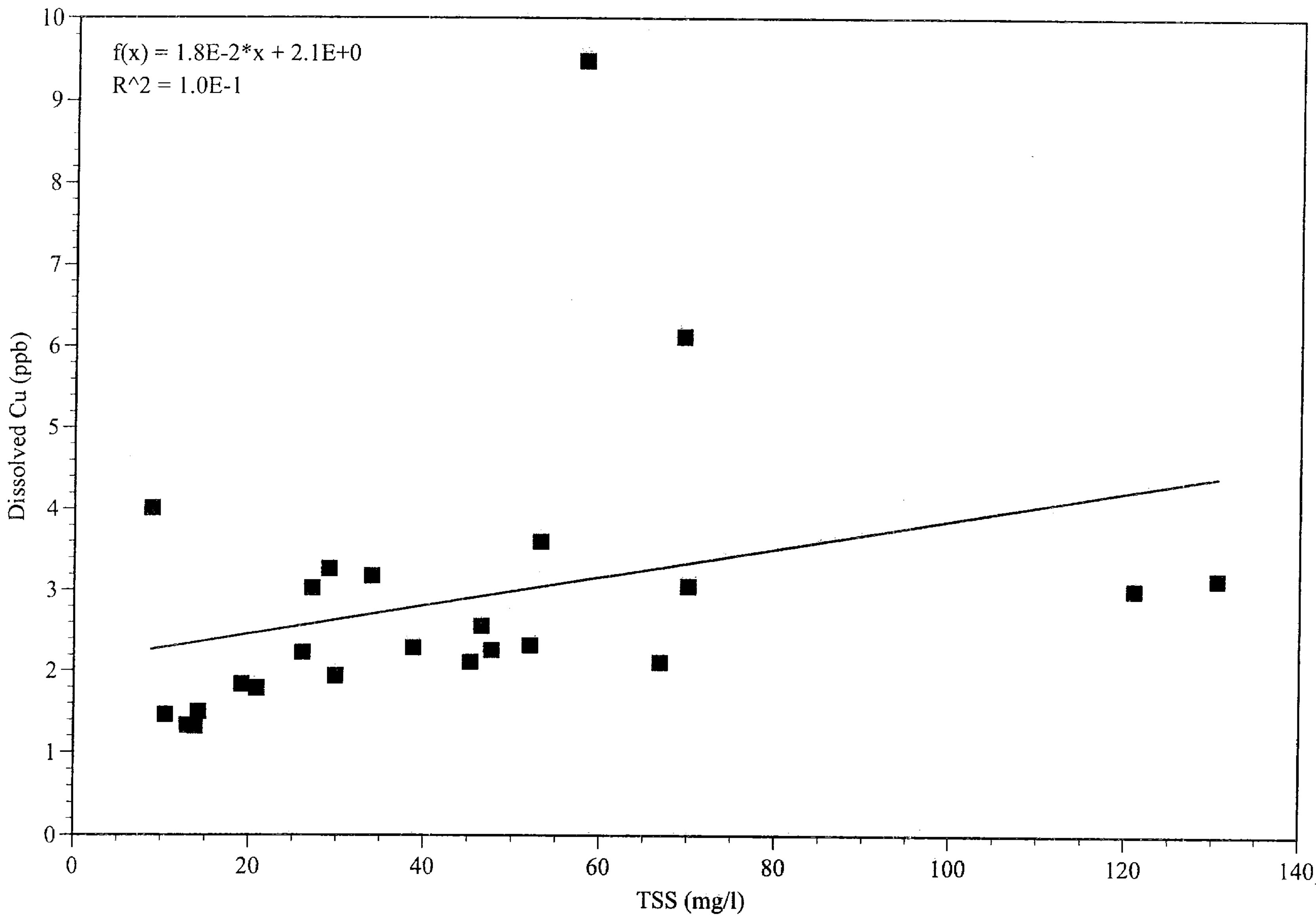

Figure 16. Regression of TSS versus dissolved (0.45 µm) copper concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

