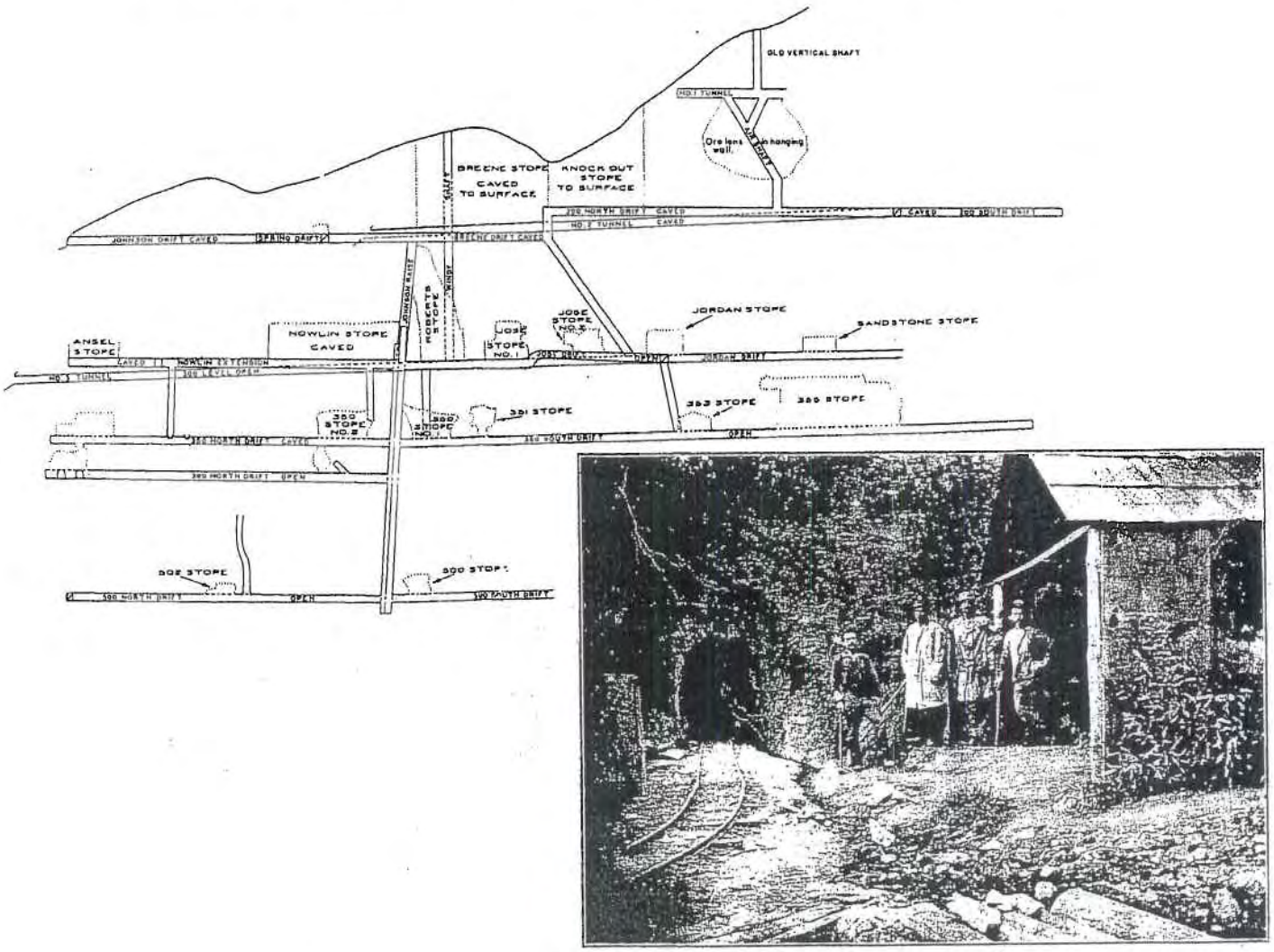
INACTIVE MINE DRAINAGE IN THE SACRAMENTO VALLEY, CALIFORNIA



STAFF REPORT OF THE

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COVER: PICTURE OF CONTRABAND TUNNEL, EL DORADO COUNTY (CSMB, 1908) AND THE UNDERGROUND WORKINGS OF SOCRATES MINE (CJMG, 1946).

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I. SUMMARY

A water quality survey was conducted between 1989 and 1991 to assess the pollutant contributions made by inactive mines in the Sacramento Valley. The goals included estimating pollutant loads and assessing impacts without assuming all mines in the watershed had been previously identified. The number of mines chosen for this study (94) were limited to those that were known or suspected water quality threats. Perennial adit drainage, waste rock, and upstream/downstream receiving waters were sampled and analyzed for several heavy metals, arsenic, and conventional parameters (flow, Eh, pH, EC). Dry weather loads were calculated with perennial adit drainage data collected largely during drought conditions (1987-1991).

Inactive mines were pervasive throughout the Valley outside the central basin and into the surrounding hills and mountains. Although not all mines had perennial adit drainage, waste rock material was observed at every site visited. Further, historical accounts and site observations indicate that ore processing operations were conducted at most of the mines, increasing the potential for water quality degradation. Minerals containing copper, lead, cadmium, and zinc were mined beginning around the mid-1800s. Other products directly or indirectly mined in the Valley included arsenic, gold, silver, mercury, and sulfur compounds. Adit drainage quality varied from unpolluted spring water to highly acidic outflow containing metals in the ppm range.

Adit releases in the Shasta Mining District exhibit characteristics typical of acid mine drainage - low pH and high metals content. Iron Mt. Mine (IMM) was the single largest loader, contributing between 57-85 percent of the estimated copper, cadmium, and zinc loads. Iron Mt. Mine loads were estimated from Spring Creek Debris Dam (SCDD) which collects water from the entire Spring Creek watershed including adit releases, waste rock erosion and seepage, and background stream flow. Unlike loads from the other mines, which were calculated using data on perennial adit drainage alone, loads from SCDD reflect the sum of year-round discharges coming from the IMM complex. The combined loads from all West Shasta District mines (Iron Mt., Mammoth, Balaklala, etc.) accounted for over 95 percent of the total copper, cadmium, and zinc inactive mine contributions to the Sacramento Valley.

Perennial mine drainage in the Sierra-Nevada mountain range was highly variable in quality. Drainage from gold mines in the Allegheny-Downieville area (Yuba River watershed) was characterized by near-neutral outflow and elevated arsenic. Positive Eh measurements indicate that the arsenic is discharged largely in the less toxic +5 state according to pH-Eh graphs. Mines in the Foothill Copper Belt (Spenceville, Valley View) exhibited typical acidic drainage but were not major loaders due to relatively small outflows.

Mercury mines are located in the Cache and Putah Creek watersheds. Although most sites were dry, a small number of western foothill mines discharged slightly acidic water characterized by high levels of iron, nickel, and carbonate compounds. Most waste rock samples contained relatively high levels of mercury.

Twenty-one of 31 receiving streams monitored during dry periods were impacted by one or more metals exceeding Inland Surface Water Plan chronic objectives. In general, the copper objective was most frequently exceeded followed by zinc and cadmium. Fewer than 9 streams exceeded the lead, nickel, and arsenic objectives and none were measured for chromium, and silver. Stream impact length appeared to depend on a variety of factors including compound-specific behavior, dilution capacity of the stream, mine loads, storm events, and the presence of complexing agents. Receiving water pollutant surges are expected during wet periods from increased adit outflows, waste rock runoff, and instream resuspension. Copper measured in Dry Creek below Spenceville Mine during a 3 inch storm event exceeded the 1-hour EPA hardness factored objective (15 ppb) by up to 8 times during a 10-hour period. Other mine influenced receiving waters are expected to experience similar impacts because of the prevalence of polluted waste rock piles at most mine sites. Waste rock runoff during the rainy season was estimated to account for 5-18 percent of the total annual copper, cadmium, and zinc loads coming from Spenceville Mine. This percentage will vary from site to site based on the magnitude of perennial loads - values range from insignificant for high volume acid mine drainage to 100 percent for dry mines. It is difficult to estimate runoff induced loads because of the variety of influencing factors including permeability, varying metals content and acidity, slope, porosity, rainfall characteristics, etc.

Almost all streams influenced by mine drainage eventually pass through one or more major reservoirs. The fraction of metals transported through a reservoir appears to depend largely on dam characteristics and the quality of upstream inputs. The concentration of several metals remained essentially unchanged between summer input-output flows at a Sierra-Nevada reservoir. The majority of the annual copper loads into Shasta Reservoir came from inactive mines which likely influenced Dam release levels - copper was approximately an order of magnitude greater than what was present in the major feeder streams not influenced by mine drainage.

II. INTRODUCTION

Mines once active in the extraction of heavy metals (e.g., mercury, gold, copper, zinc) have exposed sub-surface mineral deposits to the weathering attributes of water and air. Orebodies were mined largely around the turn of the century using underground and open pit techniques that increased the surface area of minerals highly prone to breakdown in the presence of water, oxygen, and acidophilic bacteria. Metals are leached from the minerals and transported downstream via rainfall runoff or adit discharges. These discharges can cause fish kills that have been documented as far back as 1940 (Nordstrom et al., 1977). Runoff from discarded mine soils has resulted in the issuance of health warnings against eating mercury tainted fish in Clear Lake and Marsh Creek Reservoir.

Prior to 1972, regulatory action by the regional board to abate inactive mine discharges was hindered by ineffective legislation (Miller et al., 1979). The board had limited legal means to force a mine property owner to comply. Because operations ceased altogether, the present mine/land owner was usually unwilling or economically unable to remediate the site. Further complications arose when the mine site had been sold by the original mining company. Typically, unresolved compliance was referred to the California court system because of the high costs inevitably involved. Many referrals to the District Attorney or Attorney General were not pursued, referred elsewhere, or decided in favor of the mine owner (e.g., Penn Mine in 1963; CVRWQCB, 1988). Several major mines in the Central Valley have extensive histories of regional board activity that, in some cases, exceed 30 years. Conversely, active mines permitted by the board are required to comply with the conditions of their permit as a requisite for continued operations. Regulatory options have increased since the passage of the federal Clean Water and state Porter-Cologne acts, although, some of the same cleanup impediments still remain. In many instances, government funds have been used to install control measures. Several control projects have resulted in reduced mine loads (e.g., Walker, Balaklala mines) but most attempts have not always been so successful primarily due to ineffective technology.

A water quality survey of inactive mines was conducted as part of the regional board's Basin Planning process to obtain information on pollutant loads contributed by Valley-wide sources (which also include permitted, agricultural, and urban runoff discharges). A water quality assessment using load estimates will allow us to prioritize sources of downstream impairments and help to focus control efforts on the major contributors. The cumulative input of pollutants from point and non-point sources has resulted in periodic objective exceedances for copper, zinc, cadmium, and lead in the Sacramento-San Joaquin Delta/Estuary (CVRWQCB, 1991). The regional board is responsible for developing programs to reduce overall metal loads to the Sacramento River and Delta. Although inactive mines contribute substantially to downstream concentrations, several questions remain regarding previously unsurveyed mines, waste rock runoff, and reservoir mass balance information.

This study attempted to assess the regional water quality impacts caused by inactive mines in the Sacramento Valley. In general the objectives were:

1. Estimate and compare the metals loading from known and previously unsurveyed major inactive mines.
2. Determine the pollutant contributions from waste rock runoff.
3. Assess the mass balance of metals coming into and leaving major reservoirs.

The results of this study show that most of the major mines with perennial drainage had been previously surveyed. The largest loads of copper, zinc, and cadmium came from mines located in the Shasta Mining District. The largest single loader for almost all metals was Iron Mt. Mine. Twenty-one of 31 inactive mines with perennial drainage caused impacts to downstream receiving waters using water quality objectives. Impacts are also expected at mines without perennial drainage due to runoff and seepage from waste rock piles during the wet season. Waste rock runoff caused by a 3 inch storm event significantly increased the receiving stream concentrations of suspended solids, copper, and zinc. Waste rock material was prevalent at all mines surveyed. Dam release water quality is probably influenced to some extent by upstream mine inputs.

III. MINE DRAINAGE FORMATION

Mine drainage forms as a result of past mining activities that exposed geological deposits to the natural weathering attributes of water and air. Air can enter an underground complex as advective drafts and barometric "breathing" through natural and manmade openings (e.g., shafts, vents, fractures; Shumate et al., 1971). Water entering the tunnel system originates as rainfall seepage and ground water accretion (CH2M Hill, 1984). Ground water flows intercept tunnel passageways following the path of least resistance and eventually become surface discharges when the interior floods to the level of the lowermost adit. Water participates in the weathering process as a reactant, reaction medium, and a vehicle transporting solubilized minerals out of the complex. The high humidity within a mine and large surface area of minerals exposed to oxidants are ideal conditions for reactive orebodies to degrade (Shumate et al., 1971). The volume of water discharged varies between seasons and years and outflow loads are strongly correlated with annual precipitation (Heiman, unpub. data). Drainage also originates at the surface of a mine complex where waste rock piles, composed of extracted mineral deposits, have been dumped and exposed to the same weathering forces. The off-site movement of pollutants released from waste rock material is largely limited by contact with water from sources such as precipitation, streams, and springs. The products of waste rock weathering can degrade water quality in the same manner as adit releases - elevated metals, turbidity, or acidity.

A. Acidic Drainage

Acid mine drainage is generated primarily from the oxidation of pyrite. Pyrite (FeS_2), the most common iron disulfide in California (CDMG, 1966), is susceptible to breakdown because of its high oxidation potential (Doyle and Mirza, 1989). When exposed to an oxidizing environment, the ferrous-disulfide bond is cleaved to form sulfuric acid and free iron. The generally accepted mechanism for acid formation is represented by the following pathways (from Singer and Stumm, 1970):

$$FeS_2(s) + 7/2\ O_2 + H_2O \Rightarrow Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+ \quad (1)$$

$$Fe^{2+} + 1/4\ O_2 + H^{2+} \Rightarrow Fe^{3+} + 1/2\ H_2O \quad (2)$$

$$FeS_2(s) + 14\ Fe^{3+} + 8\ H_2O \Rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+ \quad (3)$$

Reaction pathways 1 and 3 have been proposed to describe the overall kinetics involved in the breakdown of pyrite. The direct pathway (1) involves oxygen acting directly on the pyrite crystals, whereas, the indirect pathway (3) goes forward only when the iron product of pathway 1 has oxidized to sufficient quantities via 2 (Onyesko, 1985). Oxygen serves as the oxidant in 1, producing acid at rates typically observed and can proceed only when an abundant supply of both water and oxygen are available (Taylor et al., 1984; Sullivan et al., 1988a-b). Oxygen serves as the ultimate electron acceptor that cleaves the iron-sulfide bond setting into motion a series of hydrolytic reactions that lead to the formation of sulfuric acid (Nordstrom, 1982). There are many chemical, physical, and biological factors that can affect the rate of pathway 1 including temperature, residence time of the water, pH of the medium, and the presence of microbes. However, the grain size of pyrite is thought to be a major factor controlling it's rate. Framboidal pyrite crystals less than 0.25 micron are much more prone to breakdown than larger, cubic forms (Caruccio, 1975).

Equation 3 is called the indirect pathway because ferric iron (Fe^{3+}) acts as the oxidant which is produced via conversion from the reduced form largely by a bacterially catalyzed reaction (pathway 2). The reduced species of iron (Fe^{2+} - ferrous) is initially present as a product of reactions 1 and 3. The oxidation of the ferrous ion proposed by pathway 2 is strongly facilitated by a resident microbial community tolerant of low pH waters (Drever, 1988; Singer and Stumm; 1970, Erlich, 1964; Malouf and Prater, 1961; Noike et al., 1983; Sullivan et al., 1988a). Reaction pathway 2 can proceed inorganically but the amount of dissolved oxygen present in water is insufficient in itself to perpetuate the conversion at observed rates. In the presence of acidophilic bacteria, the rate of 2 can be accelerated by up to 6 orders of magnitude over the inorganic or direct pathway and is governed by the concentration of reduced iron and size of the microbial population. The ferric ion can be generated to levels in water that strongly favor the forward direction of reaction pathway 3. Therefore, in an aqueous environment, pathway 2 is considered to be the rate determining step in the production of acid.

Mine drainage is known to support a diverse microbial community including both heterotrophic (using organic carbon) and autotrophic (using inorganic carbon) strains (Wichlacz and Unz, 1981). Chemoautotrophic bacteria have been isolated as the type catalyzing ferrous oxidation and hence the facilitation of acid mine drainage formation. Carbon dioxide is used as a food source which is metabolically incorporated via energy derived from the oxidation of divalent iron. Thiobaccilus ferrooxidans and T. thiooxidans have been identified as the principal strains involved and were speciated based on their affinity for particular reduced compounds and the rate at which the compounds were oxidized (Bounds and Colmer, 1972). Optimum metabolic efficiency is generally attained within a pH range of 2.0-3.5 (Malouf and Prater, 1961)-but can vary with temperature extremes (Macdonald and Clark, 1970). Although nutrients could be substituted as an energy source (Noike et al., 1983), their survival in waters above pH 6 are limited by inter-strain competition. Acidophilic microbes are generalists with a wide range of abilities enabling them to survive in extreme environments but are displaced by specialists better equipped to compete under conditions that are more favorable (i.e., in neutral streams; Mills and Mallory, 1987). The aquatic microbes become attached to stationary objects in the streambed and propagate in layers (Macdonald and Clark, 1970) which were found to be more metabolically active than their planktonic counterparts (Mills and Mallory, 1987). The oxidation of ferrous sulfate is thought to occur at the cell wall or membrane (McDonald and Clark, 1970).

The products of pyrite oxidation, as well as the dissolution products of other sulfides (e.g., CdS, CuS, ZnS) oxidized in similar fashion, concentrate to high levels in the acidic solution and are transported out of the mine complex in a singly

complexed or ionic state ("dissolved"; Sullivan et al., 1988a). Minor amounts of dissolved compounds (metals, sulfate, other ions) crystallize as secondary minerals in the form of basic iron sulfates (e.g., copiapite, jarosite) and can be seen as red to yellow staining in the impacted streams (Ivarson, 1973; Fillpek et al., 1987).

As pH increases upon mixing with nearby receiving waters, the dissolved compounds become less soluble and precipitate out at a rate that is largely controlled by the formation of iron hydroxides. Between a pH of 2.5 and 4, iron instantaneously forms large masses of colloidal floc according to standard thermodynamic predictions (pathway 4; Jenke et al., 1983).

$$Fe^{2-3+} + 2\text{-}3\ H_2O \Rightarrow Fe(OH)_{2-3}(p) + 2\text{-}3\ H^+ \qquad (4)$$

Iron hydroxides are amorphous in nature (as opposed to crystalline) and are visible as thick, orange, streambed deposits. Other metals also precipitate as hydroxides when their individual supersaturation points are reached. However, elements such as copper, arsenic, and zinc are thought to be removed from solution primarily by co-precipitation and adsorption processes that accompany the formation of ferric and ferrous hydroxides. Metals can adsorb to the surfaces of forming colloids via electro-static attraction (Johnson, 1986). Co-precipitation can also scavenge metals when they are occluded within the forming colloids or are incorporated as part of the matrix (Harris, 1982). Arsenic, present as an oxyanion, directly integrates with iron by out-competing and replacing two hydroxides, resulting in a coordinated complex (Harrison and Berkheiser, 1982). The resultant removal rate of arsenic from solution by co-precipitation is in direct proportion to the amount of solid formed (Chapman et al., 1983), and therefore, very little arsenic remains in solution after acid mine drainage undergoes a pH shift. Alternately, copper and zinc are removed from solution mainly by electrostatic attraction forces that are weaker than the complexing forces involved in arsenic removal. Copper and zinc are largely present as aquo or anion (e.g., sulfate) pairs (Johnson and Thornton, 1987) and are attracted to, not incorporated into, the forming hydroxide material. The degree of metals sorption increases with pH (Johnson, 1986; Moore and Sutherland, 1981). As impacted water approaches neutrality, most of the metals have become components of the flocculated hydroxides. The metals remaining in solution continue to exchange with hydroxides (Windom et al., 1991) as well as other stream features such as the bed substrate, organic material, and suspended particulates (Chapman et al., 1983).

