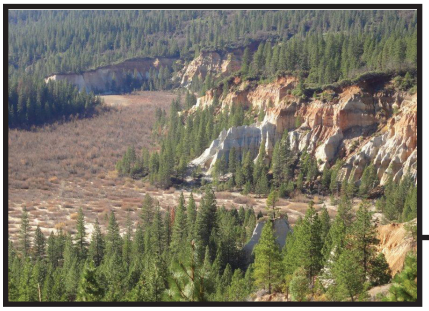

6 CABY Mercury and Sediment Abatement Initiative

ATTACHMENTS

6. CABY Mercury and Sediment Abatement Initiative

The following attachments are provided in PDF form as supplemental materials to this proposal (unless otherwise noted):

- In the online package reference documents are grouped into three PDFs that are uploaded as part of Attachment 7, entitled:
  - **Att7_IG2_TechJust_6MercRefs1_9of12.pdf** (containing references A-M)
  - **Att7_IG2_TechJust_6MercRefs2_10of12.pdf** (containing references N-R)
  - **Att7_IG2_TechJust_6MercRefs3_11of12.pdf** (containing references S-Y)

- In the hard copy package these documents are provided as separated PDFs in the folder entitled **"6 - Mercury Initiative Project."**

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MAPS

AA. Project Map

BB. Combie Project Maps and Figures

CC. Relief Hill Site Map

USGS
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Mercury Contamination from Historical Gold Mining in California

by Charles N. Alpers, Michael P. Hunerlach, Jason T. May, and Roger L. Hothem

Mercury contamination from historical gold mines represents a potential risk to human health and the environment. This fact sheet provides background information on the use of mercury in historical gold mining and processing operations in California, with emphasis on historical hydraulic mining areas. It also describes results of recent USGS projects that address the potential risks associated with mercury contamination.

Miners used mercury (quicksilver) to recover gold throughout the western United States. Gold deposits were either hardrock (lode, gold-quartz veins) or placer (alluvial, unconsolidated gravels). Underground methods (adits and shafts) were used to mine hardrock gold deposits. Hydraulic, drift, or dredging methods were used to mine the placer gold deposits. Mercury was used to enhance gold recovery in all the various types of mining operations; historical records indicate that more mercury was used and lost at hydraulic mines than at other types of mines. On the basis of USGS studies and other recent work, a better understanding is emerging of mercury distribution, ongoing transport, transformation processes, and the extent of biological uptake in areas affected by historical gold mining. This information has been used extensively by federal, state, and local agencies responsible for resource management and public health in California.

Gold Mining History

Vast gravel deposits from ancestral rivers within the Sierra Nevada contained large quantities of placer gold, derived from the weathering of gold-quartz veins. Gold mining evolved from hydraulic mining of unconsolidated placer deposits in the early days of the Gold Rush, to underground mining of hardrock deposits, and finally to large-scale dredging of low-grade gravel deposits, which in many areas included the tailings from upstream hydraulic mines.

By the mid-1850s, in areas with sufficient surface water, hydraulic mining was the most cost-effective method to recover large amounts of gold. Monitors (or water cannons, fig. 1) were used to break down placer ores, and the resulting slurry was directed through sluices (fig. 2).

Figure 1. Monitors (water cannons) were used to break down the gold-bearing gravel deposits with tremendous volumes of water under high pressure. Some mines operated several monitors in the same pit. Malakoff Diggings, circa 1860.

Figure 2. Gravel deposits were washed into sluices (from center to lower part of figure) where gold was recovered.

As mining progressed into deeper gravels, tunnels were constructed to facilitate drainage and to remove debris from the bottom of hydraulic mine pits. The tunnels also provided a protected environment for sluices and a way to discharge processed sediments (placer tailings) to adjacent waterways. Gold particles were recovered by mechanical settling in troughs (riffles) within the sluices and by chemical reaction with liquid mercury to form gold-mercury amalgam. Loss of mercury during gold processing was estimated to be 10 to 30 percent per season (Bowie, 1905), resulting in highly contaminated sediments at mine sites, especially in sluices and drainage tunnels (fig. 3). From the 1850s to the 1880s, more than 1.5 billion cubic yards of gold-bearing placer gravels were processed by hydraulic mining in California's northern Sierra Nevada region. The resulting debris caused property damage and

Figure 3. Gold pan with more than 30 grams of mercury from 1 kilogram of mercury-contaminated sediments collected in a drainage tunnel.

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CALFED Watershed Program - March 2013
Attachment 7 - CABY Mercury Initiative References 1 of 3

flooding downstream. In 1884, the Sawyer Decision prohibited discharge of hydraulic mining debris to rivers and streams in the Sierra Nevada region, but not in the Klamath-Trinity Mountains (fig. 4), where such mining continued until the 1950s.

Underground mining of placer deposits (drift mining) and of hardrock gold-quartz vein deposits produced most of California's gold from the mid-1880s to the 1930s. Another important source of gold from the late 1890s to the 1960s was gold-bearing sediment, which was mined using dredging methods. More than 3.6 billion cubic yards of gravel was mined in the foothills of the Sierra Nevada, where the dredging continued until 2003.

Mercury Mining

Most of the mercury used in gold recovery in California was obtained from mercury deposits in the Coast Range on the west side of California's Central Valley (fig. 4). Total mercury production in California between 1850 and 1981 was more than 220,000,000 lb (pounds) (Churchill, 2000); production peaked in the late 1870s (Bradley, 1918). Although most of this mercury was exported around the Pacific Rim or transported to Nevada and other western states, about 12 percent (26,000,000 lb) was used for gold recovery in California, mostly in the Sierra Nevada and Klamath-Trinity Mountains.

Use and Loss of Mercury in Gold Mining

To enhance gold recovery from hydraulic mining, hundreds of pounds of liquid mercury (several 76-lb flasks) were added to riffles and troughs in a typical sluice. The high density of mercury allowed gold and gold-mercury amalgam to sink while sand and gravel passed over the mercury and through the sluice. Large

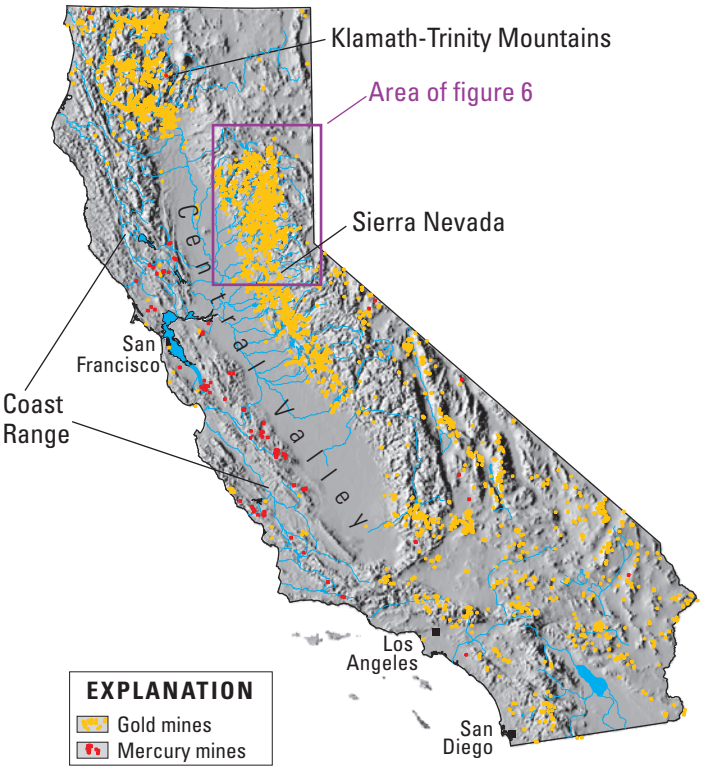

Figure 4. Locations of past-producing gold and mercury mines in California. Source: MAS/MILS (Minerals Availability System/Mineral Information Location System) database compiled by the former U.S. Bureau of Mines, now archived by the USGS.

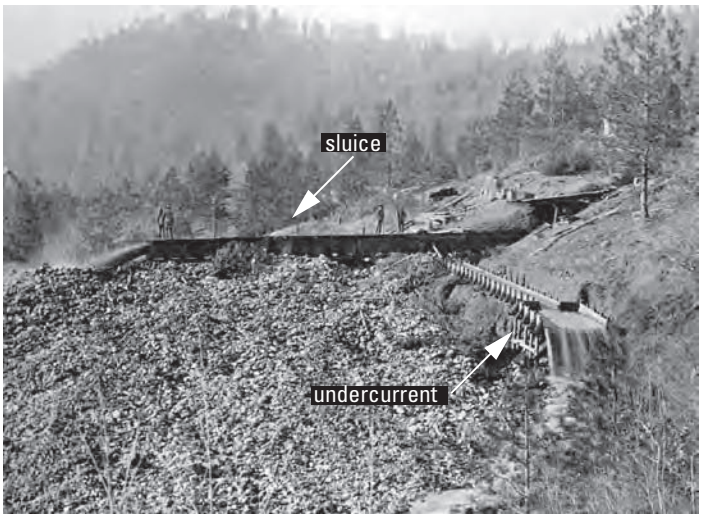

Figure 5. Undercurrent in use, circa 1860, Siskyou County, California.

volumes of turbulent water flowing through the sluice caused many of the finer gold and mercury particles to wash through and out of the sluice before they could settle in the mercury-laden riffles. A modification known as an undercurrent (fig. 5) reduced this loss. The finer grained particles were diverted to the undercurrent, where gold was amalgamated on mercury-lined copper plates. Most of the mercury remained on the copper plates; however, some was lost to the flowing slurry and was transported to downstream environments.

Gravel and cobbles that entered the sluice at high velocity caused the mercury to flour, or break into tiny particles. Flouring was aggravated by agitation, exposure of mercury to air, and other chemical reactions. Eventually, the entire bottom of the sluice became coated with mercury. Some mercury was lost from the sluice, either by leaking into underlying soils and bedrock or being transported downstream with the placer tailings. Minute particles of quicksilver could be found floating on surface water as far as 20 miles downstream of mining operations (Bowie, 1905). Some remobilized placer sediments, especially the coarser material, remain close to their source in ravines that drained the hydraulic mines.

Mercury use in sluices varied from 0.1 to 0.36 lb per square foot. A typical sluice had an area of several thousand square feet; several hundred lb of mercury were added during initial start-up, after which several additional 76-lb flasks were added weekly to monthly throughout the operating season (generally 6 to 8 months, depending on water availability). During the late 1800s, under the best operating conditions, sluices lost about 10 percent of the added mercury per year (Averill, 1946), but under average conditions, the annual loss was about 25 percent (Bowie, 1905). Assuming a 10- to 30-percent annual loss rate, a typical sluice likely lost several hundred pounds of mercury during the operating season (Hunerlach and others, 1999). From the 1860s through the early 1900s, hundreds of hydraulic placer-gold mines were operated in California, especially in the northern Sierra Nevada (fig. 6). The total amount of mercury lost to the environment from placer mining operations throughout California has been estimated at 10,000,000 lb, of which probably 80 to 90 percent was in the Sierra Nevada (Churchill, 2000).

Historical records indicate that about 3,000,000 lb of mercury were lost at hardrock mines, where gold ore was crushed

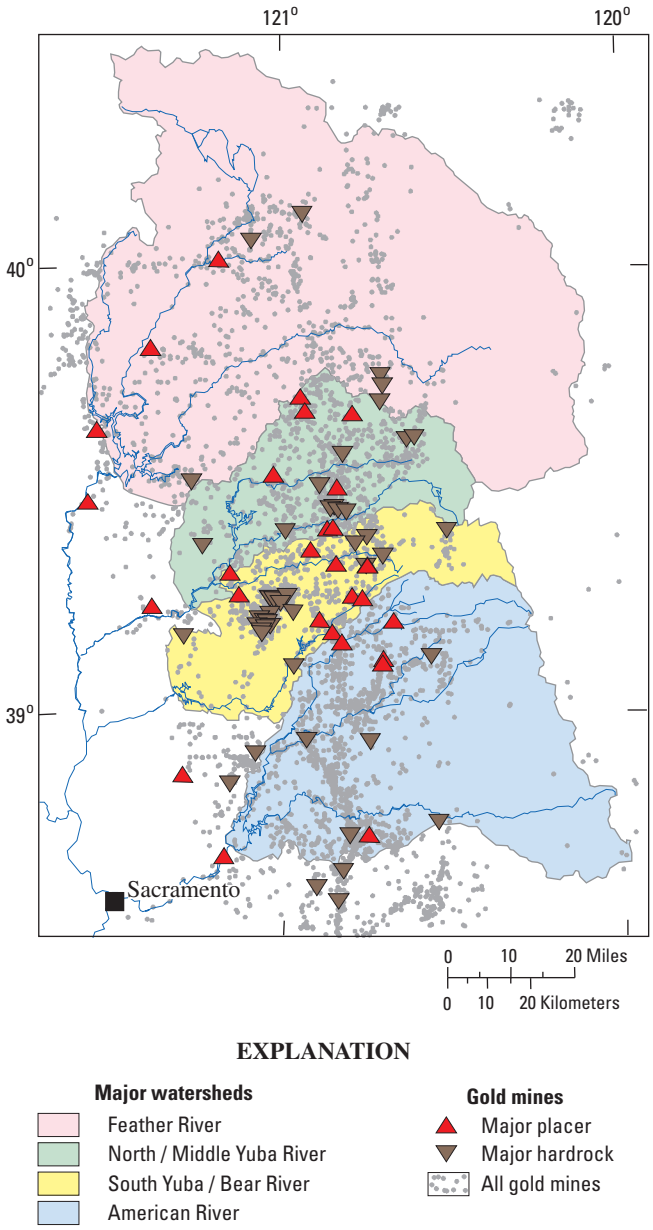

Figure 6. Watersheds (also known as drainage basins) in the northwestern Sierra Nevada of California showing past-producing gold mines (as in figure 4) and major placer and hardrock gold mines. Source: USGS Significant Deposits Database (Long and others, 1998).

using stamp mills (Churchill, 2000). Mercury was also used extensively at drift mines and in dredging operations. Mercury was used widely until the early 1960s in the dredging of auriferous sediment from alluvial flood-plain deposits. Today, mercury is recovered as a by-product from small-scale gold-dredging operations; also, mercury and gold are recovered as byproducts from some gravel-mining operations, especially in areas affected by historical gold mining. Understanding the present distribution and fate of the mercury used in historical gold mining operations is the subject of ongoing multi-disciplinary studies.

The Bear–Yuba Project

In cooperation with federal land-management agencies (the Bureau of Land Management and the U.S. Forest Service) and various state and local agencies, USGS scientists have investigated mercury contamination at abandoned mine sites and downstream environments in the Bear River and Yuba River watersheds (fig. 6) since 1999. Fish from reservoirs and streams in the Bear–Yuba watersheds (fig. 7) have bioaccumulated sufficient mercury (May and others, 2000) to pose a risk to human health (Klasing and Brodberg, 2003). A conceptual diagram (fig. 8) summarizes known mercury sources, transport mechanisms, and bioaccumulation pathways. Based primarily on data from other USGS studies (for example, Saiki and others, 2004), additional fish consumption advisories regarding mercury in other areas of northern California affected by historical gold mining (fig. 9) have been issued.

The USGS and cooperating agencies have identified several "hot spots" of mercury contamination and bioaccumulation by reconnaissance sampling of water, sediment, and biota at numerous hydraulic mine sites in the Bear–Yuba watersheds (Alpers and others, 2005). Subsequently, some mercury-contaminated mine sites have been remediated by other federal agencies, and remediation plans are being developed for other sites. Mercury contamination has also been investigated in dredge fields at lower Clear Creek (Ashley and others, 2002), the Trinity River, and the lower Yuba River (Hunerlach and others, 2004). These investigations show that total mercury concentrations in dredge tailings tend to be most elevated in the finest grained sediments. The State of California has listed several water bodies in the Bear-Yuba watersheds as impaired with regard to beneficial uses, starting a regulatory process that may include eventual mercury-load reduction through Total Maximum Daily Loads (TMDLs). The USGS is providing data and information to stakeholders through ongoing studies of mercury and methylmercury loads in the Bear River, mercury fluxes from reservoir sediments (Kuwabara and others, 2003), mercury methylation and demethylation processes in sediment, and mercury bioaccumulation in the food web of Camp Far West Reservoir.

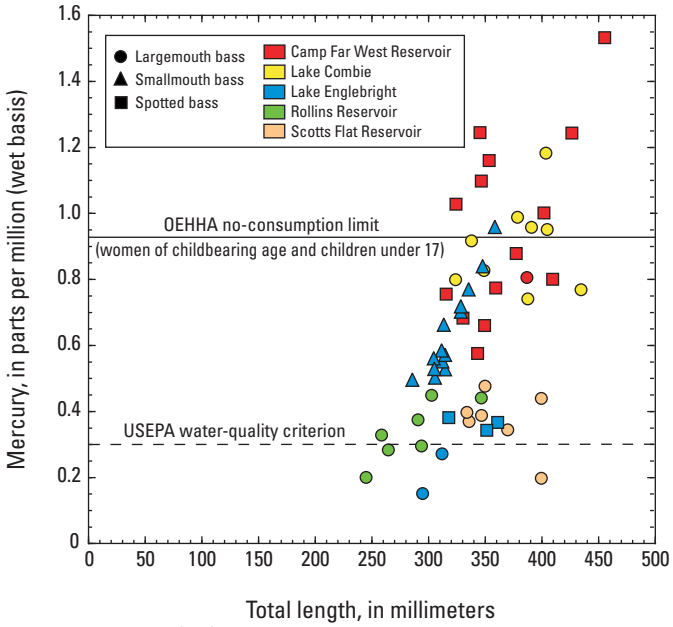

Figure 7. Mercury (Hg) concentration in relation to total length for all bass (*Micropterus spp.*) samples collected in 1999 from reservoirs in the Bear–Yuba watersheds, California (May and others, 2000). Dashed horizontal line at Hg concentration of 0.3 ppm represents criterion for methylmercury in fish tissue for the protection of human health (U.S. Environmental Protection Agency [USEPA], 2001). Solid horizontal line at Hg concentration of 0.93 ppm indicates value above which the state of California recommends no consumption of fish for women of child-bearing age and children under 17 (Klasing and Brodberg, 2003). OEHHA, Office of Environmental Health Hazard Assessment.

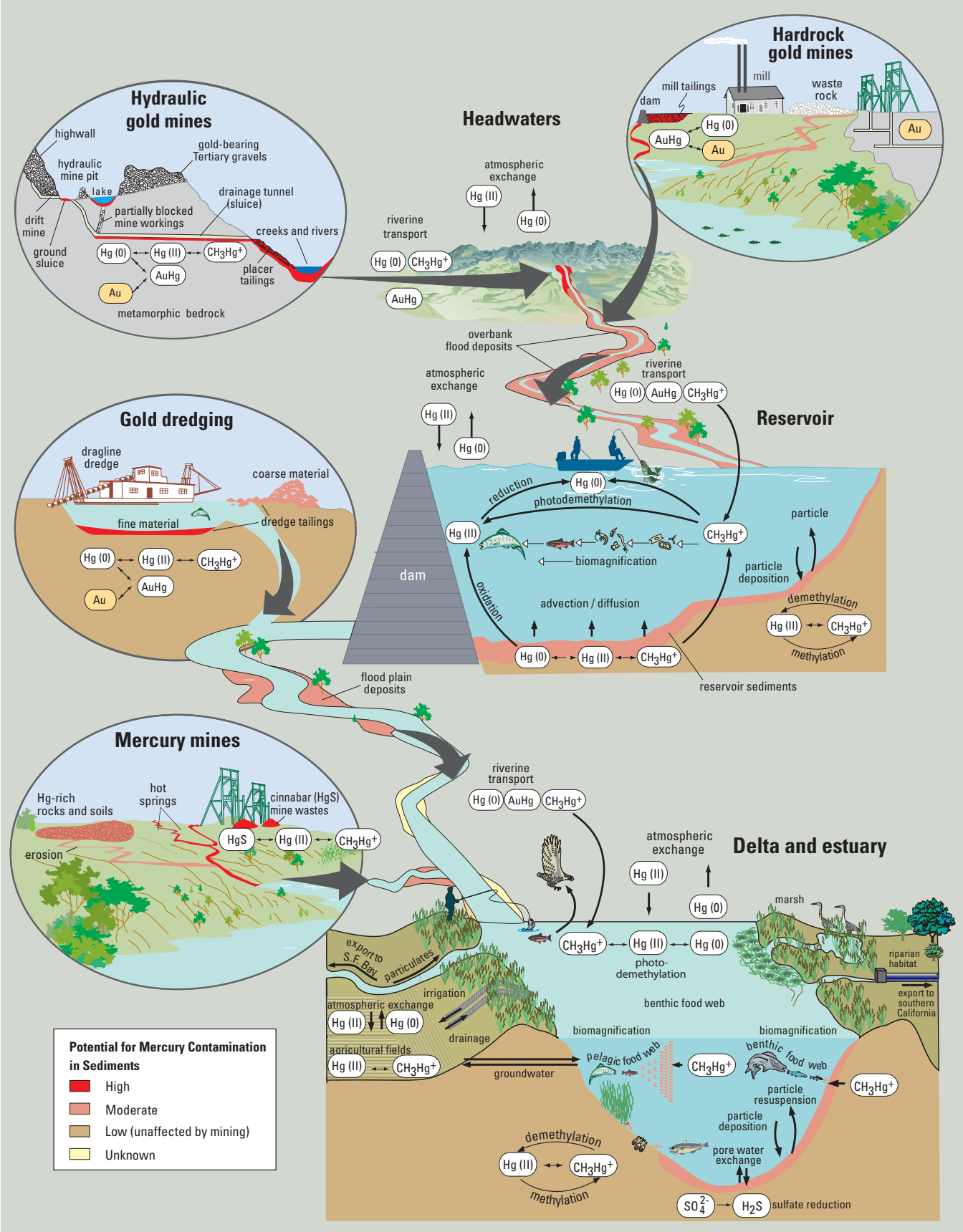

Figure 8. Schematic diagram showing transport and fate of mercury and potentially contaminated sediments from the mountain headwaters (hydraulic, drift, and hardrock mine environments) through rivers, reservoirs, and the flood plain, and into an estuary. A simplified mercury cycle is shown, including overall methylation reactions and bioaccumulation; the actual cycling is much more complex. Hg(0), elemental mercury; Hg(II), ionic mercury (mercuric ion); HgS, cinnabar; CH_3Hg^+, methylmercury; Au, gold; AuHg, gold-mercury amalgam; H_2S, hydrogen sulfide; SO_4^{2-}, sulfate ion; DOC, dissolved organic carbon. Mark Stephenson (California Department of Fish and Game) contributed to the development of this diagram.

MERCURY AND ABANDONED MINES: KEY ISSUES

Risks to Human Health

- Consumption of contaminated fish
- Improper handling of contaminated sediments
- Inhalation of mercury vapors
- Municipal drinking water supplies generally safe
- Some mine waters unsafe for consumption

Challenges for Land Management

- Public access to contaminated areas
- Physically hazardous sites
- Environmental consequences of resource development
- Remediation of affected sites

Environmental Fate of Mercury

- "Hot spots" at mine sites
- Contaminated sediments
- Transformation to methylmercury
- Transport to downstream areas
- Bioaccumulation and biomagnification in food

Mercury Methylation and Biomagnification

Mercury occurs in several different geochemical forms, including elemental mercury [Hg(0)], ionic (or oxidized) mercury [Hg(II)], and a suite of organic forms, the most important of which is **methylmercury** *(CH_3Hg^+). Methylmercury is the form most readily incorporated into biological tissues and most toxic to humans. The transformation from elemental mercury to methylmercury is a complex biogeochemical process that requires at least two steps, as shown in figure 8: (1) oxidation of Hg(0) to Hg(II), followed by (2) transformation from Hg(II) to CH_3Hg^+; step 2 is referred to as* **methylation.** *Mercury methylation is controlled by sulfate-reducing bacteria and other microbes that tend to thrive in conditions of low dissolved oxygen, such as near the sediment-water interface or in algal mats. Numerous environmental factors influence the rates of mercury methylation and the reverse reaction known as* **demethylation.** *These factors include temperature, dissolved organic carbon, salinity, acidity (pH), oxidation-reduction conditions, and the form and concentration of sulfur in water and sediments.*

The concentration of CH_3Hg^+ generally increases by a factor of ten or less with each step up the food chain, a process known as **biomagnification**. *Therefore, even though the concentrations of Hg(0), Hg(II), and CH_3Hg^+ in water may be very low and deemed safe for human consumption in drinking water, CH_3Hg^+ concentration levels in fish, especially predatory species such as bass and catfish, may reach levels that are considered potentially harmful to humans and fish-eating wildlife, such as bald eagles.*

Fish Consumption Advisories for Mercury

Methylmercury (CH_3Hg^+) is a potent neurotoxin that impairs the nervous system. Fetuses and young children are more sensitive to methylmercury exposure than adults. Methylmercury can cause many types of problems in children, including damage to the brain and nervous system, mental impairment, seizures, abnormal muscle tone, and problems in coordination. Therefore, the consumption guidelines in areas where CH_3Hg^+ is known to occur in fish at potentially harmful levels tend to be more restrictive for children as well as for pregnant women, nursing mothers, and other women of childbearing age.

In the United States, as of 2003, there were a total of 2,800 fish and wildlife consumption advisories for all substances, of which 2,140 (more than 76 percent) were for mercury. Forty-five states have issued advisories for mercury, and 19 states have statewide advisories for mercury in all freshwater lakes and (or) rivers.

As of October 2005, the state of California had issued fish consumption advisories for mercury in about 20 waterbodies, including the San Francisco Bay–Delta region and several areas in the Coast Range affected by mercury mining (fig. 9; compare with fig. 4). Water bodies with advisories based on USGS fish-tissue data include the Bear River and Yuba River watersheds of the Sierra Nevada (Klasing and Brodberg, 2003), the lower American River including Lake Natoma (Klasing and Brodberg, 2004), and the Trinity Lake area.

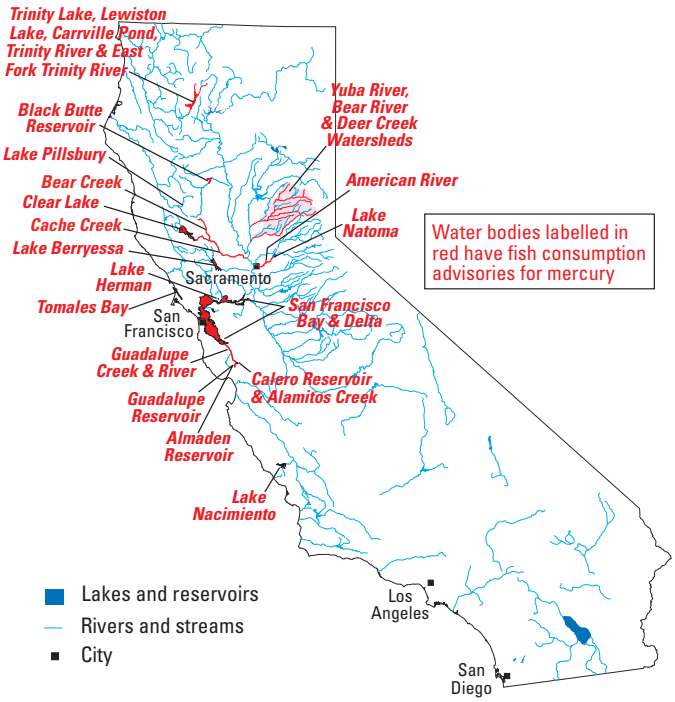

Figure 9. Locations of health advisories for mercury in sport fish consumed in California. Source: California Office of Environmental Health Hazard Assessment, accessed October 12, 2005 (*http://www.oehha.ca.gov/fish.html*).

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Cooperating Agencies and Stakeholder Groups

U.S. Forest Service

Bureau of Reclamation

California State Water Resources Control Board

California Department of Fish and Game

California Bay–Delta Authority

Nevada County Resource Conservation District

Bureau of Land Management

U.S. Environmental Protection Agency

California Department of Parks and Recreation

California Department of Conservation

California Department of Water Resources

Sacramento River Watershed Program

For more information:

Charles N. Alpers (916) 278-3134
cnalpers@usgs.gov
Michael P. Hunerlach (916) 278-3133
hunerlac@usgs.gov
Jason T. May (916) 278-3079
jasonmay@usgs.gov

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

Roger L. Hothem (707) 678-0682 ext. 626
roger_hothem@usgs.gov

U.S. Geological Survey
6924 Tremont Rd.
Dixon, CA 95620

Web links:
http://ca.water.usgs.gov/mercury
http://mine-drainage.usgs.gov
http://toxics.usgs.gov/bib/bib-mercury-on-line.html
http://minerals.usgs.gov/mercury

Prepared in cooperation with the California State Water Resources Control Board

Environmental Factors Affecting Mercury in Camp Far West Reservoir, California, 2001–03

Scientific Investigations Report 2006–5008

U.S. Department of the Interior
U.S. Geological Survey

Photographs on cover, clockwise from upper left: Middle reservoir, looking northeast, August 2003 (photograph by C.N. Alpers); bluegill, August 2003 (photograph by M.K. Saiki); Dairy Farm Mine pit lake, August 2003 (photograph by C.N. Alpers); view from Camp Far West Dam, looking southeast, August 2003 (photograph by C.N. Alpers).

Environmental Factors Affecting Mercury in Camp Far West Reservoir, California, 2001–03

By Charles N. Alpers, A. Robin Stewart, Michael K. Saiki, Mark C. Marvin-DiPasquale, Brent R. Topping, Kelly M. Rider, Steven K. Gallanthine, Cynthia A. Kester, Robert O. Rye, Ronald C. Antweiler, and John F. De Wild

Prepared in cooperation with the
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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Volume	
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic yard (yd^3)	0.7646	cubic meter (m^3)
cubic mile (mi^3)	4.168	cubic kilometer (km^3)
acre-foot (acre-ft)	1,233	cubic meter (m^3)
acre-foot (acre-ft)	0.001233	cubic hectometer (hm^3)
	Flow rate	
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Mass	
ounce, avoirdupois (oz)	28.35	gram (g)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
	Pressure	
bar	100	kilopascal (kPa)
inch of mercury at 60ºF (in Hg)	3.377	kilopascal (kPa)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L), micrograms per liter (µg/L), or nanograms per liter (ng/L).

Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Elevation, as used in this report, refers to distance above the vertical datum.

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Acronyms

ASTM, American Society for Testing and Materials
BAF, bioaccumulation factor
BRA, Bear River Arm (site 5)
CDT, Cañon Diablo Troilite
CFWR, Camp Far West Reservoir
CRV, certified reference value
CVAAS, cold vapor atomic-absorption spectrometry
CVAFS, cold vapor atomic-fluorescence spectrometry
DFA, Dairy Farm Arm (site 6)
DFI, impoundments near the Dairy Farm Mine (site 9)
DFP, Dairy Farm Mine pit lake (site 8)
DI, deionized (water)
DO, dissolved oxygen
DOC, dissolved organic carbon
EPA, U.S. Environmental Protection Agency
FDA, Food and Drug Administration
GC, gas chromatography
G.I., gastrointestinal
GMWL, Global Meteoric Water Line
IAEA, International Atomic Energy Agency
IC, ion chromatography
ICP–AES, inductively coupled plasma–atomic emission spectrometry
ICP–MS, inductively coupled plasma–mass spectrometry
MDL, method detection limit
MRS, Mid-Reservoir, Shallow (site 3)
MRT, Mid-Reservoir, Thalweg (site 4)
NAWQA, National Water-Quality Assessment Program
NRCC, National Research Council Canada
NRP, National Research Program
POC, particulate organic carbon
QA, quality assurance
QC, quality control
QFF, quartz fiber filter
RCA, Rock Creek Arm (site 7)
RPD, relative percent difference
RSD, relative standard deviation
SC, specific conductance
SRM, standard reference material
SRWS, standard reference water sample
SSC, suspended solids concentration
SSWD, South Sutter Water District
SWRCB, State Water Resources Control Board
TL, trophic level
USEPA, United States Environmental Protection Agency
USGS, United States Geological Survey
VSMOW, Vienna Standard Mean Ocean Water
WMRL, Wisconsin Mercury Research Laboratory

Abbreviations and Symbols

cm, centimeter
g, gram
kg, kilogram
L, liter
mg, milligram
mL, milliliter
µg, microgram
µm, micrometer
µmol, micromole
MΩ-cm, megaohm-centimeter
ng, nanogram
ng/L, nanogram per liter
ppb, part per billion
ppm, part per million
wt, weight
s, second
>, greater than
<, less than
%, percent
‰, permil

Chemical Notation

Elements

Al, aluminum
As, arsenic
B, boron
Ba, barium
Be, beryllium
Bi, bismuth
B, boron
Ca, calcium
Cd, cadmium
Ce, cerium
Cl, chlorine
Co, cobalt
Cr, chromium
Cs, cesium
Cu, copper
Dy, dysprosium
Er, erbium
Eu, europium
Fe, iron
Gd, gadolinium
Ho, holmium
Hg, mercury
In, indium
Ir, iridium
K, potassium
La, lanthanum
Li, lithium
Lu, lutetium
Mg, magnesium
Mn, manganese
N, nitrogen
Na, sodium
Nd, neodymium
Ni, nickel
P, phosphorus
Pb, lead
Pr, praseodymium
Rb, rubidium
Re, rhenium
Rh, rhodium
Sb, antimony
Se, selenium
Sm, samarium
Sn, tin
Sr, strontium
Tb, terbium
Te, tellurium
Th, thorium
Tl, thallium
Tm, thulium
U, uranium
V, vanadium
Y, yttrium
Yb, ytterbium
Zn, zinc
Zr, zirconium

Compounds, Isotopes, and Other Chemical Notation

D, deuterium (^{2}H)
CH_2Cl_2, methylene chloride
$CuSO_4$, copper sulfate
H_2O, water
HCl, hydrochloric acid
HF, hydrofluoric acid
HNO_3, nitric acid
Hg^0, elemental mercury
Hg^{2+}, mercuric ion (divalent mercury)
$HgCl_2$, mercuric chloride
Hg_T, total mercury
KBr, potassium bromide
MeHg, methylmercury (monomethylmercury)
$NaBEt_4$, sodium tetra-ethyl borate
N-org, organic nitrogen
NH_3, ammonia
NO_2^-, nitrite
NO_3^-, nitrate
PO_4^{3-}, (ortho)phosphate
$SnCl_2$, stannous chloride
SO_4, sulfate
δD, delta-deuterium (ratio of ^{2}H to ^{1}H relative to Vienna Standard Mean Ocean Water)
$\delta^{18}O$, delta-18-oxygen (ratio of ^{18}O to ^{16}O relative to Vienna Standard Mean Ocean Water)
$\delta^{18}O_{H2O}$, delta-18-oxygen value in water
$\delta^{18}O_{SO4}$, delta-18-oxygen value in aqueous sulfate
$\delta^{34}S$, delta-34-sulfur (ratio of ^{34}S to ^{32}S relative to Cañon Diablo Troilite standard)
$\delta^{34}S_{SO4}$, delta-34-sulfur value in aqueous sulfate

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Abstract

This report documents water quality in Camp Far West Reservoir from October 2001 through August 2003. The reservoir, located at approximately 300 feet above sea level in the foothills of the northwestern Sierra Nevada, California, is a monomictic lake characterized by extreme drawdown in the late summer and fall. Thermal stratification in summer and fall is coupled with anoxic conditions in the hypolimnion. Water-quality sampling was done at approximately 3-month intervals on eight occasions at several stations in the reservoir, including a group of three stations along a flow path in the reservoir: an upstream station in the Bear River arm (principal tributary), a mid-reservoir station in the thalweg (pre-reservoir river channel), and a station in the deepest part of the reservoir, in the thalweg near Camp Far West Dam. Stations in other tributary arms of the reservoir included those in the Rock Creek arm of the reservoir, a relatively low-flow tributary, and the Dairy Farm arm, a small tributary that receives acidic, metal-rich drainage seasonally from the inactive Dairy Farm Mine, which produced copper, zinc, and gold from underground workings and a surface pit.

Several water-quality constituents varied significantly by season at all sampling stations, including major cations and anions, total mercury (filtered and unfiltered samples), nitrogen (ammonia plus organic), and total phosphorus. A strong seasonal signal also was observed for the sulfur-isotope composition of aqueous sulfate from filtered water. Although there were some spatial differences in water quality, the seasonal variations were more profound. Concentrations of total mercury (filtered and unfiltered water) were highest during fall and winter; these concentrations decreased at most stations during spring and summer. Anoxic conditions developed in deep parts of the reservoir during summer and fall in association with thermal stratification. The highest concentrations of methylmercury in unfiltered water were observed in samples collected during summer from deep-water stations in the anoxic hypolimnion. In the shallow (less than 14 meters depth) oxic epilimnion, concentrations of methylmercury in unfiltered water were highest during the spring and lowest during the fall. The ratio of methylmercury to total mercury ($MeHg/Hg_T$) increased systematically from winter to spring to summer, largely in response to the progressive seasonal decrease in total mercury concentrations, but also to some extent because of increases in MeHg concentrations during summer.

Water-quality data for Camp Far West Reservoir are used in conjunction with data from linked studies of sediment and biota to develop and refine a conceptual model for mercury methylation and bioaccumulation in the reservoir and the lower Bear River watershed. It is hypothesized that MeHg is produced by sulfate-reducing bacteria in the anoxic parts of the water column and in shallow bed sediment. Conditions were optimal for this process during late summer and fall. Previous work has indicated that Camp Far West Reservoir is a phosphate-limited system—molar ratios of inorganic nitrogen to inorganic phosphorus in filtered water were consistently greater than 16 (the Redfield ratio), sometimes by orders of magnitude. Therefore, concentrations of orthophosphate were expectedly very low or below detection at all stations during all seasons. It is further hypothesized that iron-reducing bacteria facilitate release of phosphorus from iron-rich sediments during summer and early fall, stimulating phytoplankton growth in the fall and winter, and that the MeHg produced in the hypolimnion and metalimnion is released to the entire water column in the late fall during reservoir destratification (vertical mixing).

Mercury bioaccumulation factors (BAF) were computed using data from linked studies of biota spanning a range of trophic position: zooplankton, midge larvae, mayfly nymphs, crayfish, threadfin shad, bluegill, and spotted bass. Significant increases in total mercury in tissue with increasing organism size were observed for all three fish species and for crayfish. The BAF values were computed using the average methylmercury concentration (wet) in biota divided by the arithmetic mean concentration of methylmercury in filtered water (0.04 nanograms per liter). As expected, the BAF values increased systematically with increasing trophic position. Values of BAF were 190,000 for zooplankton; 470,000 to 930,000 for three taxa of invertebrates; 2.7 million for threadfin shad (whole body); 4.2 million for bluegill (fillet); and 10 million for spotted bass (fillet). The BAF values are high compared with those for biota in other reservoirs in northern California and elsewhere, indicating relatively efficient biomagnification of mercury in Camp Far West Reservoir.

Introduction

Extensive mercury use during historical gold mining and mineral processing resulted in widespread mercury contamination and bioaccumulation of *methylmercury* in watersheds in the northwestern Sierra Nevada (Slotton and others 1997; Alpers and Hunerlach, 2000; Alpers and others, 2005a). Estimates based on historical documents and mining records (Churchill, 2000) indicate that up to 10 million pounds of mercury were lost to the environment in California from mining of *placer gold* during the latter half of the 19th century and the early 20th century; in addition, about 3 million pounds of mercury were lost from stamp mills associated with hardrock mining. Most of the hardrock mining activity in California was in the northern Sierra Nevada.

In 1999, the U.S. Geological Survey began leading a multi-agency, multi-disciplinary investigation of mercury contamination in the watersheds of the Bear River, Deer Creek, and South Yuba River (fig. 1), with emphasis on effects of historical placer gold mining (Alpers and Hunerlach, 2000; Hunerlach and Alpers, 2003; Alpers and others, 2005a, 2005b). Elevated mercury concentrations in fish from reservoirs and streams in these three watersheds were documented by May and others (2000). Of the five reservoirs tested by May and others (2000), Camp Far West Reservoir (CFWR) had fish containing the highest levels of mercury. Spotted bass, the top predator in CFWR, had *total mercury* concentrations ranging from 0.59 to 1.5 µg/g (microgram per gram, wet weight) with a mean value of 0.92 µg/g. These concentrations led the State of California to issue a public advisory recommending no consumption of spotted bass from CFWR by women of childbearing age and children 17 years of age and under (Klasing and Brodberg, 2003), and recommending limited consumption of all bass species and other sport fish throughout the Bear River and Yuba River watersheds for all fish consumers.

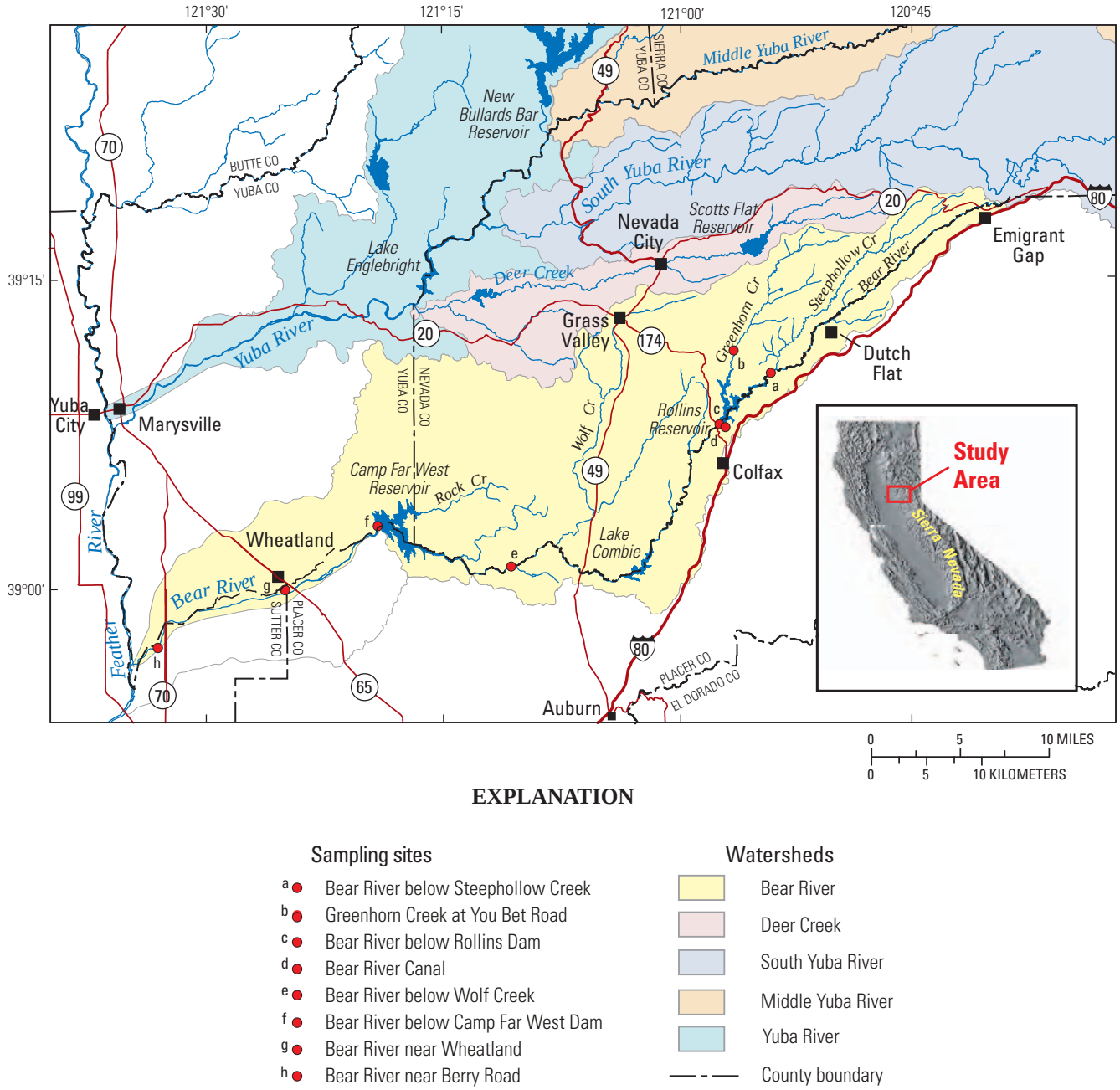
Another regulatory consequence of documenting elevated mercury in fish tissue for reservoirs and streams in the Bear–Yuba watersheds (May and others, 2000) was the inclusion of several water bodies in this area on the State of California's list of water bodies with *impaired beneficial uses*, under section 303(d) of the Clean Water Act. The 303(d) listings require that the listed water bodies be scheduled for Total Maximum Daily Load (TMDL) assessments. The TMDL assessment for Camp Far West Reservoir is scheduled for 2011 (California Regional Water Quality Control Board–Central Valley Region, 2003).

A detailed follow-up study of mercury bioaccumulation in the food web of CFWR was initiated in 2001 by the USGS and the California State Water Resources Control Board as a key component in an integrated effort referred to as the Bear River Mercury Cycling Project (BRMCP). Other components of the BRMCP include studies of mercury *methylation* potential rates and *flux* into the water column from bed sediment in CFWR (Kuwabara and others, 2003), methylmercury bioaccumulation dynamics in the food web of CFWR in relation to water quality (Stewart and others, 2008) mercury and methylmercury mass balance for CFWR and another reservoir in the Bear River watershed (Caruso and others, 2008), and assessment of the methylmercury *bioaccumulation factor* at reservoir sites (this report) and river sites n the watershed. A long-term goal of the BRMCP is to provide a sound scientific understanding of mercury cycling so that predictions can be made with reasonable certainty regarding mercury bioaccumulation.

Purpose and Scope

The overall objectives of the Bear River mercury cycling project are (1) to determine the biogeochemical and hydrologic processes that control mercury methylation, *demethylation*, and bioaccumulation in the Bear River watershed; (2) to determine mass balances for mercury and methylmercury in Camp Far West and Rollins Reservoirs in the Bear River watershed (fig. 1); (3) to test hypotheses regarding the extent that biogeochemical and ecological factors controlling bioaccumulation of mercury in sport fish help to identify potentially effective control measures (such as reducing nutrients, sulfate, and total mercury either singly or in combination); (4) to determine *loads* of mercury and methylmercury from the Bear River, Yuba River, and Feather River watersheds for comparison with other tributaries to the Sacramento River and the Sacramento–San Joaquin Delta; and (5) to assist the California State Water Resources Control Board (SWRCB) in evaluating the methodology of the U.S. Environmental Protection Agency (USEPA) for correlating methylmercury concentrations in biota with total mercury concentrations in water using bioaccumulation factors. This report documents water quality in Camp Far West Reservoir from October 2001 through August 2003, providing data that are essential for addressing overall objectives (1), (2), (3), and (5) of the BRMCP. In addition, this report describes the sampling, laboratory, and statistical methods used, and the quality assurance and quality control procedures.

Some aspects of the BRMCP that have been or will be reported separately include determination of mercury and methylmercury *fluxes* from bed sediments in CFWR (Kuwabara and others, 2003), determination of mercury and methylmercury concentrations in the Bear, Yuba, and Feather Rivers and mass balance of two reservoirs in the Bear River, including CFWR, analysis of mercury bioaccumulation and seasonal dynamics of plankton in CFWR (Stewart and others, 2008), analysis of mercury bioaccumulation in invertebrates and fish in CFWR, and analysis of mercury methylation and demethylation potential rates in CFWR bed sediments. In addition, results of the components of the BRMCP are being synthesized into a summary report.



EXPLANATION

Sampling sites

- a Bear River below Steephollow Creek
- b Greenhorn Creek at You Bet Road
- c Bear River below Rollins Dam
- d Bear River Canal
- e Bear River below Wolf Creek
- f Bear River below Camp Far West Dam
- g Bear River near Wheatland
- h Bear River near Berry Road

Watersheds

- Bear River
- Deer Creek
- South Yuba River
- Middle Yuba River
- Yuba River
- County boundary

Figure 1. Location of Camp Far West Reservoir in the Bear River Watershed, California.

Description of Study Area

Camp Far West Reservoir (CFWR) is located in the lower reach of the Bear River, which drains into the Feather River (fig. 1). The Feather River is a major tributary to the Sacramento River, the largest source of water to the San Francisco Bay–Delta Estuary and the origin of drinking water for more than two-thirds of the residents of California. Camp Far West Dam was constructed in 1963 by the South Sutter Water District, which manages the facility. The dam has a height of 185 feet and the spillway elevation is approximately 300 feet above the National Geodetic Vertical Datum of 1929 (NGVD 29). There are two outlets within the dam–one at an elevation of 220 feet above NGVD 29 that leads to a turbine operated by Pacific Gas & Electric Co. and another at an elevation of 176 feet above NGVD 29 that discharges without power generation. The lower outlet primarily is used when water levels are too low to operate the powerhouse. Flows over the spillway are gaged by the California Department of Water Resources (available from the California Data Exchange Center at http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=CFW).

Climate

The lower Bear River watershed has a Mediterranean climate, with cool, wet winters and hot, dry summers. Monthly precipitation data are shown in figure 2 for Grass Valley and Auburn, California (fig. 1). Nearly all precipitation occurs between November and May. Annual average precipitation during 1999–2002 was 33.9 inches at Grass Valley (Western Regional Climate Center, 2004a) and 49.9 inches at Auburn (Western Regional Climate Center, 2004b). Daily average temperatures (in degrees Fahrenheit, °F) at Auburn are mostly in the 40s during the winter and in the 70s and 80s during the summer (fig. 3).

CFWR is a warm, *monomictic lake* (Wetzel, 1975) typical of the coastal regions of North America. Characteristics of warm monomictic lakes include temperatures remaining above 39 °F (or 4 degrees Celsius, °C) year-round, vertical circulation in the winter and spring, and development of thermal stratification during the summer. Destratification or "turnover" occurs typically after the onset of cooler weather in the fall.

Geology and Mining History

Bedrock in the lower Bear River watershed is primarily composed of volcanic rocks and pyroclastic sedimentary rocks of Jurassic age (Clark, 1976). The volcanic rocks are chiefly mafic volcanic breccia and tuff, with some pillow lava features. In the Bear River arm of CFWR, an intrusive mafic dike strikes northwest across the river channel. There are small outcrops of granitic rocks in the lower watershed, including an area immediately to the south of Lake Combie (fig. 1). Several kilometers farther upstream in the Bear River watershed, the bedrock consists of Paleozoic metasedimentary and metavolcanic rocks of the Calaveras and Shoo Fly formations (Clark, 1976). Tertiary *auriferous* gravel deposits from the ancestral Yuba River form a north-trending paleochannel, up to 4 miles wide and 600 feet deep, that traverses the watershed near Dutch Flat and Scotts Flat Reservoir (Lindgren, 1911; Yeend, 1974).