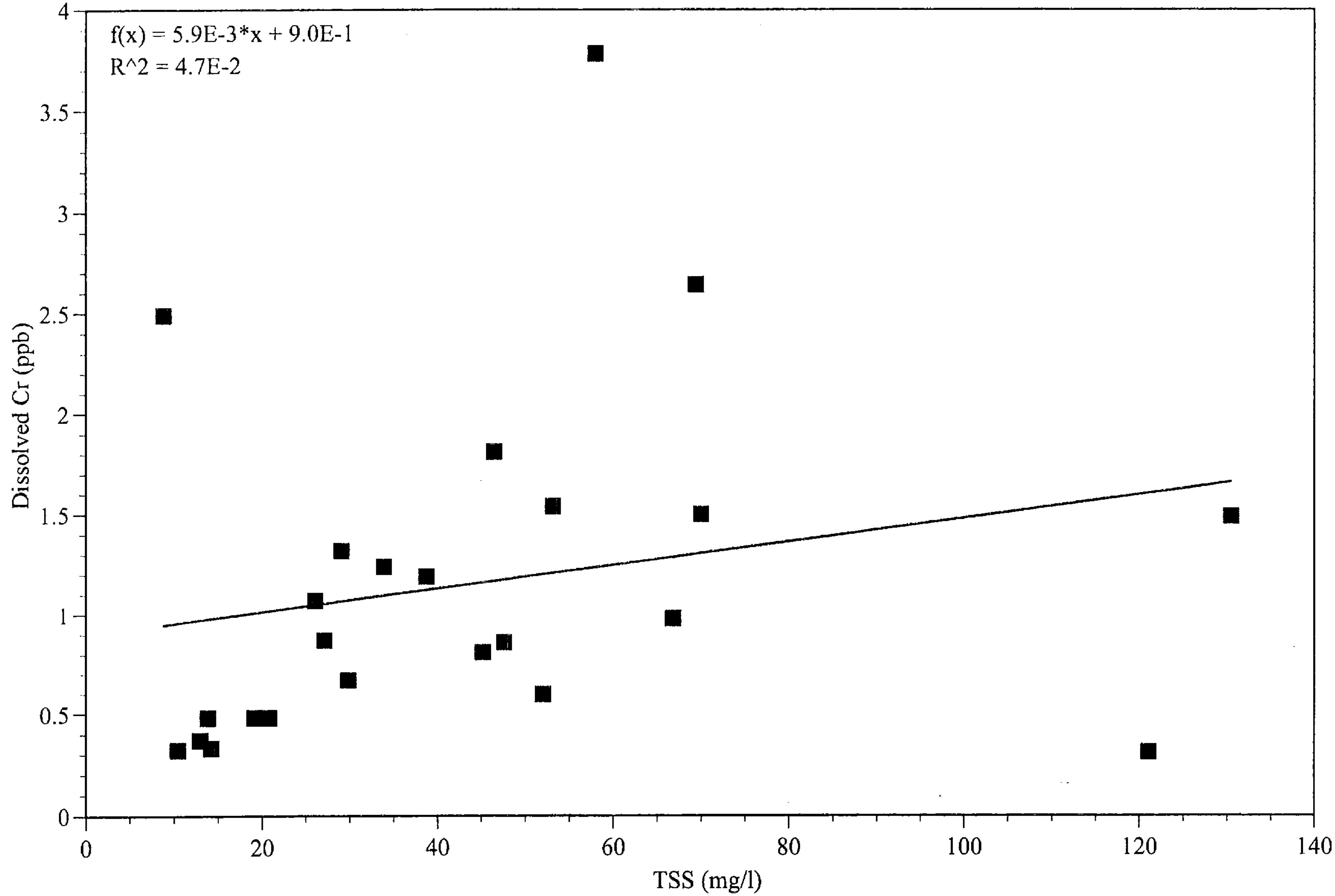

Figure 17. Regression of TSS versus dissolved (0.45 µm) chromium concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