B. Arsenic Drainage

Mine drainage with high arsenic levels is associated with Sierra-Nevada mines located in the Allegheny-Downieville area. Miners were after underground gold deposits that formed with arsenopyrite (AsFeS) and calcareous minerals (mainly $CaCO_3$; Carlson and Clark, 1956). Drainage from this area is dissimilar to typical acid mine drainage in that it is clear, neutral to alkaline in pH, and produces no objectionable iron precipitates or staining. Disproportionately higher amounts of arsenic are released from arsenopyrite undergoing oxidation (Ehrlich, 1964), partially explaining the low iron content in the drainage. Arsenic in neutral waters is largely present as an oxyanion (AsO_4^{3-}; Burau et al., 1988) and has been measured as the +5 valence species in mine drainage based on pH-Eh diagrams. Arsenate is 1 to 2 orders of magnitude less toxic than the reduced valence species - arsenite (+3) - which is present only in reducing waters of less than -0.4 mV (Moore and Ramamoorthy, 1984; Hem, 1975). In waters not affected by acid mine drainage (low iron content), 50-90 percent of the arsenic is expected to be dissolved (Johnson and Thornton, 1987).

C. Waste Rock Drainage

Waste rock material deposited above ground also undergoes oxidative weathering when in contact with water. Waste rock was present at nearly all mine sites visited in this study and can be composed of overburden, gangue material (less valuable surrounding minerals), and leftover tailings from processed ore (U.S.EPA, 1986). Mineral oxidation and off-site transport is limited to periods of precipitation when no other water sources (e.g., springs, creeks) are in contact with the waste rock. In pyritic soils, the potential to generate acid is largely controlled by the availability of water, the presence of calcareous minerals (mainly $CaCO_3$; U.S.EPA, 1986), and crystal size (Caruccio, 1975). The top 6-14 inches of material is adequately aerated to provide oxygen at levels sufficient for direct oxidation (Good, 1970). During dry periods, soluble products of mineral weathering (acid and metals) are transported to the surface via capillary action where they build up between storm events (Potter, 1976). As a result, analyte levels are higher during the initial stages of a storm event (Harries and Richie, 1983; see Appendix B). The total pollutant content does not exhibit similar first flush effects because of erosional transport. Measured rainfall runoff coefficients range between 11 and 38 percent and vary with material morphology (Harries and Richie, 1983) and rainfall characteristics such as intensity and duration (see Appendix B). Infiltrated water passing through waste rock material usually emanates with a higher pollutant level compared to surface runoff due to the increased residence time of water allowed to approach equilibration with leachable acid and metals (Harries and Richie, 1983). Simple erosional forces can transport particulates and their associated metals off-site regardless of the pH of the material.

IV. CHARACTERISTICS OF SACRAMENTO VALLEY INACTIVE MINES

A water quality survey was conducted between 1989 and 1991 to assess the pollutant contributions made by inactive mines in the Sacramento Valley. There are hundreds of mine sites in the Valley, some of which are claims or prospects with little potential for significant water quality degradation. For instance, there are 55 known mine claims in El Dorado County alone (SWRCB, 1972) and 161 historical mine sites in Sierra County (CVRWQCB, unpub. data). The number of mines included in this study (94) were limited to those that were known or suspected water quality threats (see Appendix A for selection criteria). The goals included estimating pollutant loads and assessing the impacts of inactive mines without assuming all individual contributors had been identified and characterized. To achieve this, the mines selected were those with a history of heavy activity and/or high ore production.

At mines with perennial drainage, water samples were collected and later analyzed for several heavy metals and arsenic. Conventional parameters were measured on-site at the time of sampling (flow, EC, Eh, pH). Sediment samples were collected at all mine sites visited and a limited number were analyzed for similar parameters (see Appendix A for a complete description of the methods). Mines not well characterized during previous inspections were monitored several times over a 2 year period to account for any seasonal fluctuation in flow-volumes or pollutant levels. Those mines with abundant characterization data were not sampled because load calculations and impact assessment could be made using existing information (largely mines in the Shasta Mining District). Several mines included in the survey were inaccessible or could not be located. Data from past monitoring programs and the results of this survey are reported in Appendix C. A narrative description of each mine site with respect to water quality degradation potential is presented in Appendix D.

A. Drainage Characteristics

Mine locations areally graphed in Figure IV-1 show that mining was not limited to any one area of the Sacramento Valley. Table IV-1 summarizes the physical characteristics and historical background of mines in this survey. Inactive mines were pervasive throughout the Valley outside the central basin and into the surrounding hills and mountains. There are six broadly defined mining zones in the Valley (refer to Figure IV-1 and Table IV-1 for map identification numbers [map I.D. #s]): 1) Foothill Copper Belt (map I.D. #s 2, 9, 10, 11), 2) Sierra-Nevada lode gold, 3) Alleghany-Downieville area (map I.D. #s 20, 21, 22, 24 [Kanaka Creek mines]), 4) Plumas Copper Belt (map I.D. #s 32-39), 5) Shasta Mining District (map I.D. #s 44-57), and 6) western foothill mercury mines (Plates 10-12). Although not all mines had perennial adit discharges (Table IV-1), waste rock material was observed at almost all mines visited. Further, historical accounts and site observations indicate that ore processing and/or beneficiating operations were conducted on-site at a majority of the mines in the Valley (Table IV-1). This is significant because the mechanical/chemical breakdown of extracted minerals increases the surface area exposed to weathering and results in a greater potential for water quality impacts. This potential is manifested when waste rock pollutants are transported off-site into receiving waters during storm events or from intersecting flows.

The general attributes (e.g., products, mineralogy) of Sacramento Valley mines and their drainage quality were highly variable. Valuable orebodies containing copper, cadmium, zinc, and chromium minerals were most intensively mined from the mid-1800's to mid-1900s. Other products directly or indirectly mined in the Valley included mercury, arsenic, gold, silver, sulfur compounds, and paint pigments. Drainage quality ranged from unpolluted spring water (e.g., Silver Falls Mine) to highly acidic outflow containing metals in the ppm range (e.g., West Shasta District mines; Table IV-2). Previous studies generally agree that dramatic differences in water quality and outflow are mainly related to the geological makeup of underlying minerals and depth to ground water. Underground minerals may have the potential to easily degrade, but surface releases would be absent if the water table is below the lower-most opening. Variability in discharge quality from closely located adits may be more related to differences in the residence time of water passing through a complex (Potter, 1976). Water moving slowly through underground workings solubilize pollutants to a higher level given a longer time to approach their individual saturation points. At mines with no perennial adit releases, drainage is limited to rainfall and snowmelt runoff from waste rock material.

Mines in the Foothill Copper Belt of the Sierra-Nevada range exhibited typical acid drainage characteristics, although, not all had perennial outflow (Dairy Farm and Big Buzzard were dry). Spenceville and Valley View mines drained acidic water containing high levels of most compounds such as copper, zinc, cadmium, or lead (Table IV-2). The Foothill Copper Belt identifies a series of mines situated on a geological formation of, in part, massive pyrite deposits located at the western edge of the Sierra-Nevada foothill range between an elevation of 300 and 500 feet MSL. Four mines in this belt were visited but the polymetallic lens extends down the Sierra-Nevada range, well outside the Sacramento Valley. There are other significant acid mine drainage producers in the Foothill Copper Belt not included in this study (e.g., Penn Mine, Calaverous County).

Drainage from gold mines in the Allegheny-Downieville area (located in the Yuba River Watershed) was characterized by near neutral outflow and elevated arsenic levels (Table IV-2). The mineralogy of the area has been extensively studied because of the lode-grade gold deposits. Mining journals describe gold veins that were deposited in close association with carbonate minerals and arsenopyrite (AsFeS; Carlson and Clark, 1956), which partially explains the drainage makeup. Notable arsenic sources in the area include the Plumbago and Brush Creek mines and those situated in the Kanaka Creek watershed. United States Forest Service personnel have counted over 140 mines in this watershed including 16 to 1, Kenton, and Oriental (Daniels, pers. comm.). There are also a number of smaller mines discharging in the Yuba River watershed that were not included in this survey (Higgens, pers. comm.). Arsenic from these mines remains largely in solution in the downstream receiving waters because of the low iron content and near neutral pH of the drainage - arsenic is known to be effectively removed from solution by hydroxide precipitates. Positive Eh measurements of the drainage

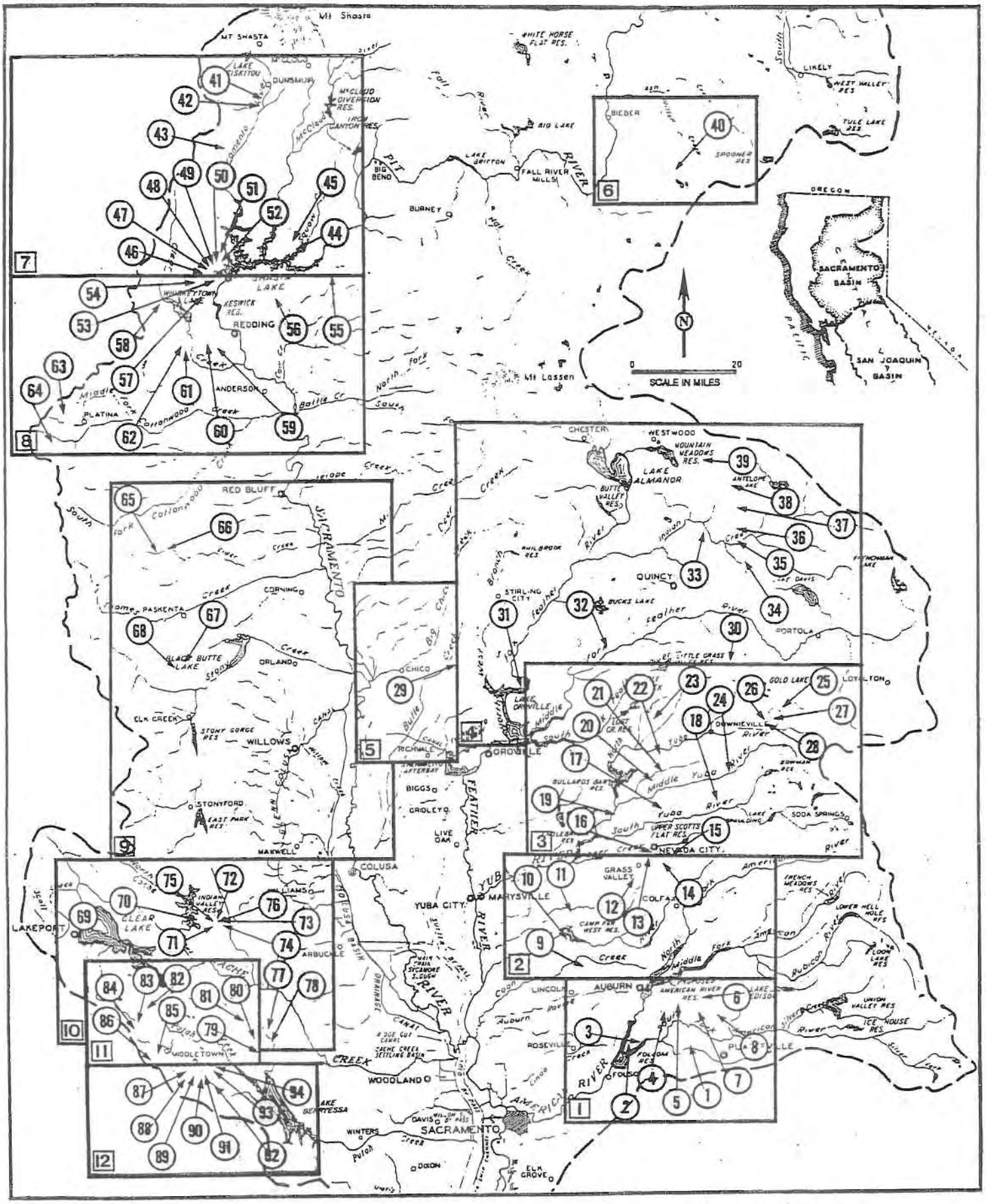

Figure IV-1. MAJOR INACTIVE MINES IN THE SACRAMENTO VALLEY. MAP I.D. NUMBERS (IN CIRCLES) ARE DEFINED IN TABLE IV-1. DETAILED WATERSHED LOCATIONS ARE PRESENTED IN PLATES 1-12 (IN SQUARES).

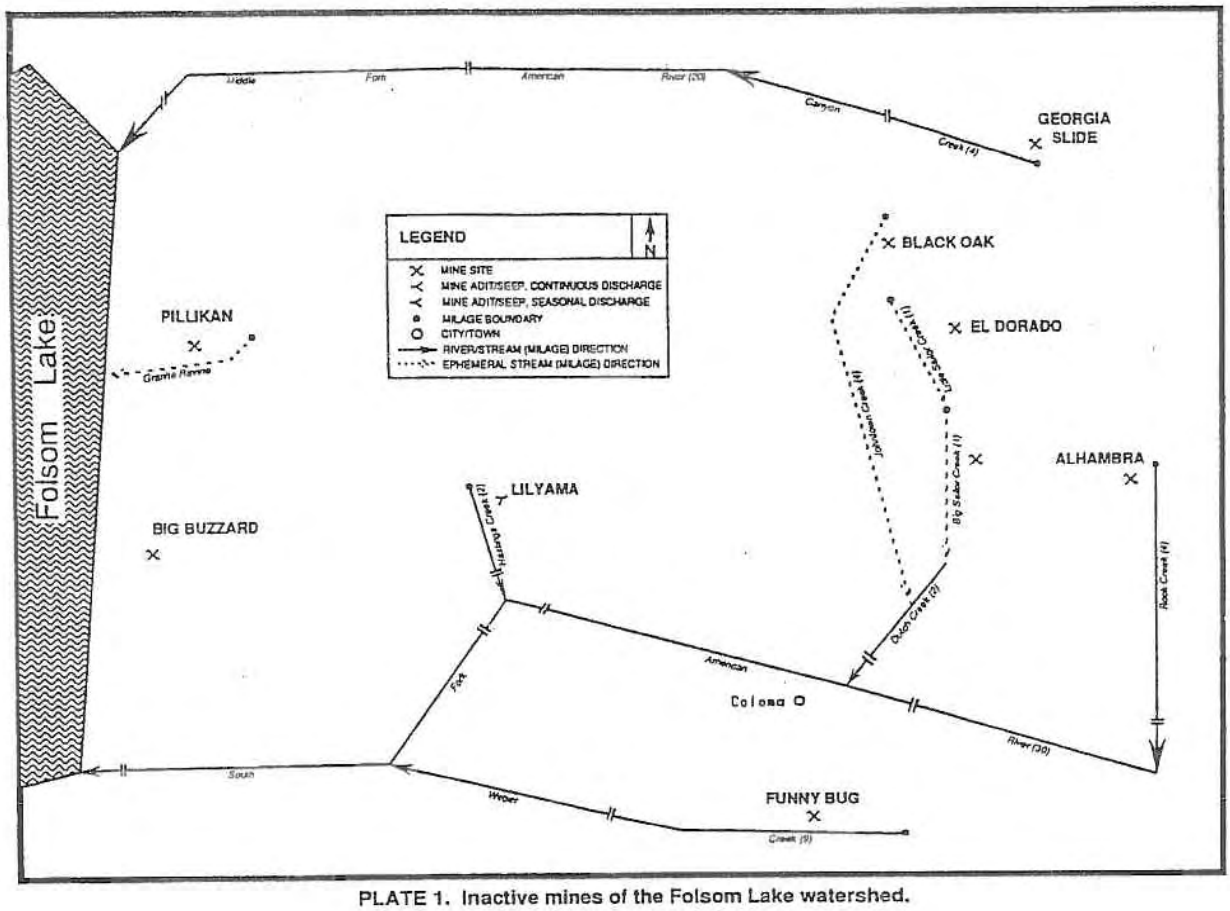

PLATE 1. Inactive mines of the Folsom Lake watershed.

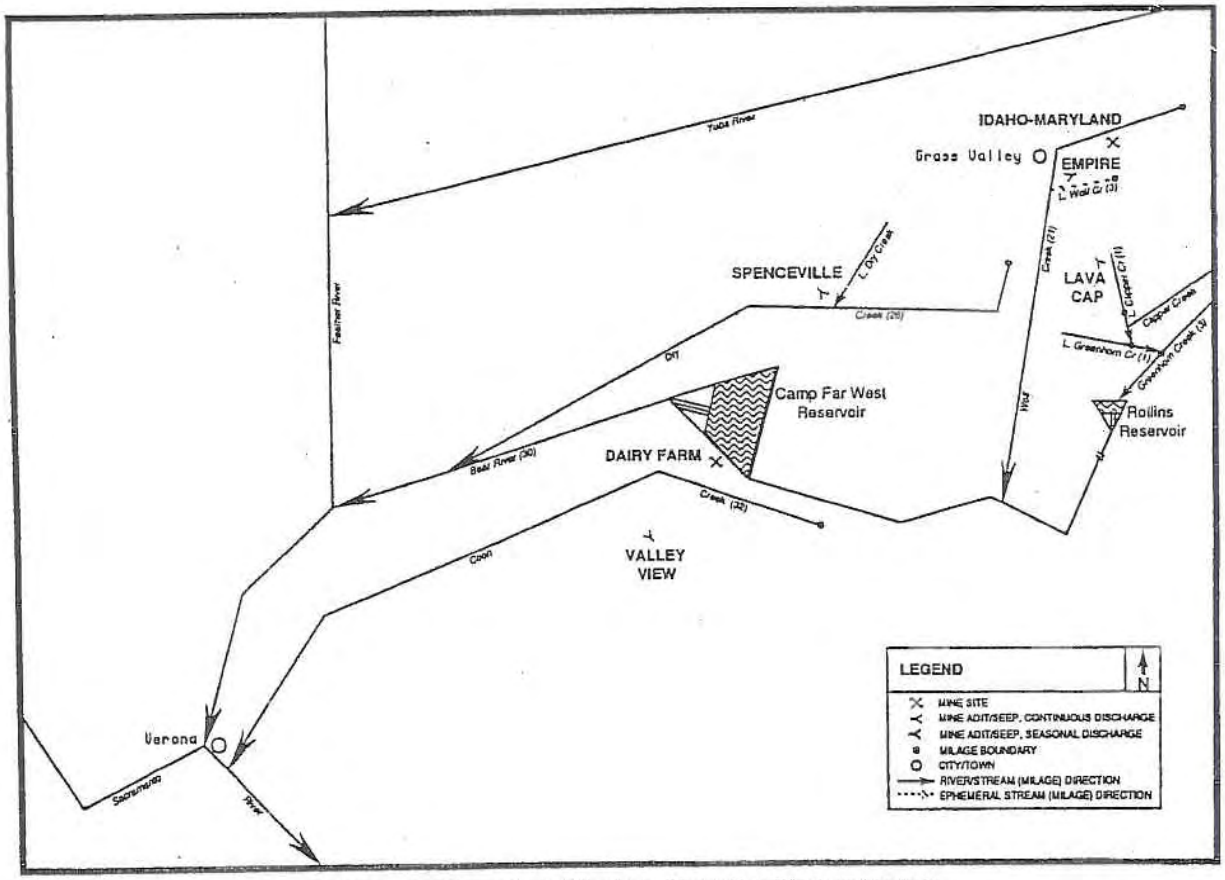

PLATE 2. Inactive mines of the Bear River / Dry Creek watershed.

