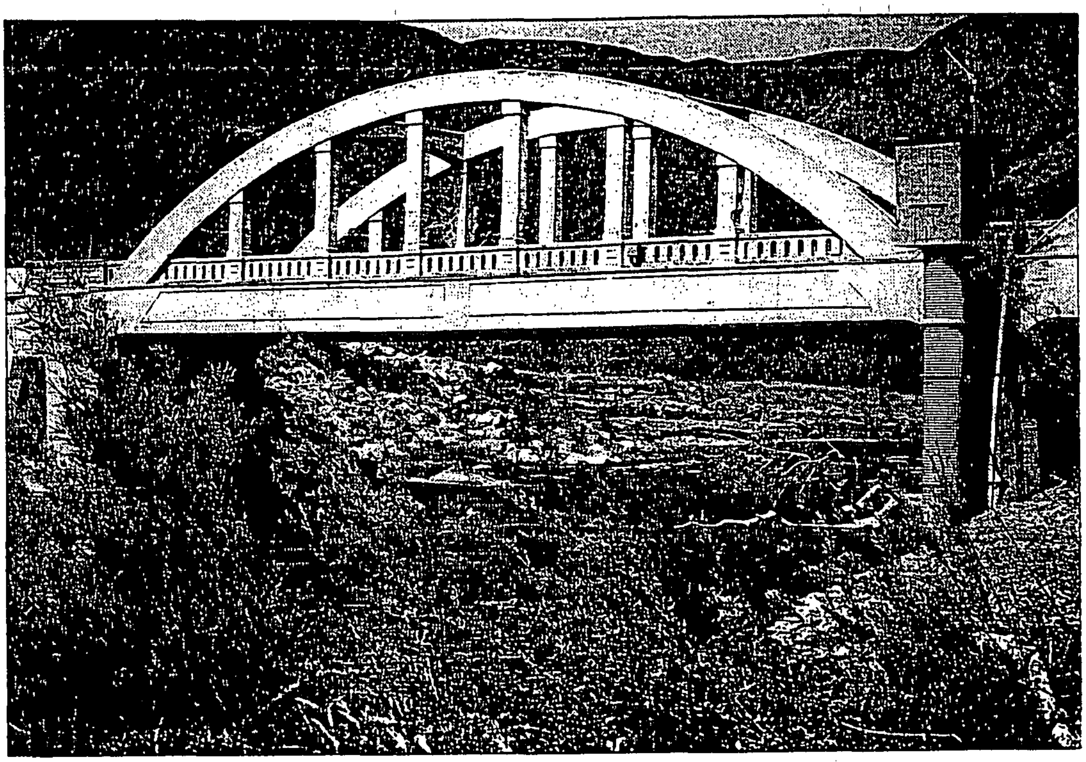
MERCURY CONCENTRATIONS AND LOADS FROM THE SACRAMENTO RIVER AND FROM CACHE CREEK TO THE SACRAMENTO-SAN JOAQUIN DELTA ESTUARY



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Cover Photo: Cache Creek at Rumsey
by Vic DeVlaming

California Regional Water Quality Control Board
Central Valley Region

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Forward

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EXECUTIVE SUMMARY During the last century mercury was mined extensively in the Coast Range and transported across the Central Valley for use in gold mining in the Sierra Nevadas. Widespread sediment mercury contamination occurred in the Coast Range, Sierra Nevadas and downstream in Central Valley rivers and in the Sacramento San Joaquin Delta-Estuary. Mercury is a potent human neurotoxin with developing fetuses and small children being most at risk. The principal route of human exposure is through consumption of mercury-contaminated fish. In 1971 a human health advisory was issued for the Sacramento-San Joaquin Delta-Estuary advising pregnant women and children not to consume striped bass. In 1994 an interim advisory was issued for San Francisco Bay recommending no consumption of large striped bass and shark because of elevated mercury levels. The Sacramento River is the major source of water for the Sacramento-San Joaquin Delta-Estuary and drains many of the major mercury mining districts north of the Estuary and all the northern gold fields.

Objectives of the study were threefold. First, measure mercury concentrations in the Sacramento River during low and high flows to ascertain whether exceedance of U.S. EPA criteria occurred. Second, use these concentrations to estimate bulk mercury loads to the Estuary from the Sacramento watershed. Finally, attempt, if exceedances of the recommended criteria were observed, to determine both the source(s) and fate of the bulk material.

Water year 1994 was classified as critically dry in the Sacramento watershed and the flow of the Sacramento River did not exceed 30,000 cfs. A positive correlation was noted between River discharge at Freeport and mercury concentration at Greene's Landing ($R^2=0.76$). The correlation suggested that exceedance of the U.S. EPA 12 ng/l total recoverable mercury criteria should occur at flow rates greater than 25,000-30,000 cfs.

Sixteen inches of rain fell in the City of Sacramento in January 1995. The combined discharge of the Sacramento River and Yolo Bypass rose rapidly and peaked on 12 January at 240,000 CFS. A second series of storms in March produced an additional 7 inches of rain. Again, the combined discharge from the Basin rose and peaked at 300,000 CFS on 13 March. Mercury concentrations were repeatedly measured in the Yolo Bypass at Prospect Slough and in the Sacramento River at Greene's Landing throughout the storm season. There was no relationship between mercury concentration and discharge rate in either waterbody. Ninety-two percent of the samples from Prospect Slough exceeded the U.S. EPA criteria of 12 ng/l; average concentration during the 4 month period was 31.75 ng/l. Similarly, at Greene's Landing the criteria was exceeded in 80 percent of the samples with an average mercury concentration of 20.0 ng/l.

Load calculations suggest that the Basin exported about 800 kg of mercury and 4 million metric tons of sediment between 1 May 1994 and 30 April 1995. About 98 percent of the material was transported during the four month high flow period. Half of the mercury and 65 percent of the sediment was exported through the Bypass.

A special study was undertaken during high flow to ascertain the spatial extent of exceedance of the U.S. EPA criteria downstream in the Estuary. The study demonstrated that riverine mercury was transported at least as far west in the Estuary as the seaward side of the Carquinez Straits at flows in excess of 110,000 CFS. This transport process appeared to sort the suspended solids, transporting the finer more mercury-enriched material further downstream. The data also suggest that exceedance of recommended U.S. EPA criteria during high flow may extend seaward to at least the landward side of the entrapment zone.

Exceedance of U.S. EPA recommended water quality criteria in both the Sacramento River and in the Yolo Bypass during high flow events suggested that there might be multiple upstream sources. Special studies were undertaken to ascertain the source of the mercury in both the upper Sacramento River and in the Yolo Bypass. Mercury concentrations were measured at 12 sites between Shasta Dam and Greene's Landing during the largest storm of the year. Elevated concentrations were observed in the upper Sacramento River between Woodsen Bridge and Ord Ferry, river miles 218 and 184. The source of the mercury was not determined. Elevated concentrations of mercury were also observed in the Yolo Bypass on 10 and 11 January 1995 (696 and 553 ng/l) suggesting a possible local source. The principal tributaries to the Yolo Bypass were sampled during two storms in 1995. The highest concentrations of mercury were consistently observed in Cache Creek implying that the watershed was a major source of mercury.

A follow-up study was initiated in Cache Creek with three objectives. First, confirm that the Basin was a major source of mercury during another water year. Second, measure mercury concentrations seasonally in the lower Basin to determine the extent of the exceedance of U.S. EPA criteria and to ascertain bulk mercury transport from the watershed. Finally, identify, if exceedances of U.S. EPA criteria were observed, the principal source(s) of the metal.

Studies conducted between 1996-1998 confirmed that Cache Creek was a major source of mercury. A correlation was noted between total mercury concentration at Road 102 and flow immediately upstream at the Town of Yolo ($R^2 = 0.83$). The relationship was employed to estimate both the frequency of exceedance of U.S. EPA criteria in the lower watershed and to determine bulk mercury exports. The correlation suggested that the U.S. EPA criteria was exceeded in the lower Basin when Cache Creek flows were greater than 100 CFS.

Cache Creek is diverted into the Settling Basin before discharge to the Yolo Bypass. Bulk mercury loads from the watershed to the Settling Basin were estimated at 980 kg/yr for water year 1995. Similarly, export to the Yolo Bypass from the Settling Basin was 495 kg/yr.

The third objective of the Cache Creek study was to determine major sources of mercury. The Cache Creek watershed is naturally divided into three subbasins: the north and south forks of Cache Creek and Bear Creek. All three waterbodies flow year-round. Thirteen mercury surveys were conducted during two hydrologic cycles and three general mercury loading patterns were observed: summer irrigation, winter non-storm runoff, and winter storm runoff events. The irrigation season occurs during the seven month period between April and October. Mercury export rates from the upper basin (above Rumsey) were on the order of 10-50 g/day with most of the metal and water coming from Clear Lake. Mercury export from the lower Basin is usually much less as most of the water (and mercury) is diverted for irrigation. The winter non-storm period is the next most common event and occurs between November and March. This study was characterized by wet winters. Mercury export rates from the upper Basin were on the order of 100-1000 g/day. Much of the mercury appeared to originate from the North Fork of Cache Creek. Finally, storm periods were least common and occurred with a frequency of 4-10 times per year. All subbasins exported significant amounts of mercury but the majority of the metal appeared to come from the Cache Creek canyon downstream of the confluence of the North and South forks but above Bear Creek. Storm export rates were on the order of 5,000-100,000 g/day. Overall, runoff from storms accounted for the majority of the mercury exported from the Basin.

Five intensive surveys were conducted during storms to attempt to identify major mercury sources in each sub-basin of the Cache Creek Watershed. Three were in Bear Creek and in the North Fork and two were float trips down the inaccessible section of Cache Creek canyon between the confluence of the North and South Forks and Bear Creek. The major source of mercury to the Bear was Sulfur Creek. Sulfur Creek drains the inactive Central, Wide Awake, Elgin, and Manzanita mercury mines and also has potentially significant natural sources of mercury from hot springs. The major sources of mercury to the North Fork were Benmore Canyon and Grizzly Creek. Both drain seven to eight square mile watersheds on the western slope of the Sulfur Creek mercury mining district. Finally, Harley Gulch was identified as a large source of mercury to the canyon area downstream of the confluence of the North and South Forks but above Bear Creek. Harley Gulch drains the inactive Abbott and Turkey Run Mines. Not yet known is whether Harley Gulch is the only major source of mercury in the canyon.

Finally, the potential bioavailability of mercury from both the Sierra Nevadas and from the Coast Range is discussed.

Introduction

Extensive deposits of mercury were discovered in the California Coast Range in the early part of the last century (Pemberton, 1983). The mines were of national significance and accounted for eighty-eight percent of the mercury extracted in the United States between 1850 and 1980. The ore was processed on site to produce elemental mercury and the waste left on steep hillsides to later erode into surface water. The mercury was used in the gold rush in the Sierra Nevadas. Gold was mined by placing sluice boxes in streams and periodically adding mercury to amalgamate the precious metal. The mercury was separated from the gold and recycled, however, over three million kilograms were believed lost in the Sierra Nevadas (Wyels, 1987). Widespread mercury sediment contamination resulted in the Coast Range and in the Sierra Nevadas and downstream in Central Valley rivers and in the Sacramento-San Joaquin Delta Estuary.

Mercury is a potent human neurotoxin with developing fetuses and small children being most at risk (White *et al.*, 1995). The principal route of human exposure is through consumption of mercury contaminated fish. In 1971 a human health advisory was issued for the Sacramento-San Joaquin Delta-Estuary advising pregnant women and children not to consume striped bass. The advisory was again released in 1993 upon review of more data. In 1994 an interim advisory was issued by the California Office of Environmental Health Hazard Assessment for San Francisco Bay recommending no consumption of large striped bass and shark because of elevated concentrations of mercury and PCBs.

Mercury biomagnifies in aquatic food chains with predacious fish, like striped bass and shark, having the highest concentrations (Wiener and Spry, 1995). At present there is uncertainty about what the appropriate mercury concentration should be in water to maintain fish at levels that do not pose a human health risk. The Central Valley Regional Water Quality Control Board's Basin Plan[1] does not have a numerical water quality objective[2] for mercury. U.S. EPA has proposed three water quality criteria[3] for mercury, two since the initiation of this study. First, in 1984 the Agency recommended that excessive concentrations in fish could be avoided if the 4-day average water concentration did not exceed 12 ng/l of total mercury more than once every three years (U.S. EPA, 1984). If concentrations were above this, then the Agency recommended that edible fish tissue be analyzed to determine whether its consumption might pose a human health risk. Second, in 1995 the Agency promulgated the National Toxics Rule recommending dissolved mercury concentrations of 1.8 ng/l to protect human health (U.S. EPA, 1995). The main

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[1] Legal document regulating water quality in the Central Valley.

[2] State adopted enforceable standard.

[3] Recommended safe value to protect all beneficial uses but, unlike a water quality objective, does not include economics or attainability in its derivation.

difference in the derivation of the two standards was that the 1995 value incorporated both bioconcentration and bioaccumulation[4] in its development while the 1985 value did not. The National Toxics Rule does not apply in California as the State had instead adopted the Inland Surface Water Plan which also contained a mercury objective. However, the Inland Plan was nullified by court action so the U.S. EPA, as required by the Clean Water Act, promulgated a draft Toxics Rule for California. The draft Ruling recommended a dissolved mercury criteria of 50 ng/l to protect human health (U.S. EPA 1997). The U.S. EPA, in deriving the draft Ruling, like with the 1985 criteria, did not consider bioaccumulation. A water quality objective for mercury will ultimately be adopted in California. Neither the method nor the value is yet known. In the interim, information is needed on ambient concentrations of mercury in the Sacramento-San Joaquin Delta-Estuary and its major tributaries to determine the values that have resulted in the present health advisories.

The Sacramento River is the major source of water for the Sacramento-San Joaquin Delta Estuary. It also drains many of the major mercury mining districts north of the Estuary and all the northern placer gold mining fields. Prior to the initiation of this study, the River was assumed to be the major source of mercury, contributing between 1 and 3 metric tons of metal per year (Gunther *et al.*, 1987). Water concentrations were thought to range between <100-300 ng/l with the higher concentrations occuring during high flow periods. However, considerable uncertainty exists about the reliability of these figures as many of the lower values were below instrument detection limits and higher concentrations were collected before the development of ultra-clean sample handling methods. Detectable mercury concentrations in surface water have dramatically decreased (often by more than two orders of magnitude) with the development of ultra-clean sample handling methods (Bloom, 1995a).

The Bay Protection Toxic Cleanup Program was created by the California Legislature in 1989 (SB 475 Torres and SB 41 Wright) and reauthorized in 1993 (SB 1084 Calderon). Purpose of the legislation was to insure protection of coastal and estuarine resources by identification of "toxic hot spots" and development of control strategies to remediate them. The definition of a hot spot included pollutants that may cause human health impacts. The presence of a striped bass mercury advisory in the Estuary was recognized as constituting a candidate hot spot. However, insufficient information was available on mercury concentrations in surface water and the source(s) and fate of the material to begin development of a control strategy.

Objectives of this study were threefold. First, measure mercury concentrations in the Sacramento River and the Sacramento-San Joaquin Delta-Estuary during low and high flow periods using ultra-clean sample handling methods to ascertain whether exceedance of U.S. EPA (1984) criteria occurred. Second, use these concentrations to estimate bulk mercury loads to the Delta- Estuary from the Sacramento watershed. Finally, attempt, if exceedances of the

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[4] Bioconcentration is a measure of the direct uptake of mercury by biota from water (mostly across gill membranes) while bioaccumulation also considers transfer through the food chain.

recommended criteria were observed, to determine both the source(s) and fate of the bulk material.

Method and Materials

Sampling for mercury was conducted in three phases. First, water samples were taken in 1993-94 at selected locations in the Sacramento-San Joaquin Delta-Estuary, including all major freshwater inputs, to establish baseline mercury concentrations. Second, the winter of 1994-95 was wet and intensive monitoring was undertaken in the Sacramento River during the high runoff period. Finally, analysis of wet weather data suggested that Cache Creek might be a major source of mercury. Therefore, extensive sampling was undertaken in the Cache Creek watershed in 1996-98 to better characterize loads and ascertain sources. The different kinds of water bodies sampled during the three phases of study necessitated using different sampling methods. Each is described below.

Estuary--Low Flow Water year[5] 1994 was classified as critically dry in the Sacramento basin. Water was collected for mercury analysis from the Sacramento River at Greene's Landing and from representative locations around the Estuary to determine baseline concentrations and estimate mercury loads from the Sacramento River during low flow (Figure 1). The location of each site is described in Appendix A. Samples were taken by boat and from the shore with a peristaltic pump as described by Goetzl and Stephenson (1993). Briefly, acid washed tubing was lowered into the fastest moving water and 10 liters of subsurface water pumped and discarded before collection of a sample. Filtered samples (0.45µm) were taken by the same method after the addition of an inline filter. A water sample was also collected by the same procedure for total suspended solids (TSS). TSS was analyzed at the UC Davis Aquatic Toxicology Laboratory using Standard Methods (1989).

High Flow The discharge rate of the Sacramento Basin increases during storms. High flows are discharged down the Sacramento River and through the Yolo Bypass. Wet weather mercury samples were collected from the lower Sacramento River at Greene's Landing and by boat from Prospect Slough at the base of the Yolo Bypass (Figure 1). Subsurface water samples were taken at both locations by triple rinsing a weighted acid-washed one gallon borosilicate glass bottle with ambient water and rapidly lowering and retrieving it from the bottom to insure that water was collected from all depths. The contents were vigorously shaken and samples decanted for mercury and TSS analysis.

Cache Creek Cache Creek is an 1100 square mile watershed in the Coast Range. Water courses are small and low flow samples were taken by wading into the stream, facing upstream, triple rinsing and filling mercury and TSS bottles with subsurface water. High flow samples were collected from the bank by dipping a pole into the fastest moving water. All TSS samples, unlike

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[5] Water year 1994 is defined as the time period between 1 October 1993 and 30 September 1994. Water years types are classified in California according to the natural water production of the major basins.

during the estuary portion of the study, were analyzed at California Laboratory Services[6] using Standard Methods (1989).

Mercury analysis Mercury was analyzed at Frontier Geosciences[7] using methods described in their 1996 operating manual. Frontier Geosciences provided, except during Cache Creek sampling, double bagged acid cleaned Teflon bottles filled with acidified ultra clean water. Because of higher mercury concentrations in Cache Creek, double bagged borosilicate glass was provided instead. All samples were collected using ultra-clean sample handling methods (Bloom, 1995b). Samples were stored on ice and sent within 3 days to Frontier Geosciences for analysis. Some samples for dissolved mercury were collected from both the Sacramento River and from Cache Creek during high flow. These were collected as whole water samples and sent to Frontier Geosciences within 3 days for filtration (0.45μm).

Flow rates Daily water discharge rates for the lower Sacramento River at Freeport and for the Yolo Bypass were obtained from the U.S. Geological Survey (1994).

Cache Creek has three main tributaries: the South and North Forks and Bear Creek (Figure 2). South Fork flows were estimated from discharge records for Clear Lake Dam (U.S. Geological Survey, 1996;1997;1998). The flow rate of the North Fork at the Highway 20 bridge was estimated from a discharge curve developed in 1996 by the California Department of Water Resources. The curve was calculated by surveying the cross sectional area of the channel at the bridge as a function of depth and multiplying the corresponding area by the measured water velocity. Next, the curve was correlated with the distance from the water surface to a fixed point on the bridge (Figure 3). High flows in late February 1997 appeared to alter the cross section. A new discharge relationship was not established as no additional need for flow estimates was anticipated. One more set of flow measurements was calculated for the North Fork for 2 February 1998. The flow at Hwy 20 was calculated from the old relationship and is labeled a "rough estimate" in the accompanying results and discussion section. Bear Creek has an electrical conductivity (EC) approximately ten times greater than Cache Creek. The flow of the Bear (F_B) was estimated from the following formula:

$$F_B = (EC_{D/S} - EC_c)/(EC_B - EC_{D/S}) \text{ X } F_R$$

where EC_B and EC_c are the electrical conductivity of Bear and Cache Creek above their confluence and $EC_{D/S}$ is the downstream value after mixing. F_R is the downstream flow of Cache Creek at Rumsey. Flow rates at Rumsey were obtained from the Department of Water Resources (California Data Exchange Center, 1997). Discharge from Cache Creek into the

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[6] California Laboratory Services, 3249 Fitzgerald Rd, Rancho Cordova, CA

[7] Frontier Geosciences Inc., 414 Pontius Ave North, Seattle, Wash.

Cache Creek Settling Basin was obtained from U.S. Geological Survey data at the town of Yolo (U.S. Geological Survey, 1996;1997;1998). Discharge rates from the Settling Basin to the Yolo Bypass were assumed to be the same as the flow rate into the impoundment.

Finally, no flow data were available for small Cache Creek tributaries during the source identification phase of the study. Instead, the area of each watershed was estimated as an indication of its potential water production rate. Watershed areas were estimated by tracing and cutting out their boundaries from a 7.5 minute U.S. Geological Survey topographic map, weighing the pieces on an AE100 Mettler balance and normalizing against the known weight of a piece of paper representing a one square mile area.

Precipitation Rainfall values were obtained for the City of Sacramento and for the Indian Valley Reservoir from the Department of Water Resources (California Data Exchange Center, 1993).

Loads Bulk daily mercury loads (kg/day) were estimated by multiplying flow (CFS) by mercury concentration (ng/l):

$$(\text{Hg concentration})(2.445 \text{ X } 10^{-6})(\text{Flow})$$

Similarly, daily sediment loads (thousand metric tons/day) were calculated by multiplying TSS (mg/l) by flow (CFS):

$$(\text{TSS})(2.445 \text{ X } 10^{-6})(\text{Flow})$$

Load estimates for longer time periods were estimated by summing the daily loads.

Mercury Quality Assurance/Quality Control Program About 15 percent of all mercury analyses were for quality assurance and quality control purposes. The program had both a field and a laboratory component.

Field The field portion consisted of the collection of blanks and field duplicates. On 16 occasions field blanks were collected. During the estuarine portion of the study, this consisted of pumping laboratory water with known mercury concentration through the peristaltic tubing in the field. Changes in concentration were determined to ascertain whether field contamination was occuring while sampling. During Cache Creek sampling the procedure was modified to consist of filling a one gallon acid-washed borosilicate glass bottle with glass distilled laboratory water and using this to triple rinse and fill a Teflon mercury bottle in the laboratory. The remaining water was transported into the field and used in a similar fashion to fill a second bottle at a randomly selected site. Differences between laboratory and field concentrations were again used to check for contamination during sampling.

On 49 occasions duplicate samples were taken in the field at randomly selected sites. A field duplicate consisted of taking a second sample after about a ten minute wait at a site. Differences in mercury concentration between the paired samples were used to assess field variability.

Laboratory The quality assurance/quality control program at Frontier Geosciences consisted of both amendments and replicate analysis of the same sample. On 39 occasions a known amount of mercury was amended into a randomly selected field sample and the percent recovery measured. On 34 occasions two analysis of the same sample were undertaken and the percent difference noted. The purpose of the amendments and of the replicate measurements was to ascertain the accuracy and precision of the analyses. Finally, on one occasion replicate samples were sent to both Texas A&M[8] and to Frontier Geosciences for analysis. The field replicates were prepared by triple rinsing each mercury bottle and an acid-washed one gallon borosilicate bottle in site water, filling the larger bottle, shaking vigorously and decanting into both sets of mercury bottles. Differences in concentration were again used to assess the accuracy and precision of the Frontier method.

Total Suspended Solids Analysis of the mercury quality assurance quality control data demonstrated an increase in variability of duplicate field samples collected in Cache Creek. Therefore, duplicate field samples were taken on several occasions for TSS to ascertain whether the increase in mercury variability was due to an increase in TSS variance.

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[8] Dr Gary Gill's Laboratory

Results and Discussion

The results are discussed in four parts. The first is an evaluation of the mercury quality assurance/quality control program. The second is a summary of concentrations, loads, sources and fate of mercury in the Sacramento-San Joaquin Delta Estuary during low and high flow periods. Cache Creek was determined to be a major source of mercury so the next section summarizes information on sources, concentrations and magnitude of loads exported from the Cache Creek Basin. Finally, the potential bioavailability of mercury from the Sierra Nevadas and from the Coast Range are discussed.

<u>Quality Assurance/Quality Control--Mercury</u> The program consisted of a laboratory and field component. The laboratory portion consisted of the analysis of intra laboratory duplicates and amendments and interlaboratory splits. On 34 occasions field samples were reanalyzed to assess precision. The mean percent difference between paired analyses during the seven year study was 3 percent (Appendix B; Table 1). No difference was noted between years ($P>0.25$, analysis of variance). On 39 occasions a known amount of mercury was amended into a field sample and percent recovery calculated to assess accuracy. The mean percent recovery was 103 percent (Appendix B; Table 2). Again, no difference was noted between years. Finally, on one occasion ten samples were split between Frontier Geosciences and Texas A&M University. The mean percent difference for total and dissolved mercury was 9 and 12 percent, respectively (Appendix B; Table 3).

The field portion of the quality assurance/quality control program consisted of the analysis of blanks and field duplicates. On 16 occasions laboratory water was carried into the field and handled in a manner analogous to a field sample to check for contamination during sampling. The mean change in mercury concentration was 0.04 ng/l, range 0-0.9 ng/l (Appendix B;Table 4) suggesting minimal field contamination. Finally, on 48 occasions duplicate field samples were collected to assess the repeatability of the measurements. Mean annual percent difference varied between 4-15 percent for large Rivers and for the Estuary but increased to 14-34 percent in Cache Creek (Appendix B;Table 5). The percent difference between Cache Creek and all other locations was statistically significant (analysis of variance, $P<0.05$). The increase in field variability in the Creek does not appear to be a laboratory artifact as no similar inter-annual difference was noted in either laboratory accuracy or precision (Appendix B;Tables 1 and 2). Rather, the data suggest that mercury concentrations were not uniform over short time periods in the turbulent, nonlinear flow characteristic of the Creek. Larger differences appeared more common in the most turbulent flow.

<u>Total Suspended Solids</u> Twenty-four duplicate field samples were collected for total suspended solids (TSS) from Cache Creek during high flow to ascertain whether differences in mercury concentration resulted from differences in TSS concentration. The mean percent difference in TSS was 8 percent (Appendix B;Table 6). The value was a quarter to a half of the annual difference in mercury concentration suggesting that changes in mercury were not primarily the

result of changes in TSS. Further evidence for the fact that differences in mercury concentration were not the result of differences in TSS was the fact that on four occasions both mercury and TSS were measured on split samples (Appendix B;Table 6). Mercury concentration varied on average by 41 percent while TSS only changed by 6 percent. The results suggest that mercury was not uniformly distributed within the TSS load in Cache Creek.

In conclusion, the mercury quality assurance/quality control program demonstrated minimal field contamination, a high degree of accuracy and precision in the laboratory analyses but a 15-35 percent difference in replicate field samples collected from Cache Creek. Higher values were obtained primarily in the turbulent nonlinear flow suggesting a non homogenous distribution of mercury in the water column. The Cache Creek results suggest that caution should be exercised in interpreting these mercury data.

Estuarine mercury Objectives of the estuarine portion of the study were to determine whether exceedances of the recommended U.S. EPA (1984) criteria occurred and to develop bulk mercury load estimates for the Sacramento River, the largest tributary to the Estuary. If exceedances of criteria were detected, then follow-up work was done to determine the source(s) and fate of the material. Results are presented below for low and high flow periods.

Low flow Water year 1994 was classified as critically dry in the Sacramento watershed and the flow of the Sacramento River did not exceed 30,000 cfs. TSS and mercury samples were collected in the Sacramento River at Greene's Landing (Table 1). A positive correlation was noted between River discharge at Freeport and both mercury (Figure 4) and TSS concentration (Figure 5). The correlation between mercury and flow suggests that exceedance of the 12 ng/l U.S. EPA criteria should occur in the Sacramento River at flow rates greater than 25,000-30,000 cfs.