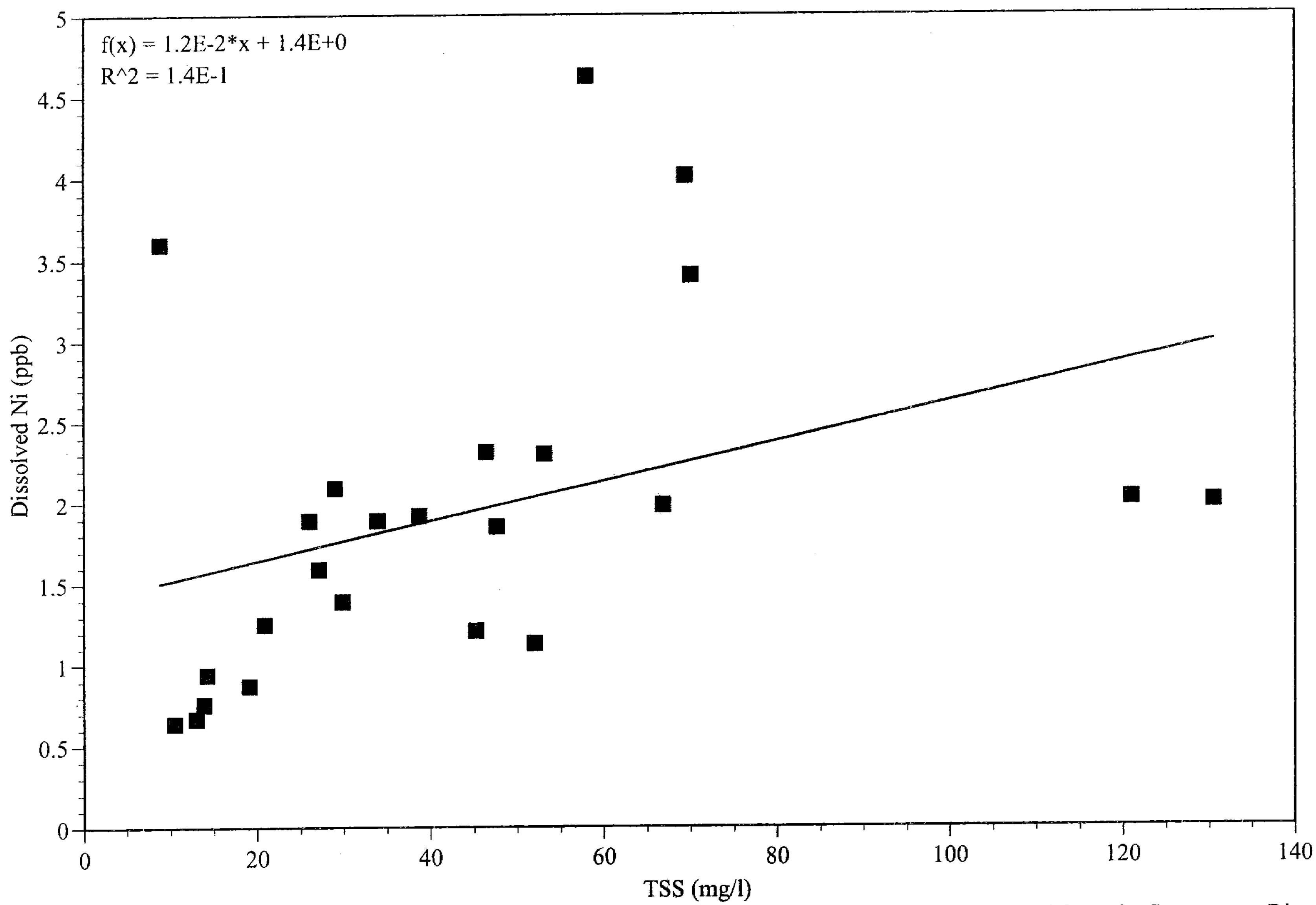

Figure 18. Regression of TSS versus dissolved (0.45 µm) nickel concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