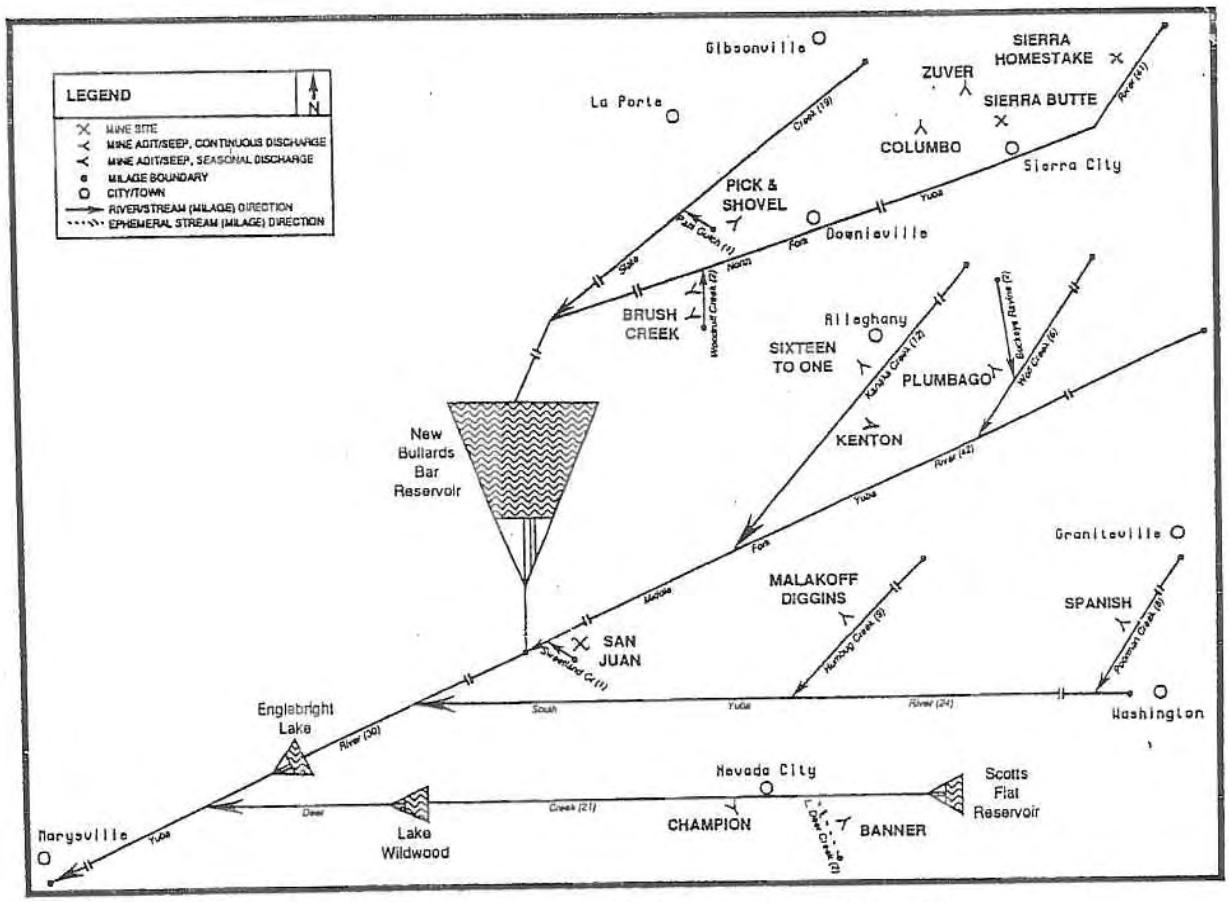

PLATE 3. Inactive mines of the Middle Fork, Yuba River Watershed

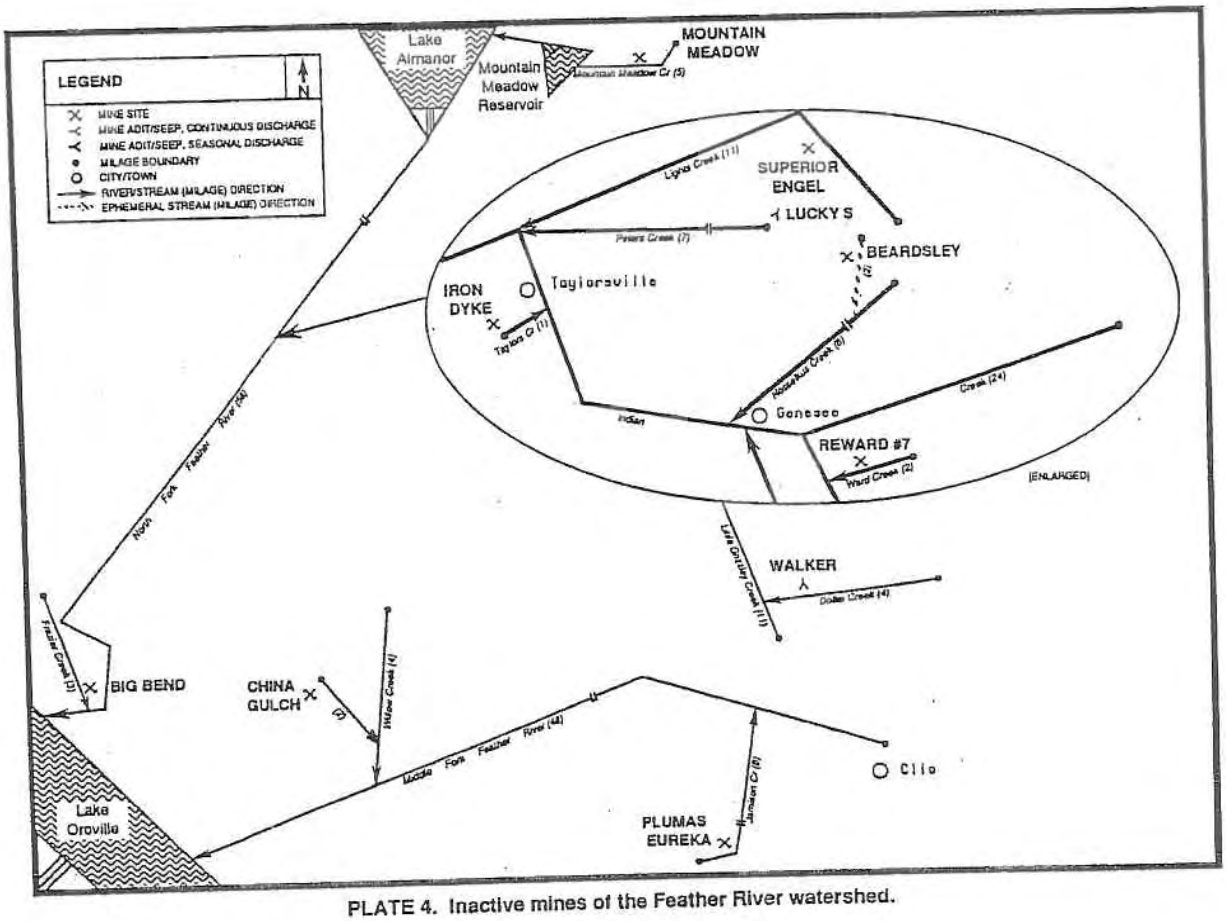

PLATE 4. Inactive mines of the Feather River watershed.

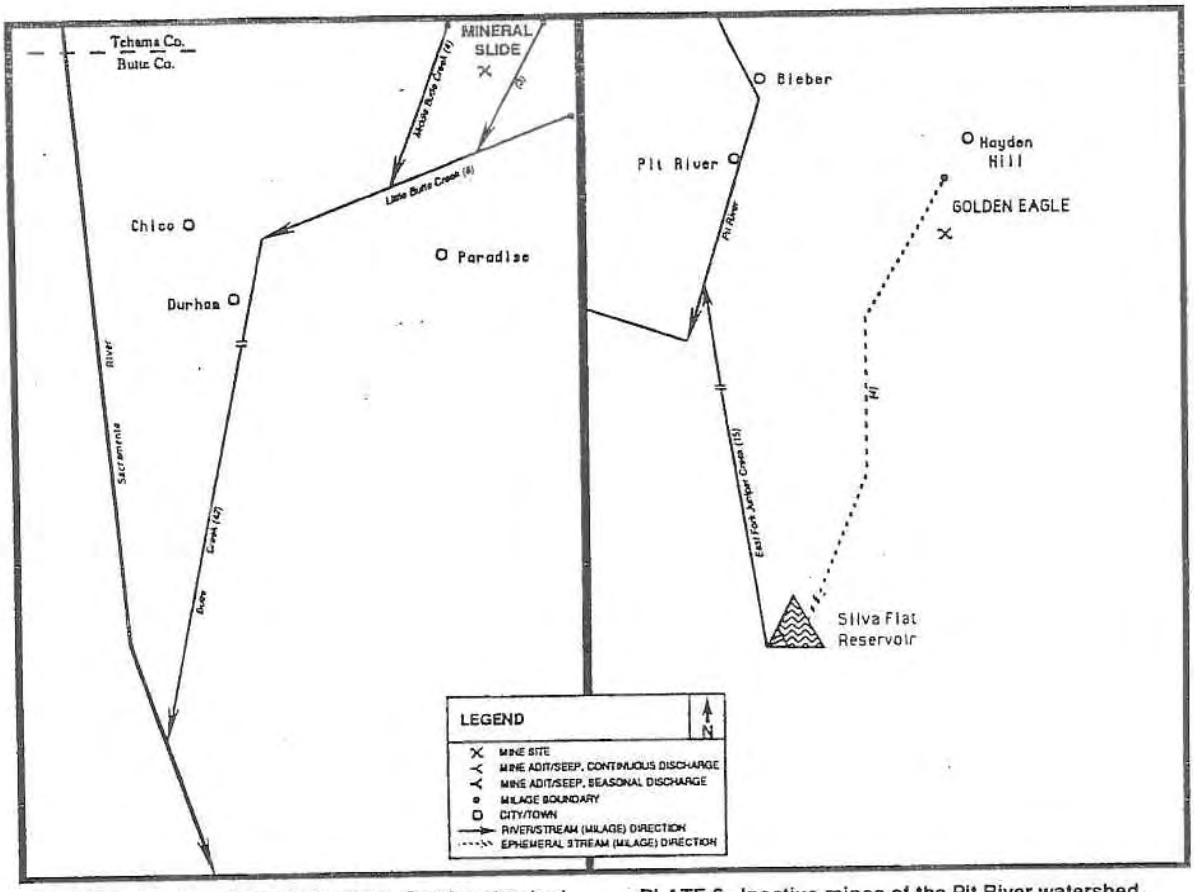

PLATE 5. Inactive mines of the Butte Creek watershed.

PLATE 6. Inactive mines of the Pit River watershed.

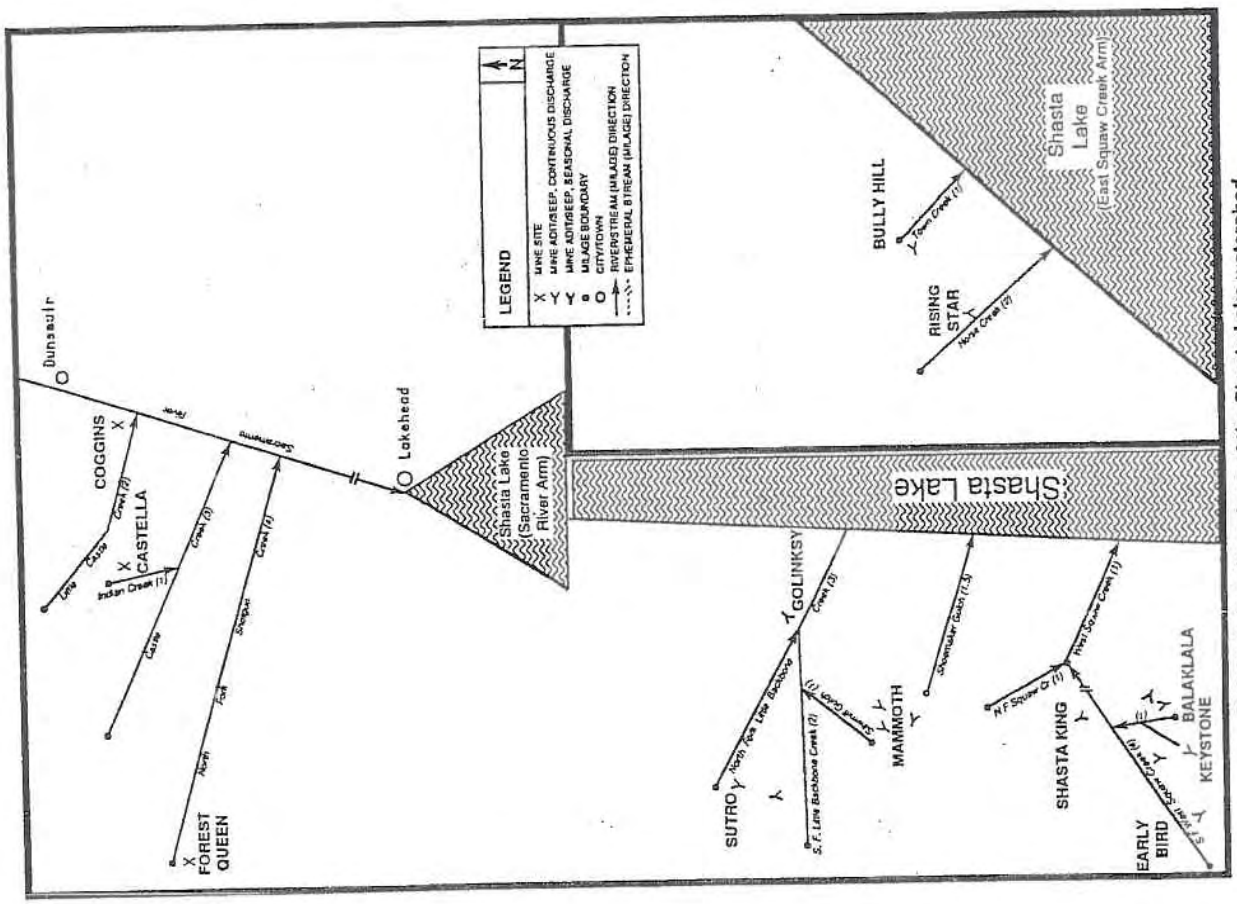

PLATE 7. Inactive mines of the Shasta Lake watershed.

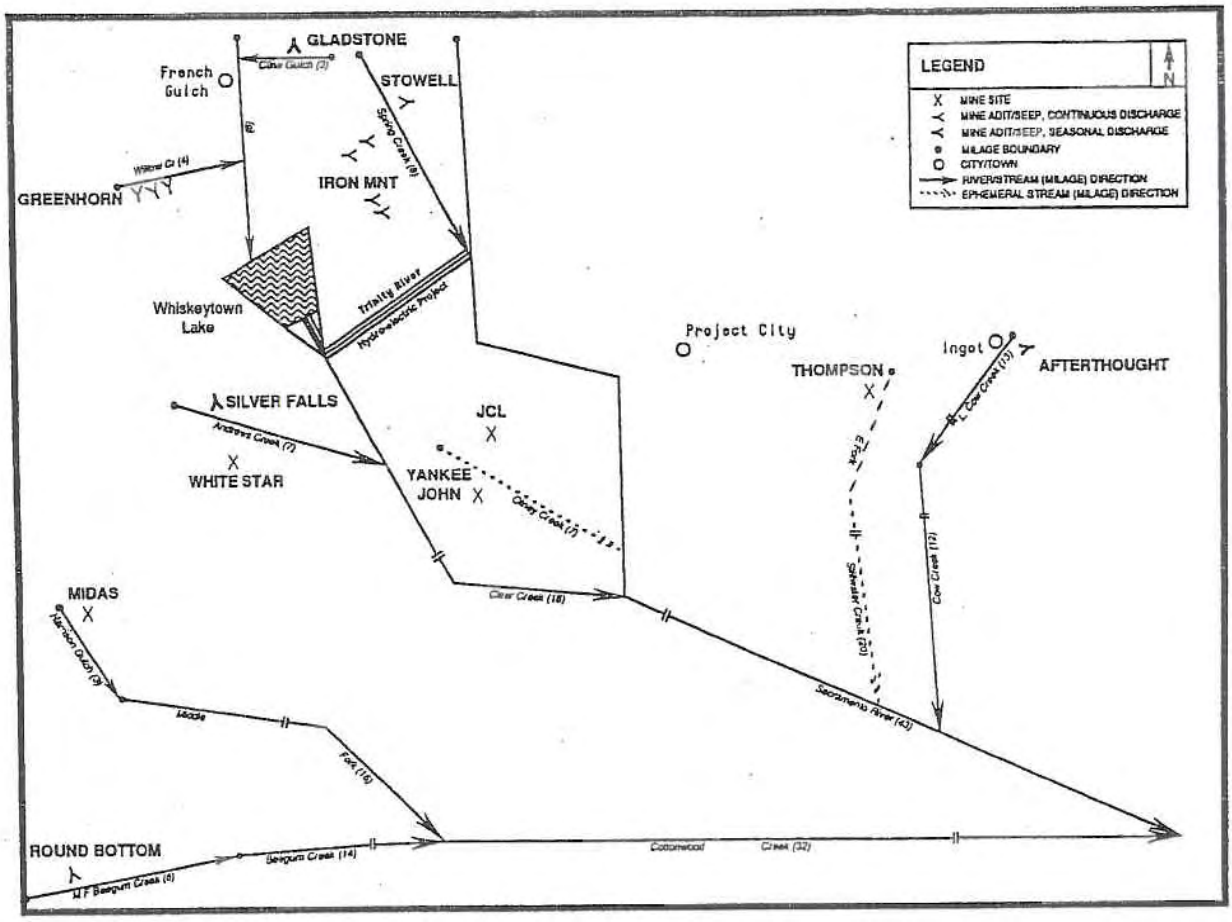

PLATE 8. Inactive mines of the Upper Sacramento River watershed.

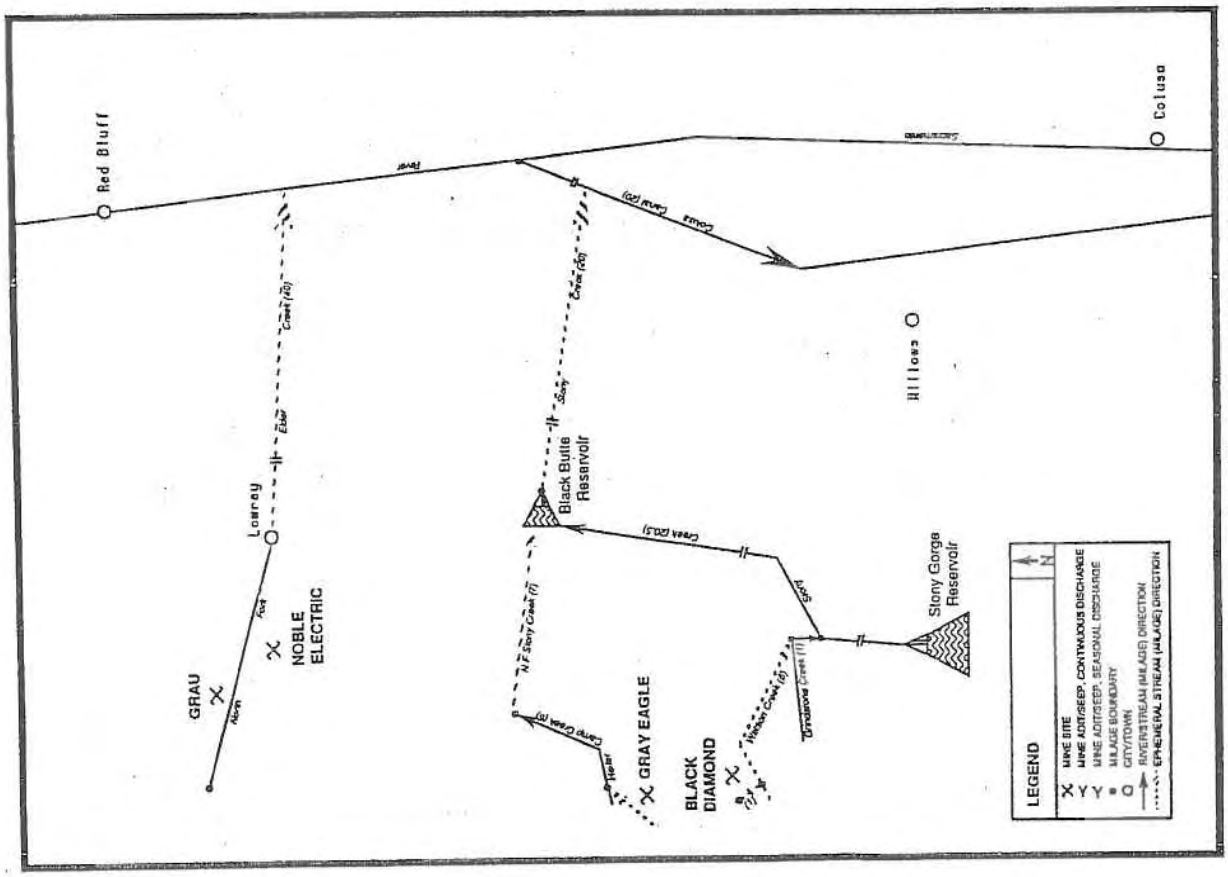

PLATE 9. Inactive mines of the Stony Creek / Elder Creek watersheds.