The auriferous gravels of the Bear River and other watersheds in the Sierra Nevada were mined extensively from the early 1850s to the mid-1880s by hydraulic mining methods (Bowie, 1905; Averill, 1946). Gilbert (1917) estimated that between the 1850s and the early 1900s, hydraulic mining displaced 254 million cubic yards of gravel and sediment in the Bear River watershed. James (1991, 1993) mapped fluvial deposits of hydraulic mine waste in the Bear River watershed and determined that coarse material has remained in tributaries to a greater extent than predicted by Gilbert (1917). *Elemental mercury* was used to amalgamate gold in the hydraulic mining process (Bowie, 1905; Averill, 1946), and several million pounds of mercury were likely lost to the environment in the Sierra Nevada because of this practice (Alpers and Hunerlach, 2000; Churchill, 2000; Alpers and others, 2005a). Reconnaissance sampling of water, sediment, and biota by the USGS in the Greenhorn Creek drainage (fig. 1) revealed extensive mercury contamination and bioaccumulation in some "hot spots" associated with historical placer gold mining (Alpers and others, 2005b). Some of the large placer (unconsolidated gravel) gold-mining districts in the watershed are the You Bet–Red Dog district, which drains into Greenhorn and Steephollow Creeks (Alpers and others, 2005b); the Lowell Hill district, which drains into Steephollow Creek; and the Dutch Flat district, which drains into the Dutch Flat Afterbay, a small impoundment on the Bear River near Dutch Flat (fig. 1) (Hunerlach and others, 1999).

Underground mining of hardrock (lode) gold-quartz vein deposits also was important in the Bear River watershed. Several large, underground mines in the Grass Valley mining district are in areas that drain into Wolf Creek, a tributary to the Bear River (fig. 1).These mines include the Empire, Northstar, Providence, Allison Ranch, and Pennsylvania mines (Clark, 1963). The Lava Cap Mine, a hardrock gold mine in the Greenhorn Creek drainage (fig. 1), is the site where an abandoned tailings dam failed during January 1997 and released high-arsenic sediments to downstream environments (CH2M Hill, 2001). Expected contaminants from hardrock gold mining include arsenic, which occurs naturally in pyrite and arsenopyrite associated with the gold-quartz vein deposits, and mercury, which was used for amalgamation in hardrock gold mining in association with stamp mills (Churchill, 2000).

The Dairy Farm Mine produced copper, zinc, and gold from a volcanogenic massive-sulfide deposit along the south shore of CFWR. Along the north shore of CFWR are pyritic outcrops and small exploration pits associated with the same mineralized geologic unit. The Dairy Farm deposit is part of the Foothill Copper-Zinc Belt which extends along the western slope of the Sierra Nevada in eastern California (Heyl, 1948). Although total production history of this mine is not well documented (Loyd, 1995), mining began during the 1860s and continued in the early 1900s and 1930s. During 1915, 350 tons of ore per day were mined and more than 500,000 tons of ore with a grade of more than 1 percent copper were blocked out as reserves (Waring, 1919). The underground mine workings followed the mineralized zone to a total depth of at least 500 feet; this massive-sulfide deposit was 10 to 60 feet thick and more than 600 feet long. A cyanide plant with a capacity of 100 tons per day was active on the site prior to 1915 (Waring, 1919). During the 1930s, gold was recovered from cyanidation of gossan, the oxidized portion of the deposit (Clark, 1963).

Open pit mining at the Dairy Farm Mine during the 1920s and 1930s resulted in a pit that extends more than 150 feet below the original land surface. When the water level in CFWR is high, the pit is inundated by the reservoir, whereas at lower water levels, the pit is hydraulically isolated.

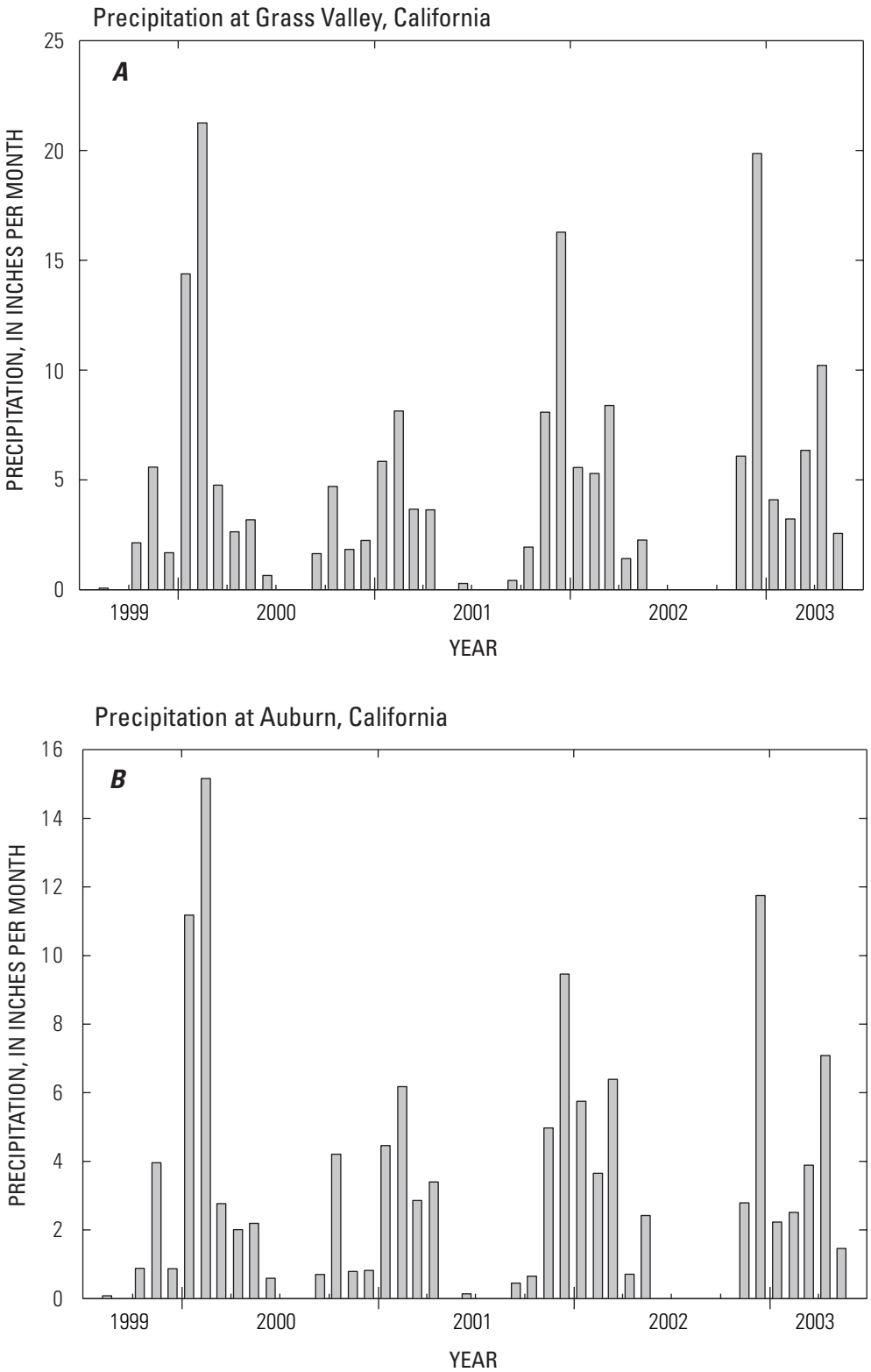


Figure 2. Monthly precipitation data, 1999–2003: (*A*) Grass Valley, California, (*B*) Auburn, California. Data from National Oceanographic and Atmospheric Administration, available on California Data Exchange Center website at the following URLs: http://cdec.water.ca.gov/cgi-progs/queryMonthly?GSV and http://cdec.water.ca.gov/cgi-progs/queryMonthly?AUB

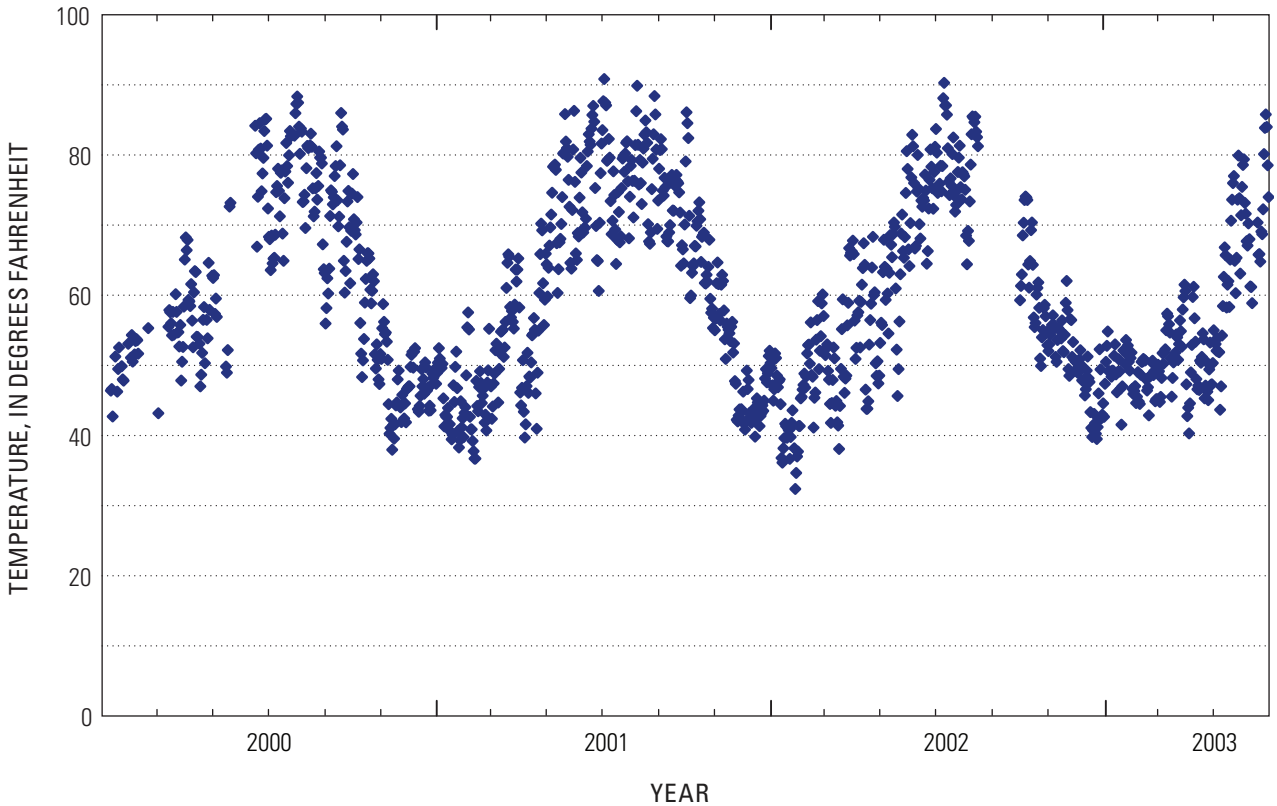


Figure 3. Average daily temperature at Auburn, California, 2000–2003. Data from National Oceanographic and Atmospheric Administration.

The topographic divide that separates the pit lake from the reservoir is at an elevation of about 270 feet above NGVD 29, or about 30 feet below the CFWR spillway elevation. Several acres of the Dairy Farm Mine property were reclaimed, in part, during the 1980s by removing pyrite-bearing waste rock and mill tailings that had led to acidic runoff and poor soil quality (G. Vaughn, California Regional Water Quality Control Board–Central Valley Region, oral commun., 2001). However, the area of the Dairy Farm Mine pit lake was not reclaimed, and the pit lake remains a likely source of trace metals, sulfate, and acidity to CFWR and the lower Bear River.

Reservoir Drawdown History

The original design storage capacity of CFWR was 104,000 acre-feet, although the current maximum storage may be lower because of sedimentation of an unknown magnitude since 1963. A curve describing reservoir storage as a function of water elevation is given in appendix A (fig. A1). Water management at CFWR is controlled by the South Sutter Water District, with the primary goal of water sales for irrigation purposes. A minimum flow for fish habitat of about 10 ft^3/s (cubic feet per second) is released below CFWR during the summer and fall. Water storage during 1999–2004 is shown in figure 4*A*. Daily averages for storage were used to compute monthly averages for 1964–2000; then these averages were grouped by specific month and a long-term (37-year) average for each month was computed (California Department of Water Resources, 2005). Long-term, average monthly water levels (1964–2000) are shown as a dotted, repeated, sinusoidal curve in figure 4*A*. The minimum long-term, average monthly storage occurs in September (43,170 acre-feet) and the maximum in March (101,029 acre-feet); these values are shown as dashed lines in figure 4*A*. A time-series plot of water storage in CFWR for 1963–2004 (fig. 4*B*) indicates that extreme annual fluctuations are common relative to the long-term, average monthly minimum and maximum (dashed lines). Reservoir drawdown during fall 2002, 2003, and 2004 was considerably more extreme than the long-term average monthly minimum, which corresponds to a water surface elevation of 259 feet above NGVD 29 (appendix A, figs. A1–A3).

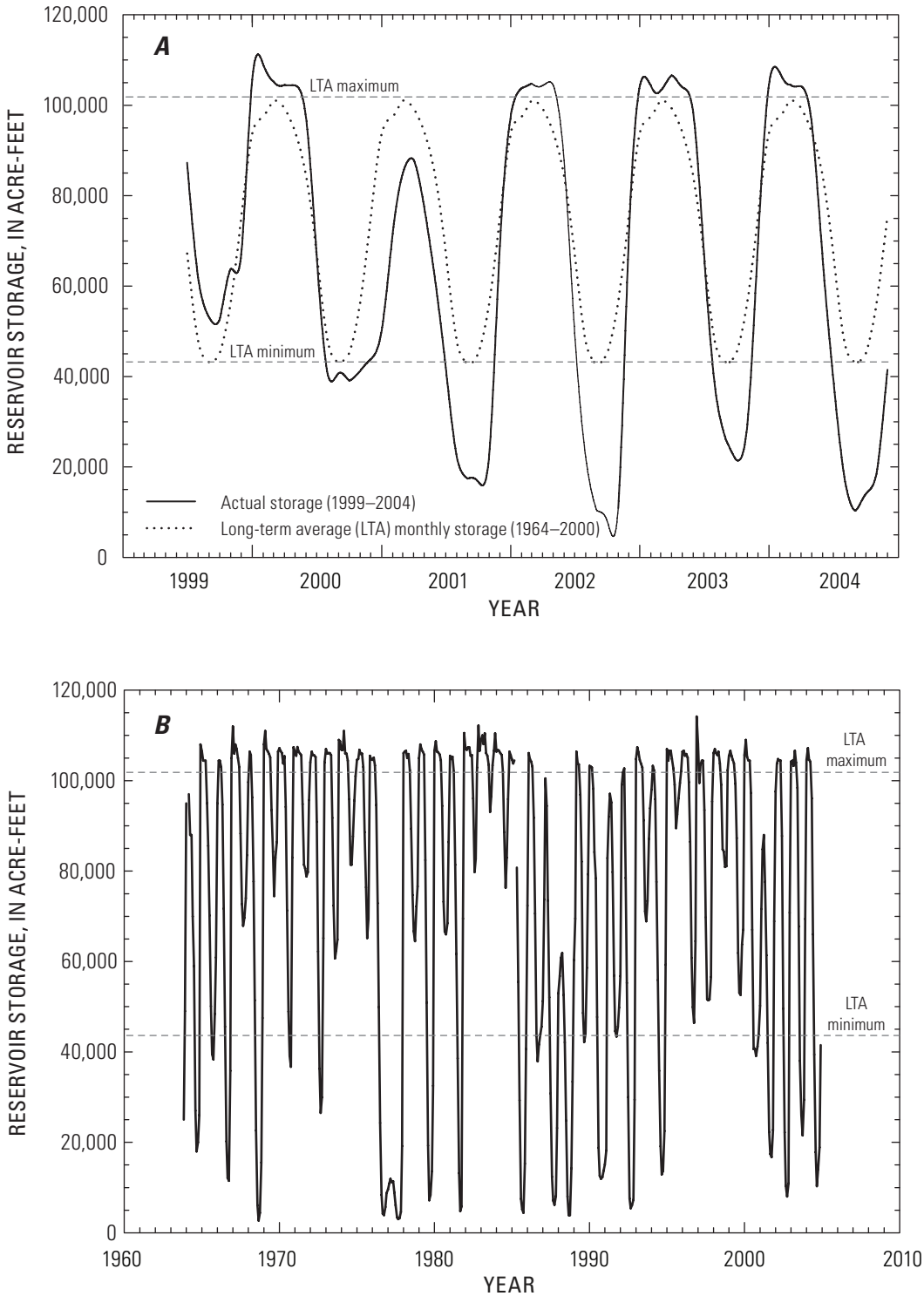


Figure 4. Water storage volume in Camp Far West Reservoir, California: (*A*) Actual monthly storage for 1999–2004 and long-term monthly average (1964–2000), (*B*) Monthly data for 1963–2004.

Study Design

This report documents the water quality at Camp Far West Reservoir (CFWR) during October 2001 through August 2003. The water-quality sampling was coordinated with parallel sampling of zooplankton (Stewart and others, 2008) and bed sediment. Water-quality analyses of samples collected monthly during the study period from tributaries to Camp Far West Reservoir and the Bear River downstream of the reservoir will be reported separately.

Field Measurement Locations

To characterize the seasonal behavior of the reservoir with regard to thermal stratification and associated chemical gradients, the parameters temperature, dissolved oxygen (DO), pH, and specific conductance were measured in vertical water-column profiles at several locations in CFWR (fig. 5). The main focus of this field effort was at 10 locations along the *thalweg* (fig. 5, sites 2, 4, 5, and 10–16). Vertical profiles were measured at three or more of these locations on 17 separate occasions during the study (appendix C, tables C1, C2) and, on some occasions, at relatively shallow-water locations near Camp Far West Dam (site 1), in the mid-reservoir area (site 3), and at locations in the Dairy Farm Arm (site 6) and the Rock Creek Arm (sites 7 and 17–20).

Water-Quality Sampling Locations

The sampling approach was designed to characterize the spatial and seasonal variability of reservoir water quality in terms of chemical and physical properties. The approach also accommodates heterogeneities in the ecological habitats in the water column and the *benthos* that are caused by extreme seasonal variations in water levels and accommodates known geochemical anomalies, such as the abandoned Dairy Farm Mine on the reservoir's south shore (fig. 5). There is a well-known linkage between sulfate reducing bacteria and methylation of mercury (for example, Compeau and Bartha, 1985; Gilmour and others, 1992). Therefore, one purpose of the BRMCP was to gather information that will be useful in quantifying the contributions of sulfate, iron, and other constituents from Dairy Farm Mine pit lake to CFWR and determining the influence of these constituents on mercury methylation and bioaccumulation in the reservoir and river systems.

Water-quality samples were collected at approximately 3-month intervals (referred to as quarterly samples) during a 2-year period, from fall 2001 through summer 2003, at several locations within CFWR (fig. 5; appendix B, table B1). A summary of the water-quality sampling frequency at the various sampling stations in CFWR is provided in appendix B (table B2). The table also indicates the sampling frequency for water, plankton, fish, invertebrates, and sediment at the sampling stations in conjunction with other components of the Bear River Mercury Cycling Project.

Some of the water-quality stations were sampled at multiple depths (table 1). Three of the quarterly sampling stations are located along the thalweg, the former river channel that represents the deepest water at a given distance from the dam. Water-quality sampling typically was done over a 3-day period, referred to as a sampling event. Water-quality sampling was coordinated closely with zooplankton sampling (Stewart and others, 2008) by collecting both within a 1–2 hour period in the same location. Sediment sampling was done within 1–2 weeks of water-quality sampling at common locations.

The thalweg sampling station near Camp Far West Dam is referred to as the Lower Reservoir, Thalweg (LRT) station (also referred to as site 2 in this report). A second station near Camp Far West Dam was established in shallower water near the northern shoreline of the reservoir. This station, referred to as the Lower Reservoir, Shallow (LRS) station (or site 1), was sampled for water quality during five of the eight quarterly sampling events. During the three other sampling events, a shallow water sample was taken at the LRT station.

In the mid-reservoir area (fig. 5), the thalweg sampling station (Mid-Reservoir, Thalweg, or MRT; site 4) was sampled during all eight quarterly sampling events. A nearby location in shallow water (Mid-Reservoir, Shallow, or MRS; site 3) was sampled on four of the eight quarterly sampling events; as with the lower reservoir stations, a shallow sample was taken at the MRT site during sampling events when the MRS site was not sampled.

The Bear River arm of CFWR receives inflows from the principal tributary to the reservoir, the Bear River (fig. 1). The Bear River Arm (BRA) station (site 5), the third of the thalweg stations (fig. 5), was sampled during all eight quarterly sampling events, on some occasions at multiple depths. The Dairy Farm Arm (DFA) station (site 6) is in a small inlet on the southern shoreline of CFWR which receives drainage from the Dairy Farm mine. During periods of extreme drawdown (for example, November 2002), it was not possible to navigate by boat to the previously sampled locations for stations BRA and DFA, so samples were taken closer to the dam.

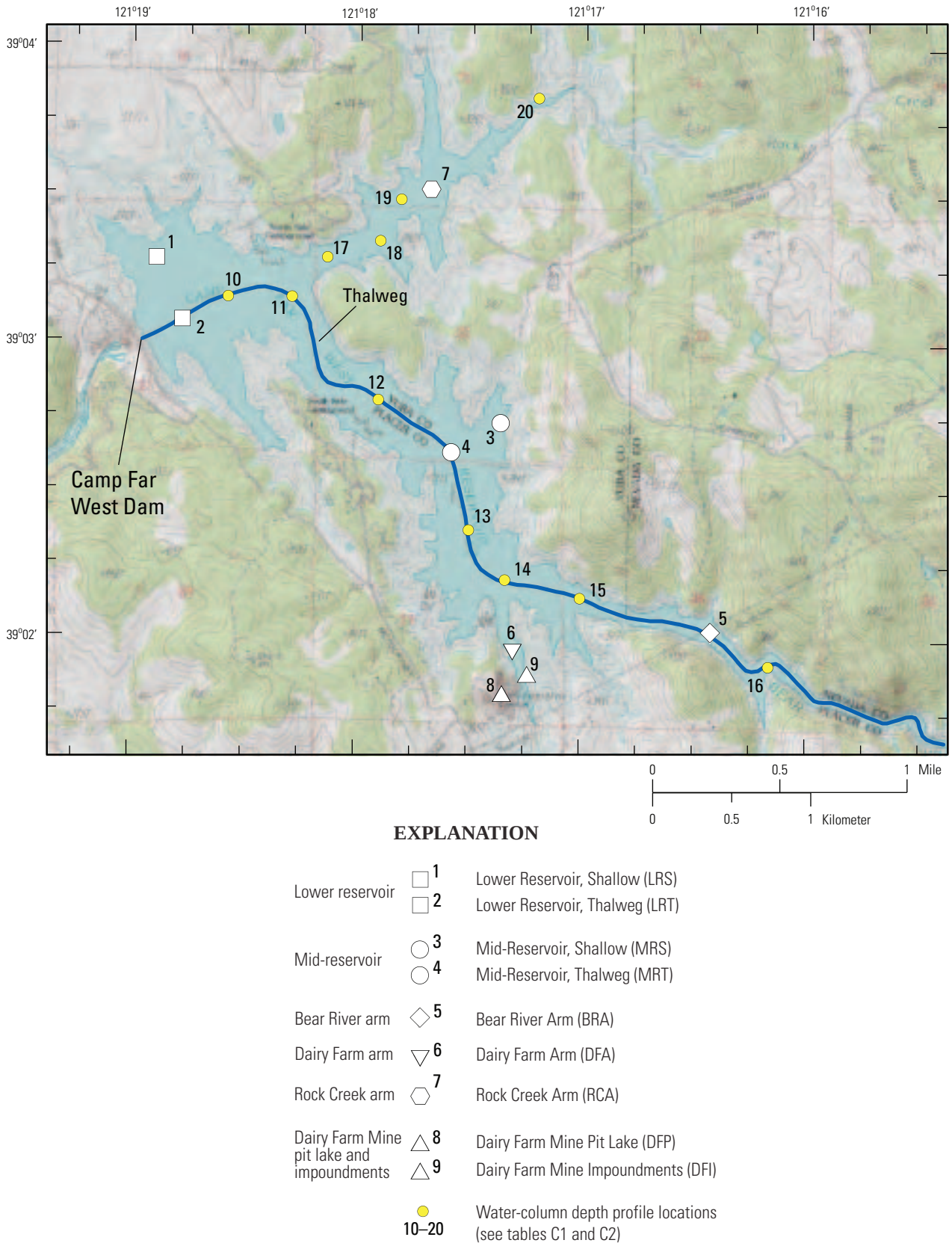


Figure 5. Locations and site numbers for monitoring stations for water-quality monitoring and water-column depth profiles, Camp Far West Reservoir, California.

Table 1. Data for water-quality parameters measured in the field, Camp Far West Reservoir, California.

[Elevations are relative to sea level in relation to the National Geodetic Vertical Datum of 1929. Sample elevation is the difference between the reservoir elevation and the depth below the reservoir surface. Number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Thalweg, former river channel (low elevation path). ft asl, feet above sea level; °C, degree Celsius; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; mm Hg, millimeter of mercury; –, not determined]

Date	Time	Depth (ft)	Reservior water surface elevation (ft asl)	Sample elevation (ft asl)	Water temperature (°C) (00010)	pH (00400)	Specific conductance (µS/cm) (00905)	Dissolved oxygen (mg/L) (00300)	Barometric pressure (mm Hg)
Site 1, LRS: Lower Reservoir, Shallow (Camp Far West Reservoir 0.3 mile north of dam abutment)									
Station number 390317121185001									
10/30/2001	5:15 PM	10	224.8	214.8	17.5	7.8	146	8.2	–
02/12/2002	12:00 PM	8	298.8	290.8	8.0	7.9	111	13.3	–
04/22/2002	3:20 PM	10	299.9	298.9	17.0	7.3	154	10.3	763
08/06/2002	4:30 PM	10	264.0	254.0	26.0	7.9	85	7.3	762
04/15/2003	10:30 AM	40	301.4	261.4	14.0	7.8	81	9.4	763
Site 2, LRT: Lower Reservoir, Thalweg (Camp Far West Reservoir in thalweg near dam near Wheatland)									
Station number 390307121183801									
11/01/2001	8:30 AM	70	225.2	155.2	11.3	6.7	101	0.2	–
02/12/2002	11:00 AM	140	298.2	158.2	7.0	7.4	93	12.3	759
04/22/2002	3:00 PM	140	299.9	159.9	9.0	6.9	155	9.6	763
08/08/2002	12:00 PM	45	262.1	217.1	21.5	6.4	74	2.0	765
08/08/2002	1:30 PM	113	262.1	149.1	10.5	7.0	89	3.5	766
11/04/2002	3:50 PM	10	204.0	194.0	14.2	7.1	114	7.3	754
11/04/2002	3:20 PM	55	204.0	149.0	11.0	6.5	124	3.9	754
01/29/2003	2:30 PM	10	298.0	288.0	10.6	7.6	88	12.0	–
01/28/2003	4:40 PM	140	297.5	157.5	8.1	7.3	70	11.5	–
04/16/2003	4:00 PM	150	300.8	150.8	9.5	7.6	75	8.0	760
08/05/2003	12:30 PM	1	275.1	274.1	27.5	8.4	84	8.9	760
08/05/2003	3:30 PM	73	275.1	202.1	12.1	6.8	78	5.7	–
08/05/2003	1:00 PM	120	275.1	155.1	10.9	6.9	84	4.4	760
Site 3, MRS: Middle Reservoir, Shallow (Camp Far West Reservoir east shoreline 1.6 miles above dam)									
Station number 390244121171801									
10/29/2001	4:15 PM	6	224.6	218.6	18.0	7.8	147	8.2	–
02/12/2002	1:30 PM	60	298.8	238.8	7.0	7.5	94	12.1	–
04/22/2002	1:50 PM	10	299.9	289.9	16.5	7.5	90	14.6	760
04/15/2003	12:40 PM	32	301.4	269.4	15.0	7.9	81	9.6	763
Site 4, MRT: Middle Reservoir, Thalweg (Camp Far West Reservoir in thalweg 1.5 miles above dam)									
Station number 390238121173101									
10/29/2001	2:45 PM	50	224.6	174.6	16.5	7.4	143	6.7	–
02/13/2002	8:30 AM	120	299.2	179.2	7.0	7.4	93	13.5	757
04/22/2002	12:20 PM	120	299.9	179.9	9.5	7.2	154	10.0	761
08/07/2002	12:10 PM	10	263.0	253.0	26.0	7.8	89	9.1	–
08/07/2002	12:40 PM	47	263.0	216.0	19.5	6.6	72	1.6	–
08/08/2002	2:50 PM	80	262.1	182.1	11.0	6.8	94	0.8	767
11/05/2002	2:30 PM	10	204.2	194.2	14.3	6.9	127	10.3	756
11/05/2002	2:10 PM	30	204.2	174.2	13.8	6.9	134	10.5	754
01/29/2003	2:00 PM	10	298.0	288.0	9.8	7.4	75	12.1	–
01/28/2003	3:30 PM	120	297.5	177.5	8.2	7.4	69	11.8	–
04/17/2003	10:30 AM	125	300.6	175.6	9.7	7.8	76	8.5	–
08/07/2003	11:30 AM	1	273.5	272.5	26.6	7.8	84	7.7	–
08/07/2003	11:50 AM	100	273.5	173.5	11.4	6.9	81	4.4	–

Table 1. Data for water-quality parameters measured in the field, Camp Far West Reservoir, California.—*Continued*

[Elevations are relative to sea level in relation to the National Geodetic Vertical Datum of 1929. Sample elevation is the difference between the reservoir elevation and the depth below the reservoir surface. Number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Thalweg, former river channel (low elevation path). ft asl, feet above sea level; °C, degree Celsius; µS/cm, microsiemens per centimeter; mg/L, milligram per liter; mm Hg, millimeter of mercury; –, not determined]

Date	Time	Depth (ft)	Reservior water surface elevation (ft asl)	Sample elevation (ft asl)	Water temperature (°C) (00010)	pH (00400)	Specific conductance (µS/cm) (00905)	Dissolved oxygen (mg/L) (00300)	Barometric pressure (mm Hg)
Site 5, BRA: Bear River arm (Camp Far West Reservoir Bear River arm near Wheatland)									
Station number 390202121162201									
10/31/2001	10:15 AM	12	225.0	213.0	15.5	7.3	138	7.3	
02/13/2002	9:00 AM	80	299.2	219.2	7.0	7.5	84	14.2	758
04/22/2002	10:40 AM	80	299.9	219.9	10.5	7.3	144	4.2	756
08/06/2002	5:50 PM	10	264.0	254.0	26.0	7.1	88	6.5	758
08/06/2002	6:20 PM	55	264.0	209.0	13.0	6.6	92	0.0	758
11/05/2002	4:10 PM	7	204.2	197.2	15.3	8.0	106	12.6	756
01/29/2003	1:20 PM	10	298.0	288.0	9.9	7.3	72	8.5	–
01/28/2003	2:50 PM	85	297.5	212.5	8.2	6.7	72	7.9	–
04/17/2003	11:30 AM	90	300.6	210.6	10.0	7.5	77	9.8	–
08/07/2003	10:00 AM	1	273.5	272.5	26.7	7.3	88	7.2	–
08/06/2003	3:00 PM	100	274.5	174.5	19.4	6.5	96	0.2	763
Site 6, DFA: Dairy Farm arm (Camp Far West Reservoir Dairy Farm arm near Wheatland)									
Station number 390159121171401									
10/31/2001	1:00 PM	4	225.0	221.0	17.6	7.7	148	8.4	–
02/13/2002	1:00 PM	20	299.2	279.2	8.5	7.7	103	12.9	758
04/23/2002	12:10 PM	20	299.9	279.9	16.0	8.1	84	10.3	759
08/07/2002	6:50 PM	57	263.0	206.0	17.5	6.5	76	0.5	–
01/30/2003	3:30 PM	55	299.0	244.0	8.7	6.8	85	10.7	–
04/17/2003	2:30 PM	55	300.6	245.6	11.1	7.4	84	10.9	759
08/07/2003	4:00 PM	1	273.5	272.5	27.2	7.6	88	7.8	–
Site 7, RCA: Rock Creek arm (Camp Far West Reservoir Rock Creek arm)									
Station number 390331121174101									
08/07/2002	03:40 PM	10	263.0	253.0	26.1	7.7	89	8.5	–
04/17/2003	01:20 PM	80	300.6	220.6	10.5	7.6	79	10.0	761
08/07/2003	01:00 PM	1	273.5	272.5	27.5	7.9	85	7.8	–
08/07/2003	01:30 PM	40	273.5	233.5	26.4	7.1	89	4.5	–
Site 8, DFP: Dairy Farm Mine Pit Lake (Dairy Farm Mine pit lake near Wheatland)									
Station number 390148121171701									
10/31/2001	2:15 PM	1	225.0	224.0	11.3	3.0	1,380	9.2	–
02/13/2002	3:10 PM	10	299.2	289.2	8.5	7.7	103	3.7	755
02/13/2002	3:30 PM	35	299.2	264.2	8.0	6.9	105	1.1	755
04/24/2002	11:10 AM	30	300.0	270.0	11.0	7.7	108	9.2	760
08/07/2002	5:00 PM	0.5	263.0	263.0	26.0	4.0	274	9.0	–
11/05/2002	2:50 PM	1	204.2	204.2	–	3.1	900	–	–
01/30/2003	12:30 PM	10	299.0	289.0	11.0	6.5	85	8.7	–
01/30/2003	1:20 PM	38	299.0	261.0	9.2	4.6	203	10.2	–
04/17/2003	4:00 PM	40	300.6	260.6	10.5	5.0	165	7.8	759
08/07/2003	4:30 PM	1	273.5	272.5	24.0	6.5	125	8.7	–
Site 9, DFI: Dairy Farm Mine Impoundments (Camp Far West Reservoir impoundment Dairy Farm Mine arm)									
Station number 390152121171001									
10/31/2001	2:40 PM	0.5	225.0	224.5	17.1	5.0	792	9.0	–
02/13/2002	2:20 PM	52	299.2	247.2	8.0	7.1	105	11.8	755
04/23/2002	1:10 PM	20	299.9	279.9	16.0	8.0	84	10.0	759
11/05/2002	2:00 PM	0.5	204.2	204.2	–	3.9	1,660	–	–

The Dairy Farm Mine pit lake (station DFP, site 8), located on the southern shore of CFWR (fig. 5), is isolated from the reservoir during low stage but is connected with the reservoir during high stage. Water-quality samples were collected at the DFP station during each of the eight quarterly sampling events. During high stage, when boat access was possible, water-quality samples were collected from multiple depths. During low stage, grab samples were collected from the shore of the pit lake. During some of the sampling events, grab samples also were collected from impoundments near the Dairy Farm Mine (station DFI; site 9), which are isolated when the reservoir is at low stage.

The Rock Creek Arm (RCA) station (site 7) is located in the northeastern part of CFWR (fig. 5). Rock Creek is a relatively minor tributary with a small drainage area. Although this location was not originally chosen for intensive sample collection, it became one of three principal sites for sampling invertebrates and fish, because insufficient habitat was found at the Mid-Reservoir, Shallow site. Water samples were taken from the RCA station during three of the eight quarterly sampling events (appendix A, table A2).

Field Methods, Sample Collection, and Processing

A multi-probe sonde (YSI model 600 XLM) was used to measure vertical profiles of temperature, pH, dissolved oxygen (DO), and specific conductance in the water column. Initially measurements were made at 5-foot intervals; then measurements were made at 1-foot intervals in parts of the profile where results varied most. The sonde was calibrated according to the specifications of the manufacturer. During the study, the sonde was returned to the manufacturer once for routine factory maintenance.

Specialized cleaning and sampling techniques were used during all stages of collection of discrete water samples to minimize sample contamination. Prior to use, all containers and equipment used for water and sediment sampling were cleaned using a dilute liquid soap followed by a 5-percent hydrochloric acid solution and multiple rinses in ultrapure, deionized (DI) water (18 MΩ-cm [megaohm-centimeter]), following standard USGS protocols (Shelton, 1994).

Water samples were pumped from discrete depths using a peristaltic pump attached to a Teflon® tubing line. After collection in containers made of Teflon® or lined with fluorinated plastic that is similar to Teflon® in its wetting and cleaning properties, the water samples were transferred to a Teflon®-lined churn for splitting. Water samples collected for analysis of suspended solids concentration (SSC) were taken from the churn and collected in pre-weighed 1-L Nalgene bottles. In contrast to all other splits, the bottles for SSC samples were not rinsed with the ambient water, to avoid introducing extraneous suspended solids to the container. The SSC samples were chilled on wet ice or refrigerated at 5 ºC until analysis.

Discrete water samples collected from specific depths in the reservoir were analyzed for six types of mercury: (1) total mercury (Hg_T) in unfiltered water, (2) Hg_T in filtered water, (3) particulate Hg_T, (4) monomethylmercury (MeHg) in unfiltered water, (5) MeHg in filtered water, and (6) particulate MeHg. (For the remainder of this report, the term methylmercury [also abbreviated as MeHg] is used instead of “monomethylmercury”; note that other methylated forms of mercury such as dimethylmercury may be present but are not included in reported methylmercury analyses.) Analyses of Hg_T in water for this study were done by two laboratories: the USGS National Research Program laboratory in Boulder, Colorado (referred to as the Boulder lab) and the USGS Wisconsin Mercury Research Laboratory (WMRL) in Middleton, Wisconsin (referred to as the Wisconsin lab). An extensive laboratory intercomparison was performed on split samples for this project and two other concurrent projects, as discussed in section, “Quality Assurance and Quality Control” of this report. All analyses of MeHg in water for this study were done by the USGS Wisconsin lab.

Two different procedures were used to filter the water samples. A Gelman Sciences polysulfone, tortuous-path capsule filter of 0.45-µm nominal pore size (model 12175) was used for most constituents. On selected samples for analysis of Hg_T and MeHg, a quartz fiber filter (QFF) of nominal 0.7-µm pore size was used. Particulate Hg_T and MeHg were determined directly using the material trapped by the QFFs. These QFF particulate concentrations were compared with the differences in concentration between unfiltered samples and filtered samples (Gelman capsule filter), as described in section “Quality Assurance and Quality Control”).

Alkalinity (a proxy for dissolved bicarbonate) was analyzed by titration in the laboratory on a filtered subsample (stored chilled in darkness until analysis), usually within 48 hours of collection. Major cations (calcium, iron, magnesium, potassium, silica, and sodium) and more than 40 trace elements were analyzed in filtered and unfiltered samples by the USGS Boulder lab. Major anions (sulfate and chloride in filtered samples only) also were analyzed by the USGS Boulder lab. Nutrients in filtered and unfiltered samples were analyzed by the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado. Forms of nitrogen (N) that were analyzed included ammonia plus organic N in both unfiltered and filtered water, and the following three forms of N in filtered water only: ammonia, nitrite, and nitrite plus nitrate. Forms of phosphorus (P) that were analyzed included total P in both unfiltered and filtered water, and orthophosphate in filtered water only. Organic carbon in filtered and particulate form was analyzed by the USGS NWQL. The USGS laboratory in Marina, California, determined concentration of suspended solids in water

samples along with the percentage of fine material (<0.063 mm diameter) in the suspended solids. These quantities were combined to compute the concentration of suspended silt and clay. The terms “suspended solids” and “suspended sediment” are used interchangeably in this report. The procedure used by the USGS Marina laboratory did not include oxidations of the samples of suspended solids (for example using hydrogen peroxide, as in Poppe and others, 2000) to remove organic matter; therefore, the material that was measured is best described as “suspended solids” rather than the term “suspended sediment,” which is often reserved to refer to residual inorganic material after organic material has been removed. Nevertheless, the results from the Marina lab appear in USGS databases as parameter code 80154, which is identified as “suspended sediment.”

Filtered and unfiltered water samples for analysis of Hg_T by the USGS Boulder lab were stored in acid-washed glass bottles provided by the laboratory and were preserved using a potassium dichromate–nitric acid solution. Filtered and unfiltered water samples for analysis of Hg_T and (or) MeHg by the Wisconsin lab were stored in acid-washed Teflon® bottles and preserved with a distilled (sub-boiling) 50-percent hydrochloric acid solution, all provided by the laboratory. Filtered and unfiltered samples for analysis of major cations and trace elements were stored in acid-washed high-density polyethylene (HDPE) bottles and preserved using distilled, nitric acid provided by the Boulder lab.

Filtered samples collected for analysis of anions were chilled on wet ice and then refrigerated at less than 5°C until analysis. Unfiltered samples collected for analysis of nutrients were preserved using a sulfuric acid solution and then chilled on wet ice followed by refrigeration; filtered nutrient samples were not acidified but were chilled until analyzed. Samples collected for analysis of stable isotopes of hydrogen and oxygen in water were stored in glass bottles with polyseal caps with minimal headspace to minimize evaporation. Aqueous sulfate was precipitated from filtered water samples at 90°C using a barium chloride solution after using HCl to lower the pH value to about 2; the resulting barium sulfate precipitate was filtered using 0.7-µm pore diameter filters and then transferred to silver-foil trays.

Laboratory data for aqueous concentrations are reported in units of mass per volume. Typical units for constituents appearing in data tables in this report are milligrams per liter (mg/L), micrograms per liter (µg/L) and nanograms per liter (ng/L). Some constituents are plotted using molar units to facilitate a more direct comparison of constituents. Converting concentration data from milligrams per liter (mg/L) to *micromoles per liter* (µmol/L) is by the formula 1,000*(mg/L)/MW = µmol/L, where MW is the molecular weight of the constituent in grams per mole (g/mol). Constituents plotted using molar units (and corresponding chemical symbol and value of MW, in g/mol) are as follows: calcium (Ca, 40.078), chloride (Cl, 35.453), nitrogen (N, 14.0067), phosphorus (P, 30.97376), sodium (Na, 22.98977), and sulfate (SO_4, 96.0626).

Laboratory Methods

For USGS-approved methods used for routine analyses by laboratories such as the USGS NWQL, relatively little method information is given in this report, and the reader is referred to published sources. More detailed information is given in this section for research methods that have not been officially approved by the USGS.

Analysis of total mercury (Hg_T) in water by the USGS Boulder lab was done using cold-vapor atomic fluorescence spectrometry (CVAFS). Mercury stock and standard solutions were made from 99.9995 percent mercuric chloride ($HgCl_2$) salt and preserved in a solution of high-purity nitric acid and primary-standard grade potassium dichromate using the same reagents and concentrations as those used to preserve samples. Deionized water (type 1, 18 MΩ-cm) was used for preparing all standards and reagent solutions. A solution of 3-percent hydrochloric acid (volume:volume, hydrochloric acid:type 1, 18 MΩ-cm DI water) was used to prepare a 2-percent stannous chloride ($SnCl_2$) solution (wt:volume, stannous chloride:3-percent hydrochloric acid), which was used to reduce mercury to its elemental form in the cold vapor reactor. The vapor was transported to the detector with a stream of argon gas. Trace concentration levels of mercury were measured using an automated, cold-vapor atomic-fluorescence spectrometer or CVAFS (PS Analytical) using methods described previously (Roth, 1994; D.A. Roth, U.S. Geological Survey, written commun., 1999). Instrument parameters for the CVAFS mercury analysis were the same as those described by Alpers and others (2000). Peak-height intensities of unknown samples were compared to a six-point calibration curve prepared from aqueous standards ranging in concentration from 0 to 50 ng/L.

Analysis of Hg_T in unfiltered and filtered water by the USGS Wisconsin lab was done using procedures described by Olson and De Wild (1999), approved as USGS production methods. Methylmercury (MeHg) in water was analyzed at the Wisconsin lab using ethylation-distillation CVAFS methods with double amalgamation, as described by Olson and De Wild (1999) and De Wild and others (2002). Analysis of MeHg in water by the WMRL was approved by the USGS Branch of Quality Assurance as a production method in August 2002 after some of the analyses for this report were completed. The method used by the Wisconsin lab to analyze MeHg in water samples in this study prior to the date of method approval was identical to the USGS-approved method. Therefore, MeHg data collected throughout the study period are expected to be of consistent quality, despite the change in the approval status of the method.

Major cations and trace metals in water were analyzed by inductively coupled plasma (ICP) methods: both atomic emission spectrometry (AES) and mass spectrometry (MS) were used. Major elements, including calcium (Ca), iron (Fe), magnesium (Mg), potassium (K), sodium (Na), and silica (Si, reported as SiO_2), were determined by ICP–AES techniques using a Perkin-Elmer Optima 3300DV multi-channel emission

spectrometer. Use of the dual-view (radial and axial) optical configuration provided optimal sensitivity for various elements regardless of concentration. A description of the analysis conditions and procedures is reported by Garbarino and Taylor (1996). Details of the operational conditions are described by Mitko and Bebek (1999, 2000). Except for mercury, trace-element determinations were done by ICP–MS using a Perkin-Elmer Elan Model 6000. Aerosols of acidified aqueous samples were introduced into the spectrometer with a cone-spray pneumatic nebulizer. Multiple internal standards (indium [In], iridium [Ir], and rhodium [Rh]), which spanned the mass range, were used to normalize the system for drift. Details of the specific analysis techniques, procedures, and instrumental settings are described by Garbarino and Taylor (1996) and Taylor (2001). Major anions in filtered water (chloride and sulfate) were analyzed by ion chromatography following procedures described by Fishman and Friedman (1989).

Nutrients in each water sample were analyzed for three forms of phosphorus (P) and five forms of nitrogen (N), as described below. The three types of phosphorus analyses included orthophosphate in filtered water, plus total phosphorus in unfiltered and filtered water. Orthophosphate was determined using an automated, colorimetric, phosphomolybdate-blue procedure, with antimony (Sb) added to increase the reduction rate (Patton and Truitt, 1992; Fishman, 1993). Total phosphorus was determined colorimetrically as orthophosphate after Kjeldahl digestion (Patton and Truitt, 1992). The five types of nitrogen analyses included the following forms in filtered water only: (1) nitrite (NO_2^-), (2) nitrite plus nitrate (NO_3^-), and (3) ammonia (NH_3), as well as ammonia plus organic nitrogen, which was analyzed in filtered and unfiltered water. The method used to analyze nitrite was diazotization using sulfanilamide and N-1-naphthylethylenediamine under acidic conditions to form a red compound, the absorbance of which was determined colorimetrically using an automated-segment flow procedure (Fishman, 1993). The concentration of nitrite plus nitrate was determined by reducing nitrate to nitrite using cadmium metal; the nitrite was then analyzed by diazotization (Fishman, 1993). Ammonia was analyzed using a alicylatehypochlorite method, in the presence of ferricyanide ions, that produces the salicylic acid analog of indophenol blue, which was analyzed colorimetrically using an automated-segment flow procedure (Fishman, 1993). The concentration of ammonia plus organic nitrogen in unfiltered and filtered samples was determined using the same Kjeldahl digestion as that used for total phosphorus, in which the organic nitrogen is reduced to the ammonium ion, followed by determination of the ammonium ion concentration by the colorimetric salicylate-hypochlorite method (Fishman and Friedman, 1989; Patton and Truitt, 1992).

Concentrations of dissolved organic carbon (DOC) were determined in 100-mL filtered water samples (0.45-µm silver membrane filter). The filtrates were acidified before analysis to remove dissolved and colloidal carbonates and bicarbonates while mitigating the effects of humic-substance precipitation. Then the organic carbon was oxidized to carbon dioxide by adding persulfate and exposing the samples to ultraviolet light. The carbon dioxide was then measured by infrared spectrometry using a Dorhmann carbon analyzer (Brenton and Arnett, 1993). Particulate organic carbon (POC) concentrations were determined in the residual material that was collected on the silver membrane filters used to prepare DOC samples. The silver membrane filters were treated with acid to dissolve inorganic forms of carbon, then were reacted with potassium persulfate in glass ampules for 4 hours at 116 to 130°C. The ampules then were broken in the carbon analyzer, releasing carbon dioxide, which was measured by infrared spectrometry using an Oceanography International carbon analyzer (Wershaw and others, 1987).

Stable isotope ratios of hydrogen ($^2H/^1H$, where ^2H is deuterium or D) and oxygen ($^{18}O/^{16}O$) in water were determined using standard methods by the laboratory in the Department of Geology at the University of California, Davis under the direction of Howard Spero. Oxygen isotope ratios in water, expressed as $\delta^{18}O_{H2O}$ in units of permil (parts per thousand, or ‰) relative to Vienna Standard Mean Ocean Water (VSMOW), were determined by conventional mass spectrometer after equilibration with carbon dioxide, a modification of the technique of Epstein and Mayeda (1953). Hydrogen isotope ratios, expressed as δD in units of permil relative to VSMOW, were determined by conventional mass spectrometer by the zinc shot technique (Coleman and others, 1982). Three working standards calibrated to VSMOW and other standard reference waters supplied by the International Atomic Energy Agency (IAEA) were analyzed in duplicate with each batch of water samples analyzed. Analytical uncertainty was ± 0.05 permil for $\delta^{18}O_{H2O}$ and ±1.0 permil for δD.

Stable isotope ratios of sulfur ($^{34}S/^{32}S$) and oxygen ($^{18}O/^{16}O$) in aqueous sulfate were analyzed at the USGS laboratory in Denver, Colorado, under the direction of Robert O. Rye using continuous flow mass spectrometer techniques (Fry and others, 1992; Kester and others, 2001). Sulfur isotopes in aqueous sulfate are expressed as $\delta^{34}S_{SO4}$ and are reported relative to the Cañon Diablo Troilite (CDT). Oxygen isotopes in aqueous sulfate are expressed as $\delta^{18}O_{SO4}$ and are reported relative to VSMOW. Analytical uncertainty was ±0.2 permil for $\delta^{34}S_{SO4}$ and ±0.5 permil for $\delta^{18}O_{SO4}$.

Statistical Methods

A large proportion of the measured concentrations of methylmercury (MeHg), especially those in filtered water, were below the method detection limit (MDL) of 0.04 ng/L. Results below the MDL are referred to as non-detects or censored data. Procedures for computing statistics of data sets with a large proportion of non-detects are described in detail by Helsel (2005). For constituents with less than 50 percent

non-detects, a parametric procedure known as the Kaplan-Meier approach is recommended. Determining the median value of such data sets is straightforward, and if it is assumed that the data fit a *lognormal distribution*, this distribution can be used to estimate values for the mean, standard error, and other characteristic values such as the 25th percentile value. For data sets with 50 to 80 percent non-detects and a total of less than 50 detected values, Helsel (2005) recommends either of two procedures: a parametric procedure known as Maximum Likelihood Estimation (MLE) or a non-parametric procedure known as Regression on Order Statistics (ROS).

Results for MeHg in unfiltered water and the ratio of MeHg to total mercury ($MeHg/Hg_T$) in unfiltered water were in the category of less than 50 percent non-detects, whereas results for MeHg and $MeHg/Hg_T$ in filtered water were in the 50 to 80 percent non-detect category. Statistical properties of the unfiltered MeHg data were evaluated using both the Kaplan-Meier and the ROS approaches, with similar results. The statistical software program MINITAB (MiniTab, Inc., State College, Penn.) was used with the macro CROS (Helsel, 2005) for this analysis. Only the ROS approach could be used for the filtered MeHg data. For consistency among all the MeHg data (unfiltered and filtered), statistical results are reported using the ROS approach for all MeHg constituents, including values of $MeHg/Hg_T$.

Other statistical quantities were computed to characterize the variability (or precision) of laboratory data. To evaluate the variability among replicate samples, the *relative percentage difference (RPD)* was computed as the absolute value of the difference between reported values divided by the average of the reported values, multiplied by 100 percent. To evaluate the variability among data representing multiple analytical observations of the same sample, the *relative standard deviation (RSD)* was computed as the standard deviation of three or more analyses divided by the average of the measurements, multiplied by 100 percent.