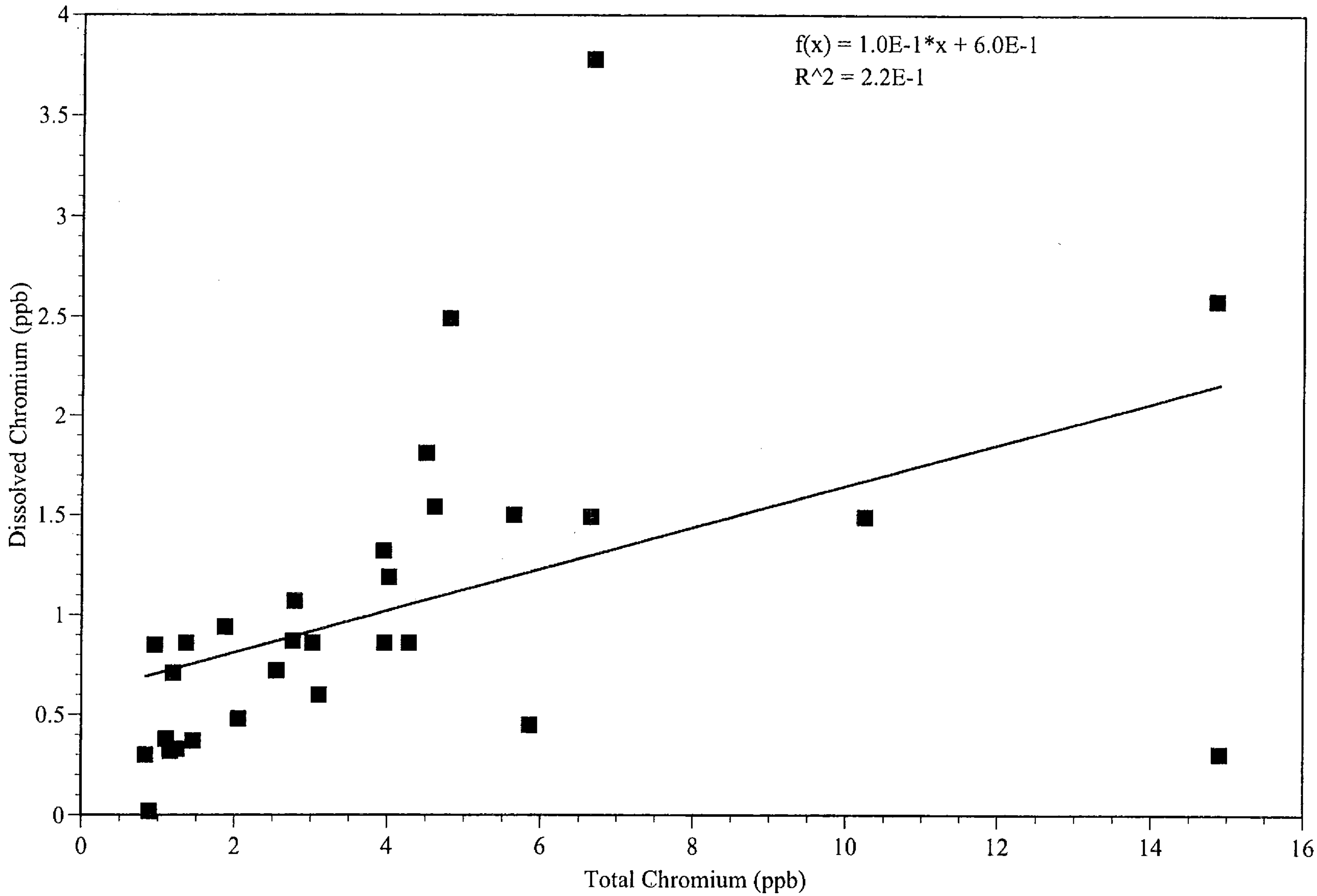

Figure 19. Regression of total recoverable chromium versus dissolved (0.45 µm) chromium in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

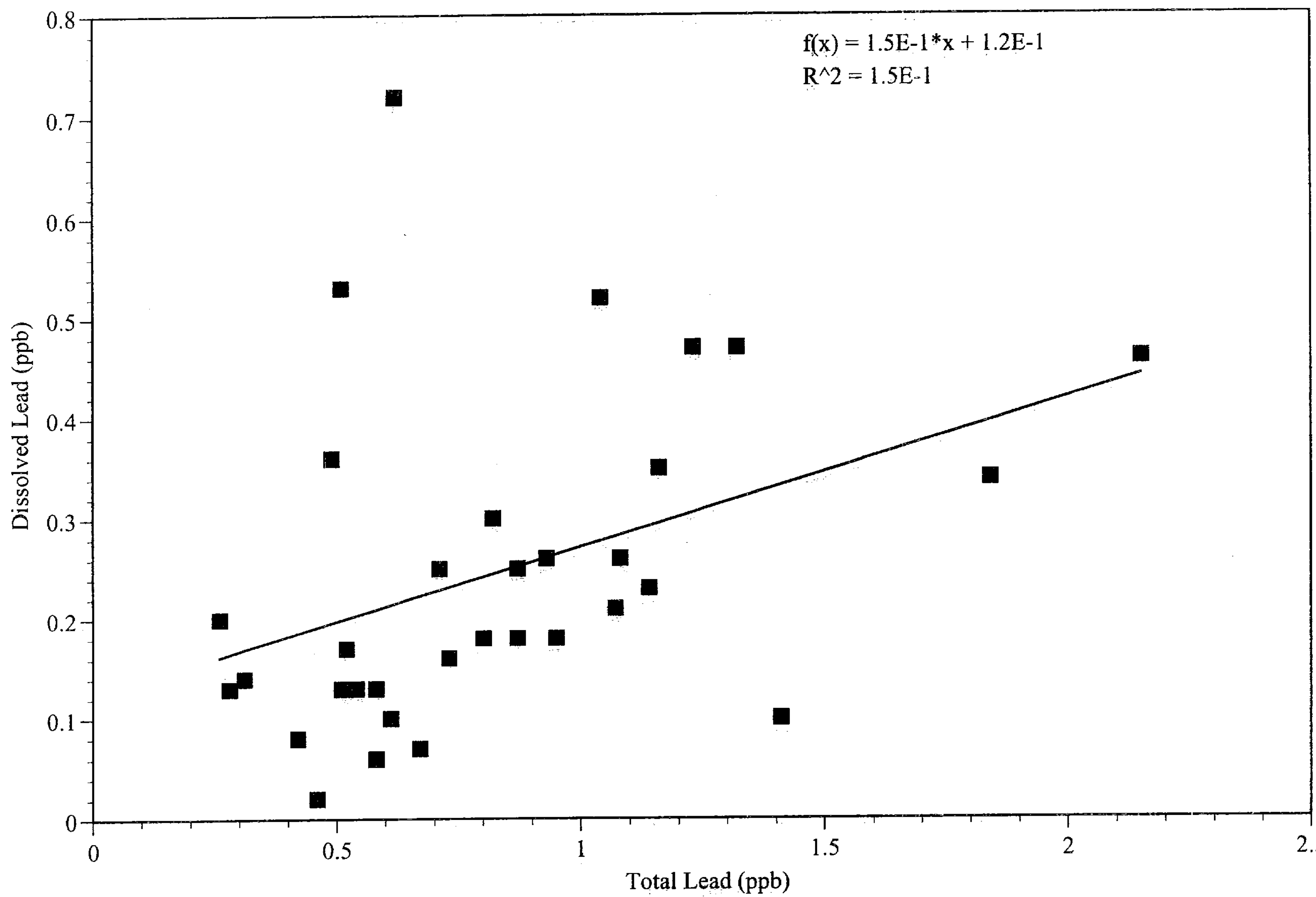

Figure 20. Regression of total recoverable lead versus dissolved (0.45 µm) lead in water samples collected from the Sacramento River at Greene's Landing during Water Year 1994.