On four occasions water was collected in 1993-94 for mercury analysis from all three major riverine inputs to the Delta--the Sacramento, San Joaquin, and Mokelumne Rivers and also from selected downstream locations (Table 2;Figure 1). All concentrations were less than the recommended U.S. EPA criteria of 12 ng/l, half were less than 4 ng/l. Furthermore, on seven occasions dissolved mercury concentrations were measured. Dissolved values ranged between 0.97 and 1.61 ng/l or about 35 percent of the total mercury concentration. No value exceeded the U.S. EPA National Toxics Rule value of 1.8 ng/l (U.S. EPA, 1997).

Mercury and TSS loads were determined for the Sacramento River by multiplying the daily discharge rate by the correlation equation relating flow to either mercury or TSS and summing over the time period of 1 May 1994 to 1 January 1995. The results suggested that the River exported about 20 kg mercury and 100 thousand metric tons of sediment during the nine month period (Table 3).

High flow Sixteen inches of rain fell in the City of Sacramento in January 1995 (Figure 6). The combined discharge of the Sacramento River at Freeport and of theYolo Bypass at U.S. Interstate

5 rose rapidly and peaked on 12 January at 240,000 CFS. A second series of storms in March produced an additional 7 inches of rain. Again, the combined discharge from the Basin rose and peaked at 300,000 CFS on 13 March.

TSS and mercury were measured almost daily during the first storm at Greene's Landing in the Sacramento River and at Prospect Slough in the Yolo Bypass (Table 4;Figures 7 and 8). Only periodic sampling was conducted during the second storm.

The Yolo Bypass discharges back into the Sacramento River through Prospect and Skag Sloughs (Figure 1). Water samples were collected from both Sloughs on 5 occasions and analyzed for mercury and TSS to determine whether Bypass water was mixed upon reentry to the Sacramento River (Table 5). No statistical difference was noted between sites for either parameter (paired T-test, $P>0.1$) suggesting that the values reported for Prospect Slough could be considered representative of the entire discharge from the Bypass.

A strong positive correlation was noted between TSS and mercury concentration at Prospect Slough ($R^2=0.97$) and at the Sacramento River at Greene's Landing ($R^2=0.87$) suggesting that most of the metal was bound to sediment. Four dissolved mercury samples were collected from the Slough and from the River. Dissolved concentrations ranged between 1.6 and 5.8 ng/l and were consistently about 20 percent of the total concentration lending additional support to the hypothesis that most of the metal was attached to particulate material.

There was no apparent relationship between either TSS or mercury and discharge rate in either the Sacramento River or in Prospect Slough during high flow ($P>0.05$; $N>30$ samples at each location). This is contrary to the low flow findings (Figures 4 and 5).

Mercury concentrations were measured on 26 and 47 occasions in Prospect Slough and in the Sacramento River at Greene's Landing during the January to April high flow period (Table 4). Ninety-two percent of the time the concentration at Prospect Slough exceeded the U.S. EPA criteria of 12 ng/l. The average concentration during the 4 month period was 31.75 ng/l. Similarly, at Greene's Landing the criteria was exceeded 80 percent of the time. The average mercury concentration was 20.0 ng/l.

Three dissolved mercury measurements were taken at Greene's Landing and one at Prospect Slough (Table 4). No value exceeded the California Toxics Rule concentration of 50 ng/l. However, 2 of the three measurements at Greene's Landing and the single value for Prospect Slough exceeded the National Toxics Rule concentration. The dissolved and total recoverable mercury data demonstrate that exceedance of the U.S. EPA recommended 12 ng/l and of the National Toxics Rule value of 1.8 ng/l are common in winter during high flow.

Loads during high flow were estimated by multiplying discharge by the average TSS or mercury concentration for the entire period. Load calculations suggested that the Basin exported about 800 kg of mercury and 4 million metric tons of sediment between 1 May 1994 and 30 April 1995

(Table 3). About 98 percent of both materials were transported during the four month high flow period between January and April. Half of the mercury and 65 percent of the sediment was exported through the Bypass. The mercury load estimate appears consistent with results of a study by Larry Walker and Associates (1997) who calculated that the Sacramento watershed exported 620 kg of mercury between October 1994 and September 1995. The Larry Walker load estimate did not include inputs from the Coast Range to the Yolo Bypass. Like this study, Larry Walker found that most of the mercury was mobilized at high flow. Research in other river systems have also noted that most of the mercury load is transported during high flow (Balogh *et al.*, 1998;Hoffman and Taylor, 1998).

The total suspended solid loads transported by the Sacramento River into the Estuary represent "new" surficial sediment. No difference was noted in the mercury content (Hg/TSS) of material moved by the Sacramento River during low and high flow periods (Table 1 and 4; P>0.1, t-test). The average mercury concentration of TSS in the Sacramento River was 0.23 ppm dry weight. In contrast, the mercury content of suspended sediment in the Yolo Bypass was lower than in the Sacramento River during high flow periods and averaged 0.19 ppm (Table 4;Figure 9). However, the concentration of all this material was higher than the reported average crustal abundance of mercury (0.08 ppm dry weight;Taylor, 1964). The values are also greater than the 0.05 ppm mercury concentration reported for sediment deposited in the Estuary prior to the gold rush (Bouse *et al.* 1997). Interestingly, all Sacramento watershed values are less than the average surficial sediment concentration of 0.32 ppm dry weight now present in San Pablo Bay (Schoellhamer, 1997).

Fate A special study was undertaken during high flow to ascertain the spatial extent of exceedance of the U.S. EPA criteria downstream in the Estuary and to determine the fate of the mercury loads exported from the Central Valley.

The Sacramento Basin had a relatively constant combined outflow of about 116,000 CFS (range: 110,400-138,000 CFS) between 27 January and 3 February 1995 (Table 4). Mercury concentrations were taken daily at Greene's Landing and four times during the seven day period at Prospect Slough. Mercury, TSS, and electrical conductivity were averaged for each water body and flow weighted to estimate an average export concentration for the seven-day time period at Rio Vista (Table 6). The estimated average seven-day concentration for mercury, TSS and electrical conductivity was 18.0 ng/l, 95.4 mg/l, and 89.0 µmho/cm.

The travel time of water masses through the western Delta is not well established. However, diazinon pulses were followed down the Estuary in 1994 when the system had a combined export rate of 60,000 cfs (Kuivila and Foe, 1995). Travel times between Rio Vista and Chipps Island and between Rio Vista and Martinez were 2 and 5 days, respectively. Downstream travel rates were likely to have been faster in 1995 than in 1994 as the average flow rate in 1995 (116,144 CFS) was almost twice that of 1994. These velocities imply that a water mass located off Rio Vista on 27 January-3 February 1995 should, conservatively, have been transported to Chipps Island by 29 January-5 February and to Martinez by 1 to 8 February.

A special survey was undertaken on 5-6 February 1995 to measure mercury, TSS, and electrical conductivity in the lower Estuary (Table 7, Figure 1). All samples were taken at mean lower low tide. Electrical conductivity gradually increased seaward from 115 at Chipps Island to 220 µmho/cm on the surface under the I-80 bridge off Mare Island. The water column was well mixed at both Chipps Island and at Martinez with surface and bottom conductivities being similar. Strong depth stratification was observed at Mare Island suggesting a large gravitational circulation in the western Carquinez Straits.

Mercury concentration remained similar seaward with values at Martinez and on the surface at Mare Island being 90 and 97 percent of those calculated for Rio Vista (Table 7). No mercury value is available for the bottom landward flow at Mare Island as controlled experiments demonstrated that the Van Doren bottle used to collect the sample was contaminated. TSS, in contrast to mercury, decreased westward in the Estuary. Values at Martinez and on the surface at Mare Island were 61 and 62 percent of those at Rio Vista. TSS concentrations on the bottom at Mare Island were higher than on the surface and were similar to Rio Vista. The mercury and TSS data are consistent with the conclusion that material from the Sacramento watershed is transported at least as far west in the estuary as the entrance to San Pablo Bay. The data also suggest that exceedance of the recommended U.S. EPA criteria may occur as far west in the Estuary as Mare Island under high flow conditions characteristic of the winter and spring of 1995.

Schoellhamer (1995) measured TSS concentrations at mid depth in San Pablo Bay at 15 minute intervals during 1995 and reported elevated TSS concentrations in both January and March associated with both high outflow events. The elevated TSS was attributed to runoff from the Sacramento watershed. In contrast, the RMP (1995) sampled trace elements including mercury in the western Estuary on 13-15 February 1995, about ten days after this study. Flows had decreased significantly (Figure 6) and electrical conductivity off Pacheco Creek (several miles upstream of Martinez) had increased to 7,900 µhmos/cm. Mercury concentrations between San Pablo Bay and the confluence of the Sacramento River ranged between 6 and 20 ng/l and no longer reflected an elevated riverine input. Evaluation of data from Schoellhamer, the RMP and this study emphasize the importance of short term episodic events in controlling the transport and loading of contaminants in the Estuary.

Schoellhamer (1995;1997) reported a strong positive correlation between TSS and mercury concentrations in San Francisco Bay. The ratio of mercury/TSS was about 0.32 ppm. Consistent with this value is the observation of Bouse *et al.* (1997) that surficial sediments in San Pablo Bay average 0.15 to 0.35 ppm mercury. These observations seem at variance with the conclusion of this study and of Bouse *et al* (1997) that riverine inputs are a major source of estuarine mercury. Mercury/TSS ratios for the Yolo Bypass and for the Sacramento River averaged 0.19 and 0.25 ppm dry weight for the high flow period (Table 4;Figure 9). However, these disparate facts may be reconciled by the observation that TSS decreased more rapidly than did mercury concentration upon transport downstream in the Estuary (Table 7). As a result, the ratio of mercury/TSS increased from 0.19 at Rio Vista to 0.30 ppm in surface water off Mare Island on 6 February

1995. The underlying mechanism may be density separation with the heavier, coarser TSS particles settling out more rapidly than the presumably more mercury-enriched fines. Other researchers have reported that the fine, more organically enriched suspended sediment has higher mercury concentrations (Baldi and Bargagli, 1981;Benoit *et al.*, 1994; Rust and Waslenchwek, 1976) but to our knowledge no one has yet suggested that this non-uniform distribution may result in an increase in mercury concentration in surficial sediment upon transport seaward in the Estuary.

In conclusion, the special mercury fate study demonstrated that riverine mercury was transported at least as far west in the Estuary as the seaward side of the Carquinez Straits at flows in excess of 110,000 CFS. This transport process may act to sort the TSS, transporting the lighter more mercury enriched samples further downstream. The data also suggest that exceedance of recommended U.S. EPA criteria during high flow may extend seaward to at least the landward side of the entrapment zone.

Sources Exceedance of U.S. EPA recommended criteria in both the Sacramento River and in the Yolo Bypass during high flow events suggested that there might be multiple upstream sources. Special studies were undertaken to ascertain the source(s) of mercury in both the upper Sacramento River and in the Yolo Bypass. Each is described below.

Upper Sacramento River A special survey was undertaken between 10 and 13 March 1995 to ascertain the origin of the sediment and mercury loads measured at Greene's Landing. Samples were taken on the Sacramento River from all the major bridges between Shasta Dam and Greene's Landing and also from several of the largest tributary inputs. The sampling period corresponded to the largest storm of the year (Figure 6); combined outflows from the basin peaked on 13 March at 297,000 CFS.

Results of the special survey provided a snapshot of a river basin rapidly filling with water (Table 9 and Figure 10). Most of the water volume was contained in the mid section of River between Woodsen Bridge and Ord Ferry. Discharge from Shasta Dam on 10 March was 9,800 CFS. Flows increased downstream peaking at 130,000 CFS at Woodsen Bridge and declining thereafter to 42,000 CFS at the City of Colusa (97 and 175 miles from Shasta, respectively). Most of this large mass of water must have originated from the many small creeks located between Bend and Woodsen Bridge. On the westside these include Springs, Reeds, Red Bank and Elder Creeks and on the eastside Paynes, Antelope and Mill Creeks. Both TSS and mercury concentrations increased with the increasing volume of water. Maximum concentrations at Woodsen Bridge were 852 mg/l and 87 ng/l, respectively. As with flow, the concentration of both constituents declined thereafter to a minimum at the City of Colusa. Calculations suggest that 271,000 metric tons of sediment and 27.8 kg of mercury were transported past Woodsen Bridge on 10 March.

These observations are consistent with the conclusions of both Larry Walker and Associates (1997) and Alpers (personal communication). Larry Walker and Associates noted that the largest loads of mercury in the Sacramento River came during storms from above the confluence of the Feather River. Similarly, a metal transport study by Alpers consistently noted an increase in mercury load in the Sacramento River between the Cities of Redding and Colusa during both wet and dry weather. Neither study identified the source(s).

Results of this study suggest that one or more major mercury sources are located in the 40-mile reach of Sacramento River between Bend and Woodsen Bridge. The drainage is above any known Coast Range mercury deposits and Sierra Nevada placer gold mining activity. Likely initial mercury source(s) for evaluation are the many small east and westside tributaries that are believed to have contributed most of the volume of water. Detailed studies are needed to identify the major source(s) of this mercury.

High flows were also observed in the Feather and American Rivers. However, unlike the upper Sacramento River, both contained much lower concentrations of mercury (Table 8 and Figure 10). As a result the two River basins are calculated to have exported only 3.5 and 0.3 kg of mercury on 11 March 1995. These loads are again consistent with the conclusions of Larry Walker and Associates (1997) who found that the Sacramento Basin above the confluence of the Feather River contributed 58 percent of the basin's annual mercury load. The Feather and American Rivers were only estimated to have exported 31 and 9 percent, respectively.

The capacity of the Sacramento River below Greene's Landing is 100,000 CFS. The Sacramento and Fremont Weirs are gradually opened at flows greater than 60,000 CFS and increasing volumes of water allowed to pass down the Yolo Bypass (Figure 1). All additional water is diverted into the Bypass at flows greater than 100,000 CFS. The combined flow of the American and Feather Rivers on 11 March was 112,000 CFS (Table 8). Therefore, most of the water flowing past Greene's Landing is expected to have originated from these two watersheds while the majority of the flow in the Bypass should have come from the upper Sacramento River.

The ratio of mercury/TSS at Greene's Landing is consistent with an American and Feather River origin. Values for 9 to 18 March vary between 0.28 and 0.30 ppm (Table 4). Values for the American and Feather Rivers on 11 March were 0.40 and 0.63 ppm, respectively.. Some decrease in the average of the two ratios might be expected because of bedload scour. In contrast, with the exception of the Sacramento River at Redding, the ratio of mercury/TSS in the upper Basin varied between 0.07 and 0.15. The ratio at Redding was 0.4 ppm. The amount of suspended sediment load at Redding is small (Table 8) and should have been diluted out by the large volume of unenriched mercury material entering downstream.

The ratio of mercury/TSS observed at Greene's Landing on 9 to 18 March was similar to values measured in the lower River between 8 January and 5 February 1995 (Figure 9). All the latter values fluctuated between 0.20-0.35 except for 7 to 10 January when the ratio was at or below 0.2. The combined discharge of the American and Feather Rivers between 7 and 10 January was less than 16,000 CFS and much of the water from the upper Sacramento Basin should have flowed past Greene's Landing. This would have lowered the mercury/TSS ratio as was observed. In contrast, almost all mercury/TSS values measured in the Yolo Bypass in January 1995 varied between 0.12 and 0.20 (Figure 9). This is similar to ratios measured on 10 March in the upper Basin, confirming that much of the water, mercury, and sediment present in the Bypass originated from there.

In conclusion, the mercury observed at Greene's Landing during the large March storm likely originated from the Feather and American River watersheds while most of the sediment and mercury from the upper Sacramento River should have been transported down the Yolo Bypass. The source(s) of the elevated concentrations of mercury in the upper Sacramento River between Woodsen Bridge and Ord Ferry are not known. However, likely candidate source(s) are one or more of the small east and westside tributary creeks which appear to have contributed much of the water volume.

Cache Creek Basin Elevated mercury concentrations in the Yolo Bypass on 10 and 11 January (696 and 553 ng/l) suggested a possible local source (Figure 8). All local inputs, except the Sacramento River, were sampled on at least one occasion during two succeeding storms (Table 9). An accurate assessment of the contribution of the Sacramento River is impossible to make at its discharge point into the Bypass as the Sacramento and Feather Rivers and the Sutter Bypass all join immediately upstream (Figure 1) and are not well mixed upon discharge through the weir. Therefore, each of the three tributaries was sampled individually. The highest concentrations of mercury were consistently observed in Cache Creek (Table 9) suggesting that the watershed might be a major source of mercury.

A follow-up study was initiated in the Cache Creek Basin upon obtaining these results. The study had three objectives. First, confirm that the Basin was a major source of mercury during another water year. Second, measure mercury concentrations seasonally in the lower Basin to determine the extent of the exceedance of U.S. EPA criteria and to ascertain bulk mercury transport from the watershed. Finally, identify, if exceedances of U.S. EPA criteria were observed, the principal source(s) of the metal.

Studies conducted between 1996-1998 confirmed that Cache Creek was a major source of mercury. A correlation was noted between total mercury concentration at Road 102 and flow immediately upstream at the Town of Yolo ($R^2 = 0.83$;Figure 11). This relationship was employed to estimate both the frequency of exceedance of U.S. EPA criteria in the lower watershed and to determine bulk mercury exports.

Frequency of exceedance of criteria The frequency of exceedance of the U.S. EPA 12 ng/l mercury criteria was estimated for the lower Cache Creek Basin from the correlation between concentration and flow (Figure 11) and from reported daily discharge rates at the Town of Yolo. Results have been summarized by month for a critically dry (1994), and two wet (1995 and 1996) Sacramento Basin water year types (Table 10). A Sacramento Basin water year categorization was employed as no similar standard is available for the Coast Range and precipitation conditions in the Sacramento watershed are thought to be sufficiently similar to those in Cache Creek to provide a general indication of the relative amount of annual precipitation and water runoff.

The correlation suggests that the U.S. EPA recommended mercury criteria of 12 ng/l is predicted to be exceeded when Cache Creek flows are greater than 100 CFS (Figure 11). Flows of this magnitude occur in the lower Basin about 3 and 35-40 percent of the time during critically dry and wet water year types (Table 10). Months during wet years with a high frequency of exceedance are January through April while during the 1994 dry year only the month of February was sufficiently wet. The results emphasize the importance of storm runoff during wet winters in producing exceedances of the U.S. EPA criteria in the lower Basin.

Loads Cache Creek is diverted into an area called the Settling Basin before discharge to the Yolo Bypass (Figure 2). Purpose of the Settling Basin is to trap suspended sediment and help maintain the capacity of the Bypass to transport large volumes of Sacramento River flood water during storm events. The Settling Basin is periodically dredged to maintain its depth and settling capacity. The concentration of mercury and TSS entering (Road 102, site 2) and leaving (Spillway, site 1) the Settling Basin were compared on 16 occasions to ascertain the settling efficiency of the impoundment. The results suggest that the Settling Basin acts as a sink, trapping about half the mercury and sediment entering it at flows greater than 730 CFS (Table 11). In contrast, the Basin exports three to four times the amount of material entering it at discharge rates less than 150 CFS.

Bulk mercury loads from the Cache Creek watershed to the Settling Basin were estimated for three water years. Loads were calculated by multiplying the reported daily flow at the Town of Yolo by the correlation of mercury concentration and flow (Figure 11) and summing by day over the water year. The results suggest that the watershed exported 0.6, and 221-980 kg/yr of mercury during a critically dry and two wet Sacramento River water year types (Table 10). The majority of the load was transported during the months of January to March in wet years.

Bulk mercury export to the Yolo Bypass from the Settling Basin was also estimated for the three water years. Loads were calculated by multiplying the estimated daily load transported into the Settling Basin by either 0.5 or 3.2 depending on whether the flow rate was greater or less than 730 CFS and again summing by day over the water year. The results suggest that the Cache Creek Settling Basin exported 1.2 and 114-495 kg/yr of mercury during a critically dry and two wet water years (Table 10). The results demonstrate, as with the exceedance of U.S. EPA criteria, the importance of wet winters in mobilizing and transporting mercury from the Basin into the Estuary.

To place these loads in perspective, it is estimated that the Sacramento watershed[9] is about 23 times larger than Cache Creek. In water year 1995 the Sacramento watershed is estimated to

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[9] The Sacramento watershed is about 16 million acres while the Cache Creek Basin is only 0.7 million (Basin Plan; Sorenson and Elliott, 1981).

have exported 640 kg of mercury (Larry Walker and Associates, 1997). The Larry Walker estimate excluded all Coast Range inputs to the Yolo Bypass. By comparison, Cache Creek is estimated to have exported 980 kg to the Settling Basin or 1.5 times that of the much larger Sacramento watershed. About half of this mercury was trapped in the Settling Basin while the remainder was exported to the Yolo Bypass.

Hydrologic Mercury Loading Patterns The third objective of the Cache Creek study was to attempt to determine major local sources of mercury. The main area of interest was the 81-mile reach between Clear Lake and the Settling Basin (Figure 2). Within this area the watershed is naturally divided into three sub-basins: the north and south forks and Bear Creek. All three water bodies flow year round. The north and south forks flows are controlled by dams at Indian Valley and at Clear Lake, respectively with winter storm runoff being trapped in both reservoirs for release during irrigation season. Annual irrigation storage from the two impoundments may be as much as 393,000 acre-feet with Clear Lake providing 80% of the water[10] (Sorensen and Elliott, 1981). Bear Creek has no major dams.

The upper Cache Creek basin (above Rumsey) is largely undeveloped chaparral and shrub oak habitat and is primarily used as rangeland. Large areas are highly erosive. The gradient of the Creek in the 33 mile reach between Clear Lake and Rumsey is steep, dropping an average of 22 ft/mile (Sorensen and Elliott,1981). This drop is sufficient to ensure good sediment transport during all but the lowest flow periods.

There are three inactive mercury mining districts in the upper Basin (Figure 2). The Clear Lake District includes Sulfur Bank Mine, an EPA superfund site. The second mining district is Sulfur Creek. This district includes the Elgin, Empire, Abbot and Wide Awake mines. These drain predominately to Bear Creek. Finally, the Knoxville District is located in both the Putah and Cache Creek watersheds. Reed mine is part of the Knoxville District and is the site of the McLaughlin gold mine. The Homestake Mining Company constructed Davis Creek Reservoir as a local water source for the McLaughlin mine and remediated much of the Reed Mine site to reduce off-site movement of mercury. Lake Davis Reservoir has been documented to trap and settle as much as 200-300 kg/yr of mercury eroding off the inactive Reed Mine (Slotton, 1991;Reuter *et al.*, 1996). Lake Davis drains into Davis Creek which is tributary to Cache Creek above the confluence of Bear Creek.

The lower Basin (downstream of Rumsey) is intensively farmed with row, orchard and rice cultivation being the major agricultural activities. An inflatable dam is constructed each irrigation season at Capay and water diverted into the Winters and Adams Canals. During peak irrigation much of Cache Creek below Capay Dam is dry with only small intermittent ponded areas where the groundwater table is high. The stream bed is broad and flat, dropping an average

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[10] Actual releases during the 1996 and 1997 irrigation season from Clear Lake were 359,774 and 130,750 acre-feet. Similarly, the releases from Indian Valley were 36,162 and 101,322 acre-feet.

of 6 ft/mile during the 30 miles between Capay Dam and the Bypass. The broad flat floodplain ensures continuous erosion and redeposition of sediment during all but the highest flows. Several tailwater irrigation return flows enter above the town of Yolo providing some discharge from the lower basin to the Yolo Bypass during the dry season. This occurred during much of this study.

Thirteen mercury surveys were conducted during two hydrologic cycles in an attempt to characterize mercury concentrations and loads and to identify sources. The strategy involved sampling each of the three subbasins near their confluence with the main stem Creek to determine their relative importance. Once the general seasonal mercury loading patterns were ascertained, then intensive sampling was conducted in subbasins responsible for the majority of the load to determine sources.

Three distinct mercury loading patterns were noted. These have been classified according to the time period when they were most commonly observed: irrigation season; non-irrigation non-precipitation runoff; and precipitation runoff events. Each is described below.

<u>Irrigation season</u> Three surveys were conducted during the April through October irrigation season (Table 12). The 11 June 1996 survey is thought typical and is presented graphically in Figure 12. Overall, the irrigation season is the time period of the lowest mercury and sediment transport in the Basin. As previously mentioned, the source of most of the irrigation water is from Clear Lake and so it is not surprising that most of the suspended sediment and mercury also originates from here. Presumably, the source of the mercury in Clear Lake is from Sulfur Bank Mine. During the irrigation season most of the flow in the Creek is diverted at Capay Dam for agriculture. Mercury and suspended sediment loads in the diverted water are either deposited on farmland or passed through as irrigation tailwater. A much smaller volume of water, predominately irrigation return flow, is present at Road 102. Interestingly, during our surveys this return water always contained higher mercury and suspended sediment concentrations than the water exported at Capay Dam. Presumably the source of the mercury is from erosion off cultivated fields and from remobilization of sediment deposited in the lower Creek bed. An exception to the almost total diversion of upstream water at Capay Dam occurred on 4 April 1996 (Table 12). This survey was conducted immediately after a series of late spring rainstorms (Figure 13a) and no water was needed for irrigation. Therefore, diversion water was being allowed to flow downstream. Also, no rain runoff was visible in the small creeks in the lower watershed. Consequently, the flow rate was constant down Cache Creek (Table 12). A large increase in mercury load was still noted between Rumsey and Road 102 suggesting that much of the sediment and mercury being transported during irrigation season at Road 102 might result from the remobilization of material previously deposited in the lower creek bed.

An advantage of load calculations is that the loads in a watershed must be additive for conservative elements like total mercury and sediment unless large amounts of deposition and remobilization occur. The steepness of the upper watershed should preclude significant deposition. Therefore, variance in mercury and sediment loads in the upper Basin may best be considered an indication of the reliability of the load estimates. Major potential sources of error are inaccuracies in either measuring mercury concentrations, flow or in collecting representative field samples for an accurate assessment of loads. The latter is probably the major source of error in this study as single subsurface grab samples were employed. In general, the data suggest that mercury load estimates during the irrigation season are accurate to within a factor of two or three. For example, 37 grams of mercury were reported to have been exported from a combination of Clear Lake and the North Fork on 11 June 1996 (Figure 12;Table 12) but only 24 g/day were measured 24 miles downstream at the confluence of the Bear and Cache Creek. Bear Creek added an additional gram for a total of 25 g/day but only 12 g/day were measured 9 miles downstream at Rumsey. Most of the water was diverted at Capay Dam so the small mercury load at Road 102 probably results from the remobilization of bedload material. The inaccuracy in load estimates is greater than would be expected from replicate field mercury samples but the error in the loads is assumed to be real as no evidence of mercury field contamination was observed in the mercury quality assurance and quality control program.

Examination of the mercury loading estimates (Table 12) indicate that transport in the upper basin during the six month irrigation season is on the order of 10-50 g/day. Exports from the lower watershed to the Settling Basin are usually less because of diversions at Capay Dam. Exceptions are on the few occasions, such as 4 April 1996, when irrigation releases upstream are high but no diversion at Capay Dam occurred. It must be emphasized, though, that these irrigation loads estimates are based upon only a few measurements and more surveys are needed to confirm these results.

Comparison of mercury concentrations with recommended U.S. EPA criteria demonstrate few exceedances of the 12 ng/l criteria in the upper basin during irrigation season except on Bear Creek (Table 12). All Bear Creek values exceeded the 12 ng/l limit except on 29 September 1997. On 29 September Bear Creek mercury concentrations were 8.65 ng/l. Much less dissolved mercury data is available (Table 12). No value exceeded the proposed California Toxics Rule value of 50 ng/l. Only concentrations on Bear Creek appear to routinely be greater than the recommended National Toxics Rule concentration of 1.8 ng/l. More dissolved mercury data is needed from throughout the watershed to better establish baseline concentrations.