Results below the MDL are represented on scatter plots by plotting points at one-half the MDL with an error bar extending from the MDL to the axis. In these situations, the value of one-half of the MDL is not intended to represent an estimate of the concentration for these samples, but rather is used so that identifying characteristics of the sample, such as location and season of collection, can be displayed in a manner similar to other samples with detected concentration values.

Quality Assurance and Quality Control

A variety of measurements and analyses were used to determine the quality of the data generated in this study (appendixes E and F). The quality-assurance (QA) program consisted of quality-control (QC) measures including field and laboratory blanks, standard reference materials (SRM) where available, spike recoveries, and replicate samples. Quality-control measures used during analysis of MeHg in water were described by De Wild and others (2002). Water samples were analyzed in batches of 11 samples plus three laboratory blanks, a matrix spike, and a matrix spike duplicate. The reported values for MeHg concentrations were corrected for daily blank values, as described by De Wild and others (2002).

Detection Limits

The method for total mercury (Hg_T) used by the USGS Boulder lab had a method detection limit (MDL) of 0.4 ng/L, whereas the USGS Wisconsin lab's method had an MDL for Hg_T of 0.04 ng/L, one order of magnitude lower. The concentrations of Hg_T detected in all environmental samples collected for this study were above the MDL for the Wisconsin lab: however, the Hg_T concentrations in some of the filtered samples were below the MDL for the Boulder lab. The MDL for MeHg in water at the USGS Wisconsin lab, defined using standard protocol (U.S. Environmental Protection Agency, 1990), was 0.025 ng/L during 1999–2000 and 0.04 ng/L during 2001–03. A conservative MDL for MeHg of 0.04 ng/L is used throughout this report.

Major and trace elements in water were analyzed by inductively coupled plasma (ICP) methods; each analysis consisted of at least four replicate instrumental measurements. Each filtered and unfiltered sample was collected in duplicate and analyzed in triplicate. The triplicate analyses were analyzed statistically and the analyses were accepted if the standard deviation was within standard tolerances of precision (generally less than 15 percent of the amount present). The error tolerance is increased for analyses close to the detection limit for a given analyte. Median detection limits for trace elements and selected major elements analyzed by ICP methods are given in appendix E (table E11).

Blanks

Data for Hg_T in unfiltered and filtered blanks are given in appendix E (tables E1 and E2), respectively, for analyses by the USGS Boulder lab and in tables E3 and E4, respectively, for analyses by the USGS Wisconsin lab. To present the most realistic indication of possible Hg_T contamination, tables E1–E4 include data for all blanks submitted to the respective laboratories by the USGS California Water Science Center during the period when samples were analyzed for this study, including blanks collected at some field sites outside Camp Far West Reservoir using similar equipment and techniques.

Several purified water sources were used for Hg_T blanks, including a MilliQ purification system at the USGS laboratory in Sacramento, California, an in-house deionization system in Sacramento capable of preparing ASTM Class 1 deionized water, a polished water system in Sacramento designed to produce organic-free water, and the deionized water system at the USGS Wisconsin lab. The Hg_T concentration in the source-blank waters ranged from below the Wisconsin lab's method detection limit (less than 0.04 ng/L)(table E3) to

2.5 ng/L(table E1). Because the MilliQ and the polished water systems produced unexpectedly high Hg_T concentrations (2.3 and 2.5 ng/L, respectively) early in the study (October 2001 to January 2002), deionized water from the USGS Trace Metals Laboratory in Sacramento and the USGS Wisconsin lab were used for the remainder of the study, resulting in source blank Hg_T concentrations less than 1.0 ng/L (tables E1, E3).

To determine the central tendency of Hg_T concentrations in blanks, median values and upper confidence limits were calculated separately for filtered and unfiltered blanks using the Kaplan-Meier method (Helsel, 2005). This approach, as implemented in the USGS library of S-Plus, was used to determine the cumulative probability distribution from ranked data and to estimate summary statistics. The method was selected because it is non-parametric (that is, it does not assume normally distributed data) and because it can incorporate censored data with multiple detection limits. For the unfiltered blanks (tables E1, E3), the median concentration of Hg_T was 0.11 ng/L and the upper 95-percent confidence level was 0.32 ng/L. For the filtered blanks (tables E2, E4), the median concentration of Hg_T was 0.08 ng/L and the upper 95-percent confidence level was 0.14 ng/L. In addition, percentiles for the Hg_T blank data were calculated using the binomial distribution applied to ranked data. For the unfiltered data (tables E1, E3), the 90th percentile with a 90-percent confidence level was 0.94 ng/L, a value less than the minimum Hg_T concentration (1.0 ng/L) detected in environmental samples. For the filtered blanks (tables E2, E4), the 90th percentile at an 88-percent confidence level was 0.88 ng/L. In comparison, the median values for all unfiltered and filtered Hg_T in environmental samples analyzed in this study were 4.3 and 0.9 ng/L, respectively. The 25th percentile value for Hg_T in filtered environmental samples for this study was 0.4 ng/L.

Thus, some of the filtered blank values for Hg_T are in the same concentration range as the values for some of the filtered environmental samples. In some cases, the elevated blank results correspond to elevated Hg_T in blank water sources. The standard procedure of rinsing sampling equipment and sample bottles with the ambient water reduces potential Hg_T contamination from deionized water used to clean equipment. Nevertheless, low-level values for Hg_T in filtered environmental samples must be interpreted with due caution.

Concentrations of MeHg in unfiltered and filtered blanks analyzed at the USGS Wisconsin lab during this study are given in tables E5 and E6, respectively. Source water for MeHg blanks was provided by the USGS Wisconsin lab. Methylmercury concentrations in all source blanks, equipment blanks, and process blanks analyzed during the study period were below the MDL (0.04 ng/L).

Concentration values for trace metals and major elements in blanks are given in table E7 (unfiltered: equipment blanks, preservation acid blanks, and source blanks) and table E8 (filtered: process blanks and filter blanks). Results for trace elements in blanks (tables E7 and E8) generally were near or below method detection limits (table E11). Data for anion blanks are given in table E9. Data for blanks for nutrients and organic carbon are shown in table E10. Values for anion, nutrients, and organic carbon blanks were uniformly low, indicating high data quality.

Standard Reference Materials

When each batch of samples was analyzed by ICP for trace element and major cations, several standard reference materials (SRM) also were analyzed as part of the QA program. A similar procedure was used with each batch of samples analyzed for mercury by CVAFS at the USGS Boulder lab. Plots of reported values in relation to observed values for certified SRM, USGS standard reference water samples (SRWS), and specific rare-earth element reference materials (PPREE1 and SCREE1; Verplanck and others, 2001) are shown in appendix F (figs. F1–F7). For nearly all elements considered, the SRMs span ranges of concentrations comparable to the ranges of concentrations for environmental samples in this study. The number of times each standard was analyzed during 2001–03 is indicated in the explanation of each figure; the standards typically were analyzed several hundred times during the study period. There is excellent agreement between all reported and observed values for the standards. Regression correlation coefficients were derived from correlation plots of observed and reported values for the analysis of standard reference materials for 21 selected trace elements (table E12); these coefficients ranged from a minimum of 0.9969 for selenium to a maximum of 1.000 for eight trace elements (beryllium, cadmium, cobalt, copper, lead, manganese, molybdenum, and strontium).

Spiked Blanks and Spiked Samples

Data for spiked blanks for the elements arsenic, cadmium, copper, lead, and zinc for analyses made during 2002–04 are given in appendix F (fig. F8). In nearly all cases, spike recoveries were within the control range of 80 to 120 percent of the expected amount. Data for spiked blanks having an expected Hg_T concentration of 5 ng/L (fig. F9) indicate that nearly all results fell within the control range of 80 to 120 percent recovery. Field samples were spiked at levels generally three to ten times the ambient concentration of each element. Results for spiked field samples for the same five trace elements as were used for the spiked blanks (fig. F10) and for mercury (fig. F11) indicate again that nearly all spike recoveries were within the control range of 80 to 120 percent of the expected value.

Replicate Analyses

Split samples for analysis of trace elements and total mercury by the USGS Boulder lab were collected in pairs of bottles designated as split replicates “1 of 2” and “2 of 2.” Because replicate split samples were routinely analyzed as separate unknowns and each replicate was analyzed in triplicate, plots of replicate 1 versus replicate 2 indicate analytical precision and variability in the sampling-splitting procedure as well as possible contamination of bottles and (or) sample-splitting equipment. The plots in figures F12–F13 show that there were very few outliers for replicate analyses of 12 elements analyzed by the USGS Boulder lab during the study period. The relative standard deviation (RSD) of replicate analyses is another measure of analytical precision. A plot of the relation between RSD and concentration for six elements (fig. F14) shows, as expected, that RSD values generally were smaller at higher concentrations. For antimony, cadmium, copper, gadolinium, and lead, nearly all RSD values were less than 10 percent when concentrations were greater than 100 times the MDL, and most values were less than 20 percent when concentrations were between 10 and 100 times the MDL. For magnesium, RSD values were less than 20 percent for all concentrations, Average concentrations and standard deviations for replicate analyses of total mercury by the USGS Boulder lab are shown for filtered water (fig. F15) and unfiltered water (fig. F16). As with other constituents, standard deviations for analyses of total mercury represented a larger proportion of the amount present (corresponding to larger RSD values) at concentrations closer to the MDL. Therefore, the relative variability between replicate samples is highest at low concentrations.

Split-Sample Comparison for Total Mercury

During the study, a transition was made from the USGS Boulder lab to the USGS Wisconsin lab for the analysis of Hg_T to take advantage of the lower detection limit of the methods used at the Wisconsin lab. Split-samples containing Hg_T in filtered and unfiltered water were compared using 14 samples taken during the sampling events in November 2002 and January 2003. Two replicate bottles of each sample were sent to the Boulder lab and one replicate bottle was sent to the Wisconsin lab. Comparison of the results of the replicate analyses by the two laboratories (figs. F17 and F18) indicates excellent agreement for all samples with Hg_T concentrations greater than 0.4 ng/L, the MDL for Hg_T at the Boulder lab.

Filter Comparisons

Two different filter types were used for Hg_T and MeHg analyses: a Gelman capsule filter (C45, nominal pore diameter 0.45 micrometer) and a quartz fiber filter (QFF, nominal pore diameter 0.7 micrometer). The QFF was used so that particulate Hg_T and MeHg could be measured directly, instead of by calculating the difference between unfiltered and filtered concentrations. Theoretically, one should get more precise data with lower variability, and a lower detection limit for particulate Hg_T or MeHg using the QFF approach. An advantage to using both filter types is to increase comparability with other studies. The Gelman capsule filter has been used extensively by the USGS in northern California and nationally, including studies for the National Water-Quality Assessment Program (NAWQA; for example, Domagalski and others, 2000), a study of metals transport in the Sacramento River (Alpers and others, 2000), and several ongoing studies in the Sierra Nevada. The QFF approach has been used for mercury analysis by the USGS and other researchers in the Florida Everglades, in the USGS NAWQA National Mercury Project (Brigham and others, 2003), and in the Guadalupe River watershed of San Francisco Bay (Kuwabara and others, 2005).

Because of the different pore diameter, the QFF filtrate was expected to be higher in Hg_T and MeHg than the C45 filtrate. Comparison of the filtrate data for total mercury (fig. F19*A*) indicates that this was indeed true for all but a small number of the samples. A linear least-squares regression for the 28 samples analyzed by the Wisconsin lab (fig. F19*B*) has a slope of 1.55, indicating that about 55 percent more mercury passed through the QFF than through the C45 filters. Combining the QFF filtrate concentration with the particulate concentration trapped on the QFF for each sample should give an equivalent whole-water Hg_T concentration that is similar to the Hg_T concentration measured directly on an unfiltered sample. The results of this comparison (fig. F20) indicate a good to excellent correspondence for 42 of 45 samples from the two laboratories; three unexplained outliers had considerably more Hg_T in the unfiltered split sample compared to the sum of QFF filtrate and particulate fractions. A similar comparison for MeHg (fig. F21) indicates excellent agreement for all samples with detectable MeHg. With regard to the comparison of MeHg concentrations in C45 and QFF filtrates (fig. F21), a large proportion of samples were non-detects by both procedures; in total, 54 samples were processed by both methods, of which 26 were non-detects for both filtered splits. An additional 7 samples had no MeHg detected in one split (MDL 0.04 ng/L), whereas the other split had 0.04 or 0.05 ng/L detected. MeHg was detected in both splits in 18 of the samples; only 3 of the 54 samples are considered to be unexplained outliers. A comparison of results on split samples processed by different filter types (QFF and capsule filter) and analyzed for MeHg is shown in figure F22. The overall consistency of results provides confidence that the sum of QFF filtrate and particulate concentration could be used in cases where results from analysis of unfiltered samples were not available for either Hg_T or MeHg.

Results

This section contains subsections describing results of field and laboratory measurements, followed by a subsection describing relations between concentrations of mercury and methylmercury and other water-quality constituents. A subsection on mercury bioaccumulation factors also is included.

Field Measurements

Camp Far West Reservoir goes through a seasonal cycle characterized by extreme drawdown in the late summer and early fall accompanied by thermal stratification with depth. Destratification occurs in the late fall, and the reservoir remains unstratified (vertically mixed) through winter and spring. This monomictic behavior is illustrated by field data for seasonal water-column profiles from three stations in the thalweg profile: site 2 (LRT, fig. 6*A*), site 4 (MRT, fig. 6*B*) and site 5 (BRA, fig. 6*C*). Representative seasonal profiles of field measurements from these stations indicate a strong seasonality, especially with regard to the vertical distribution of temperature and dissolved oxygen. The plots in figure 6 are constructed with a consistent vertical axis so that the seasonal variations in reservoir-surface elevation can been seen (for temporal variations in reservoir storage and surface elevation, see also fig. 4 and appendix A). Results of field measurements for the water-column profiles at all sites are given in appendix C (table C1) and plots of individual profiles are compiled in appendix D (figs. D1–D110). A summary of locations and dates when water-column profile data were collected within the reservoir is given in table C2.

In lakes or reservoirs with thermal stratification, three zones are defined (Wetzel, 1975): the *hypolimnion* is the relatively cold, deep water, the *metalimnion* is the transition zone, and the *epilimnion* is the relatively warm, surface layer. At times when the water column is not thermally stratified, the entire water column is considered to be the epilimnion. Field measurements at the time of sampling (table 1) were used to characterize each water-quality sample as representing either hypolimion, metalimnion, or epilimnion, and this property is indicated in figures throughout the report using distinct symbols. Thermal stratification in the summer and early fall is often accompanied by low values of dissolved oxygen (DO) at depth. In some cases, DO concentrations are less than 1 mg/L, indicating anoxic conditions at depth. During the summer, when stratification of the water column is most widespread throughout the reservoir, the transition with depth from high DO to low DO commonly occurs in the metalimnion. At the LRT (fig. 6*A*) and MRT (fig. 6*B*) stations, the summer DO profiles show a minimum value in the metalimnion and somewhat higher DO values with depth. The summer depth profiles of pH and specific conductance (SC) at these stations show variations in the metalimnion that indicate a more complex stratification during that season. One possible interpretation is that sulfate reduction coupled with oxidation of organic carbon is taking place at the top of the hypolimnion, as discussed in section, "Relations of Mercury and Methylmercury with Other Constituents: Sulfur Isotopes."

The seasonal trends in temperature, DO, pH, and SC also can be seen in time-series plots showing measurements taken during water-quality sampling events (figs. 7*A–D*). During the winter, the lake is well mixed and relatively cold; in February 2002, temperatures ranged from 7 to 9°C, whereas in January 2003, the range was 8 to 12°C. During summer stratification in 2002 and 2003, the minimum hypolimnion bottom-water temperatures usually were around 10–11°C. Epilimnion temperatures reached highs of 26 to 28°C during August 2002 and 2003. Dissolved oxygen concentrations generally were low (less than or equal to 2 mg/L), indicating suboxic to anoxic conditions in the hypolimnion; however, there were occasions such as fall 2002 and summer 2003 at the LRT station (site 2) when moderate DO values of 4 to 6 mg/L were observed in the hypolimnion (fig. 6*A*). Also, during winter 2002, DO values of 1 to 4 mg/L were observed in the Dairy Farm Mine pit lake (site 8) when this part of the reservoir was not thermally stratified (fig. 7*B*).

Acid mine drainage in the Dairy Farm Mine pit lake (station DFP; site 8) and associated impoundments (station DFI, site 9) typically had pH values in the range of 3 to 5 during the summer and fall (fig. 7*C*) when these areas were isolated from CFWR, and near-neutral values during winter and spring when the water bodies were connected because of higher water levels in CFWR. During the fall sampling events, the pit-lake water surface was at its lowest elevation, resulting in lowest pH values and highest values of specific conductance (SC), indicative of higher concentrations of many constituents. In CFWR, SC values generally were highest in the fall (fig. 7*D*), also associated with lowest water levels. Evaporative concentration is a likely contributing factor to the higher values of SC in the fall in both the pit lake and reservoir environments, as discussed in later sections on major elements and stable isotopes. Values of pH in the hypolimnion of CFWR generally were lower than epilimnion values by about 0.5 to 1.0 unit, which likely reflects higher total dissolved carbon dioxide associated with the respiring microbes and decomposing organic matter (Wetzel, 1975), processes that may be linked to sulfate reduction.

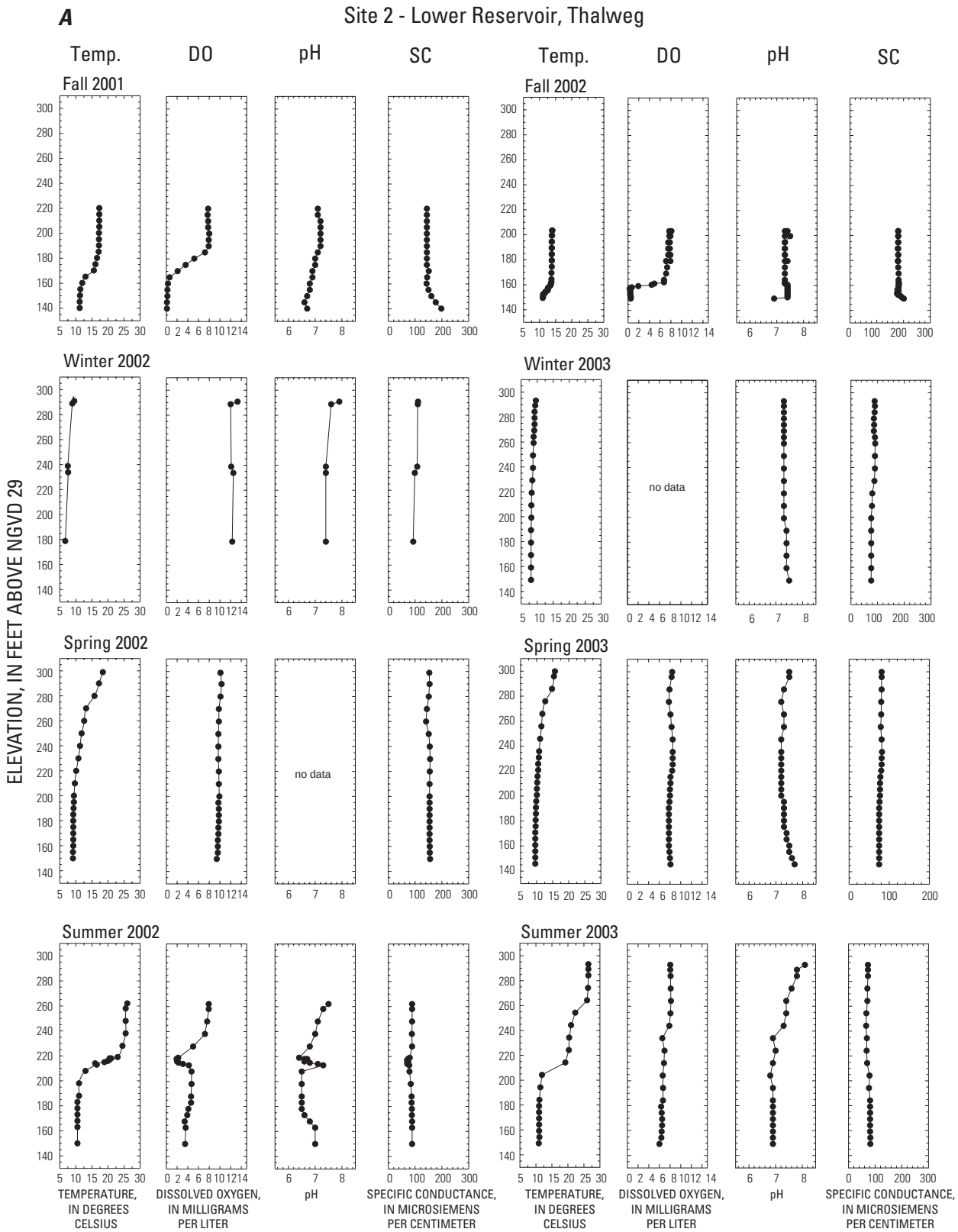


Figure 6. Water-column depth profiles of field measurements (temperature, dissolved oxygen, pH, and specific conductance) quarterly from fall 2001 to summer 2003 at Camp Far West Reservoir, California: (*A*) Site 2, Lower Reservoir, Thalweg, (*B*) Site 4, Mid-Reservoir, Thalweg, (*C*) Site 5, Bear River Arm.

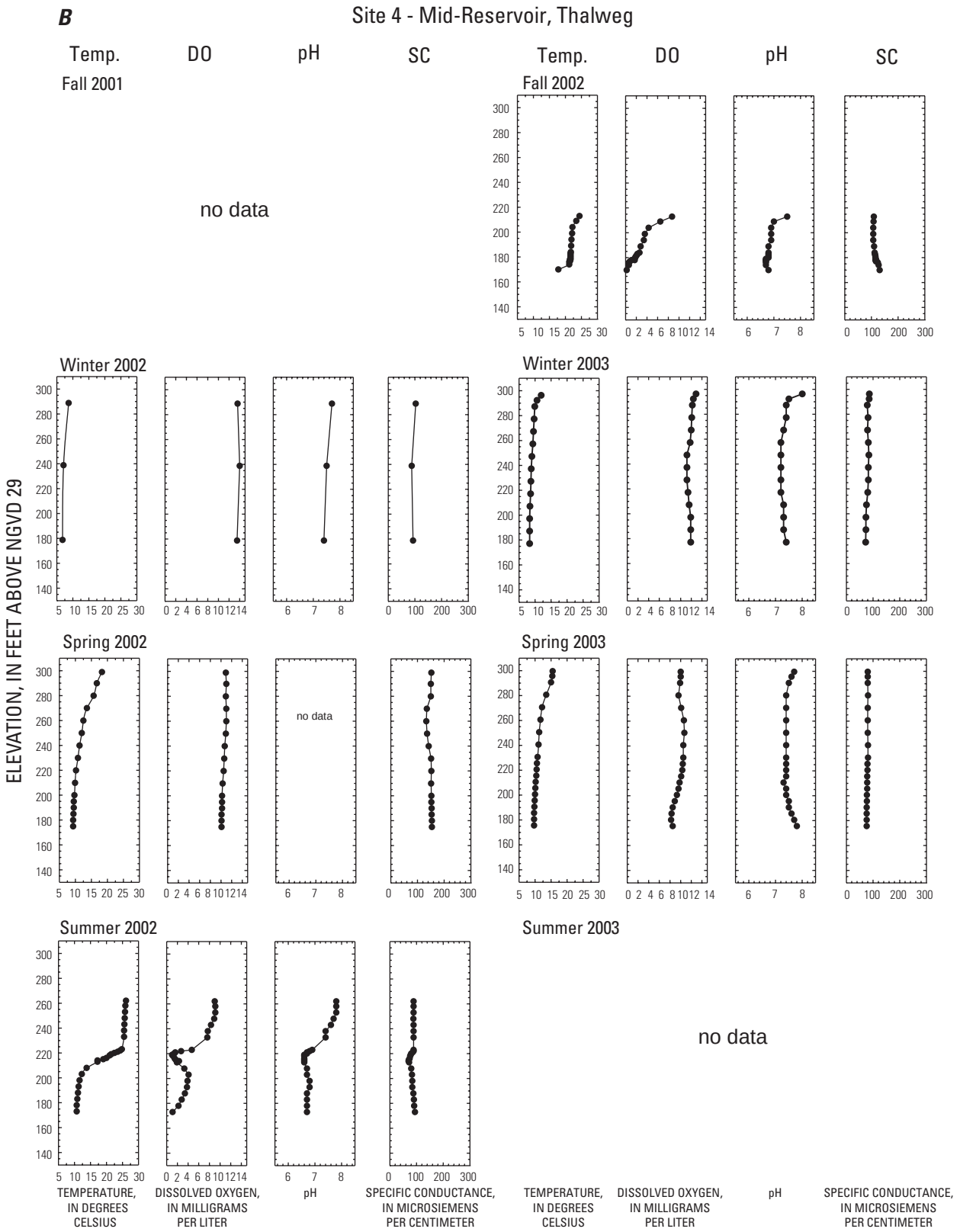


Figure 6. Continued.

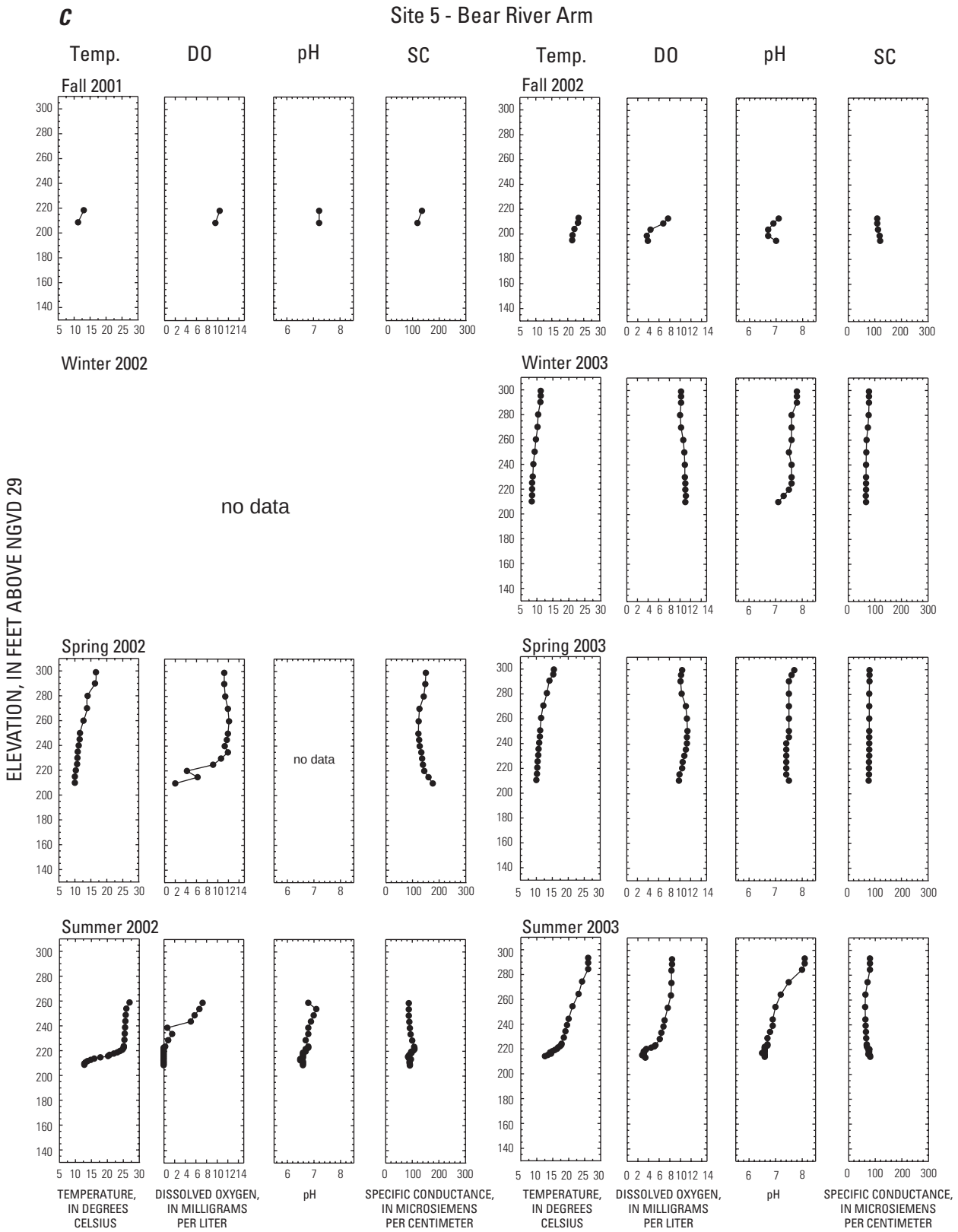


Figure 6. Continued.

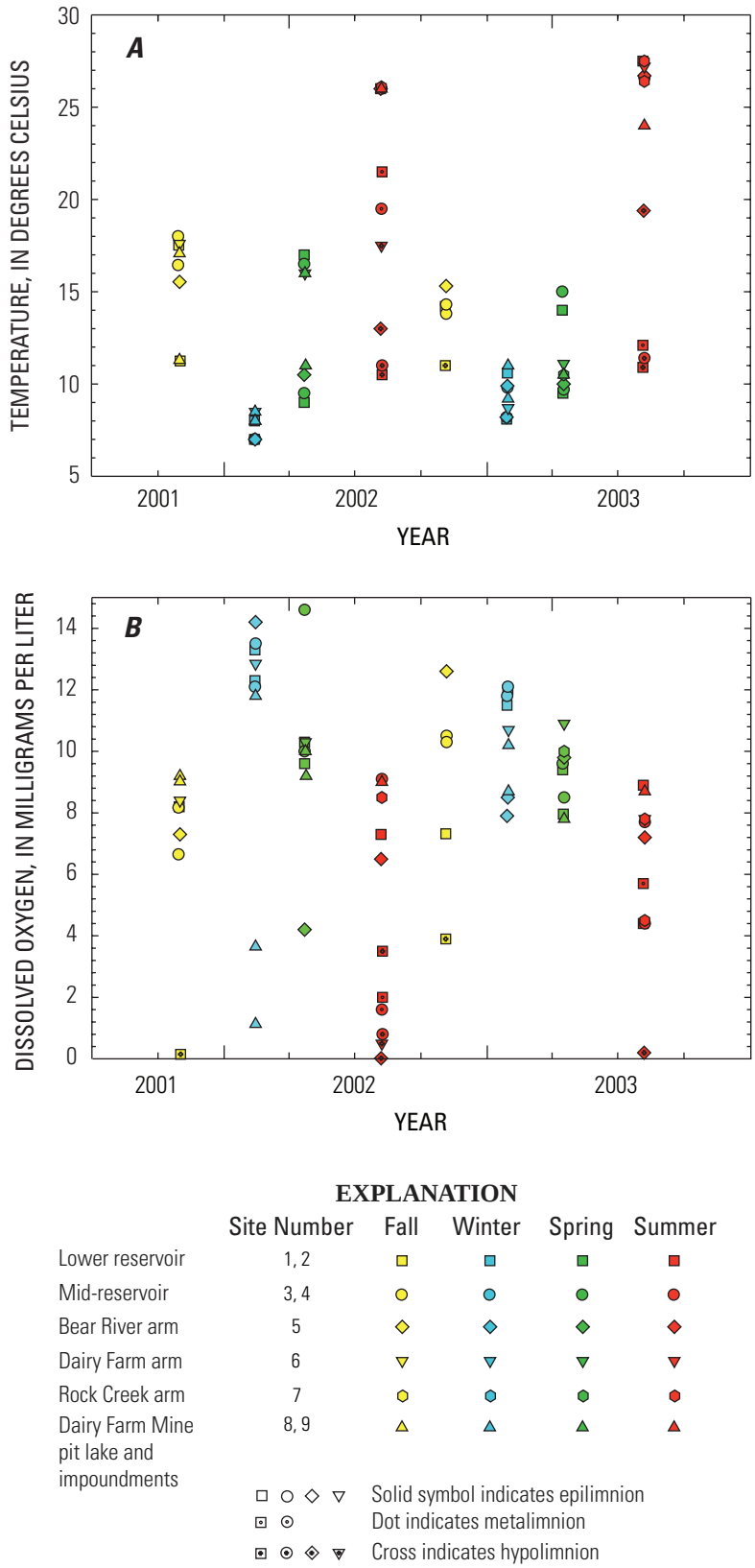


Figure 7. Field measurements for sampling stations in Camp Far West Reservoir, California, 2001–03: (*A*) Temperature, (*B*) Dissolved oxygen, (*C*) pH, (*D*) Specific conductance.

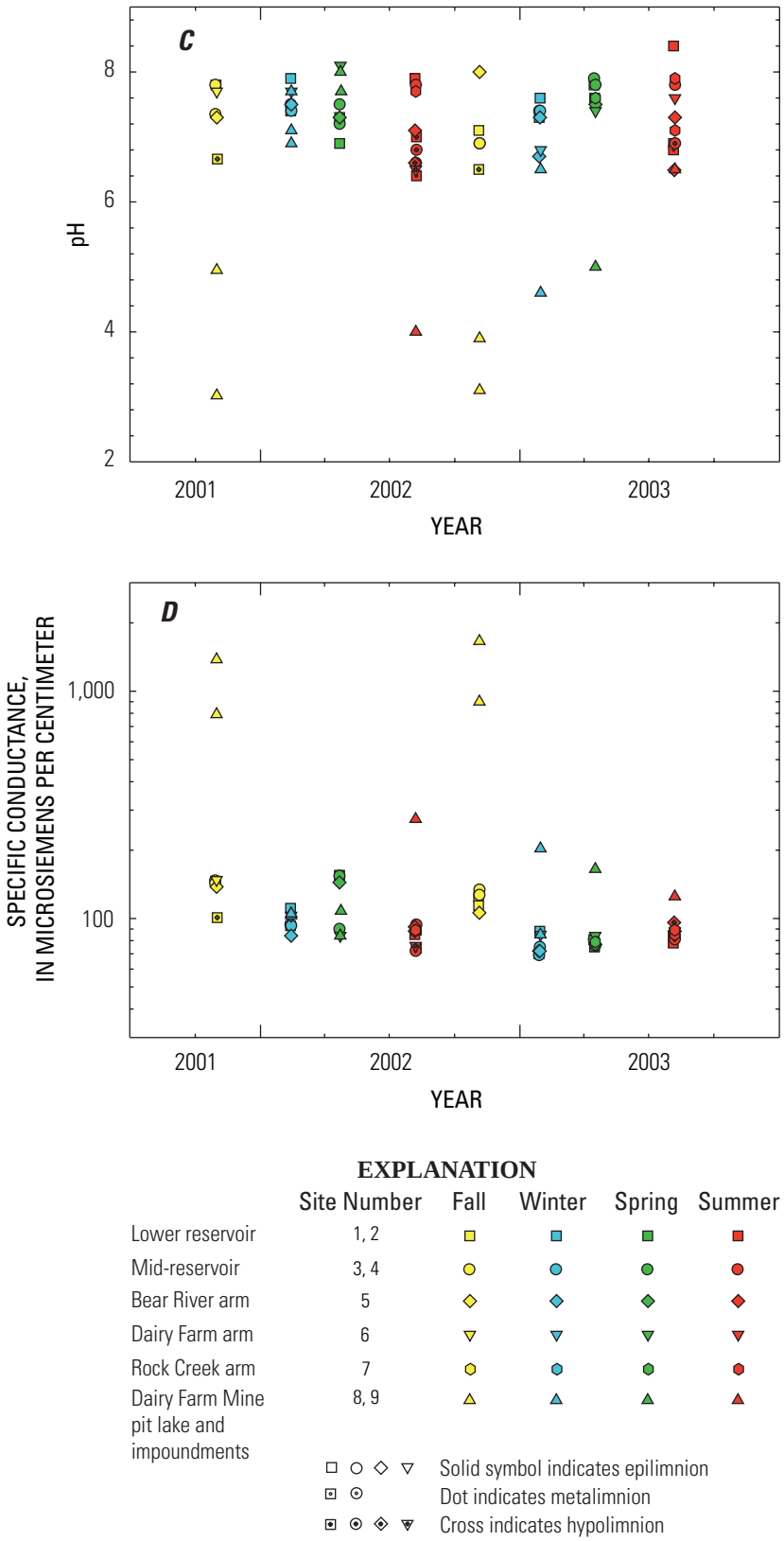


Figure 7. Continued.

Laboratory Measurements

Results of laboratory measurements for constituents in water samples collected from Camp Far West Reservoir (CFWR) during October 2001 through August 2003 are shown in tables 2–7 and in appendix G (tables G1–G5). Seasonal and spatial variations of total mercury and methylmercury concentrations and their interpretation are the primary focus of this report. Raw concentration data for total mercury in water are given in appendix G (table G1 for unfiltered samples and table G2 for filtered and particulate samples); because two laboratories were used for total mercury determinations and many replicate determinations were made, best values of total mercury concentration were selected for each sample, as shown in table 6. Methylmercury concentration data are given in table 7. Data for other water-quality constituents are presented and discussed in the context of hydrobiogeochemical processes and effects on mercury and methylmercury cycling; these constituents include suspended solids (table 2), trace metals and major cations (appendix G, tables G3 and G4), major anions (table 3), nutrients and organic carbon (table 5), and chlorophyll (appendix G, table G5). Stable isotopes of oxygen and hydrogen in water (table 4) are presented and discussed in the context of understanding evapoconcentration effects and the elevation of precipitation and recharge; stable isotopes of sulfur and oxygen in aqueous sulfate (table 4) are relevant to understanding possible sources of sulfate and processes of sulfate reduction.

Table 2. Data for suspended solids in water samples, Camp Far West Reservoir, California.

[Thalweg, former river channel (low elevation path). The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Suspended silt plus clay is the product of suspended sediment concentration and percent suspended sediment sieved. Organic material is included in suspended sediment concentration, which is used interchangeably with suspended solids concentration in this report; ft, foot; mm, millimeter; mg/L, milligram per liter; % <, percent less than; –, not determined]

Date	Time	Depth (ft)	Suspended sediment (mg/L) (80154)	Suspended sediment sieved (% <0.063 mm) (70331)	Suspended silt plus clay (mg/L)
Site 1, LRS: Lower Reservoir, Shallow (Camp Far West Reservoir 0.3 mile north of dam abutment)					
Station number 390317121185001					
10/30/2001	5:15 PM	10	8	92	7
02/12/2002	12:00 PM	8	10	93	9
04/22/2002	3:20 PM	10	5	87	4
08/06/2002	4:30 PM	10	<1	67	<1
04/15/2003	10:30 AM	40	14	10	1
Site 2, LRT: Lower Reservoir, Thalweg (Camp Far West Reservoir in thalweg near dam near Wheatland)					
Station number 390307121183801					
11/01/2001	8:30 AM	70	22	91	20
02/12/2002	11:00 AM	140	5	85	4
04/22/2002	3:00 PM	140	5	74	4
08/08/2002	12:00 PM	45	6	92	6
08/08/2002	1:30 PM	113	7	86	6
11/04/2002	3:50 PM	10	16	99	16
11/04/2002	3:20 PM	55	11	99	11
01/29/2003	2:30 PM	10	1	80	1
01/28/2003	4:40 PM	140	6	90	5
04/16/2003	4:00 PM	150	10	93	9
08/05/2003	12:30 PM	1	28	63	18
08/05/2003	3:30 PM	73	12	92	11
08/05/2003	1:00 PM	120	11	90	10

Table 2. Data for suspended solids in water samples, Camp Far West Reservoir, California.—*Continued*

[Thalweg, former river channel (low elevation path). The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Suspended silt plus clay is the product of suspended sediment concentration and percent suspended sediment sieved. Organic material is included in suspended sediment concentration, which is used interchangeably with suspended solids concentration in this report; ft, foot; mm, millimeter; mg/L, milligram per liter; % <, percent less than; –, not determined]

Date	Time	Depth (ft)	Suspended sediment (mg/L) (80154)	Suspended sediment sieved (% <0.063 mm) (70331)	Suspended silt plus clay (mg/L)
Site 3, MRS: Middle Reservoir, Shallow (Camp Far West Reservoir east shoreline 1.6 miles above dam)					
Station number 390244121171801					
10/29/2001	4:15 PM	6	4	93	4
02/12/2002	1:30 PM	60	7	96	7
04/22/2002	1:50 PM	10	9	93	8
04/15/2003	12:40 PM	32	15	64	10
Site 4, MRT: Middle Reservoir, Thalweg (Camp Far West Reservoir in thalweg 1.5 miles above dam)					
Station number 390238121173101					
10/29/2001	2:45 PM	50	30	100	30
02/13/2002	8:30 AM	120	5	84	4
04/22/2002	12:20 PM	120	5	92	5
08/07/2002	12:10 PM	10	3	52	2
08/07/2002	12:40 PM	47	9	80	7
08/08/2002	2:50 PM	80	9	92	8
11/05/2002	2:30 PM	10	10	93	9
11/05/2002	2:10 PM	30	21	99	21
01/29/2003	2:00 PM	10	1	92	1
01/28/2003	3:30 PM	120	3	96	3
04/17/2003	10:30 AM	125	4	87	3
08/07/2003	11:30 AM	1	27	94	25
08/07/2003	11:50 AM	100	11	94	10
Site 5, BRA: Bear River arm (Camp Far West Reservoir Bear River arm near Wheatland)					
Station number 390202121162201					
10/31/2001	10:15 AM	12	17	97	16
02/13/2002	9:00 AM	80	11	91	10
04/22/2002	10:40 AM	80	8	88	7
08/06/2002	5:50 PM	10	3	56	2
08/06/2002	6:20 PM	55	6	72	4
11/05/2002	4:10 PM	7	9	94	8
01/29/2003	1:20 PM	10	1	90	1
01/28/2003	2:50 PM	85	3	96	3
04/17/2003	11:30 AM	90	10	88	9
08/07/2003	10:00 AM	1	27	62	17
08/06/2003	3:00 PM	100	19	87	17

Table 2. Data for suspended solids in water samples, Camp Far West Reservoir, California.—*Continued*

[Thalweg, former river channel (low elevation path). The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Suspended silt plus clay is the product of suspended sediment concentration and percent suspended sediment sieved. Organic material is included in suspended sediment concentration, which is used interchangeably with suspended solids concentration in this report; ft, foot; mm, millimeter; mg/L, milligram per liter; **%** <, percent less than; –, not determined]

Date	Time	Depth (ft)	Suspended sediment (mg/L) (80154)	Suspended sediment sieved (% <0.063 mm) (70331)	Suspended silt plus clay (mg/L)
Site 6, DFA: Dairy Farm arm (Camp Far West Reservoir Dairy Farm arm near Wheatland)					
Station number 390159121171401					
10/31/2001	1:00 PM	4	6	97	6
02/13/2002	1:00 PM	20	5	97	5
04/23/2002	12:10 PM	20	3	91	3
08/07/2002	6:50 PM	57	5	97	5
01/30/2003	3:30 PM	55	2	93	2
04/17/2003	2:30 PM	55	11	97	11
08/07/2003	4:00 PM	1	27	83	22
Site 7, RCA: Rock Creek arm (Camp Far West Reservoir Rock Creek arm)					
Station number 390331121174101					
08/07/2002	03:40 PM	10	3	81	2
04/17/2003	01:20 PM	80	11	95	10
08/07/2003	01:00 PM	1	28	97	27
08/07/2003	01:30 PM	40	26	88	23
Site 8, DFP: Dairy Farm Mine Pit Lake (Dairy Farm Mine pit lake near Wheatland)					
Station number 390148121171701					
10/31/2001	2:15 PM	1	–	–	–
02/13/2002	3:10 PM	10	8	88	7
02/13/2002	3:30 PM	35	5	93	5
04/24/2002	11:10 AM	30	6	91	5
08/07/2002	5:00 PM	0.5	3	73	2
11/05/2002	2:50 PM	1	6	54	3
01/30/2003	12:30 PM	10	1	86	1
01/30/2003	1:20 PM	38	<1	50	<1
04/17/2003	4:00 PM	40	11	43	5
08/07/2003	4:30 PM	1	24	89	21
Site 9, DFI: Dairy Farm Mine Impoundments (Camp Far West Reservoir impoundment Dairy Farm Mine arm)					
Station number 390152121171001					
10/31/2001	02:40 PM	0.5	–	–	–
02/13/2002	2:20 PM	52	6	89	5
04/23/2002	1:10 PM	20	5	92	5
11/05/2002	2:00 PM	0.5	5	90	5

Table 3. Data for major anions (chloride, sulfate, and alkalinity, a proxy for bicarbonate) in filtered water samples, Camp Far West Reservoir, California.

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Thalweg, former river channel (low elevation path). $CaCO_3$, calcium carbonate; ft, foot; mg/L, milligram per liter; –, not determined]

Date	Time	Depth (ft)	Chloride (Cl) (mg/L) (00940)	Sulfate (SO_4) (mg/L) (99113)	Alkalinity (mg/L as $CaCO_3$) (29803)
Site 1, LRS: Lower Reservoir, Shallow (Camp Far West Reservoir 0.3 mile north of dam abutment)					
Station number 390317121185001					
10/30/2001	5:15 PM	10	7.1	8.8	52
02/12/2002	12:00 PM	8	4.9	7.0	33
04/22/2002	3:20 PM	10	4.5	5.4	27
08/06/2002	4:30 PM	10	5.2	4.8	27
04/15/2003	10:30 AM	40	4.1	4.4	26
Site 2, LRT: Lower Reservoir, Thalweg (Camp Far West Reservoir in thalweg near dam near Wheatland)					
Station number 390307121183801					
11/01/2001	8:30 AM	70	5.4	6.3	60
02/12/2002	11:00 AM	140	4.7	6.0	27
04/22/2002	3:00 PM	140	4.3	5.5	27
08/08/2002	12:00 PM	45	4.6	4.2	24
08/08/2002	1:30 PM	113	5.0	5.1	31
11/04/2002	3:50 PM	10	5.7	6.2	41
11/04/2002	3:20 PM	55	6.1	6.7	40
01/29/2003	2:30 PM	10	4.4	5.9	21
01/28/2003	4:40 PM	140	3.6	4.4	20
04/16/2003	4:00 PM	150	4.0	4.1	22
08/05/2003	12:30 PM	1	4.6	3.9	28
08/05/2003	3:30 PM	73	4.1	4.2	23
08/05/2003	1:00 PM	120	4.1	4.0	32
Site 3, MRS: Middle Reservoir, Shallow (Camp Far West Reservoir east shoreline 1.6 miles above dam)					
Station number 390244121171801					
10/29/2001	4:15 PM	6	7.2	7.5	51
02/12/2002	1:30 PM	60	4.9	7.0	33
04/22/2002	1:50 PM	10	4.7	5.0	27
04/15/2003	12:40 PM	32	4.1	4.5	25
Site 4, MRT: Middle Reservoir, Thalweg (Camp Far West Reservoir in thalweg 1.5 miles above dam)					
Station number 390238121173101					
10/29/2001	2:45 PM	50	6.9	6.9	51
02/13/2002	8:30 AM	120	4.5	6.7	29
04/22/2002	12:20 PM	120	4.4	5.5	28
08/07/2002	12:10 PM	10	5.4	5.0	30
08/07/2002	12:40 PM	47	4.8	4.4	29
08/08/2002	2:50 PM	80	5.0	4.9	30
11/05/2002	2:30 PM	10	6.2	7.5	43
11/05/2002	2:10 PM	30	6.6	8.7	45
01/29/2003	2:00 PM	10	4.1	5.2	–
01/28/2003	3:30 PM	120	3.7	4.5	21
04/17/2003	10:30 AM	125	4.1	4.1	24
08/07/2003	11:30 AM	1	4.9	4.1	23
08/07/2003	11:50 AM	100	4.4	4.0	32

Table 3. Data for major anions (chloride, sulfate, and alkalinity, a proxy for bicarbonate) in filtered water samples, Camp Far West Reservoir, California.—*Continued*

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Thalweg, former river channel (low elevation path). $CaCO_3$, calcium carbonate; ft, foot; mg/L, milligram per liter; – not determined]

Date	Time	Depth (ft)	Chloride (Cl) (mg/L) (00940)	Sulfate (SO_4) (mg/L) (99113)	Alkalinity (mg/L as $CaCO_3$) (29803)
Site 5, BRA: Bear River arm (Camp Far West Reservoir Bear River arm near Wheatland)					
Station number 390202121162201					
10/31/2001	10:15 AM	12	7.5	9.2	–
02/13/2002	9:00 AM	80	4.7	6.1	25
04/22/2002	10:40 AM	80	4.5	5.1	26
08/06/2002	5:50 PM	10	5.4	4.9	31
08/06/2002	6:20 PM	55	5.0	4.4	32
11/05/2002	4:10 PM	7	6.2	7.7	43
01/29/2003	1:20 PM	10	3.6	4.0	21
01/28/2003	2:50 PM	85	3.7	4.4	–
04/17/2003	11:30 AM	90	4.1	3.9	26
08/07/2003	10:00 AM	1	5.1	4.1	24
08/06/2003	3:00 PM	100	4.7	3.8	26
Site 6, DFA: Dairy Farm arm (Camp Far West Reservoir Dairy Farm arm near Wheatland)					
Station number 390159121171401					
10/31/2001	1:00 PM	4	7.5	9.8	50
02/13/2002	1:00 PM	20	4.6	7.5	32
04/23/2002	12:10 PM	20	4.6	5.6	30
08/07/2002	6:50 PM	57	5.1	4.9	30
01/30/2003	3:30 PM	55	3.9	5.3	–
04/17/2003	2:30 PM	55	4.4	5.3	27
08/07/2003	4:00 PM	1	4.7	6.1	26
Site 7, RCA: Rock Creek arm (Camp Far West Reservoir Rock Creek arm)					
Station number 390331121174101					
08/07/2002	03:40 PM	10	5.3	4.9	31
04/17/2003	01:20 PM	80	4.2	4.2	25
08/07/2003	01:00 PM	1	5.0	4.0	28
08/07/2003	01:30 PM	40	4.8	3.6	23
Site 8, DFP: Dairy Farm Mine Pit Lake (Dairy Farm Mine pit lake near Wheatland)					
Station number 390148121171701					
10/31/2001	2:15 PM	1	4.3	636	–
02/13/2002	3:10 PM	10	5.1	8.5	29
02/13/2002	3:30 PM	35	–	–	26
04/24/2002	11:10 AM	30	4.5	7.8	23
08/07/2002	5:00 PM	0.5	6.4	112	–
11/05/2002	2:50 PM	1	5.2	381	–
01/30/2003	12:30 PM	10	4.5	77	26
01/30/2003	1:20 PM	38	4.1	6.3	23
04/17/2003	4:00 PM	40	4.1	92	–
08/07/2003	4:30 PM	1	4.8	37	5
Site 9, DFI: Dairy Farm Mine Impoundments (Camp Far West Reservoir impoundment Dairy Farm Mine arm)					
Station number 390152121171001					
10/31/2001	2:40 PM	0.5	66	355	–
02/13/2002	2:20 PM	52	4.6	11	28
04/23/2002	1:10 PM	20	4.5	5.6	28
11/05/2002	2:00 PM	0.5	11	1,145	–

Table 4. Data for oxygen and sulfur isotopes in aqueous sulfate and oxygen and hydrogen isotopes in water, Camp Far West Reservoir, California.