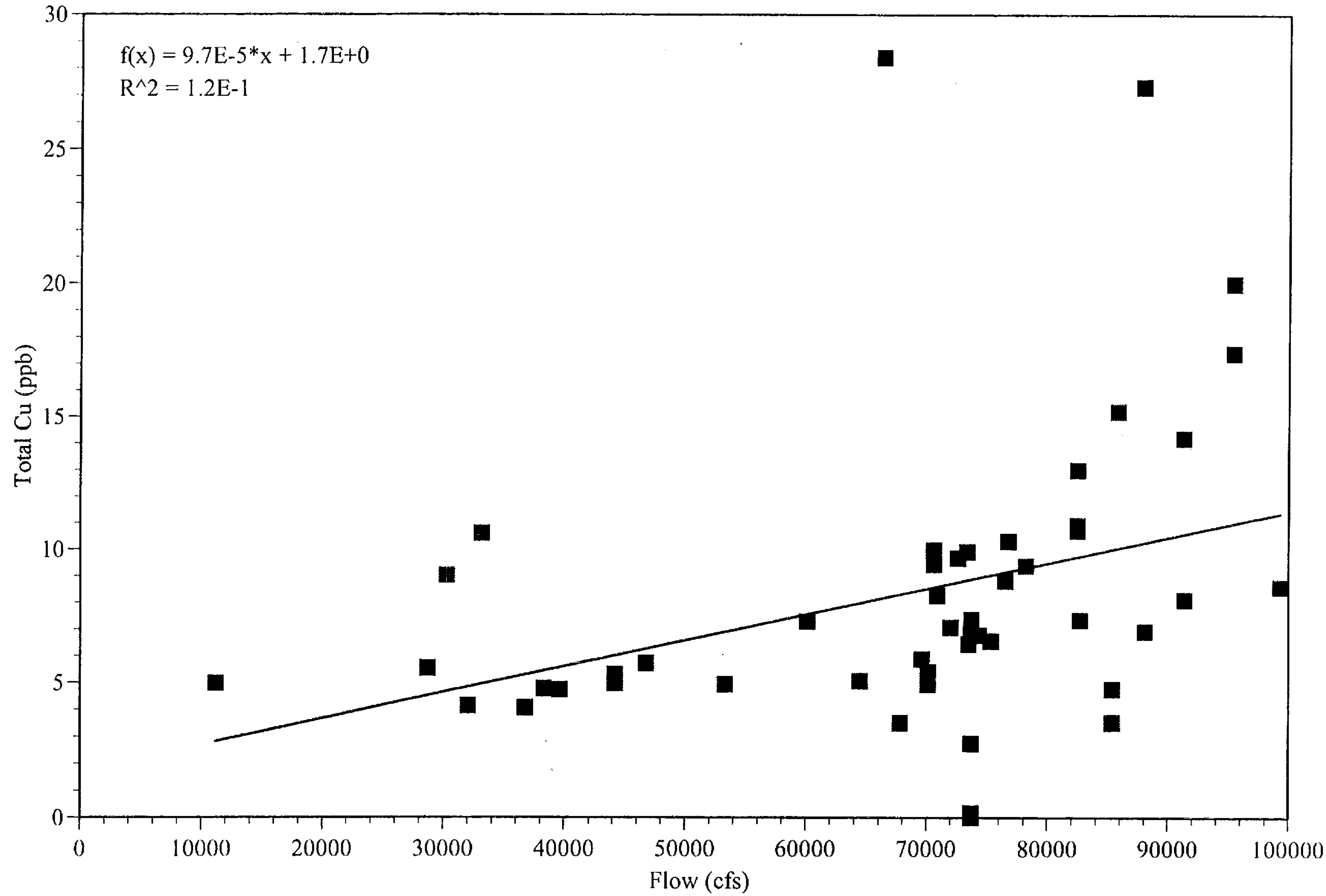

Figure 21. Regression of flow versus total recoverable copper concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1995.