The ratio of mercury/TSS varied, except for Bear Creek, between 0.2 and 0.7 ppm dry weight for the upper watershed (Table 12). Sediment mercury concentrations for Bear Creek were about an order of magnitude higher (4.2-8.4) suggesting, like the mercury water concentration data, that Bear Creek is the most contaminated of the three drainages.

<u>Non-precipitation runoff</u> Irrigation ceases in October and baseline flows from Clear Lake and Indian Valley Reservoirs drop to 3-7 and 10 CFS, respectively. Bear Creek always appears to discharge a small amount of water (0.5-2 CFS). These three flows plus groundwater seepage result in an almost continuous discharge of water as far downstream as Capay Dam whereupon Creek flow becomes intermittent. The first large rain storms in California typically occur in December. Bear Creek and the North Fork have more of their watershed located below reservoirs

than does the South Fork, Therefore, these two contribute most of the initial flow. As precipitation continues, Clear Lake and Indian Valley Reservoir levels rise and both impoundments begin to release water. Typical runoff from the North and South Fork are of about equal magnitude during late winter and early spring. Bear Creek, having a much smaller watershed, has less discharge.

No mercury surveys were undertaken between the end of irrigation and the beginning of the rainy season as little mercury was thought to be transported during these low flow conditions. The 27 February 1996 event was taken after a seven day dry period (Figure 13a). About half an inch of rain fell in the late afternoon but no runoff was visible during sampling. The flow was about equally divided between the North and South forks, however, the North Fork contributed about ten times as much mercury and suspended sediment (Table 13;Figure 14). Mercury and suspended sediment loads appear to steadily increase downstream with loads at Road 102 being about 1.5 times larger than at Rumsey. The increase in mercury loads downstream again suggest remobilization of bedload material below Rumsey.

The accuracy of non-irrigation season mercury loads are not known as insufficient measurements were made. Therefore, it is assumed that the reliability of the measurements are similar to those obtained during the irrigation season which were estimated to be within a factor of 2 to 3 of the true value. If correct, mercury loads from the upper basin during winter non-storm periods may be on the order of 100 to 1,000 g/day. This is about 10 to 20 times more mercury than was believed exported during irrigation season. Again, the load estimates are based upon few measurements. More sampling is needed to confirm these values.

Comparison of instream mercury concentrations with the U.S. EPA criteria demonstrate that all values collected in the watershed exceed 12 ng/l (Table 13). Some concentrations from the lower basin are greater than the recommended criteria by at least two orders of magnitude. No dissolved mercury data was collected.

Like during the irrigation season, the ratio of Hg/TSS varied between 0.2 and 0.4 ppm dry weight. The only exception was Bear Creek with ratios of 1.5 to 3.8 ppm. The higher ratios in Bear Creek again suggest runoff from a more mercury enriched environment.

<u>Precipitation Runoff</u> The third loading pattern was observed during and immediately after large storms. Storm-induced mercury runoff is the least frequent of the three load patterns and only occurred after sufficient rain had fallen in the watershed to saturate the soil profile and induce sheet runoff. The 1996 and 1997 water years were classified as wet in the Sacramento watershed and about 4-10 major rainstorms occurred per year as evidenced by short term increases in Cache Creek flow at Rumsey (Figure 13a,b). The frequency of storm runoff was higher in 1998, a third wet year (Figure 13c).

Eight storm surveys were conducted (Table 14). Load estimates during rainfall periods were emphasized as the mercury loading patterns at the Settling Basin suggested that these might be critical events to understand. Results of the 21 February 1996 event are presented in Figure 15. Both the source and volume of flow during storm events is highly variable. Early in the season reservoirs are low and the majority of water is from overland runoff, mostly originating from the Bear and from the North Fork watersheds. The relative contribution from Bear Creek is greatest at this time. Later in the season flows are a combination of reservoir discharge and overland runoff. Typically, late season flows are much larger and are dominated by reservoir discharge from the North and South Forks.

Only one early storm-season event was sampled (23 December 1996). The event was unique in that Bear Creek contributed about half of the flow and a large part of the mercury load in the upper Basin. During all other events, most of the flow was from the North and South Forks. On these occasions the major source of mercury originated from a section of Creek located downstream of the confluence of the North and South Forks but above Bear Creek (Figure 15; Table 14). This section of Cache runs through an inaccessible portion of canyon. Throughout the study period, the canyon accounted for more than 90% of the mercury load above Rumsey[11]. The only exception was during the early (23 December 1996) and late (2 and 3 April 1996) storm season when the contribution from the canyon was 30-50% of the load above Rumsey. The fact that large loads only appear to be present in the canyon after large storms suggest that the source(s) may be one or more ephemeral streams that only discharge then.

The largest mercury loads were exported from the upper Basin after storms. For example, 25,128-63,558 g/day of mercury were estimated to have been transported past Rumsey on 26 January 1997 (Table 14). The load is equivalent to between 3-35 years of irrigation season runoff or between 25-600 days of winter non-storm runoff. Obtaining precise estimates of both the frequency and magnitude of these events is important. However, good estimates of either are beyond the scope of this study. The 1996 to 1998 rainfall data suggest, though, that large storms with several days of runoff may occur multiple times during wet years. Estimates of the amount of mercury transported in the upper basin during these occasions varied between 14,000-63,000 g/day (Table 14). As on other occasions, concern exists about the accuracy of the estimates. Replicate field samples were taken on 2 April 1996 and again on 26 January 1997 to provide an indication of the repeatability of the mercury load measurements (Table 14). These estimates, similar to that seen during the irrigation season, appear to vary by a factor of 2-3 suggesting that the true export value may range between 5,000 and 180,000 g/day. The upper value is likely high as repeated measurements 19 miles downstream at Capay on 26 January (when 63,000 g/day mercury was measured at Rumsey) demonstrate an upper value of 92,000 g/day. The latter value is also consistent with loading estimates at Road 102[12]. Therefore, mercury transport in the

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[11] Canyon loads were determined by subtracting the sum of the loads from the North and South Forks from those at site 6.

[12] The maximum mercury concentration observed in this study was about 2,000 ng/l at around 20,000 CFS (Figure 11). This is equivalent to about

upper Basin, unless much larger rainstorms occur than were measured in this study, are likely to be on the order of 5,000-100,000 g/day.

Comparison of instream mercury concentrations with the recommended U.S. EPA criteria demonstrate that all values obtained in the Basin, accept at Clear Lake and during the late storm season on the North Fork, exceeded the recommended value of 12 ng/l (Table 14). Mercury concentrations in Clear Lake appear to be near 12 ng/l. On three occasions the recorded value was greater than the recommended criteria while in two instances it was below it. Mercury concentrations on the North Fork on 2 and 3 April were 4.34 and 2.59 ng/l. All other values measured in the Basin were above the criteria with some concentrations from Rumsey and Capay exceeding it by more than two orders of magnitude. As on other occasions, little dissolved data was collected. No value exceeded the California Toxics Rule concentration of 50 ng/l. In contrast, all numbers, except for 2 April 1996 at site 6, were above the National Toxics Rule value of 1.8 ng/l. The dissolved mercury concentration on 2 April at site 6 was 1.67 ng/l. As noted before, much more data is needed to adequately characterize dissolved mercury concentrations in Cache Creek.

The ratio of Hg/TSS is important during storms as that is when most of the sediment is moved in the basin. Bear Creek, as during other times, consistently exported mercury enriched sediment (range 1.9-12.7 ppm dry weight). However, unlike on other occasions, mercury concentrations in sediment at site 6 on Cache Creek were also often elevated. The highest concentrations were measured on occasions with the greatest flow (21, 22, 23 February 1996 and 26 January 1997). The mercury/TSS ratio on these dates varied between 1.8-14.5 ppm. On these occasions the elevated ratio was often maintained downstream suggesting that the unknown canyon source(s) were dominating suspended sediment mercury concentrations. Exceptions were on 21 and 23 February 1996 when high sediment values were only observed at site 6.

To summarize, three general mercury loading patterns were observed in Cache Creek: summer irrigation, winter non-storm runoff, and winter storm-runoff events. The irrigation season occurs during the seven-month period between April and October. Mercury export rates from the upper basin were on the order of 10-50 g/day with most of the metal coming from Clear Lake. Mercury export from the lower Basin is usually much less as most of the water (and mercury) is diverted for irrigation. The winter non-runoff period is the next most common event occurring between November and March. This study was characterized by wet winters. Mercury export rates from the upper Basin were on the order of 100-1000 g/day. Much of the mercury appeared to originate from the North Fork of Cache Creek. Finally, storm mercury export periods were least common and occurred with a frequency of 4-10 times per year. All subbasins exported significant amounts of mercury but the majority of the metal appeared to come from the Cache Creek canyon downstream of the confluence of the North and South forks but above the Bear Creek inflow. Storm mercury export rates were on the order of 5,000-100,000 g/day. Overall,

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100,000 g/day.

infrequent storm runoff events account for the majority of the mercury exported from the Basin.

Sources Five intensive surveys were conducted during storms to attempt to identify major sources of mercury in each sub basin. Three were in Bear Creek and in the North Fork and two were float trips down the inaccessible section of Cache Creek canyon between the confluence of the North and South Forks and Bear Creek (Figure 2). There was insufficient time during these trips to collect flow data for each tributary so calculations of loads were impossible. Instead, the strategy consisted of sampling above, in and below tributaries to ascertain whether they might enhance or dilute instream mercury and suspended sediment concentrations. The drainage area of each tributary was estimated to provide a rough indication of potential storm runoff volumes. Results are summarized below by each sub-basin: Bear Creek, North Fork, the canyon area including Harley Gulch, and lower Cache Creek .

Bear Creek Sulfur Creek appeared to be the major source of mercury in Bear Creek (Figure 16). Sulfur Creek is the largest tributary to Bear Creek and drains a 10 square mile area including the inactive Central, Wide Awake, Elgin, and Manzanita mercury mines. The drainage also has several active geothermal springs which may also be sources of mercury. Mercury concentrations in Sulfur Creek on 26 January 1997 and on 2 February 1998 were 5,316 and 11,421 ng/l[13] (Table 15). These concentrations were sufficient to increase downstream mercury concentrations in Bear Creek four to sixfold. The ratio of mercury to suspended solids also support the hypothesis that Sulfur Creek was a major source of sediment contaminated mercury. The ratio varied between 16.1-22.4 ppm dry weight. Addition of this sediment to Bear Creek resulted in a four to five fold increase in the ratio downstream for Bear Creek at the Highway 20 bridge.

A more limited survey was undertaken on 16 February 1998. Mercury concentrations were about 32 times higher in Sulfur Creek (1,964 ng/l) than upstream on Bear Creek (Table 15). No downstream measurements were made so it is not known how much this increased downstream Bear Creek mercury concentrations.

The data also suggest the possibility of a second mercury source(s) between where Bear Valley Road first crosses the Bear (site 16) and Sulfur Creek (Figure 16). Instream mercury concentrations increased seven to ninefold on 26 January 1997 and on 2 February 1998 in this four mile stretch. Three small unsampled creeks drain the northern portion of the Sulfur Creek mercury mining district. One, an unnamed creek, flows past the Rathburn mercury mine. More work is needed to identify the source of mercury in this stretch of Bear Creek.

North Fork On 26 February 1997 Indian Valley Reservoir was discharging 10 cfs but flows at the Highway 20 bridge were estimated at 3,500 cfs (Table 17). Mercury concentrations increased from 21 ng/l at Indian Valley to 125 ng/l at Highway 20 suggesting a large mercury input in the

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[13] Dissolved mercury concentrations were 52 and 76 ng/l on both dates, respectively.

12 mile reach[14]. Mercury concentrations decreased downstream of here to 104 ng/l at the confluence of the South Fork implying that there were no additional large inputs. Much of the flow above Highway 20 came from Wolf and Long Valley Creeks (Figure 17), consistent with their large drainage areas. Mercury was detected in both but not at a sufficiently high concentration to explain the results observed at Highway 20.

On 2 February 1998 ten cfs was again discharged from Indian Valley Reservoir and about 2,000 cfs was present at Highway 20 (Table 15). Mercury concentrations doubled between Chalk Mountain (Site 21, two miles downstream of Indian Valley Dam) and Highway 20, again suggesting the presence of a large input(s) between the two locations[15]. Benmore Canyon and Grizzly Creek were sampled in addition to Wolf and Long Valley Creeks. Wolf and Long Valley were again found to carry insufficient mercury to account for the increase observed downstream at Highway 20. In contrast, Benmore and Grizzly Creeks transported 2,149 and 3,022 ng/l of mercury, respectively. Both drain seven to eight-square mile watersheds on the western slope of the Sulfur Creek mercury mining district. These two had large flows and appeared to explain much of the increase in mercury observed at Highway 20. The two were also found to transport large amounts of suspended sediment (14,000-16,000 mg/l) and this may explain the large increase in TSS observed at Highway 20.

A follow up survey was conducted on 16 February 1998 (Table 15). Mercury concentrations in Benmore and Grizzly Creeks were 9-12 times greater than immediately upstream on the North Fork confirming that these two watersheds are major sources of mercury during rainstorms.

The ratio of mercury/TSS was uniformly low in the North Fork (0.1-0.3 ppm dry weight, Table 15). Similarly, low concentrations were observed in Benmore and Grizzly Creeks. These values are in contrast to the ratios measured on Sulfur Creek (16-22 ppm) suggesting that much of the mercury in the North Fork may originate from sheet erosion off the steep slopes characteristic of this portion of the watershed. A detailed assessment should be undertaken in Benmore and Grizzly Creeks to determine the source of the mercury and the feasibility of controlling local erosion.

<u>Harley Gulch</u> Harley Gulch is the only tributary to the inaccessible portion of the Cache Creek canyon that can be accessed by car for sampling. This portion of Cache Creek has previously been shown to be responsible for most of the mercury exported from the watershed during storms. The western branch of Harley Gulch drains a 0.6 square mile portion of watershed that includes the Abbott and Turkey Run Mines. The eastern gulch drains about 2.1 square miles of the southern portion of the Sulfur Creek mining district. Both halves join immediately below

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[14] Mercury loads for the North Fork at Indian Valley Dam and at Highway 20 were 0.5 and 1,072 g/day, respectively.

[15] Mercury loads for the North Fork at Chalk Mountain and for HWY 20 were 12 and 5,325/6,759 g/day.

Highway 20 before dropping into the canyon. Harley Gulch appears to be ephemeral with significant flow only after rainstorms.

On 2 February 1998 Harley Gulch west was found to be discharging 359,448 ng/l of mercury (Table 15). The eastern portion of the Gulch had the larger flow but a lower mercury concentration (925 ng/l).

Both streams were resampled two weeks later on 16 February. Harley Gulch west had a mercury concentration of 146,039 ng/l confirming that it is a major source of mercury during storms.

The ratio of mercury/TSS was also high on both occasions (53.6 and 27 ppm dry weight) demonstrating that the Gulch drains a highly enriched mercury environment.

Cache Creek Canyon Two float trips were taken down the Cache Creek canyon to sample tributaries and attempt to determine the source of the large mercury loads observed leaving the area during storms. Both runs were largely inconclusive as they occurred after moderate rainstorms. Only Harley Gulch consistently had elevated concentrations but on both occasions these were insufficient to increase the downstream concentration on Cache Creek.

The first trip occurred on 2 April 1996 after 1.5 inches of rain fell over two days at Indian Valley Reservoir (Figure 13a). Most of the initial water volume was from Clear Lake with Cache Creek flow doubling by the confluence of the Bear (Table 16). Mercury concentrations rose steadily from 12.18 ng/l at Clear Lake to 17.63/23.58 above the Bear (Figure 18). Mercury loads tripled from 30 g/day at Clear Lake to 82-110 g/day above the confluence of the Bear. Only Harley Gulch had a greater concentration than Cache Creek, though the addition of mercury from the Gulch was insufficient to increase instream concentrations. Most of the increase in mercury concentration in Cache Creek appeared to occur downstream of Davis Creek but above the Bear. There are no tributaries in this reach suggesting the possibility that much of the increase in mercury load may have come from resuspension of bedload.

The second float trip was on 16 January 1998. This trip was again after a series of moderate rainstorms (Figure 13c). On this occasion most of the discharge was (visually) from the North Fork although no flow estimates were made. After the North and South Forks mixed, mercury concentrations were stable at 51-52 ng/l down canyon. Only Stemple (103.8 ng/l) and Harley Gulch (78.47) had higher concentrations than Cache Creek.

The ratio of mercury/TSS in the Cache Creek canyon on both float trips varied between 0.1-0.2 ppm dry weight (Table 16). Interestingly, elevated sediment mercury levels were observed on both trips in all tributaries except Stemple and Rocky Creeks suggesting the possibility that many of these tributaries might export sediment with elevated mercury concentrations during storm events. Particularly important may be Davis Creek because of its large watershed[16] and the fact that it previously carried mercury contaminated runoff from the Reed Mine. Contaminated sediment may have settled in flatter portions of the Creek to be eroded later during high flows.

Additional sampling is needed in the canyon area to conclusively identify the source of the elevated mercury loads. This information is essential so that remediation studies can be undertaken to determine whether mercury loads during storms may be reduced.

Lower Watershed Periodic increases in mercury concentration were noted in Cache Creek below Rumsey. Not known was whether these resulted from tributary inputs or remobilization of bedload material. Most of the tributary inputs are located between Rumsey and Capay Dam (Figure 18). On 2 February 1998 all seven inputs between Capay and Rumsey were sampled (Table 15). Mercury concentrations increased from 74.40 ng/l at Rumsey to 391.5 ng/l at Capay Dam. However, all seven tributaries had lower mercury concentrations than Cache Creek at Rumsey suggesting that each was acting as a dilution flow. The source of the mercury downstream of Rumsey appears to be from remobilization of bedload material.

Bioavailability Mercury loads to the Sacramento-San Joaquin Delta Estuary are of concern because of fish advisories. Mercury is a potent human neurotoxin with developing fetuses and small children being most at risk (White *et al.*, 1995). The principal route of human exposure is through consumption of mercury contaminated fish. This study has identified Cache Creek as a source of bulk mercury and confirmed the observations of Larry Walker and Associates (1997) and Alpers (personal communication) that the Feather, American and upper Sacramento Rivers are also major sources.

Factors which promote mercury accumulation in fish tissue are not well understood. However, mercury is known to biomagnify in the aquatic food chain with top predator fish often having a million times more mercury, on a per weight basis, than ambient water concentrations (Wiener and Spry, 1995). Methyl mercury is the primary form accumulating in the aquatic food chain and over ninety percent of the mercury in fish tissue is the neurologically important organic species (Bloom, 1995b). Conversion of inorganic to organic mercury is primarily controlled by sediment microorganisms, mostly sulfur reducing bacteria. Bulk water or sediment mercury concentrations are not by themselves well correlated with mercury fish tissue concentrations (Gilmour, 1995; Slotton, personal communication). Other factors which appear to influence the conversion rate of inorganic to organic mercury include the amount of organic matter and redox potential of the sediment, the oxidation state of the mercury, and water temperature, pH, alkalinity and salinity (Gilmour, 1994).

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[16] The drainage area below Davis Creek Reservoir was estimated at 9.2 square miles.

The aquatic environment of the Sierra Nevada is very different from that of the Coast Range and this may affect local bioavailability. Sierra streams originate from snow melt in granitic watersheds. They are colder, more oligotrophic and have lower alkalinity and hardness than Coast Range water which drains from uplifted, low elevation, marine sedimentary material. In addition, the oxidation state of the mercury imported into the Sierras was in an elemental form. The faster moving, oxic Sierra Nevada waters are not a strongly reducing environment and most of that mercury should have remained in an oxidized state. In contrast, most of the bulk mercury present in the Coast Range is cinnabar (mercuric sulfide) which was formed underground at high temperature and pressure[17] (Pickthorn, 1993). As a result, local bioavailability of Coast Range mercury may be very different from that deposited in the Sierra Nevada Mountains. Furthermore, the relative bioavailability of both forms may change upon transport into the estuary. Neither the primary locations of methyl mercury production nor the principal factors controlling methylation rates are yet known for any waterway in California. Determining these should be a primary focus of future aquatic mercury research. In addition, emphasis should be placed upon ascertaining the relative bioavailability of mercury derived from the coastal range and from the Sierra Nevada mountains and whether decreases in loads from either would reduce fish tissue levels in the Rivers and Estuary.

Mercury concentrations in aquatic invertebrates and fish in the historic gold mining region of the Sierra Nevada Mountains have been evaluated by Slotton *et al.* (1997a). Concentrations of mercury in aquatic indicator organisms increased in a predictable fashion with increasing trophic level. A clear signature of mine derived mercury was found associated with the most intensively worked river stretches. Mercury concentrations were lower in non mined areas of the Feather and American Rivers. While sample sizes were small, fish tissue levels in Englebright Reservoir on the Yuba River and in other Foothill Reservoirs exceed the National Academy of Sciences guideline of 0.5 ppm and approach the U.S. Food and Drug Administrations Action Level of 1.0 ppm to protect human health. Larry Walker and Associates (1997) recommended that a comprehensive fish sampling study be performed in Sierra Foothill Reservoirs to determine the human health risk posed by consumption of these fish.

Foothill reservoirs have been found to operate as sinks for both bioavailable and sediment associated inorganic mercury (Slotton et al, 1997a; Larry Walker and Associates, 1997). Significantly lower levels of mercury were found in aquatic organisms below reservoirs as compared to concentrations both in and above them. Similarly, these studies showed that bulk loads of mercury entering foothill reservoirs were greater than the amounts exported. This suggests that the reservoirs in gold mining districts may act as interceptors of mercury, trapping and preventing downstream transport to the Estuary. This may explain the smaller than expected

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[17] A small amount of elemental mercury may also be present naturally in the mercury deposits (Pemberton, 1983) and more may have been formed and left around mine retorts as a result of the conversion of cinnabar (Hg^{+2}) to elemental mercury (Hg^0).

loads measured in both the American and Feather Rivers by this study and by Larry Walker and Associates (1997). The mercury loads now present after storms in Sierra rivers may primarily result from resuspension of bedload material located below dams.

In the spring of 1996 benthic invertebrate samples were collected in the upper Cache Creek basin to determine bioavailability (Slotton *et al.*, 1997b). The most elevated samples were associated with known mercury mine drainage including Sulfur Creek, Harley Gulch, and Davis Creek. These invertebrate concentrations were much higher than any observed in comparable samples from the Sierra Nevada Mountains. The highly localized nature of the contamination was demonstrated by lower tissue concentrations in adjacent streams without mercury mining activity. Invertebrate tissue concentrations decreased with increasing distance from mine areas. Similar phenomena have been noted at Mt Diablo Mercury Mine in the Coast Range (Slotton *et al.* 1996) and at Sulfur Bank Mine in Clear Lake (Suchanek *et al.* 1997).

Invertebrates were collected at five locations along the upper mainstem Creek between Clear Lake Dam and Rumsey and at two sites on the North Fork between the Highway 20 bridge and the confluence with the South Fork (Figure 2). No data was collected in the lower watershed. Tissue concentrations were similar at all seven locations and were comparable to the highest values observed in the Sierra Nevada Mountains. The results suggest that, while Cache Creek invertebrate tissue concentrations are high, much of the large bulk mercury loads observed in the present study may not be highly bioavailable while in the upper watershed. No information is available on the bioavailability of Cache Creek mercury once transported into the Estuary, although cinnabar deposits from mine wastes in both the Philippines and in the Tyrrhenian Sea have been reported to be transformed to bioavailable forms upon release in the marine environment (Benoit *et al.*, 1994; Baldi and Bargagli, 1982; Baldi *et al.*, 1987;89; Barghigiani *et al.*, 1986).

Yolo County contracted with U.C. Davis to determine mercury levels in Cache Creek fish (Davis, 1998). Sixty-four fish from twelve species were collected in the lower watershed. Most were small (<0.5 kg). However, 20 percent (13 fish) of these had tissue concentrations above the National Academy of Science guideline of 0.5 ppm. Two were above the U.S. Food and Drug Administration action level of 1.0 ppm to protect human health. While sample sizes were small, white crappie, squawfish, and small mouth bass had the highest tissue levels. These averaged 0.49, 0.5 and 0.94 ppm wet weight, respectively. Similar to the Sierras, a comprehensive fish tissue and fish consumption study should be undertaken in Cache Creek to evaluate the potential risk to the public of consuming local fish. The study should be conducted in cooperation with the Office of Environmental Health Hazard Assessment and the Yolo County Health Department to ensure that health advisories are posted, if necessary.

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Table 1. Summary of mercury, total suspended solids (TSS), and the ratio of the two for low flow conditions (<30,000 cfs) at Greene's Landing in the Sacramento River during 1993-94.

Date	Mercury (ng/l)	TSS (mg/)	Hg/TSS[2] (ppm)	Flow (cfs)
11/11/93	1.99/2.47/2.61[1]			11,932
11/12/93	3.93/2.87/2.51			12,146
1/11/94	3.25			12,644
1/18/94	1.61	8.2	0.20	12,505
1/23/94	2.56	13.8	0.19	12,008
1/24/94	2.30	12.9	0.19	13,351
1/25/94	5.41	25.2	0.21	16,335
1/26/94	7.15			21,949
1/27/94	8.11/7.85	45.2	0.18	24,084
1/28/94	14.14	53.1	0.27	22,365
1/29/94	7.23	33.9	0.21	19,355
1/30/94	5.75	29.0	0.20	17,114
2/1/94	4.19/4.19	19.9	0.22	13,593
2/7/94	2.51	19.1	0.13	13,512
2/8/94	6.44	44.8	0.14	20,080
2/10/94	18.17/15.64	123.3	0.14	29,972
2/11/94	14.71	69.4	0.21	26,464
2/12/94	13.87	65.4	0.21	28,784
2/13/94	9.43	28.6	0.32	23,496
2/17/94	4.15	26.0	0.16	16,157
2/18/94	4.60	29.8	0.15	17,022
2/19/94	6.06	47.6	0.12	19,338

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[1] Duplicate field measurement [2] ng/mg

Table 1. (Continued).

Date	Mercury (ng/l)	TSS (mg/l)	Hg/ TSS (ppm)	Flow (cfs)
2/20/94	6.0	66.8	0.09	23,458
2/21/94	10.78	70.0	0.15	25,116
2/22/94	9.82/9.77	130.5	0.08	28,909
2/23/94	16.91	121	0.14	28,238
2/24/94	8.91	58	0.15	25,596
2/25/94	6.42	46.4	0.14	22,998
2/27/94	5.30	75.2	0.07	19,321
2/28/94	5.41	38.7	0.14	17,952
3/1/94	3.74/3.83	27.1	0.14	18,275
3/4/94	4.11	52	0.08	17,077
3/10/94	2.66	20.8	0.13	15,151
3/15/94	3.27	14.2	0.23	13,055
3/16/94	18.70/18.90/18.57/18.47			13,098
3/23/94	4.15			11,739
4/1/94	2.98			9,015
4/12/94	2.39/2.42			8,366

Table 2. Summary of total and dissolved mercury concentrations at selected locations in the Sacramento-San Joaquin Delta Estuary during low flow conditions in 1993-94.