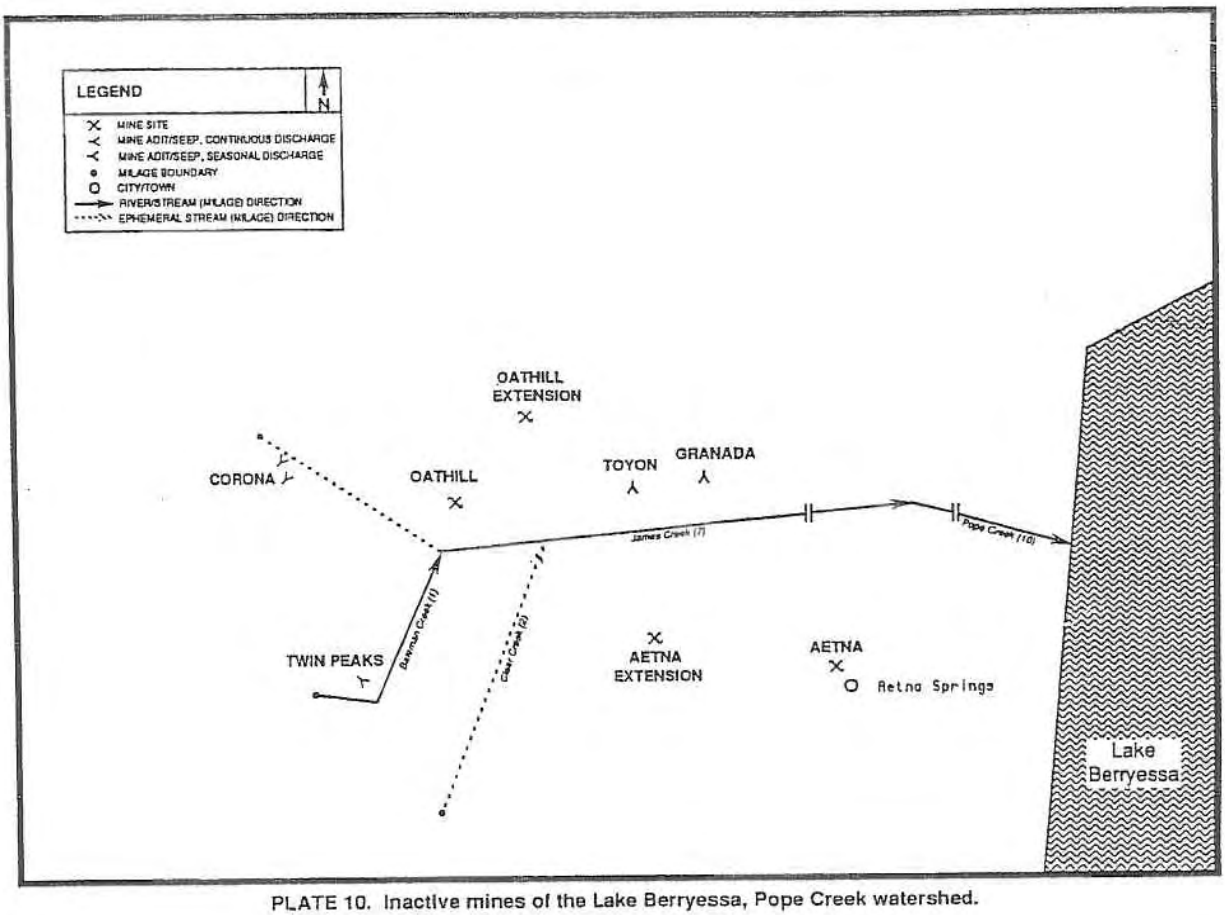

PLATE 10. Inactive mines of the Lake Berryessa, Pope Creek watershed.

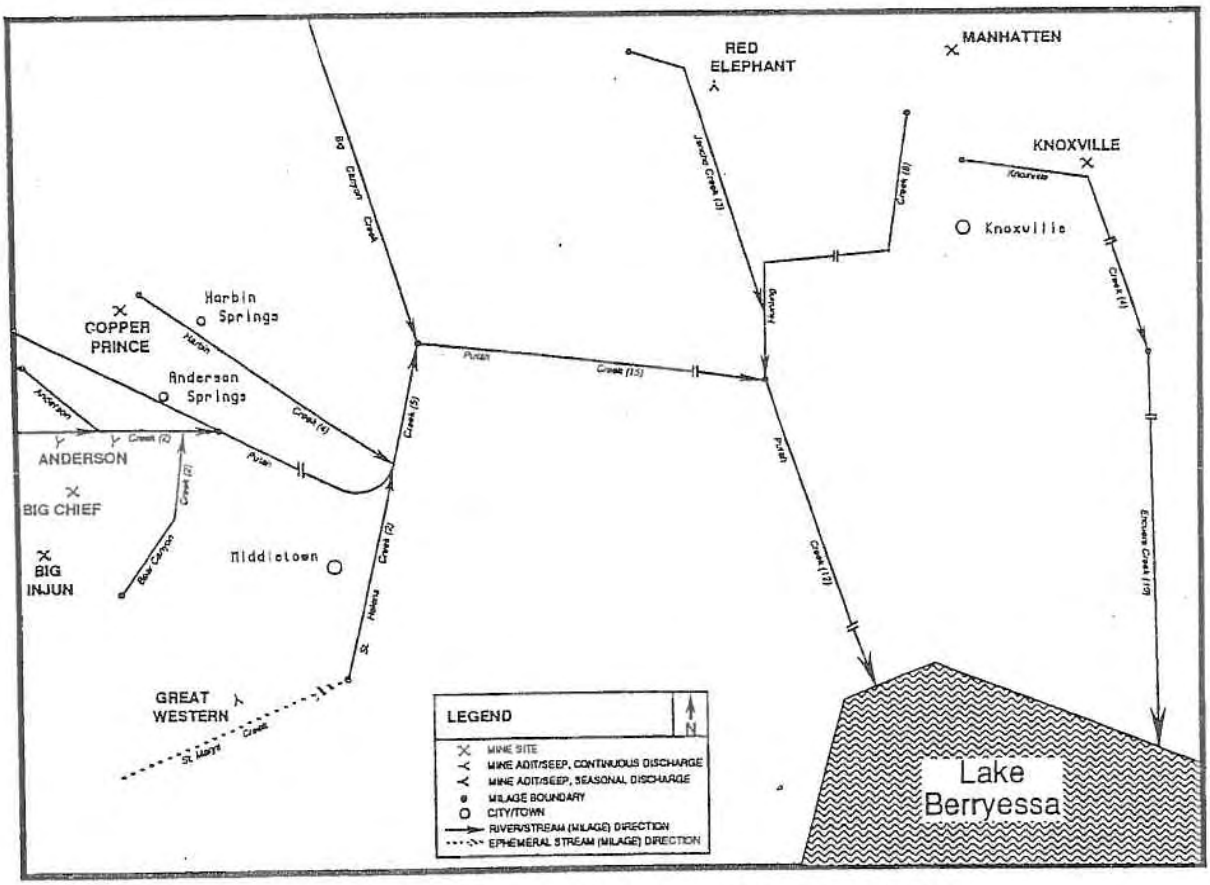

PLATE 11. Inactive mines of the Lake Berryessa, Putah Creek watershed.

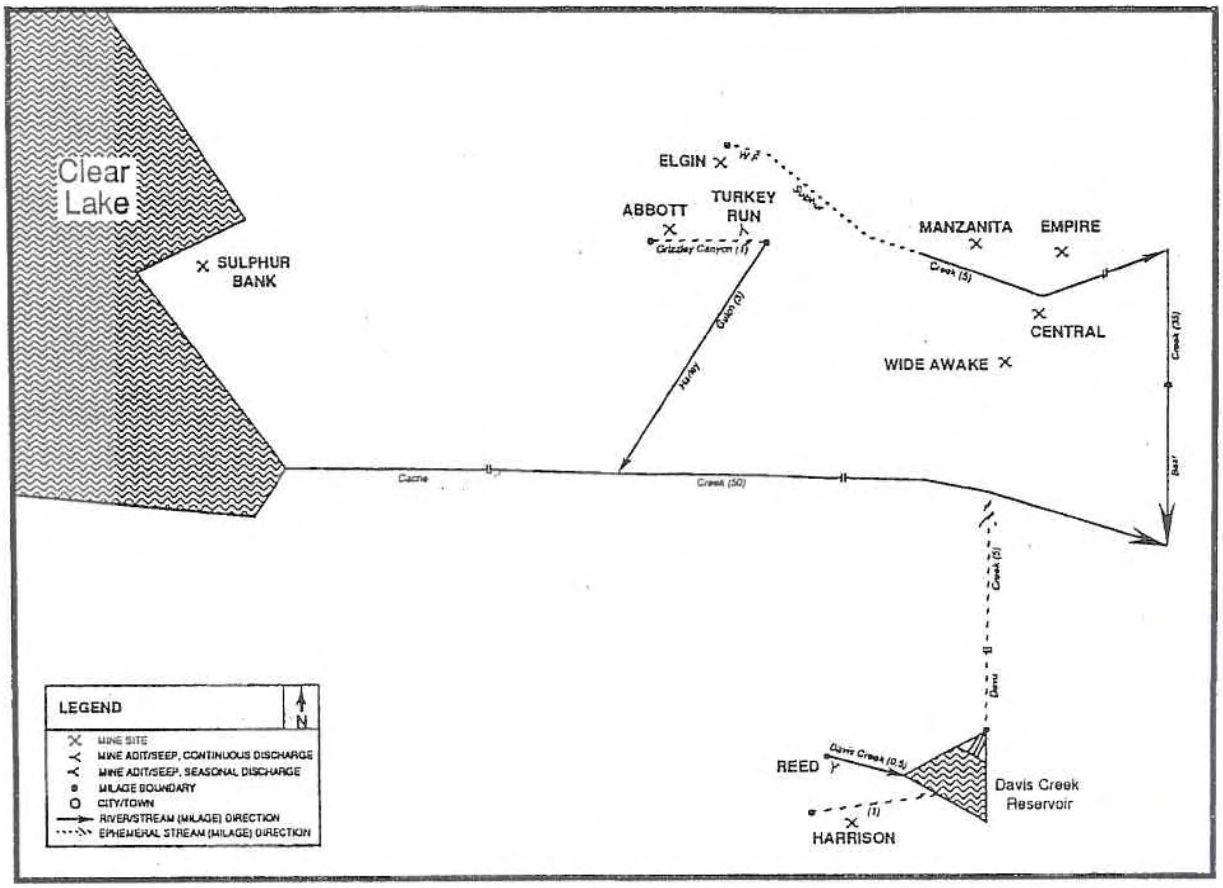

PLATE 12. Inactive mines of the Cache Creek watershed.

Table IV-1. SACRAMENTO VALLEY INACTIVE MINE CHARACTERISTICS. 1/

MAP ID	MINE NAME	COUNTY	RECEIVING WATER SEQUENCE	USGS QUADRANGLE TITLE (MINUTES)	TOWNSHIP-RANGE	DISTRICT	PRODUCT	ORE MINERALOGY	PERENNIAL DISCHRG?	ONSITE PROCESS	START-UP
** WATERSHED : Folsom Lake											
1	Funnybug	El Dorado	Weber Cr - SF American Riv - Folsom Lake	Shingle Springs (7.5)	Sec 3 T12N R10E	Foothill	Cu, Au	Pyrite,chalcopyrite,sphaleri te,arsenopyrite,stibnite,gal ena,hematite	unk		
2	Big Buzzard	El Dorado	Folsom Lake	Pilot Hill (7.5)	Sec 29 T11N R8E	W. Foothill	Cu,Au, Zn	Sphalerite, pyrite, chalcopyrite, galena	no	5 stamp mill	
3	Pillikan(areas 1-11)	El Dorado	NF American Riv - Folsom Lake	Pilot Hill (7.5)	Secs 21,28 T11N R8E	Flagstaff Hill	Cr	Chromite, dunite, pyroxenite, garnierite	no	Mill	1894
4	Lilyama	El Dorado	Hastings Cr - SF American Riv - Folsom Lake	Coloma (7.5)	Sec 3 T11N R9E	W. Foothill	Cu,Au, Ag	Chalcopyrite, bornite, hematite, scheelite, pyrite	yes	Ball mill, flotation plant	1860
5	Black Oak	El Dorado	Johntown Cr - Dutch Cr - SF American Riv - Folsom Lake	Garden Valley (7.5)	Sec 27,34 T12N R10E	Garden Valley	Au	Pyrite	no	Ball mill, flotation plant	
6	Georgia Slide	El Dorado	Canyon Cr - MF American Riv - Folsom Lake	Georgetown (7.5)	Sec 3 T12N R10E		Au	pyrite	unk	Stamp mill	
7	El Dorado	El Dorado	Little Sailor Cr - Big Sailor Cr - Dutch Cr - SF American Riv	Garden Valley (7.5)	Sec 34 T12N R10E	Foothill	Cu, Au	Chalcopyrite, pyrrotite, pyrite	unk		
8	Alhambra	El Dorado	Rock Creek - SF American Riv - Folsom Lake	Garden Valley (7.5)	Sec 6 T11N R11E		Au	Arsenopyrite, pyrite	yes	Mill and flotation plant	1883
** WATERSHED : Bear River/Dry Creek											
9	Valley View	Placer	Coon Cr - Feather Riv	Lincoln (7.5)	Sec 13 T13N R6E	Dairy Farm	Cu, Au, Ag	Chalcopyrite, cuprite, pyrite, zinc sulphides	yes	40 stamp mill	186-
10	Dairy Farm	Placer	Camp Far West Lake	Camp Far West (7.5)	Sec 27 T14N R6E	Dairy Farm	Cu, Ag, Au	Copper sulfides	no	Cyanide plant	1904
11	Spenceville	Nevada	Little Dry Cr - Dry Cr - Bear Riv	Camp Far West (7.5)	Sec 26,35 T15N R6E	Spenceville	Cu, H2SO4	Gossan, chalcopyrite, pyrite, bornite	yes	Smelter	1862
12	Empire	Nevada	Little Wolf Cr - Wolf Cr - Bear Riv	Grass Valley (15)	Sec 35 T16N R8E	Sulphur Creek	Hg	Cinnabar	yes	Cyanide plant, 20, 60 stamp mills, tailings pond	
13	Idaho-Maryland	Nevada	Wolf Cr - Bear Riv	Grass Valley (15)	Sec 26 T16N R8E	Grass Valley	Au	Pyrite, chalcopyrite, galena	no	20 stamp mill	1865
14	Lava Cap	Nevada	Little Clipper Cr - Clipper Cr - Little Greenhorn Cr - Greenhorn Crk - Bear Riv	Colfax (15)	Sec 28 T16N R9E	Nevada City	Au	Pyrite, arsenopyrite, sphalerite, galena	yes	Stamp mill, cyanide plant	1861
** WATERSHED : Yuba River											
15	Banner	Nevada	Little Deer Cr - Deer Cr - SF Yuba Riv - Yuba Riv	Colfax (15)	Sec 16 T16N R9E	Nevada City	Au	Pyrite, arsenopyrite, sphalerite, galena	unk	None	1889
16	Champion	Nevada	Deer Cr - Yuba Riv	Nevada City (15)	Sec 11,12 T16N R9E	Nevada City	Au	Pyrite, chalcopyrite, galena	yes	40 stamp mill, cyanide plant, tube mill, flotation plant	
17	Malakoff Diggin's	Nevada	Humbug Cr - South Yuba River	Alleghany (15)	Sec 4 T18N R10E		Au		yes		
18	Spanish	Nevada	Poorman Cr - SF Yuba Riv - Yuba Riv	Alleghany (15)	Sec 31 T18N R11E	Washington	Cu, Ba	Barite	yes	10 Stamp mill, flotation plant	1883
19	San Juan	Nevada	Sweetland Cr - Yuba Riv	French Corral (7.5)	Sec 12 T17N R7E	North San Juan	Au, Cu	Auriferous sulfides, chalcopyrite	no	Unknown	
20	Kenton	Sierra	Kanaka Cr - MF Yuba Riv - Yuba Riv	Alleghany (15)	Sec 4 T18N R10E	Alleghany	Au	Quartz	yes	Stamp mill	
21	Sixteen to One	Sierra	Kanaka Cr - MF Yuba Riv - Yuba Riv	Alleghany (15)	Sec 34 T19N R10E	Alleghany	Au	Arsenopyrite	yes		

Table IV-1. SACRAMENTO VALLEY INACTIVE MINE CHARACTERISTICS.