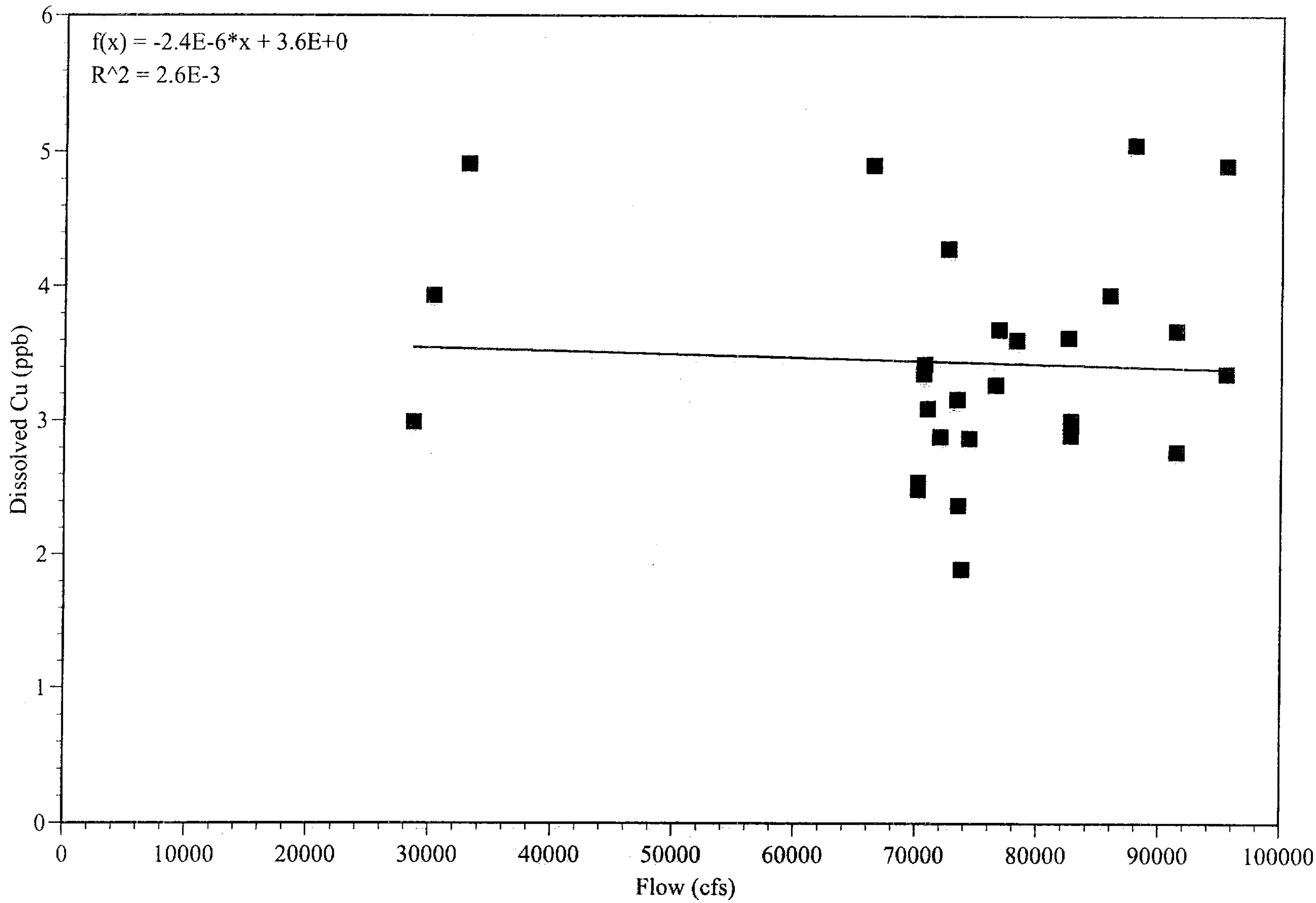

Figure 22. Regression of flow versus dissolved (0.45 μm) copper concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1995.