Location	Date	Total Mercury (ng/l)	Dissolved Mercury (ng/l)
Mokelumne @ New Hope Rd.	10/14/93	4.79	1.68/1.54
	12/13/93	7.25/7.56	
	4/12/94	5.11	
	5/10/94	6.0	
Sacramento R. @ Hood	10/14/93	3.63	0.99
	12/13/93	8.06	
	4/12/94	2.60/2.47	
	5/10/94	3.35	
Sacramento R. @ Rio Vista	10/14/93	4.17	1.38/1.09
	12/13/93	7.72/3.89	
	4/12/94	2.99	
	5/10/94	3.88	
Middle R. @ Bullfrog	10/29/93	1.71	1.32
	11/29/93	2.42/2.23	
	1/11/94	2.13/2.05	
	4/27/94	2.13	
San Joaquin R. @ Vernalis	10/29/93	6.81	1.62
	1/11/94	3.98	
	4/27/94	8.90/9.30	
San Joaquin R. @ Stockton	10/29/93	4.40	1.47/1.43
	11/29/93	3.85	
	1/11/94	10.27	
San Joaquin R. @ Pt Antioch	10/25/93	5.41	0.97
	11/29/93	3.45/3.25	
	10/14/93	6.33	

Table 3. Estimate of mercury and sediment loads to the Sacramento-San Joaquin Delta Estuary from the Sacramento watershed between 1 May 1994 and 30 April 1995.

	Mercury (kg)			Sediment (million metric tons)		
Period	Bypass	River	Combined	Bypass	River	Combined
May-Dec '94	0.0	19.5(2%)	19.5(2%)	0.0	0.1(3%)	0.1(3%)
Jan-April '95	375[1](47%)	406[2](51%)	781(98%)	2.5[3](64%)	1.3[4](33%)	3.8(98%)
Total			800.5(100%)			3.9(100%)

Assumes:

[1] 31.75 ng/l mercury
[2] 20.0 ng/l mercury
[3] 209.26 mg/l sediment
[4] 70.0 mg/l sediment

Table 4. Summary of mercury (ng/l) and total suspended solid (TSS, mg/l) concentrations in the Sacramento River at Greene's Landing and in the Yolo Bypass at Prospect Slough during high flow in 1995.

	Greene's Landing[2]				Prospect Slough[3]			
Date	Hg	TSS	Hg/TSS	Flow	Hg	TSS	Hg/TSS	Flow
1/7/95	20.0	98.7	0.20	30,300				1,500
1/8/95	24.0	106.2	0.23	33,100				2,360
1/9/95	30.7	184.4	0.17	44,200				12,100
1/10/95	62.3	374.3	0.17	66,100	695.6	2300.7	0.30	22,100
1/11/95	87.4	327.3	0.27	87,900	553.7	1454.4	0.38	82,700
1/12/95	50.8	191.7	0.27	95,700	92.2	471.9	0.20	144,000
1/13/95	42.7/39.5[1]	167.8	0.25	91,100	45.2	234.2	0.19	133,000
1/14/95	34.5	156.4	0.22	85,700	67.3	512.7	0.13	127,000
1/15/95	32.6/34.7	109.8	0.31	82,400	50.5/51.0	360.6	0.14	123,000
1/17/95	21.7	87.3	0.25	78,100	31.3	184.0	0.17	85,300
1/18/95	21.8	88.5	0.25	76,700	42.8			58,200
1/20/95	22.7	91.6	0.25	72,600				28,200
1/22/95	22.6	80.6	0.28	69,900	26.6	137.0	0.19	21,100

[1] Duplicate field samples.

[2] Dissolved Hg was measured at Greene's Landing on 29 and 31 Jan and 21 Feb 1995. Values were 3.24, 2.72 and 1.64 ng/l

[3] Dissolved Hg was measured at Prospect Slough on 31 January at 3.54 ng/L.

Table 4. (Continued)

	Greene's Landing[2]				Prospect Slough[3]			
Date	Hg	TSS	Hg/TSS	Flow	Hg	TSS	Hg/TSS	Flow
1/23/95	16.91	73.71	0.23	70,600	24.86	142.7	0.17	21,500
1/24/95	14.26	59.6	0.24	70,900				23,000
1/25/95	14.7	68.8	0.22	71,900	14.03	84.8	0.17	29,000
1/26/95	15.58	74.3	0.21	73,400	23.98	201	0.12	35,800
1/27/95	16.9	86.1	0.20	76,600	23.1	153.3	0.15	42,800
1/28/95	20.44	94.1	0.22	91,200	22.87	154.33	0.15	46,800
1/29/95	15.58	61.7	0.26	82,600				43,500
1/30/95	19.89	54.9	0.37	74,300				39,400
1/31/95	19.06	58	0.33	73,700	18.35/19.77	109.2	0.17	41,200
2/1/95	13.7	50.9	0.27	70,600				39,800
2/2/95	11.13	45.1	0.25	69,400				42,100
2/3/95	14.65	64.5	0.23	75,300	36.85	93.6	0.40	46,500
2/4/95	13.71	73.5	0.19	75,200				51,300

[1] Duplicate field samples.

Table 4. (Continued).

	Greens Landing[2]				Prospect Slough[3]			
Date	Hg	TSS	Hg/TSS	Flow	Hg	TSS	Hg/TSS	Flow
2/6/95	12.78	58.7	0.22	73,400	29.83	143.7	0.21	41,100
2/10/95	9.60	36.0	0.27	70,600	11.33	48.0	0.24	20,500
2/14/95	9.06/8.60	40.3	0.22	65,200	17.19/17.80	91.2	0.19	9,080
2/17/95	17.44	92.6	0.19	60,100	13.60	52.0	0.26	4,740
2/21/95	12.46	55.8	0.22	44,200				2970
2/22/95	7.92	45.0	0.18	41,700				2,490
2/23/95	9.0	46.7	0.19	38,300				2,180
2/24/95	32.38	138.4	0.23	36,700				2,040
2/28/95	8.47	35.9	0.24	32,100	7.18	129.6	0.06	<1,000
3/3/95	12.04	45.5	0.28	34,800				<1,000
3/5/95	11.48	49.4	0.23	53,300				<1,000
3/7/95	12.26	61.3	0.20	46,700				<1,000
3/9/95	13.37	44.5	0.30	49,400				2,350

[1] Duplicate field samples.

Table 4. (Continued).

	Greens Landing[2]				Prospect Slough[3]			
Date	Hg	TSS	Hg/TSS	Flow	Hg	TSS	Hg/TSS	Flow
3/11/95	29.69	101.6	0.29	99,500				79,500
3/14/95	16.19	56.2	0.29	88,100				199,000
3/18/95	11.3	40.5	0.28	80,700				146,000
3/21/95	11.71	35.3	0.33	83,800	17.77	84.7	0.21	108,000
3/22/95	12.87/13.11	36.3	0.36	85,400				106,000
3/24/95	16.14	39.3	0.41	86,700				112,000
5/1/95	16.81			65,900	35.97			1,880
5/5/95	10.57	42.13	0.25	87,900				78,000
5/31/95				46,900	24.16	95.17	0.25	<1,000
6/27/95				35,700	15.65	80.50	0.20	<1,000
7/20/95					16.47			

[1]Duplicate field samples.

Table 5. Comparison of mercury and total suspended solid (TSS) concentrations in Prospect and Skag Sloughs during 1995. The two sloughs are the only drainage channels from the Yolo Bypass into the Sacramento-San Joaquin Delta-Estuary. No statistical difference was noted between sites for either parameter.

	Prospect Slough		Skag Slough	
Date	Hg (ng/l)	TSS (mg/l)	Hg (ng/l)	TSS (mg/l)
1/22/95	26.6	137	23.9	129.6
1/23/95	24.86	142.6	32.16	199.3
1/28/95	22.87	154.33	29.83	156.7
2/14/95	17.19/17.80[1]	91.2	11.80	42.9
3/21/95	17.77	84.7	24.53	121.0

[1] Duplicate field measurement

Table 6. Summary of mercury, total suspended solids (TSS), electrical conductivity (EC) and flow at Greene's Landing and at Prospect Slough for the time period of 26 January through 3 February 1995. Mercury, total suspended solids and electrical conductivity were averaged by station and flow weighted to calculate an average concentration upon mixing at Rio Vista.

Site	Date	Hg (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	EC μmho/cm	Flow (cfs)
Greene's Landing	1/26	15.58	74.3	0.20	80	73,400
	1/27	16.90	86.9	0.20	75	76,600
	1/28	20.44	94.1	0.21	70	91,200
	1/29	15.58	61.7	0.25	74	82,600
	1/30	20.01/19.77[2]	54.9	0.36	82	74,300
	1/31	14.8/13.61[2]	58.0	0.23	83	73,700
	2/1	13.7	50.9	0.27	85	70,600
	2/2	11.13	45.1	0.25	88	69,400
	2/3	19.65	64.5	0.30	88	75,300
Prospect Slough	1/26	23.10	153.3	0.15	105	29,000
	1/27	22.87	154.3	0.15	105	35,800
	1/28					42,800
	1/29					46,800
	1/30					43,500
	1/31	18.3/19.8	109.2	0.17	104	39,400
	2/1					41,200
	2/3	35.9/37.8	193.6	0.19	105	46,500
Rio Vista[1]	1/26-2/3	18.03	95.42	0.19	89.0	116,144

[1] Flow weighted average for 26 January to 3 February 1995..

[2] Duplicate samples.

Table 7. Estimated mercury, total suspended solids (TSS) and electrical conductivity (EC) at Rio Vista for the time period of 26 January to 3 February 1995 and measured concentrations downstream in the Estuary.

Location	Date	Depth (ft)	Hg (%)[3] (ng/l)	TSS (%)[3] (mg/l)	EC (μmho/cm)	Hg/TSS (ppm)
Rio Vista[1]	[2]	45	18.03 (100%)	95.42 (100%)	89.0	0.19
Chipps Island	2/5	55	16.04 (89%)	80.7 (85%)	115	0.20
Grizzly Bay	2/5	5	12.78 (71%)	61.0 (64%)	149	0.21
Martinez	2/5	51	16.28 (90%)	57.9 (61%)	130	0.28
Mare Is. off I-80 bridge (top)	2/6	10	17.58 (97%)	44.5 (47%)	220	0.30
Mare Is. off I-80 bridge (bottom)	2/6	150+		96.1 (100%)	1,210	

[1] Flow weighted average (see Table 6).

[2] Average of values for 26 January-3 February 1995.

[3] (Percent of Rio Vista value).

Table 8. Mercury and suspended sediment concentrations and loads in the Sacramento River basin in March 1995 during the largest storm of the year.

							Loads	
Location	Date	River mile	Hg (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Sediment 10^3 (t/d)	Hg (kg/d)
Shasta Dam	3/10	315	1.38	<1.0		9,815	<0.02	0.03
Sacrament R. @ Redding	3/10	295	5.78	14.50	0.4	18,000	0.6	0.3
Little Cow Creek	3/10	280	19.50	150.00	0.13	10,009	3.7	0.5
Sacramento R. @ Balls Ferry	3/10	276	14.70	96.33	0.15			
Cottonwood Creek	3/10	273	90.95	1,136.70	0.08	12,700	35.3	2.8
Sacramento R. @ Bend	3/10	258	35.46	339.67	0.10	55,000	45.7	4.8
Sacramento R. @ Tehama	3/10	229	74.19	1026.67	0.07			
Sacramento R. @ Woodson	3/10	218	87.29	852.38	0.10	130,046	271.0	27.8
Sacramento R. @ Ord Ferry	3/10	184	68.68	525.00	0.13	129,168	165.8	21.7
Sacramento R. @ Colusa	3/10	144	79.85	662.22	0.12	42,120	68.2	8.2
Sutter Bypass	3/13	81	21.6	108.67	0.20			
Feather River	3/11	80	18.25	29.0	0.63	77,800	5.5	3.5
American River	3/11	60	3.9	9.83	0.40	34,500	0.8	0.3
Greene's Landing	3/9	38	13.37	44.50	0.30	49,400	5.4	1.6
Greene's Landing	3/11	38	29.69	101.60	0.30	99,500	24.7	7.2
Greene's Landing	3/14	38	16.19	56.17	0.29	88,100	12.1	3.5
Greene's Landing	3/18	38	11.30	40.50	0.28	80,700	8.0	2.2

Table 9. Mercury concentrations (ng/l) in tributaries to the Yolo Bypass during two storms in 1995.

	Location						
Date	Cache Ck	Putah Ck	Willows Sl	Colusa Basin Drain	Sacramento R.	Feather R.	Sutter Bypass
1-31-95	422.6	19.8	12.3	10.1	19.3	9.0	8.6
3-9-95	2,210.0	485.0	258.5	46.8			
3-10-95	1775/1804				79.9		
3-11-95	1297/1266					18.3	
3-12-95	998.1	41.4	49.1	43.4			21.6

Table 10. Estimated amounts of mercury imported into and exported from the Cache Creek Settling Basin by month for three different water years. Also presented is the frequency of exceedance of the recommended U.S. EPA 12 ng/l criteria for the same time interval at the entrance to the Settling Basin. The data demonstrate the importance of wet years in the transport of mercury .

	Water year 1994[1]			Water year 1995[2]			Water year 1996[2]		
	Load (kg/mo)		Exceedance Frequency (%)	Load (kg/mo)		Exceedance Frequency (%)	Load (kg/mo)		Exceedance Frequency (%)
Month	Import	Export		Import	Export		Import	Export	
October	0.01	0.02	0	0	0	0	0.06	0.2	0
November	0	0.01	0	0	0	0	0.01	0.02	0
December	0.005	0.17	16	00	0.01	0	2.04	1.79	47
January	0.03	0.08	7	482.64	241.43	87	32.06	16.11	55
February	0.49	0.82	61	35.3	18.31	100	124.03	62.01	100
March	0.04	0.10	10	411.52	206.08	100	59.84	30.65	100
April	0	0	0	45.57	23.53	100	2.85	2.86	100
May	0	0	0	4.77	4.58	97	0.10	0.31	19
June	0	0	0	0.04	0.12	3	0.03	0.12	0
July	0	0	0	0.02	0.07	0	0.03	0.09	0
August	0	0	0	0.01	0.03	0	0.04	0.15	0
September	0	0	0	0.02	0.07	0	0.07	0.19	3
Annual	0.62	1.22	-	979.89	495.45	-	221.15	114.48	-

[1] Critically dry water year. [2] Wet water year.

Table 11. Comparison of total suspended solids (TSS) and mercury concentrations entering (RD 102, site 2) and leaving (spillway, site 1) the Cache Creek Settling Basin.

		Enter		Leave		Leave/Enter	
Date	Flow (CFS)	TSS (mg/l)	Hg (ng/l)	TSS (mg/l)	Hg (ng/l)	TSS (mg/l)	Hg (ng/l)
High Flow							
6 Jan 97	6,820	920	768.5	680	246.4	0.7	0.3
20 Jan 97	2,920	160	40.7	72	26.7	0.5	0.7
21 Jan 97	2,670	160	59.6	41	14.2	0.3	0.2
26 Jan 97	19,800	1,900	1,295.3	1,500	984.6	0.8	0.8
2 Feb 97	6,370	515	145.5	235	71.8	0.5	0.5
23 Feb 97	731	575	36.6	515	17.1	0.9	0.5
2 Feb 98	7,040	1,500	519.85	570	161.8	0.4	0.3
8 Feb 98	16,983	1,800	886	1,900	957	1.1	1.1
14 Feb 98	9,870	2,400	922.3	360	129.1	0.2	0.1
16 Feb 98	7,262	770	501	370	145.1	0.5	0.3
22 Feb 98		2,400	1,098	1,400	615.5	0.6	0.6
Low Flow					mean	0.6	0.5
23 Dec 96	106	20	8.3	62	29.1	3.1	3.5
6 May 97	128	22	13.1	140	63.1	6.4	3.9
27 May 97	146	32	22.7	57	30.1	1.8	1.3
11 Jun 97	122	25	6.8	89	30.8	3.6	4.5
29 Oct 97	120	18	4.3	broke	12.3		2.9
					mean	3.7	3.2

Table 12. Summary of the movement of mercury and sediment (TSS) loads in the Cache Creek Basin during selected dates in the 1996 and 1997 irrigation season. See Figure 2 for site locations.

Date	Location (Site #)	Hg (dissolved) ng/l	Hg (total) ng/l	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg load (g/d)	TSS load (t/day)
4-4-96	Clear Lake (10)		5.41	18.7	0.3	2,200	29	101
	North Fork (8)		2.25			<100	1[1]	
	Cache Ck (6)		4.19/5.53[2]	19.9	0.2	2,014	21/27	98
	Bear Ck (5)		20.11	2.4	8.4	259	13	2
	Rumsey (4)		7.83	31.0	0.3	2,273	44	97
4-4-96	Rd 102 (2)		34.41	106.3	0.3	2,110	178	549
6-11-96	Clear Lake (10)		11.06	17.8	0.6	775	36	28
	North Fork (8)		2.40/2.82[2]	3.82	0.7	<100	1[1]	1[1]
	Cache Ck (6)	1.11	13.49	25.4	0.5	732	24	46
	Bear Ck (5)	7.85	18.53	19.2	4.2	18	1	0
	Rumsey (4)		6.70	26.3	0.3	750	12	48
6-11-96	Rd 102 (2)		16.19	36.4	0.4	52	2	5

[1] Assumes a flow of 100 cfs.

[2] Duplicate field measurement.

Table 12 (Continued)

Date	Location (Site #)	Hg (dissolved) ng/l	Hg (total) ng/l	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg load (g/d)	TSS load (t/day)
6-11-97	Clear Lake (10)		4.08/3.34[2]	20.0	0.2	512	5/4	25
	North Fork (8)		broke	9.0		150[3]		6
	Cache Ck (6)	0.50	5.62/4.60[2]	18.0	0.2	662	16/13	29
	Bear Ck (5)	5.55	20.01/18.70[2]	12.0		6	1/0	0
	Rumsey (4)		5.13	19.0	0.3	668	8	31
	Capay Dam (3)		5.68	25.0	0.2	668	9	41
6-11-97	Rd 102 (2)		6.80	25.0	0.3	122	2	7

[1] Assumes a flow of 100 cfs.
[2] Duplicate field measurement.
[3] Estimated by subtracting the flow at site 6 from that at the Clear Lake Dam

Table 13. Summary of the movement of mercury and sediment (TSS) loads in the Cache Creek Basin on 27 February 1996 during a winter non storm period . See Figure 2 for site locations.

Date	Location (Site #)	Hg (dissolved) ng/l	Hg (total) ng/l	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg load (g/d)	TSS load (t/day)
2-27-96	Clear Lake (10)		7.38	22.1	0.3	1,920	35	104
	North Fork (8)		57.28	194.7	0.3	2,450	343	1,167
	Cache Ck (6)		28.81	190.5	0.2	4,761	336	2,219
	Bear Ck (5)		52.61	13.8	3.8	110	14	4
	Rumsey (4)		35.26	208.2	0.2	4,871	420	2,482
2-27-96	Rd 102 (2)		90.34	352.2	0.3	4,460	986	3,844

[1] Assumes a flow of 100 cfs.

Table 14. Movement of mercury and sediment (TSS) loads in the Cache Creek Basin during storms in 1996, 1997, and 1998

Date	Location (Site #)	Hg dissolve (ng/l)	Hg total (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg load (g/d)	TSS load (t/day)
2-21-96	Clear Lake (10)		17.53	67.2	0.3	2,220	95	365
	North Fork (8)		67.19	516.0	0.2	3,900	641	4,924
	Cache Ck (6)		1,112.48	608	1.8	9,095	24,759	13,531
	Bear Ck (5)		758.59	349	2.2	891	1,653	761
	Rumsey (4)		1,296.09	1,244.2	0.1	9,986	31,670	30,403
2-21-96	Rd 102 (2)		940.82	2,556.8	0.1	9,580	22,054	59,937
2-22-96	Clear Lake (10)		10.04	21.3	0.5	2,350	58	123
	North Fork (8)		37.43	241.1	0.2	3,400	311	2,005
	Cache Ck (6)		2,228.16	352.5	6.3	5,462	29,780	4,711
	Bear Ck (5)		128/125[1]	71.0	1.9	404	127/123	70
	Rumsey (4)		1,132.99	374.6	3.5	5,866	18,990	5,377
2-22-96	Rd 102 (2)		336.52	836.67	1.2	7,270	5,987	14,884
2-23-96	Clear Lake (10)		10.64	24.6	0.4	2,120	55	128
	North Fork (8)		25.01	175.6	0.1	3,250	199	1,397
	Cache Ck (6)		3,938.62	272.0	14.5	5,602	53,991[3]	3,732
	Bear Ck (5)		65.43	29.3	2.2	331	53	24
	Rumsey (4)		987.12	300.7	0.3	5,933	14,331	4,366
2-23-96	Rd 102 (2)		258.17			5,830	3,683	

[1] Field replicates. [2] Assumes flow = 100 cfs. [3] This value is likely high as much smaller loads were observed at Rumsey.

Table 14. (Continued)

Date	Location (Site #)	Hg dissolved (ng/l)	Hg Total (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg load (g/d)	TSS load (t/day)
4-2-96	Clear Lake (10)		12.18	46.4	0.3	956	29	109
	North Fork (8)		4.34	16.6	0.3	<100	1.0[2]	4[1]
	Cache Ck (6)	1.67	17.63/23.58[1]	108.5	0.2	1,906	82/110	506
	Bear Ck (5)	22.90	61.65/64.50[1]	23.0	2.8	170	26/25	10
	Rumsey (4)		30.77	106.3	0.3	2,076	156	540
4-2-96	Rd 102 (2)		256.56	1,327.3	0.2	2,310	1450	7,503
4-3-96	Clear Lake (10)		12.0	45.1	0.3	1,950	57	2.5
	North Fork (8)		2.59	75	0.3	<100	1[2]	2[2]
	Cache Ck (6)		21.94	119.3	0.2	1,999	107	584
	Bear Ck (5)		21.84	1.7	12.7	54	3	0
	Rumsey (4)		15.85	77.2	0.2	2,053	80	388
4-3-96	Rd 102 (2)		61.77	177.1	0.4	2,050	310	888
12-23-96	Clear Lake (10)		12.09	<5.0		7.0	0.2	
	North Fork (8)		8.13	23	0.4	<100	2.0[2]	10
	Cache Ck (6)		25.82	91	0.3	228	14	14
	Bear Ck (5)		109.76	46	2.4	140	38	16
	Rumsey (4)		121.76	420	0.3	369	110	378
	Capay Dam (3)		53.66	93	0.6	369	48	84
12-23-96	Rd 102 (2)		8.29	20	0.4	106	2	5

Table 14. (Continued).

Date	Location (Site #)	Hg dissolved (ng/l)	Hg total (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg load (g/d)	TSS load (t/day)
1-26-97	South Fork (9)		34.85	195	0.2	3,790	316	1,808
	North Fork (7)		104.3	935	0.1	3,500	893	8,007
	Cache Ck (6)		no sample					
	Bear Ck (5)	7.72	1,290.2	670	1.9	500[3]	1,578	819
	Rumsey (4)	5.04	1,142/2,886[1]	1,650	0.7/1.8	9,000	25,128/ 63,558	36,337
	Capay (3)		3,004/4,196[1]	2,250	1.3/1.9	9,000	66,157/ 92,408	49,551
1-26-97	Rd 102 (2)		1,295	1,900	0.7	19,800	62,743	92,056
2-2-98	South Fork (9)							
	North Fork (7)	6.81	1,381/1,088					
	Cache Ck (6)							
	Bear Ck (5)	9.53	984					
	Rumsey (4)							
2-2-98	Rd 102 (2)	4.38	469					

[1] Field replicates. [2] Assumes flow = 100 cfs.

Table 15. Summary of mercury monitoring to locate sources during storms. Sulfur Creek was identified as the major mercury source in Bear Creek, Benmore and Grizzly Creeks in the North Fork, and Harley Gulch in the Canyon section of Cache Creek.

Date	Location (site #)	Area (Mile^2)[1]	Hg (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg Load (g/d)	TSS Load (t/d)
	Bear CREEK							
1-26-97	Culvert (16)	48.2	30.09	290	0.1			
	Above Sulfur Ck (14)		254.0	300	0.9			
	Sulfur Creek (13)	10.1	5,316.4	320	16.1			
	Hwy 20 (12)		1,595.9	415	3.9			
	Cache (5)		1,290.2	670	1.9			
	North FORK.							
	Indian Valley Dam (22)		20.84	33	0.6	10	0.5	0.9
	Chalk Mt. (21)	4.0	23.49	50	0.5	10	0.6	4.2
	Wolf Creek (20)	18.7	24.24	135	0.2			
	Long Valley (19)	37.6	54.35	1400	0.0			
	Hwy 20 (8)		125.2	1,050	0.1	~3,500	1,072	8,972
	N.F. confluence (7)		104.3	935	0.1	3,500	893	8,007
	S.F. confluence (9)	14.8	34.18	195	0.2	3,790	316	1,800
1-26-97	Rumsey (4)		1,141/ 2,886.7	1,650	0.7/ 1.8	9,000	25,128/ 63,558	36,337

[1] Estimated area of watershed draining through sampling site. In the case of reservoirs includes to dam face.

Table 15. (Continued).

Date	Location (site #)	Area (miles^2)	Hg (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg Load (g/d)	TSS Load (t/day)
	BEAR CREEK							
2-2-98	Culvert (16)	48.2	13.29	400	0.0			
	Above Sulfur (14)		89.20	300	0.3			
	Sulfur Creek (13)	10.1	8,401.7/ 1,142.1^2	510	16.5/ 22.4			
	Hwy 20 (12)		328.2	240	1.4			
	Thompson (11)	6.2	142.0	990	0.1			
	Above Cache (5)		142/ 984^2	95	1.5/ 10.4			
	NORTH FORK.							
	Chalk Mt. (21)	4.0	501.7	2,100	0.2	10	12	51
	Wolf Creek (20)	18.7	55.37	670	0.1			
	Long Valley (19)	37.6	209.5	1,500	0.1			
	Benmore Cyn (18)	7.4	2,149.7	14,000	0.1			
	Grizzly Creek (17)	8.0	3,022.5	16,000	0.2			
2-2-98	Hwy 20 (8)		1,381/ 1,088^2	4,500	0.3/ 0.2	~2,000	6,759/ 5,325	22,023

Table 15. (Continued).

Date	Location (site #)	Area (miles^2)	Hg (ng/l)	TSS (ng/l	Hg/TSS (ppm)	Flow (cfs)	Hg Load (g/d)	TSS Load (t/day)
	CACHE CANYON							
2-2-98	Harley G.East (31b)	2.1	925.2	3,800	0.2			
	Harley G. West (31a)	0.6	359,448	6,700	53.6			
	LOWER CANYON							
	Rumsey (4)		74.40	300	0.3	4,958	903	
	Rumsey Canyon (23)	1.1	12.29	64	0.2			
	Johnson Canyon (24)	3.9	50.31	100	0.5			
	Cross-Hamilton (25)	12.9	12.48	70	0.2			
	Angus-Black Mt.(26)	11.1	15.46	99	0.2			
	McKinney-Smith (27)	9.3	14.67	78	0.2			
	Mossy Creek (28)	14.5	18.06	130	0.1			
	Taylor-Chimney (29)	24.3	12.71	90	0.1			
	Capay (3)		391.5	1,470	0.3			
2-2-98	Rd. 102 (2)		469.2/ 570.5	1,500	0.3/ 0.4	7,040	8.082/ 9,828	25,840

---

[2] Field replicates.

Table 15. (Continued).

Date	Location (site #)	Area (miles^2)	Hg (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg Load (g/d)	TSS Load (t/day)
2-16-98	**BEAR CREEK**							
	Above Sulfur (14)		62.65	66	0.9			
	Sulfur Creek (13)	10.1	1,964.7	140	14.0			
	CACHE CANYON							
	Harley G.East(31b)	2.1	58.93	110	0.5			
	Harley G.West(31a)	0.6	146,039	5,400	27.0			
	NORTH FORK.							
	Chalk Mt. (21)	4.0	86.31	290	0.3			
	Benmore Cyn (18)	7.4	749.2	4,800	0.2			
2-16-98	Grizzly Creek (17)	8.0	1,108.9	6,800	0.2			

Table 16. Summary of mercury concentrations in the Cache Creek Canyon during float trips.