MAP I D	MINE NAME	COUNTY	RECEIVING WATER SEQUENCE	USGS QUADRANGLE TITLE (MINUTES)	TOWNSHIP-RANGE	DISTRICT	PRO-DUCT	ORE MINERALOGY	PERENNIAL DISCHRG?	ONSITE PROCESS	START -UP
22	Brush Creek	Sierra	Woodruff Cr - NF Yuba Riv - Yuba Riv	Goodyears Bar (7.5)	Sec 17, T19N R10E	Downieville	Au	Auriferous arsenopyrite, galena, pyrite, chlorlite, serpentine	yes	None	
23	Pick & Shovel	Yuba	Pats Gulch - Slate Cr - MF Yuba Riv - Yuba Riv	La Porte (7.5)	Sec 23 T21N R9E				yes		
24	Plumbago	Sierra	Buckeye Ravine - Wolf Cr - MF Yuba Riv - Yuba Riv	Alleghany (15)	Sec 1 T18N R10E	Alleghany	Au	Quartz	yes	Unknown	
25	Sierra Homestake	Sierra	N Yuba Riv - Yuba Riv	Sierra City (15)	Sec 1 T20N R12E	Alleghany	Au	Malachite, chalcopyrite	unk		
26	Zuver	Sierra	NF Yuba Riv - Yuba Riv	Sierra City (15)	Sec 12 T20N R12E	Allegheny	Cu		no		
27	Sierra Buttes	Sierra	N Yuba Riv - Yuba Riv	Sierra City (15)	Sec 29 T20N R12E	Allegheny	Au, Ag		unk	Rod mill, cyanide mill	
28	Columbo	Sierra	NF Yuba Riv - Yuba Riv	Sierra City (15)	Sec 19 T20N R12E	Sierra City	Au	Andesite	yes	10 stamp mill, cyanide mill, ball mill	1875
** WATERSHED : Butte Creek											
29	Mineral Slide	Butte	Little Butte Cr - Butte Cr - Sacramento Riv	Paradise (7.5)	Sec 3 T22N R3E		Au		unk	None	1887
** WATERSHED : Feather River											
30	Plumas-Eureka	Plumas	Jamison Cr - MF Feather Riv - Oroville Lake	Downieville (15)	Sec 23,26 T22N R11E	Johnsville	Au	Pyrite, chalcopyrite, arsenopyrite, galena	no	60 stamp mill	1851
31	Big Bend	Butte	Frazier Cr - NF Feather Riv - Lake Oroville	Big Bend Mountain (15)	Sec 8 T21N R5E				unk		
32	China Gulch	Plumas	Willow Cr - MF Feather Riv - Lake Oroville	Bucks Lake (15)	Sec 34 T23N R7E		Cu		unk		
33	Iron Dyke	Plumas	Taylors Cr - Indian Cr - EBNF Feather Riv - NF Feather Riv - Lake Oroville	Greenville (15)	Sec 34 T25N R10E	Taylorsville	Cu,Ag, Au	Malachite, azurite, pyrrhotite, chalcopyrite	no		1860
34	Walker	Plumas	Little Grizzly Cr - Indian Cr - EBNF Feather Riv - NF Feather Riv - Oroville Lake	Mt. Ingalls (7.5)	Sec 7 T24N R12E	Genessee	Cu, Au	Chalcopyrite,tetrahedrite,pyrite,pyrrotite,chlcocite,sphalerite,galena	yes	Flotation plant, ball mill, crusher unknown	1915
35	Reward #7	Plumas	Ward Cr - Indian Cr - EBNF Feather - NF Feather Riv	Genesee Valley (7.5)	Sec 14,23 T25N R11E	Genessee	Cu	Epidote, garnet, pyrite, chalcopyrite, bornite	no		
36	Beardsley	Plumas	WF Davis Cr - Davis Cr - Hosselkers Cr - Indian Cr - EBNF Feather - NF Feather Riv	Genesee Valley (7.5)	Sec 14 T26N R11E	Genessee	Cu, Au	Chalcopyrite, Bornite	no		1913
37	Lucky S	Plumas	Peters Cr - Lights Cr - Indian Cr - EBNF Feather - NF Feather Riv	Kettle Rock (15)	Sec 28,33 T27N R11E	Genessee	Cu, Au	Pyrite, sphalerite, chalcopyrite, galena	yes	5 stamp mill	
38	Superior-Engel	Plumas	Lights Cr - Indian Cr - EBNF Feather Riv - NF Feather Riv - Oroville Lake	Greenville (15)	Sec 17 T27N R11E	Lights Creek	Cu,Ag	Chalcopyrite, bornite	no	Stamp mill and oil flotation plant	1894
39	Mountain Meadows	Lassen	Mtn Meadows Cr - Mtn Meadows Res - Lake Almanor	Westwood (7.5)	Sec 29 T28N R10E		Cu		no		
** WATERSHED : Pit River											
40	Golden Eagle	Lassen	Silva Flat Reservoir - EF Juniper Creek - Pit River	Hayden Hill (15)	Sec 37 T36N R9E	Hayden Hill	Au		no	Mill and cyanide plant	
** WATERSHED : Shasta Lake											
41	Coggins	Shasta	Little Castle Cr - Sacramento Riv - Shasta Lake	Dunsmuir (15)	Sec 16 T38N R4W		Cr		no		1942
42	Castella	Shasta	Indian Cr - Castle Cr - Sacramento Riv - Shasta Lake	Dunsmuir (15)	Sec 16 T38N R4W	Dunsmuir	None	None	no	Chromite mill	
43	Forest Queen	Shasta	NF Shotgun Cr - Sacramento Riv - Shasta Lake	Dunsmuir (15)	Sec 22,27 T37N R5W	Dunsmuir	Cr	Chromite	no	None	

Table IV-1. SACRAMENTO VALLEY INACTIVE MINE CHARACTERISTICS.

MAP I D	MINE NAME	COUNTY	RECEIVING WATER SEQUENCE	USGS QUADRANGLE TITLE (MINUTES)	TOWNSHIP-RANGE	DISTRICT	PRO-DUCT	ORE MINERALOGY	PERENNIAL DISCHRG?	ONSITE PROCESS	START-UP
44	Bully Hill	Shasta	Town Cr - Shasta Lake	Bollibokka Mtn (15)	Sec 16,22 T34N R3W	E. Shasta	Cu,Zn, Pb,Cd	Pyrite, sphalerite, chalcopyrite, galena, tetrahedrite, bornite	yes	Smelter, flotation plant	1860
45	Rising Star	Shasta	Horse Cr - Shasta Lake	Bollibokka Mtn (15)	Sec 15,21 T34N R3W	E. Shasta	Cu,Zn, Pb,Cd	Pyrite, sphalerite, chalcopyrite, galena, tetrahedrite, bornite	yes	Smelter, flotation plant	1860
46	Keystone	Shasta	West Squaw Cr - Shasta Lake	French Gulch (15)	Sec 14 T33N R6W	W. Shasta	Cu,Au, Ag,Zn	Copper sulfides	yes	Unknown	
47	Early Bird	Shasta	West Squaw Cr - Shasta Lake	French Gulch (15)	Sec 10 T33N R6W	W. Shasta	Cu, Zn	Chalcopyrite	yes		
48	Balaklala	Shasta	West Squaw Cr - Shasta Lake	Shasta Dam (7.5)	Sec 12 T33N R6W	W. Shasta	Cu, Zn, Ag,	Pyrite, chalcopyrite, sphalertite, galena, covellite	yes	Smelter near Coram	1890
49	Shasta King	Shasta	West Squaw Cr - Shasta Lake	Shasta Dam (7.5)	Sec 1 T33N R6W	W. Shasta	Cu,Zn, Cd,Au		yes		
50	Mammoth	Shasta	Little Backbone Cr - Shasta Lake	Lamoine (15)	Sec 32 T33N R6W	W. Shasta	Cu,Zn, Au,Ag	Pyrite, chalcopyrite, sphalerite	yes	Smelter 4 miles away near Kennett	1900
51	Sutro	Shasta	Little Backbone Cr - Shasta Lake	Lamoine (15)	Sec 29,30 T34N R5W	W. Shasta	Cu		yes		
52	Golinsky	Shasta	Little Backbone Cr - Shasta Lake	Lamoine (15)	Sec 28 T34N R5W	W. Shasta	Cu,Zn, Au	Copper sulfides	yes	Unknown	
** WATERSHED : Sacramento Riv, Upper											
53	Stowell	Shasta	Spring Cr - Sacramento Riv	Shasta Dam (7.5)	Sec 13 T33N R6W	W. Shasta	Cu	Chalcopyrite	yes		
54	Gladstone	Shasta	Cline Gulch - Clear Cr - Whiskeytown Lake - Sacramento Riv	French Gulch (15)	Sec 18 T33N R6W	French Gulch	Au	Quartz, pyrite, galena, sphalerite, arsenopyrite	no	30 stamp mill	
55	Afterthought	Shasta	Little Cow Cr - Cow Cr - Sacramento Riv	Millville (15)	Sec 10,11 T33N R2W	E. Shasta	Cu,Zn, Au,Cd	Sphalerite, chalcopyrite	yes	Flotation plant, smelter	1903
56	Thompson	Shasta	EF Stillwater Cr - Stillwater Cr - Sacramento Riv	Project City (7.5)	Sec 34 T33N R4W	E. Shasta	Cu	Pyrite, chalcopyrite, bornite, quartz	no	Unknown	
57	Iron Mountain	Shasta	Spring Cr - Keswick Res - Sacramento Riv	French Gulch (15)	Sec 34,35 T33N R6W	W. Shasta	Cu,Zn, Au,Ag	Pyrite, chalcopyrite, sphalerite	yes	Flotation mill, cyanide plant	1879
58	Greenhorn	Shasta	Willow Cr - Crystal Cr - Clear Cr - Whiskeytown Lake	French Gulch (15)	Sec 31 T33N R7W	French Gulch	Cu,Au, Ag,Cd	Pyrite, chalcopyrite, chalcocite	yes	Copper sedimentation plant	1900
59	JCL	Shasta	Olney Cr - Sacramento Riv - Shasta Lake	Redding (7.5)	Sec 8 T31N R5W				unk		
60	Yankee John	Shasta	Olney Cr - Sacramento Riv	Redding (7.5)	Sec 17 T31N R5W				no		
61	White Star	Shasta	Andrews Cr - Clear Cr - Sacramento Riv	French Gulch (15)	Sec 18,19 T31N R6W				no		
62	Silver Falls	Shasta	Andrews Cr - Clear Cr - Sacramento Riv	French Gulch (15)	Sec 18,19 T31N R6W	Igo	Ag,Au	Tetrahedrite, galena, pyrite, sphalerite, chalcopyrite	yes	Unknown	
63	Midas	Shasta	Harrison Gulch - MF Cottonwood Cr - Cottonwood Cr - Sacramento Riv	Chanchenulla Pk (15)	Sec 3,4 T29N R10W	Harrison Gulch	Au	Quartz	no	20 stamp mill, cyanide plant	
64	Round Bottom	Shasta	MF Beegum Cr - Beegum Cr - Cottonwood Cr - Sacramento Riv	Dubakella Mtn (15)	Sec 5 T28N R10W	Platina	Cr	Chromite	yes	Unknown	
** WATERSHED : Stony Cr / Elder Cr											
65	Grau	Tehama	NF Elder Cr - Sacramento Riv	Raglin Ridge (7.5)	Sec 17 T25N R7W		Cr	Chromite, serpentine	no		
66	Noble Electric	Tehama	NF Elder Crk - Sacramento Riv	Raglin Ridge (7.5)	Sec 17 T25N R7W		Cr	Chromite, serpentine	no		1915

Table IV-1. SACRAMENTO VALLEY INACTIVE MINE CHARACTERISTICS.

MAP ID	MINE NAME	COUNTY	RECEIVING WATER SEQUENCE	USGS QUADRANGLE TITLE (MINUTES)	TOWNSHIP-RANGE	DISTRICT	PRODUCT	ORE MINERALOGY	PERENNIAL DISCHRG?	ONSITE PROCESS	START-UP
67	Grey Eagle	Glenn	Heifer Camp Cr - NF stony Creek - Black Butte Reservoir - Stony Cr - Colusa Drain	Chrome (7.5)	Sec 25 T22N R7W		Cr	Chromite	no		
68	Black Diamond	Glenn	Watson Cr - Grindstone Cr - Stony Cr - Black Butte Reservoir - Stony Cr - Colusa Drain	Chrome (7.5)	Sec 25 T22N R7W		Cr	Chromite	no	None	1892
** WATERSHED : Cache Creek											
69	Sulfur Bank	Lake	Clear Lake	Clearlake Highlands (7.5)	Sec 6 T13N R7W	Clear Lake	Hg, sulphur	Cinnabar, marcasite, pyrite	no	Knox-Osborne, 3 Scott furnaces, several D-retorts and rotary furnace	1873
70	Elgin	Colusa	WF Sulphur Cr - Sulphur Cr - Bear Cr - Cache Cr	Wilbur Spring (15)	Sec 13 T14N R6W	Sulphur Creek	Hg,sulphur	Cinnabar	unk	Retort furnace	
71	Empire	Colusa	Sulphur Cr - Bear Cr - Cache Cr	Wilbur Spring (15)	Sec 29 T14N R5W	Sulphur Creek	Hg	Cinnabar	no	D-Retort	
72	Manzanita	Colusa	Sulfur Cr - Bear Cr - Cache Cr	Wilbur Spring (15)	Sec 29 T14N R5W	Sulphur Creek	Hg,Au, sulph	Cinnabar	no	Stamp and Huntington mills, retort furnace	1863
73	Central	Colusa	Sulphur Cr - Bear Cr - Cache Cr	Wilbur Spring (15)	Sec 28 T14N R5W	Sulphur Creek	Hg	Cinnabar	no		
74	Wide Awake	Colusa	Sulfur Cr - Bear Cr - Cache Cr	Wilbur Spring (15)	Sec 29 T14N R5W		Hg	Cinnabar	no	Large Scott Furnace, small pipe furnace	1875
75	Abbott	Lake	Grizzly Canyon - Harley Gulch - Cache Cr	Wilbur Springs (15)	Sec 32 T14N R5W	Sulphur Creek	Hg	Cinnabar	no	Scott furnace, rotary kiln, cyclone dust collector	1862
76	Turkey Run	Lake	Grizzly Canyon - Harley Gulch - Cache creek	Wilbur Springs (15)	Sec 32 T14N R5W	Sulphur Creek	Hg		yes		
77	Reed	Yolo	Davis Cr - Cache Cr	Knoxville (15)	Sec 25 T12N R5W	Knoxville			yes		
78	Harrison	Yolo	Davis Cr - Cache Cr	Knoxville (15)	Sec 35 T12N R5W				unk		
** WATERSHED : Lake Berryessa,Putah											
79	Knoxville	Napa	Knoxville Cr - Eticuera Cr - Lake Berryessa	Morgan Valley (15)	Sec 7 T11N R4W	Knoxville	Hg	Cinnabar, pyrite	no	Scott furnace, D-retort, rotary pipe furnace	1862
80	Manhattan	Napa	Hunting Cr - Putah Cr - Lake Berryessa	Morgan Valley (15)	Sec 1 T11N R5W		Hg	Cinnabar	unk		1863
81	Red Elephant	Napa	Jericho Cr - Hunting Cr - Putah Cr - Lake Berryessa	Morgan Valley (15)	Sec 3 T11N R5W	Knoxville	Hg	Cinnabar	no	Rotary furnace	
82	Copper Prince	Lake	Putah Cr - Lake Berryessa	Whispering Pines (7.5)	Sec 19 T11N R7W		Cu	Azurite, malachite, sulphide	unk		
83	Big Chief	Lake	Anderson Cr - Putah Cr - Lake Berryessa	Whispering Pines (7.5)	Sec 35 T11N R8W	Mayacmas	Hg	Cinnabar	no	Rotary kiln	1916
84	Big Injun	Lake	Bear Canyon Cr - Putah Cr - Lake Berryessa	Whispering Pines (7.5)	Sec 35 T11N R8W	Mayacmas	Hg	Cinnabar	no		
85	Anderson	Lake	Anderson Cr - Putah Cr - Lake Berryessa	Whispering Pines (7.5)	Sec 35 T11N R8W	Mayacmas	Hg	Cinnabar, pyrite, calcite	yes	Pipe retort furnace, D-retort furnace	

Table IV-1. SACRAMENTO VALLEY INACTIVE MINE CHARACTERISTICS.

MAP I D	MINE NAME	COUNTY	RECEIVING WATER SEQUENCE	USGS QUADRANGLE TITLE (MINUTES)	TOWNSHIP-RANGE	DISTRICT	PRO-DUCT	ORE MINERALOGY	PERENNIAL DISCHRG?	ONSITE PROCESS	STARY -UP
86	Great Western,old/new	Lake	St. Marys Creek - St. Helena Creek - Putah Creek - Lake Berryessa	Mount St Helena (15)	Sec 16,17 T10N R7W	Mayacma	Hg	Cinnabar, pyrite	yes	Brick, Scott, and Herreshoff furnace, 4 D-retort furnaces	1873
** WATERSHED : Lake Berryessa,Pope											
87	Corona	Napa	James Cr - Pope Cr - Lake Berryessa	Detert Reservoir (7.5)	Sec 32 T10N R6W	Mayacmas	Hg, Cu	Cinnabar, serpentine, pyrite	yes	Scott and pipe furnaces	1895
88	Twin Peaks	Napa	Bateman Cr - James Cr - Pope Cr - Lake Berryessa	Detert Reservoir (7.5)	Sec 4 T9N R6W	Mayacmas	Hg	Cinnabar, serpentine, chromite, millerite (nickel sulphide)	yes	Rotary pipe furnace	1902
89	Oat Hill	Napa	James Cr - Pope Cr - Lake Berryessa	Detert Reservoir (7.5)	Sec 33 T10N R6W	Mayacmas	Hg	Cinnabar, calcite, pyrite	no	Scott Furnace, rotary furnace	1867
90	Aetna Extension	Napa	James Cr - Pope Cr - Lake Berryessa	Detert Reservoir (7.5)	Sec 34 T10N R6W	Aetna Springs	Hg	Cinnabar, millerite	no		1864
91	Oat Hill Extension	Napa	James Cr - Pope Cr - Lake Berryessa	Detert Reservoir (7.5)	Sec 27 T10N R6W	Mayacmas	Hg	Cinnabar	no		
92	Aetna	Napa	James Cr - Pope Cr - Lake Berryessa	Detert Reservoir (7.5)	Sec 3 T9N R6W		Hg	Cinnabar	no	Scott furnace, rotary furnace, mill, 2 D-retort furnaces	
93	Grenada	Napa	James Cr - Pope Cr - Lake Berryessa	Detert Reservoir (7.5)	Sec 34 T10N R6W	Mayacmas	Hg	Cinnabar	no	None	
94	Toyon	Napa	James Cr - Pope Cr - Lake Berryessa	Detert Reservoir (7.5)	Sec 34 T10N R6W	Mayacmas	Hg	Cinnabar	no	Small furnace	

1/ The mineralogical characteristics of the mines were taken from DOM, 1957; DMG, 1966, 1970a-b; CJMG, 1956, 1937a-b, 1936a-b, 1942, 1946, 1947a-b; and CSMB, 1918, 1915, 1916. Map Identification Numbers correspond to mines areally located on Figure IV-1. Mineral formulas, names, and abundances in California can be found in Table F-1.

Table IV-2. AVERAGE WATER QUALITY CHARACTERISTICS OF SACRAMENTO VALLEY MINE DRAINAGE OR DRAINAGE INFLUENCED STREAMS SAMPLED BETWEEN 1987 AND 1991 (AVERAGES FROM TABLE C-1 AND C-2).