[$\delta^{34}S\ SO_4$, delta-sulfur-34 in aqueous sulfate; $\delta^{18}O\ SO_4$, delta-oxygen-18 in aqueous sulfate; $\delta^{18}O\ H_2O$, delta-oxygen-18 in water; $\delta D\ H_2O$, delta-deuterium in water. VSMOW, Vienna Standard Mean Ocean Water; CDT, Cañon Diablo Troilite; (1 of 2) and (2 of 2) refer to replicate analyses. ft, foot; permil, per thousand; –, not determined]

Date	Time	Depth (ft)	Replicate							
			$\delta^{18}O\ SO_4$ (permil VSMOW)		$\delta^{34}S\ SO_4$ (permil CDT)		$\delta^{18}O\ H_2O$ (permil VSMOW)		$\delta D\ H_2O$ (permil VSMOW)	
			1 of 2	2 of 2	1 of 2	2 of 2	1 of 2	2 of 2	1 of 2	2 of 2
Site 1, LRS: Lower Reservoir, Shallow (Camp Far West Reservoir 0.3 mile north of dam abutment)										
Station number 390317121185001										
10/30/2001	5:15 PM	10	1.3	–	2.5	–	–8.2	–	–68	–
02/12/2002	12:00 PM	8	1.5	–	1.3	–	–9.7	–	–72	–
04/22/2002	3:20 PM	10	–	–	–	–	–10.0	–	–73	–
08/06/2002	4:30 PM	10	–	–	–	–	–9.1	–	–73	–
04/15/2003	10:30 AM	40	1.8	–	1.2	–	–	–	–	–
Site 2, LRT: Lower Reservoir, Thalweg (Camp Far West Reservoir in thalweg near dam near Wheatland)										
Station number 390307121183801										
11/01/2001	8:30 AM	70	2.2	–	3.2	–	–10.2	–	–76	–76
02/12/2002	11:00 AM	140	2.4	–	0.9	–	–10.4	–	–77	–
04/22/2002	3:00 PM	140	–	–	–	–	–10.2	–	–74	–
08/08/2002	12:00 PM	45	1.2	–	–0.4	–	–10.6	–	–80	–
08/08/2002	1:30 PM	113	2.2	–	0.3	–	–10.4	–	–75	–
11/04/2002	3:20 PM	55	0.1	–	2.4	–	–8.8	–	–71	–
11/04/2002	3:50 PM	10	2.3	–	2.0	–	–9.4	–	–73	–
01/28/2003	4:40 PM	140	2.1	–	0.4	–	–10.1	–	–79	–
01/29/2003	2:30 PM	10	1.6	–	1.5	–	–9.7	–	–71	– 71
04/16/2003	4:00 PM	150	1.3	–	0.6	–	–10.6	–10.6	– 77	–
08/05/2003	12:30 PM	1	1.3	–	0.9	–	–10.3	–	–70	–
08/05/2003	1:00 PM	120	2.1	–	0.4	0.5	–10.3	–	–75	–74
08/05/2003	3:30 PM	73	2.1	–	–0.4	–	–10.4	–	–75	–
Site 3, MRS: Middle Reservoir, Shallow (Camp Far West Reservoir east shoreline 1.6 miles above dam)										
Station number 390244121171801										
10/29/2001	4:15 PM	6	2.5	–	2.4	–	–8.2	–	–68	–
02/12/2002	1:30 PM	60	2.3	–	1.4	–	–9.8	–	–72	–
04/22/2002	1:50 PM	10	–	–	0.0	–	–10.1	–	–74	–
04/15/2003	12:40 PM	32	1.6	–	1.6	1.2	–10.0	–	–74	–
Site 4, MRT: Middle Reservoir, Thalweg (Camp Far West Reservoir in thalweg 1.5 miles above dam)										
Station number 390238121173101										
10/29/2001	2:45 PM	50	3.3	–	2.9	–	–8.3	–	–69	–
02/13/2002	8:30 AM	120	–	–	0.6	–	–10.5	–	–76	–
04/22/2002	12:20 PM	120	–	–	0.8	–	–10.3	–	–76	–
08/07/2002	12:10 PM	10	–0.6	–	–0.2	–	–9.1	–	–73	–
08/07/2002	12:40 PM	47	1.2	–	0.0	–	–10.5	–	–79	–
08/08/2002	2:50 PM	80	0.9	0.4	0.2	–	–10.6	–	–77	–
11/05/2002	2:10 PM	30	–0.9	–	2.5	–	–8.7	–8.8	–71	–
11/05/2002	2:30 PM	10	1.9	1.6	2.3	–	–8.8	–	–71	–
01/28/2003	3:30 PM	120	2.3	–	0.3	–	–10.5	–	–78	–
01/29/2003	2:00 PM	10	2.0	–	0.9	–	–10.0	–	–74	–74
04/17/2003	10:30 AM	125	1.9	–	0.8	–	–10.4	–	–77	–
08/07/2003	11:30 AM	1	1.0	–	–0.4	–	–9.2	–	–69	–
08/07/2003	11:50 AM	100	2.8	–	0.4	–	–10.0	–10.3	–73	–

Table 4. Data for oxygen and sulfur isotopes in aqueous sulfate and oxygen and hydrogen isotopes in water, Camp Far West Reservoir, California.—*Continued*

[$\delta^{34}S\ SO_4$, delta-sulfur-34 in aqueous sulfate; $\delta^{18}O\ SO_4$, delta-oxygen-18 in aqueous sulfate; $\delta^{18}O\ H_2O$, delta-oxygen-18 in water; $\delta D\ H_2O$, delta-deuterium in water. VSMOW, Vienna Standard Mean Ocean Water; CDT, Cañon Diablo Troilite; (1 of 2) and (2 of 2) refer to replicate analyses. ft, foot; permil, per thousand; –, not determined]

Date	Time	Depth (ft)	Replicate							
			$\delta^{18}O\ SO_4$ (permil VSMOW)		$\delta^{34}S\ SO_4$ (permil CDT)		$\delta^{18}O\ H_2O$ (permil VSMOW)		$\delta D\ H_2O$ (permil VSMOW)	
			1 of 2	2 of 2	1 of 2	2 of 2	1 of 2	2 of 2	1 of 2	2 of 2
Site 5, BRA: Bear River arm (Camp Far West Reservoir Bear River arm near Wheatland)										
Station number 390202121162201										
10/31/2001	10:15 AM	12	1.6	–	2.7	–	–8.2	–	–69	–
02/13/2002	9:00 AM	80	–	–	–0.5	–	–10.8	–	–79	–
04/22/2002	10:40 AM	80	–	–	–0.2	–	–10.5	–	–76	–
08/06/2002	5:50 PM	10	–0.5	–	0.0	–	–9.2	–	–71	–
08/06/2002	6:20 PM	55	1.4	–	0.2	–	–10.2	–	–78	–
11/05/2002	4:10 PM	7	–	–	–	–	–8.7	–	–70	–
01/28/2003	2:50 PM	85	2.1	–	0.5	–	–10.5	–10.3	–79	–78
01/29/2003	1:20 PM	10	1.4	–	–0.3	–	–10.6	–	–77	–
04/17/2003	11:30 AM	90	2.2	–	1.0	–	–10.4	–	–75	–
08/06/2003	3:00 PM	100	3.8	–	0.2	–	–10.5	–	–78	–
08/07/2003	10:00 AM	1	0.8	–	–0.2	–	–	–	–69	–
Site 6, DFA: Dairy Farm arm (Camp Far West Reservoir Dairy Farm arm near Wheatland)										
Station number 390159121171401										
10/31/2001	1:00 PM	4	1.0	1.1	2.1	–	–8.2	–8.2	–67	–
02/13/2002	1:00 PM	20	2.2	–	1.3	–	–9.9	–	–72	–
04/23/2002	12:10 PM	20	–	–	–0.2	–	–10.1	–	–74	–
08/07/2002	6:50 PM	57	1.4	–	0.0	–	–10.2	–	–77	–76
01/30/2003	3:30 PM	55	1.2	–	1.5	–	–10.0	–10.2	–74	–
04/17/2003	2:30 PM	55	0.7	–	1.2	–	–10.2	–10.3	–73	–75
08/07/2003	4:00 PM	1	–	–	–	–	–9.1	–9.9	–69	–
Site 7, RCA: Rock Creek arm (Camp Far West Reservoir Rock Creek arm)										
Station number 390331121174101										
08/07/2002	3:40 PM	10	0.3	–	–0.1	–	–9.1	–	–71	–
04/17/2003	1:20 PM	80	1.7	–	1.1	–	–10.3	–10.5	–76	–77
08/07/2003	1:00 PM	1	1.4	–	–0.4	–	–8.9	–	–67	–
08/07/2003	01:30 PM	40	–	–	–	–	– 9.9	–	– 73	–
Site 8, DFP: Dairy Farm Mine Pit Lake (Dairy Farm Mine pit lake near Wheatland)										
Station number 390148121171701										
10/31/2001	2:15 PM	1	–1.5	–	1.3	–	–4.5	–	–50	–51
02/13/2002	3:10 PM	10	1.2	–	1.2	–	–9.9	–	–73	–
02/13/2002	3:30 PM	35	0.3	–	0.5	–	–	–	–	–
04/24/2002	11:10 AM	30	–	–	–	–	–10.6	–	–73	–
08/07/2002	5:00 PM	0.5	–1.6	–	0.1	–	–8.7	–	–69	–
11/05/2002	2:50 PM	1	–	–	–	–	–5.6	–	–54	–
01/30/2003	12:30 PM	10	1.4	–	1.1	–	–9.9	–	–73	–
01/30/2003	1:20 PM	38	–	–	–	–	– 9.4	–	– 71	–
04/17/2003	4:00 PM	40	–	–	–	–	–10.3	–	–75	–
08/07/2003	4:30 PM	1	–	–	–	–	–9.0	–8.9	–64	–70
Site 9, DFI: Dairy Farm Mine Impoundments (Camp Far West Reservoir impoundment Dairy Farm Mine arm)										
Station number 390152121171001										
10/31/2001	2:40 PM	0.5	–2.3	–	0.4	0.3	–8.6	–	–67	–
02/13/2002	2:20 PM	52	1.6	–	0.5	–	–10.1	–	–74	–
04/23/2002	1:10 PM	20	–	–	–	–	–10.1	–	–73	–
11/05/2002	2:00 PM	0.5	–	–	–	–	–6.2	–	–54	–

Table 5. Data for nutrients and organic carbon in water samples, Camp Far West Reservoir, California.

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Elements: N, nitrogen; P, phosphorus; C, carbon. Thalweg, former river channel (low elevation path). ft, foot; mg/L, milligram per liter; E, estimated; <, less than; –, not determined]

Date	Time	Depth (ft)	Nitrogen, ammonia, filtered (mg/L as N) (00608)	Nitrogen, ammonia plus organic, filtered (mg/L as N) (00623)	Nitrogen, ammonia plus organic, unfiltered (mg/L as N) (00625)	Nitrogen, nitrite plus nitrate, filtered (mg/L as N) (00631)	Nitrogen, nitrite, filtered (mg/L as N) (00613)	Total nitrogen, particulate (mg/L) (49570)
Site 1, LRS: Lower Reservoir, Shallow (Camp Far West Reservoir 0.3 mile north of dam abutment)								
Station number 390317121185001								
10/30/2001	5:15 PM	10	E0.02	0.20	0.20	<0.05	E0.007	–
02/12/2002	12:00 PM	8	<0.04	0.18	0.28	0.37	<0.008	–
04/22/2002	3:20 PM	10	<0.04	0.13	0.15	E0.05	<0.008	–
08/06/2002	4:30 PM	10	<0.04	0.12	0.13	<0.05	<0.008	–
04/15/2003	10:30 AM	40	<0.04	0.14	0.17	0.10	<0.008	0.18
Site 2, LRT: Lower Reservoir, Thalweg (Camp Far West Reservoir in thalweg near dam near Wheatland)								
Station number 390307121183801								
11/01/2001	8:30 AM	70	0.52	0.60	0.7	<0.05	–	–
02/12/2002	11:00 AM	140	<0.04	0.10	0.10	0.33	<0.008	–
04/22/2002	3:00 PM	140	<0.04	0.09	0.11	0.27	<0.008	–
08/08/2002	12:00 PM	45	<0.04	0.084	0.11	E0.023	<0.008	–
08/08/2002	1:30 PM	113	<0.04	0.089	0.11	0.36	<0.008	–
11/04/2002	3:50 PM	10	0.08	0.18	0.35	0.13	0.012	–
11/04/2002	3:20 PM	55	<0.04	0.16	0.27	0.21	<0.008	–
01/29/2003	2:30 PM	10	<0.04	0.15	0.25	0.34	<0.008	0.08
01/28/2003	4:40 PM	140	<0.04	0.14	0.15	0.19	<0.008	<0.02
04/16/2003	4:00 PM	150	<0.04	0.11	0.11	0.20	<0.008	<0.02
08/05/2003	12:30 PM	1	<0.04	0.10	0.17	<0.06	<0.008	0.05
08/05/2003	3:30 PM	73	<0.04	0.10	E0.09	0.19	<0.008	<0.02
08/05/2003	1:00 PM	120	<0.04	0.10	0.12	0.32	<0.008	0.05
Site 3, MRS: Middle Reservoir, Shallow (Camp Far West Reservoir east shoreline 1.6 miles above dam)								
Station number 390244121171801								
10/29/2001	4:15 PM	6	<0.04	0.20	0.20	<0.05	E0.006	–
02/12/2002	1:30 PM	60	<0.04	0.16	0.29	0.37	<0.008	–
04/22/2002	1:50 PM	10	<0.04	0.12	0.14	0.05	<0.008	–
04/15/2003	12:40 PM	32	<0.04	0.17	0.18	0.09	<0.008	0.05
Site 4, MRT: Middle Reservoir, Thalweg (Camp Far West Reservoir in thalweg 1.5 miles above dam)								
Station number 390238121173101								
10/29/2001	2:45 PM	50	0.09	0.26	0.37	<0.05	E0.005	–
02/13/2002	8:30 AM	120	<0.04	0.12	0.15	E0.31	<0.008	–
04/22/2002	12:20 PM	120	<0.04	E0.10	0.13	0.26	<0.008	–
08/07/2002	12:10 PM	10	<0.04	0.12	0.17	<0.05	<0.008	–
08/07/2002	12:40 PM	47	<0.04	E0.08	0.10	E0.02	<0.008	–
08/08/2002	2:50 PM	80	<0.04	E0.09	0.11	0.29	<0.008	–
11/05/2002	2:30 PM	10	E0.03	0.16	0.23	0.16	E0.004	–
11/05/2002	2:10 PM	30	0.08	0.19	0.32	0.14	E0.007	–
01/29/2003	2:00 PM	10	<0.04	0.11	0.21	0.21	<0.008	0.09
01/28/2003	3:30 PM	120	<0.04	E0.08	0.10	0.18	<0.008	<0.02
04/17/2003	10:30 AM	125	<0.04	0.14	0.12	0.22	<0.008	0.03
08/07/2003	11:30 AM	1	<0.04	E0.08	0.14	<0.06	<0.008	0.05
08/07/2003	11:50 AM	100	<0.04	E0.08	0.12	0.32	<0.008	0.03

Table 5. Data for nutrients and organic carbon in water samples, Camp Far West Reservoir, California.—*Continued*

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological survey computerized data system. Elements: N, nitrogen; P, phosphorus; C, carbon. Thalweg, former river channel (low elevation path). ft, foot; mg/L, milligram per liter; E, estimated; <, less than; –, not determined]

Date	Time	Depth (ft)	Nitrogen, ammonia, filtered (mg/L as N) (00608)	Nitrogen, ammonia plus organic, filtered (mg/L as N) (00623)	Nitrogen, ammonia plus organic, unfiltered (mg/L as N) (00625)	Nitrogen, nitrite plus nitrate, filtered (mg/L as N) (00631)	Nitrogen, nitrite, filtered (mg/L as N) (00613)	Total nitrogen, particulate (mg/L) (49570)
Site 5, BRA: Bear River arm (Camp Far West Reservoir Bear River arm near Wheatland)								
Station number 390202121162201								
10/31/2001	10:15 AM	12	0.15	0.31	0.37	E0.02	E0.005	–
02/13/2002	9:00 AM	80	<0.04	E0.08	0.13	E0.17	<0.008	–
04/22/2002	10:40 AM	80	<0.04	E0.09	0.11	0.17	<0.008	–
08/06/2002	5:50 PM	10	0.06	0.16	0.17	E0.023	<0.008	–
08/06/2002	6:20 PM	55	<0.04	0.11	0.20	<0.05	<0.008	–
11/05/2002	4:10 PM	7	0.05	0.25	0.57	0.13	E0.005	–
01/28/2003	2:50 PM	85	<0.04	E0.10	0.10	0.17	<0.008	<0.02
01/29/2003	1:20 PM	10	<0.04	E0.06	E0.10	0.10	<0.008	0.03
04/17/2003	11:30 AM	90	<0.04	0.10	0.20	0.17	<0.008	0.05
08/06/2003	3:00 PM	100	0.11	0.20	0.51	E0.04	<0.008	0.28
08/07/2003	10:00 AM	1	<0.04	0.10	0.16	<0.06	<0.008	0.06
Site 6, DFA: Dairy Farm arm (Camp Far West Reservoir Dairy Farm arm near Wheatland)								
Station number 390159121171401								
10/31/2001	1:00 PM	4	0.05	0.21	0.24	<0.05	0.008	–
02/13/2002	1:00 PM	20	<0.04	0.15	0.18	E0.38	<0.008	–
04/23/2002	12:10 PM	20	<0.04	0.14	0.18	E0.04	<0.008	–
08/07/2002	6:50 PM	57	<0.04	0.10	0.15	<0.05	E0.004	–
01/30/2003	3:30 PM	55	<0.04	E0.09	0.16	0.21	<0.008	0.13
04/17/2003	2:30 PM	55	<0.04	0.13	0.14	0.11	<0.008	–
08/07/2003	4:00 PM	1	<0.04	0.10	0.17	<0.06	<0.008	0.05
Site 7, RCA: Rock Creek arm (Camp Far West Reservoir Rock Creek arm)								
Station number 390331121174101								
08/07/2002	3:40 PM	10	<0.04	0.10	0.20	<0.05	E0.004	–
04/17/2003	1:20 PM	80	<0.04	0.10	0.10	0.17	<0.008	0.57
08/07/2003	1:00 PM	1	<0.04	E0.10	0.20	<0.06	<0.008	–
08/07/2003	1:30 PM	40	<0.04	E0.07	0.18	<0.06	<0.008	–
Site 8, DFP: Dairy Farm Mine Pit Lake (Dairy Farm Mine pit lake near Wheatland)								
Station number 390148121171701								
10/31/2001	2:15 PM	1	3.3	3.2	3.3	0.12	<0.008	–
02/13/2002	3:10 PM	10	<0.04	0.15	0.25	0.39	<0.008	–
02/13/2002	3:30 PM	35	E0.02	0.14	0.18	0.35	<0.008	–
04/24/2002	11:10 AM	30	E0.03	0.11	0.15	0.09	<0.008	–
08/07/2002	5:00 PM	0.5	0.16	0.21	0.25	0.13	<0.008	–
11/05/2002	2:50 PM	1	1.9	1.9	1.9	0.25	<0.008	–
01/30/2003	12:30 PM	10	<0.04	0.12	0.29	0.23	<0.008	0.12
01/30/2003	1:20 PM	38	0.15	0.20	0.20	0.49	E0.004	–
04/17/2003	4:00 PM	40	0.41	0.50	0.50	0.13	<0.008	<0.02
08/07/2003	4:30 PM	1	E0.02	E0.08	0.24	0.08	<0.008	0.03
Site 9, DFI: Dairy Farm Mine Impoundments (Camp Far West Reservoir impoundment Dairy Farm Mine arm)								
Station number 390152121171001								
10/31/2001	2:40 PM	0.5	–	–	–	–	–	–
02/13/2002	2:20 PM	52	E0.03	0.13	0.18	0.36	<0.008	–
04/23/2002	1:10 PM	20	<0.04	0.15	0.16	E0.04	<0.008	–
11/05/2002	2:00 PM	0.5	1.5	1.6	1.6	E0.04	<0.008	–

Table 5. Data for nutrients and organic carbon in water samples, Camp Far West Reservoir, California.—*Continued*

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological survey computerized data system. Elements: N, nitrogen; P, phosphorus; C, carbon. Thalweg, former river channel (low elevation path). ft, foot; mg/L, milligram per liter; E, estimated; <, less than; –, not determined]

Date	Time	Depth (ft)	Total phosphorus, filtered (mg/L as P) (00666)	Phosphorus, orthophosphate, filtered (mg/L as P) (00671)	Total phosphorus, unfiltered (mg/L as P) (00665)	Carbon, inorganic plus organic, particulate (mg/L as C) (00694)	Total carbon, inorganic, particulate (mg/L as C) (00688)	Carbon, organic, filtered (mg/L as C) (00681)	Carbon, organic, particulate (mg/L as C) (00689)
Site 1, LRS: Lower Reservoir, Shallow (Camp Far West Reservoir 0.3 mile north of dam abutment)									
Station number 390317121185001									
10/30/2001	5:15 PM	10	0.005	<0.02	0.015	–	–	2.3	0.2
02/12/2002	12:00 PM	8	0.006	<0.02	0.021	–	–	3.0	0.3
04/22/2002	3:20 PM	10	<0.004	<0.02	0.014	–	–	2.1	<0.2
08/06/2002	4:30 PM	10	<0.004	<0.02	0.012	–	–	2.5	0.6
04/15/2003	10:30 AM	40	0.006	<0.02	0.018	0.8	<0.1	2.6	0.8
Site 2, LRT: Lower Reservoir, Thalweg (Camp Far West Reservoir in thalweg near dam near Wheatland)									
Station number 390307121183801									
11/01/2001	8:30 AM	70	0.006	–	0.024	–	–	–	0.8
02/12/2002	11:00 AM	140	0.007	<0.02	0.016	–	–	2.3	<0.2
04/22/2002	3:00 PM	140	0.009	<0.02	0.018	–	–	2.1	<0.2
08/08/2002	12:00 PM	45	E0.002	<0.02	0.0076	–	–	2.0	0.32
08/08/2002	1:30 PM	113	E0.003	<0.02	0.0089	–	–	1.5	0.21
11/04/2002	3:20 PM	55	E0.004	<0.02	0.022	–	–	2.4	0.4
11/04/2002	3:50 PM	10	E0.003	<0.02	0.034	–	–	2.0	0.5
01/28/2003	4:40 PM	140	0.007	<0.02	0.012	<0.1	<0.1	1.7	<0.1
01/29/2003	2:30 PM	10	0.006	<0.02	0.018	0.4	<0.1	2.6	0.4
04/16/2003	4:00 PM	150	0.006	<0.02	0.012	<0.1	<0.1	1.9	<0.1
08/05/2003	12:30 PM	1	E0.003	<0.02	0.008	0.3	<0.1	2.0	0.3
08/05/2003	1:00 PM	120	0.009	<0.02	0.014	0.2	<0.1	2.1	0.2
08/05/2003	3:30 PM	73	E0.004	<0.02	0.008	<0.1	<0.1	1.7	<0.1
Site 3, MRS: Middle Reservoir, Shallow (Camp Far West Reservoir east shoreline 1.6 miles above dam)									
Station number 390244121171801									
10/29/2001	4:15 PM	6	E0.004	<0.02	0.014	–	–	2.6	0.4
02/12/2002	1:30 PM	60	E0.004	<0.02	0.023	–	–	3.0	0.3
04/22/2002	1:50 PM	10	<0.004	<0.02	0.013	–	–	1.8	0.3
04/15/2003	12:40 PM	32	0.009	<0.02	0.010	0.3	<0.1	2.8	0.3
Site 4, MRT: Middle Reservoir, Thalweg (Camp Far West Reservoir in thalweg 1.5 miles above dam)									
Station number 390238121173101									
10/29/2001	2:45 PM	50	0.006	<0.02	0.051	–	–	2.4	0.4
02/13/2002	8:30 AM	120	0.010	<0.02	0.015	–	–	2.3	<0.2
04/22/2002	12:20 PM	120	0.012	E0.01	0.017	–	–	2.0	<0.2
08/07/2002	12:10 PM	10	E0.003	<0.02	0.011	–	–	2.2	0.5
08/07/2002	12:40 PM	47	E0.003	<0.02	0.008	–	–	2.0	0.3
08/08/2002	2:50 PM	80	E0.003	<0.02	0.009	–	–	1.5	0.2
11/05/2002	2:10 PM	30	0.005	<0.02	0.035	–	–	2.3	0.6
11/05/2002	2:30 PM	10	0.005	<0.02	0.025	–	–	2.2	0.6
01/28/2003	3:30 PM	120	0.007	<0.004	0.012	–	<0.1	1.7	<0.1
01/29/2003	2:00 PM	10	0.005	<0.02	0.018	0.5	<0.1	2.2	0.5
04/17/2003	10:30 AM	125	0.009	<0.02	0.019	<0.1	<0.1	1.9	<0.1
08/07/2003	11:30 AM	1	E0.003	<0.02	0.008	0.3	<0.1	1.9	0.3
08/07/2003	11:50 AM	100	0.007	<0.02	0.011	0.1	<0.1	1.9	0.1

Table 5. Data for nutrients and organic carbon in water samples, Camp Far West Reservoir, California.—*Continued*

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological survey computerized data system. Elements: N, nitrogen; P, phosphorus; C, carbon. Thalweg, former river channel (low elevation path). ft, foot; mg/L, milligram per liter; E, estimated; <, less than; –, not determined]

Date	Time	Depth (ft)	Total phosphorus, filtered (mg/L as P) (00666)	Phosphorus, orthophosphate, filtered (mg/L as P) (00671)	Total phosphorus, unfiltered (mg/L as P) (00665)	Carbon, inorganic plus organic, particulate (mg/L as C) (00694)	Total carbon, inorganic, particulate (mg/L as C) (00688)	Carbon, organic, filtered (mg/L as C) (00681)	Carbon, organic, particulate (mg/L as C) (00689)
Site 5, BRA: Bear River arm (Camp Far West Reservoir Bear River arm near Wheatland)									
Station number 390202121162201									
10/31/2001	10:15 AM	12	0.005	<0.02	0.029	–	–	2.4	–
02/13/2002	9:00 AM	80	0.004	<0.02	0.009	–	–	1.7	<0.2
04/22/2002	10:40 AM	80	0.006	<0.02	0.013	–	–	1.8	0.2
08/06/2002	5:50 PM	10	0.008	<0.02	0.012	–	–	2.3	0.6
08/06/2002	6:20 PM	55	E0.003	<0.02	0.033	–	–	2.3	0.5
11/05/2002	4:10 PM	7	0.012	<0.02	0.056	–	–	2.6	1.9
01/29/2003	1:20 PM	10	E0.004	<0.02	0.012	0.1	<0.1	1.5	0.1
01/28/2003	2:50 PM	85	0.007	<0.02	0.012	–	<0.1	1.7	<0.1
04/17/2003	11:30 AM	90	0.011	<0.02	0.019	<0.1	<0.1	2.2	<0.1
08/07/2003	10:00 AM	1	0.005	<0.02	0.008	0.3	<0.1	2.1	0.3
08/06/2003	3:00 PM	100	E0.004	<0.02	0.12	2.6	<0.1	2.1	2.6
Site 6, DFA: Dairy Farm arm (Camp Far West Reservoir Dairy Farm arm near Wheatland)									
Station number 390159121171401									
10/31/2001	1:00 PM	4	E0.003	<0.02	0.012	–	–	2.3	<0.2
02/13/2002	1:00 PM	20	E0.004	<0.02	0.012	–	–	2.7	<0.2
04/23/2002	12:10 PM	20	<0.004	<0.02	0.010	–	–	2.0	<0.2
08/07/2002	6:50 PM	57	E0.002	<0.02	0.012	–	–	2.0	0.4
01/30/2003	3:30 PM	55	0.006	<0.02	0.015	0.1	<0.1	2.0	0.1
04/17/2003	2:30 PM	55	0.007	<0.02	0.022	<0.1	<0.1	2.2	<0.1
08/07/2003	4:00 PM	1	<0.004	<0.02	0.011	0.2	<0.1	1.9	0.2
Site 7, RCA: Rock Creek arm (Camp Far West Reservoir Rock Creek arm)									
Station number 390331121174101									
08/07/2002	3:40 PM	10	E0.002	<0.02	0.013	–	–	2.2	0.7
04/17/2003	1:20 PM	80	0.01	<0.02	0.018	0.2	<0.1	2.0	0.1
08/07/2003	1:00 PM	1	E0.0029	<0.02	0.012	0.2	<0.1	1.1	0.2
08/07/2003	1:30 PM	40	<0.004	<0.02	0.012	0.3	<0.1	1.7	0.3
Site 8, DFP: Dairy Farm Mine Pit Lake (Dairy Farm Mine pit lake near Wheatland)									
Station number 390148121171701									
10/31/2001	2:15 PM	1	E0.003	<0.02	0.004	–	–	<0.3	0.4
02/13/2002	3:10 PM	10	0.005	<0.02	0.015	–	–	2.8	0.2
02/13/2002	3:30 PM	35	0.009	<0.02	0.012	–	–	2.2	<0.2
04/24/2002	11:10 AM	30	<0.004	<0.02	0.011	–	–	1.5	<0.2
08/07/2002	5:00 PM	0.5	<0.004	<0.02	0.004	–	–	0.58	0.4
11/05/2002	2:50 PM	1	<0.004	<0.02	0.004	–	–	E0.2	<0.2
01/30/2003	12:30 PM	10	0.008	<0.02	0.021	0.7	<0.1	2.3	0.7
01/30/2003	1:20 PM	38	<0.004	<0.02	0.004	<0.1	<0.1	1.2	<0.1
04/17/2003	4:00 PM	40	E0.003	<0.02	<0.004	<0.1	<0.1	1.2	<0.1
08/07/2003	4:30 PM	1	<0.004	<0.02	E0.003	0.2	<0.1	1.2	0.2
Site 9, DFI: Dairy Farm Mine Impoundments (Camp Far West Reservoir impoundment Dairy Farm Mine arm)									
Station number 390152121171001									
10/31/2001	2:40 PM	0.5	–	–	–	–	–	–	–
02/13/2002	2:20 PM	52	E0.004	<0.02	0.015	–	–	2.5	0.2
04/23/2002	1:10 PM	20	<0.004	<0.02	0.012	–	–	1.9	0.2
11/05/2002	2:00 PM	0.5	E0.002	<0.02	0.008	–	–	0.3	<0.2

Table 6. Best values for concentrations of total mercury in water samples, Camp Far West Reservoir, California.

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Source of best values: a, sum of quartz filter filtrate and quartz filter particulates; b, average of two replicates, Boulder, Colo., laboratory (lab); c, weighted average of two replicates, Boulder lab, and one replicate, Wisconsin lab; d, Wisconsin lab, single sample; e, Boulder lab, single sample; f, quartz filter filtrate; g, quartz filter particulates; h, difference of filtered and unfiltered best values. Thalweg, former river channel (low elevation path). ft, foot; Hg, mercury; ng/L, nanogram per liter]

Date	Time	Depth (ft)	Unfiltered total Hg (ng/L) (50286)		Filtered total Hg (ng/L) (50287)		Particulate total Hg (ng/L)	
			Value	Source	Value	Source	Value	Source
Site 1, LRS: Lower Reservoir, Shallow (Camp Far West Reservoir 0.3 mile north of dam abutment)								
Station number 390317121185001								
10/30/2001	5:15 PM	10	6.2	a	0.8	f	5.4	g
02/12/2002	12:00 PM	8	5.4	b	1.8	b	3.7	h
04/22/2002	3:20 PM	10	2.4	b	0.9	b	1.5	h
08/06/2002	4:30 PM	10	1.6	b	0.4	b	1.2	h
04/15/2003	10:30 AM	40	3.9	d	1.0	d	2.9	h
Site 2, LRT: Lower Reservoir, Thalweg (Camp Far West Reservoir in thalweg near dam near Wheatland)								
Station number 390307121183801								
11/01/2001	8:30 AM	70	12.1	a	2.5	f	9.6	g
02/12/2002	11:00 AM	140	7.8	b	1.5	b	6.4	h
04/22/2002	3:00 PM	140	4.3	b	1.1	b	3.2	h
08/08/2002	12:00 PM	45	1.9	b	0.3	b	1.7	h
08/08/2002	1:30 PM	113	1.8	b	0.6	b	1.2	h
11/04/2002	3:50 PM	10	8.2	c	0.3	d	7.9	h
11/04/2002	3:20 PM	55	5.6	c	0.3	d	5.3	h
01/29/2003	2:30 PM	10	5.7	c	1.7	c	4.0	h
01/28/2003	4:40 PM	140	7.1	c	1.5	c	5.6	h
04/16/2003	4:00 PM	150	2.9	d	0.9	d	2.0	h
08/05/2003	12:30 PM	1	2.5	d	0.4	d	2.1	h
08/05/2003	3:30 PM	73	3.3	d	0.7	d	2.6	h
08/05/2003	1:00 PM	120	2.1	d	0.9	d	1.2	h
Site 3, MRS: Middle Reservoir, Shallow (Camp Far West Reservoir east shoreline 1.6 miles above dam)								
Station number 390244121171801								
10/29/2001	4:15 PM	6	4.1	a	0.6	f	3.5	g
02/12/2002	1:30 PM	60	4.9	b	1.7	b	3.3	h
04/22/2002	1:50 PM	10	2.7	b	0.9	b	1.8	h
04/15/2003	12:40 PM	32	2.4	d	0.9	d	1.4	h
Site 4, MRT: Middle Reservoir, Thalweg (Camp Far West Reservoir in thalweg 1.5 miles above dam)								
Station number 390238121173101								
10/29/2001	2:45 PM	50	12.6	a	1.0	f	11.6	g
02/13/2002	8:30 AM	120	8.0	b	1.3	b	6.7	h
04/22/2002	12:20 PM	120	4.5	b	1.0	b	3.5	h
08/07/2002	12:10 PM	10	1.7	b	0.4	b	1.3	h
08/07/2002	12:40 PM	47	1.0	b	0.3	b	0.7	h
08/08/2002	2:50 PM	80	2.6	b	0.4	b	2.2	h
11/05/2002	2:30 PM	10	4.7	c	0.3	c	4.3	h
11/05/2002	2:10 PM	30	10.4	c	0.3	c	10.1	h
01/29/2003	2:00 PM	10	4.9	c	1.6	c	3.3	h
01/28/2003	3:30 PM	120	7.0	c	1.5	c	5.5	h
04/17/2003	10:30 AM	125	3.8	d	0.9	d	2.9	h
08/07/2003	11:30 AM	1	1.2	d	1.0	d	0.2	h
08/07/2003	11:50 AM	100	2.8	d	0.7	d	2.1	h

Table 6. Best values for total mercury concentrations, Camp Far West Reservoir, California.—*Continued*

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Source of best values: a, sum of quartz filter filtrate and quartz filter particulates; b, average of two replicates, Boulder, Colo., laboratory (lab); c, weighted average of two replicates, Boulder lab, and one replicate, Wisconsin lab; d, Wisconsin lab, single sample; e, Boulder lab, single sample; f, quartz filter filtrate; g, quartz filter particulates; h, difference of filtered and unfiltered "best values." Thalweg, former river channel (low elevation path). ft, foot; Hg, mercury; ng/L, nanogram per liter]

Date	Time	Depth (ft)	Unfiltered total Hg (ng/L) (50286)		Filtered total Hg (ng/L) (50287)		Particulate total Hg (ng/L)	
			Value	Source	Value	Source	Value	Source
Site 5, BRA: Bear River arm (Camp Far West Reservoir Bear River arm near Wheatland)								
Station number 390202121162201								
10/31/2001	10:15 AM	12	9.7	a	0.6	b	9.2	h
02/13/2002	9:00 AM	80	8.5	b	1.4	b	7.2	h
04/22/2002	10:40 AM	80	4.6	b	0.8	b	3.8	h
08/06/2002	5:50 PM	10	1.5	b	0.5	b	1.1	h
08/06/2002	6:20 PM	55	3.2	b	0.4	b	2.8	h
11/05/2002	4:10 PM	7	4.8	c	0.3	c	4.5	h
01/29/2003	1:20 PM	10	6.9	c	1.6	c	5.3	h
01/28/2003	2:50 PM	85	6.9	c	1.5	c	5.4	h
04/17/2003	11:30 AM	90	6.0	d	1.4	d	4.6	h
08/07/2003	10:00 AM	1	1.4	d	0.4	d	1.0	h
08/06/2003	3:00 PM	100	43.6	d	0.6	d	43	h
Site 6, DFA: Dairy Farm arm (Camp Far West Reservoir Dairy Farm arm near Wheatland)								
Station number 390159121171401								
10/31/2001	1:00 PM	4	3.9	a	0.7	f	3.2	g
02/13/2002	1:00 PM	20	6.3	b	1.6	b	4.8	h
04/23/2002	12:10 PM	20	2.5	e	1.0	b	1.5	h
08/07/2002	6:50 PM	57	2.8	b	0.4	b	2.4	h
01/30/2003	3:30 PM	55	7.3	c	1.8	c	5.5	h
04/17/2003	2:30 PM	55	5.2	d	1.5	d	3.7	h
08/07/2003	4:00 PM	1	1.8	d	0.4	d	1.4	h
Site 7, RCA: Rock Creek arm (Camp Far West Reservoir Rock Creek arm)								
Station number 390331121174101								
08/07/2002	03:40 PM	10	1.6	b	0.3	b	1.3	h
04/17/2003	01:20 PM	80	4.0	d	0.9	d	3.1	h
08/07/2003	01:00 PM	1	1.5	d	0.4	d	1.1	h
08/07/2003	01:30 PM	40	2.5	d	0.5	d	2.0	h
Site 8, DFP: Dairy Farm Mine Pit Lake (Dairy Farm Mine pit lake near Wheatland)								
Station number 390148121171701								
10/31/2001	2:15 PM	1	10.8	a	5.3	f	5.5	g
02/13/2002	3:10 PM	10	5.8	b	3.6	f	2.3	h
02/13/2002	3:30 PM	35	6.4	b	3.2	f	3.2	h
04/24/2002	11:10 AM	30	3.2	b	0.8	b	2.5	h
08/07/2002	5:00 PM	0.5	3.1	b	0.2	b	2.9	h
11/05/2002	2:50 PM	1	4.3	b	1.4	b	2.9	h
01/30/2003	12:30 PM	10	1.2	c	0.3	c	0.9	h
01/30/2003	1:20 PM	38	4.6	c	1.7	c	2.9	h
04/17/2003	4 :00 PM	40	1.0	d	0.4	d	0.6	h
08/07/2003	4:30 PM	1	7.0	d	0.1	d	6.9	h
Site 9, DFI: Dairy Farm Mine Impoundments (Camp Far West Reservoir impoundment Dairy Farm Mine arm)								
Station number 390152121171001								
10/31/2001	2:40 PM	0.5	5.3	a	2.1	f	3.2	g
02/13/2002	2:20 PM	52	7.1	b	3.5	f	3.6	h
04/23/2002	1:10 PM	20	2.6	b	1.1	f	1.5	h
11/05/2002	2:00 PM	0.5	3.0	b	0.3	b	2.7	h

Table 7. Data for methylmercury in water samples, Camp Far West Reservoir, California.

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. Thalweg, former river channel (low elevation path). C45, 0.45-micrometer capsule filter; Q, quartz fiber filter; MeHg, methylmercury; ft, foot; ng/L, nanogram per liter; E, estimated. <, less than detection limit; –, not determined]

Date	Time	Depth (ft)	MeHg unfiltered (ng/L) (50284)	MeHg filtered (C45) (ng/L) (50285)	MeHg filtered (Q) (ng/L) (50285)	MeHg particulate (Q) (ng/L)
Site 1, LRS: Lower Reservoir, Shallow (Camp Far West Reservoir 0.3 mile north of dam abutment)						
Station number 390317121185001						
10/30/2001	5:15 PM	10	–	–	<0.04	–
02/12/2002	12:00 PM	8	0.06	<0.04	<0.04	0.028
04/22/2002	3:20 PM	10	0.07	<0.04	<0.04	0.026
08/06/2002	4:30 PM	10	0.12	<0.04	<0.04	<0.044
04/15/2003	10:30 AM	40	0.09	<0.04	<0.04	<0.029
Site 2, LRT: Lower Reservoir, Thalweg (Camp Far West Reservoir in thalweg near dam near Wheatland)						
Station number 390307121183801						
11/01/2001	8:30 AM	70	–	–	–	–
02/12/2002	11:00 AM	140	0.06	0.04	0.05	0.01
04/22/2002	3:00 PM	140	0.06	0.04	0.06	0.011
08/08/2002	12:00 PM	45	E0.07	<0.04	<0.04	<0.043
08/08/2002	1:30 PM	113	0.04	<0.04	<0.04	<0.043
11/04/2002	3:50 PM	10	0.09	<0.04	<0.04	0.097
11/04/2002	3:20 PM	55	<0.04	<0.04	<0.04	<0.029
01/29/2003	2:30 PM	10	<0.04	<0.04	<0.04	<0.029
01/28/2003	4:40 PM	140	0.06	0.04	0.05	<0.029
04/16/2003	4:00 PM	150	0.07	0.05	<0.04	<0.029
08/05/2003	12:30 PM	1	0.04	0.04	<0.04	<0.029
08/05/2003	3:30 PM	73	<0.04	<0.04	–	<0.029
08/05/2003	1:00 PM	120	0.06	0.05	0.04	<0.029
Site 3, MRS: Middle Reservoir, Shallow (Camp Far West Reservoir east shoreline 1.6 miles above dam)						
Station number 390244121171801						
10/29/2001	4:15 PM	6	–	–	<0.04	–
02/12/2002	1:30 PM	60	0.04	<0.04	0.04	0.033
04/22/2002	1:50 PM	10	0.06	<0.04	<0.04	0.023
04/15/2003	12:40 PM	32	0.07	0.04	0.06	<0.029
Site 4, MRT: Middle Reservoir, Thalweg (Camp Far West Reservoir in thalweg 1.5 miles above dam)						
Station number 390238121173101						
10/29/2001	2:45 PM	50	–	–	<0.04	–
02/13/2002	8:30 AM	120	0.04	<0.04	<0.04	0.01
04/22/2002	12:20 PM	120	0.07	0.05	0.06	0.014
08/07/2002	12:10 PM	10	0.06	<0.04	<0.04	<0.047
08/07/2002	12:40 PM	47	0.08	<0.04	0.04	<0.045
08/08/2002	2:50 PM	80	0.05	<0.04	<0.04	<0.043
11/05/2002	2:30 PM	10	0.05	<0.04	<0.04	0.54
11/05/2002	2:10 PM	30	< 0.04	<0.04	<0.04	<0.029
01/29/2003	2:00 PM	10	0.07	<0.04	0.04	0.037
01/28/2003	3:30 PM	120	0.06	0.05	E0.05	<0.029
04/17/2003	10:30 AM	125	0.12	0.04	0.04	<0.029
08/07/2003	11:30 AM	1	E0.04	<0.04	<0.04	<0.029
08/07/2003	11:50 AM	100	<0.04	<0.04	–	<0.029

Table 7. Data for methylmercury in water samples, Camp Far West Reservoir, California.—*Continued*

[The number in parentheses is the data parameter code, a five-digit code used in the U.S. Geological Survey computerized data system. thalweg, former river channel (low elevation path). C45, 0.45-micrometer capsule filter; Q, quartz fiber filter; MeHg, methylmercury; ft, foot; ng/L, nanogram per liter; E, estimated. <, less than; –, not determined]

Date	Time	Depth (ft)	MeHg unfiltered (ng/L) (50284)	MeHg filtered (C45) (ng/L) (50285)	MeHg filtered (Q) (ng/L) (50285)	MeHg particulate (Q) (ng/L)
Site 5, BRA: Bear River arm (Camp Far West Reservoir Bear River arm near Wheatland)						
Station number 390202121162201						
10/31/2001	10:15 AM	12	<0.04	–	<0.04	–
02/13/2002	9:00 AM	80	0.07	0.05	0.05	0.018
04/22/2002	10:40 AM	80	0.12	0.05	0.06	0.02
08/06/2002	5:50 PM	10	<0.04	<0.04	<0.04	<0.046
08/06/2002	6:20 PM	55	0.46	0.22	0.32	0.16
11/05/2002	4:10 PM	7	0.05	<0.04	0.15	<0.030
01/29/2003	1:20 PM	10	0.06	0.05	0.06	<0.029
01/28/2003	2:50 PM	85	0.07	E0.05	0.05	<0.029
04/17/2003	11:30 AM	90	0.08	0.06	0.06	<0.029
08/07/2003	10:00 AM	1	0.05	0.04	<0.04	<0.029
08/06/2003	3:00 PM	100	0.30	0.06	0.08	0.39
Site 6, DFA: Dairy Farm arm (Camp Far West Reservoir Dairy Farm arm near Wheatland)						
Station number 390159121171401						
10/31/2001	1:00 PM	4	0.04	–	<0.04	–
02/13/2002	1:00 PM	20	0.06	<0.04	<0.04	0.018
04/23/2002	12:10 PM	20	0.06	<0.04	0.04	0.014
08/07/2002	6:50 PM	57	0.19	0.08	0.06	0.08
01/30/2003	3:30 PM	55	0.06	0.05	0.05	<0.029
04/17/2003	2:30 PM	55	0.15	0.07	0.07	0.046
08/07/2003	4:00 PM	1	<0.04	<0.04		<0.029
Site 7, RCA: Rock Creek arm (Camp Far West Reservoir Rock Creek arm)						
Station number 390331121174101						
08/07/2002	03:40 PM	10	0.07	0.04	0.04	<0.045
04/17/2003	01:20 PM	80	0.10	0.06	<0.04	0.051
08/07/2003	01:00 PM	1	0.06	0.08	–	<0.029
08/07/2003	01:30 PM	40	<0.04	<0.04	–	<0.029
Site 8, DFP: Dairy Farm Mine Pit Lake (Dairy Farm Mine pit lake near Wheatland)						
Station number 390148121171701						
10/31/2001	2:15 PM	1	–	–	<0.04	–
02/13/2002	3:10 PM	10	0.06	<0.04	<0.04	0.015
02/13/2002	3:30 PM	35	<0.04	<0.04	<0.04	0.013
04/24/2002	11:10 AM	30	0.07	0.05	0.05	0.026
08/07/2002	5:00 PM	0.5	<0.04	<0.04	<0.04	<0.046
11/05/2002	2:50 PM	1	<0.04	<0.04	<0.04	
01/30/2003	12:30 PM	10	<0.04	<0.04	<0.04	<0.029
01/30/2003	1:20 PM	38	0.08	<0.04	<0.04	0.049
04/17/2003	4:00 PM	40	<0.04	<0.04	0.04	<0.029
08/07/2003	4:30 PM	1	<0.04	<0.04	–	<0.029
Site 9, DFI: Dairy Farm Mine Impoundments (Camp Far West Reservoir impoundment Dairy Farm Mine arm)						
Station number 390152121171001						
10/31/2001	2:40 PM	0.5	–	–	–	–
02/13/2002	2:20 PM	52	0.04	–	0.06	0.018
04/23/2002	1:10 PM	20	0.06	<0.04	<0.04	0.011
11/05/2002	2:00 PM	0.5	<0.04	<0.04	<0.04	<0.029

Suspended Solids and Major Elements

The suspended-solids concentration (SSC) in water samples from Camp Far West Reservoir ranged from less than the MDL of 1 mg/L to a maximum of 30 mg/L during the study period (tables 2 and 8). The SSC values were highest during the fall of 2001 and 2002, and the summer of 2002 (fig. 8*A*). Concentrations of particulate iron, computed as the difference between unfiltered and filtered concentrations (tables G3, G4, respectively), vary seasonally (fig. 8*B*) in a pattern partly similar to that for SSC, with elevated values in the fall of 2001 and 2002; however, the situation was different during summer 2002, when SSC concentrations were relatively high but particulate Fe concentrations were relatively low in most samples.

Concentrations of calcium in filtered water (table G4, fig. 8*C*) were highest in the acidic water samples from the Dairy Farm Mine pit lake and impoundments (sites 8 and 9). At other stations in the reservoir, calcium concentrations were higher in the fall than in the other seasons by a factor of about two. A similar seasonal pattern is evident for concentrations of other major cations, such as magnesium, sodium, and potassium (table G4). Sulfate (SO_4) concentrations (table 3, fig. 8*D*) show a pattern similar to that of calcium, with highest values associated with the acid mine waters, and fall concentrations about twice those of the other seasons at other stations.

Correlation plots of major cations (such as sodium and calcium) and anions (chloride and sulfate) in filtered water (figs. 9*A*–9*D*) indicate that seasonal differences appear to be more significant than spatial differences within the reservoir. The data also indicate that elevated concentrations of major constituents in the fall are similar to the composition of input water from the Bear River during this period. Average-concentration data for eight fall-season samples collected at approximately monthly intervals during 2001–03 from the Bear River below Wolf Creek near Lucas Hill, USGS station 390107121102101 are shown by a black circle on figures 9*A*–9*D* for comparison (error bars indicate standard deviations for eight samples). Sodium (Na) and chloride (Cl) concentrations in water samples from Camp Far West Reservoir correlate closely; data for all sites except sites 8 and 9 are close to the 1:1 molar ratio line (fig. 9*A*). The average of fall data for Na and Cl from the Bear River below Wolf Creek plots within the range of the fall data for Camp Far West Reservoir. The correlation between calcium and chloride (fig. 9*B*) also is positive but less consistent than that between Na and Cl; molar concentrations of Ca are less than the corresponding molar concentrations of Cl for all samples except one from the Dairy Farm Mine area. The correlation between Cl and SO_4 (fig. 9*C*) indicates that Cl is more abundant than SO_4 on a molar basis in all water samples from CFWR except those most acutely affected by acid mine drainage associated with the Dairy Farm Mine. The correlation between Ca and SO_4 (fig. 9*D*) is similar to those of Ca and Cl (fig. 9*B*) and Cl and SO_4 (fig. 9*C*). The diagonal line on figure 9*D* labeled $Ca:SO_4 = 1:1$ represents an equimolar increase of Ca and SO_4, a trend that would result from the dissolution of gypsum ($CaSO_4 \cdot 2H_2O$), a common mineral in marine sedimentary rocks. The diagonal line labeled $Ca:SO_4 = 4:1$ approximates the trend in the data for most samples from CFWR, indicating that gypsum dissolution is not a likely explanation for the coupled increase in Ca and SO_4 concentrations between summer and fall. As in figure 9*A*, the data in figures 9*B*–9*D* show that the composition of water entering Camp Far West Reservoir from the Bear River is consistent with the seasonal shift to larger concentrations of major elements in the fall. Because of the extreme drawdown of CFWR during fall, the residence time of solutes is much lower and it is reasonable to expect that a shift in the composition of the input water could cause a fairly rapid shift in the composition of CFWR.