Date	Location (site #)	Area (Mile^2)	Hg (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg Load (g/d)	TSS Load (t/day)
4-2-96	Clear Lake Dam (10)		12.18	46.4	0.3	956	29	109
	North Fork Hwy 20 (8)		4.34	16.6	0.3	<100	1[1]	4[1]
	North Fork above confluence (7)		3.93	20.5	0.2	<100	1[1]	5[1]
	South Fork above confluence (9)	14.8	12.90	70.0	0.2	95.6	30.2	163
	Stemple Creek (30)	2.6	1.88	5.4	0.4			
	Harley Gulch (31)	5.1	29.47	1.8	16.3			
	Rocky Creek (32)	14.8	11.46	29.3	0.4			
	Cache Creek below Rocky Creek (33)		13.17	69.3	0.2			
	Judge Davis Creek (35)	2.4	1.74	1.3	1.3			
	Bushy Creek (36)	3.1	2.53	0.8	3.2			
	Petrified Canyon (37)	1.3	2.44	0.3	8.1			
	Trout Creek (38)	2.9	5.21	1.1	4.7			
4-2-96	Cache Creek below Trout Creek (39)		14.76	78.0	0.2			

[1] Assumes a flow of 100 cfs.

Table 16. (Continued)

Date	Location (site #)	Area (Mile^2)	Hg (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg Load (g/d)	TSS Load (t/day)
4-2-96	Crack Canyon (40)	3.4	1.72	3.6	0.5			
	Cache Creek below Crack Cyn (41)		14.41	83.8	0.2			
	Davis Ck @ Davis Lake (42a)		12.42/11.38[1]	3.5	3.6/3.3			
	Davis Creek (42)	9.2	8.58	3.2	2.7			
	Cache below Davis Creek (43)		14.41	84.0	0.2			
	Cache above Bear Creek[2] (6)		17.63/23.58	108.5	0.2	1906	82/110	506
	Cache above Bear Creek[3] (6)		18.37	86.8	0.2	1906	86	405
	Bear Creek[2] (5)		61.65/64.50	23.0	2.8	170	26/25	10
	Rumsey[2] (4)		30.77	106.0	0.3	2076	156	540
4-2-96	Rd. 102[2] (2)		256.56	1327.3	0.2	2310	1450	7503

[1] Replicate field sample.
[2] Car sampling crew (see Table 14)
[3] Float trip sampling crew.

Table 16. (Continued).

Date	Location (site #)	Area (miles^2)	Hg (ng/l)	TSS (mg/l)	Hg/TSS (ppm)	Flow (cfs)	Hg load (g/d)	TSS load (t/d)
1-16-98	North Fork (7)		61.02	446	0.1			
	South Fork (9)		32.46	189.0	0.2			
	Stemple Ck (30)	2.6	103.8	1023	0.1			
	Harley G. (31)	5.1	78.47	47.3	1.7			
	Rocky Creek (32)	14.8	31.78	174.5	0.2			
	Cache below Jack(34)		51.35	472.0	0.1			
	Judge Davis (35)	2.4	2.73	1.9	1.4			
	Bushy Creek (36)	3.1	2.95	2.3	1.3			
	Petrified Ck(37)	1.3	1.51	2.6	0.6			
	Trout Creek (38)	2.9	2.04	2.7	0.8			
	Cache below Trout(39)		52.89	488	0.1			
	Crack Creek (40)	3.4	2.42	3.0	0.8			
	Davis Creek (42)	9.2	4.59	2.3	2.0			
	Cache below Davis(43)		51.65	445	0.1			
	Bear Creek (5)		98.41	62.0	1.6			
1-16-98	Rumsey (4)					1507		

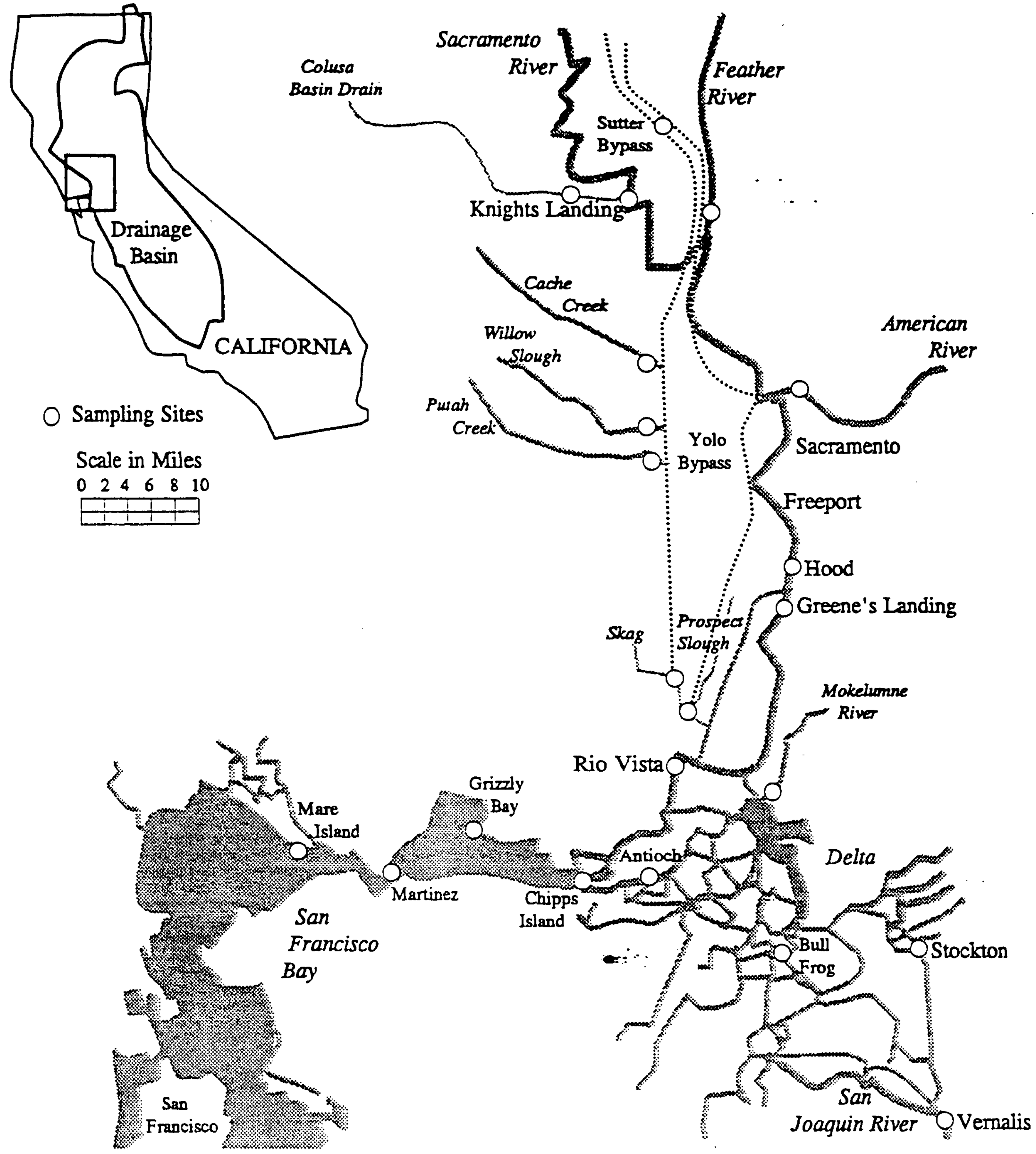


Figure 1. Map of the Sacramento-San Joaquin Delta Estuary and its major tributaries. Mercury sampling sites are identified by open circles.

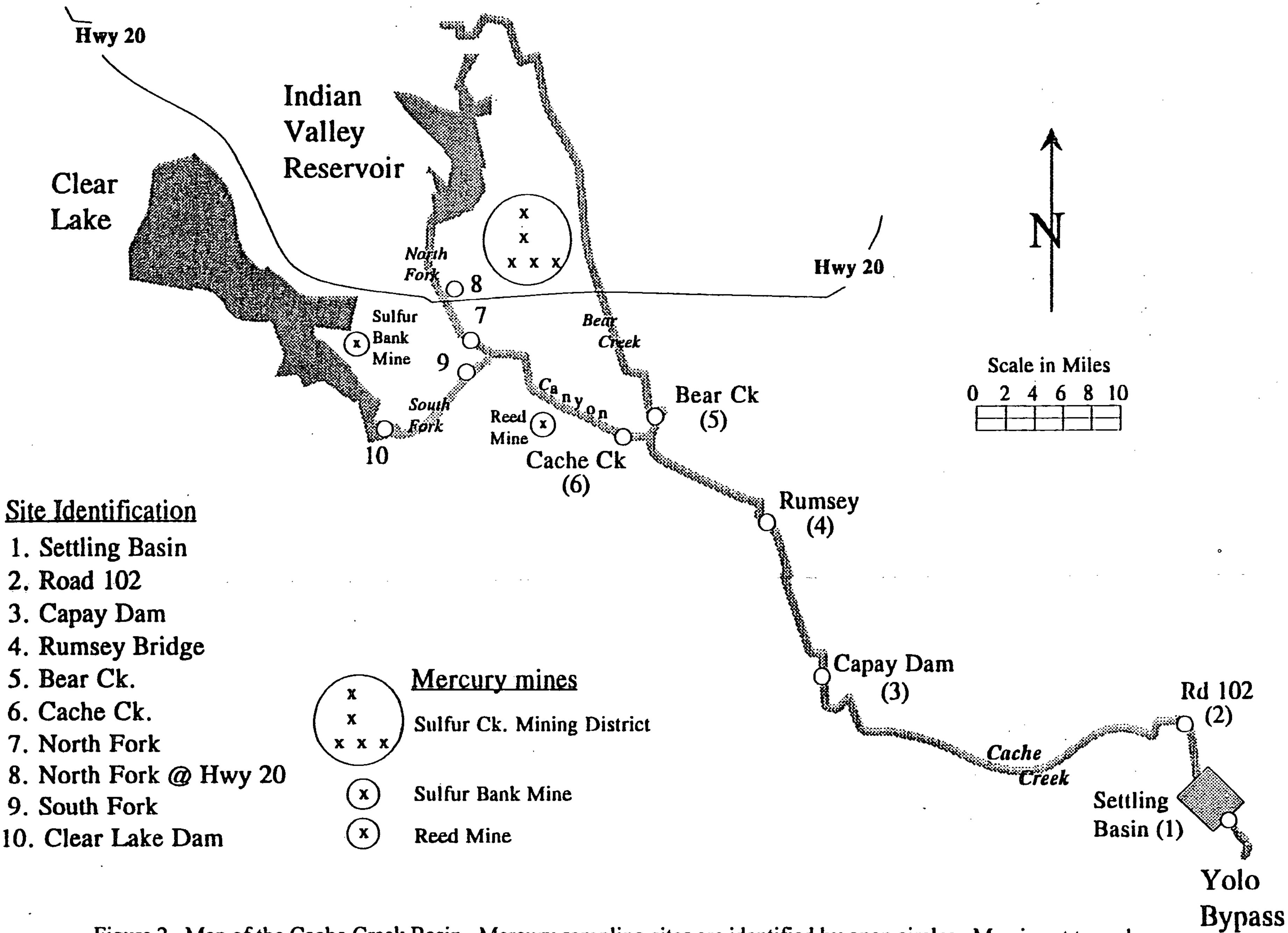


Figure 2. Map of the Cache Creek Basin. Mercury sampling sites are identified by open circles. Map is not to scale.

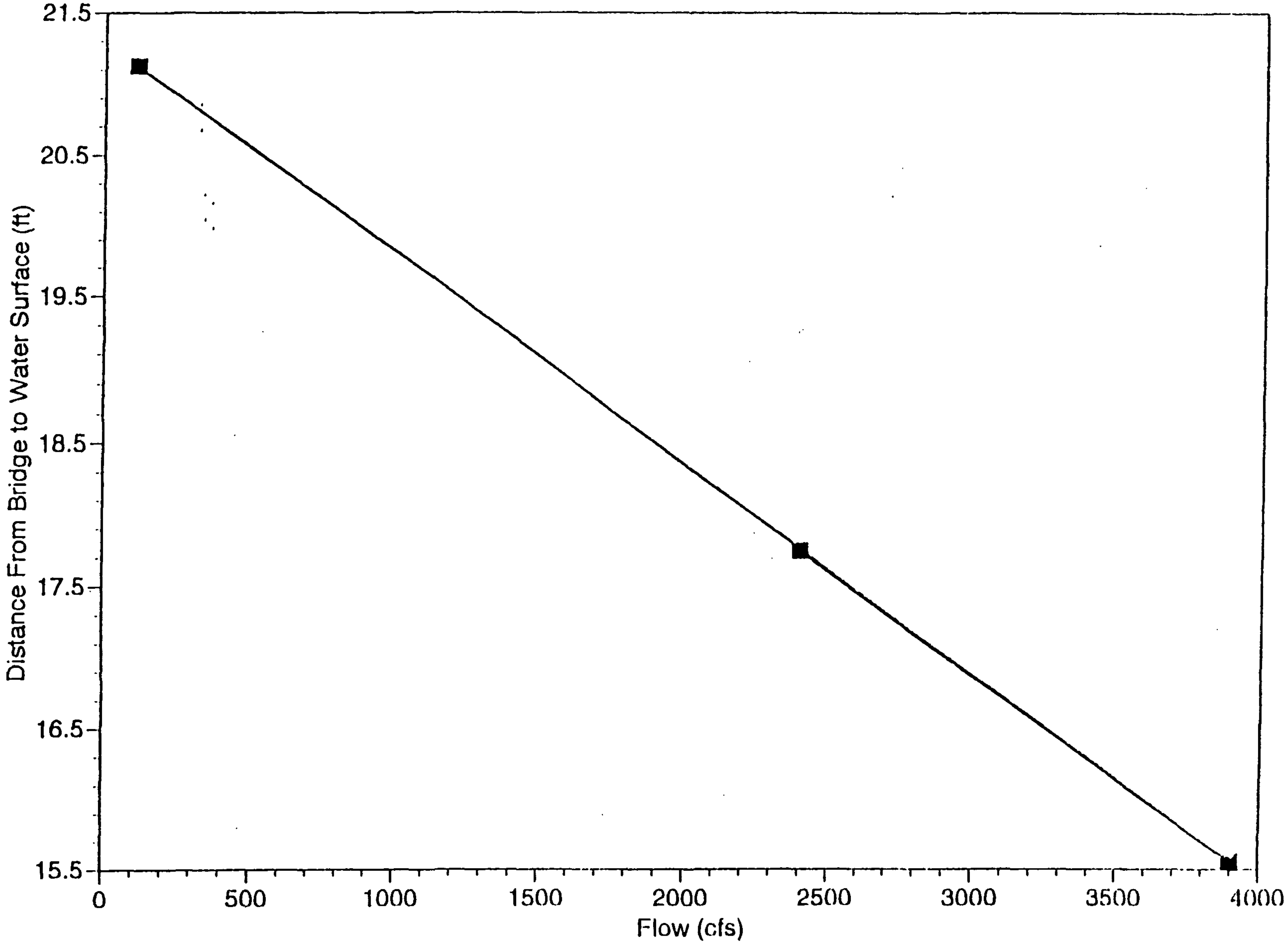


Figure 3. Correlation between the flow rate of the North Fork of Cache Creek at the HWY 20 bridge and the distance between a fixed point on the bridge railing and the water surface.

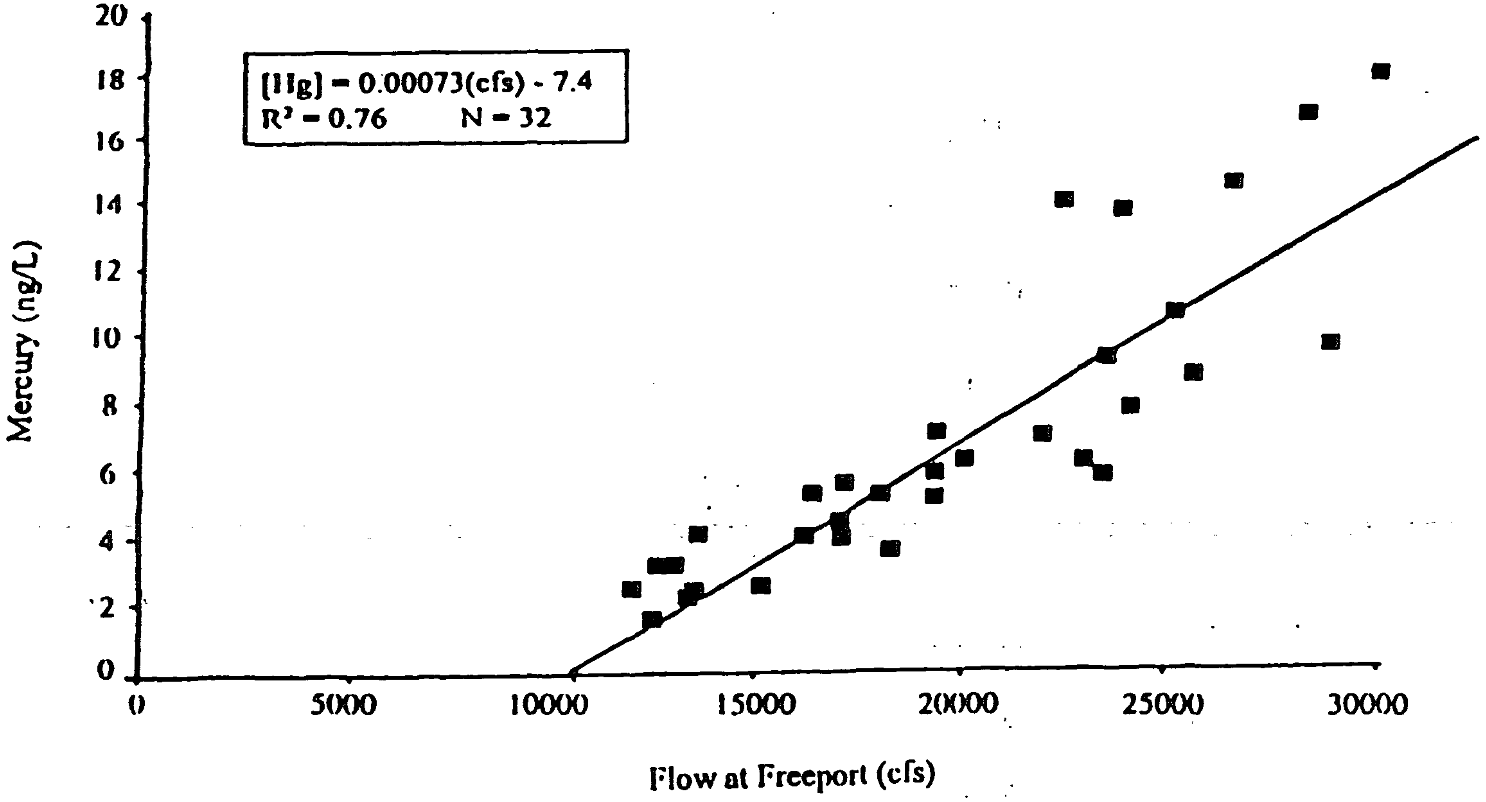


Figure 4. Correlation between mercury concentration in the Sacramento River at Greene's Landing and flow at Freeport during low flow conditions in 1993-94. Data is fromTable 1.

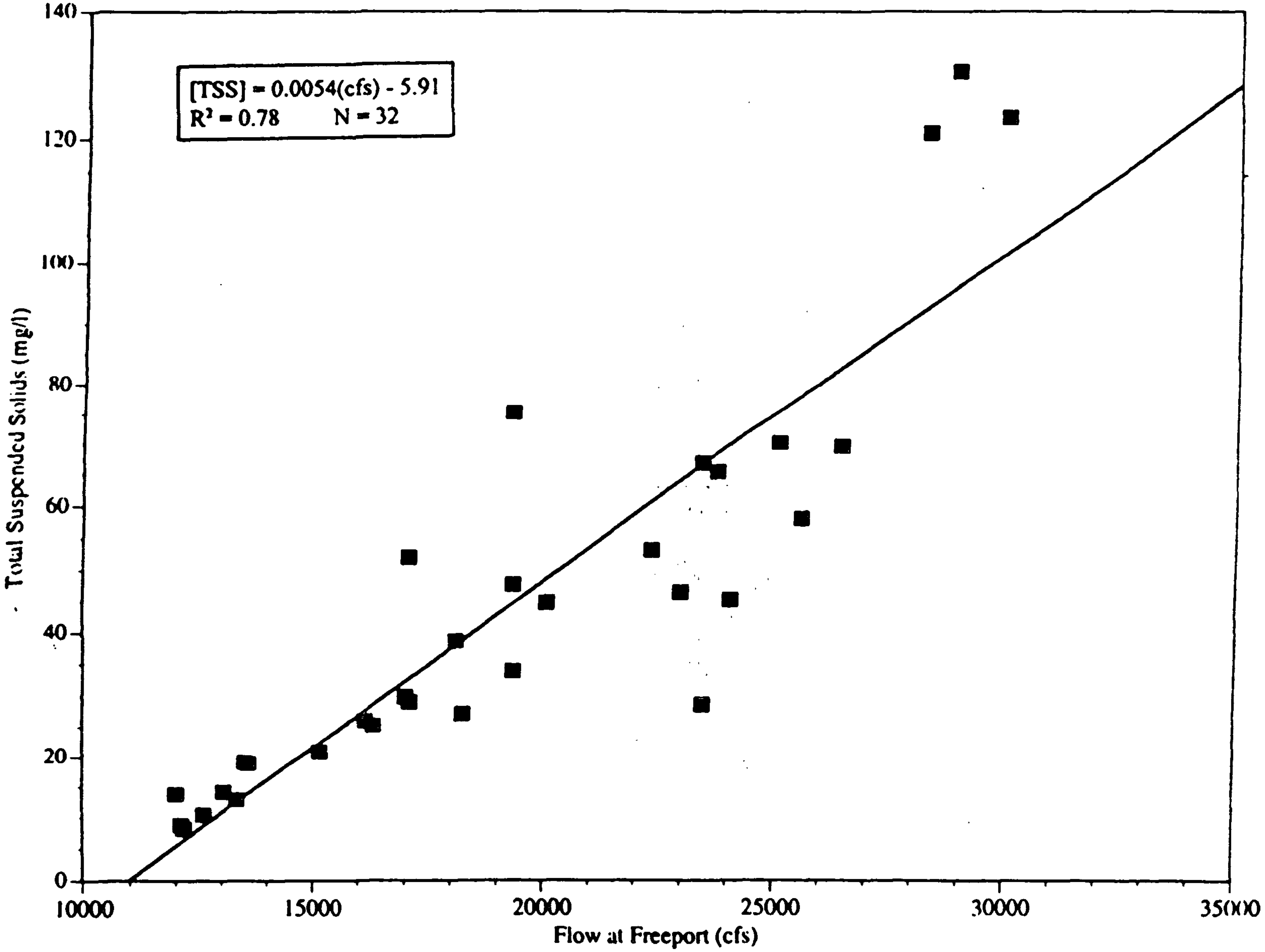


Figure 5. Correlation between total suspended solids at Greene's Landing and flow at Freeport during low flow conditions in 1993-94. Data is from Table 1.

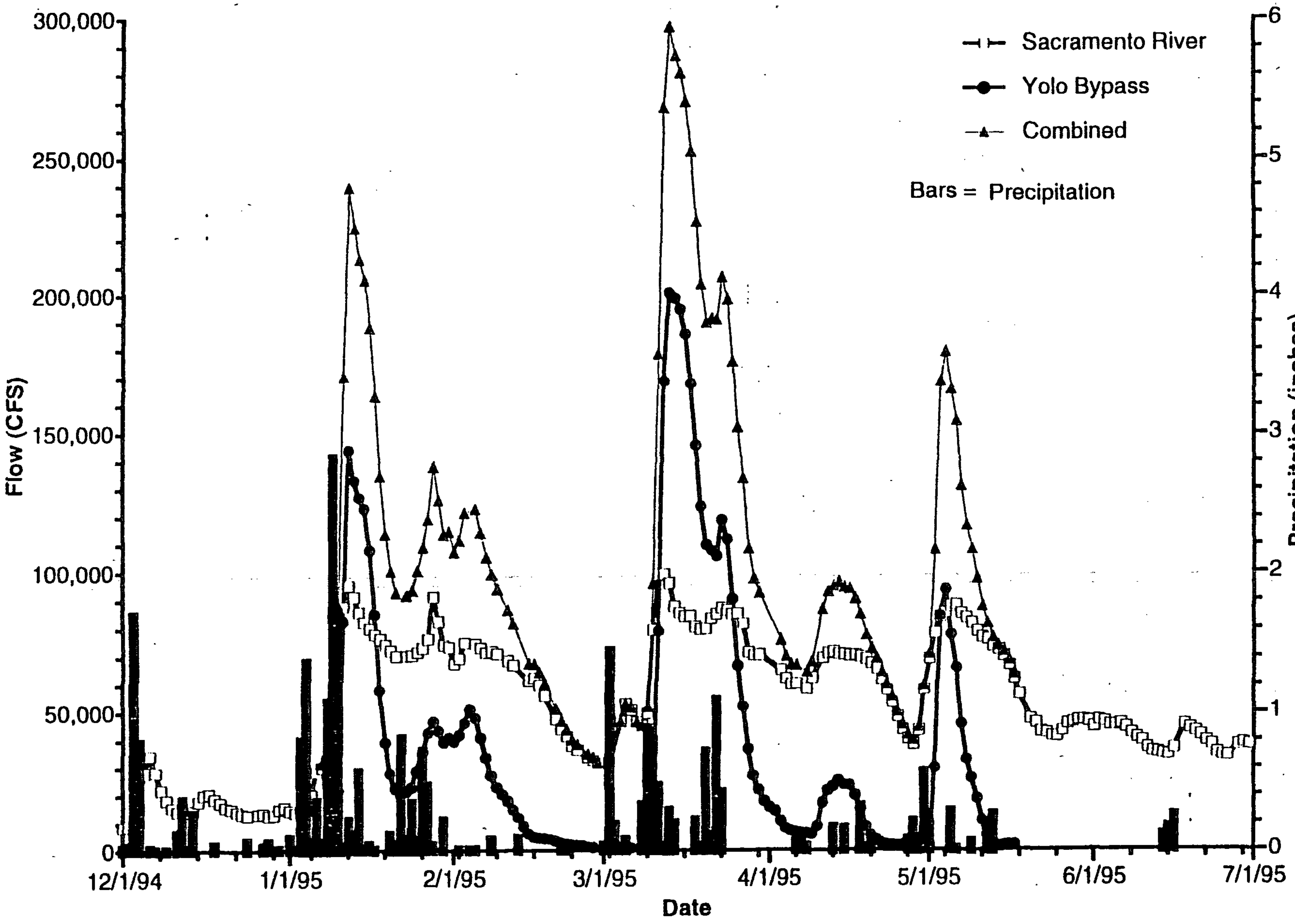


Figure 6. Precipitation and flow pattern in the Sacramento Basin during the winter and spring of 1995.