MAP I.D. NO.	MINE	ADIT	AVE. Eh (mV)	AVE. FLOW (l/s)	MEDIAN pH	AVERAGE TOTAL CONCENTRATION (UG/L) ARSENIC	CADMIUM	CHROMIUM	COPPER	LEAD	NICKEL	ZINC	SILVER	TOTAL IRON (MG/L)
	Kanaka Creek mines 4/		191	752	6.46	20	<0.1	1	<1	<5	<4	<10	<1	<0.030
9	Valley View		427	0.11	1.70	75	5,500	170	123,500	39	650	245,000	<10	660
11	Spenceville 2/			15.5	7.08	3.1	0.18	<1	375	<5	<4	299	<1	1.09
12	Empire (Nevada Co.)		229	8.13	6.66	49	<0.1	<1	<1	<5	<4	11	<1	4.7
14	Lava Cap		275	5.86	7.60	57	0.2	<1	2	<5	<4	19	<1	0.16
16	Champian			2.26		<1	0.7	<1	1	<5	<4	11	<1	1.5
17	Malakoff Diggn's		176	21.9	6.52	4.5	<0.1	34	21	<5	44	41	<1	19
18	Spanish	Upper	68	2.30	5.67	16	3.8	<1	193	110	19	21	<1	37
		16 to 1	240	2.92	3.50	6.2	5.3	1	267	29	110	2,050	<1	2.05
22	Brush Creek	Main	83	26.9	7.62	221	<0.1	2.1	1	<5	133	<10	<1	<0.030
		Upper	87	6.51	7.10	62			<1		29			
23	Pick & Shovel		126	2.21	6.28	1.5	<0.1	1	<1	<5	137	14	<1	0.03
24	Plumbago		235	3.27	7.90	264	<0.1	2.2	2	<5	15	<10	<1	0.065
28	Columbo		166	31	7.01	0.8	<0.1	2.5	<1	1	<4	<10	<1	<0.03
34	Walker			0.55	7.34	<1	0.1	<1	250	<5	<4	10	<1	
37	Lucky-S		130	3.64	6.04	<2	2.7	<1	72	<5	<4	298	<1	25
44	Bully Hill			0.85	4.30	<2	248	<1	5,053	31	24	13,375	<1	0.223 3/
45	Rising Star			2.66	3.30	865	130	3	3,100	45	12	30,000		153 3/
46	Keystone			2.15	3.18		78		9,658	21 3/		16,705		17.9
47	Early Bird 1/			0.17	2.50		487		99,365			116,400		
48	Balaklala	Main		3.85	2.91		320		18,800			27,692		147 3/
		Weil		0.28	2.71		42		109,463			172,308		8,720 3/
49	Shasta King 1/	Upper 3/		0.3	2.25		334		64,000			58,900		223
		Lower		0.15	2.20	320 3/	349	20 3/	63,800	100 3/		67,200		1,008
50	Mammoth	300 level		0.04	1.79		1,450		166,675			257,475		883
		Gossen #2		2.09	2.16	20 3/	183		104,920	<50 3/		25,438		19.2
		Friday-Lowden		9.63	2.91		70		6,547			11,910		24.2
51	Sutro 3/	Upper		2.7	3.80		8		960			410		1.06
		Middle		8.13	6.80		1.5		107			387		0.23
		Lower		19.2	6.5		17.3		1,210			1883		0.45
52	Golinsky 3/			0.86	2.90		309		12,413		24	27,035		29.6
53	Stowell			1.26	3.48		31		4,625			6,615		26.8 3/
55	Afterthought			0.88 3/	2.70	25	340	2	14,000	91	32	93,000	<1	104 3/
	Spring Creek Debris Dam 5/		518	807	2.80	44	94	11	3,077	20	12	19,460	<1	125 3/
58	Greenhorn	North	424	0.04	2.34	105	665	10	69,333	30	137	160,000	<1	890
		Middle	171	0.49	5.16	8	2.75	<1	2,450	<5	<4	1,450	<1	29
		South	135	0.05	5.74	<1	12.5	<1	200	<5	<4	4,600	<1	120
62	Silver Falls			0	6.7	<1	<0.1	<1	<1	<5	<4	6	<1	
76	Turkey Run			0.19	7.83	<1	<0.1	3	<1	<5	<4	<1	<1	
77	Reed		94	0.16	6.33	59	<0.1	46	<1	<5	1,200	20	<1	
85	Anderson	West	-85	0.14	6.77	3.3	<0.1	4.3	9	<5	107	156	<1	7.00
		East	91	0.5	6.61	9.3	<0.1	<1	15	<5	92	73	<1	2.70
86	Great Western		172	0.33	7.36	<1	<0.1	4	1	<5	34	15	<1	0.79
87	Corona	Main		0.3	7.40	2.5	<0.1	33	0.5	<5	2,950	43	<1	53
		Water tunnel	120	2.87	5.73	<2	<0.1	41	<1	<5	9,350	197	<1	250
88	Twin Peaks		143	0.24	6.30	<1	0.13	5.7	<1	<5	1,800	29	<1	15

1/ Post-plug average.
2/ Below mine in Little Dry Creek.
3/ 1981-86 data.
4/ Drains watershed containing many mines including 16-to-1 and Kenton.
5/ Drains watershed containing Iron Mt. and Stowell Mines.

indicate that arsenic is present largely in the less toxic +5 state based on pH-Eh graphs. This is significant since arsenite (As^{3+}) is 1 to 2 orders of magnitude more toxic to aquatic organisms than the arsenate (As^{5+}) species (Moore and Ramamoorthy, 1984).

Other mines in the Sierra-Nevada range exhibited dissimilar characteristics. The commodities mined at individual sites included polymetallic (e.g., Spanish Mine), gold, chromium (mines in the American River watershed), and copper (Plumas Copper Belt) minerals. Spanish Mine outflows were slightly acidic (pH = 4-6) and contained low to moderate levels of most metals analyzed (Table IV-2). An air vent at the large gold mine, Empire, discharged slightly acidic water containing only nominal levels of nickel and arsenic. Chromite was mined in the American River watershed (Figure IV-1, Plate 1) using both surface and underground extraction techniques, although, water ponded in the open pits was relatively free of mining pollutants. Mines in the Feather River watershed (Plumas Copper Belt; Plate 4) exhibited the most anomalous drainage makeup. The main adit at Walker Mine had, at one time, discharged high volumes of low pH water to the N. F. Feather River watershed (Croyle, pers. comm.). The adit was plugged in 1986 and presently releases near neutral water containing moderate levels of copper originating from the raceway in front of the plug. Other metals were virtually absent in the drainage (Table IV-2). Adit outflows from the Lucky-S copper Mine tested slightly acidic and contained low to moderate levels of cadmium, copper, and zinc. Although the mineralogical surveys suggest otherwise (Table IV-1), the high acid and iron content typical of acid mine drainage waters was absent from Lucky-S outflows. Several reasons may explain these conditions including mineral morphology, residence time of the water, and the high elevation (6,800 feet MSL) in which low temperatures may preclude extensive mineral oxidation.

In the northern Sacramento Valley, adit releases from mines in the Shasta Mining District (map I.D. #s 44-58; Plates 7 and 8) exhibited quality conditions typical of classic acid mine drainage - low pH and high metals content (Table IV-2). Geological surveys for the area describe the presence of massive pyritic deposits that are easily degraded. High annual precipitation (40-80 inches/year) also contributes to the formation and discharge of strongly polluted water. The orebodies in the area were very mineralogically diverse as reflected in the wide range of compounds directly or indirectly mined including silver, arsenic, gold, copper, lead, and zinc. Most of these metals were also found in drainage which generally contained copper, iron, and zinc in the ppm range and lead, arsenic, and nickel in the tens of ppb. The low pH (2-4) and strong oxidizing conditions (Eh ca 500 mV; Table IV-2) keep the metals in solution. The largest discharging mines are located around Shasta Reservoir in the West Shasta Mining District and include the Iron Mt., Balaklala, Keystone, and Mammoth mine complexes.

Mines located in the western foothills were largely either chromite (Grau, Noble Electric, Grey Eagle) or mercury mines with little or no adit outflow (Table IV-1). Western foothill chromite mines were located in the rain shadow of Tehema and Glenn counties (Plate 9) and, although, the topography of the area is steep and mountainous, the absence of perennial drainage is likely due to limited rainfall. Further, ponded water in an open pit at Grey Eagle Mine tested neutral and was relatively free of metals, indicating unreactive mineralogy.

Inactive cinnabar (HgS) extraction mines are located in the Cache and Putah Creek watersheds (Table IV-1). Most of the western foothill mercury mines were dry with no perennial discharges. Adit drainage from a few mines (map I.D. #s 77, 85, 86, 87, 88) was characteristically high in iron, nickel, and carbonates (Table IV-2). Corona Mine discharged the highest volumes (2-3 l/s [ca 1/10 CFS]) of nickel-iron polluted water with the pH averaging around 5.7. The high nickel levels (measured up to 12 ppm) are explained by geological surveys reporting nickel sulfide (pentlandite or millerite) composing up to 5 percent of the surrounding orebody (CSMB, 1915). An extremely high carbonate concentration (300-600 mg/l Ca- and $MgCO_3$) buffers a solution that is calculated to have an acid content of around pH 2-3 in the absence of the carbonates. High iron levels measured in the waste stream confirm the acidity (assuming pyrite oxidation) and were spontaneously plating out as slightly ordered oxides ($HFeO_2$, FeO_3; Walker, pers. comm. from CDMG [Sacramento, CA] analysis; Chapman et al., 1983). The secondary minerals also contained other metals in high quantities such as tin and nickel, suggesting that if the water remained unaltered, soluble pollutants would become insoluble precipitates provided enough surface area was available for nucleation. Iron oxide formations were also observed at two mines located in the Sierra-Nevada range (Pick and Shovel and Spanish, upper adit). Other mercury mines in the area (e.g., Twin Peaks, Reed) exhibited similar drainage characteristics but with smaller outflows and lower constituent levels. Anderson Mine was anomalous in that the drainage was tested in a reducing state (Eh = -85 mV), although arsenic was undetectable or present at very low levels.

Silver was not found in any perennial drainage sampled (detection limit = <1 ppb). Other work shows mine water can contain silver in the pptr range but that 99 percent of it is sorbed to particulates and unfiltrable even in low pH waters (Jones, 1986).

B. Waste Rock Characteristics

Waste rock material excavated as a result of active mining operations is defined as either development waste or tailings (U.S.EPA, 1986). Mine development waste can include soils, overburden, or sub-grade ore removed to gain access to the more valuable ore. Tailings include the altered remains of ore after it undergoes physical and/or chemical treatment to extract the desired compound(s). One or both types were observed at almost every mine visited. In most cases, waste rock was removed from the site by dumping it into the nearest water course. It was apparent at these mines that high flows during the rainy season had eroded much of the material away into downstream waters, and only a fraction of the waste rock originally generated remained on-site.

The soil pH of waste rock material varied dramatically from site to site, ranging between 1.4 and 8.8 (Table IV-3), with no apparent large-scale geographical trends other than providing a representation of the diverse makeup of ore material in the Sacramento Valley. Soil pH is an instantaneous measure of acid at one point in time (Tucker et al., 1987). Further changes in pH occur from degradative weathering processes that generate more acid, make mineral bound carbonates available for buffering, or both. The test needed to determine potential acidity shifts is called net acid generation potential and is discussed below. Soil pH indicates the relative ease with which metals can migrate through, or off, a waste rock pile. Available metals are more mobile when dissolved in an acidified solution, and so, soil pH can be an important factor in determining the relative water quality threat of similarly sized waste rock piles. To determine site variability, replicate samples were collected from 10 mines and individually analyzed. With the exception of two mines, the intra-mine site variability (coefficient of variation) of pH was low, ranging from 1 to 13 percent (Table IV-4). Although 2-3 replicates hardly represent the total variability expected at a site, the method of collection attempted to obtain the most visually disparate material based on color, composition, and proximity to processing equipment. The variability is due completely to site conditions since laboratory replicates showed perfect precision (Appendix A). Waste rock material exhibiting a relatively homogenous acid content may indicate that acid is de-localized from source material and distributed throughout the pile during periods of saturation. It can also simply mean that the waste rock composition itself is homogenous with respect to pH influencing material. Sixteen of 52 samples tested at pH 4 or less which is considered the dividing line for defining a waste as "acid-toxic" (Sobek et al., 1978). From a recieving water standpoint, other factors such as slope, water contact, metals content, etc., may be more important in causing impacts, and therefore, soil pH is one of many factors used to assess what problems may result from any particular waste rock material.

Mercury levels were highest at western foothill mercury mines. It was difficult to determine the age of particular waste material but the highest levels between the mercury mines tested (0.2-140 g/kg, dw; Table IV-3) may be reflective of older operations (mid-1800s) that were less efficient at extracting mercury from the cinnabar ore. Calcine, the leftover ore after heat extraction, was collected at most of the mines as part of this study and had some of the highest levels of mercury. Pipe furnace and retort equipment used to extract mercury were apparently very inefficient - at one site, free mercury was found in the calcine tailings. There were no other strong geographic trends with any of the other metals which were highly variable between mine sites (up to 4 orders of magnitude for copper). The intra-site variability of waste rock metals content was also high, averaging around 50-70 percent and ranging up to 141 percent (Table IV-4). Inter- and intra-mine site variability would make runoff loading predictions very difficult. Regardless, the high metals content of most waste rock material indicates that site runoff can pose a substantial water quality threat.

The net acid generation potential (NAGP) of seven representative samples ranged from -48 to 11 tons of calcium carbonate needed to neutralize 1000 tons of material (the amount of material in an approximate acre-foot [Sobek et al., 1978];Table IV-5). Positive values indicate a tendency for acid to be formed beyond what inherent buffering compounds could neutralize. The test measures the full potential of a material to produce or neutralize acid from the products of leachable minerals. A digestion step releases alkaline compounds, mimicking the weathering conditions that exposed soils may experience over time. A soil pH below 6 is generally thought to indicate an acid generating material (Sobek et al., 1978). This held true for the samples tested in Table IV-5, however, soils with pH values above 6 are not good indicators of positive or negative NAGP measurements. This was apparent at Engle/Superior and Grey Eagle mines with measured pH values of 7.0 and 7.1 respectively corresponding to NAGP values of 4.8 (acid generating) and -48 (strongly alkaline). The low potential for Grey Eagle (-48) is expected from western foothill soils typically high in calcareous minerals. There was a complete lack of correlation between NAGP and pH due to the present unavailability of influencing compounds under normal saturating conditions. Further, the test may not be completely accurate in predicting pH shifts which also likely contributes to the lack of correlation. Soils with a pH below 6 may be good indicators of positive NAGP, although, positive potential was not limited to low pH soils. Material with a value of 5.0 or greater is defined as "potentially toxic material" (Sobek et al., 1978), but as with pH values, NAGP is only one factor in the overall assessment of waste rock material.

Table IV-3. WASTE ROCK CHARACTERISTICS OF SACRAMENTO VALLEY MINES.

WATERSHED	MAP I.D. #	MINE	pH 1/	TOTAL CONCENTRATION (MG/KG, DRY WEIGHT) 2/ ARSENIC	CADMIUM	CHROMIUM	COPPER	LEAD	MERCURY	ZINC	NICKEL	SILVER
Folsom Lake	2	Big Buzzard	3.5	4.6	0.8	6.4	210	270	1.4	86	ND	4.7
Bear River	9	Valley View	2.7	41	246	14	390	189	1.24	480	7.6	9
	10	Dairy Farm	1.9	91	2	17.9	1,350	370	3.8	455	12.5	14.5
	11	Spenceville	3.0	40	1.23	15.2	277	152	1.26	148	4.1	23.5
	13	Idaho Maryland	7.4									
	14	Lava Cap 3/	7.2	3,600	1.6	99	140	100	1.6	230	84	16
Yuba River	17	Malakoff Diggin's	4.5	1.7	ND	50	15	6	0.28	9.4	7	ND
	18	Spanish	5.1	340	ND	7.6	56	330	4.4	130	29	7
	20	Kenton	7.3									
	24	Plumbago	7.9						1.8			
Feather River	33	Iron Dyke	3.4	5	1.2	80	1,600	63	1.9	270	30	29
	34	Walker (tailings)	4.8	9	ND	2.3	790	70	0.15	44	ND	5.9
	34	Walker (mine)	4.1	20	ND	15	2,000	43	1.6	96	8	16
	35	Reward #7	7.4						4.8			
	36	Beardsley	4.4	55	2.4	2.8	16,000	2,700	3.4	240	3.4	2.1
	37	Lucky S	2.7	1200	4.2	21	640	4,300	3.2	890	24	39
	38	Superior/Engle	7.0	105	ND	13	6,550	50	0.95	165	13	15.8
	39	Mountain Meadows	8.0									
Pit River	40	Golden Eagle	7.8									
Shasta Lake	41	Coggins	7.0									
	43	Forest Queen	6.5	7.5	ND	2500	21	9	0.47	37	1,600	ND
	44	Bully Hill	3.6	690	24	14	3,005	1,620	19.3	2,975	5.2	7.5
	45	Rising Star	2.8	625	29	3.8	1,350	105	16	3,500	ND	4.7
	52	Golinsky	6.3									
Sacramento R., upper	54	Gladstone	5.1	800	ND	38	170	76	0.73	140	45	1.4
	55	Afterthought	4.7	500	17	7.8	1,090	4,000	17.2	4,300	5.6	28
	56	Thompson	3.9	11	2	20	940	13	5	260	4.2	3.3
	57	Iron Mt loadng area	1.4	180	4.3	16	480	76	4	580	7.4	0.7
	58	Greenhorn	3.8	140	ND	24	520	30	0.38	120	12	2.2
	60	Yankee John	7.3									
	62	Silver Falls	6.7									
	63	Midas	8.0									
	64	Round Bottom	7.6									
Stony Crk./Elder Crk	65	Grau	8.8									
	66	Noble Electric	8.7	2.8	ND	400	7.6	5.3	0.37	40	2,400	ND
	67	Grey Eagle	7.1									
	71	Empire (sulphur cr)	7.2						17			
Cache Creek	72	Manzanita	3.6	25	ND	54	40	4.1	785	21	22	1
	74	Wide Awake	7.9						13			
	75	Abbott	7.9						910			
	77	Reed	3.8	38	ND	440	52	9.3	19	50	870	ND
Lake Berryessa, Putah	79	Knoxville	7.9						4/			
	81	Red Elephant	7.3						240			
	83	Big Chief	2.5	16	15	23	22	19	840	94	10	0.7
	86	Great Western	7.6									
Lake Berryessa, Pope	87	Corona	2.6	4.7	ND	175	17	21.5	1,370	35.5	350	0.4
	88	Twin Peaks	2.6	ND	2.3	240	53	13	21	28	500	ND
	89	Oat Hill	5.8						590			
	90	Aetna Extension	7.6						6.8			
	92	Aetna	4.5	7	ND	23	36	24	620	56	27	ND
	93	Grenada	7.9									
	94	Toyon	8.2						86			

1/ Paste method.
2/ Samples prepared according to U.S.EPA, 1979.
3/ Complete dissolution with HCl before analysis.
4/ 14%.

Table IV-4. VARIABILITY OF WASTE ROCK METALS CONCENTRATIONS AT SEVERAL MINES.

MINE		TOTAL CONCENTRATION (MG/KG, DRY WEIGHT)									
		pH	ARSENIC	CADMIUM	CHROMIUM	COPPER	LEAD	MERCURY	NICKEL	SILVER	ZINC
Valley View		2.4	16	736	23	660	340	0.77	4.6	10	860
		3.7	22	ND	10	150	68	0.74	5.2	2.1	79
		1.9	85	2.4	8.6	360	160	2.2	13	15	500
	AVERAGE	2.7	41	246	14	390	189	1.24	7.6	9.0	480
	COV	28	76	141	47	54	60	55	50	59	67
Dairy Farm		1.8	42	1.2	3.8	1300	440	3.8	9	19	200
		2	140	2.8	32	1400	300	3.7	16	10	710
	AVERAGE	1.90	91	2.00	17.9	1350	370	3.8	12.5	15	455
	COV	5	54	40	79	4	19	1	28	31	56
Spenceville		3.1	6	0.8	16	270	76	1.8	6.1	6.4	120
		2.6	88	0.7	2.7	110	230	0.59	ND	51	43
		3.2	26	2.2	27	450	150	1.4	6.2	13	280
	AVERAGE	2.97	40	1.23	15	277	152	1.26	4.10	23	148
	COV	9	87	56	65	50	41	40	71	84	67
Afterthought		4.4	500	16	7.3	1300	4900	25	4.8	38	4000
		5	500	18	8.2	880	3100	9.4	6.3	18	4600
	AVERAGE	4.70	500	17	7.75	1090	4000	17	5.55	28	4300
	COV	6	0	6	6	19	23	45	14	36	7
Oat Hill		7.7						880			
		3.8						300			
	AVERAGE	5.75						590			
	COV	34						49			
Big Buzzard		3.8									
		3.1									
	AVERAGE	3.45									
	COV	10									
Bully Hill		3.5	1200	22	12	960	2600	34	3.1	1	2000
		3.6	180	26	16	5050	640	4.5	7.3	14	3950
	AVERAGE	3.55	690	24	14	3005	1620	19	5.2	7.5	2975
	COV	1	74	8	14	68	60	77	40	87	33
Corona		2.8	4.4	ND	200	14	16	940	480	0.8	26
		2.3	4.9	ND	150	20	27	1800	220	ND	45
	AVERAGE	2.55	4.65	0.00	175	17	22	1370	350	0.40	36
	COV	10	5		14	18	26	31	37	100	27
Manzanita		4	ND	ND	68	45	ND	270	20	ND	26
		3.1	50	ND	40	35	8.2	1300	24	2	16
	AVERAGE	3.55	25	0.00	54	40	4.10	785	22	1.00	21
	COV	13	100		26	13	100	66	9	100	24
Engle		7.9	10	ND	14	1100	ND	0.29	10	1.8	120
		6.1	200	ND	11	12000	100	1.6	16	14	210
	AVERAGE	7.00	105	0.00	13	6550	50	0.95	13	7.90	165
	COV	13	90		12	83	100	69	23	77	27

Table IV-5. NET ACID GENERATION POTENTIAL OF WASTE ROCK FROM SEVERAL MINES.