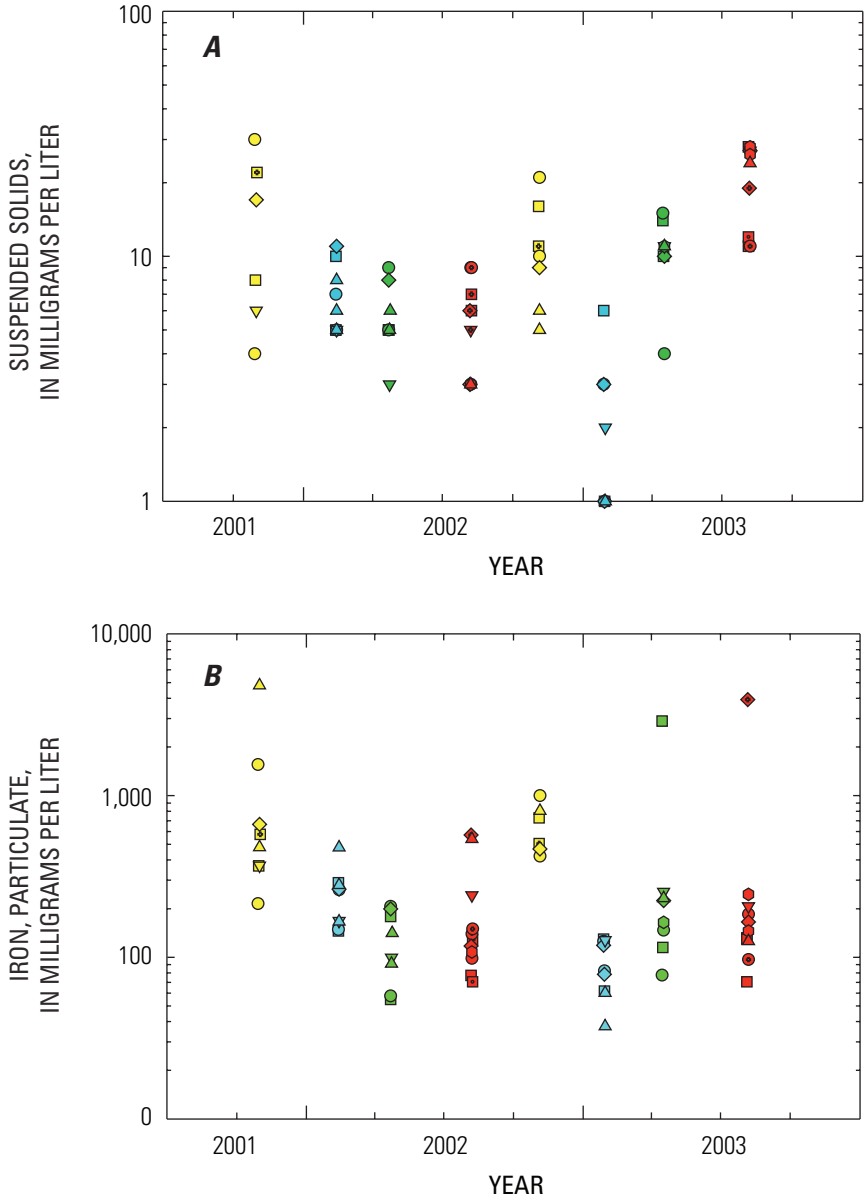
Stable Isotopes of Water and Aqueous Sulfate

The relation between stable isotopes of oxygen and hydrogen in water from Camp Far West Reservoir is most easily understood in the context of similar data from sampling stations in the Bear River. On a plot of isotopic data from water samples collected throughout the Bear River watershed (fig. 10*A*), two important trends with distinct slopes are evident. Most of the data plot parallel to the Global Meteoric Water Line (GWML), which defines a world-wide trend for precipitation by the relation $\delta D = \delta^{18}O + 10$ (Craig and others, 1963). Isotope data for samples from stations that are dominated by flow from higher elevations in the watershed, such as Bear River below Steephollow Creek near Chicago Park (USGS station 391023120541301) (station a, fig. 1), and Bear River below Rollins Dam near Colfax (USGS station 11422500) (station c, fig. 1), have the smallest values of $\delta^{18}O$ and δD, consistent with precipitation forming at lower temperatures and falling at higher elevations (Craig and others, 1963). Samples from Greenhorn Creek at You Bet Road near Nevada City (USGS station 391116120562501) (station a, fig. 1) plot along the GMWL but at larger values of $\delta^{18}O$ and δD, consistent with precipitation falling at higher temperatures and lower elevations (Ingraham, 1998).

Table 8. Statistical data for field measurements and suspended solids concentrations, Camp Far West Reservoir, California.

[Suspended silt plus clay is the product of suspended solids concentrations and percent suspended solids sieved. °C, degree Celsius; mg/L, milligram per liter; µS/cm, microsiemens per centimeter; n, number of samples]

	Temperature (°C)	Dissolved oxygen (mg/L)	pH	Specific conductance (µS/cm)	Total suspended solids (mg/L)	Suspended silt plus clay (mg/L)
All samples						
Mean	14.6	8.1	7.0	164	9.8	8.4
Standard error of mean	0.78	0.44	0.13	32	1.0	0.9
Standard deviation	6.5	3.7	1.1	267	7.9	7.1
Minimum	7.0	0.0	3.0	69	0	0
25th percentile	9.6	6.6	6.8	84	5	3
Median	11.4	8.7	7.3	90	7.5	6
75th percentile	17.6	10.3	7.7	127	11	10
Maximum	27.5	14.6	8.4	1,660	30	30
n	69	69	71	71	68	68
All reservoir samples (excluding Dairy Farm Mine Pit Lake and Impoundments)						
Mean	14.8	8.1	7.3	98	10.4	8.9
Standard error of mean	0.86	0.5	0.06	3.4	1.1	1.0
Standard deviation	6.5	3.8	0.47	26	8.1	7.2
Minimum	7.0	0.0	6.4	69	0	0
25th percentile	9.8	6.1	6.9	81	5	4
Median	13.0	8.5	7.4	88	9	7
75th percentile	17.8	10.6	7.7	109	13	11
Maximum	27.5	14.6	8.4	155	30	30
n	57	57	57	57	57	57
Epilimnion (excluding Dairy Farm Mine Pit Lake and Impoundments)						
Mean	15	9.6	7.5	100	10	9
Standard error of mean	1.1	0.36	0.05	4.1	1.3	1.2
Standard deviation	7.1	2.4	0.36	27	8.8	7.8
Minimum	7.0	4.2	6.7	69	0	0
25th percentile	9.3	7.9	7.3	83	3.5	3
Median	14.0	9.6	7.5	88	8	7
75th percentile	17.8	11.7	7.8	121	14.5	10.5
Maximum	27.5	14.6	8.4	155	30	30
n	45	45	45	45	45	45
Hypolimnion and Metalimnion						
Mean	14.1	2.3	6.7	88	10.7	9.6
Standard error of mean	1.2	0.58	0.06	4.2	1.5	1.4
Standard deviation	4.1	2.0	0.2	15	5.2	4.8
Minimum	10.5	0.0	6.4	72	5	4
25th percentile	11.0	0.3	6.5	77	6.3	6
Median	11.8	1.8	6.7	87	10	9
75th percentile	18.9	4.3	6.9	96	12	11
Maximum	21.5	5.7	7.0	124	22	20
n	12	12	12	12	12	12



EXPLANATION

	Site Number	Fall	Winter	Spring	Summer
Lower reservoir	1, 2	□	□	■	■
Mid-reservoir	3, 4	○	○	●	●
Bear River arm	5	◇	◇	◆	◆
Dairy Farm arm	6	▽	▽	▼	▼
Rock Creek arm	7	⬡	⬡	⬢	⬢
Dairy Farm Mine pit lake and impoundments	8, 9	△	△	▲	▲

□ ○ ◇ ▽ Solid symbol indicates epilimnion
⊡ ⊙ Dot indicates metalimnion
⊠ ⊗ ◈ ▼ Cross indicates hypolimnion

Figure 8. Showing concentrations of water-quality constituents for sampling stations in Camp Far West Reservoir, California, 2001–03: (*A*) Suspended solids, (*B*) Particulate iron, (*C*) Calcium in filtered water, (*D*) Sulfate in filtered water. In (*B*), particulate iron computed as the difference between the concentrations of iron in unfiltered and filtered water.

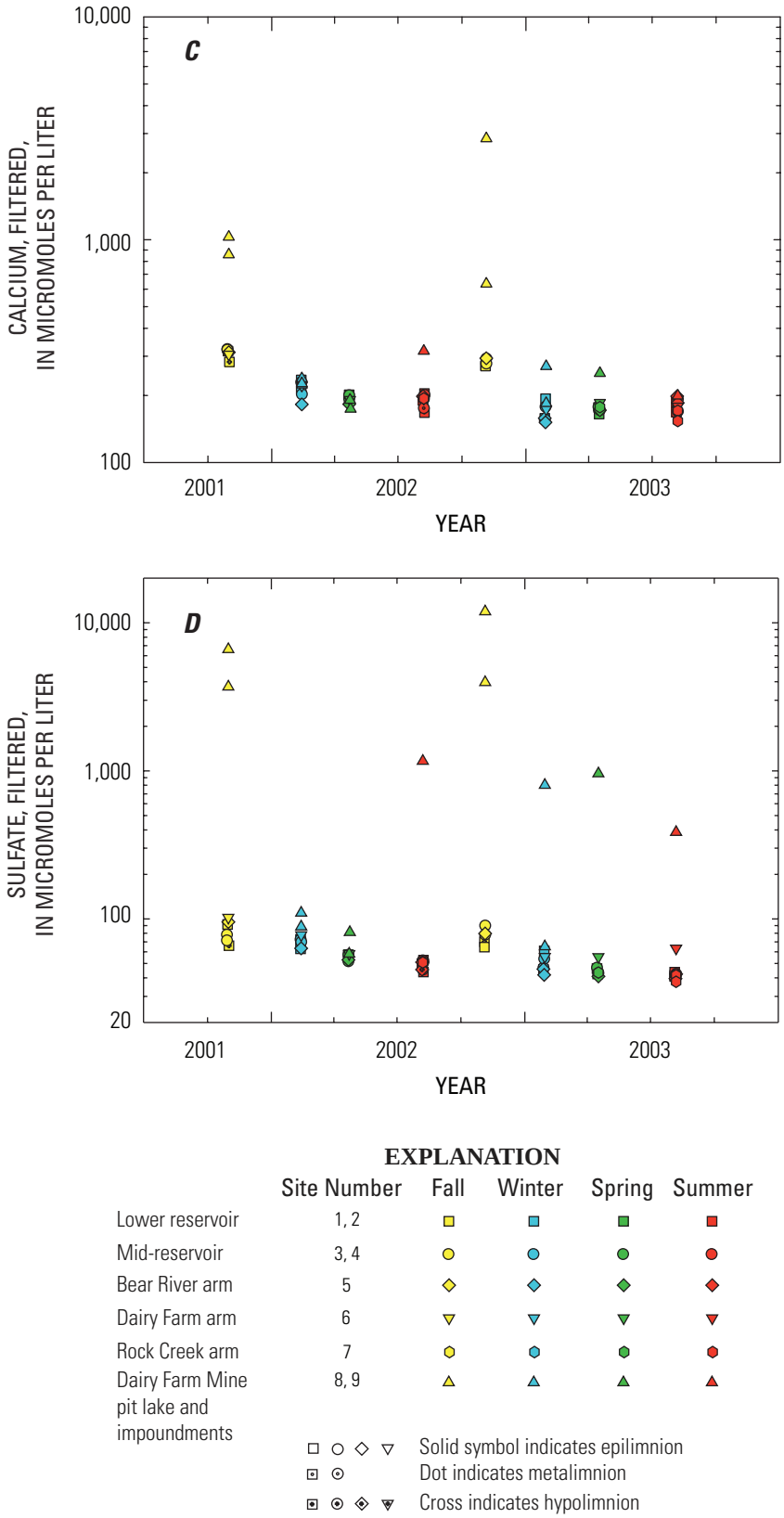


Figure 8. Continued.

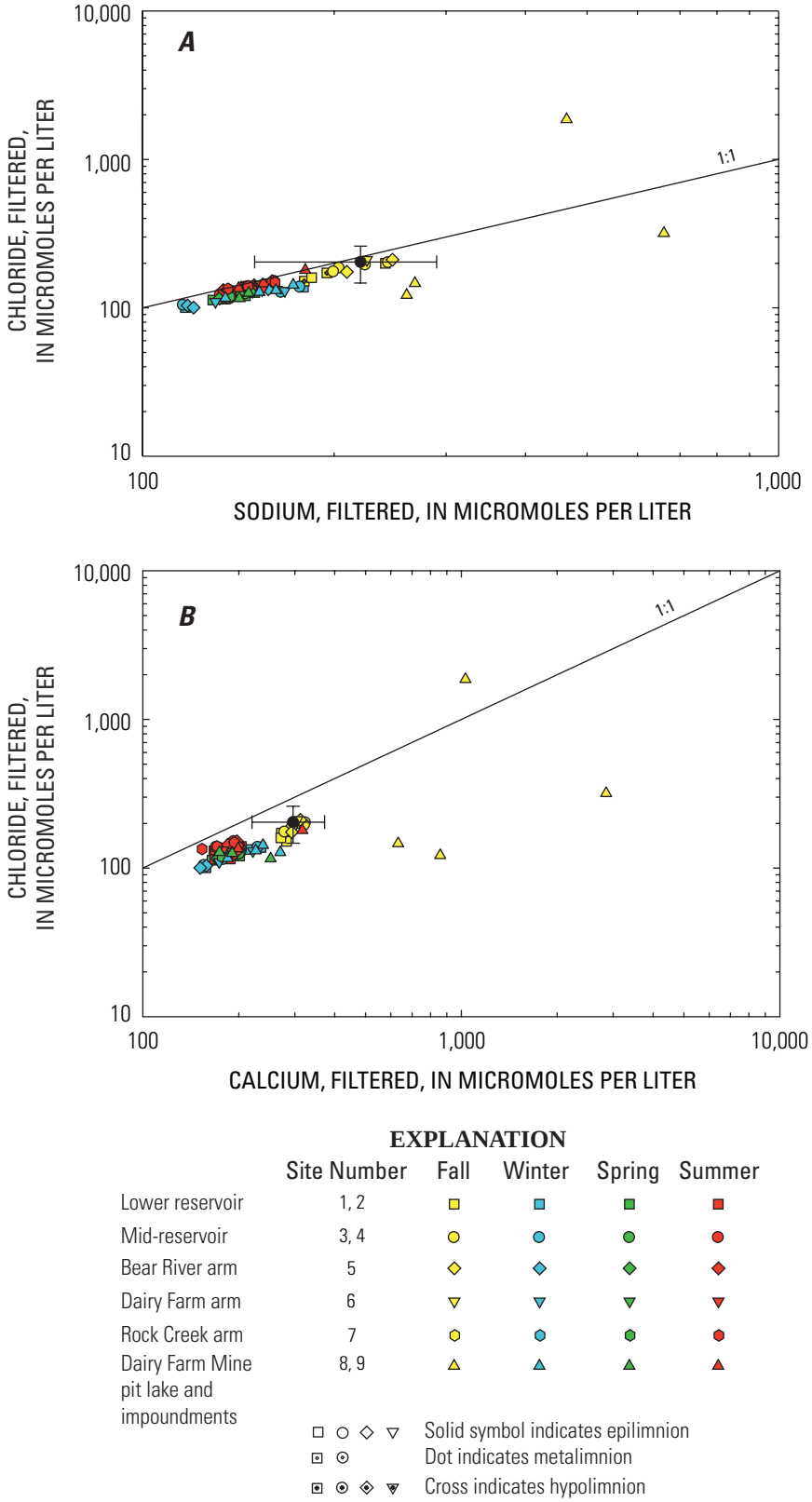
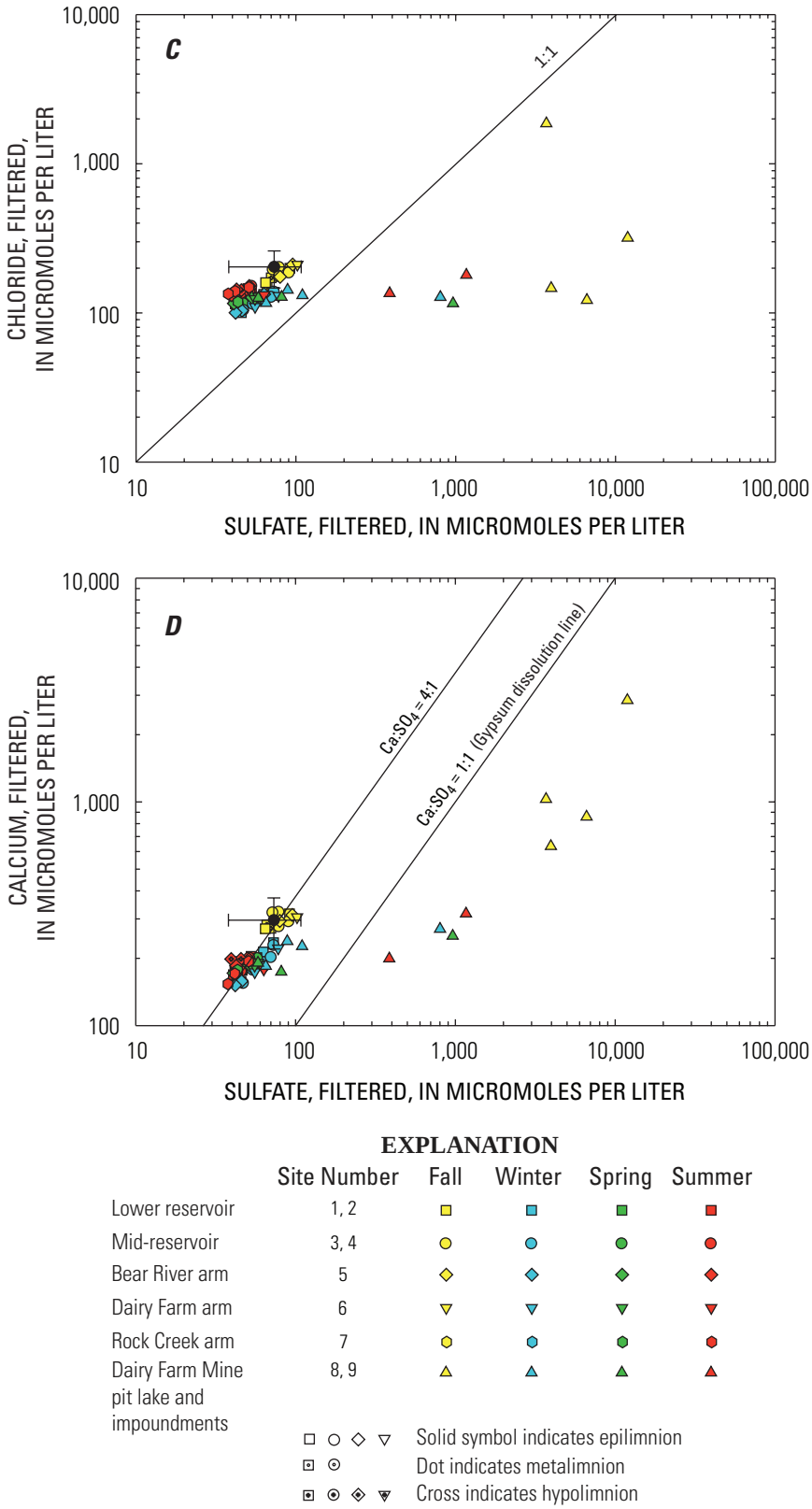


Figure 9. Relations among major elements in filtered water in Camp Far West Reservoir, California, 2001–03: (*A*) Sodium and chloride, (*B*) Calcium and chloride, (*C*) Sulfate and chloride, (*D*) Calcium and sulfate. Filled, black circle with error bars represents average concentrations and standard deviations for eight fall-season samples collected at approximately monthly intervals from the Bear River below Wolf Creek near Lucas Hill (USGS station 390107121102101) (station e, fig. 1).



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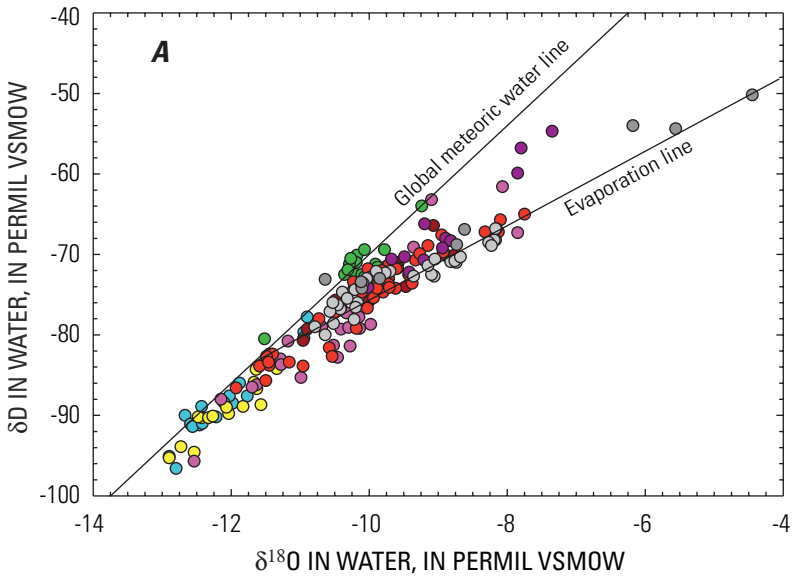
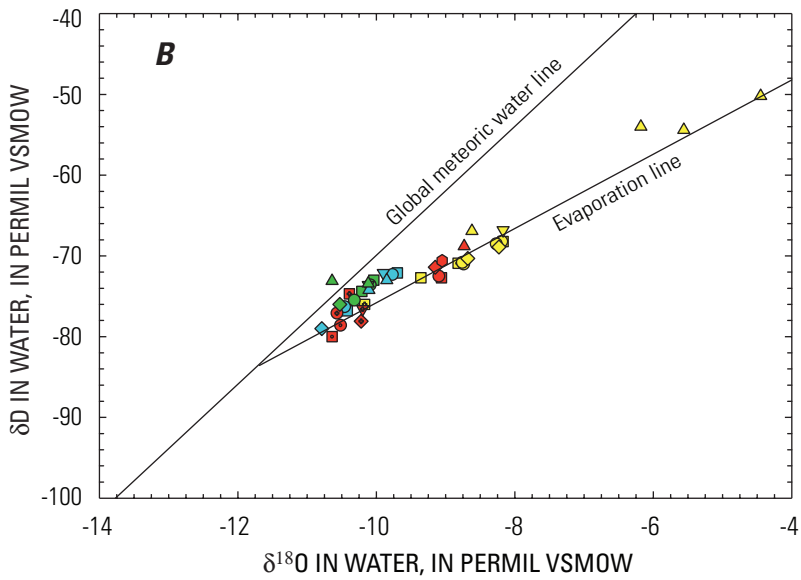


EXPLANATION

- Bear River below Steephollow Creek
- Greenhorn Creek at You Bet Road
- Bear River below Rollins Dam
- Bear River Canal
- Bear River below Wolf Creek
- Bear River below Camp Far West
- Bear River near Berry Road
- Bear River near Wheatland
- Camp Far West Reservoir
- Dairy Farm Mine Pit Lake and Impoundments

Figure 10. Relation between oxygen and hydrogen isotopes in unfiltered water: (*A*) Bear River stations, including Camp Far West Reservoir, 2001–03, (*B*) Camp Far West Reservoir stations, 1999–2003. Global Meteoric Water Line from Craig and others (1963). δD, delta-deuterium; $\delta^{18}O$, delta-18-oxygen; VSMOW, Vienna Standard Mean Ocean Water.



EXPLANATION

	Site Number	Fall	Winter	Spring	Summer
Lower reservoir	1, 2	□	□	■	■
Mid-reservoir	3, 4	○	○	●	●
Bear River arm	5	◇	◇	◆	◆
Dairy Farm arm	6	▽	▽	▼	▼
Rock Creek arm	7	⬡	⬡	⬢	⬢
Dairy Farm Mine pit lake and impoundments	8, 9	△	△	▲	▲

□ ○ ◇ ▽ Solid symbol indicates epilimnion
⊡ ⊙ Dot indicates metalimnion
⊠ ⊗ ⊘ ⊽ Cross indicates hypolimnion

Figure 10. Continued.

Stable isotope data for water samples from CFWR and some of the stations in the lower part of the watershed, such as the Bear River near Wheatland (USGS station 11424000) (station g, fig. 1) follow a trend line with a shallower slope of about 4, consistent with evaporation (fig. 10*A*). Looking at only the isotopic data from CFWR with seasons color-coded (fig. 10*B*), the evaporative trend is most apparent for summer and fall samples from the epilimnion, whereas winter and spring samples plot closer to the GMWL. The samples showing evaporation at the Bear River near Wheatland and other downstream stations (figs. 1, 10*A*) probably reflect evaporation that took place within CFWR. A time-series plot of $\delta^{18}O$ for Camp Far West Reservoir water samples (fig. 11*A*) shows that an evaporative shift to values about 2 permil higher in the summer and fall is limited to epilimnion samples.

There is a significant seasonal trend in the sulfur isotopes of dissolved sulfate in CFWR—decreasing values of $\delta^{34}S$ from fall to winter to spring to summer, followed by a dramatic shift to higher values again in the fall (fig. 11*B*). Oxygen isotope values in aqueous sulfate ($\delta^{18}O_{SO4}$) show a less systematic seasonal variation than the sulfur isotope values (figs. 11*C*, 12*A*). Excluding the data from sites 8 and 9, there appears to be a trend toward smaller values of $\delta^{18}O_{SO4}$ (about 1 permil less, on average) in summer 2002 compared with fall 2001.

The relations between $\delta^{34}S_{SO4}$values and aqueous SO_4 and Ca concentrations (figs. 12*B*, 12*C*) are useful for determining whether seasonal shifts in $\delta^{34}S$ may be caused by variation in geologic (or possible anthropogenic) sources. Sulfate concentration tends to decrease from fall to winter to spring, stay low into summer, and increase again each fall. The fall increase in SO_4 concentration may be caused to some extent by evaporative concentration, as discussed above in the context of oxygen and hydrogen isotopes in water. The samples with by far the highest sulfate concentration are those from the Dairy Farm Mine pit lake and impoundments (sites 8 and 9). It is clear from the hydrologic setting that oxidizing sulfide minerals in the Dairy Farm Mine area contribute dissolved sulfate to CFWR. Each year, the pit lake becomes isolated from CFWR during summer and fall and turns severely acidic, with low values of pH (table 1), and elevated concentrations of sulfate (table 3) and trace metals (tables G3, G4). The $\delta^{34}S_{SO4}$values in the pit lake and impoundments range from 0.1 to 1.3 permil (table 4), with a median value of 0.5 permil. Values of $\delta^{34}S$ in the fall for water samples from CFWR stations (excluding the Dairy Farm Mine pit lake and impoundments, sites 8 and 9) range from 2.0 to 3.2 permil, distinctly higher than the other seasons (figs. 11–12). It appears that this variation is best explained by the input to CFWR from the Bear River, which also has relatively high values of $\delta^{34}S_{SO4}$ and relatively high concentrations of Ca and SO_4 in the fall.

Nutrients and Organic Carbon

Nutrients are a crucial water-quality component in this study because of their role in affecting primary production (phytoplankton), the base of the food web in the reservoir (Stewart and others, 2008). As described earlier for major cations and anions, seasonal differences for several nutrient constituents appear to be more significant than spatial differences among sampling stations in the reservoir.

A time-series plot of total phosphorus (P) in unfiltered water (fig. 13*A*) shows a generally declining trend at several sites from fall to winter and spring to summer. An exception to the trend is two hypolimnion samples from summer 2002 and 2003 from the BRA station, which had anomalously high values of total P in contrast to samples from the other stations collected during the same sampling events, consistent with observations by Kuwabara and others (2003). No clear seasonal trends are apparent for filtered total phosphorus (fig. 13*B*), for which concentrations generally are much lower than unfiltered total phosphorus (fig. 13*A*). Particulate total P concentrations were calculated as the difference between unfiltered and filtered samples (table 5). (Values equal to one-half the MDL were substituted for filtered samples with non-detected concentrations.) A time-series plot of particulate total P (fig. 13*C*) shows a pattern very similar to that for total P in unfiltered water.

A conceptual model has been proposed in which microbial activity, which likely takes place mainly in shallow sediments and the lower, anoxic part of the water column within the reservoir thalweg, includes iron reduction that causes the release of P associated with hydrous iron oxide particles. For samples taken in this study, concentrations of orthophosphate in filtered water were consistently below the MDL of 0.02 mg/L (table 5), which is equivalent to 0.21 micromoles per liter; however, Kuwabara and others (2003) used a more sensitive analytical method for samples collected during two of the eight quarterly sampling events at three of the CFWR stations. Measured orthophosphate concentrations in filtered samples taken at depth in CFWR were greater than those in shallower samples (Kuwabara and others (2003). Thus, it is hypothesized that the release of orthophosphate to the water column during the summer and fall may be an important step in triggering a phytoplankton bloom that peaks in the fall and winter. (See data for chlorophyll-a and pheophytin in appendix G, table G5; more extensive data for chlorophyll-a and pheophytin were collected by Stewart and others, 2008.)

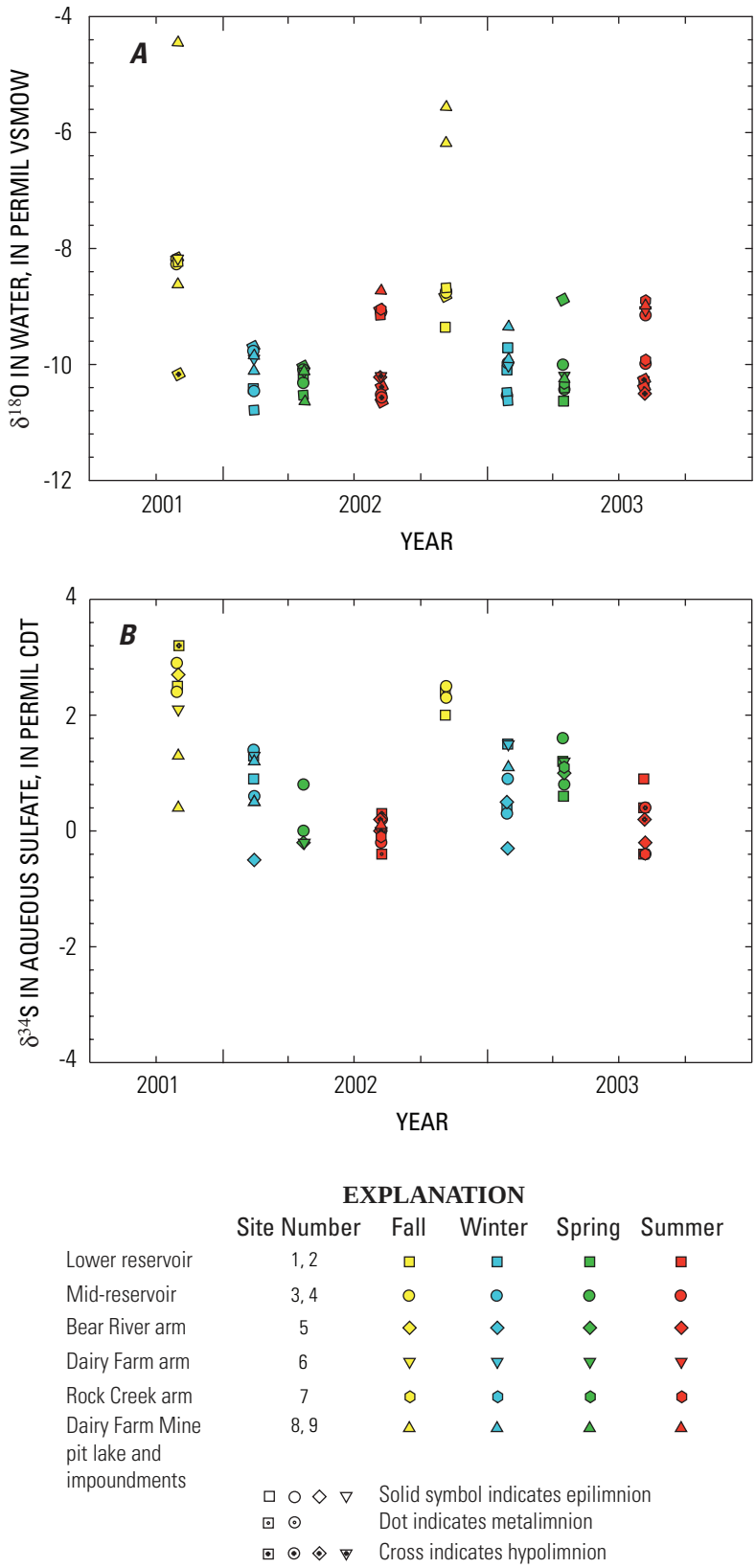
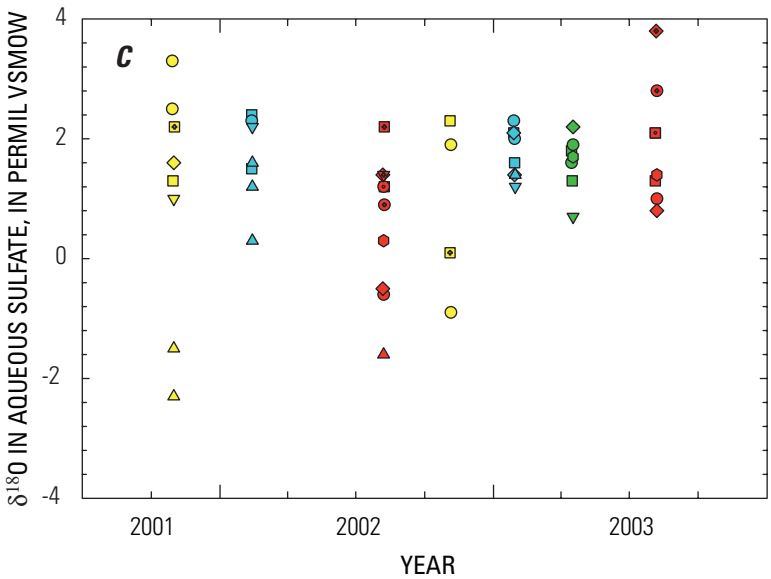


Figure 11. Stable isotope data for Camp Far West Reservoir, California, 2001–03: (*A*) Oxygen isotopes in water, (*B*) Sulfur isotopes in aqueous sulfate. $\delta^{18}O$, delta-18-oxygen; $\delta^{34}S$, delta-34-sulfur; VSMOW, Vienna Standard Mean Ocean Water; CDT, Cañon Diablo Troilite.



EXPLANATION

	Site Number	Fall	Winter	Spring	Summer
Lower reservoir	1, 2	□	□	■	■
Mid-reservoir	3, 4	○	●	●	●
Bear River arm	5	◇	◆	◆	◆
Dairy Farm arm	6	▽	▼	▼	▼
Rock Creek arm	7	⬡	⬢	⬢	⬢
Dairy Farm Mine pit lake and impoundments	8, 9	△	▲	▲	▲

□ ○ ◇ ▽ Solid symbol indicates epilimnion
⊡ ⊙ Dot indicates metalimnion
⊠ ⊗ ◈ ▽̸ Cross indicates hypolimnion

Figure 11. Continued.

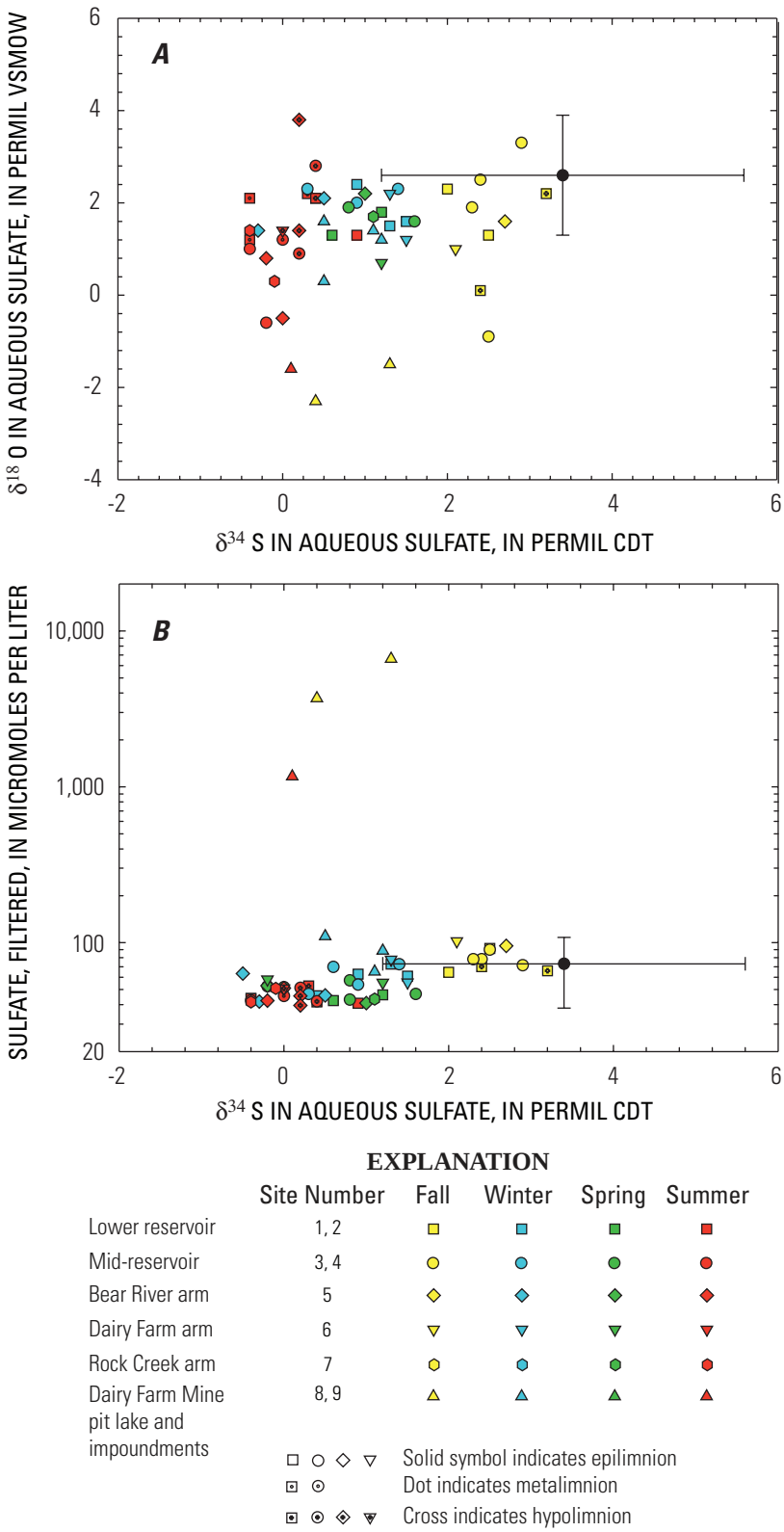
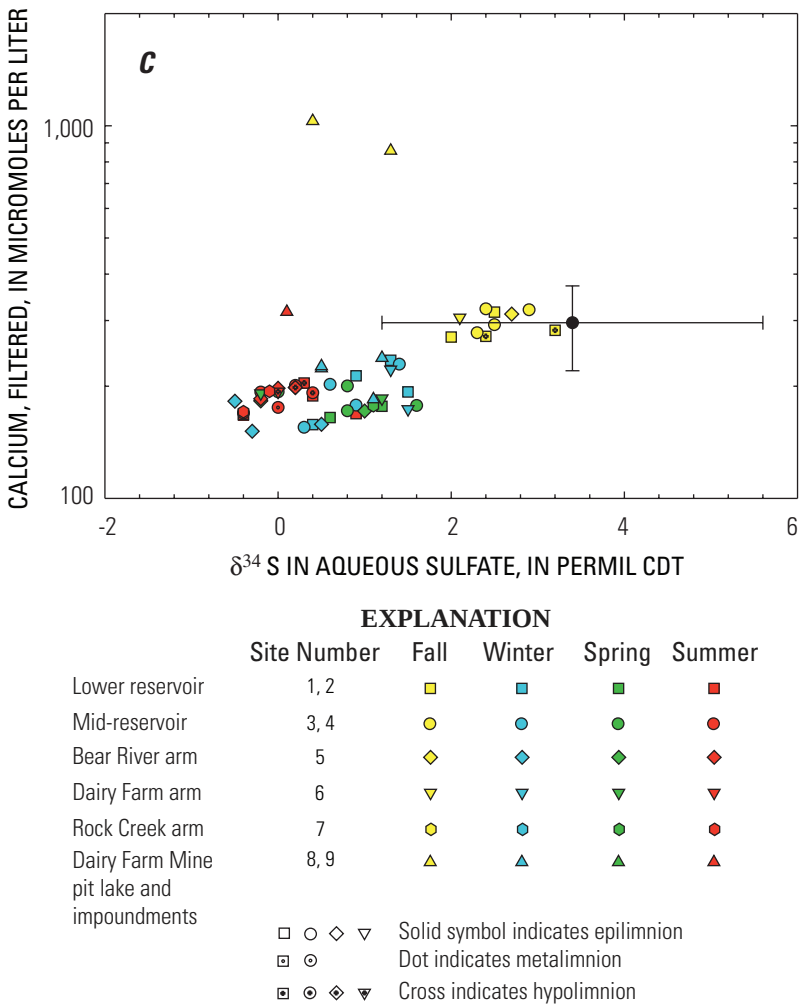


Figure 12. Relations between sulfur isotopes in aqueous sulfate and other water-quality constituents in Camp Far West Reservoir, California, 2001–03: (*A*) Oxygen isotopes in aqueous sulfate, (*B*) Sulfate concentration in filtered water, (*C*) Calcium concentration in filtered water. Filled, black circle with error bars represents average concentrations and standard deviations for eight fall-season samples collected at approximately monthly intervals from the Bear River below Wolf Creek near Lucas Hill (USGS station 390107121102101). δ^{18}O, delta-18-oxygen; δ^{34}S, delta-34-sulfur; VSMOW, Vienna Standard Mean Ocean Water; CDT, Cañon Diablo Troilite.



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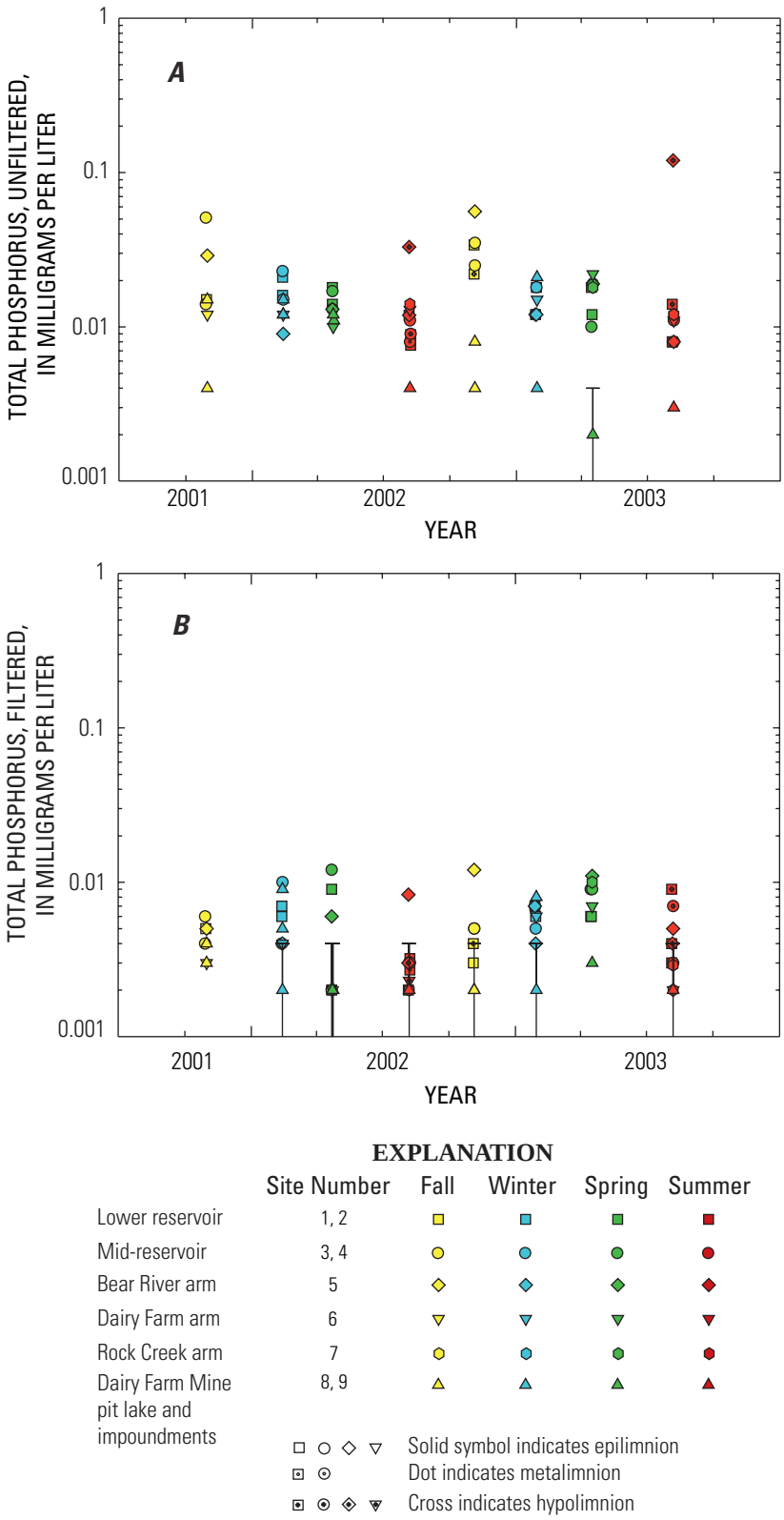


Figure 13. Total phosphorus concentrations in Camp Far West Reservoir, California, 2001–03: (*A*) Unfiltered water, (*B*) Filtered water, (*C*) Particulate. Particulate total phosphorus concentrations calculated as difference between total phosphorus in unfiltered water and total phosphorus in filtered water. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

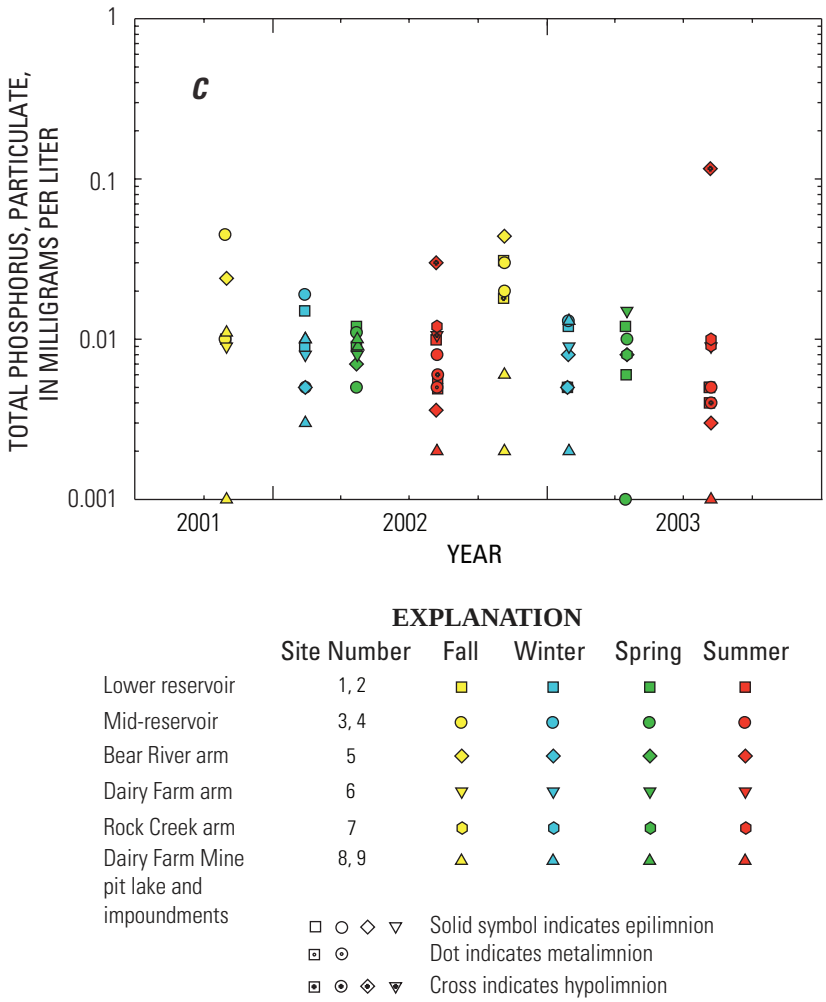


Figure 13. Continued.

Results for ammonia plus organic nitrogen in unfiltered and filtered water, and ammonia in filtered water (table 5), indicate that very little to no ammonia is present at sampling sites 1-7. In contrast, sites 8 and 9 had elevated ammonia concentrations associated with acid mine drainage. At sites 1-7, the dominant form of N is organic. Time-series plots of ammonia plus organic nitrogen in unfiltered and filtered water (figs. 14*A*–14*B*, respectively) indicate that the fall samples have the most elevated concentrations, with a declining trend from fall to winter to spring to summer. A time-series plot of nitrate plus nitrite (fig. 14*C*) indicates that non-detect values occurred only during summer and fall. Concentrations of nitrite plus nitrate in filtered water essentially represent nitrate only, as nitrite concentrations were not detected or were very low (table 5). Nitrate concentrations spanned a fairly wide range among reservoir stations during each of the sampling events (fig. 14*C*).

Particulate organic carbon (fig. 15*A*) did not display as strong a seasonal trend as the N and P species discussed above; however the concentrations were highest during summer and fall. Dissolved organic carbon concentrations (table 5, fig. 15*B*) at sites 1–7 ranged from 1.5 to 3.0 mg/L and averaged 2.0 with a standard deviation of 0.58; concentrations were consistently greater than or equal to 2.0 at sites 1–7 during fall.

The relation between concentrations in unfiltered and filtered water for total P (fig. 16*A*) indicates that the proportion of P passing through the capsule (C45) filter was 10 to 67 percent for most samples. In contrast, the analogous relation for ammonia plus organic nitrogen (fig. 16*B*) indicates that typically 50 to 100 percent passed through the filter. The elevated ammonia concentrations in the samples from sites 8 and 9 are equal in unfiltered and filtered splits, indicating that the ammonia is in a dissolved or colloidal form. A comparison of dissolved organic carbon (DOC) with particulate organic carbon (POC) (fig. 16*C*) indicates that DOC concentrations are typically higher than POC concentrations by a considerable margin. Among more than 60 samples, POC concentrations exceeded DOC only once each at two sites, 5 and 8 (fig. 16*C*, table 5).