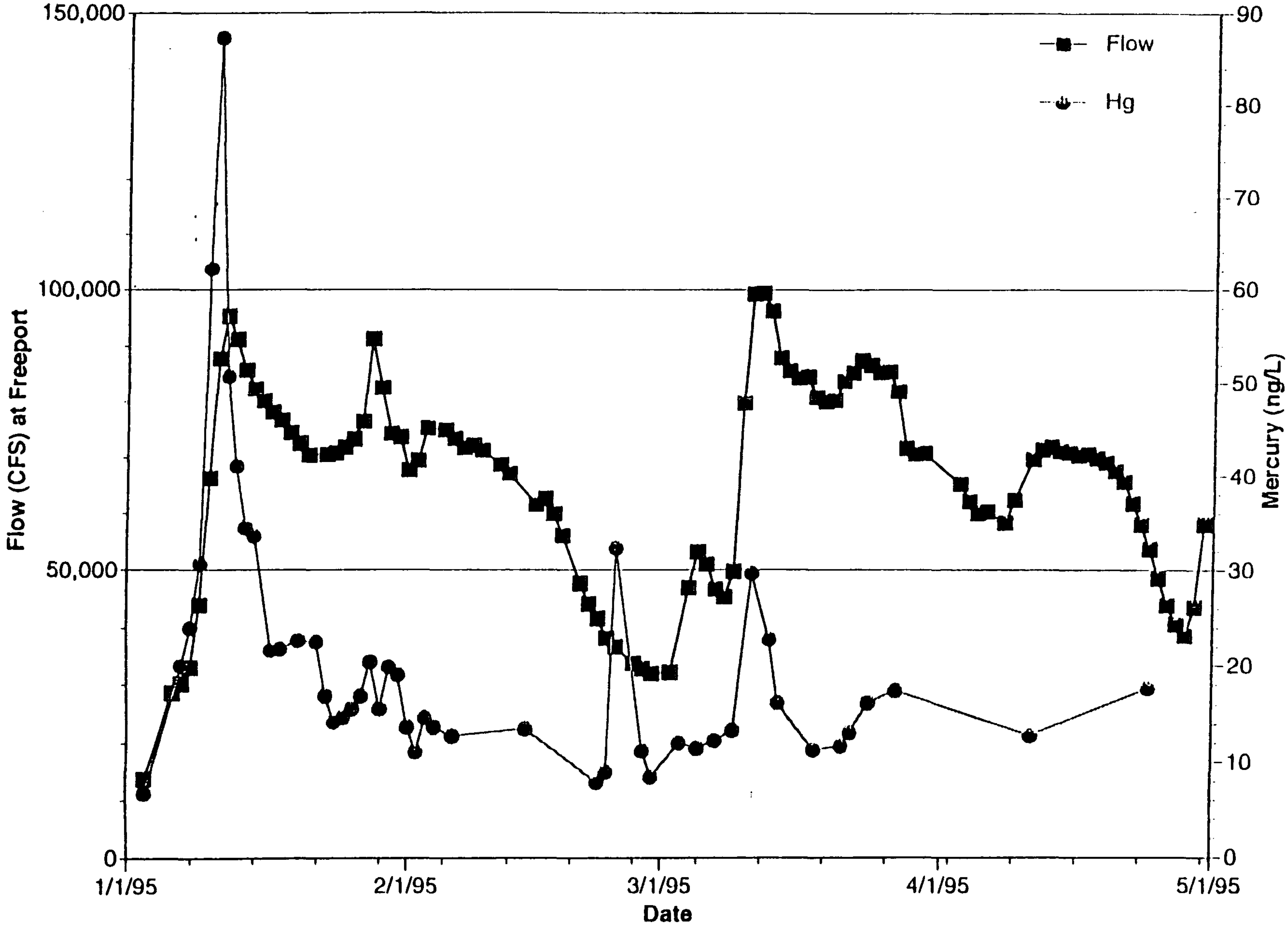


Figure 7. Mercury concentration in the Sacramento River at Greene's Landing and flow at Freeport during high flow conditions in 1995. Data is from Table 4.

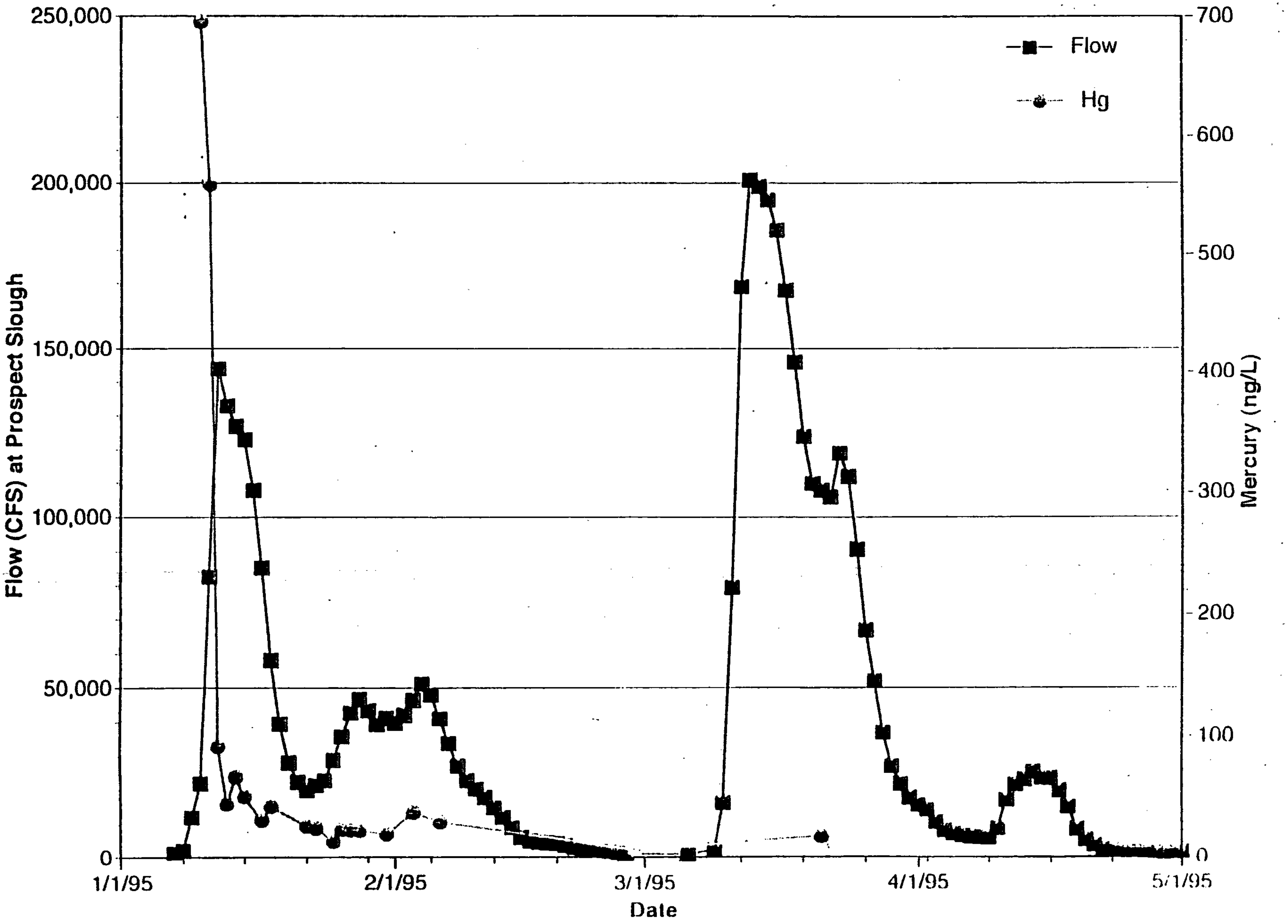


Figure 8. Mercury concentrations at Prospect Slough and flow in the Yolo Bypass during high flow conditions in 1995. Data is from Table 4.

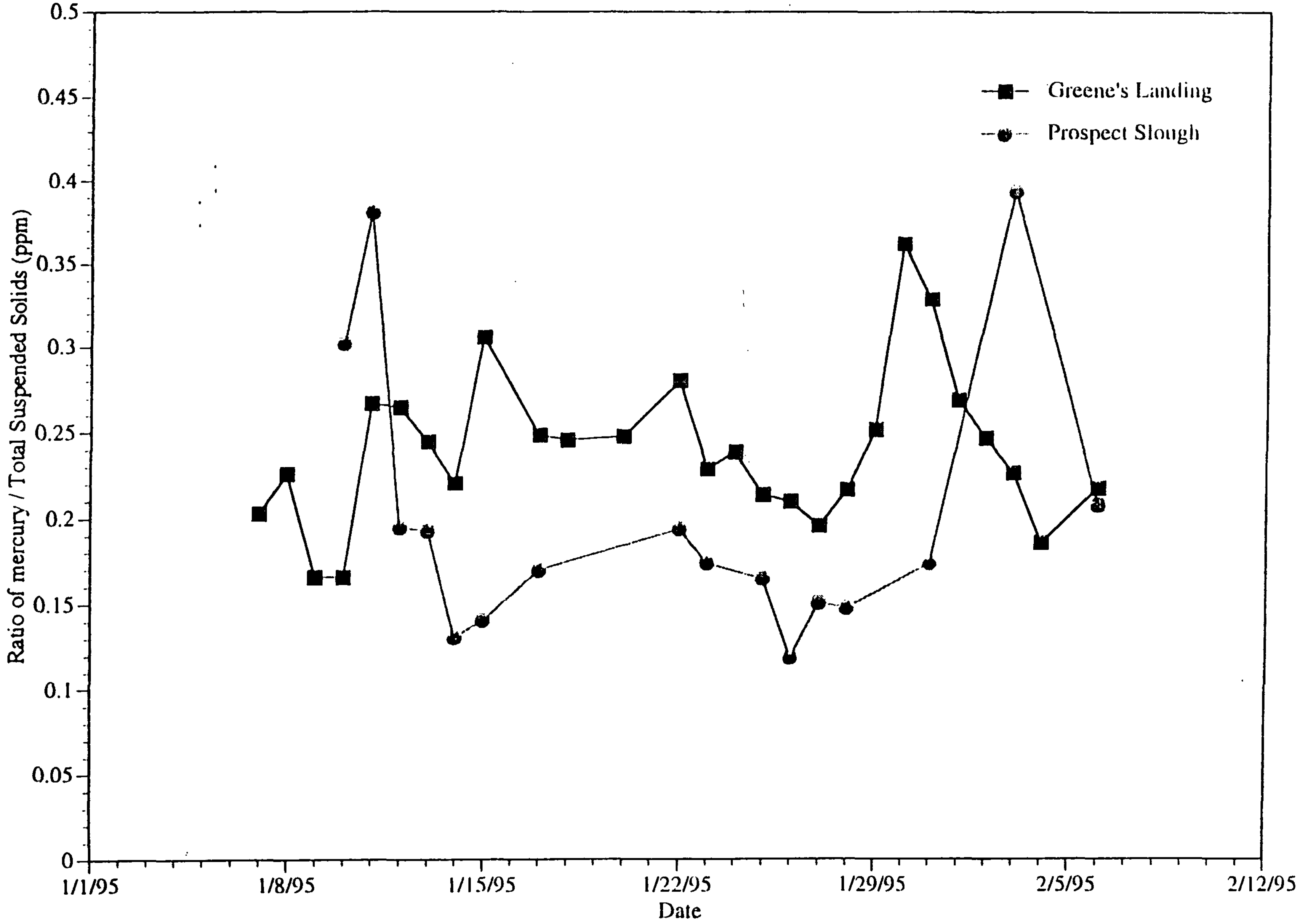


Figure 9. Ratio of mercury to total suspended solid concentrations in water samples collected in the Sacramento River at Greene's Landing and in the Yolo Bypass at Prospect Slough during high flow..

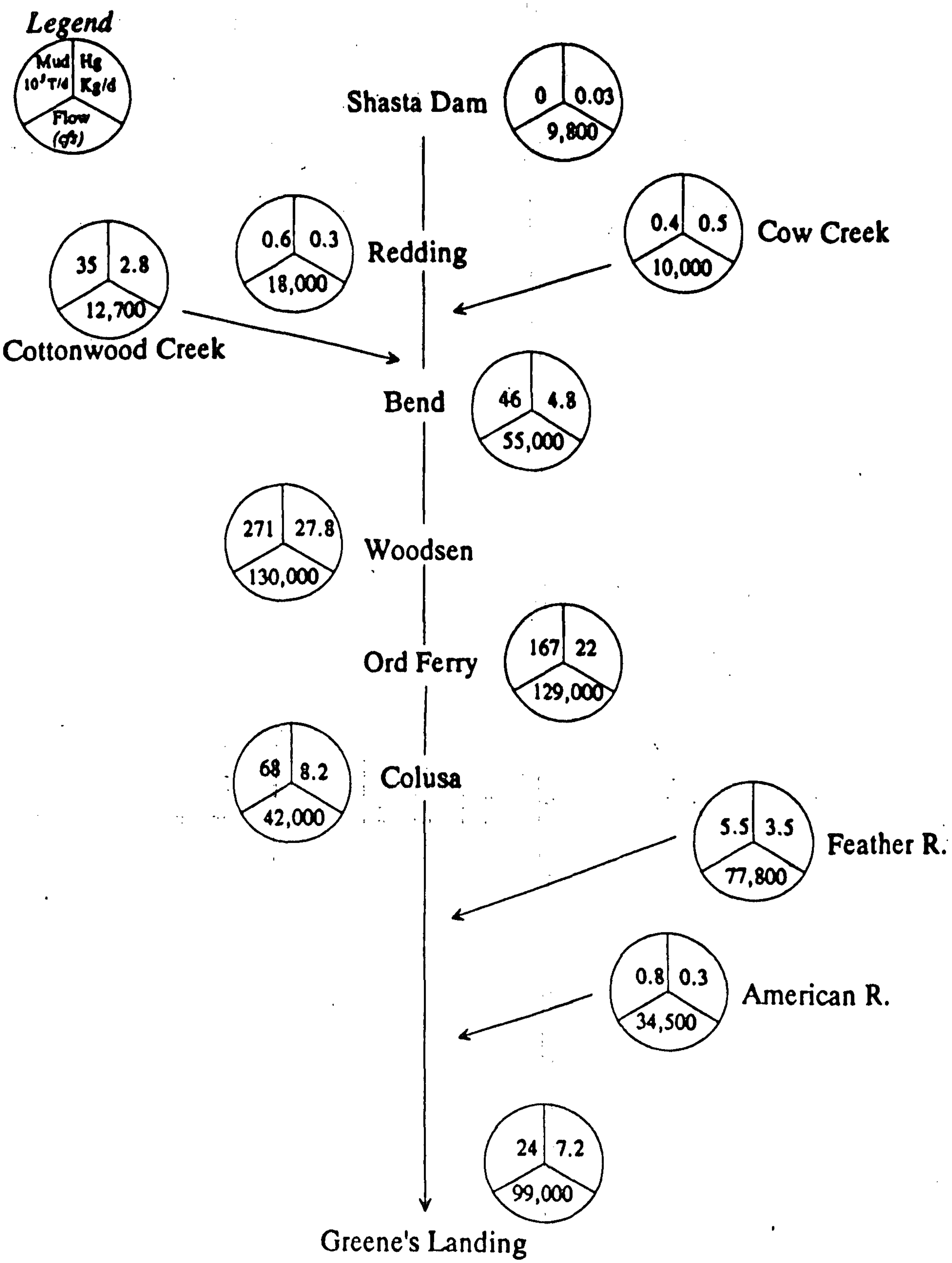


Figure 10. Schematic of mercury and suspended sediment loads in the Sacramento River and in its major tributaries during the largest storm of the year in March 1995. The results suggest an unknown riverine mercury source between Bend and Woodsen Bridge.

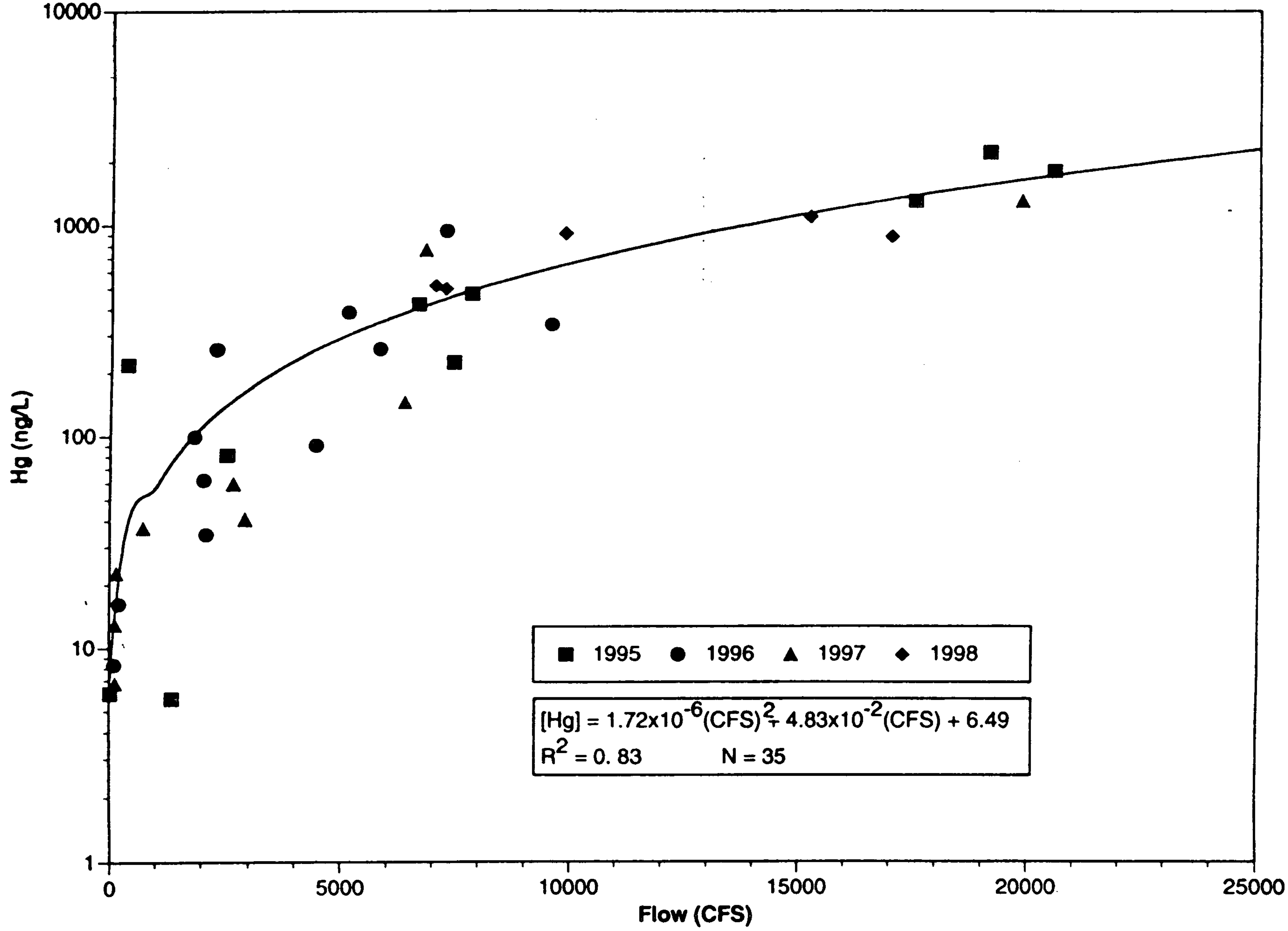


Figure 11. Correlation between mercury concentrations in Cache Creek at Road 102 and flow immediately upstream at the Town of Yolo.

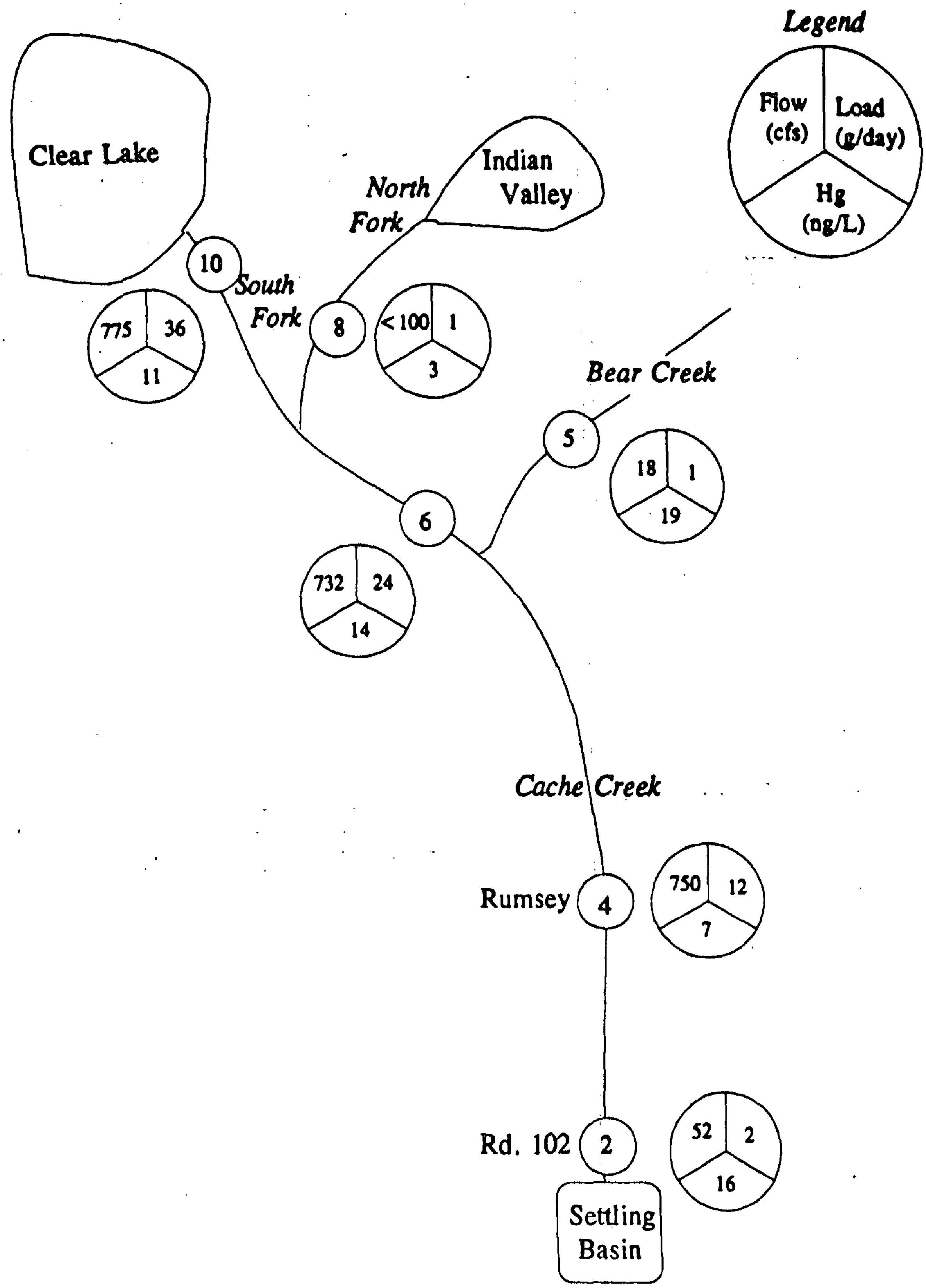


Figure 12. Mercury concentrations and loads in Cache Creek on 11 June 1996 during irrigation season. Clear Lake was the major source of mercury.

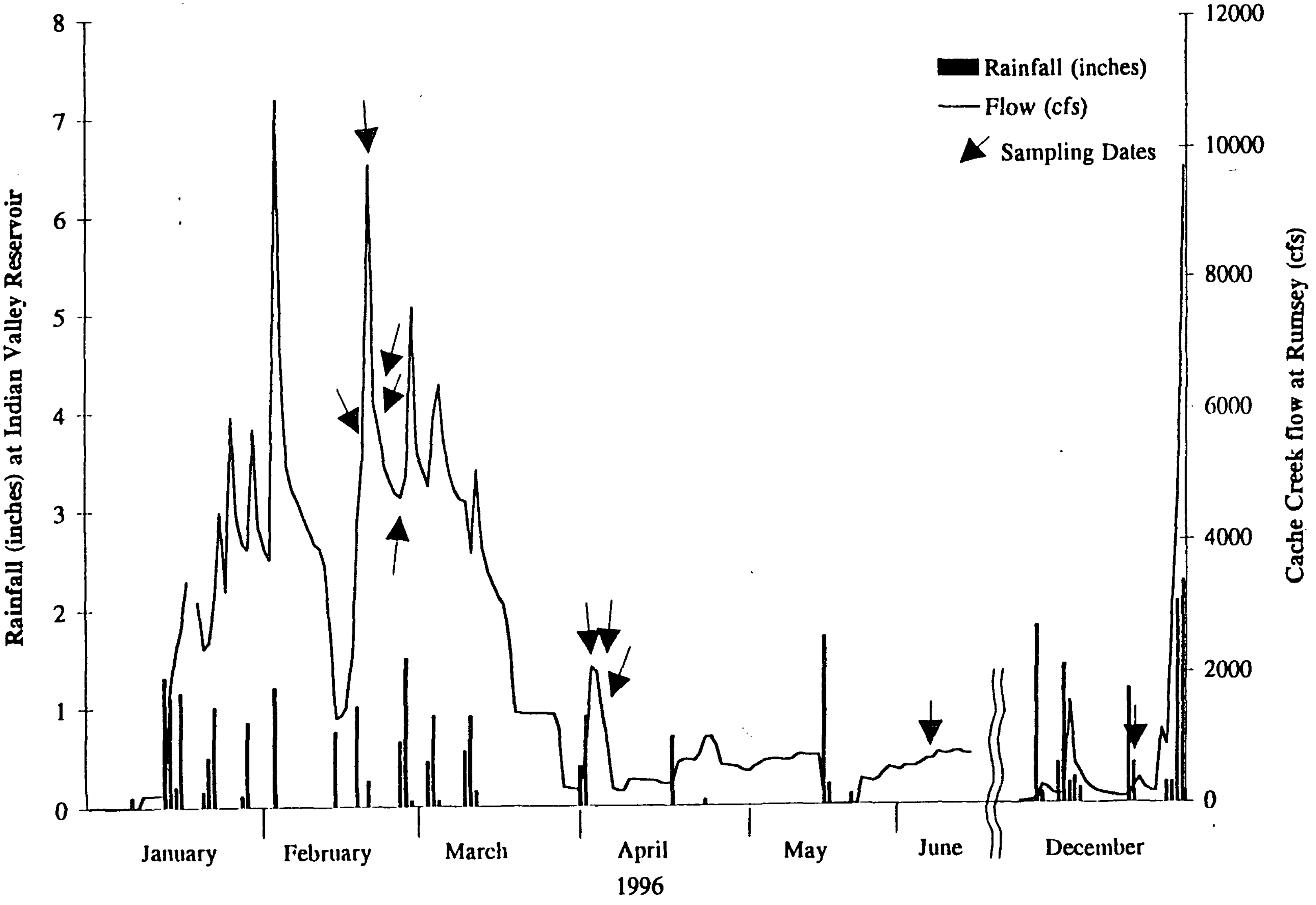


Figure 13a. Rainfall at Indian Valley Reservoir and flow at Cache Creek at Rumsey in 1996. Sampling dates are indicated by an arrow.