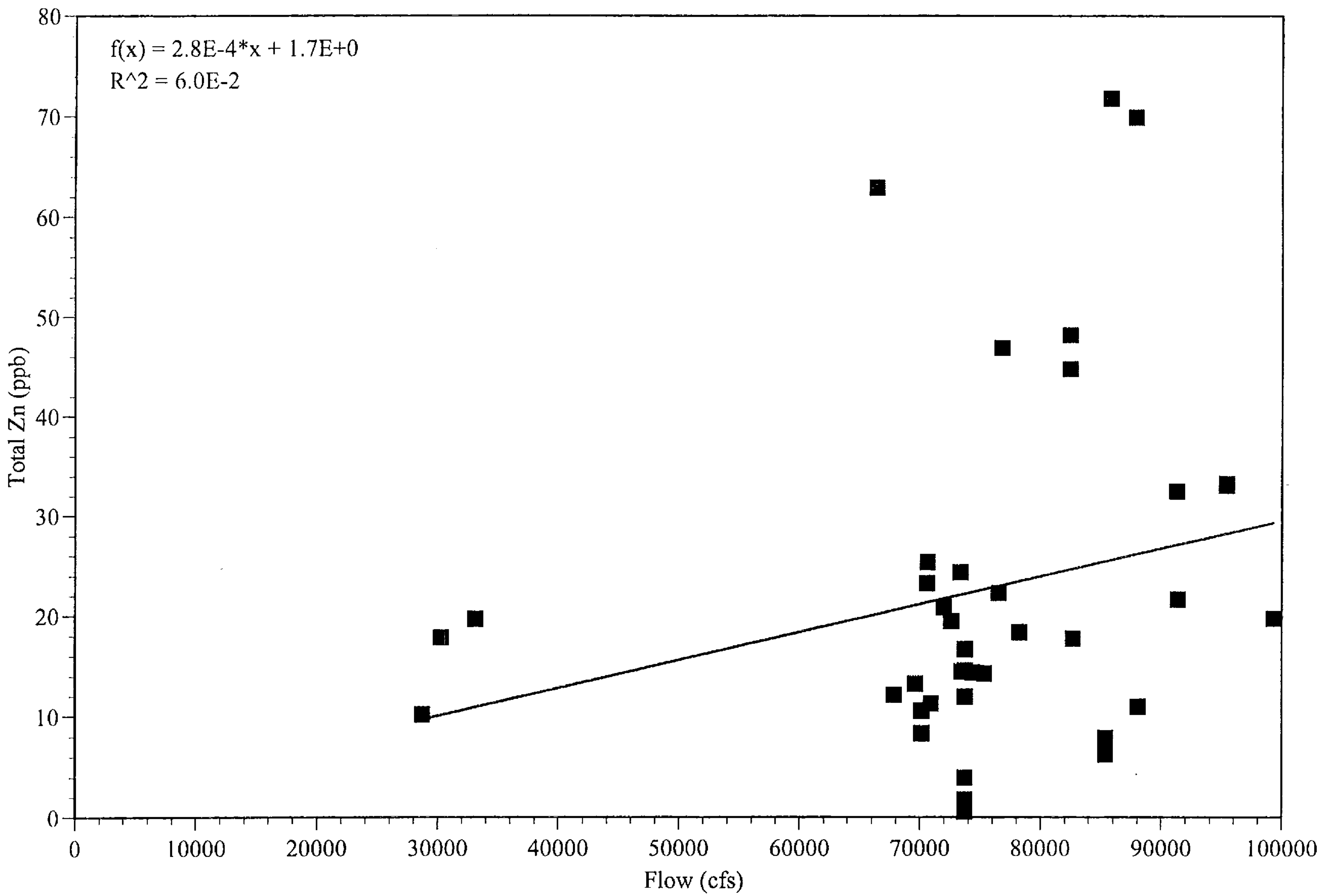

Figure 23. Regression of flow versus total recoverable zinc concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1995.