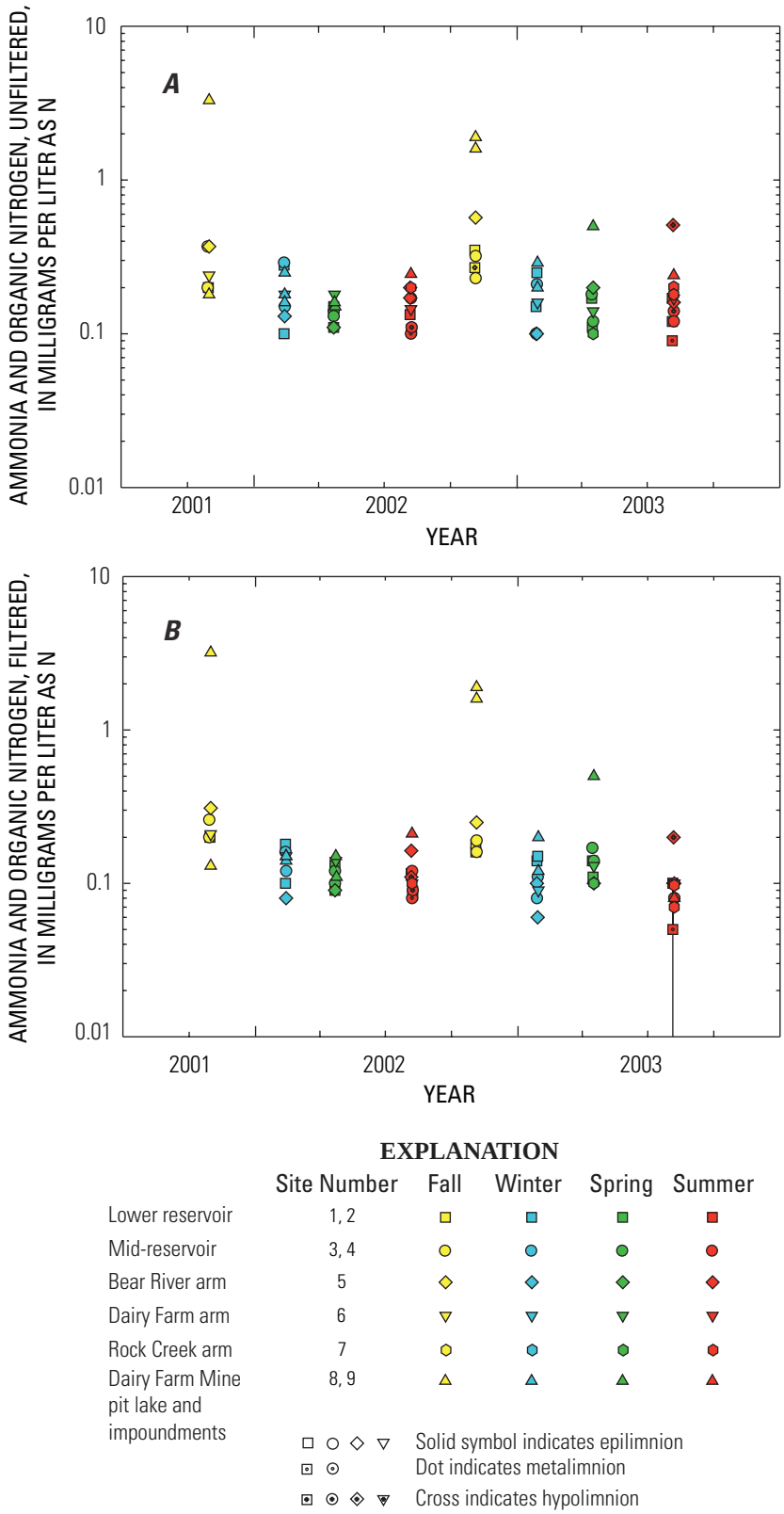
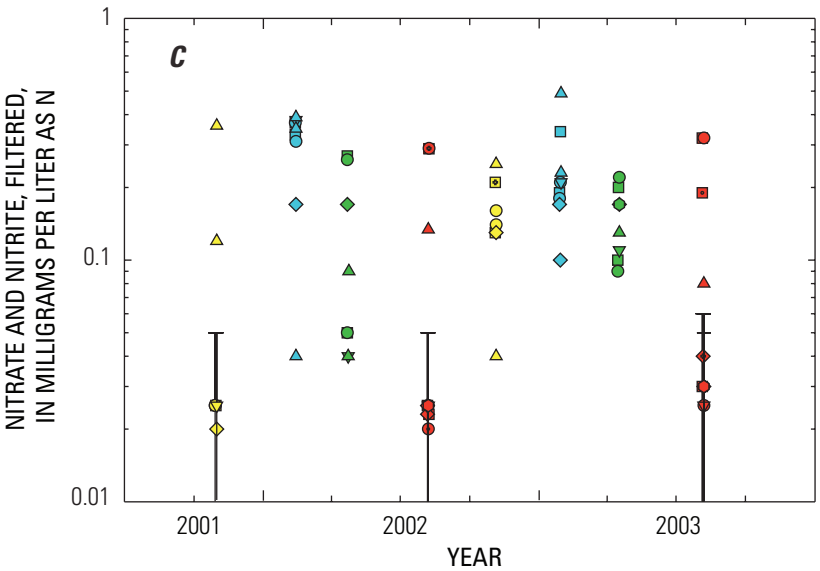


Figure 14. Nitrogen species concentrations in Camp Far West Reservoir, California, 2001–03: (*A*) Ammonia and organic nitrogen in unfiltered water, (*B*) Ammonia and organic nitrogen in filtered water, (*C*) Nitrite plus nitrate in filtered water. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.



EXPLANATION

	Site Number	Fall	Winter	Spring	Summer
Lower reservoir	1, 2	□	□	□	□
Mid-reservoir	3, 4	○	○	○	○
Bear River arm	5	◇	◇	◇	◇
Dairy Farm arm	6	▽	▽	▽	▽
Rock Creek arm	7	⬡	⬡	⬡	⬡
Dairy Farm Mine pit lake and impoundments	8, 9	△	△	△	△

□ ○ ◇ ▽ Solid symbol indicates epilimnion
⊡ ⊙ Dot indicates metalimnion
⊠ ⊗ ◈ ▼ Cross indicates hypolimnion

Figure 14. Continued.

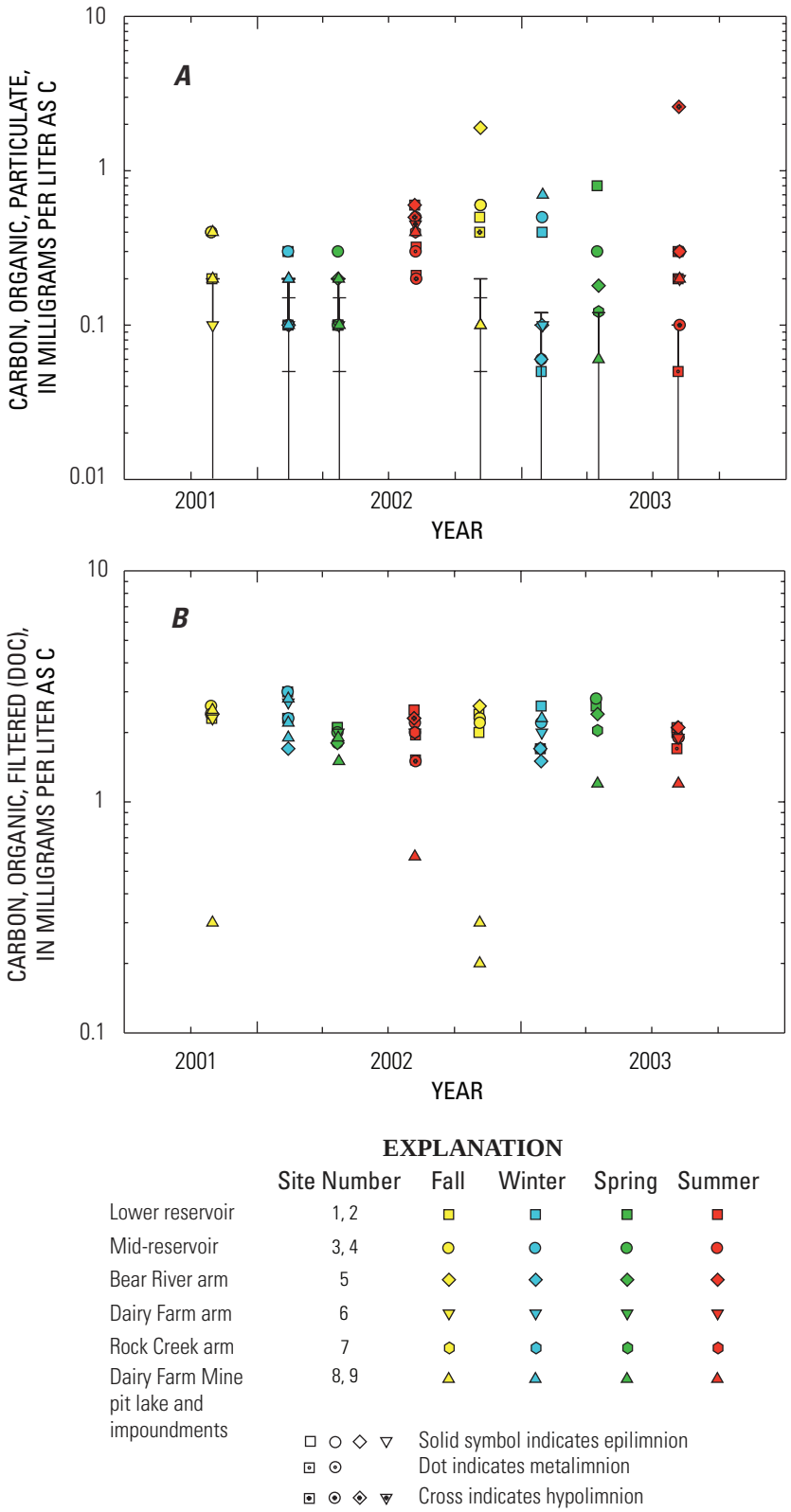


Figure 15. Carbon species concentrations in Camp Far West Reservoir, California, 2001–03: (*A*) Particulate organic carbon, (*B*) Dissolved organic carbon. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

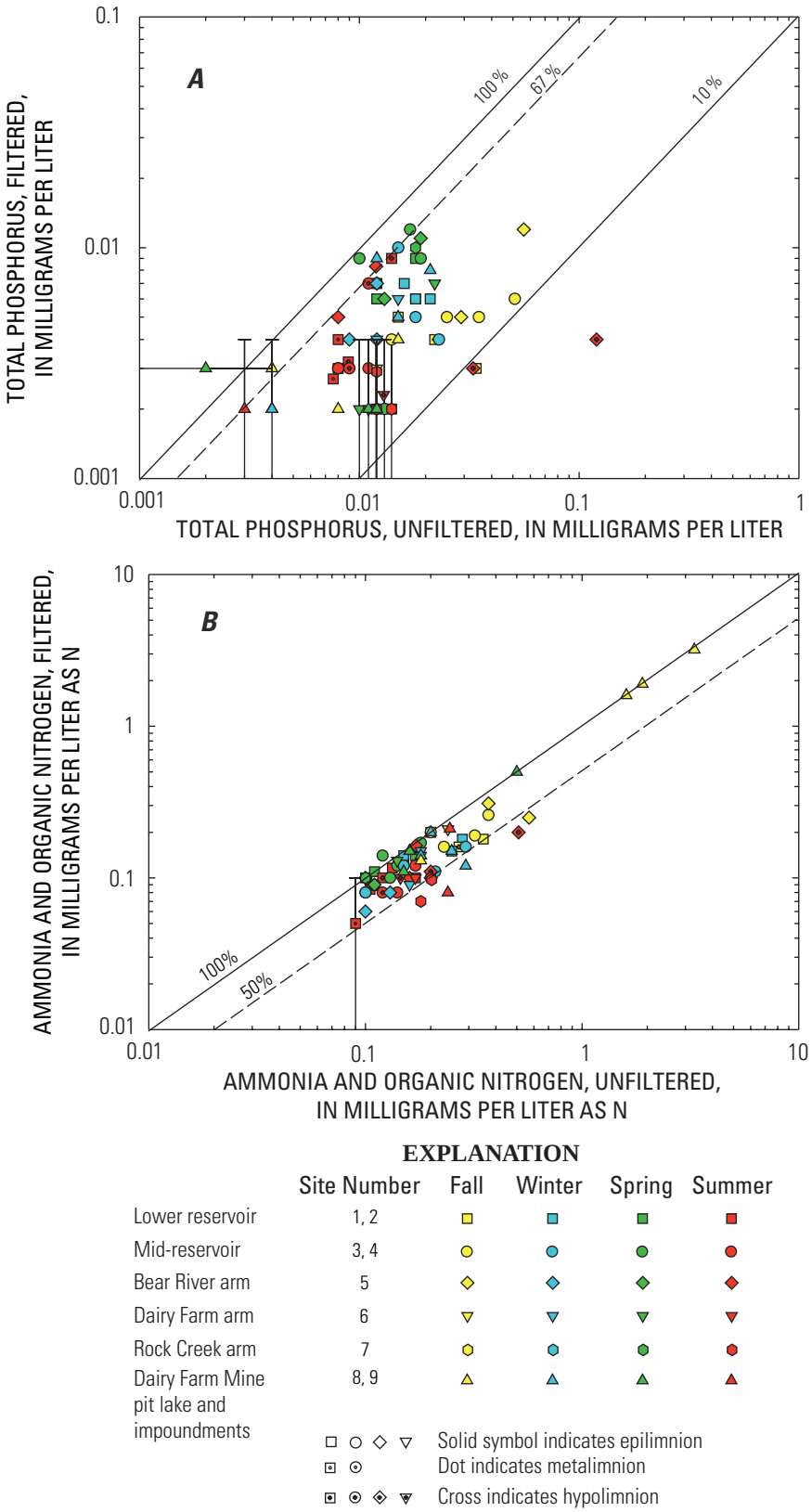


Figure 16. Relations among concentrations of nutrients and carbon species in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) Total phosphorus in unfiltered and filtered water, (*B*) Ammonia plus organic nitrogen in unfiltered and filtered water, (*C*) Particulate and dissolved organic carbon. In (*A*) and (*B*), diagonal lines indicate percentage of constituent passing through the filter. In (*C*), diagonal line indicates equal amounts of particulate and dissolved species. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

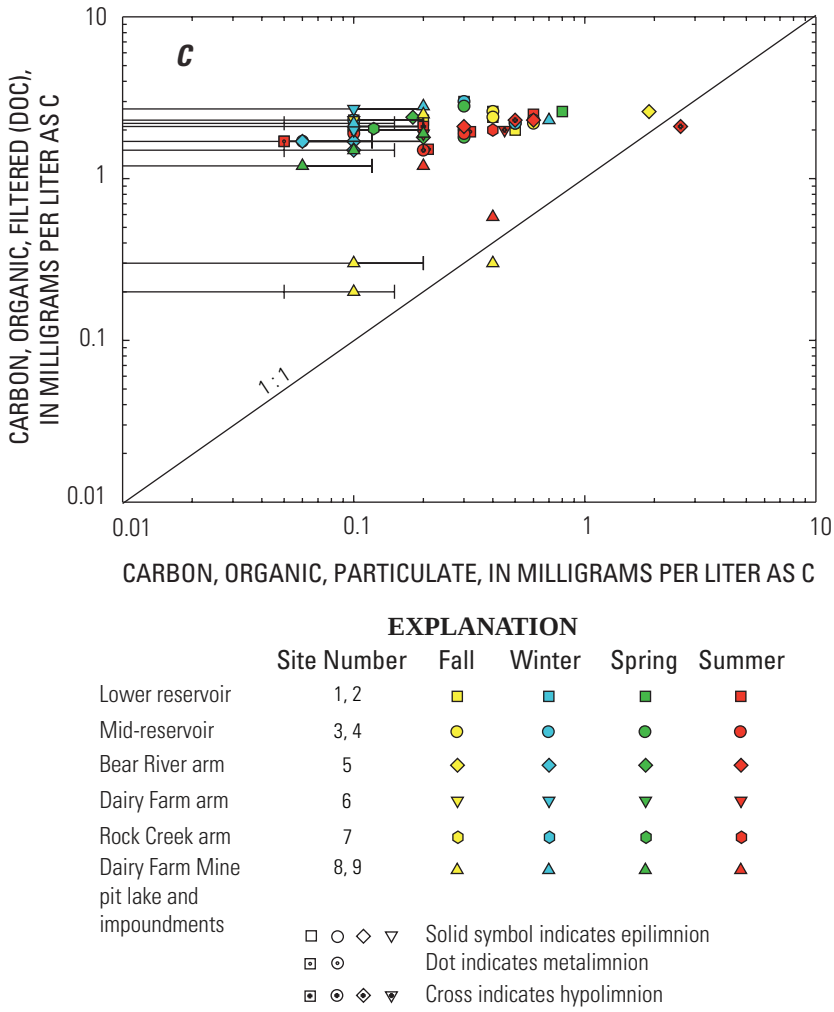
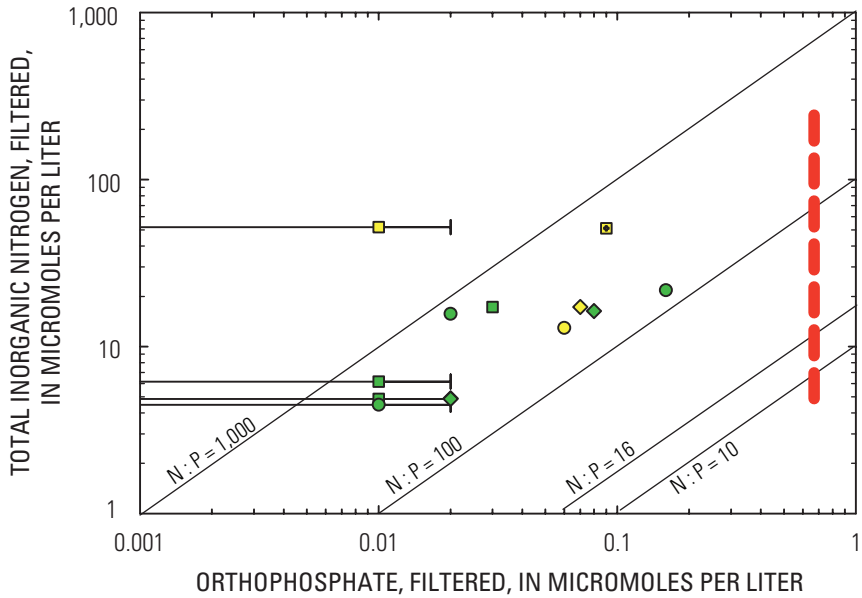


Figure 16. Continued.

The relative abundance of various forms of N and P are useful in determining limiting factors with regard to nutrient cycling and primary production of phytoplankton in aquatic system including freshwater reservoirs such as CFWR. The most biologically active forms of nutrients with regard to use by phytoplankton are inorganic N (primarily nitrate, nitrite, and ammonia) and inorganic P (orthophosphate, PO_4^{3-}). Using the data of Kuwabara and others (2003) for orthophosphate and total inorganic nitrogen (nitrite and nitrate, plus ammonia) in filtered water, N-to-P molar ratios between 136 and greater than 2,600 were computed (table 5, fig. 17*A*) for the three CFWR stations sampled in April and November 2002. These values are about one to two orders of magnitude greater than the Redfield N-to-P molar ratio of 16 (Wetzel, 2001), and hence are an unequivocal indication of P-limitation. Samples collected for the present study had mostly detectable concentrations of total inorganic nitrogen but no detectable concentrations of orthophosphate in nearly all samples (table 6) consistent with the elevated N-to-P ratios found by Kuwabara and others (2003).

The relation between total P and NH_3+N-org in unfiltered water (fig. 17*B*) for samples from sites 1–7 shows a generally positive correlation. Ammonium concentrations were minimal in samples from sites 1–7, so NH_3+N-org concentrations represent primarily organic nitrogen at these sites. A linear least-squares regression (excluding data from stations DFP and DFI) in log-transformed coordinates gives an R^2 value of 0.57. Values of the N:P molar ratio for these nutrients ranged from about 10 to 50, with most values greater than the Redfield ratio of 16. The equivalent data for filtered samples (fig. 17*C*) do not indicate a correlation between total P and NH_3+N-org concentrations. The N:P molar ratios for the filtered samples are between 16 and about 200. The overall seasonal trend both for total P and for NH_3+N-org is a general decline from fall to winter to spring to summer. This depletion in nutrients could be caused by uptake in organisms, primarily phytoplankton, starting with a bloom in the fall (Stewart and others, 2008).



EXPLANATION

Data from Kuwabara and others (2003a):

	Fall	Spring
Lower reservoir	□	■
Mid-reservoir	○	●
Bear River arm	◇	◆

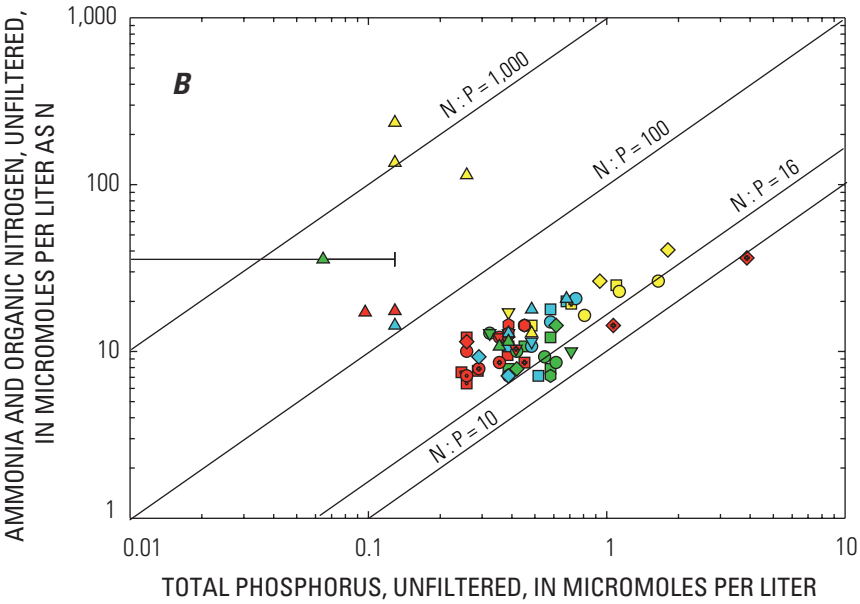
□ ○ ◇ Solid symbol indicates epilimnion
⊡ Cross indicates hypolimnion

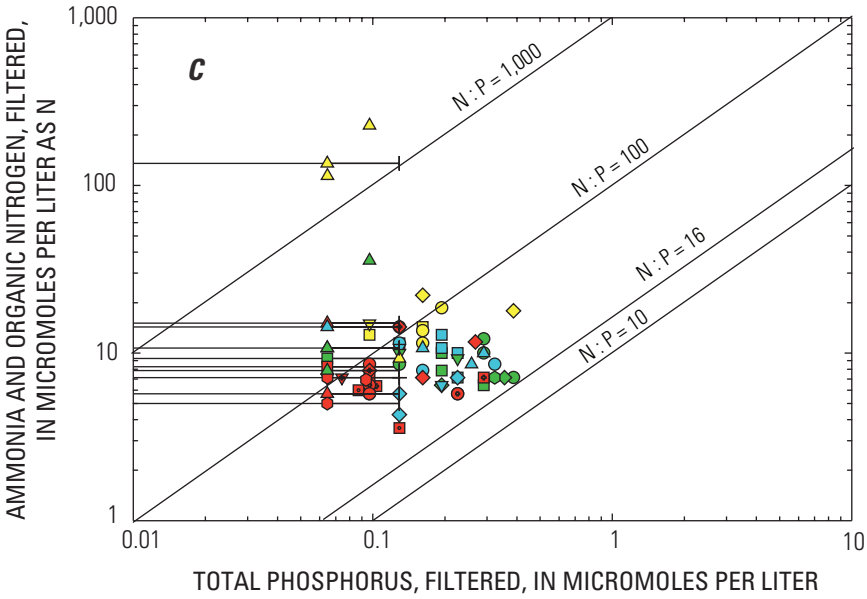
Data from this study:

Range of values for total inorganic nitrogen plotted at value of detection limit of orthophosphate.

Figure 17. Relations between concentrations of phosphorus and nitrogen compounds in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) total inorganic nitrogen and orthophosphate in filtered water (data from Kuwabara and others, 2003), (*B*) ammonia plus organic nitrogen and total phosphorus in unfiltered water, (*C*) ammonia plus organic nitrogen and total phosphorus in filtered water. Diagonal lines indicate constant values of the molar ratio of nitrogen (N) to phosphorus (P). In (*A*), total inorganic nitrogen calculated as sum of nitrite, nitrate, and ammonia. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

At reservoir sites 1–7, the two dominant forms of nitrogen were nitrate and organic N (table 5). A comparison of these two constituents in filtered water indicates that nitrate was more abundant than organic N during winter sampling events at all sites, whereas the organic N was apparently more abundant than nitrate at most stations during the fall. Results for spring and summer varied more than the other seasons.





EXPLANATION

	Site Number	Fall	Winter	Spring	Summer
Lower reservoir	1, 2	□	□	■	■
Mid-reservoir	3, 4	○	○	●	●
Bear River arm	5	◇	◇	◆	◆
Dairy Farm arm	6	▽	▽	▼	▼
Rock Creek arm	7	⬡	⬡	⬢	⬢
Dairy Farm Mine pit lake and impoundments	8, 9	△	△	▲	▲

□ ○ ◇ ▽ Solid symbol indicates epilimnion
⊡ ⊙ Dot indicates metalimnion
⊠ ⊙ ◈ ▼ Cross indicates hypolimnion

Figure 17. Continued.

Mercury and Methylmercury

The data for total mercury in filtered and unfiltered water samples (table 6) are a compilation of best values based on multiple sample-processing approaches. In cases where data for unfiltered samples were not available, the sum of filtrate and particulate concentrations from the quartz fiber filter was used, as discussed previously in the Quality Assurance section. Raw data for Hg_T in unfiltered, filtered, and particulate samples are given in appendix G; data for unfiltered samples are given in table G1 and data for Hg_T in filtered and particulate samples are given in table G2. The values for particulate Hg_T in table 6 are consistent with the difference between the filtered and unfiltered analyses. Statistical data for Hg_T, MeHg, and MeHg/Hg_T in unfiltered, filtered, and particulate samples are given in table 9.

The time-series plots of best values of unfiltered, filtered, and particulate Hg_T (figs. 18*A*–18*C*, respectively) show systematic seasonal trends. Unfiltered total mercury concentrations (fig. 18*A*) were highest at most stations during the fall and winter, and declined during spring and summer. Filtered Hg_T concentrations (fig. 18*B*) followed a somewhat different seasonal pattern than the unfiltered concentrations, higher at most stations during winter and spring and lower during summer and fall. Particulate Hg_T concentrations (fig. 18*C*) showed a systematic decrease from fall to winter to spring to summer at most stations.

Time-series plots for unfiltered, filtered, and particulate MeHg (figs. 18*D*–18*F*, respectively) show a seasonal trend that is generally opposite of that for Hg_T—the MeHg concentrations increase at most sites from fall to winter to spring. MeHg concentrations during summer are highly variable but include the highest values for unfiltered and filtered MeHg recorded during the study at a time when Hg_T concentrations are generally at a minimum.

Plots of the relation between concentrations in unfiltered and filtered constituents can be used for two purposes—as a quality control check (the filtered concentrations should always be lower) and to ascertain the proportion of the constituent that passes through the filter. The proportion passing through the filter is an approximation of the dissolved phase; however, this terminology is not used in this report with the exception of carbon and sulfate. With regard to mercury and other trace metals, it is likely that a significant part of the material passing through the filter consists of colloidal particles smaller than the filter pore size (for example, see Alpers and others, 2000; Roth and others, 2001; Choe and Gill, 2001, 2003; Choe and others, 2003). Metals associated with the dissolved and colloidal phases generally are more biologically available than metals associated with coarser particulates. A plot of unfiltered versus filtered concentrations for Hg_T (fig. 19*A*) indicates that about 10 to 50 percent of the mercury passed through the capsule (C45) filter at most stations during winter and spring, whereas less than 10 percent of the mercury was filterable at several of the stations during fall and at a smaller number of stations during summer. A similar plot for MeHg (fig. 19*B*) indicates that about 50 percent passed through the filter for most of the samples for which MeHg was detected in unfiltered and filtered water.

The ratio of MeHg to Hg_T (MeHg/Hg_T) is a useful quantity for assessing mercury geochemistry because it normalizes MeHg concentration to the amount of Hg_T present. Values of MeHg/Hg_T in water or sediment can reflect the methylation efficiency of a watershed (for example, Krabbenhoft and others, 1999). In water samples for which the value of MeHg was a non-detect, a maximum value of the ratio can be computed. Scatter plots showing the concentrations of Hg_T and MeHg for unfiltered (fig. 20*A*) and filtered (fig. 20*B*) samples indicate that values of MeHg/Hg_T are most commonly between about 1 and 10 percent. The seasonal trend in MeHg/Hg_T that is apparent from the color of the symbols in figure 20 can be seen even more clearly in the time series plots of figure 21. Considering all CFWR stations, the maximum values of MeHg/Hg_T in unfiltered water increased systematically from winter to spring to summer, and the minimum values of MeHg/Hg_T increased from fall to winter to spring and then decreased during summer (fig. 21*A*). Seasonal variations MeHg/Hg_T in filtered water (fig. 21*B*) were similar to the trends for unfiltered water during 2002 but the trends during 2003 were less systematic.

A comparison of MeHg/Hg_T values for unfiltered and filtered samples (fig. 22) indicates that the values in filtered samples are systematically higher. A linear least-squares regression using 24 data points with detected values (fig. 22*A*) has a slope of 3.6 and an intercept near the origin ($R^2 = 0.89$); a similar regression excluding the data point with the highest values has a slope of 2.5 with a reduced value of the correlation coefficient ($R^2 = 0.56$). A plot of the same data on logarithmic axes (fig. 22*B*) shows that the winter samples are tightly clustered, whereas the summer data extend to high values of the ratio for both unfiltered and filtered in close proportion to the overall slope. Some of the spring data points deviate from the relation, with approximately equal values of MeHg/Hg_T for unfiltered and filtered splits. The overall result that MeHg/Hg_T value is higher for filtered samples is consistent with the observation that proportionately more MeHg than Hg_T passes through the filter (figs. 19*A*–19*B*).

Table 9. Statistical data for mercury and methylmercury concentrations in water, Camp Far West Reservoir, California.

[Data for total mercury are "best values" as explained in table 6. MeHg, methylmercury; Hg_T, total mercury; Hg, mercury; n, number of samples; C45, Gelman capsule filter; Q, quartz fiber filter; ROS, regression on order statistics (Helsel, 2005); non-detect, result less than the detection limit. Bolding indicates statistical values less than detection limit for methylmercury in filtered and unfiltered water, 0.04 ng/L; ng/L, nanogram per liter; %, percentage of]

	Unfiltered Hg_T (ng/L)	Filtered Hg_T (ng/L)	Particulate Hg_T (ng/L)	Unfiltered MeHg (ng/L)	Filtered MeHg (C45) (ng/L)	Filtered MeHg (Q) (ng/L)	Particulate MeHg (ng/L)	MeHg/Hg_T, unfiltered	MeHg/Hg_T, filtered (C45)	MeHg/Hg_T, particulate
All environmental samples										
Computation method				ROS	ROS	ROS	ROS	ROS	ROS	ROS
Mean	5.2	1.1	4.1	0.069	**0.036**	**0.039**	0.032	0.021	0.047	0.0073
Standard error of mean	0.65	0.11	0.63	0.0083	0.0038	0.0055	0.0067	0.002	0.0098	0.0011
Standard deviation	5.4	0.9	5.3	0.066	0.03	0.043	0.052	0.023	0.076	0.0082
Minimum	1.0	0.1	0.2	**0.014**	**0.0077**	**0.0058**	0.0048	0.003	0.011	0.0015
25th percentile	2.5	0.4	1.7	0.04	**0.018**	**0.017**	0.014	0.0082	0.018	0.0039
Median	4.3	0.9	3.2	0.06	**0.029**	**0.029**	0.018	0.012	0.028	0.0051
75th percentile	6.5	1.5	5.3	0.07	0.05	0.05	0.029	0.026	0.044	0.0077
Maximum	43.6	5.3	43	0.46	0.22	0.32	0.39	0.15	0.55	0.057
n (total)	70	70	70	64	62	63	61	64	60	61
n of non-detects	0	0	0	16	37	36	36	15	35	35
% non-detects	0	0	0	25	60	57	59	23	58	57
All reservoir samples (excluding Dairy Farm Mine Pit Lake and Impoundments)										
Computation method				ROS	ROS	ROS	ROS	ROS	ROS	ROS
Mean	5.3	0.9	4.4	0.075	**0.039**	0.042	0.034	0.023	0.053	0.0072
Standard error of mean	0.78	0.07	0.77	0.0097	0.0044	0.0066	0.0079	0.0034	0.012	0.0013
Standard deviation	5.9	0.53	5.8	0.071	0.031	0.047	0.057	0.024	0.082	0.0089
Minimum	1	0.3	0.2	**0.016**	**0.009**	**0.006**	0.004	0.003	0.011	0.0015
25th percentile	2.5	0.4	1.6	0.04	**0.021**	**0.017**	0.014	0.0086	0.022	0.0034
Median	4.1	0.9	3.2	0.06	**0.032**	**0.030**	0.019	0.014	0.032	0.0047
75th percentile	6.6	1.4	5.4	0.07	0.05	0.04	0.032	0.029	0.048	0.0077
Maximum	43.6	2.5	43	0.46	0.22	0.32	0.39	0.146	0.55	0.057
n (total)	57	57	57	53	51	51	51	53	50	51
n of non-detects	0	0	0	9	27	27	31	9	27	31
% non-detects	0	0	0	17	53	53	61	17	54	61

Table 9. Statistical data for mercury and methylmercury concentrations in water, Camp Far West Reservoir, California.—*Continued*

[Data for total mercury are "best values" as explained in table 6. MeHg, methylmercury; Hg_T, total mercury; Hg, mercury; n, number of samples; C45, Gelman capsule filter; Q, quartz fiber filter; ROS, regression on order statistics (Helsel, 2005); non-detect, result less than the detection limit. Bolding indicates statistical values less than detection limit for methylmercury in filtered and unfiltered water, 0.04 ng/L; ng/L, nanogram per liter; %, percentage of]

	Unfiltered Hg_T (ng/L)	Filtered Hg_T (ng/L)	Particulate Hg_T (ng/L)	Unfiltered MeHg (ng//L)	Filtered MeHg (C45) (ng/L)	Filtered MeHg (Q) (ng/L)	Particulate MeHg (ng/L)	MeHg/Hg_T, unfiltered	MeHg/Hg_T, filtered (C45)	MeHg/Hg_T, particulate
Epilimnion (excluding Dairy Farm Mine Pit Lake and Impoundments)										
Computation method				ROS	ROS	ROS	ROS	ROS	ROS	ROS
Mean	4.8	0.96	3.9	0.064	**0.039**	**0.039**	0.023	0.019	0.04	0.0058
Standard error of mean	0.41	0.073	0.38	0.0042	0.0022	0.0036	0.0026	0.0022	0.0053	0.00066
Standard deviation	2.7	0.49	2.6	0.027	0.014	0.023	0.016	0.0144	0.033	0.0041
Minimum	1.2	0.3	0.2	**0.025**	**0.018**	**0.012**	0.0068	0.0038	0.015	0.0015
25th percentile	2.5	0.45	1.7	0.04	**0.029**	**0.024**	0.014	0.0087	0.024	0.0031
Median	4.6	0.9	3.5	0.06	**0.038**	**0.034**	0.018	0.012	0.032	0.0045
75th percentile	6.9	1.5	5.4	0.07	0.05	0.05	0.027	0.027	0.044	0.0071
Maximum	12.6	1.8	11.6	0.15	0.08	0.15	0.097	0.077	0.21	0.017
n (total)	45	45	45	42	40	42	40	42	39	40
n of non-detects	0	0	0	6	20	23	23	6	20	23
% non-detects	0	0	0	14	50	55	58	14	51	58
Hypolimnion and Metalimnion										
Computation method				ROS	ROS	ROS	ROS	ROS	ROS	ROS
Mean	6.9	0.68	6.2	0.12	0.044	0.063	0.062	0.039	0.11	0.013
Standard error of mean	3.4	0.18	3.4	0.043	0.019	0.033	0.036	0.013	0.046	0.0051
Standard deviation	12	0.61	12	0.14	0.064	0.10	0.12	0.043	0.15	0.017
Minimum	1.0	0.3	0.7	**0.0066**	**0.0018**	**0.0027**	0.00093	0.0066	0.046	0.0023
25th percentile	2.0	0.33	1.3	**0.018**	**0.0055**	**0.0072**	0.0031	0.0066	0.046	0.0051
Median	2.8	0.5	2.3	0.06	**0.016**	0.04	0.0078	0.023	0.056	0.0051
75th percentile	5.0	0.7	4.7	0.19	0.06	0.07	0.08	0.068	0.11	0.009
Maximum	43.6	2.5	43	0.46	0.22	0.32	0.39	0.15	0.55	0.057
n (total)	12	12	12	11	11	9	11	11	11	11
n of non-detects	0	0	0	3	7	4	8	3	7	8
% non-detects	0	0	0	27	64	44	73	27	64	73

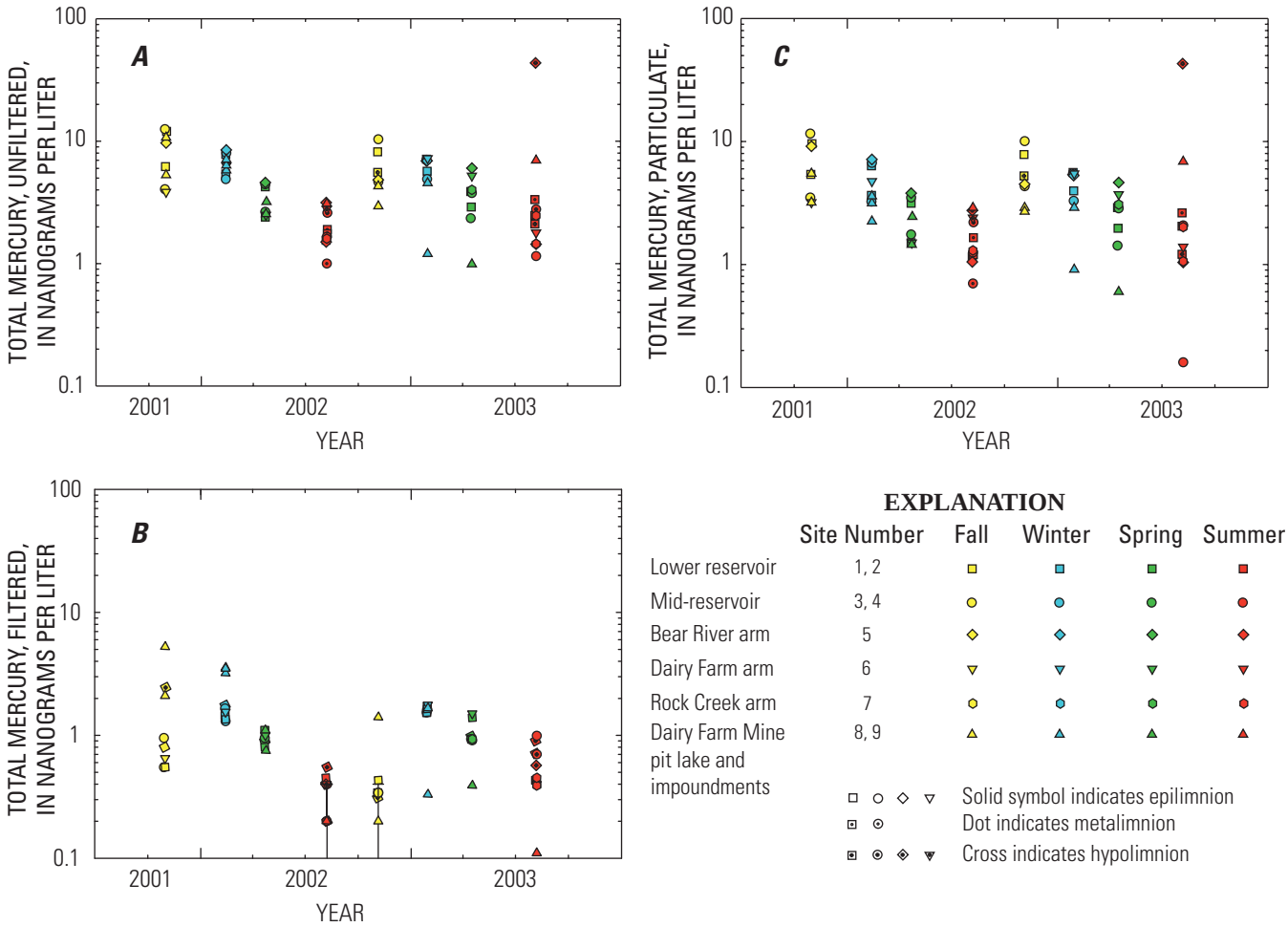


Figure 18. Concentrations of mercury and methylmercury species for sampling stations in Camp Far West Reservoir, California, 2001–03: (*A*) Total mercury in unfiltered water, (*B*) Total mercury in filtered water, (*C*) Total mercury, particulate, (*D*) Methylmercury in unfiltered water, (*E*) Methylmercury in filtered water, (*F*) Methylmercury, particulate. In (*A*), (*B*), and (*C*), best values of total mercury used, as explained in text and in table 6. In (*E*), capsule filter data used (table 7). Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

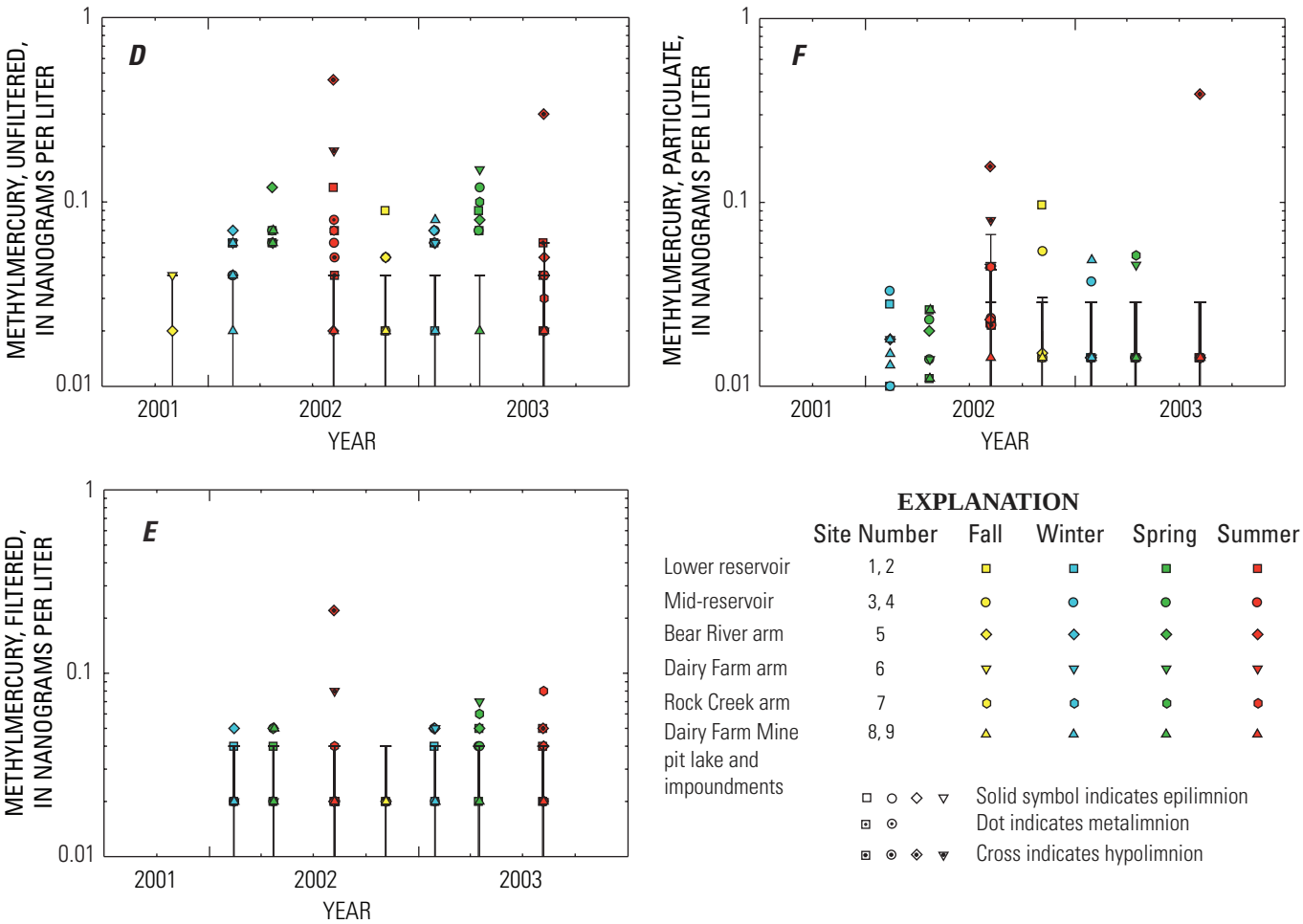


Figure 18. Continued.