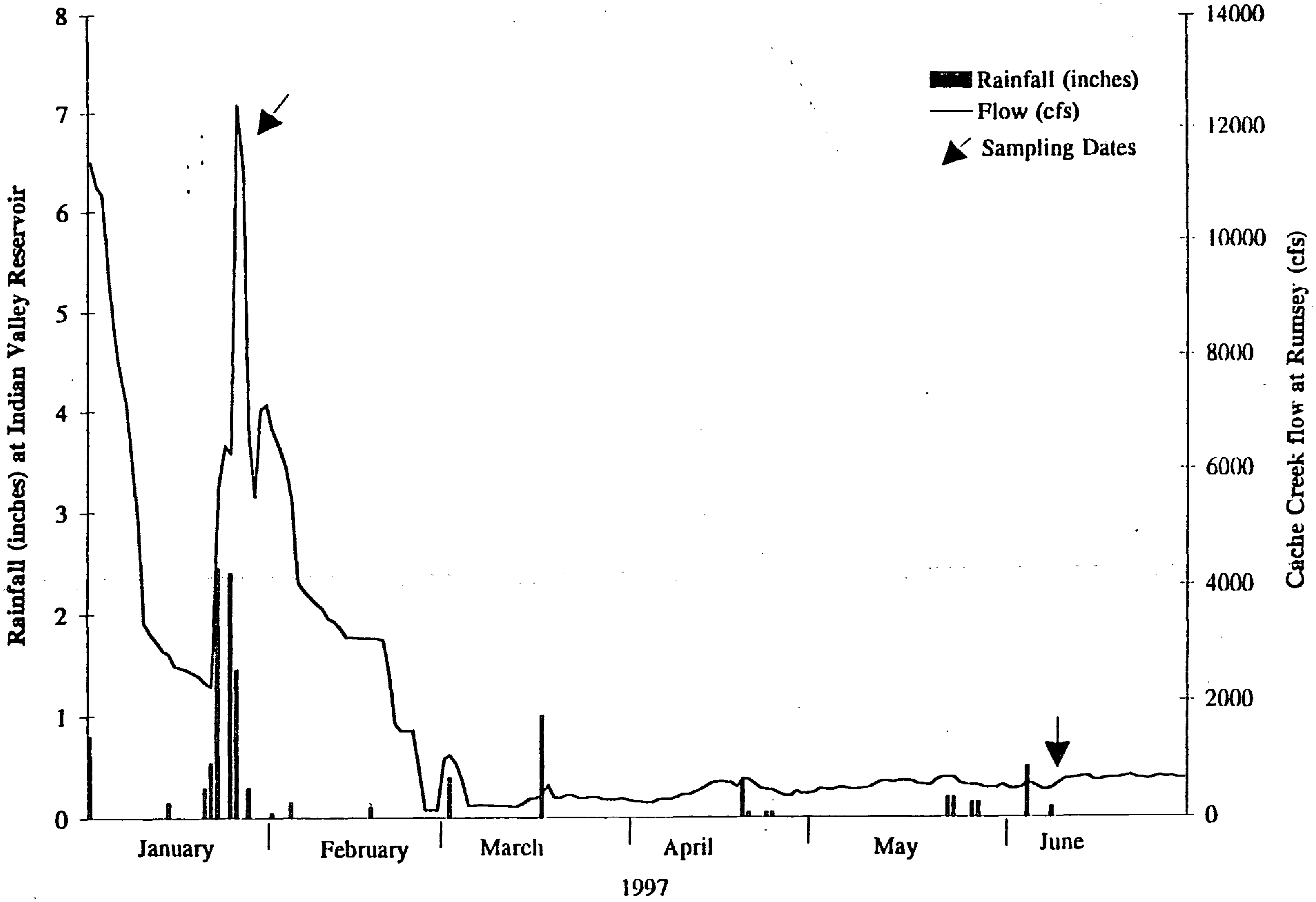


Figure 13b. Rainfall at Indian Valley Reservoir and flow at Cache Creek at Rumsey in 1997. Sampling dates are indicated by an arrow.

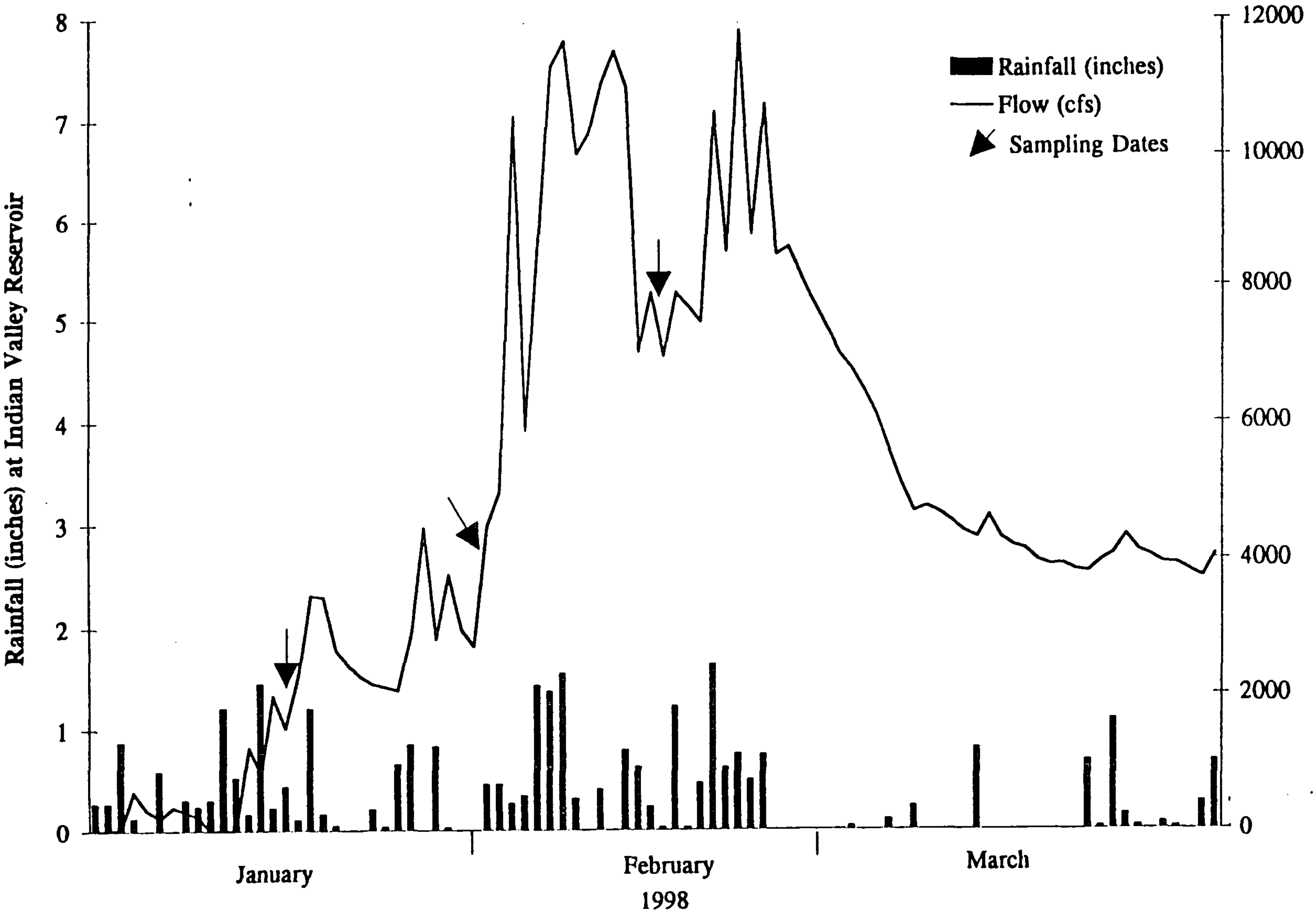


Figure 13c. Rainfall at Indian Valley Reservoir and flow at Cache Creek at Rumsey in 1998. Sampling dates are indicated by an arrow.

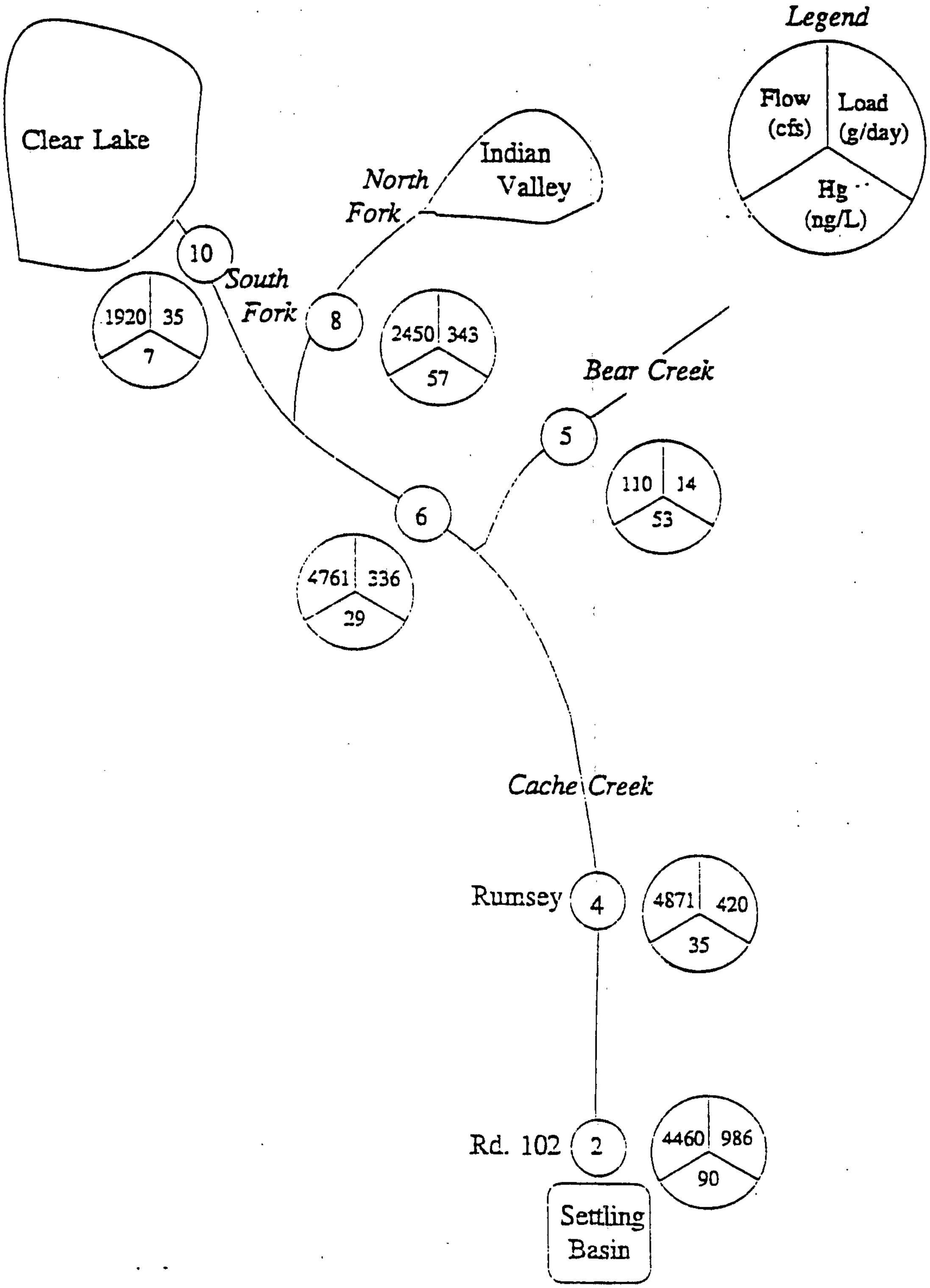


Figure 14. Mercury concentrations and loads in Cache Creek on 27 February 1996 during a non precipitation runoff event. The North Fork was the major source of mercury.

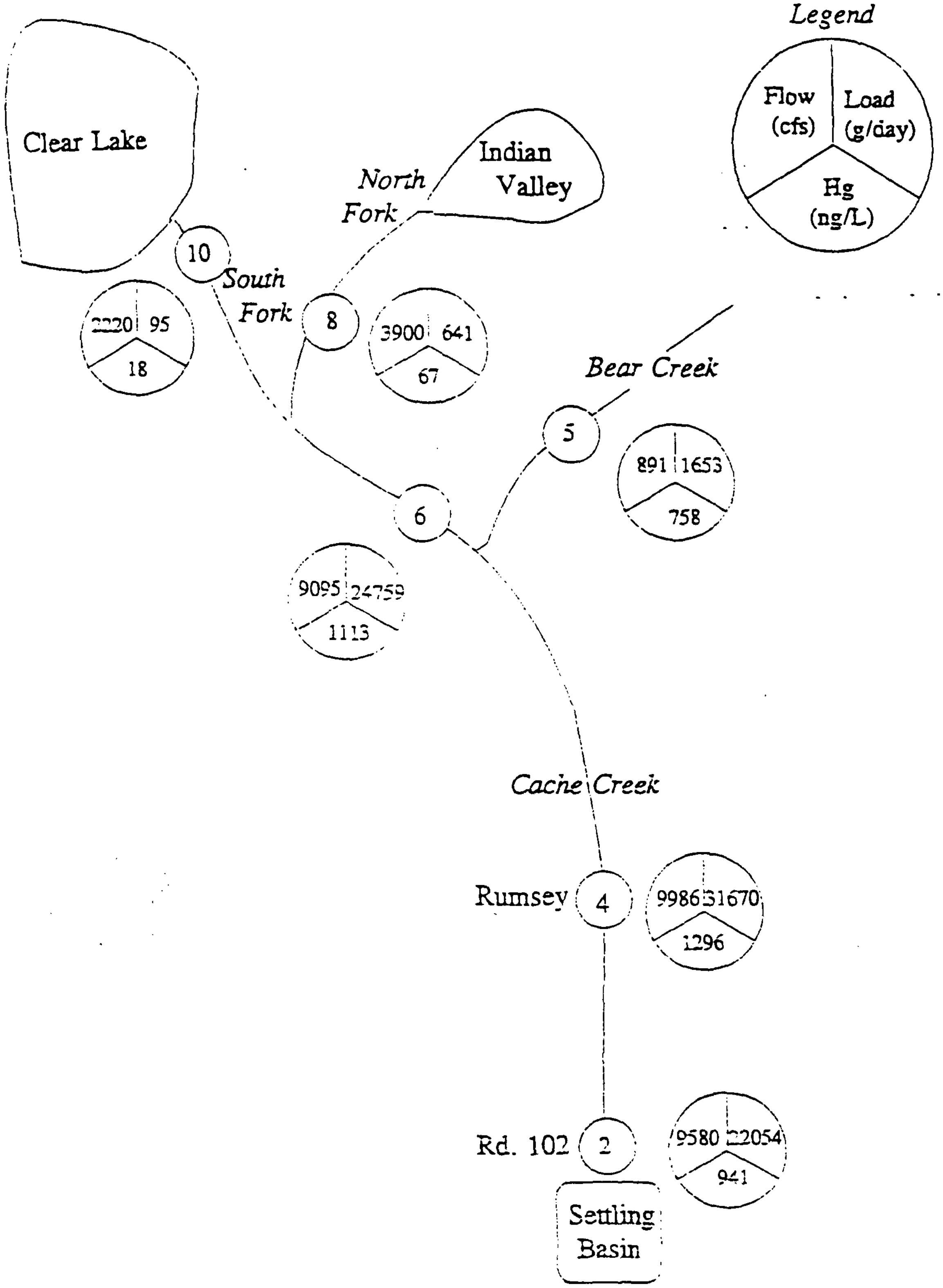
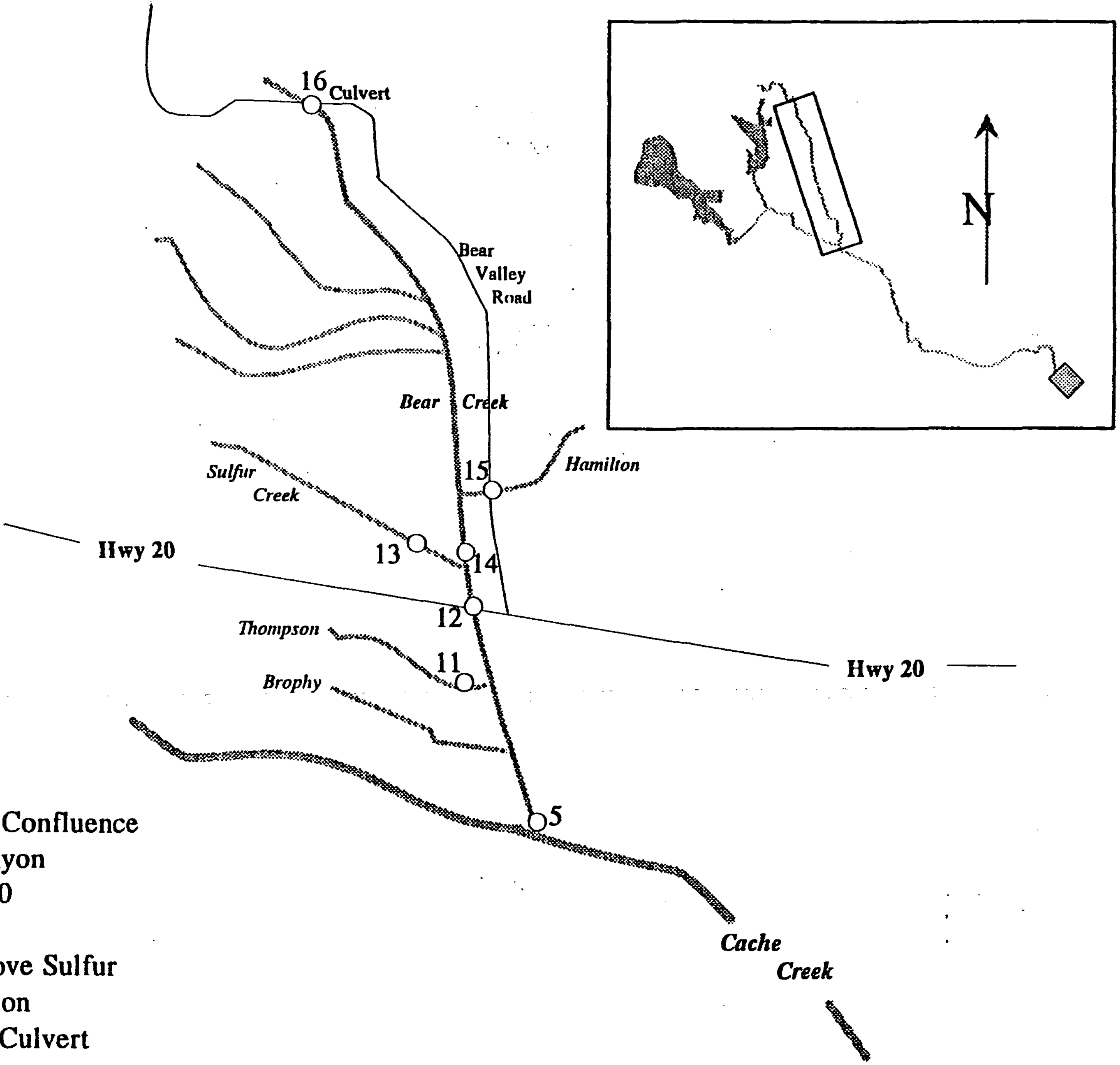


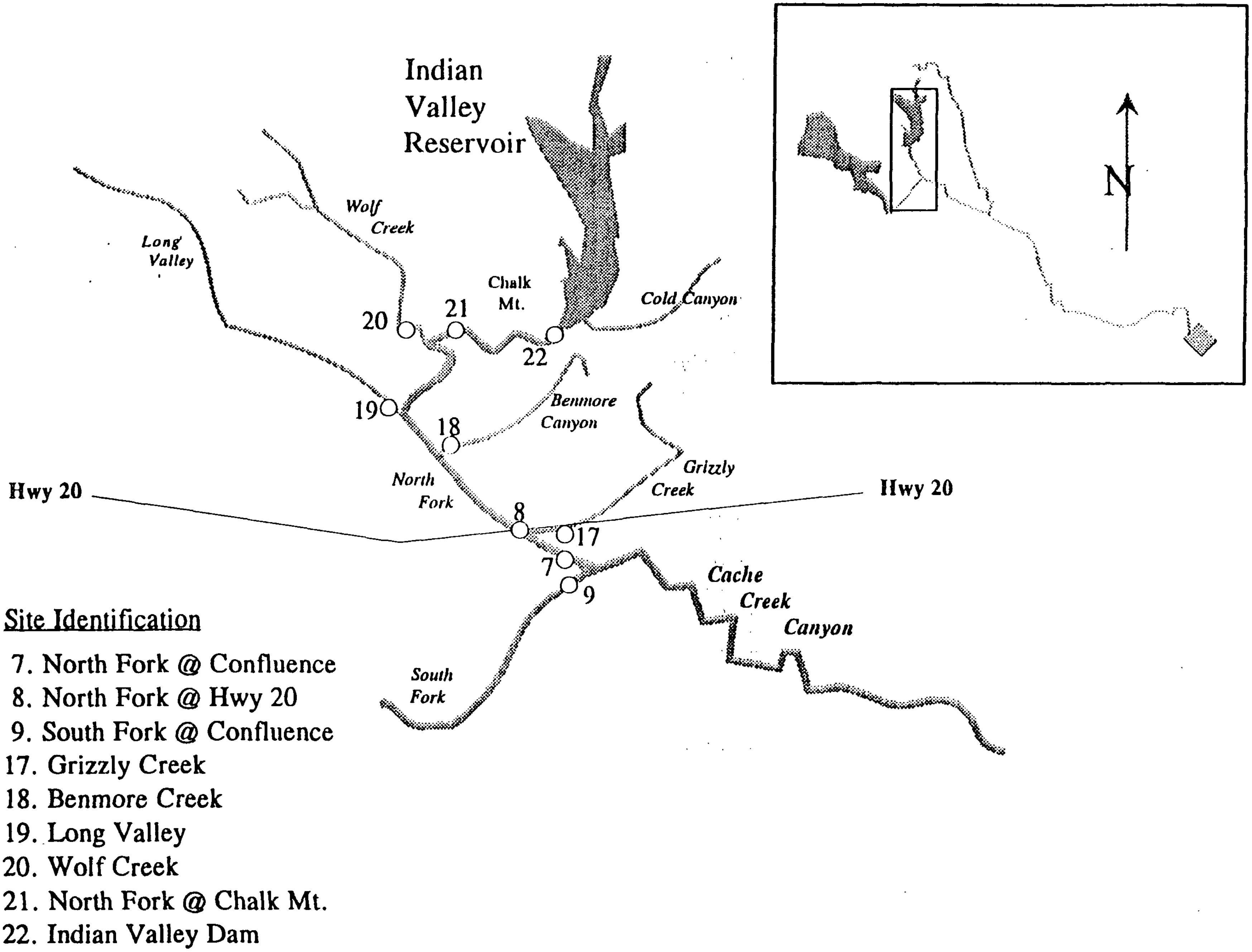
Figure 15. Mercury concentrations and loads in Cache Creek during a storm on 21 February 1996. The Cache Creek Canyon, located between the confluence of the North and South Forks and Bear Creek, was the major source of mercury.



Site Identification

5. Bear Creek @ Confluence
11. Thompson Canyon
12. Bear @ Hwy 20
13. Sulfur Creek
14. Bear Creek above Sulfur
15. Hamilton Canyon
16. Bear Creek @ Culvert

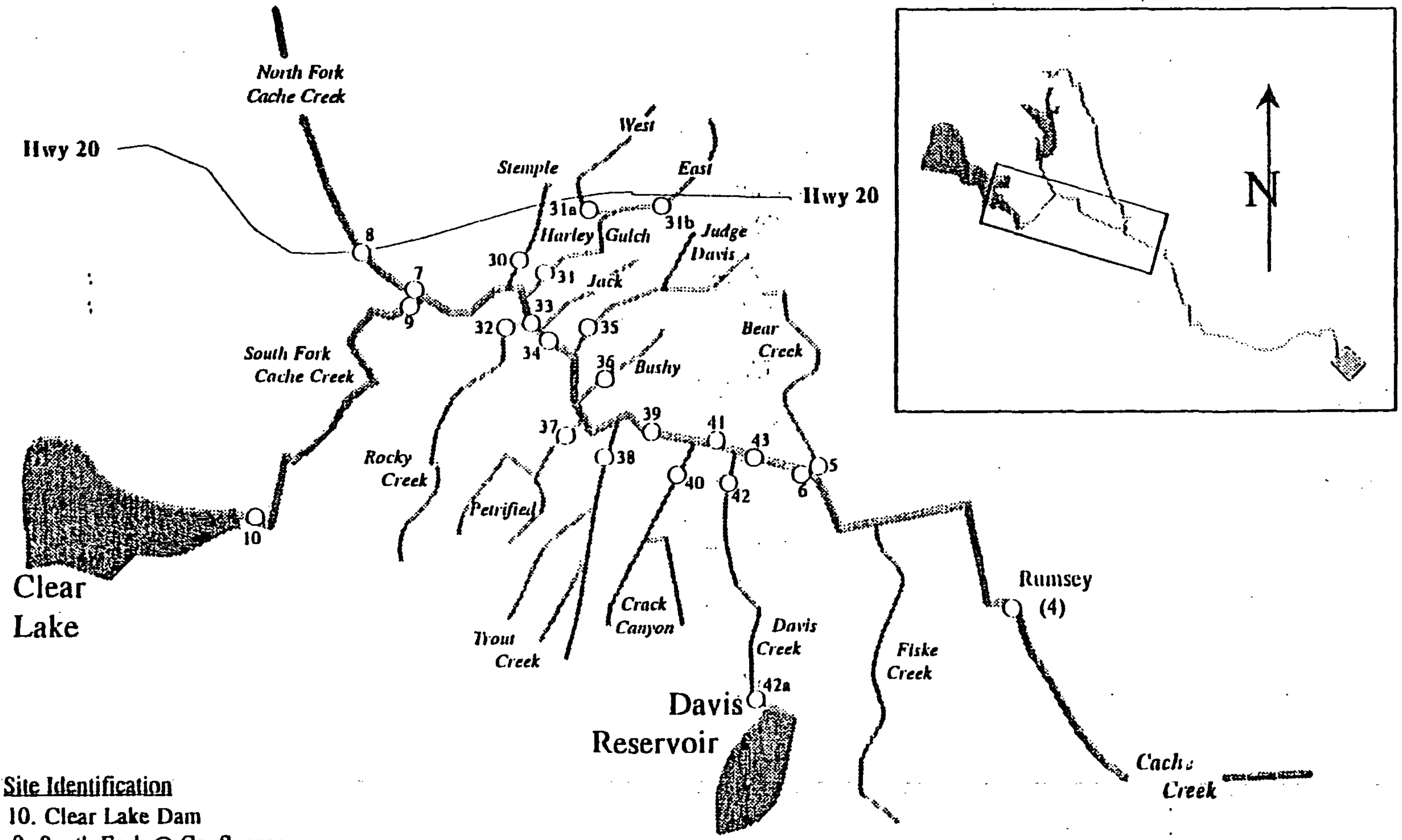
Figure 16. Location of sampling sites to identify mercury sources in Bear Creek. Map not to scale.