MINE SITE	SOIL pH (PASTE)	NEUTRALIZATION POTENTIAL 1/	ACID GENERATION POTENTIAL 2/	NET ACID GENERATION POTENTIAL 1/
Iron Mt. Mine, loading area	1.4	-3.8	6.5	10
Big Chief	2.5	-4.1	6.5	11
Corona	2.6	-2.6	3.5	6.1
Valley View	2.7	-1.6	5.5	7.1
Afterthought	4.7	-4.9	6.5	11
Engle/Superior	7.0	4.2	9	4.8
Grey Eagle	7.1	49	1.5	-48

1/ As tons CaCO3 equivalent per 1000 tons of material.
2/ As tons CaCO3 equivalent to neutralize the acid formed by 1000 tons of material.

V. MASS LOADS

Loads were calculated for Sacramento Valley mines with perennial discharges using flow and concentration measurements taken largely between 1987 and 1992. The loads are somewhat comparable between sites because of the continued drought conditions during that period. For smaller discharging mines, loads were calculated with data collected primarily during this survey. Estimates for West Shasta District mines were made using 1989-92 data. Further, with the exception of Iron Mt. Mine, the loads represent a mass per time statistic during dry periods. Because of the strong correlation between loading and precipitation, the numbers presented here are considered to be underestimates. Actual loads would be higher with the inclusion of waste rock runoff/seepage contributions and an accounting for normal or extreme rainy seasons. Detailed load calculation methods are presented in Appendix A.

Iron Mountain Mine (IMM) was the single largest loader of mine drainage pollutants to the Sacramento Valley. Loads from IMM were calculated using weekly Spring Creek Debris Dam (SCDD) metals and outflow data collected by U.S. Bureau of Reclamation and regional board (Redding office) staff and are considered to be accurate (Heiman, pers. comm.). The SCDD collects and discharges water from the entire Spring Creek watershed including adit releases, waste rock erosion and seepage, and background stream flow. Between 57 and 85 percent of the estimated copper, cadmium, and zinc loads came from this source (Table V-1). Overall, 67 percent of the standard equivalent loads came from SCDD indicating that, with respect to freshwater metal objectives, it is the largest inactive mine source of the most toxic metals detected. Stowell Mine also drains to this watershed but contributes only about 1 percent to total SCDD loading (Heiman, pers. comm.). A certain amount of the loads from SCDD are intercepted at a small Sacramento River reservoir (Keswick) and settle out, never fully making it down the river under normal flow conditions.

Leaching processes within SCDD are likely facilitating the release of metals from waste rock alluvium. The low pH and exposed nature of the reservoir should provide ideal habitat for acidophilic bacteria to break down sulfide and metal containing minerals flushed into the reservoir during the rainy season. Other investigators have shown increased leaching when similar conditions existed in underground workings. Further, SCDD water exhibits an elevated oxidizing potential with Eh measurements averaging around 500 mV. Under these conditions waste rock material is continuously exposed to breakdown forces that are greater than what is found in natural stream waters. The high conductivity of the water allows greater electrical transference which enhances oxidation processes (similar to the way rusting activity increases in coastal environments because of salty air). As waste rock degrades, metals held within the mineral matrix are released and solubilized in water acidified from sulfide oxidation. Even though conditions in SCDD probably enhance the release of metals, mass balance estimates show that about 15 percent of the incoming metal loads are retained in the reservoir. As might be expected, most of the metals leaving the reservoir are dissolved in the water.

Mines in the Little Backbone Creek watershed contributed about 22 percent of the standard equivalent loads, second only to IMM (Table V-1). Mammoth, Golinsky, and Sutro mines drain to this creek which flows into Shasta Reservoir. Shoemaker Gulch drains the southern end of the Mammoth Mine complex and also flows to Shasta Reservoir. Load calculations were made by averaging instream loads measured below the mine complex and the sum of all individually measured discharges (see Appendix A). Although the two methods should intuitively produce similar loading values, this was not the case because of unquantified banking processes going on in the watershed. During dry periods, polluted mine drainage sometimes never fully arrives downstream, leading to a certain amount of build-up in the watershed which is subsequently flushed out under high flow conditions (Heiman, pers. comm.). Further, there may be subsurface flow in the shallow weathered bedrock (Walker, pers. comm.) that would not be visible as it enters the lake. The movement of mine pollution with ground water has been documented at Penn Mine (Bond, pers. comm.). Regardless of the mechanisms, the phenomenon is also observed in the West Squaw Creek watershed draining Balaklala, Keystone, Early Bird, and Shasta King mines (Heiman, pers. comm.). West Squaw Creek also enters Shasta Lake and contributed about 7 percent of the standard equivalent loads (Table V-1) with calculation methods identical to those used for Little Backbone Creek. With respect to copper, cadmium, and zinc, the 3 aforementioned sources located in the West Shasta District discharged loads that were significantly higher than other Valley mines (Figure V-1). The relative magnitude of other, smaller, acid mine sources depends on the pollutant of concern.

With the exception of IMM, the loads in Table V-1 are underestimates because they did not account for discharge increases expected during the wet season. Short duration adit surges result from rainfall or snow-melt moving into tunnel complexes through porous/fractured overburdens, vertical air shafts, and caved stopes (CH2MHill, 1984; Croyle, pers. comm.). Evidence of adit surges can be seen in Table C-2 where Balaklala Mine outflows were measured at 589 l/s during January 1983 from an average dry period flow of about 1-30 l/s. Rainfall runoff from waste rock also contributes to seasonal loading surges but is difficult to accurately characterize. A pilot study was conducted at Spenceville Mine to measure various parameters of rainfall runoff. By extrapolating measurements taken during a single storm event, surface runoff was estimated to account for approximately 5-18 percent of the total annual loads coming from this site (wet + dry season). The study results and loading methods are detailed in Appendix B. Most rainfall infiltrates into permeable waste rock material and seeps out later near the streambed low-point. Seepage water can strip pollutants from waste rock to a greater degree than surface runoff because of a longer residence time. Therefore, measuring surface runoff would not account for the total load increases induced by rainfall. Regardless, the relative pollutants contribution caused by precipitation at an individual site would depend on the magnitude of any existing perennial discharge and, thus, would affect cleanup priorities. For mines with no perennial releases, wet season discharges would represent 100 percent of the total loads

Table V-1. LOADING ESTIMATES FROM INACTIVE MINES WITH PERENNIAL DISCHARGES DURING A DROUGHT PERIOD, 1987-91.

MINE SITE DISCHARGE	TOTAL ANNUAL LOADS IN KILOGRAMS (PERCENT OF TOTAL IN PARENTHESES) (NA=NOT AVAILABLE; ND=NOT DETECTED) 8/							STANDARD EQUIVALENT LOADS 1/
	ARSENIC	CADMIUM	CHROMIUM	COPPER	NICKEL	ZINC	LEAD	IRON	
SCDD 4/	858 (50)	1,529 (85)	214 (74)	36,300 (57)	234 (18)	209,352 (80)	390 (69)	NA	378,162 (67)(60)
Little Backbone Crk. & Shoemaker Gulch mines 6/	59 (3.4)	186 (10)	15 (5.21)	18,961 (30)	32 (2.51)	36,760 (14)	81 (14)	NA	123,559 (22)(20)
West Squaw Crk. mines 5/	ND (0.00)	38 (2.1)	ND (0.00)	6,928 (11)	ND (0.00)	7,537 (2.9)	ND (0.00)	NA	39,674 (7)(6)
SRCSD (1985) 3/	ND	60	1,676	2,863	1,573	15,340	359	ND	34,872 (6)
Afterthought 2/	0.7 (0.04)	12 (0.66)	0.06 (0.02)	488 (0.76)	0.88 (0.07)	3,008 (1.15)	2.5 (0.45)	2,873	4,640 (0.8)(0.7)
Rising Star	73 (4.2)	12 (0.66)	0.25 (0.09)	260 (0.41)	0.60 (0.05)	2,603 (1.00)	3.8 (0.68)	5,311	3,800 (0.7)(0.6)
Valley View	0.26 (0.02)	19 (1.1)	0.59 (0.20)	428 (0.67)	2.3 (0.18)	850 (0.33)	0.14 (0.02)	2,290	3,469 (0.6)(0.5)
Kanaka Creek mines	474 (28)	NA (0.00)	24 (8.3)	NA (0.00)	ND (0.00)	NA (0.00)	ND (0.00)	ND	3,013 (0.5)(0.5)
Spanish (upper+lower)	1.7 (0.10)	0.66 (0.037)	0.06 (0.02)	61 (0.09)	10.4 (0.82)	191 (0.07)	83 (15)	334	2,461 (0.4)(0.4)
Brush Creek	200 (12)	ND (0.00)	3.6 (1.24)	1.3 (0.002)	52 (4.12)	ND (0.00)	ND (0.00)	NA	1,294 (0.2)(0.2)
Bully Hill	ND (0.00)	7 (0.37)	NA (0.00)	135 (0.21)	1.4 (0.11)	359 (0.14)	0.8 (0.15)	288	1,192 (0.2)(0.2)
Spenceville	0.67 (0.04)	0.09 (0.005)	ND (0.00)	175 (0.27)	ND (0.00)	144 (0.06)	ND (0.00)	452	942 (0.2)(0.1)
Greenhorn	0.3 (0.01)	1 (0.05)	0.01 (0.003)	122 (0.19)	0.2 (0.01)	232 (0.09)	0.04 (0.01)	1,326	765 (0.1)(0.1)
Corona	0.02 (0.001)	ND (0.00)	4.0 (1.38)	ND (0.00)	875 (69)	18 (0.01)	ND (0.00)	73,384	326 (0.1)(0.1)
Plumbago	27 (1.6)	ND (0.00)	0.23 (0.08)	0.21 (0.00)	1.6 (0.12)	ND (0.00)	ND (0.00)	6.7	174 (0.03)(0.03)
Malakoff Diggings	3.1 (0.18)	ND (0.00)	24 (8.2)	14 (0.02)	30 (2.39)	28 (0.01)	ND (0.00)	1,037	122 (0.02)(0.02)
Empire	13 (0.73)	ND (0.00)	ND (0.00)	ND (0.00)	ND (0.00)	2.9 (0.00)	ND (0.00)	1,204	81 (0.01)(0.01)
Lucky S	ND (0.00)	0.31 (0.02)	ND (0.00)	8.2 (0.01)	ND (0.00)	34 (0.01)	ND (0.00)	2,870	73 (0.01)(0.01)
Lava Cap	10 (0.61)	0.04 (0.002)	ND (0.00)	0.37 (0.001)	ND (0.00)	3.4 (0.00)	ND (0.00)	30	72 (0.01)(0.01)
Columbo	0.77 (0.04)	ND (0.00)	2.4 (0.83)	ND (0.00)	ND (0.00)	ND (0.00)	0.93 (0.17)	ND	28 (0.005)(0.00)
Walker	ND (0.00)	0.002 (0.00)	ND (0.00)	4 (0.01)	ND (0.00)	0.18 (0.00)	ND (0.00)	NA	21 (0.004)(0.00)
Iron Dyke(Taylors Cr)	ND (0.00)	0.032 (0.002)	ND (0.00)	1.3 (0.002)	ND (0.00)	1.1 (0.00)	ND (0.00)	NA	9 (0.002)(0.00)
Twin Peaks	ND (0.00)	0.001 (0.000)	0.04 (0.01)	ND (0.00)	14 (1.09)	0.22 (0.00)	ND (0.00)	115	5 (0.001)(0.00)
Pick & Shovel	0.11 (0.006)	ND (0.00)	0.05 (0.02)	ND (0.00)	9.5 (0.75)	0.98 (0.00)	ND (0.00)	2.1	5 (0.001)(0.00)
Reed	0.30 (0.02)	ND (0.00)	0.23 (0.08)	ND (0.00)	6.1 (0.48)	0.10 (0.00)	ND (0.00)	NA	4 (0.001)(0.00)
Anderson Springs	0.16 (0.01)	ND (0.00)	0.02 (0.01)	0.27 (0.00)	1.9 (0.15)	1.8 (0.00)	ND (0.00)	73	4 (0.001)(0.00)
Champion	ND (0.00)	0.05 (0.003)	ND (0.00)	0.07 (0.00)	ND (0.00)	0.78 (0.00)	ND (0.00)	NA	3 (0.001)(0.00)
Great Western	ND (0.00)	ND (0.00)	0.04 (0.01)	0.01 (0.00)	0.36 (0.03)	0.16 (0.00)	ND (0.00)	8.3	0.3 (0.000)(0.00)
Turkey Run	ND (0.00)	ND (0.00)	0.02 (0.01)	ND (0.00)	ND (0.00)	ND (0.00)	ND (0.00)	NA	0.00 (0.000)(0.00)
TOTAL LOADS 7/	1,722	1,805	288	63,889	1,273	261,128	562	91,602	563,900

1/ The sum of [(average concentration(i)*average flow(i))/Inland Surface Water Plan Objectives(i)] for each metal excluding iron. Hardness = 50 mg/l.
2/ Loads were calculated using data from 1984.
3/ Sacramento Regional County Sanitation District wastewater treatement plant loads, 1985.
4/ SCDD = Spring Creek Debris Dam release. The SCDD watershed drains Iron Mt. and Stowell Mines.
5/ The sum of the loads coming from Balaklala, Keystone, Early Bird, and Shasta King mines.
6/ The sum of the loads coming from Mammoth, Golinsky, and Sutro Mines.
7/ Excludes SRCSD loads.
8/ Loading values do not exclude uncertain digits.

AMENDED: 3/29/93

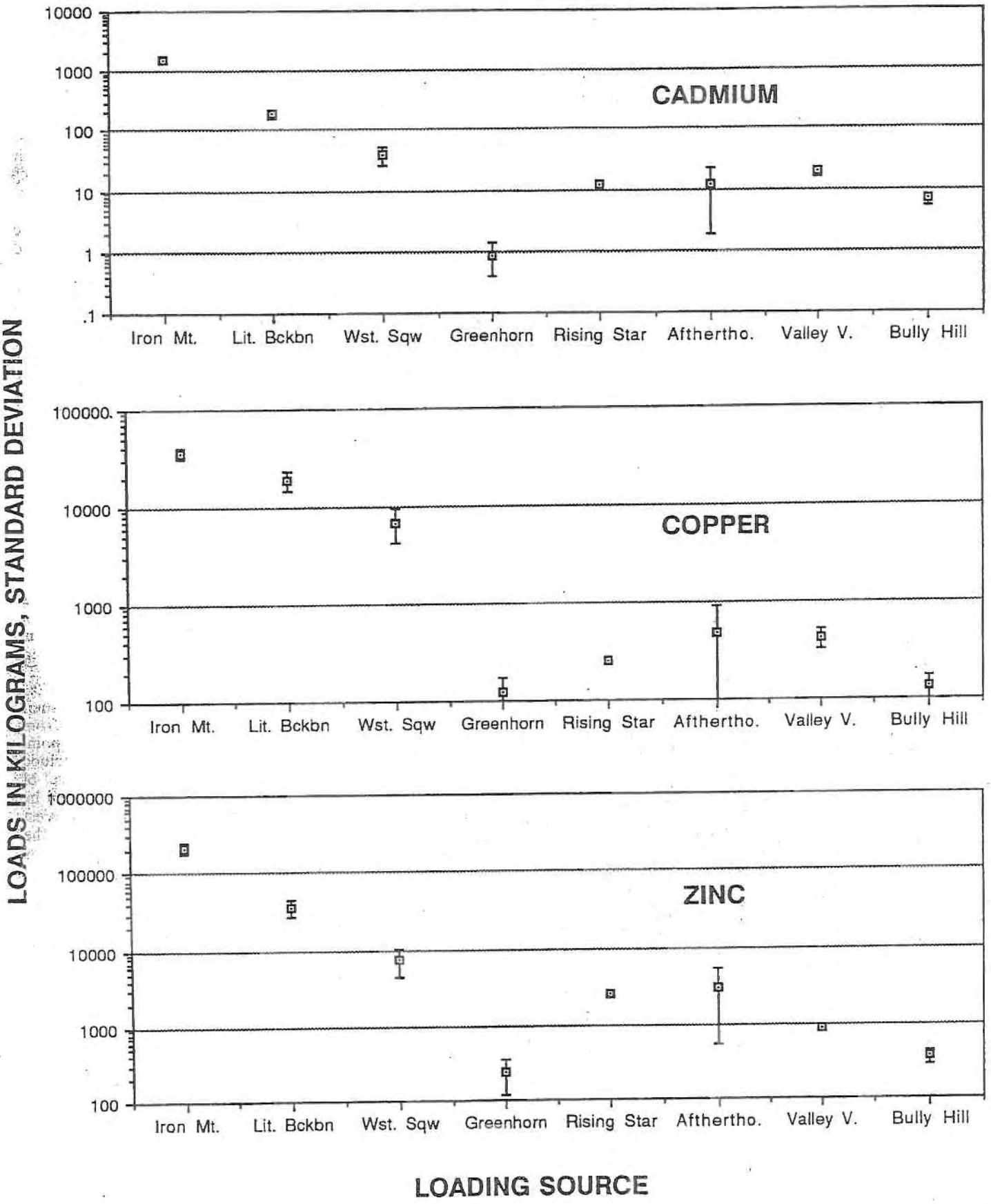

Figure V-1. VARIABILITY OF COPPER, CADMIUM, AND ZINC LOADING ESTIMATES.

coming from that site. At other mines, waste rock runoff is not as significant as adit releases - e.g., West Shasta District mines (Heiman, pers. comm.). The load estimates presented in Table V-1 largely do not account for these and other rainy season surges. It would be difficult to predict waste rock runoff loads because of the number of parameters involved including surface area, permeability, metals content, slope, rainfall characteristics, etc.

The present drought conditions also skew the load estimates in Table V-1 to the low end. Past estimates for SCDD show zinc loads have varied from 1.5 to 4 times the 209 thousand kg estimate (ca 45-52 inches precipitation in 1989-90) in Table V-1 for a normal rainfall year (ca 60 inches in 1984) and an extremely wet year (ca 115 inches in 1983), respectively (Heiman, unpub. data). Extrapolating these load increases to other mines and metals to account for the effect of varying annual precipitation may not be inappropriate.

Loads from the Sacramento Regional County Sanitation District (SRCSD) wastewater/sewage treatment plant were included for comparison. It ranked fourth in standard equivalent loads (ca 6 %) due, in part, to high lead discharges and made up about 3-6 percent of the combined copper, cadmium, and zinc loads.

Almost all of the mining regions are drained by watersheds intercepted with one or more major reservoir which have the potential to retain a certain fraction of the pollutants coming in from upstream. Pollutants attached to heavy particulate matter in feeder streams can settle out and become part of the sediment. The mass balance of pollutants through a reservoir is little understood but is important because dam releases have a substantial influence on the quality of downstream waters. To better define this transport component, the mass balance of copper into, and out of, Shasta Reservoir was estimated using data collected during the current drought period. The major inputs to the lake included 3 mine influenced streams (Shoemaker Gulch, West Squaw and Little Backbone Creeks) and four of the largest stream inputs without mine impacts (Big Backbone, Pit, McCloud, and Sacramento Rivers). The volumes and loads were used to calculate the concentration of copper expected in the dam releases, simulating the reservoir as a large mixing bowl where multiple inputs of differing quality are mixed to produce a final concentration with no physico-chemical interactions. The loading inputs were made largely for 1989 and compared to the copper concentration actually measured in release water between 1988 and 1991. The calculated copper concentration of Shasta Dam release water (5.74 ug/l) was higher than the average annual concentration reported by other studies (2.4 to 4.2 ug/l; Figure V-2 - details of the graph are presented in Table G-1). The 5.74 value was calculated with data collected largely during 1989 and is more comparable to the 4.2 ug/l copper average taken from fiscal year 1988-89 dam release data (from Heiman, 1989). The 2.4 ug/l value was averaged from fiscal year 1990-91 data. No statistical significance could be discerned because the calculated concentration was estimated using only 2 available measurements, causing the confidence interval to widen to useless proportions even though the relative standard deviation was rather low. Conversely, the actual copper concentration of Shasta Reservoir releases statistically declined by almost half over a 2 year period (Figure V-2). This decline may have resulted from drought induced loading reductions which are strongly correlated to annual precipitation (Heiman, unpub. data). Further, when feeder stream loads were changed to simulate no mine drainage input, the calculated copper concentration of 0.27 ug/l simply reflected upstream river quality (upper Sacramento [0.270 ug/l]; Pit [0.240 ug/l]; and McCloud Rivers [0.245 ug/l]; from Connor, unpub., Table H-1). Dam release water is not expected to exactly mimic upstream inputs if their quality represents unaffected background water. Reservoir water can pick up elements present in natural sediments from dissolution and physical resuspention. Other factors that can affect release quality include rainy season surges, draw point elevation, phased time differences of inputs and outputs, concentration differences, etc. All of these combined preclude the value of specifying a mass balance statistic based on this data. Regardless, Shasta Dam releases contain a level of copper that is approximately an order of magnitude greater than what is present in the incoming streams unaffected by mine drainage. This difference is probably influenced, to some extent, by mine drainage from Little Backbone and West Squaw creeks. It is expected that once the low pH streams reach the lake, a quick rise in pH to neutral would cause the metals to deposit to the lake bed, leaving only a small fraction in solution. What may be occurring is a continuous suspension of lighter floc and other particulates caused by wave action. Preliminary data on the lower Sacramento River shows an increasing metals gradient with depth, likely related to low density particulates and colloids travelling near the river bottom. Although there is more suspension energy in a river, there may be a related explanation that describes solids transport in a lake system. Work presently being conducted at Camanche Reservoir will help to understand how hydroxides (initially formed at the stream-lake confluence) and other particulate-bound metals are suspended or re-suspended and carried through reservoir bodies (Bond, pers. comm.).