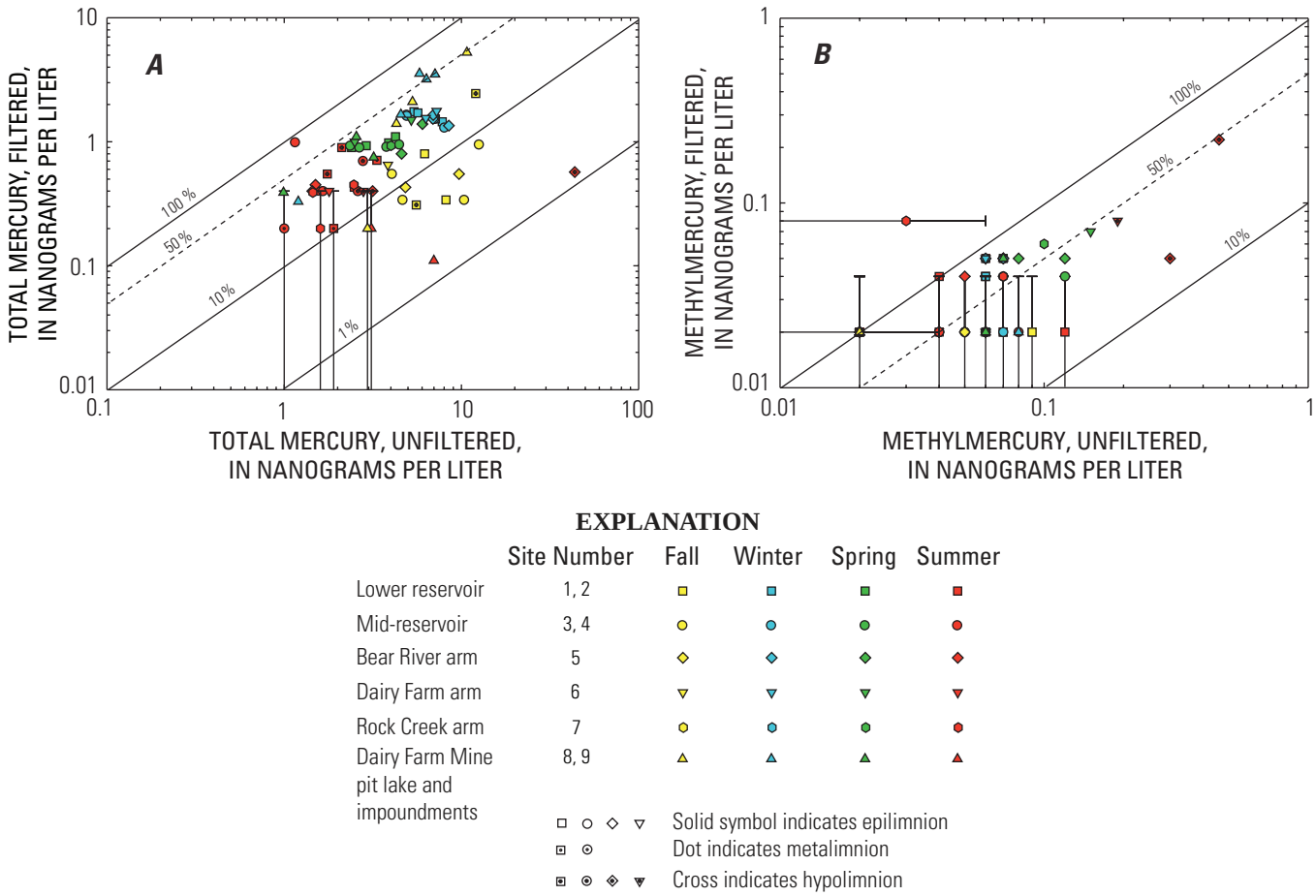


Figure 19. Relation between concentrations in unfiltered and filtered water samples from Camp Far West Reservoir, California, 2001–03: (*A*) Total mercury, (*B*) Methylmercury. Diagonal lines represent percentage passing through filter. In (*A*), best values of total mercury used, as explained in text and in table 6. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

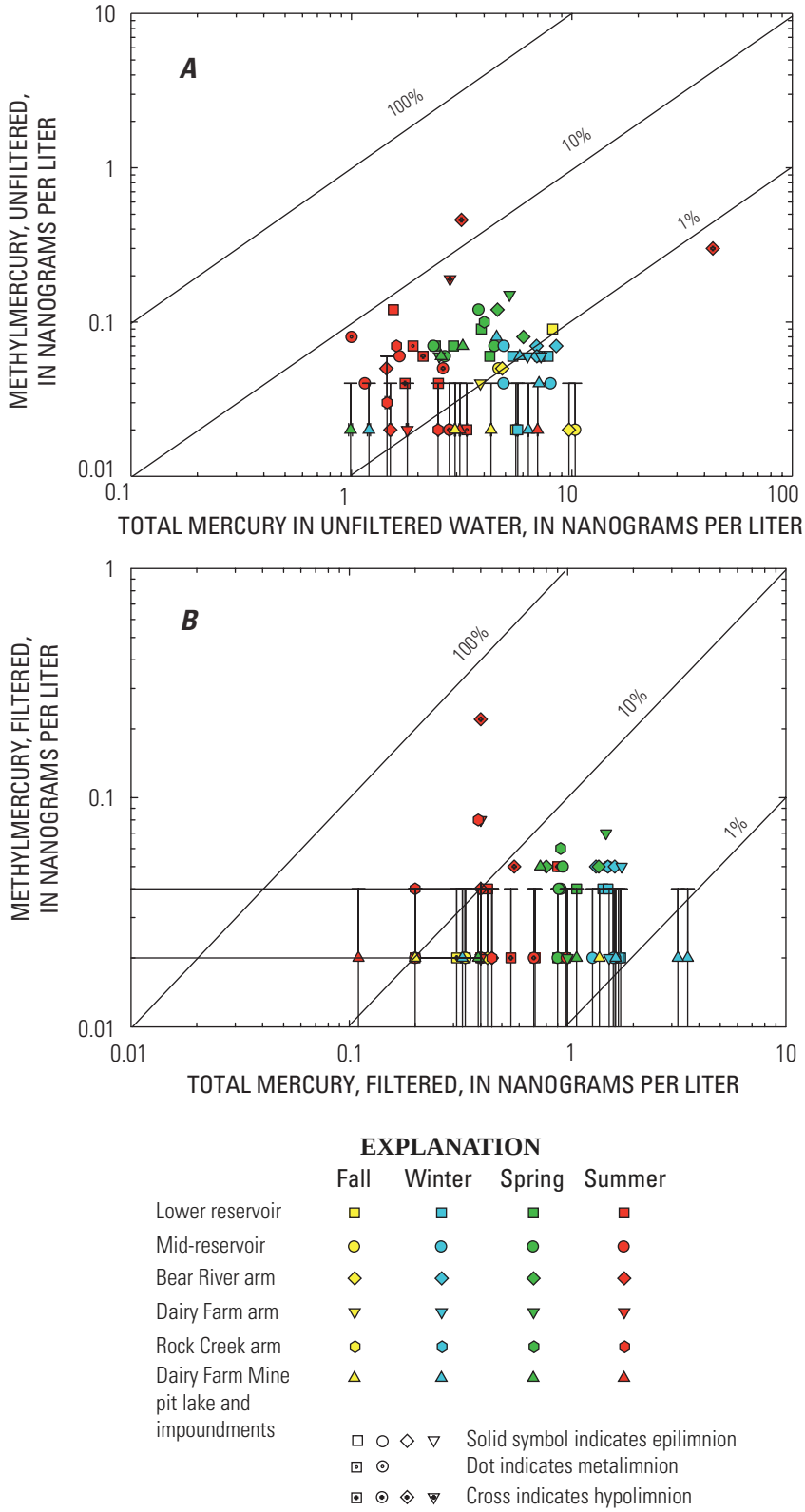


Figure 20. Relation between total mercury and methylmercury concentrations in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) Unfiltered water, (*B*) Filtered water. Diagonal lines represent constant values of the ratio of methylmercury to total mercury, expressed as a percentages. Best values of total mercury used, as explained in text and in table 6. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

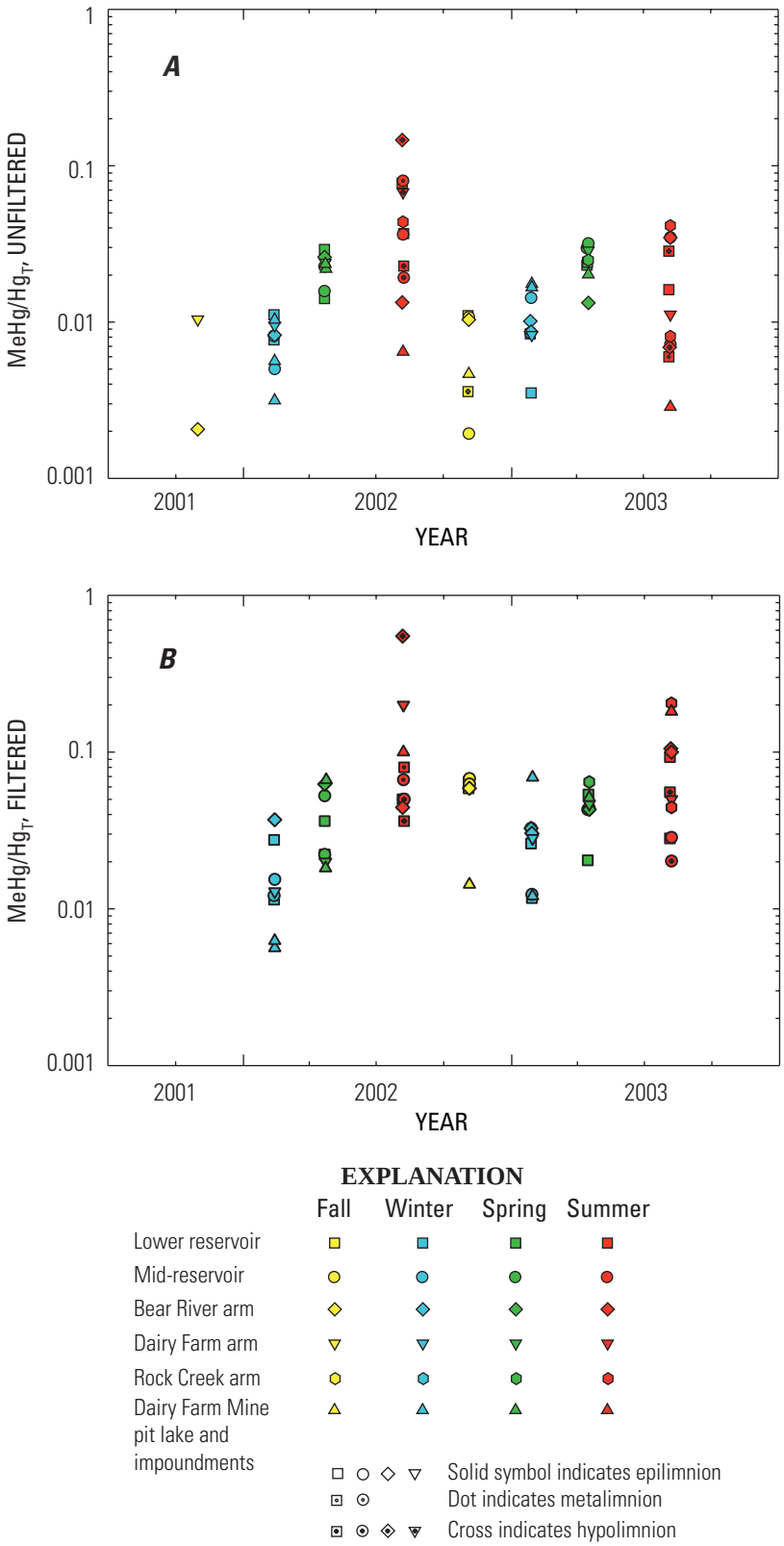


Figure 21. Ratio of methylmercury to total mercury in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) Unfiltered water, (*B*) Filtered water. MeHg/Hg$_T$, ratio of methylmercury to total mercury

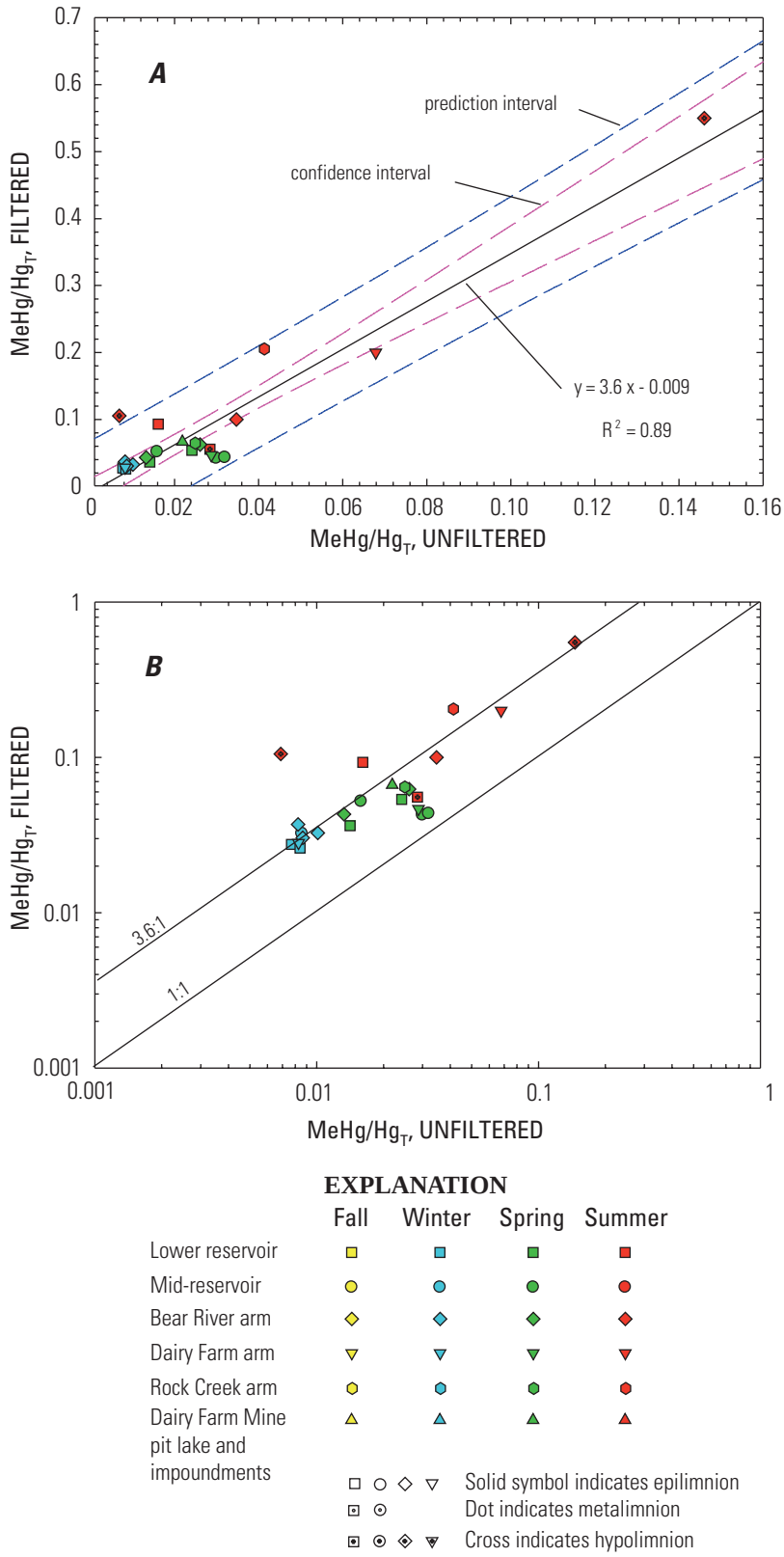


Figure 22. Relation between ratio of methylmercury to total mercury in unfiltered and filtered water, Camp Far West Reservoir, California, 2001–03: (*A*) Linear plot indicating results of least-squares regression (*B*) Log-log plot showing regression line. Only detected values shown in plots and used in regression analysis. $MeHg/Hg_T$, ratio of methylmercury to total mercury, R^2, regression correlation coefficient.

Relations of Mercury and Methylmercury with Other Constituents

Dissolved Oxygen

Several other studies have documented correlations between elevated methylmercury concentrations and low concentrations of dissolved oxygen (DO) in freshwater systems (for example, Regnell and others, 1996; K. Abu-Saba, Applied Marine Sciences, Inc., Santa Cruz, Calif., written commun., 2003; Kuwabara and others, 2005). Such a correlation is not surprising, given that anoxic conditions favor sulfate-reducing bacteria, which are thought to be largely responsible for MeHg formation (Compeau and Bartha, 1985; Gilmour and others, 1992). The relations between DO and MeHg in unfiltered and filtered water sampled from CFWR (figs. 23*A*–23*B*) are consistent with this hypothesis; the highest MeHg concentrations (>0.2 ng/L unfiltered and >0.1 ng/L filtered) were found in water with the lowest concentrations of DO, typically less than 1 mg/L in the hypolimnion. However, these relations are far from systematic at higher values of DO. Both detected values and nondetects for MeHg (filtered and unfiltered) span the full range of DO concentration, which indicates that factors other than DO may be more important in controlling MeHg distribution within CFWR.

Organic Carbon

Plots showing the relations between dissolved organic carbon (DOC) and Hg_T in unfiltered water (fig. 24*A*) and filtered water (fig. 24*B*) indicate no apparent correlations; DOC concentrations do not vary seasonally to the same extent as Hg_T concentrations. A plot showing the relation between particulate Hg_T and particulate organic carbon (POC; fig. 24*C*) also indicates little to no correlation.

The relations between DOC and MeHg in unfiltered water (fig. 24*D*) and filtered water (fig. 24*E*) also show no apparent correlations. These results are in contrast to other systems, such as freshwaters in Minnesota, Michigan, and Wisconsin, where a strong association was found between MeHg and filterable organic carbon (Babiarz and others, 2001). A plot of the relation between POC and particulate MeHg (fig. 24*F*) shows a single, summer hypolimnion sample from the Bear River Arm containing elevated concentrations of both constituents, but no apparent correlation among the other samples.

Suspended Solids

The relation between concentrations of suspended solids and trace elements in unfiltered water samples can be useful for evaluating the apparent concentration of the trace elements on the suspended material. For Hg_T, a set of four plots illustrates different ways of evaluating apparent Hg_T concentration in suspended particles. On the plot of unfiltered Hg_T concentration and total suspended solids (fig. 25*A*), diagonal contour lines of constant concentration of Hg_T in the suspended solids are shown. During spring and fall, apparent Hg_T concentrations for most stations are between 0.4 and 1.0 µg/g (equivalent to part per million, or ppm). This range of concentrations is similar to that observed for the top 4 cm of bed sediment, sampled at six locations on six occasions between fall 2001 and winter 2003. The apparent Hg_T concentrations in suspended solids during winter are considerably higher, with most of the samples indicating values greater than 1.0 ppm. In contrast, most of the data for summer samples indicate apparent Hg_T concentrations in suspended solids less than 0.4 ppm, with some samples less than 0.1 ppm. The winter and summer data are anomalous, and warrant further investigation. (Some possible explanations for these observations are offered in the Discussion section of this report.) A similar plot (fig. 25*B*) using suspended silt and clay (material passing through a 63 micrometer sieve) gives results similar to those of the plot for total suspended solids.

Using unfiltered water samples for plots such as figures 25*A*–25*B* can lead to misleading conclusions because material passing though the filter is considered part of the suspended material and is counted toward the apparent concentration in the suspended solids. To the extent that the material passing through the filter is colloidal (very fine particulate material), this leads to a consistent interpretation. However, another approach is to consider the particulate concentration, operationally defined as the material that does not pass through a filter of a certain pore diameter. For this study, we have used pore diameters of 0.45 and 0.7 micrometer, so the particulate concentrations of Hg_T and MeHg are defined as relating to particles that did not pass through these filters. Plots of particulate Hg_T versus total suspended solids (fig. 25*C*) or versus suspended silt and clay (fig. 25*D*) indicate similar apparent concentrations and a similar seasonal pattern. Using particulate concentrations instead of unfiltered ones reduces the concentration by the filtered amount, which shifts the points to the right on the diagrams and results in lower apparent concentrations of Hg_T in the suspended solids. The shift tends to be greater (on a logarithmic scale) for data with lower Hg_T concentrations.

A similar analysis of apparent MeHg concentrations in suspended solids is presented in figures 26*A*–26*D*. Using MeHg concentrations in unfiltered water samples, apparent MeHg concentrations in suspended solids ranged from about 2 to 100 ppb for samples in which MeHg was detected (figs. 26*A*–26*B*). Maximum apparent suspended-solid-MeHg concentrations for most non-detects ranged from about 1 to 10 ppb. When particulate MeHg concentrations are used (figs. 26*C*–26*D*), apparent suspended-solid-MeHg concentrations are considerably lower for most samples, although a small number of the winter and summer samples exceed 10 ppb.

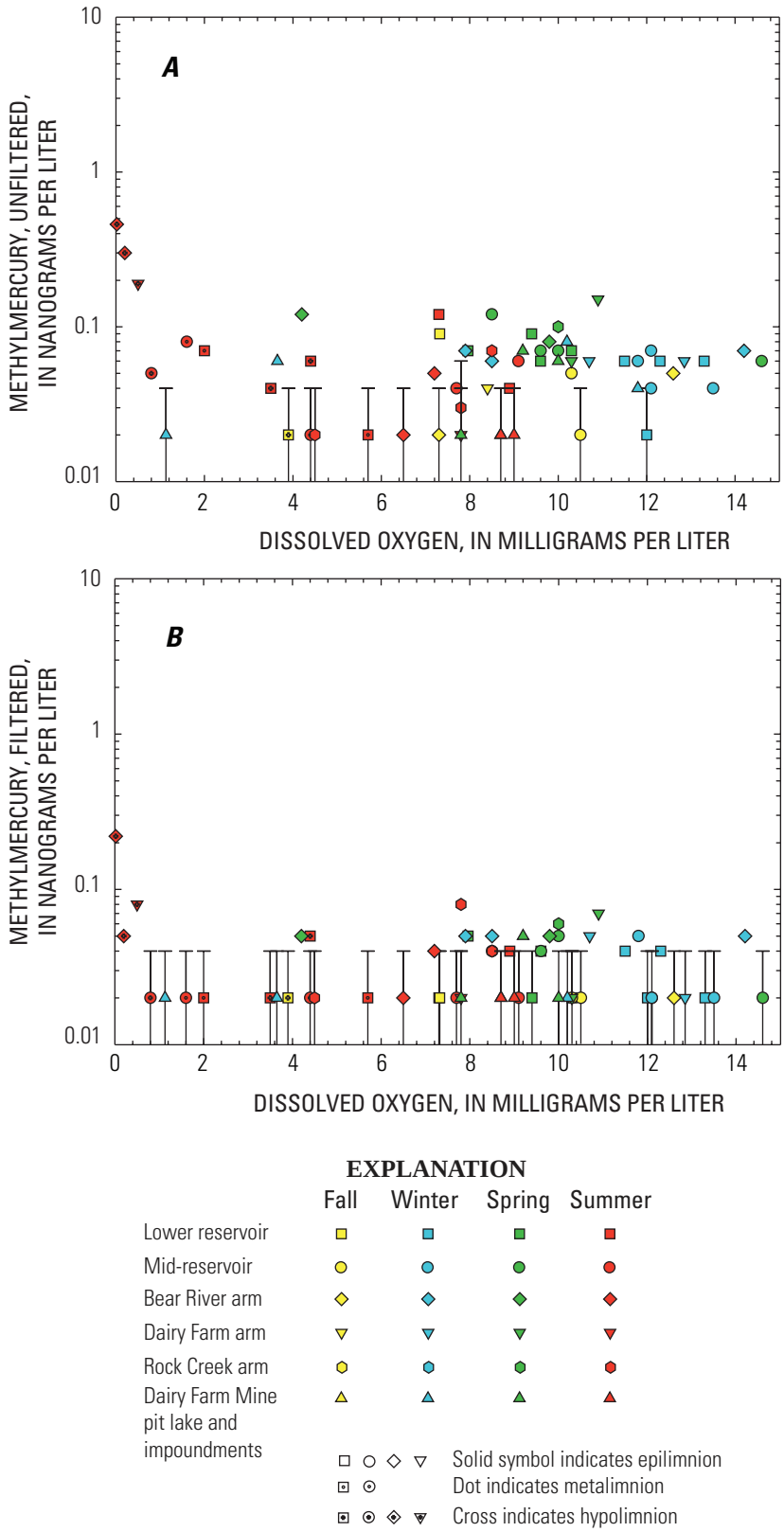


Figure 23. Relations between concentrations of methylmercury and dissolved oxygen in Camp Far West Reservoir, California, 2001–03: (*A*) unfiltered methylmercury, (*B*) filtered methylmercury. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

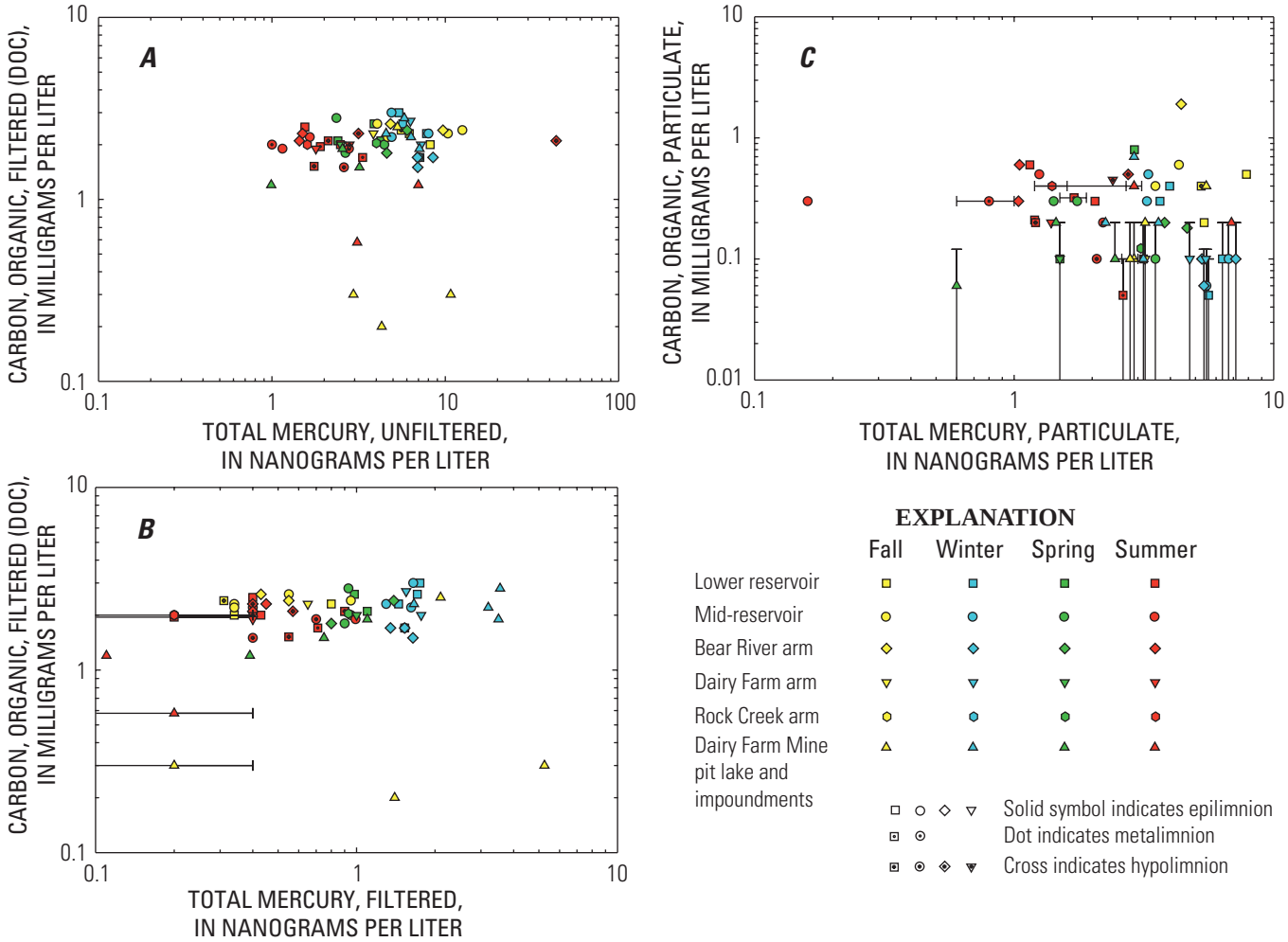
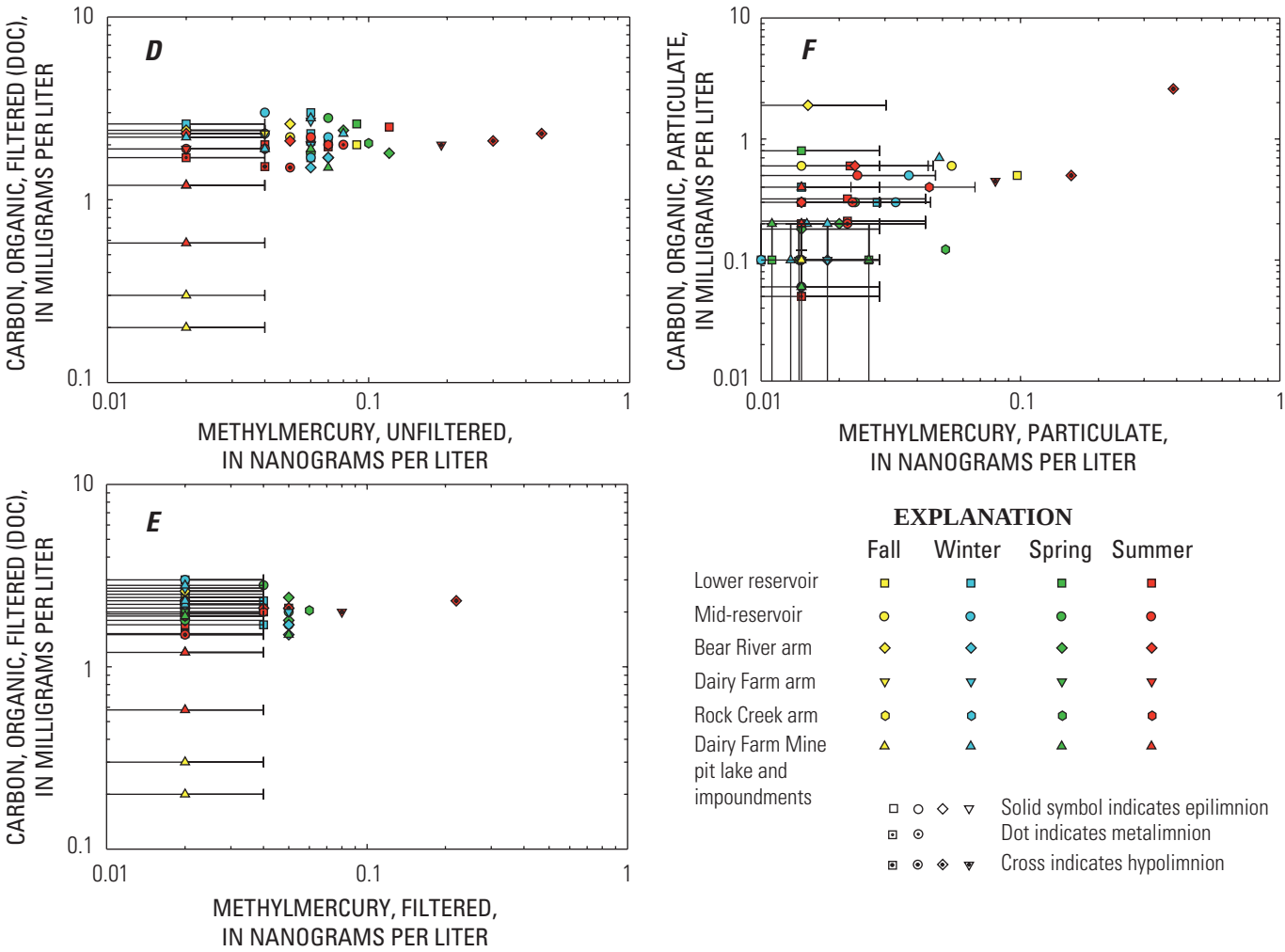


Figure 24. Relations between concentrations of mercury and carbon species in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) Unfiltered total mercury and dissolved organic carbon (DOC), (*B*) Filtered total mercury and dissolved organic carbon, (*C*) Particulate total mercury and particulate organic carbon, (*D*) Unfiltered methylmercury and dissolved organic carbon, (*E*) Filtered methylmercury and dissolved organic carbon, (*F*) Particulate methylmercury and particulate organic carbon. In (*A*), (*B*), and (*C*) best values of total mercury used, as explained in text and in table 6. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.



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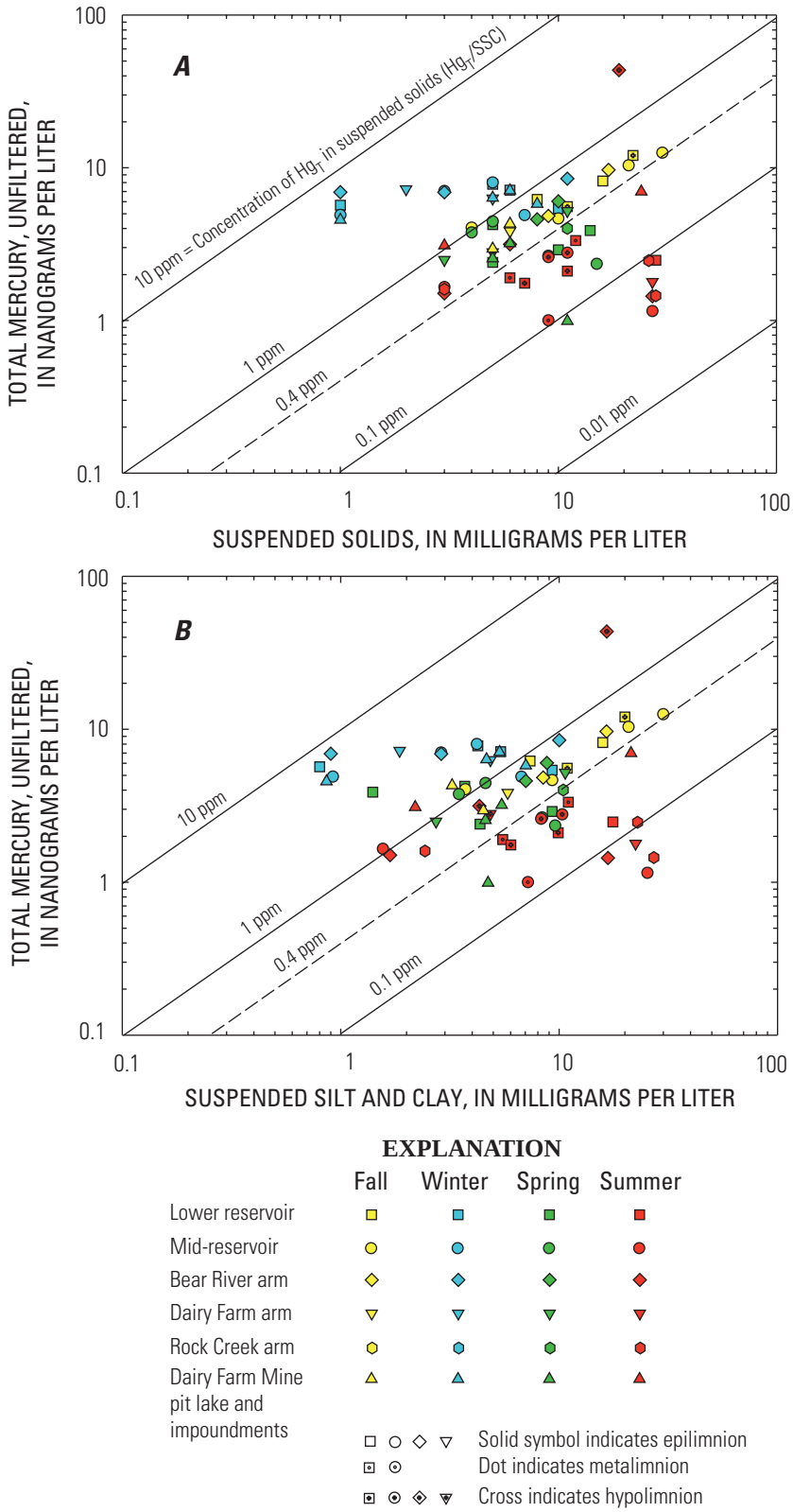
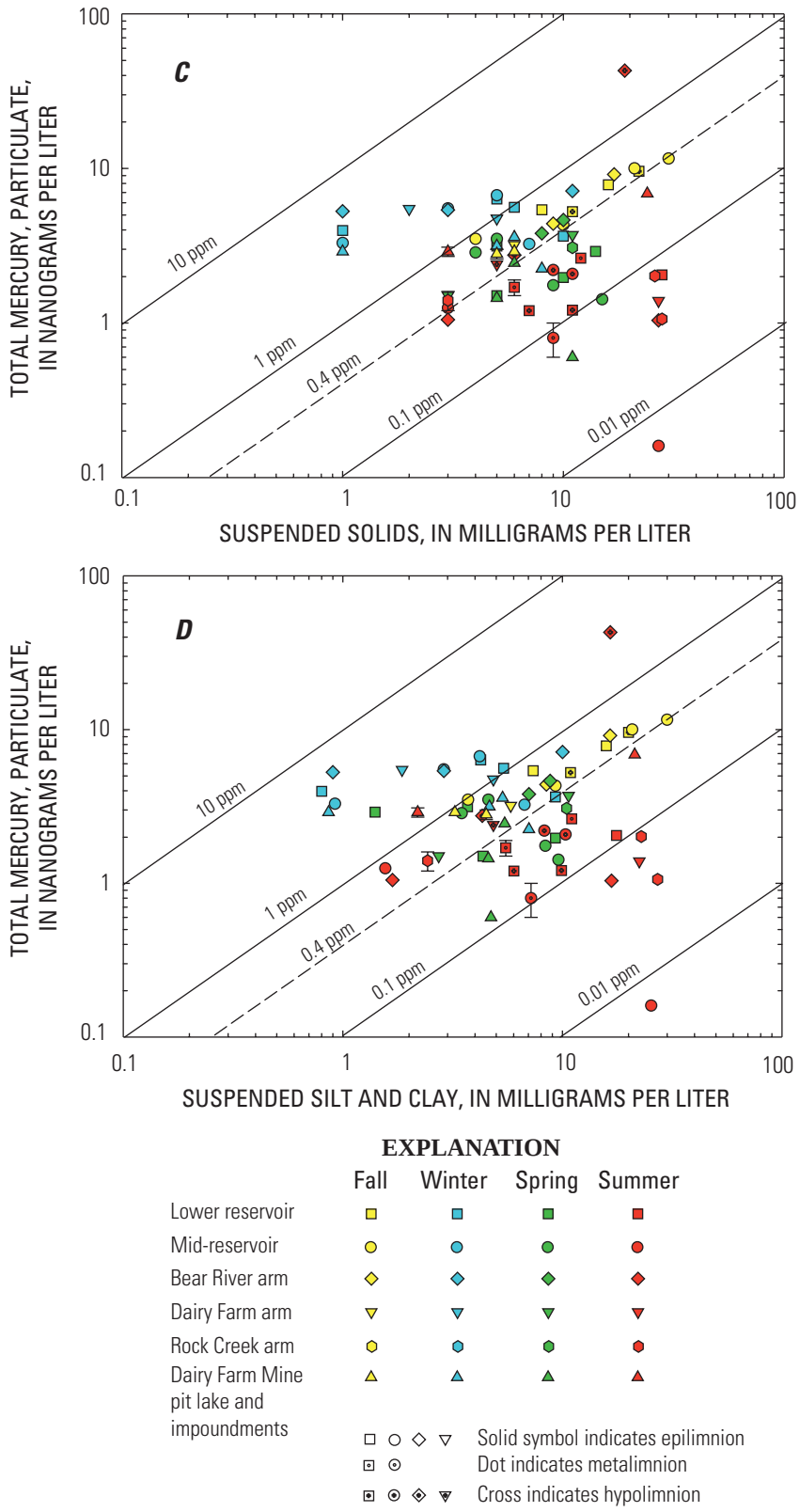


Figure 25. Relations between concentrations of total mercury and suspended solids in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) Unfiltered total mercury (Hg_T) and total suspended solids, (*B*) Unfiltered total mercury and suspended silt plus clay, (*C*) Particulate total mercury and total suspended solids, (*D*) Particulate total mercury and suspended silt plus clay. Diagonal lines represent contours of the ratio of total mercury to suspended solids, which is equal to the apparent concentration of total mercury in the suspended solids, in ppm (parts per million), equivalent to micrograms per gram. Best values of total mercury used, as explained in text and in table 6. Concentrations of silt plus clay in (*B*) and (*D*) calculated from suspended solids concentration (SSC) and percentage of material passing through 0.063 micrometer screen, as described in text and in table 2.



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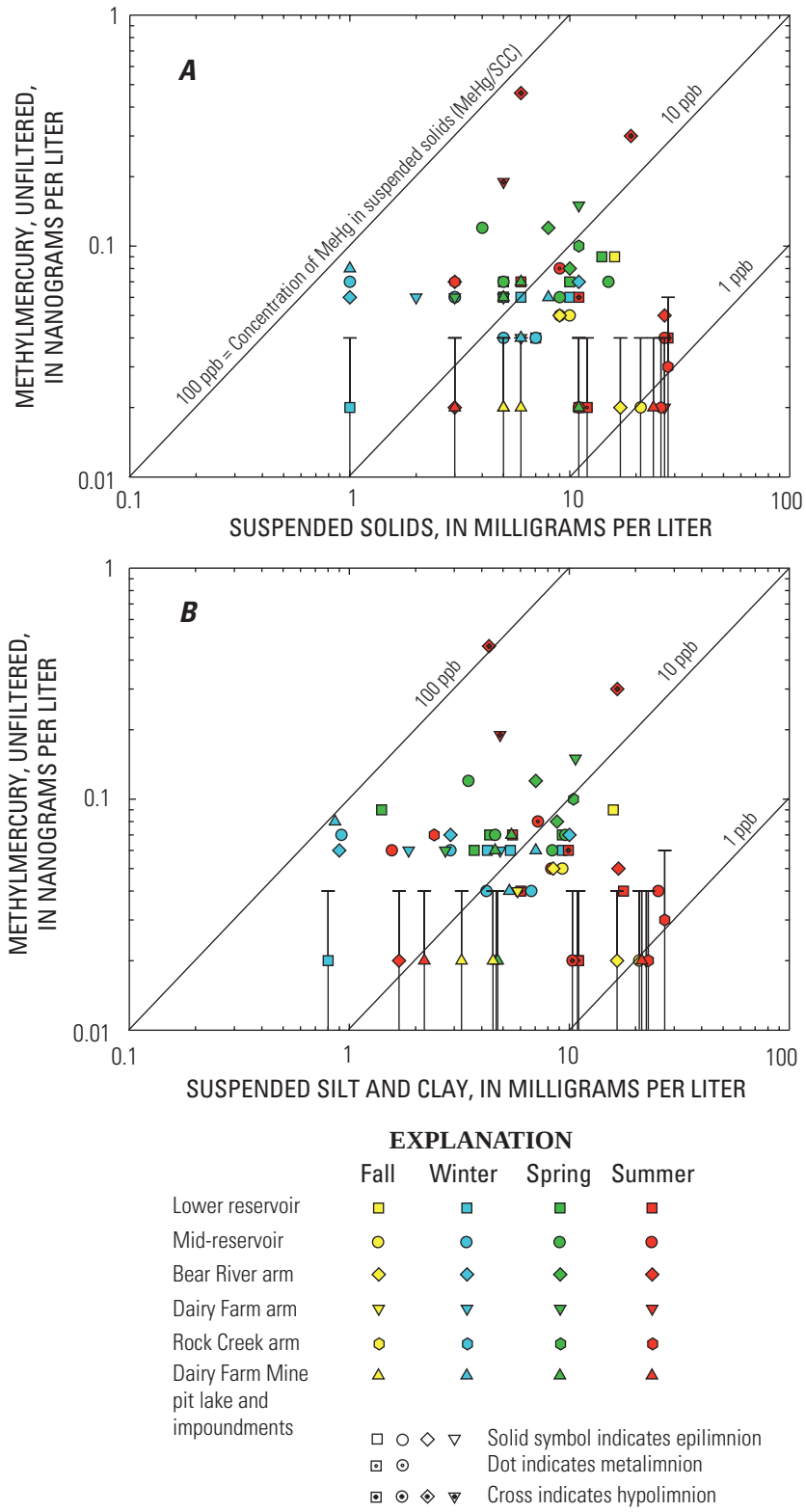


Figure 26. Relations between concentrations of methylmercury and suspended solids in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) Unfiltered methylmercury and suspended solids, (*B*) Unfiltered methylmercury and suspended silt plus clay, (*C*) Particulate methylmercury and suspended solids, (*D*) Particulate methylmercury and suspended silt plus clay. Diagonal lines represent contours of the ratio of methylmercury to suspended solids, which is equal to the apparent concentration of methylmercury in the suspended solids, in ppb (parts per billion) equivalent to nanograms per gram. Concentrations of silt plus clay in (*B*) and (*D*) calculated from suspended solids concentration and percentage of material passing through 0.063 micrometer screen, as described in text and in table 2. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

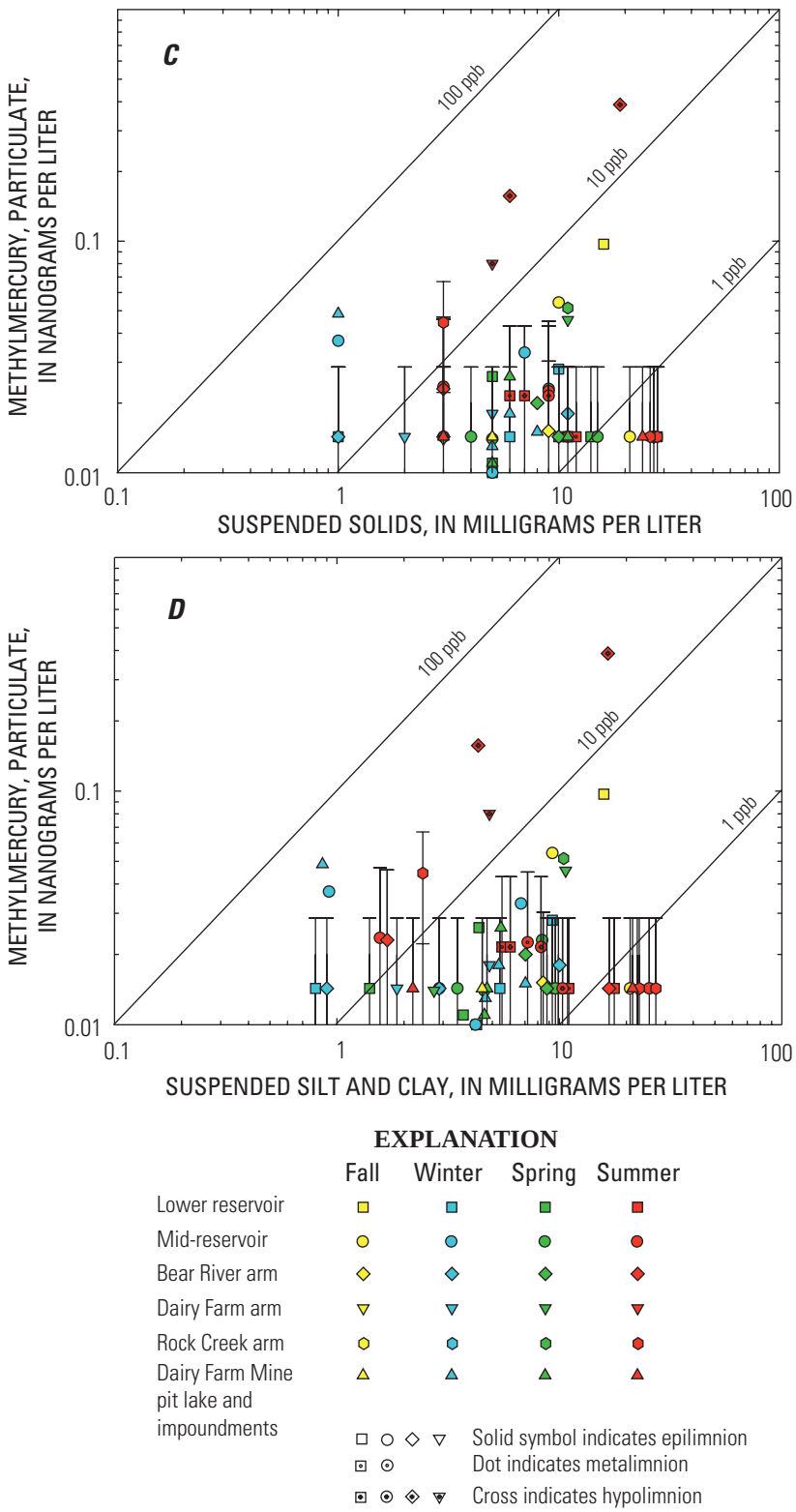


Figure 26. Continued.

Nutrients

The relations between concentrations of total phosphorus (P), total mercury (Hg_T), and methylmercury (MeHg) provide some insights into possible links between the cycling of mercury and nutrients within CFWR. In unfiltered water, Hg_T and P appear to have a positive correlation (fig. 27*A*), which is not surprising because these constituents followed similar seasonal trends (figs. 18*A* and 13*A*, respectively). Most of the summer samples were low in both Hg_T and P, with the notable exception of a hypolimnion sample from the BRA station (site 5). Most fall samples were relatively elevated in both Hg_T and P concentrations, whereas winter and spring samples had intermediate Hg_T and P concentrations. A linear least-squares regression of the log-transformed data in figure 27*A*, from sites 1–7 (excluding the DFP and DFI stations [fig. 5]), has an R^2 value of 0.48. A plot of the relation between particulate Hg_T and particulate total P (fig. 27*B*) shows a similar trend to the unfiltered data, On a plot of total P and MeHg concentrations in unfiltered water (fig. 27*C*), a seasonal pattern can also be identified. Starting with intermediate P concentrations in the winter and spring, there is a general decline in P into the summer with the exception of two hypolimnion samples from the BRA station with relatively high concentrations of both total P and MeHg. The fall samples had lower concentrations of MeHg but were still relatively high in total P. A plot of particulate MeHg and particulate total P (fig. 27*D*) shows a better correlation than that for the analogous unfiltered data (fig. 27*C*).

The relations between ammonia plus organic nitrogen (NH_3+N-org), Hg_T, and MeHg also show systematic seasonal patterns. For most unfiltered samples, there is a general decline in both Hg_T and NH_3+N-org from fall and winter to spring, and then Hg_T declines further to summer as the range in NH_3+N-org remains about the same in spring and summer (fig. 28*A*). A similar seasonal pattern is evident for Hg_T and NH_3+N-org concentrations in filtered water samples (fig. 28*B*); a systematic decline in Hg_T was observed from winter to spring to summer with NH_3+N-org concentrations in a fairly narrow range (0.06 to 0.2 mg/L), then in the fall the NH_3+N-org concentrations increased at most stations (0.15 to 0.3 mg/L) and especially at the DFP and DFI stations (1 to 3 mg/L). The relation between particulate Hg_T and particulate NH_3+N-org (fig. 28*C*) shows some seasonal variation but overall there is no apparent correlation. The relation between MeHg and NH_3+N-org in unfiltered water (fig. 28*D*) is similar to that observed between for total P and MeHg (fig. 27*C*) in unfiltered water.

Sulfur Isotopes

Concentrations of Hg_T in both unfiltered and filtered water show systematic decline from fall to winter to spring to summer (figs. 18*A*–18*B*), a pattern that is somewhat similar to the seasonal shift in sulfur isotopes of aqueous sulfate (fig. 11*B*). Plots showing the relations between sulfur isotopes in aqueous sulfate and Hg_T concentrations in unfiltered water (fig. 29*A*) and filtered water (fig. 29*B*) are useful in terms of understanding seasonal variations. The fall is characterized by large values of $\delta^{34}S_{SO4}$, elevated concentrations of Hg_T in unfiltered water, and relatively low concentrations of Hg_T in filtered water at most sampling sites. Concentrations of Hg_T in both filtered and unfiltered water generally decrease during from winter to spring and from spring to summer, and the values of $\delta^{34}S_{SO4}$ also decrease slightly during this period. The increase of $\delta^{34}S_{SO4}$ between summer and fall corresponds to an increase in Hg_T concentration in filtered water. On the basis of correlations of $\delta^{34}S_{SO4}$ with concentrations of sulfate and calcium (figs. 12*B*–12*C*), and correlations among sulfate, calcium, and other major cations and anions (fig. 9), the principal source of aqueous sulfate causing the fall increase in $\delta^{34}S_{SO4}$ appears to be the Bear River input to CFWR. The correlation between $\delta^{34}S_{SO4}$ and Hg_T in unfiltered water (fig. 29*A*) may indicate that the principal source of the increased Hg_T concentration is also the Bear River input.

Mercury and sulfur cycling are linked by the role that sulfate-reducing bacteria play in methylating mercury, a process that likely takes place in shallow sediments and possibly also in anoxic parts of the water column. It is possible that hydrogen sulfide produced by sulfate-reducing bacteria combines with available inorganic mercury to make mercury sulfide, a relatively insoluble precipitate that would effectively scavenge dissolved mercury from the water column, explaining the relatively low concentrations of Hg_T in filtered water in the summer and fall when this process appears to be most active. Microbially mediated sulfate reduction tends to cause a shift to larger values of $\delta^{34}S_{SO4}$ because the microbes preferentially reduce ^{32}S rather than ^{34}S (Seal and others, 2000). The shift to larger values of $\delta^{34}S_{SO4}$ in the CFWR water column in the fall may be partly influenced by this process; however, such effects are expected to be confined to the hypolimnion prior to destratification. Because the fall samples were taken before destratification (figs. 6, 7*A*–7*B*) and the shift in $\delta^{34}S_{SO4}$ values is seen in both hypolimnion and epilimnion samples throughout the reservoir, it is unlikely that microbial sulfate reduction within CFWR is the principal cause of the S-isotope shift. Nevertheless, microbial sulfate reduction and its seasonality within CFWR sediments play an important role in Hg methylation. However, the seasonal changes in $\delta^{34}S_{SO4}$ of Bear River input water coupled with the extreme drawdown of CFWR during fall confounds the use of sulfur isotopes to track sulfate reduction processes in the reservoir.