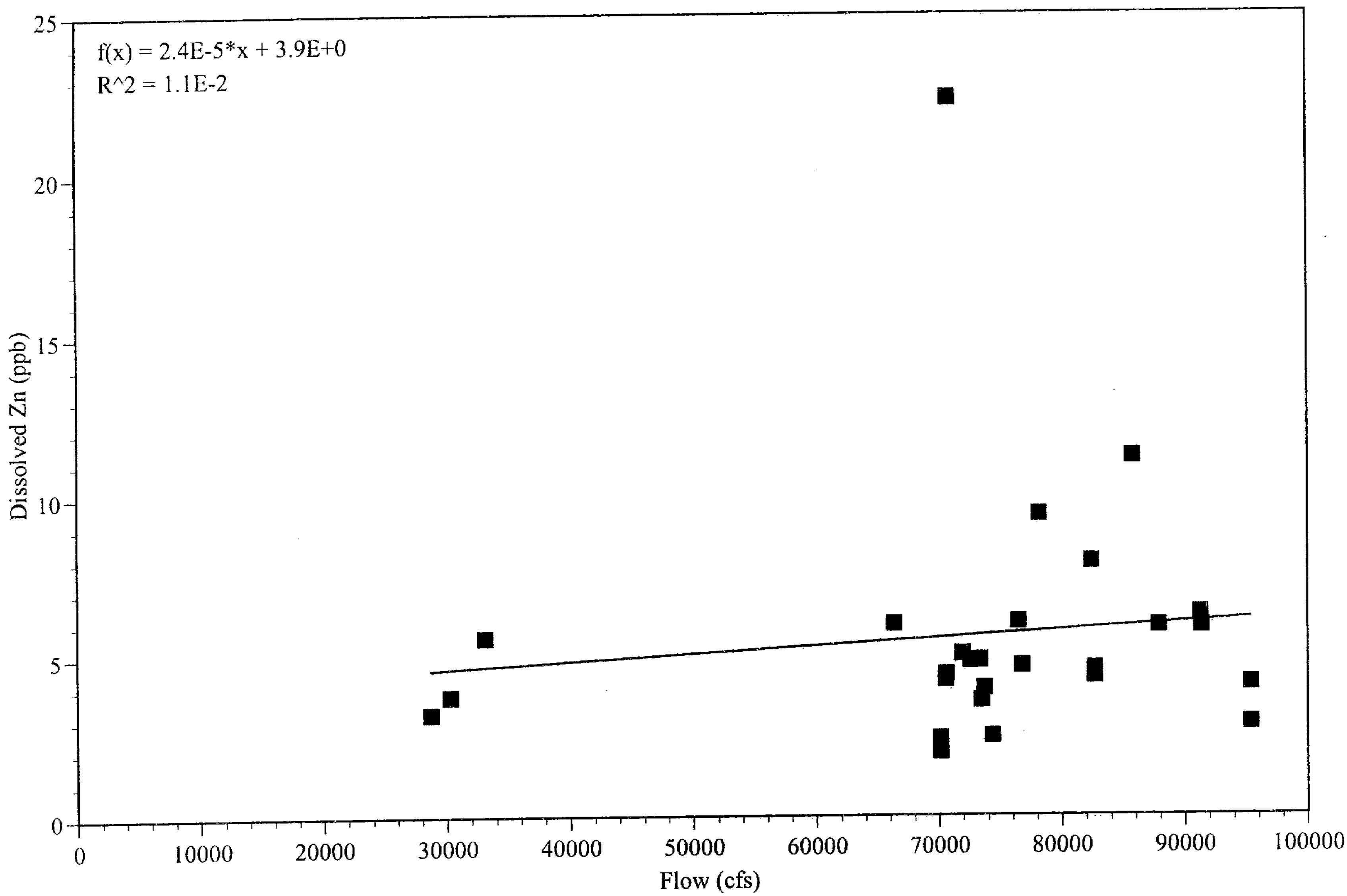

Figure 24. Regression of flow versus dissolved (0.45 µm) zinc concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1995.

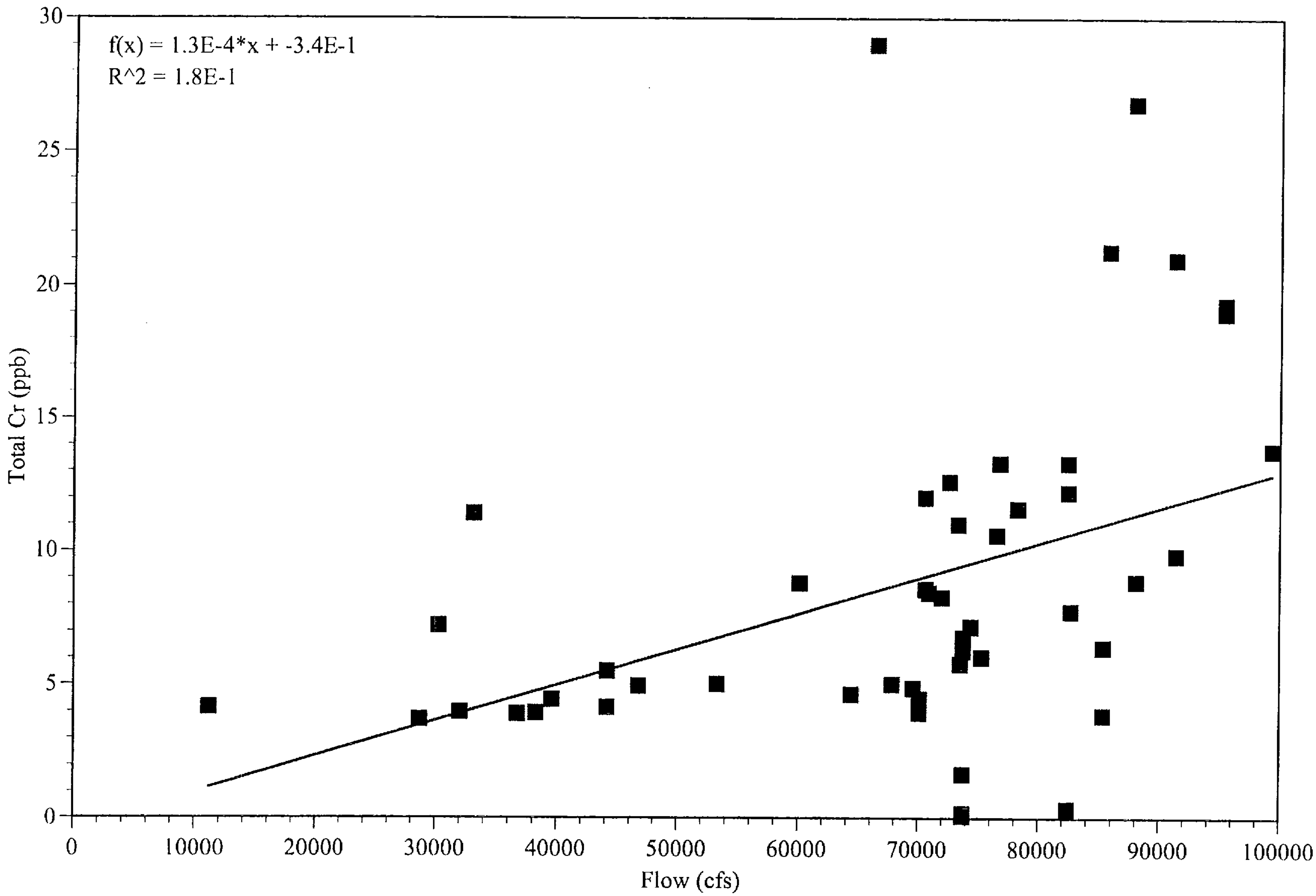

Figure 25. Regression of flow versus total recoverable chromium concentration in water samples collected from the Sacramento River at Greene's Landing during Water Year 1995.