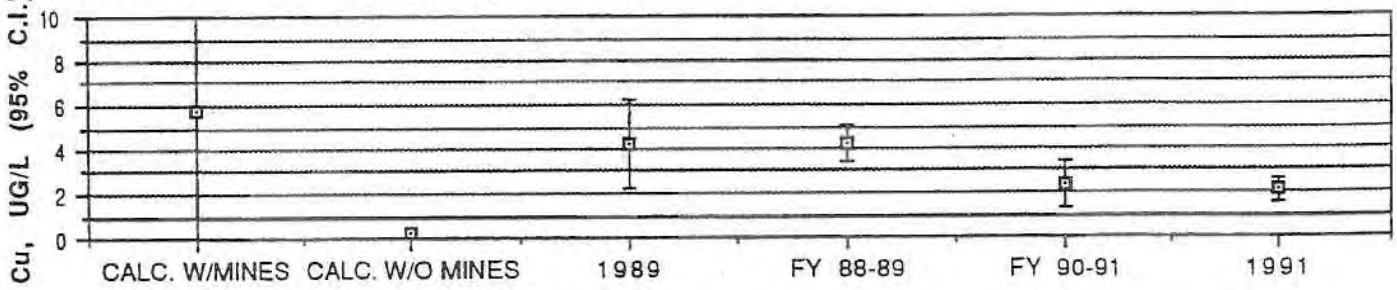

Figure V-2. COPPER CONCENTRATIONS IN SHASTA DAM RELEASE WATER. "CALC. W/MINES" = CONCENTRATION CALCULATED FROM STREAM AND MINE INPUTS; "CALC. W/O MINES" = CONCENTRATON CALCULATED FROM JUST STREAM INPUTS (N=2). ACTUAL CONCENTRATIONS MEASURED IN DAM RELEASE WATER WERE IDENTIFIED BY THE TIME PERIOD IN WHICH DATA WAS COLLECTED (N = 7 TO 22 PER TIME PERIOD). SEE TABLE G-1 FOR MORE SPECIFIC INFORMATION.

VI. RECEIVING WATERS

An assessment was made of the water quality impacts caused by inactive mines. Metals were analyzed in mine site receiving waters and compared to Inland Surface Water Plan (ISWP) objectives adopted to protect both human health and freshwater aquatic biota (SWRCB, 1991). Heavy metal objectives taken from the ISWP are EPA's hardness factored chronic criteria for freshwater biota. The 5.0 ppb arsenic level for human consumption was more conservative. A calcium carbonate concentration of 50 mg/l was used when site-specific hardness levels were unavailable. Most stream samples were collected during dry weather conditions at a distance below the mine where drainage was sufficiently mixed. Multiple sample concentrations were averaged and presented in Table VI-1. To indicate which compounds exceeded the objectives and the relative magnitude, the concentration/objective ratio is shown in parentheses to the right of the average.

Twenty-one of 31 receiving streams monitored were impacted by one or more metals exceeding ISWP objectives. In general, the copper objective was most frequently exceeded followed by zinc and cadmium. Ten streams showed exceedances for lead, nickel, and arsenic and none were measured for chromium or silver. Extremely high levels (100-1,500 times the objectives) were measured in streams with low dilution and minimal buffering capacity.

Impact length was not defined at all mine sites but can be inferred from stream flow and mine loading data. Where acid loading is large enough to overwhelm the buffering capacity of a stream, metals and other pollutants remain in solution. At watersheds in the Shasta Mining District, these conditions result in impacts that extend the length of the stream from the mine site (e.g., West Squaw and Little Backbone Creeks). Impact length at mine sites with atypical drainage characteristics (low- or non-acidic) is not as strongly controlled by pH. Other factors such as metal-specific behavior and the presence or absence of complexing agents appeared to determine how far a pollutant traveled downstream. For instance, nickel in drainage from Corona mine decreased in James Creek from 5 ppm, directly below the mine, to 3 ppm approximately 1.5 miles downstream. The decrease was largely due to dilution from two other stream inputs as the prevalence of iron hydroxides coating the streambed indicated that no significant co-precipitation or adsorption was occurring. Further, natural streams with unnaturally high metals levels loose the ability for sorption when all the available binding sites are filled (Chapman et al., 1983). Arsenic from mines in the Yuba River watershed (Allegheny-Downieville area) was also freely transported in receiving streams. The highest stream concentrations were recorded in Woodruff Creek (up to 30 ug/l) as a result of Brush Creek Mine drainage. Based on average flows for June, the mine was estimated to contribute about 0.3 ppb to the N.F. Yuba River concentration (Table VI-2). The increasing arsenic concentration from Downieville (1.3 ug/l) to Highway 49 (1.6 ug/l) appears to have been largely caused by Brush Creek Mine. Precision analyses (Appendix A) accounted for only a maximum possible increase of 0.2 ug/l due to indeterminant error. Arsenic is easily transported in streams not affected by acid mine drainage because it is present largely in the dissolved phase (50-90 %; Johnson and Thornton, 1987). Arsenic is endemic to this region as exhibited by it's presence in all feeder streams monitored (Table VI-2 and Table E-1) and by the mineralogical surveys conducted in the area showing the extensive presence of arsenopyrite (Carlson and Clark, 1956). Although the watershed makes a substantial contribution to overall Delta arsenic loading, concentrations in the Yuba River were below the drinking water objective (5.0 ug/l).

The Sacramento River periodically experiences objective exceedances (for copper, cadmium, and zinc) both below IMM at Keswick Reservoir and 250 miles downstream at Freeport. Objective exceedances at Freeport may be more frequent than originally thought when accounting for depth related concentration increases. There are a multitude of other inputs to the River along it's length including agriculture and urban runoff, but mine drainage has been previously shown to contribute the bulk of the copper, cadmium, and zinc loads (CVRWQCB, 1988). The Sacramento River has incurred the greatest impact from an incremental increase in metals discharged from the sum of all inactive mines around the Valley.

Stream impacts from mines with smaller discharges usually diminished quickly with distance from the site. A variety of plating and precipitation processes are probably responsible for declines that cannot be explained by dilution alone. For instance, at the Pick and Shovel Mine, low level nickel discharges (59 ppb) decreased to non-detectable about one mile below the mine. Similarly, copper levels decreased from 80 ppb to below detection (<1 ppb) over a 2 mile stretch of Devils Canyon Creek (from upper Spanish Mine adit), whereas the flow only increased by 4 times (Table C-1). Therefore, stream impact length can depend on a variety of factors including the specific behavior of the metal or metalloid, dilution capacity of the stream, mine loads, and the presence (or absence) of complexing agents.

Receiving water concentration surges are expected during wet periods from instream resuspension and increased mine site discharges. Metals deposited in the streambed during low-flow periods are scoured and transported downstream during high flows, freeing up new binding and deposition sites. Further, rainfall and snow-melt are known to flush out tunnel precipitates, resulting in immediate adit surges (CH2M Hill, 1986; Croyle, pers. com.). One lesser understood wet weather contribution is rainfall runoff from waste rock piles. To assess the severity of this discharge, Dry Creek was monitored above and below Spenceville Mine during a 3 inch rainfall event. The potential for impact was great because the waste rock material was highly enriched with several metals. Dry Creek copper levels below the mine ranged between 23 and 120 ppb and exceeded the 1-hour, hardness factored, copper objective (15 ppb) by up to 8 times for a 10-hour period (see Appendix B). The copper concentration in Dry Creek upstream the mine remained just above the detection limit (d.l. = <1 ppb) throughout the storm. Although the stream reached an extremely high flood stage condition during the storm, it was not enough to completely dilute copper discharges coming from the mine site which averaged around 3 ppm. Mine runoff also resulted in a 4 fold increase in the total suspended solids content over upstream levels (6.5-25 mg/l upstream and 25-114 mg/l below the mine; see Appendix B). Typically, an increase in suspended solids would indicate a greater capacity for the water to complex free metal ions. However, most waste rock particulate matter is already saturated with metals and is immediately stripped of the easily leachable fraction upon entering the stream (Brugam et al., 1988). Pollutants discharged under flood stage conditions are transported far downstream into tributary waters carried by high energy, fast

Table VI-1. AVERAGE METALS CONCENTRATIONS IN RECEIVING WATERS ABOVE AND BELOW SACRAMENTO VALLEY MINES (FROM APPENDIX C).

MINE	WATERBODY	LOCATION	CaCO3 (MG/L)	AVERAGE CONCENTRATION, UG/L (CONCENTRATION/CRITERIA) 6/ ARSENIC	CADMIUM	CHROMIUM	COPPER	LEAD	NICKEL	ZINC
Afterthought	Little Cow Crk	above		ND	ND	ND	12 (1.4)	ND	ND	5
		below	71	ND	0.4	ND	25 (2.8)	ND	ND	177 (2.2)
Anderson Springs	Creek near West adit	above		ND					6	8
		below	160	1			ND		3	5
	Anderson Springs Crk	above								
		below		ND	ND	1.5	0.5	ND	ND	ND
Balaklala, Keystone, Early Bird, and Shasta King	West Squaw Crk	above		NA	4 (6.1)	NA	32 (4.9)	NA	NA	55
		below		ND	11 (17)	ND	1653 (254)	4 (3.1)	ND	1947 (33)
Beardsley 4/	Hosselkus Crk	above								
		below		ND	ND	ND	2	ND	ND	ND
Brush Creek	Woodruff Crk	above 1/								
		below	100	22 (4.4)	ND	2	2	ND	11	ND
Bully Hill	Town Crk	above		ND	ND	ND	ND	ND	ND	ND
		below		NA	140 (212)	NA	3481 (536)	83 (64)	NA	11533 (195)
Corona	James Crk	above				0.5			125	ND
		below	450	ND		9	1		5400 (9.6)	145
	1.5 mi.	below 4/	540	ND	ND	1	1	ND	3000 (2.8)	23
Empire (Nev. Co.)	Wolf Crk	above		ND	ND	ND	2	ND	ND	2
		below		ND	ND	1	2	ND	ND	5
Engle/Superior 4/	Lights Crk	above		ND	ND	ND	4	ND	ND	ND
		below		ND	ND	ND	3	ND	ND	ND
	3 mi.	below		3	ND	ND	12 (1.8)	ND	ND	ND
Gladstone 4/	Cline Crk	above								
		below		23 (4.6)	ND	ND	ND	ND	ND	ND
Great Western	St. Marys Crk	above 3/								
		below		ND	ND	3.5	ND		4	60 (1)
Greenhorn	Willow Crk	above		ND	ND	ND	7	ND	ND	ND
		below	99	ND	6 (5.3)	1	619 (53)	ND	5	859 (8.2)
Iron Dyke 4/	Taylors Crk	above		ND	ND	ND	ND	ND	ND	ND
		below		ND	0.5	ND	21 (3.2)	ND	ND	18
Iron Mt. 7/	Sacramento R., Keswick Res.	above			.19		3.0			9.6
		below			.53 (2.4)		7.7 (1.4)			38.8 (2.4)
Kanaka Creek mines	Kanaka Ck @ M.F.Yuba R	below 8/	62	20 (4)	NA	1	NA	ND	ND	NA
Lucky-S 4/	Peters Crk	above 3/								
		below	28	ND	2.1 (5)	ND	67 (14)	ND	ND	299 (8.3)
Mammoth	Little Backbone Crk	below		NA	6.2 (8.9)	NA	597 (85)	NA	NA	963 (15)
Malakoff Diggn's	Humbug Crk	above	61	ND	ND	ND	1	ND	10	ND
		below	51			ND			15	8
Midas 4/	Harrison Gulch	above	ND	ND	ND	ND	ND	ND	ND	ND
		below	4	ND	ND	ND	ND	ND	ND	ND
Noble Electric 4/	N.F. Elder Crk	above		ND	ND	2	ND	ND	ND	5
		below		ND	ND	2	ND	ND	ND	5
Pick & Shovel	Pats Gulch	above		ND	ND	1	ND	ND	ND	ND
		below	78	ND	ND	0.5	ND	ND	59	9
	1 mi.	below 4/		ND	ND	ND	ND	ND	ND	ND
Plumas Eureka 4/	Jamison Crk	above 2/								
		below		ND	ND	ND	ND	ND	ND	ND
Plumbago	Buckeye Ravine	above		0.9	ND	10	ND	ND	4.4	ND
		below	130	170 (3.4)	NA	9	NA	ND	ND	ND
Reed	Davis Crk	above		ND	ND	1	1	ND	2	10
		below	820	15 (3.0)	ND	16	1	ND	446	9
Reward #7	Ward Crk	above		ND						
		below	47	ND 5/	ND	ND	ND	ND	ND	ND
Rising Star	Horse Crk	above		NA	10 (15)	NA	110 (17)	NA	NA	60
		below		4	293 (444)	3	9933 (1528)	38 (29)	18	40000 (678)
Spanish	Poorman Crk	above		ND	0.1	ND	ND	ND	ND	5
		below	22	ND	0.0	ND	1	ND	ND	15
	Devils Canyon Crk	above		ND	ND	ND	ND			
	1 mi.	below		ND	0.7 (1.1)	ND	20 (3.1)			
	2 mi.	below		ND	ND	2	6.7 (1.0)	ND	6	2
Spenceville	Little Dry Crk	above	71	2.3	ND	ND	16 (1.3)	ND	ND	5.8
		below	102	4.2	0.5	ND	368 (31)	ND	ND	299 (1.9)
	Dry Crk	above	79	ND	ND	ND	2.4	ND	ND	1
		below	84	ND	0.1	ND	63 (5.0)	ND	ND	43
Twin Peaks	Bateman Crk	above		ND	ND	ND	ND	ND	ND	2
		below	78	NA	ND	1	1	ND	115	2.3
Valley View	irrigation water	above		ND	ND	4.6	4.4	ND	ND	ND
		below		ND	129 (195)	1.8	3010 (463)	ND	30	8650 (147)
Walker	Dollie Crk	above		ND	ND	1	3.5	ND	ND	12
		below		ND	ND	ND	59 (9.1)	ND	ND	5

1/ A significant portion of the upstream flow is composed of an upper adit discharge.
2/ No upstream site was discernable. 3/ The upstream portion was ephemeral. 4/ Based on one sample.
5/ One high detectable value was considered to be an analytical error.
6/ 4-day, hardness corrected EPA freshwater quality criteria. A hardness of 50 mg/l was used when no stream-specific hardness was available. The human consumption arsenic level = 5.0 ug/l.
7/ From Heiman, 1988, 1990 and site specific objectives for the upper Sacramento River.
8/ Kanaka Creek below all mines in the watershed.

moving flows. Further, infiltrated water emanating from a waste rock pile moves at a slower velocity than surface runoff and probably extends the duration of impact beyond the period of rainfall. Runoff from waste rock increased the downstream concentration of total metals and likely increased the streambed metals content. Other mine influenced receiving waters are expected to experience similar impacts and, therefore, Table VI-1 is an underestimate of the actual average concentration the streams experience year-round as a result of mine drainage.

Stream concentrations are also influenced by direct contact with waste rock piles regardless of the season. For instance, at Iron Dyke Mine, Taylors Creek disappears under a waste rock pile that was deposited directly in the streambed. The stream emerges from the other side with levels of cadmium (0.5 ug/l), copper (21 ug/l), and zinc (18 ug/l) above what was measured upstream (<0.1, <1, and <10 ug/l, respectively). Therefore, waste rock piles have the potential to enrich streams with an easily and freely leachable fraction not dependent on pH declines. Simple diffusion processes bring the metals into solution upon contact with water. Mining operations commonly removed unwanted waste rock from the site by dumping it into stream watercourses and allowing high winter flows to wash it away. At many mine sites waste rock still composes a portion of the stream bank.

Almost all streams influenced by mine drainage eventually pass through one or more major reservoirs. Reservoirs have the potential to alter the input-output balance between metals coming in from natural/man-caused sources and those leaving via dam releases. At Camp Far West, a reservoir in the Sierra-Nevada foothill range, upstream inputs from Bear River and Rock Creek were monitored along with dam release water. Arsenic levels were very slightly elevated in the release water (1.6 versus 1.3 and 1.1 ppb) but chromium (3.8 versus 2.8 and 5.3 ppb) and copper (2.9 versus 2.8 and 1.4 ppb) remained essentially unchanged based on laboratory variability measurements for that batch submission. Sampling occurred in June when the streams exhibited low flow conditions with no observable turbidity. It would appear that these metal inputs were simply passing through the reservoir system with very little concentration change. However, when streams are highly turbid, metals associated with heavy particulate matter are expected to settle out to the lakebed. After deposition, undisturbed metals can become even more tightly bound to carbonate, sulfide, and organic carbon material and are not easily leached from the sediment (Brugam et al., 1988; DiToro et al., 1989). By the time incoming particulate matter has been transported to the lake bottom, most of the leachable metals have been released to the water column (Brugam et al., 1988). Reservoir characteristics such as temperature and flow differentials, draw point elevation, distance to the dam release, stratification, etc., are also expected to influence release quality. For instance, during a storm event, rainfall runoff from Penn Mine travelled the length of Camanche Reservoir along the inundated Mokelumne riverbed (Rectenwald et al., 1978). The colder, heavier, runoff water eventually reached the dam's base where out-flows resulted in salmonid fish kills at the hatchery below. Based on this assessment, and the one presented in Section V, it appears that the fraction of metals transported through a reservoir depends on a variety of factors including dam characteristics and the quality of upstream inputs.

Mines can also cause receiving water impacts from increased siltation. Waste rock sediments flushed into adjacent streams can produce a transitory benthic environment prone to movement and scouring. This can shift the macro-invertebrate population to more sediment tolerant species such as the mayfly and caddisfly (Duba and Penrose, 1980). Further, sediment from inactive mines can prevent fishes such as sculpin, darters, and trout from inhabiting a stream because of the lack of clean gravel (Reash et al., 1988). Although acid and metals may be diluted to levels tolerated by resident biota, the long-term impacts from increased siltation are more subtle and can result in a faunal shift to more sediment tolerant organisms.

Table VI-2. ARSENIC LEVELS IN THE NORTH FORK FEATHER RIVER, 9 JUNE 1989 (FROM TABLE E-1).

FEEDER STREAM TRIBUTARY	ARSENIC (UG/L)	N. F. YUBA RIVER LOCATION	ARSENIC (UG/L)
		Bassett	1.1
Howard Creek	10		
Salmon Creek	1.2		
Sierra Buttes stream	1.2		
		Downieville	1.3
Downie River	2.1		
Goodyears Creek	1.8		
Woodruff Creek	21		
Fiddle Creek	1.7		
		Hwy 49	1.6

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