Site Identification

7. North Fork @ Confluence
8. North Fork @ Hwy 20
9. South Fork @ Confluence
17. Grizzly Creek
18. Benmore Creek
19. Long Valley
20. Wolf Creek
21. North Fork @ Chalk Mt.
22. Indian Valley Dam

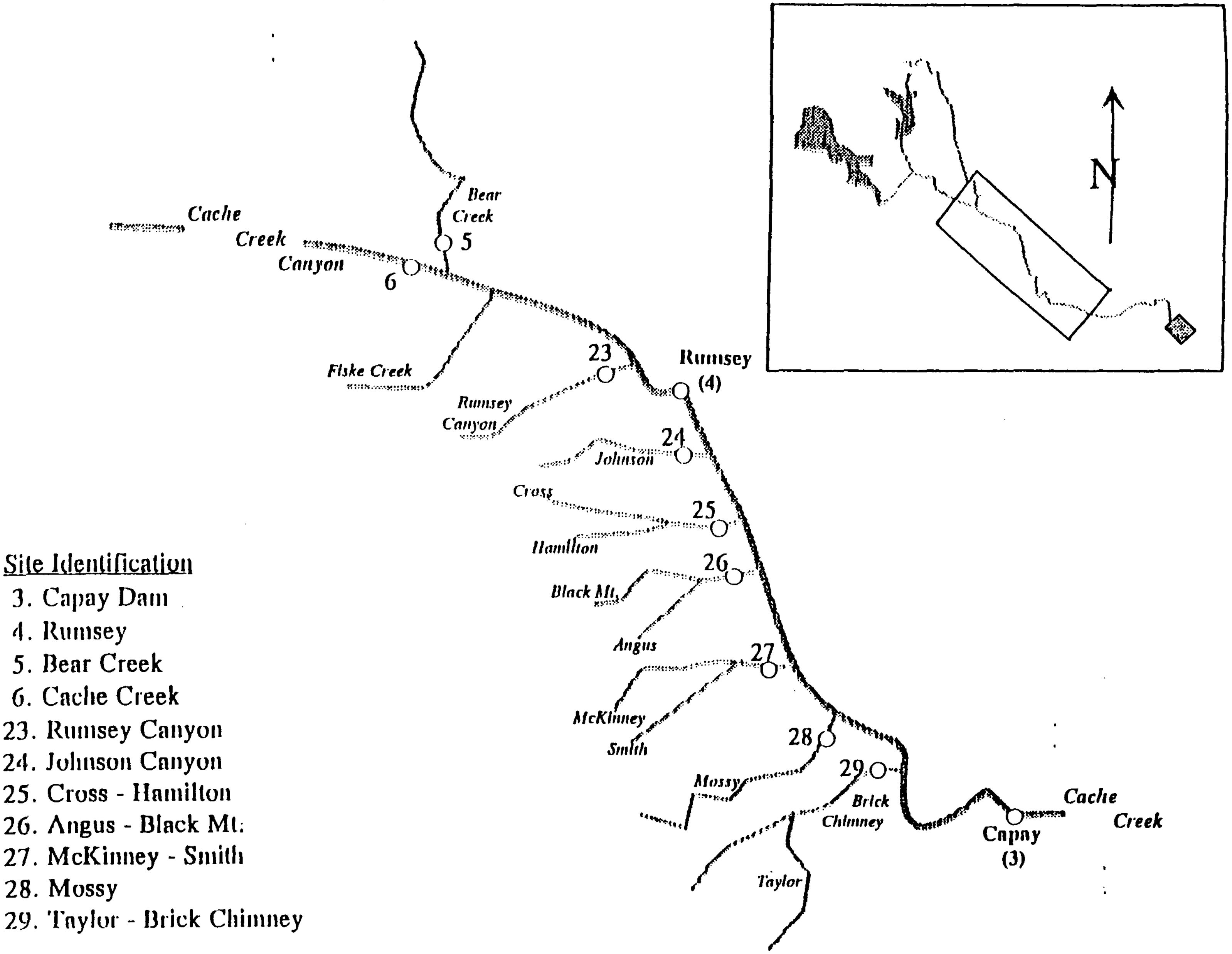
Figure 17. Location of sampling sites to identify mercury sources in the North Fork of Cache Creek. Map is not to scale.



Site Identification

10. Clear Lake Dam
9. South Fork @ Confluence
7. North Fork @ Confluence
8. North Fork @ Hwy 20
30. Stemple Creek
31. Harley Gulch
31a. West Harley Gulch
31b. East Harley Gulch
32. Rocky Creek
33. Cache Creek below Rocky Creek
34. Cache Creek below Jack Creek
35. Judge Davis Creek
36. Bushy Creek
37. Petrified
38. Trout Creek
39. Cache Creek below Trout
40. Crack Canyon
41. Cache Creek below Crack Canyon
42. Davis Creek
42a. Davis Creek below Davis Lake
43. Cache Creek below Davis Creek
6. Cache Creek above Bear Creek
5. Bear Creek above Cache Creek
4. Rumsey

Figure 18. Location of sampling sites to identify mercury sources in the Cache Creek Canyon between the confluence of the North and South Forks and Bear Creek. Map is not to scale.



Site Identification

3. Capay Dam
4. Rumsey
5. Bear Creek
6. Cache Creek
23. Rumsey Canyon
24. Johnson Canyon
25. Cross - Hamilton
26. Angus - Black Mt.
27. McKinney - Smith
28. Mossy
29. Taylor - Brick Chimney

Figure 19. Location of sampling sites to identify mercury sources in lower Cache Creek. Map is not to scale.

APPENDIX A:

DESCRIPTION OF SAMPLING LOCATIONS

The description of monitoring locations are arranged according to the section of the mercury study in which they were sampled.

Estuarine Study

Greene's Landing Sacramento River sampled from end of the U.S. Bureau of Reclamation water quality pier off Randall Island Road. Site is about 3 miles downstream of Hood. Samples collected on outgoing tide.

Propect Slough. Sampled by boat at junction of Prospect Slough and Toe drain. Prospect Slough is the main channel draining the Yolo Bypass. Samples collected on an outgoing tide.

Skag Slough. Sampled from middle of Liberty Island Road bridge. Skag Slough is the secondary channel draining the Yolo Bypass. Samples collected on an outgoing tide.

Mokelumne River. Samples collected from shore approximately one mile downstream of confluence with the Consumnes River off New Hope Road. Samples collected on an outgoing tide.

Hood. Sacramento River samples collected by boat from mid channel off steps on east bank of River upstream of Hood. Samples collected on outgoing tide.

Rio Vista. Sacramento River samples collected at low tide in mid channel by boat about 1 mile downstream of HWY 12 bridge.

Bullfrog. Middle River samples collected on an incoming tide at mid channel off Bacon Island Road Bridge.

Vernalis. San Joaquin River samples collected off middle of Airport Way Bridge (Rd J3).

City of Stockton. Samples collected by boat off entrance to McLeod Lake.

Point Antioch. San Joaquin River samples collected by boat in mid channel at low tide off Point Beenar. Site is about 5 miles upstream of confluence of Sacramento River

Mercury Fate Study

Chipps Island. Sacramento River samples collected by boat in mid channel off Chipps Island at lower low tide.

Grizzly Bay. Sample collected by boat at lower low tide in mid Bay off pilings.

Martinez. Sample collected by boat at lower low tide in mid channel about 2 miles downstream of the Interstate 680 bridge.

I-80 Bridge. Surface and bottom samples collected by boat at lower low tide in mid channel about 1 mile upstream of the interstate 80 bridge.

Sacramento River Mercury Source Study

Shasta Dam. Sacramento River sample collected from east bank below Shasta Dam at Powerhouse..

Redding. Sacramento River sample collected in mid channel from Cypress Ave bridge.

Little Cow Creek. Sample collected from mid channel off the Dersch Road bridge outside of Anderson.

Balls Ferry. Sacramento River sample collected in mid channel off the Balls Ferry Road bridge.

Cottonwood Creek. Sample collected in mid channel off the Interstate 5 frontage road bridge about 1 mile south of town of Cottonwood.

Bend. Sacramento River sample collected in mid channel off bridge at Bend Bridge Park.

Tehama. Sacramento River sample collected in mid channel off County Road A8 bridge.

Woodsen. Sacramento River sample collected in mid channel off South Avenue Bridge at Woodsen Bridge State Recreation area.

Ord Ferry. Sacramento River sample collected in mid channel off the Ord Ferry Road bridge.

Colusa. Sacramento River sample collected on west side of channel off River Road bridge.

Sutter Bypass. Sample collected about one third of way across the Bypass on north side of channel off HWY 113 bridge.

American River. Sample collected in mid channel off bridge at Sacramento State University in the City of Sacramento.

Feather River. Sample collected at intersection of Garden Highway and Lee Road.

Cache Creek Studies

Putah Creek. Sampled collected in mid channel off Road 104 bridge outside of El Macero.

Willow Slough. Sample collected in mid channel off Road 102 bridge outside of Davis.

Colusa Basin Drain. Sample collected in mid channel off Road 99E bridge outside of Knight's Landing.

Settling Basin (site 1). Sample collected at discharge from Settling Basin. Site is approached off Main Street in Woodland on dirt road just prior to entering the Yolo Bypass. Low flow samples collected immediately downstream of block house; high flow samples collected from south side of spillway.

Road 102 (site 2). Bank sample collected immediately downstream on west side of Creek adjacent to the Road 102 bridge.

Capay Dam (site 3). Sample collected from west bank immediately upstream of Capay Dam.

Rumsey (site 4). Sample collected from west side of channel of Rumsey bridge.

Bear Creek (site 5). Sample collected by wading into creek immediately upstream of confluence with Cache Creek.

Cache Creek (site 6). Sample collected by fording Bear Creek and walking several hundred yards upstream on Cache. Sample collected by wading into North side of Creek.

North Fork Confluence (site 7). Sample collected by wading into the North Fork about a 100 yards above the confluence with the South Fork.

North Fork @ HWY 20 (site 8). Sample collected during low flows by wading into Creek at Bridge; during high flows from west bank under bridge.

South Fork Confluence (site 9). Sample collected by wading into the South Fork about a 100 yards above the confluence with the North Fork.

Clear Lake Dam (site 10). Sample collected from the bank about 100 yards downstream of Dam on north side of Creek.

Thompson Creek (site 11). Thompson Creek is tributary to Bear Creek. Sample collected by wading into Thompson Creek about 100 yards upstream of the confluence.

Bear Creek at HWY 20 (site 12). Sample collected by wading to Creek about 100 yards downstream of bridge.

Sulfur Creek (site 13). Sample collected by wading into the Creek about 100 yards upstream of its confluence with Bear Creek.

Bear above Sulfur Creek (site 14). Sample collected from bank about 100 yards above the confluence with Sulfur Creek.

Hamilton Creek (site 15). Hamilton Creek is tributary to Bear Creek. Sample collected from culvert under the Bear Valley Road.

Bear Creek at Culvert (site 16). Sample collected immediately downstream of where Bear Valley Road first crosses Bear Creek.

Grizzly Creek (site 17). Grizzly Creek is tributary to the North Fork. Sample collected from bank about 300 yards above the confluence with the North Fork.

Benmore Canyon (site 18). Benmore is tributary to the North Fork. Sample collected from north bank about 100 yards before its confluence with the North Fork.

Long Valley Creek (site 19). Long Valley Creek is tributary to the North Fork. Sample collected immediately above the Long Valley Road bridge.

Wolf Creek (site 20). Wolf Creek is tributary to the North Fork. Sample collected from bank above Spring Creek bridge Road.

Chalk Mountain (site 21). Chalk Mountain is on North Fork about 2 miles below Indian Valley dam. Sample collected at Chalk Mountain Road bridge.

Indian Valley Dam (site 22). Sample collected by wading into creek immediately below Indian Valley Dam.

Rumsey Canyon (site 23). Rumsey Canyon is tributary to lower Cache Creek. Sample collected by wading into Creek at HWY 16 bridge.

Johnson Creek (site 24). Johnson Creek is tributary to lower Cache Creek. Sample collected by wading into Creek at HWY 16 bridge.

Cross-Hamilton (site 25). Cross-Hamitlon is tributary to lower Cache Creek. Sample collected by wading into Creek at HWY 16 bridge.

Black Mountain-Angus Creeks (site 26). Black Mountain-Angus Creeks is tributary to lower

Cache Creek. Sample collected by wading into Creek at HWY 16 bridge.

McKinney-Smith (site 27). Mckinney-Smith is tributary to lower Cache Creek. Sample collected by wading into Creek at HWY 16 bridge.

Mossy Creek (site 28). Mossy Creek is tributary to lower Cache Creek. Sample collected by wading into Creek at HWY 16 bridge.

Taylor-Brick Chimney Creek (site 29). Taylor-Brick Chimney is tributary to lower Cache Creek. Sample collected by wading into Creek at HWY 16 bridge.

Stemple Creek (site 30). Stemple Creek is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Harley Gulch (site 30). Harley Gulch is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Harley Gulch West (Site 31a). Harley Gulch West drains the Abbott and Turkey Run Mines. Sample collected from south side of HWY 20 immediately before creek joins the east branch.

Harley Gulch East (site 31b). Sample collected from south side of HWY 20 immediately before creek joins the west branch.

Rocky Creek (site 32). Rocky Creek is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Cache Creek below Rocky Creek (site 33). Sample collected from mid channel several hundred yards downstream of Rocky Creek.

Cache Creek below Jack Creek (site 34). Sample collected from mid channel several hundred yards downstream of Jack Creek.

Judge Davis Creek (site 35). Judge Davis Creek is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Bushy Creek (site 36). Bushy Creek is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Petrified Creek (site 37). Petrified Creek is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Trout Creek (site 38). Trout Creek is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Cache Creek below Trout Creek (site 39). Sample collected by boat from mid channel several hundred yards downstream of Trout Creek.

Crack Canyon (site 40). Crack Canyon is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Cache Creek below Crack Canyon (site 41). Sample collected by boat from mid channel several hundred yards downstream of Crack Canyon.

Davis Creek (site 42). Davis Creek drains the old Reed mercury mine and is tributary to Cache Creek. Sample collected by floating Cache Creek and collecting sample about a 100 yards above the Creek's confluence with Cache.

Davis Reservoir Dam (site 42a). Davis Creek was impounded at Davis Reservoir to provide water for Homestake Mining Company. Davis Creek drains the old Reed mercury mine. Sample collected from immediately below the dam.

Cache Creek below Davis Creek (site 43). Sample collected by boat from mid channel several hundred yards downstream of Davis Creek.

APPENDIX B

QUALITY ASSURANCE AND QUALITY CONTROL TABLES

Table 1. Percent difference in mercury concentration (ng/L) of a second analysis of the same field sample. The overall mean percent difference during the six-year study was 3.0 percent[1].

Date	Location	Type Analysis	Split 1	Split 2	Percent Difference	Mean Annual Difference
10/14/93	Rio Vista	dissolved	1.38	1.09	21.0	
10/29/93	Stockton	dissolved	1.47	1.43	2.7	
10/29/93	Vernalis	dissolved	1.62	1.61	0.6	5.8
11/12/93	Greene's Landing	total	3.98	3.88	2.5	
12/13/93	Rio Vista	total	3.93	3.84	2.3	
4/12/94	Greene's Landing	total	2.41	2.43	0.8	
4/12/94	Hood	total	2.43	2.50	2.8	1.7
4/27/94	San Joaquin River	total	8.94	8.86	0.9	
5/10/94	Hood	total	3.39	3.32	2.1	
1/11/95	Prospect Slough	total	548.4	559.1	1.9	
1/22/95	Greene's Landing	total	22.9	22.2	3.1	
1/30/95	Greene's Landing	total	20.01	19.77	1.2	
2/3/95	Prospect Slough	total	35.91	37.78	5.0	
2/14/95	Skag Slough	total	11.91	11.68	1.9	2.7
3/10/95	Cache @ Rd 102	total	1775.0	1804.0	1.6	
2/28/95	Greene's Landing	total	8.14	8.35	2.5	
2/28/95	Clear Lake Dam	total	145.8	157.9	7.7	
3/21/95	Skag Slough	total	24.53	24.53	0.0	
5/1/95	Greene's Landing	total	16.93	16.68	1.5	
6/1/95	Cache @ Rd 102	total	1.46	1.42	2.7	

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[1] Percent difference =(high-low/high)x100

Table 1. (Continued).

Date	Location	Type Analysis	Split 1	Split 2	Percent Difference	Mean Annual Difference
2/20/96	Cache @ Rd 102	total	373.87	399.64	6.4	
2/27/96	N. Fork HWY 20	total	55.86	58.70	4.8	
4/2/96	Cache (site 6)	total	19.35	22.57	14.3	6.4
4/2/96	North Fork Cache	total	4.18	4.49	6.9	
4/2/96	Bear Ck	total	63.01	60.28	4.3	
4/4/96	Bear Ck	total	20.21	20.01	1.0	
12/23/96	Rumsey	total	50.24	46.80	6.9	
1/6/97	Cache @ Rd 102	total	774.4	762.6	1.5	
1/21/97	Rumsey	total	18.81	18.13	3.6	
1/26/97	Bear (site 16)	total	30.11	30.07	0.1	
1/26/97	Bear (site 14)	total	247.9	260.0	4.7	2.0
2/23/97	Spillway	total	223.4	225.3	0.8	
9/29/97	Sulfur Creek	dissolved	219.7	218.1	0.7	
2/2/98	Johnson Cyn	total	50.51	50.10	0.8	0.8

Table 2. Percent recovery of the amendment of known amounts of mercury into field samples. The mean percent recovery during the six year study was 102.5 percent.

Date	Location	Type Analysis	Base Concentration	Amendment	Result	Percent Recovery	Mean Percent Recovery
10/19/93	Greene's Landing	dissolved	0.99	7.04	8.0	99.6	
1/5/93	Middle River	dissolved	1.32	10.0	11.13	101.7	101.8
12/3/93	Stockton	total	3.85	7.63	11.11	103.3	
12/17/93	Greene's Landing	total	8.06	8.0	16.20	102.5	
1/26/94	Greene's Landing	total	7.15	8.0	14.80	95.6	
1/27/94	Greene's Landing	dissolved	0.50	8.0	8.17	95.9	97.8
4/1/94	Greene's Landing	total	2.98	8.0	11.02	100.4	
5/19/94	Greene's Landing	total	4.07	7.93	11.95	99.4	
1/12/95	Prospect Slough	total	92.2	40.0	134.2	104.9	
1/18/95	Greene's Landing	total	21.8	40.0	61.7	99.8	
1/28/95	Prospect Slough	total	22.87	40.0	59.12	90.6	
1/31/95	Knights Landing	total	19.30	40.0	56.96	94.2	
2/4/95	Greene's Landing	total	13.71	40.0	54.36	101.6	
2/14/95	Prospect Slough	total	17.80	10.0	28.19	103.8	103.4
2/17/95	Greene's Landing	total	17.44	10.0	28.91	114.7	
3/11/95	Feather River	total	18.25	20.0	37.57	96.6	

Table 2. (Continued).

Date	Location	Type Analysis	Base Concentration	Amendment	Result	Percent Recovery	Mean Percent Recovery
3/5/95	Greene's Landing	total	11.81	20.0	31.82	101.7	
3/18/95	Greene's Landing	total	11.30	20.40	33.20	107.4	
3/21/95	Greene's Landing	total	11.71	20.0	32.92	106.1	
5/5/95	Greene's Landing	total	10.57	20.0	30.68	100.6	
5/31/95	Prospect Slough	total	24.16	40.0	67.01	107.1	
6/27/95	Glass Control	total	0.13	2	2.47	117.1	
2/20/96	Clear Lake Dam	total	9.96	20.0	29.11	95.8	
2/22/96	Lab blank	total	0.62/1.01[2]	20.0	18.83	90.1	
2/27/96	North Fork Cache	total	55.86/58.7[1]	50	98.15	79.7	
4/2/96	Bear Creek	total	34.5	28.13	73.00	137.9	103.7
4/2/96	Cache @ Site 19	total	11.93	20.0	33.25	106.6	
4/2/96	Cache @ Site 11	total	14.41	20.0	36.23	109.1	
6/11/96	Bear Creek	total	18.53	20.0	29.14	106.5	
1/26/97	Bear Ck @ Site 16	total	30.09	105.3	132.4	97.2	
1/26/97	Bear Ck @ Site 14	total	254.0	526.3	819.9	107.5	

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[2] Duplicate field sample

Table 2. (Continued).

Date	Location	Type Analysis	Base Concentration	Amendment	Result	Percent Recovery	Mean Percent Recovery
2/23/97	Spillway	total	115.8	421.1	557.6	104.9	
5/27/97	Spillway	total	30.3	80.8	112.4	101.8	
6/11/97	Cache Ck (Site 6)	total	5.62	20.2	31.41	127.7	105.1
6/11/97	Indian Valley Dam	total	4.74	20.2	24.98	100.2	
9/29/97	Spillway	total	12.34	30.3	43.01	101.2	
1/16/97	Davis Creek	total	4.59	20.2	24.87	100.4	
2/2/98	Rumsey	total	12.29	20.2	31.83	96.7	
2/16/98	Cache @ Rd 102	total	301.0	1052.6	1676.8	111.7	104.2

Table 3. Percent difference in mercury concentration (ng/l) of split field samples collected on 29 September 1997 and analyzed by both Frontier Geosciences and Dr. Gary Gill's Laboratory at Texas A&M University.

Location (site #)	Type Analysis	Frontier Geosciences	Texas A&M University	Percent Difference[3]
Spillway (1)	total	12.34	12.04	2.4
Spillway (1)	dissolved	0.77	0.75	2.6
Cache Ck (6)	total	4.10	4.54	9.7
Cache Ck (6)	dissolved	0.52	0.68	23.5
Bear Ck (5)	total	8.65	9.63	9.2
Bear Ck (5)	dissolved	4.19	3.71	11.5
Sulfur Ck (13)	total	770.30	736.0	4.5
Sulfur Ck (13)	dissolved	218.90	187.0	14.6
Sulfur Ck (13) Disturbed	total	12,390.00	10,160.0	18.0
Sulfur Ck (13) Disturbed	dissolved	97.84	90.9	7.1

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[3] Percent difference = (high-low/high)x100

Table 4. Change in mercury concentration (ng/L) of laboratory water after being pumped through peristatic tubing or after being decanted into teflon bottles in the field. Both methods were analogous to those used to collect field samples.

	Tubing			Bottles		
Date	Before	After	Difference	Before	After	Difference
1/9/94	0.34	0.43	0.09			
1/9/94	0.34	0.73	0.39			
3/9/94	0.34	0.34	0.00			
3/14/95				0.29	0.28	-0.01
6/27/95				0.13	0.24	0.11
2/22/96				0.82	0.24	-0.58
2/23/96				0.82	0.39	-0.43
4/3/96				0.43	0.35	-0.08
4/4/96				0.43	0.45	0.02
6/11/96				0.69	0.77	0.08
1/26/97				0.87	0.59	-0.28
5/6/97				0.59	0.48	-0.11
5/27/97				0.47	1.38	0.91
6/11/97				0.08	0.04	-0.04
9/29/97				0.05	0.05	0.00
2/2/98				0.21	0.69	0.48

Table 5. Mean percent difference in mercury concentration (ng/L) of duplicate field samples collected during the 6 year study. Mean annual variability ranged between 4-15% for main stem rivers and for the Estuary but increased to 15-35% in Cache Creek.

Date	Location	Duplicate 1	Duplicate 2	Percent[4] Difference	Mean Annual Percent Difference
10/14/93	Mokelumne R.	1.68	1.54	8.3	
11/29/93	Middle R.	2.42	2.23	7.9	
11/29/93	San Joaquin R.	3.45	3.25	5.8	
11/11/93	Greene's Landing	1.99	2.47	19.4	
11/12/93	Greene's Landing	3.90	2.87	12.5	15.4
12/13/93	Rio Vista	3.93/3.84[2]	7.72	49.6	
12/13/93	Mokelumne R.	7.25	7.56	4.1	
1/27/94	Greene's Landing	8.11	7.85	3.2	
2/1/94	Greene's Landing	4.19	4.19	0.0	
2/10/94	Greene's Landing	18.17	15.64	13.9	
1/11/94	Middle R.	2.13	2.05	3.8	
2/22/94	Greene's Landing	9.82	9.77	0.5	
3/1/94	Greene's Landing	3.74	3.83	2.3	3.7
3/16/94	Greene's Landing	18.90	18.47	2.2	
4/12/94	Greene's Landing	2.39	2.41/2.43	1.2	
4/12/94	Hood	2.60	2.43/2.50	5.4	
4/27/94	San Joaquin R.	8.94/8.86	9.30	4.3	
1/13/95	Greene's Landing	39.5	42.7	7.5	
1/15/95	Prospect Slough	50.5	51.0	1.0	
1/15/95	Greene's Landing	32.6	34.7	6.1	
1/31/95	Greene's Landing	14.8	13.61	8.0	7.3

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[1] Percent difference = (high-low/high)x100

[2] Duplicate analysis

Table 5. (Continued).

Date	Location	Duplicate 1	Duplicate 2	Percent[1] Difference	Mean Annual Percent Difference
1/31/95	Prospect Slough	18.35	19.77	7.2	
3/11/95	Cache Ck @ 102	1297.0	1266.0	2.4	
3/13/95	Rumsey	222.3	168.2	24.3	
3/22/95	Greene's Landing	12.87	13.11	1.8	
2/22/96	Bear Creek	125.5	128.49	2.6	
4/2/96	Cache (site 6)	17.63	23.58	25.2	
4/2/96	Bear Creek	63.01/60.28	64.50	4.4	14.3
4/4/96	Cache (Site 6)	4.19	5.53	24.2	
6/11/96	North Fork Cache	2.40	2.82	14.9	
1/6/97	Bear Creek	47.71	43.44	8.9	
1/6/97	Cache (Site 6)	679.8	90.82	86.6	
1/26/97	Capay Dam	3004.9	4196.1	28.3	
1/26/97	Rumsey	1141.1	2886.7	60.4	
2/23/97	Spillway	224.4	115.8	48.4	
2/23/97	Cache @ Rd 102	42.4	31.8	25.0	
5/6/97	Cache @ Rd 102	15.49	10.68	31.1	27.0
5/6/97	Spillway	60.81	65.33	6.9	
6/11/97	Bear Creek	20.01	18.70	6.6	
6/11/97	Cache (Site 6)	5.62	4.60	18.2	
6/11/97	Indian Valley Dam	5.01	4.74	5.4	
6/11/97	Clear Lake Dam	4.08	3.34	18.1	
6/11/97	Sulfur Creek	245.0	266.2	8.0	

Table 5. (Cont)

Date	Location	Duplicate 1	Duplicate 2	Percent[1] Difference	Mean Annual Percent Difference
2/2/98	North Fork	1381.2	1088.6	21.2	
2/2/98	Bear Creek	142.0	984.3	85.6	
2/2/98	Sulfur Creek	8401.7	11421.0	26.4	34.3
2/2/98	Spillway	180.4	143.2	20.6	
2/2/98	Cache @ Rd 102	469.2	570.5	17.8	

Table 6. Summary of percent difference in the total suspended solid (TSS) concentration of duplicate field samples collected during 1997 from the Cache Creek watershed. Overall mean percent difference was 8.1 percent. For comparison the percent difference in mercury concentration (ng/L) of similar samples is also listed. The average percent difference in mercury concentration was 40.6 percent.

		TSS (mg/L)			Hg (ng/L)		
Date	Location	Duplicate 1	Duplicate2	Percent Difference[5]	Duplicate 1	Duplicate 2	Percent Difference[1]
1/6/97	Rumsey	490	510	3.9			
1/6/97	Bear Creek	18	19	5.3			
1/6/97	Cache (site 6)	350	290	17.1			
1/26/97	Spillway	1400	1600	12.5			
1/26/97	Capay Dam	2200	2300	4.3	3004.9	4196.1	28.4
1/26/97	Rumsey	1600	1700	5.8	1141.1	2886.7	60.4
1/26/97	Bear Creek	630	710	11.3			
1/26/97	Rd 102	1800	2000	10.0			
1/26/97	Bear Hwy 20	370	460	19.6			
1/26/97	Sulfur Ck	320	340	5.9			
1/26/97	Bear (site14)	300	300	0.0			
1/26/97	Bear (site 16)	280	290	3.5			

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[5] Percent difference = (high-low/high)x100

Table 6. (Continued)

		TSS (mg/L)			Hg (ng/L)		
Date	Location	Duplicate 1	Duplicate 2	Percent Difference[6]	Duplicate 1	Duplicate 2	Percent Difference[2]
1/26/97	S.Fork (site 7)	190	200	5.0			
1/26/97	N.Fork (site 9)	940	930	1.0			
1/26/97	N. Fork Hwy 20	1000	1100	9.0			
1/26/97	Wolf Ck	130	140	7.1			
1/26/97	Long Valley Ck	1400	1400	0.0			
1/26/97	N.F. Chalk Mt.	48	53	9.4			
1/26/97	Indian Valley Dam	33	39	15.3			
2/2/97	Cache @ Rd 102	490	540	9.3			
2/2/97	Spillway	270	200	25.9			
2/23/97	Spillway	280	310	9.7	224.4	115.8	48.4
2/23/97	Cache @ Rd 102	63	66	4.5	31.8	42.4	25.0

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[6] Percent difference = (high-low/high)x100