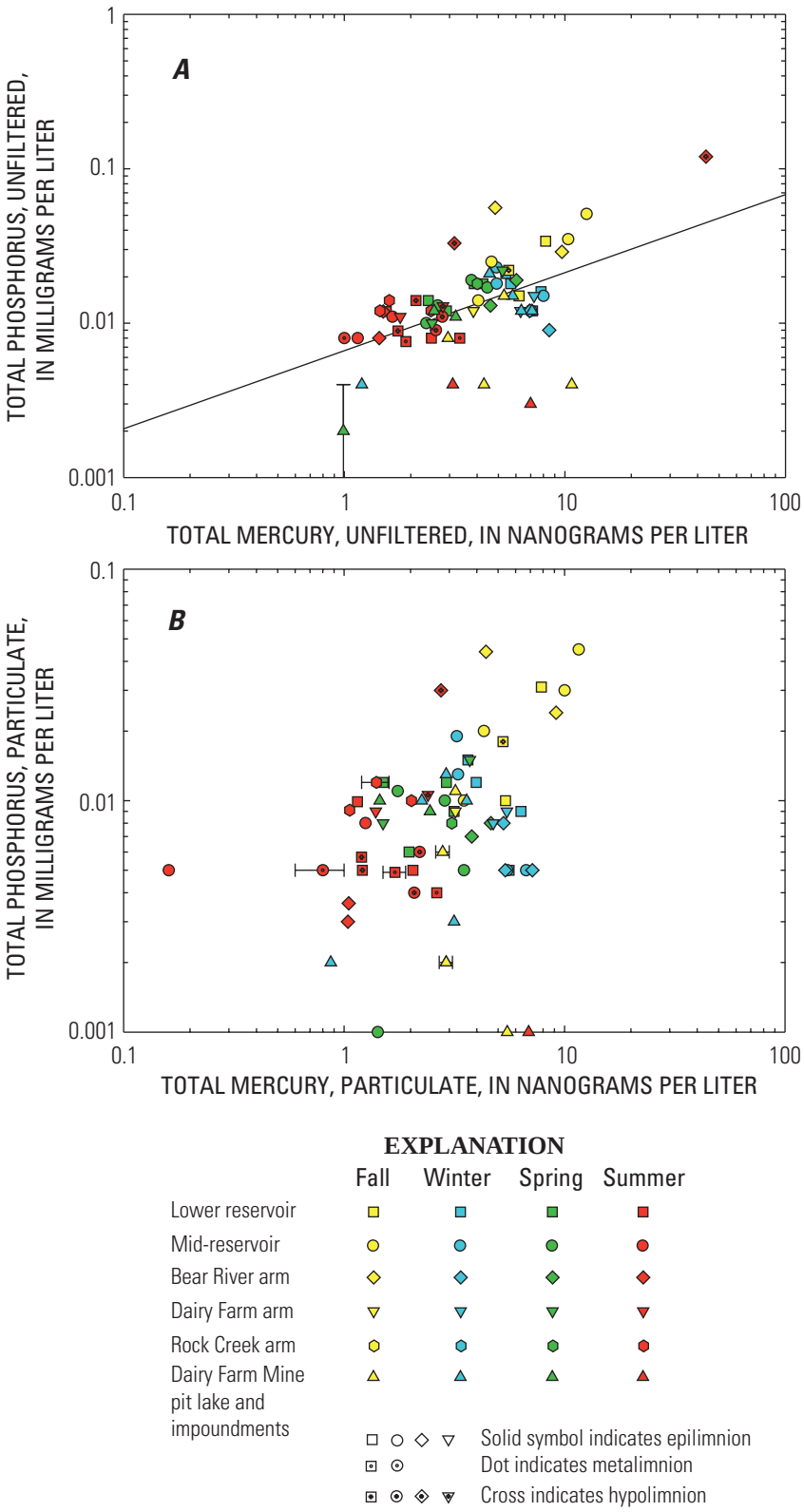
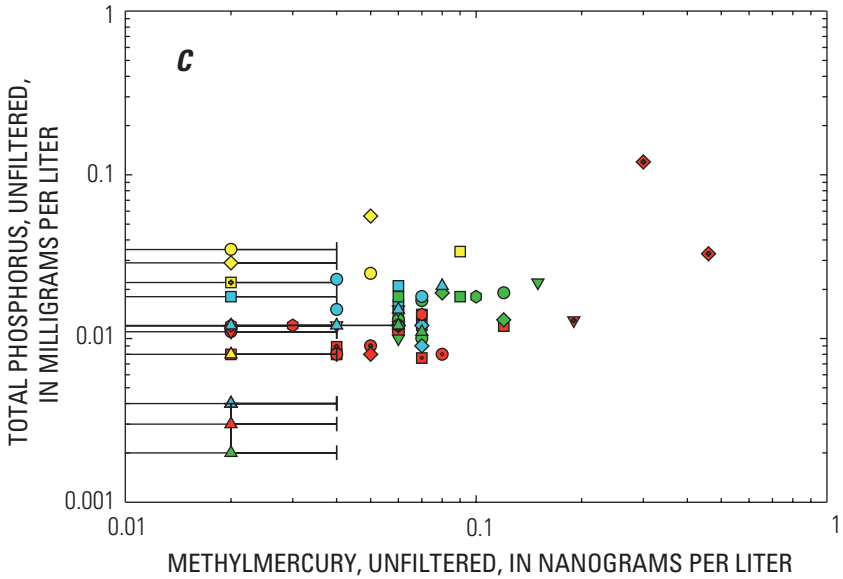
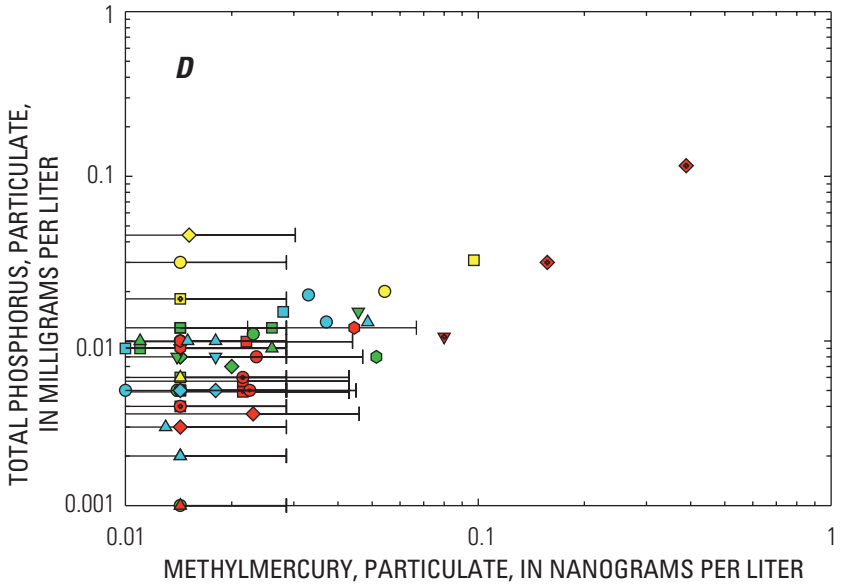


Figure 27. Relations between concentrations of mercury species and phosphorus in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) Total mercury and total phosphorus in unfiltered water, (*B*) Particulate total mercury and particulate total phosphorus, (*C*) Methylmercury and total phosphorus in unfiltered water, (*D*) Particulate methylmercury and particulate total phosphorus. Best values of total mercury used, as explained in text and in table 6. Particulate total phosphorus concentrations calculated as difference between total phosphorus in unfiltered water and total phosphorus in filtered water. Line in (*A*) is linear least-squares regression in log-log transform coordinates. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.





EXPLANATION

	Fall	Winter	Spring	Summer
Lower reservoir	□	□	□	□
Mid-reservoir	○	○	○	○
Bear River arm	◇	◇	◇	◇
Dairy Farm arm	▽	▽	▽	▽
Rock Creek arm	⬡	⬡	⬡	⬡
Dairy Farm Mine pit lake and impoundments	△	△	△	△

□ ○ ◇ ▽ Solid symbol indicates epilimnion
⊡ ⊙ Dot indicates metalimnion
▣ ◉ ◈ ▼ Cross indicates hypolimnion

Figure 27. Continued.

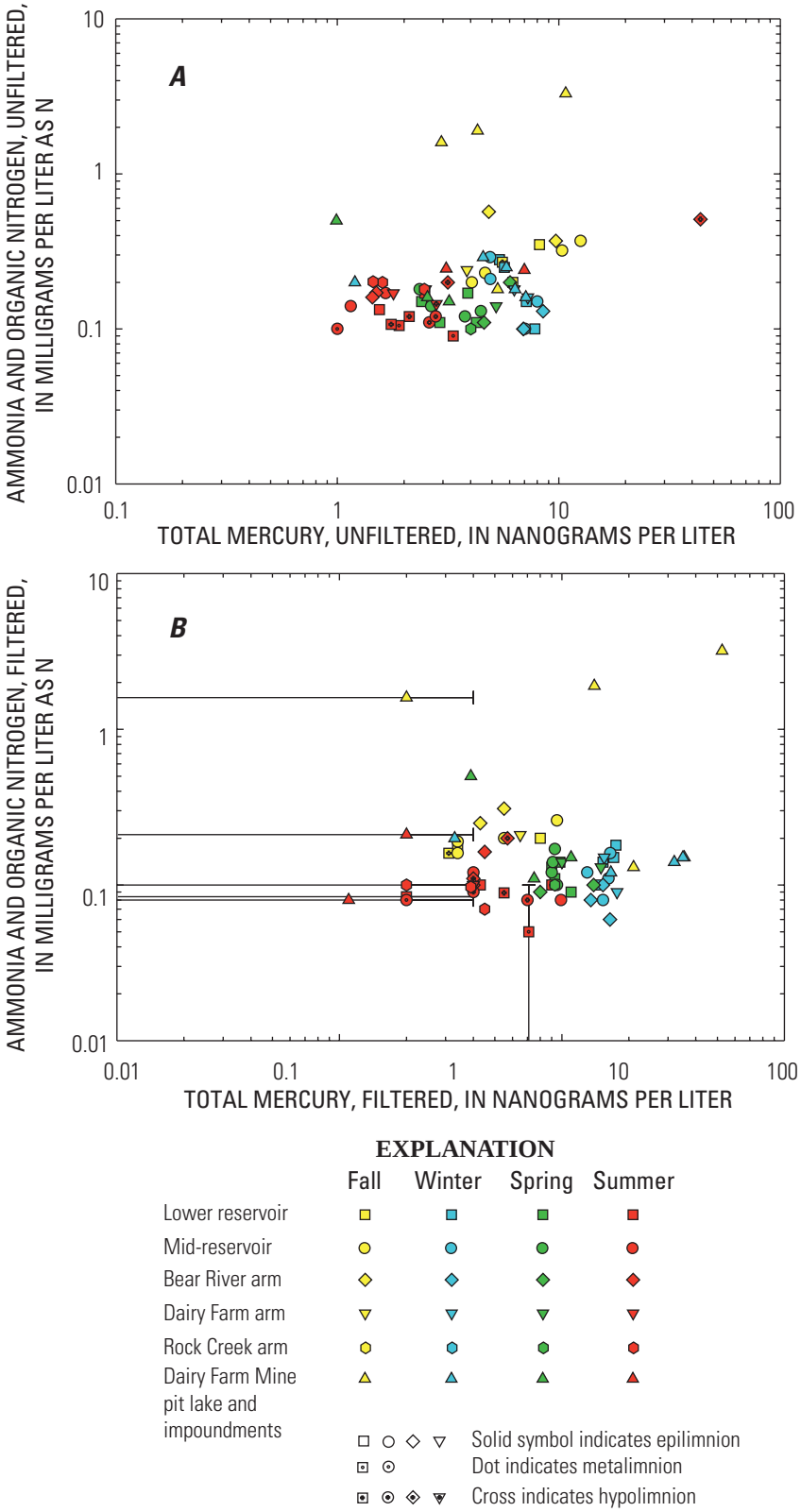


Figure 28. Relations between mercury and nitrogen concentrations in water samples from Camp Far West Reservoir, California, 2001–03: (*A*) total mercury and ammonia plus organic nitrogen in unfiltered water, (*B*) total mercury and ammonia plus organic nitrogen in filtered water, (*C*) total particulate mercury and particulate ammonia plus organic nitrogen, (*D*) methylmercury and ammonia plus organic nitrogen in unfiltered water. Best values of total mercury used, as explained in text and in table 6. Particulate ammonia plus organic nitrogen (N) concentrations calculated as difference between total ammonia plus organic nitrogen in unfiltered water and ammonia plus organic nitrogen in filtered water. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

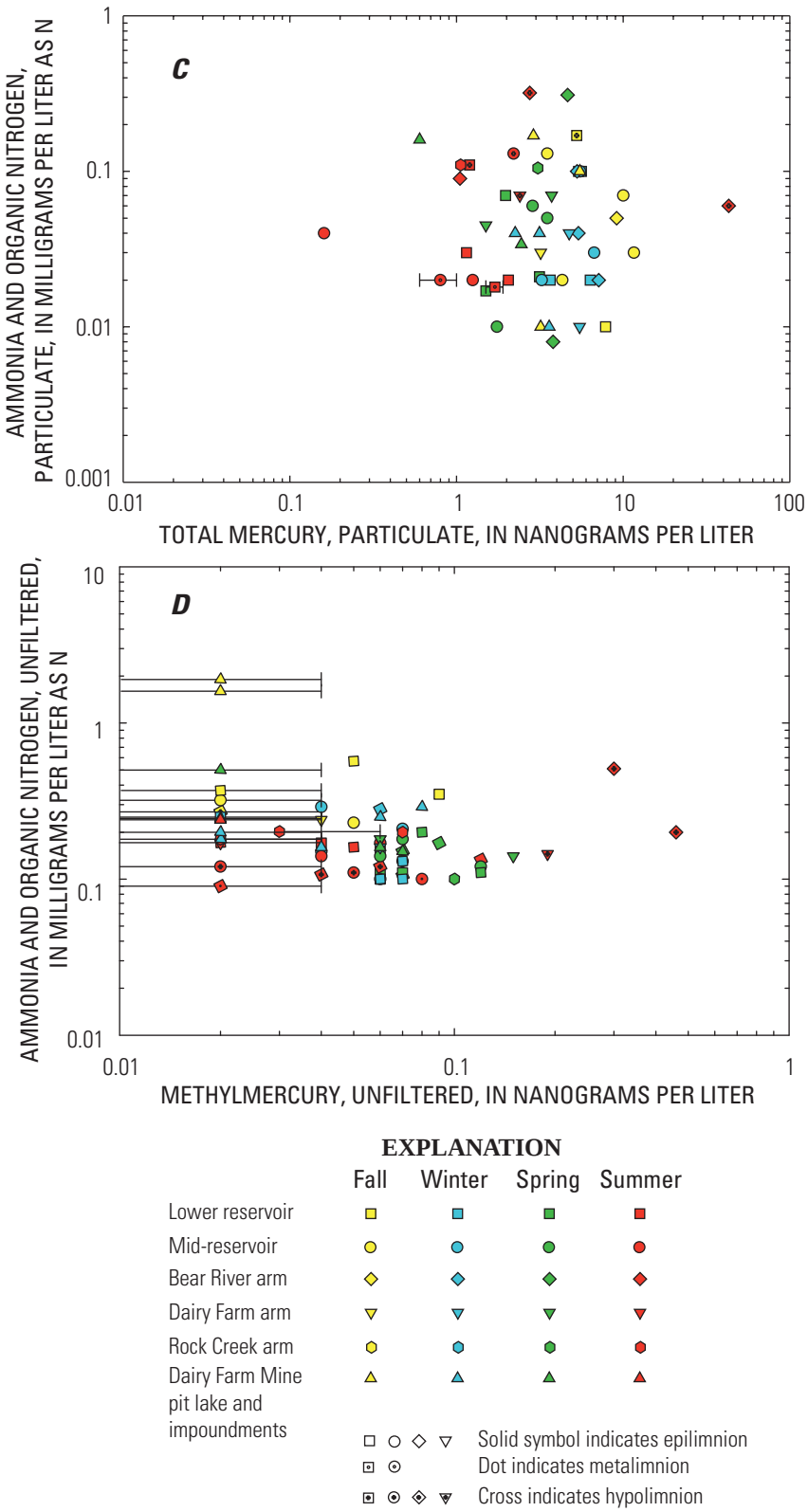


Figure 28. Continued.

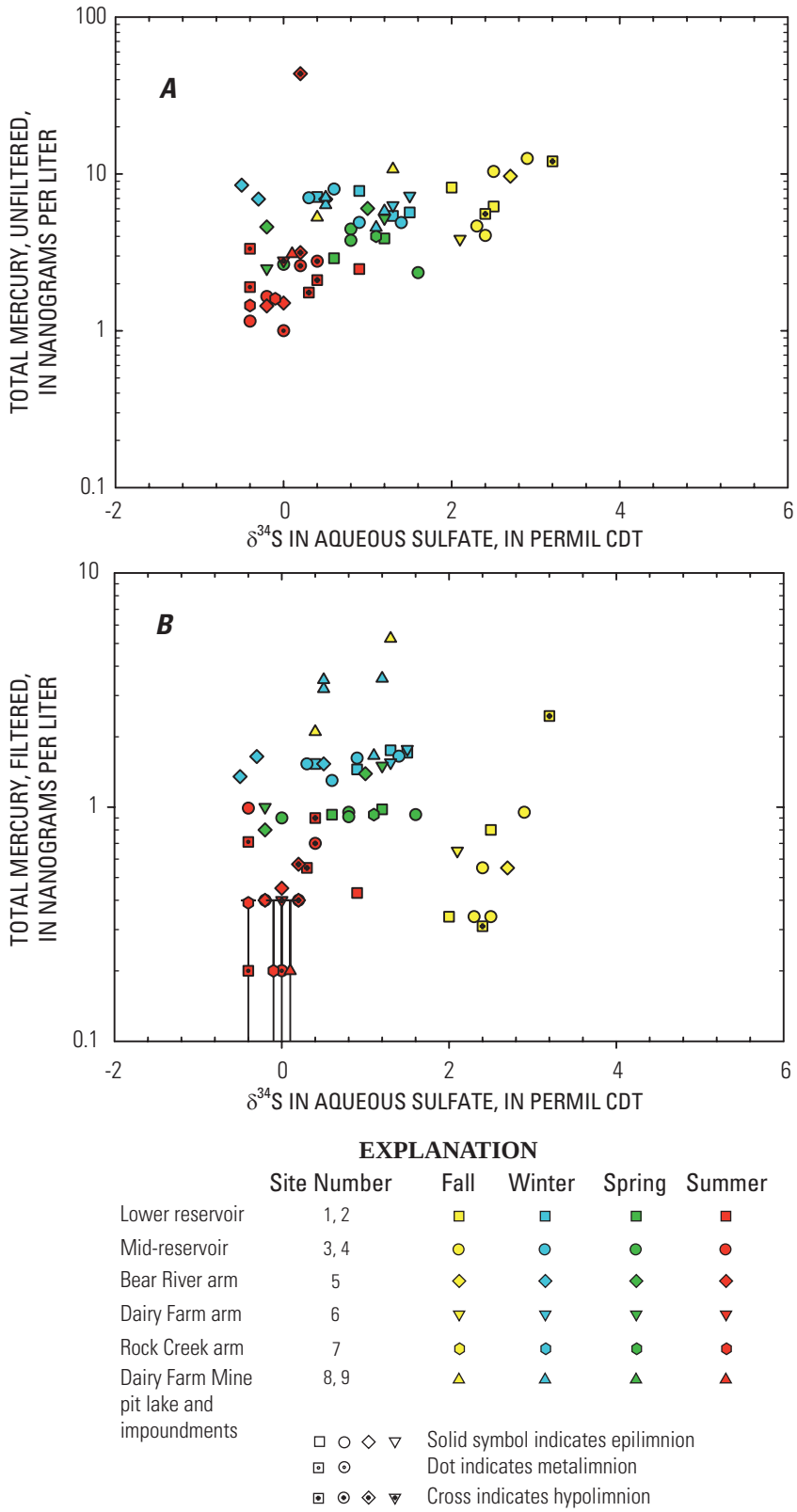


Figure 29. Relation between sulfur isotopes in aqueous sulfate and total mercury in water, 2001–03: (*A*) total mercury in unfiltered water, (*B*) total mercury in filtered water. Best values of total mercury used, as explained in text and in table 6. $\delta^{34}S$, delta-34-sulfur value, CDT, Cañon Diablo Troilite. Error bars represent measurements less than method detection limit (MDL), with corresponding symbol plotted at 50 percent of MDL.

Bioaccumulation Factors

Bioaccumulation factors (BAF) were computed using data from linked studies of mercury bioaccumulation in seven biological taxa: spotted bass, bluegill, threadfin shad, crayfish, mayfly nymphs, midge larvae, and zooplankton (Stewart and others, 2008). A simplified approach to assigning pelagic biota to trophic levels that was used by the U.S. Environmental Protection Agency (1997) in its assessment of mercury bioaccumulation factors is used and extended in this report for BAF analysis. The USEPA approach makes the simplifying assumption that aquatic food chains can be adequately represented using four trophic levels. According to the U.S. Environmental Protection Agency (1997),

> "These trophic levels are the following: level 1 - phytoplankton (algal producers); level 2 - zooplankton (primary herbivorous consumers); level 3 - small forage fish (secondary consumers); and level 4 - larger, piscivorous fish (tertiary consumers). This type of food chain typifies the pelagic assemblages found in large freshwater lakes, and has been used extensively to model bioaccumulation of hydrophobic organic compounds. It is recognized, however, that food chain structure can vary considerably among aquatic systems resulting in large differences in bioaccumulation in a given species of fish. In addition, this simplified structure ignores several important groupings of organisms, including benthic detritivores, macroinvertebrates, and herbivorous fishes."

According to the USEPA classification system, spotted bass are considered trophic level (TL) 4, bluegill and threadfin shad are TL 3, and zooplankton are TL 2. Although invertebrates such as those sampled in CFWR are not strictly addressed in the USEPA classification system, midge larvae and mayfly nymphs are largely detritivores and would be analogous to TL 2, and crayfish are secondary consumers that would be analogous to TL 3.

Significant variations of total mercury in tissue and organism length were observed for all three fish species (figs. 30*A*–30*C*) and for total mercury and length in crayfish (fig. 30*D*). Samples for these four taxa were divided into size classes, and average concentrations and standard deviations were computed for each size class (figs. 31*A*–31*D*). Bioaccumulation factors (BAF) were computed (table 10, and appendix H, tables H1–H6) using the average methylmercury concentration (wet) in biota divided by the mean concentration of methylmercury in filtered water (0.04 nanogram per liter). For the three fish species, total mercury concentrations in fillet tissue were used as an approximation of methylmercury concentrations. Analyses of fish from CFWR and elsewhere indicate that $MeHg/Hg_T$ in fish tissue is usually between 0.61 and 0.95 (Bloom, 1992; Mason and others, 2006). Average $MeHg/Hg_T$ values for spotted bass and bluegill from CFWR were 0.87 and 0.93, respectively. As expected, the BAF values increased systematically with trophic level. Values of BAF were 190,000 for zooplankton (TL 2); 470,000 to 930,000 for three taxa of invertebrates (analogous to TLs 2 and 3); 2.7 million for threadfin shad (whole body; TL 3); 4.2 million for bluegill (fillet; TL 3); and 10 million for spotted bass (fillet; TL 4). The U.S. Environmental Protection Agency (1997) computed MeHg BAF values for TL 4 by a number of methods using carefully screened data from a small number

Table 10. Summary of methylmercury bioaccumulation factors, Camp Far West Reservoir, California, 2002–03.

[BAF, bioaccumulation factor; L/kg, liter per kilogram; –, not determined]

Organism	Sample type	Trophic level	Total number of samples	Overall BAF (wet basis) (L/kg)	Overall log BAF (wet basis)	Minimum BAF (smallest size class or season) (L/kg)	Maximum BAF (largest size class or season) (L/kg)	Ratio of maximum BAF to minimum BAF
Spotted Bass	Fillet	4	180	1.0×10^7	7.0	2.9×10^6	2.5×10^7	8.6
Spotted Bass	Wholebody	4	180	8.0×10^6	6.9	2.5×10^6	1.9×10^7	7.8
Bluegill	Fillet	3	120	4.2×10^6	6.6	2.9×10^6	5.5×10^6	1.9
Bluegill	Wholebody	3	120	3.2×10^6	6.5	2.2×10^6	4.3×10^6	2.0
Threadfin Shad	Wholebody	3	104	2.7×10^6	6.4	1.7×10^6	4.1×10^6	2.4
Crayfish	Wholebody	–	44	9.3×10^5	6.0	6.7×10^5	1.1×10^6	1.6
Mayfly nymphs	Composite	–	7	5.9×10^5	5.8	–	–	–
Midge larvae	Composite	–	9	4.7×10^5	5.7	–	–	–
Zooplankton	Composite	2	21	1.9×10^5	5.3	2.0×10^4	3.9×10^5	19.3

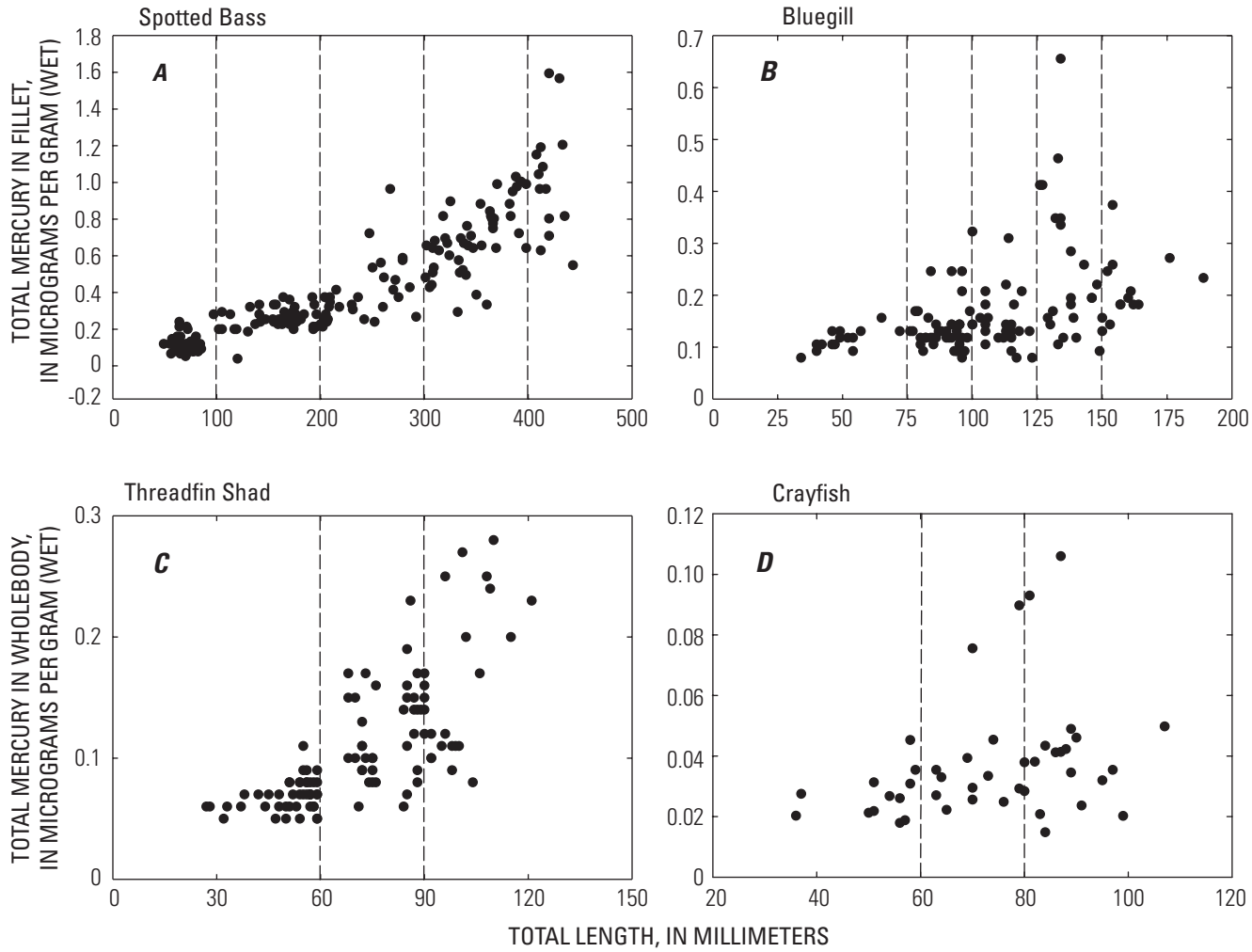


Figure 30. Plots showing relations of total length and total mercury in tissue of selected fishes and crayfish, Camp Far West Reservoir, 2002–03: (A) Spotted bass, (B) Bluegill, (C) Threadfin shad, (D) Crayfish. Dashed vertical lines represent boundaries between size classes selected for calculation of methylmercury bioaccumulation factors. Concentrations of mercury in fillet tissue of spotted bass and bluegill calculated from whole body concentrations using results of linear least-squares regression (20 samples for spotted bass, 15 samples for bluegill).

of studies around the country and derived a recommended value of 6.8 million. The BAF value for spotted bass at CFWR (10 million) is around the 80th percentile of the distribution presented by U.S. Environmental Protection Agency (1997) for TL 4. For TL 3, the U.S. Environmental Protection Agency (1997) computed a BAF of 1.6 million. The BAFs for threadfin shad and bluegill at CFWR were higher than this value. The threadfin shad BAF (2.7 million) is between USEPA's 50th and 85th percentiles for TL3 and the bluegill BAF (4.2 million) is between USEPA's 87.5th and 95th percentiles. The BAFs from CFWR also are somewhat higher than those observed in other reservoirs in northern California (for example, Kuwabara and others, 2005), indicating a relatively efficient biomagnification of mercury in Camp Far West Reservoir.

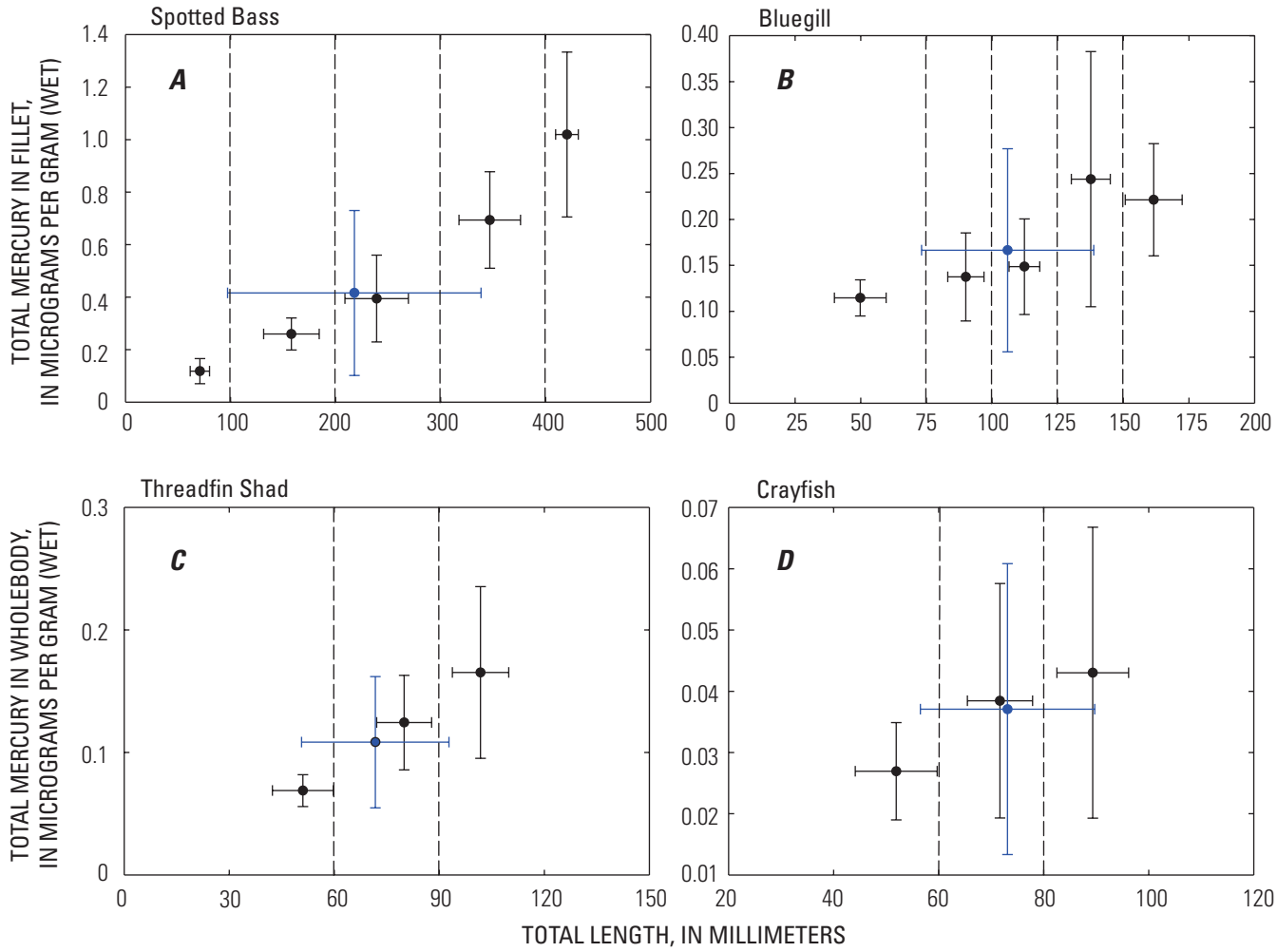


Figure 31. Plot showing relation of average and standard deviation of total length and total mercury in fillet tissue in selected size classes of fishes and crayfish from Camp Far West Reservoir, California, 2002–03: (A) Spotted bass, (B) Bluegill, (C) Threadfin shad, (D) Crayfish. Dashed vertical lines represent boundaries between size classes selected for calculation of methylmercury bioaccumulation factors. Average and standard deviation for individual size classes shown in black; average and standard deviation for all samples of each species shown in blue. Concentrations of total mercury in fillet tissue of spotted bass and bluegill calculated from whole body concentrations using results of linear least-squares regression (20 samples for spotted bass, 15 samples for bluegill).

Summary and Conclusions

The water quality in Camp Far West Reservoir (CFWR) was characterized by eight quarterly sampling events over a 2-year period (fall 2001 through summer 2003) at several locations within the reservoir as part of a multi-disciplinary project focused on mercury transport, transformation, and bioaccumulation in the Bear River watershed. Robust seasonal variations were observed in several water-quality constituents including major cations and anions, total mercury (in both filtered and unfiltered samples), nitrogen (ammonia plus organic), and total phosphorus. A strong seasonal signal also was observed for the sulfur isotope composition of aqueous sulfate from filtered water. The reservoir experienced severe drawdown to less than 8 percent of its total storage during October and November 2002, which had the effect of accentuating seasonal trends in water quality caused by variations in the chemistry of input water from the Bear River.

The reservoir is monomictic, with thermal stratification developing in the summer and continuing into the early fall. During stratified conditions, low concentrations of dissolved oxygen generally were observed in the lower, cool zone (hypolimnion) and occasionally in the transition zone (metalimnion). Because of extreme drawdown during late summer and early fall, the hypolimnion was available for sampling only at the deepest sites in the thalweg (original river channel). Evaporative effects are seen by a shift of about 2 permil in $\delta^{18}O_{H2O}$, confined to the epilimnion (surface layer) in the summer and fall. The Dairy Farm Mine pit lake becomes hydrologically separated from CFWR during low stage (summer and fall), during which time it becomes acidic and metalliferous. When water levels rise in winter, the sulfate-rich, acidic water of the pit lake mixes with CFWR, so the mine acts a source of sulfate and metals to CFWR.

Highest concentrations of total mercury (filtered and unfiltered water) were observed during fall and winter; these concentrations declined at most stations during spring and into summer. Aqueous methylmercury concentrations were highest during summer sampling at deep-water stations in the anoxic, hypolimnion zone, especially in the Bear River arm of the reservoir. The ratio of methylmercury to total mercury ($MeHg/Hg_T$) increased systematically from winter to spring to summer, largely in response to the decrease in total mercury concentrations, but also to some extent because of increases in MeHg during the summer.

It is hypothesized that MeHg is produced in the anoxic parts of the water column and also in shallow bed sediment by sulfate-reducing bacteria. Conditions are optimal for this during late summer and early fall when the reservoir is thermally stratified. This coincides with the timing of a phytoplankton bloom. Primary production of phytoplankton in CFWR is phosphate-limited. Concentrations of orthophosphate were very low or below detection at all stations. It has been hypothesized that iron-reducing bacteria release phosphorus from iron-rich sediments in CFWR during summer and early fall, stimulating the phytoplankton bloom. When the reservoir destratifies (turns over) in the late fall, the MeHg produced in the hypolimnion (and perhaps also the metalimnion) is released to the entire water column.

Stable isotopes of sulfur in aqueous sulfate indicate a shift toward larger values of $\delta^{34}S$ in the fall. Based on correlations of $\delta^{34}S_{SO4}$ with concentrations of sulfate and calcium and correlations among the major cations and anions, the principal source of aqueous sulfate causing the fall increase in $\delta^{34}S_{SO4}$ appears to be the Bear River input to CFWR. Microbially mediated sulfate reduction and its seasonality within CFWR sediments likely plays an important role in Hg methylation; however, the seasonal changes in $\delta^{34}S_{SO4}$ of Bear River input water coupled with the extreme drawdown of CFWR during fall precludes the use of sulfur isotopes to track sulfate-reduction processes in the reservoir.

Bioaccumulation factors were computed using data from linked studies of mercury bioaccumulation in seven biological taxa over a range of trophic levels: zooplankton, midge larvae, mayfly nymphs, crayfish, threadfin shad, bluegill, and spotted bass. Significant increases in total mercury in fillet tissue with fish size were observed for all three fish species and for crayfish. Bioaccumulation factors (BAF) were computed using the average total mercury or methylmercury concentration (wet) in biota divided by the mean concentration of methylmercury in filtered water (0.04 nanograms per liter). As expected, the BAF values increased systematically with increasing trophic level (TL, based on U.S. Environmental Protection Agency, 1997). Values of BAF were: 190,000 for zooplankton (TL 1); 470,000 to 930,000 for three taxa of invertebrates (TL 2); 2.7 million for threadfin shad (whole body; TL 3); 4.2 million for bluegill (fillet; TL 3) and 10 million for spotted bass (fillet; TL 4). The BAF values are somewhat higher than those observed in other reservoirs in northern California, indicating a relatively efficient biomagnification of mercury in Camp Far West Reservoir.

Acknowledgments

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Appendixes

Appendix data can be accessed by downloading files at http://pubs.usgs.gov/sir/2006/5008.

Appendix A. Plots Showing Relations of Reservoir Storage, Surface Water Elevation, and Time, Camp Far West Reservoir, California.

Appendix B. Tables Describing Sampling Stations and Frequency of Sampling, Camp Far West Reservoir and Vicinity, California.

Appendix C. Tables of Data Describing Water-Column Profiles, Camp Far West Reservoir, California.

Appendix D. Plots Showing Water-Column Depth Profiles of Temperature, Dissolved Oxygen, pH, and Specific Conductance, Camp Far West Reservoir, California, 2001–03.

Appendix E. Tables of Data Related to Quality Assurance and Quality Control.

Appendix F. Quality Assurance and Quality Control Figures.

Appendix G. Data for Total Mercury, Other Trace Elements, Major Elements, and Chlorophyll.

Appendix H. Data Tables for Methylmercury Bioaccumulation Factors, Camp Far West Reservoir, California.

Glossary

auriferous Gold-bearing.

benthos Forms of aquatic life that are bottom dwelling.

bioaccumulation factor (BAF) The concentration ratio of a constituent in biological tissue divided by the concentration of that same constituent in water. In the case of methylmercury, BAF values presented in this report are computed as the concentration in fish or invertebrate tissue divided by the concentration of methylmercury in filtered water.

demethylation (of methylmercury) The process of converting methylmercury to an inorganic form of mercury. Demethylation may be caused by abiotic processes (such as exposure to ultraviolet light) as well as biotic processes (such as microbial activity).

elemental mercury The pure form of mercury, the only element to be stable as a liquid at room temperature; also known as quicksilver.

epilimnion In thermally stratified lakes or reservoirs, the upper, more or less uniformly warm, circulating, and fairly turbulent water.

flux Transport of a constituent. Bed sediment flux in a reservoir refers to transport of a constituent from the pore water of the bed sediment to the overlying water column by the process of aqueous diffusion.

impaired beneficial use The condition of a water body that is not meeting water-quality standards, according to the federal Clean Water Act of 1972.

hypolimnion In thermally stratified lakes or reservoirs, the deep, cold, and relatively undisturbed region.

load The quantity of material carried by a natural transporting agent per unit time. For aqueous constituents in rivers, the load (mass per time) is computed as the product of the aqueous concentration (mass per volume) and the discharge rate (volume per time). Typical units for sediment loads are tons per day and for mercury loads are grams or kilograms per year.

lognormal distribution The probability distribution of any random variable whose logarithm is normally distributed. If x is a random variable with a normal distribution, then exp(x) has a log-normal distribution.

metalimnion In thermally stratified lakes or reservoirs, the transition zone between the upper, warm zone (epilimnion) and lower, cold zone (hypolimnion).

methylation (of mercury) The process of converting an inorganic form of mercury to methylmercury, an organic (carbon-bearing) form. It is generally accepted that mercury methylation is largely caused by the activity of microbes, particularly sulfate-reducing bacteria.

methylmercury (MeHg) An organic form of mercury (formula CH_3Hg^+) that is readily bioaccumulated. It is more toxic to humans and other biota than native (elemental) mercury.

micromole per liter Concentration unit for aqueous constituents. Conversion of concentration data from milligrams per liter (mg/L) to micromoles per liter (µmol/L) is by the formula 1,000*(mg/L)/MW= µmol/L, where MW is the molecular weight of the constituent in units of grams per mole.

monomictic lake (or reservoir) A water body that is thermally stratified during one part of the year and circulates freely during the remainder of the year. Warm monomictic lakes (those with temperatures that do not drop below 4° Celsius) typically stratify in the summer (Wetzel, 1975).

placer gold Gold grains or flakes in an unconsolidated sediment deposit. Also known as alluvial gold.

Relative Percentage Difference (RPD) Quantity computed for the evaluation of precision (or variability) of laboratory analytical data using randomly submitted split samples.
RPD = 100 × (absolute value of difference between reported values) / (average reported value)

Relative Standard Deviation (RSD) A quantity computed for the evaluation of precision (or variability) of data. Relative standard deviation is the standard deviation of a series of measurements divided by the average of those measurements times 100
RSD = 100 × (standard deviation) / (average reported value)

thalweg The submerged river channel that represents the deepest water in a reservoir at a given distance from the dam.

total mercury (Hg_T) The sum of all forms or species of mercury in a sample of water, sediment, or biota.

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For more information concerning the research in this report, contact the
Director, California Water Science Center,
U.S. Geological Survey, 6000 J Street Placer Hall
Sacramento, CA 95819
http://ca.water.usgs.gov

SWAMP
Surface Water Ambient Monitoring Program

CONTAMINANTS IN FISH FROM CALIFORNIA LAKES AND RESERVOIRS, 2007-2008: SUMMARY REPORT ON A TWO-YEAR SCREENING SURVEY

J.A. Davis
A.R. Melwani
S.N. Bezalel
J.A. Hunt
G. Ichikawa
A. Bonnema
W.A. Heim
D. Crane
S. Swenson
C. Lamerdin
M. Stephenson

Prepared for the Surface Water Ambient Monitoring Program

May 14, 2010

California Water Boards

http://www.waterboards.ca.gov/water_issues/programs/swamp

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Bioaccumulation Oversight Group (BOG) Members

Terry Fleming, USEPA
Bob Brodberg, OEHHA
Chris Foe, Region 5 Water Board
Mary Adams, Region 3 Water Board
Michael Lyons, Region 4 Water Board
Karen Taberski, Region 2 Water Board
Jennifer Doherty, State Water Board
Jay Davis, SFEI
Mark Stephenson, CDFG
Dave Crane, CDFG
Gary Ichikawa, CDFG
Autumn Bonnema, CDFG
Aroon Melwani, SFEI
Cassandra Lamerdin, MLML
Marco Sigala, MLML
Tom Maurer, USFWS
Scott McReynolds, DWR
Jay Rowan, CDFG

SWAMP Bioaccumulation Peer Review Panel

Jim Wiener, Distinguished Professor, University of Wisconsin, La Crosse
Chris Schmitt, USGS, Columbia, Missouri
Ross Norstrom, Canadian Wildlife Service (retired); Carleton University, Ottawa, Canada

San Francisco Estuary Institute

Project Management Support: Lawrence Leung, Rainer Hoenicke, Frank Leung, Irene Poche, Linda Russio, and Stephanie Seto

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Dissection: Stephen Martenuk, Erik Adams, Kyle Skaff, L.A. Solano, Jason Whitney
Mercury and Selenium Analysis: April Sjoboen, Brent Hughes, Jon Goetzl.
SWAMP Data Management Team: Cassandra Lamerdin, Mark Pranger, Stacey Swenson, Susan Mason, Marco Sigala, George Radojevic, Brian Thompson, Kyle Reynolds
SWAMP Quality Assurance Team: Beverly van Buuren, Eric von der Geest

California Department of Fish and Game Water Pollution Control Laboratory

Fish collection: Glenn Sibbald, Matt Rock
Sample prep: Laurie Smith, David Gilman, Rafia Mohammed
Sample analysis: Kathleen Regalado, Gary Munoz
Data entry and QA: Loc Nguyen

SWAMP Staff

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Statistical Consultant

Don Stevens, Oregon State University

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Appendix 1

Concise summary of year 1 results of the SWAMP Lakes Survey: composites or averages at each location

Appendix 2

List of lakes identified for trend analysis

EXECUTIVE SUMMARY E

This summary report presents results from a two-year screening survey of contaminants in sport fish in California lakes and reservoirs. This survey was performed as part of the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP). This effort marks the beginning of a new, long-term, statewide, comprehensive bioaccumulation monitoring program for California surface waters. This screening study was the first step in an effort to identify and quantify contaminants in California's lakes to evaluate exposure and risk in humans and wildlife.

This report provides a concise technical summary of the findings of the survey. This report is intended for agency scientists that are charged with managing water quality problems related to bioaccumulation of contaminants in California lakes and reservoirs. Another version of the report is also available (Davis et al. 2010) that provides a more detailed presentation of the methods and findings from the survey.

The Lakes Survey represents a major step forward in understanding the extent of chemical contamination in sport fish in California lakes and reservoirs, and the impact of this contamination on the fishing beneficial use. The study has shown that mercury accumulation in fish is a significant problem throughout much of the state. However, comparison to USEPA's national survey indicate that the degree of mercury contamination in California is not unusual compared to the rest of the country, in spite of the intensive mercury and gold mining that has occurred here. For other contaminants, concentrations were much lower relative to thresholds for human health concern. It should also be noted that this survey focused on the species that accumulate the highest contaminant concentrations. Concentrations in some of the other species can be expected to be substantially lower than observed for the predators and bottom-feeders evaluated in this study.

The Lakes Survey was a preliminary screening of contamination in sport fish. The species selected for sampling (primarily rainbow trout, largemouth bass, and common carp) are known to accumulate high concentrations of contaminants and are therefore good indicators of contamination problems. This screening study did not provide enough information for consumption guidelines – this would require monitoring a broader array of species, larger numbers of fish, and a much higher level of funding.

Fish tissue concentrations were evaluated using thresholds developed by the California Office of Environmental Health Hazard Assessment (OEHHA) for methylmercury, PCBs, dieldrin, DDTs, chlordanes, and selenium, and a State Water Resources Control Board threshold for mercury in tissue that is being used for identification of impaired water bodies.

In 2007 and 2008 the study team collected 4,905 fish representing 23 species from 272 lakes and reservoirs. The survey identified problems in certain areas of the state, with methylmercury and polychlorinated biphenyls (PCBs) being the contaminants of greatest concern.

Methylmercury poses the most widespread potential health risk to persons who consume fish caught in California lakes. Twenty-one percent of the lakes surveyed had at least one fish species with an average methylmercury level high enough (> 0.44 ppm) that OEHHA would consider recommending no consumption of the contaminated species for women between 18 and 45 years of age and children from 1 to 17 years of age. In northern California, the study commonly found low concentrations in high-elevation lakes (above two thousand feet) in the Sierra Nevada and Trinity Alps. Trout were the most frequently caught species in these lakes, and tend to accumulate relatively low methylmercury concentrations. In contrast, methylmercury concentrations in bass were higher than OEHHA's 0.44 ppm threshold in 48% of the lower elevation lakes (below two thousand feet) surveyed in northern California. Southern California had moderate methylmercury contamination, with 15% of the sampled lakes above 0.44 ppm.

Mercury contamination of California water bodies is largely a legacy of historic mercury and gold mining, but can also reach lakes from local and global emissions to the atmosphere. In spite of the extensive mining activity in California, however, the degree of mercury contamination in the state's lakes is not that unusual and comparable to the average condition observed across the U.S. in a recent national lakes survey.

PCBs were second to methylmercury as a potential health concern to consumers of fish caught from California lakes. However, only 1% of the lakes sampled had a species with an average concentration that exceeded OEHHA's threshold for considering a recommendation of no consumption (120 ppb). PCBs are persistent chemicals that are now banned, but were commonly used in electrical, industrial and other applications. Concentrations of other pollutants (dieldrin, DDT, chlordane, and selenium) were generally low, and infrequently exceeded OEHHA thresholds.

This screening survey has raised many questions, and left other questions unanswered. Several areas where additional information would be of great value in addressing management issues are listed below.

1) Data for additional species at lakes with high contaminant concentrations to support development of consumption guidelines.

High priority waters in this regard with elevated concentrations were discussed in the mercury and PCB sections. Development of consumption guidelines requires data from a broader spectrum of species, so anglers can be directed to cleaner species if they are present (as is often the case). Significant funding would be needed to perform this follow-up work at the many lakes with concentrations above thresholds.

2) Focused evaluations of selected lakes to identify sources, controlling factors, and likely outcomes

Distinguishing the relative importance of legacy contamination from mining, atmospheric deposition, and other sources is critical to effective management of methylmercury contamination. More detailed, site-specific field work could be performed to assess the contributions from different sources. Identifying and sampling lakes without mining influence could yield valuable insights. Other controlling factors that can be important in determining accumulation in the food web, such as food web structure and limnology, also need to be understood as a basis for management.

3) Assessment of risks to wildlife from bioaccumulative contaminants

Although this study did not focus on risks to wildlife due to funding limitations, they are likely to be a significant concern. Exposures and risks to wildlife, including fish and fish-eating birds (Sandheinrich and Wiener 2009), are likely to be substantially higher than for humans in some instances. The best approach would be to conduct monitoring targeted at addressing this question.

4) Emerging contaminants

Again due to funding limitations, this study did not evaluate emerging contaminants. Two of these contaminants, polybrominated diphenyl ethers (PBDEs) and perfluorinated compounds (PFCs), are known to accumulate in fish. Human health thresholds for these chemicals in fish are anticipated (PBDEs) or available (PFC screening values have been developed by the state of Minnesota). These and other emerging contaminants accumulate in fish and should be tracked to provide information that managers need in order to act before they become the legacy contaminants of tomorrow.

5) Trends

Lake and reservoir food webs are contaminated with mixtures of contaminants, some with declining concentrations, some rising, and some not changing appreciably. Tracking these trends is essential to effective management of water quality in these ecosystems. Large-scale processes such as climate change can influence trends. Contaminant trends in lakes are affected by a host of sources and processes operating at global (e.g., atmospheric deposition) and local scales. An effective program to monitor trends is needed.

SECTION 1 INTRODUCTION

This summary report presents results from a two-year screening survey of contaminants in sport fish in California lakes and reservoirs. This survey was performed as part of the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP). This effort marks the beginning of a new long-term, statewide, comprehensive bioaccumulation monitoring program for California surface waters.

This report provides a concise technical summary of the findings of the survey. This report is intended for agency scientists that are charged with managing water quality problems related to bioaccumulation of contaminants in California lakes and reservoirs. Another version of the report (Davis et al. 2010) has also been prepared that provides more technical detail on the survey and was the basis for scientific peer review of the work.

Oversight for this project is being provided by the SWAMP Roundtable. The Roundtable is composed of State and Regional Board staff and representatives from other agencies and organizations including US Environmental Protection Agency (USEPA), the California Department of Fish and Game, and the California Office of Environmental Health Hazard Assessment (OEHHA). Interested parties, including members of other agencies, consultants, or other stakeholders also participate.

The Roundtable has formed a subcommittee, the Bioaccumulation Oversight Group (BOG) that specifically guides SWAMP bioaccumulation monitoring. The BOG is composed of State and Regional Board staff and representatives from other agencies and organizations including USEPA, the Department of Fish and Game, OEHHA, and the San Francisco Estuary Institute. The members of the BOG possess extensive experience with bioaccumulation monitoring.

The BOG has also convened a Bioaccumulation Peer Review Panel that is providing evaluation and review of the bioaccumulation program. The members of the Panel are internationally-recognized authorities on bioaccumulation monitoring.

The BOG has developed and begun implementing a plan to evaluate bioaccumulation impacts on the fishing beneficial use in all California water bodies. Sampling of sport fish in lakes and reservoirs was conducted in the first two years of monitoring (2007 and 2008). In 2009 and 2010, sport fish from the California coast, including bays and estuaries are being sampled. Sport fish from rivers and streams will be sampled in 2011. In 2012 the plan is to again begin a two year effort on lakes and begin another five-year cycle of sampling these water body types.

THE LAKES SURVEY

Management Questions for This Survey

Three management questions were articulated to guide the design of the Lakes Survey. These management questions are specific to this initial monitoring effort; different sets of management questions will be established to guide later efforts.

Management Question 1
What is the condition of California lakes with respect to bioaccumulation in sport fish?

Answering this question has been the goal of assessments related to Section 305(b) of the federal Clean Water Act (CWA). In the past, 305(b) reports have provided water quality information to the general public and served as the basis for USEPA's National Water Quality Inventory Report to Congress. The report provided a statewide, comprehensive assessment of the status of California water bodies with respect to support of designated beneficial uses (e.g., SWRCB [2003]). Beginning in 2010, an Integrated Report provides the recommendations of the staff of the State Water Board for changes to the Clean Water Act Section 303(d) List of impaired water bodies and the Clean Water Act Section 305(b) report on the quality of waters in California (CWA Section 303(d) is discussed further below). Answering this question also provides the state and the public with information that helps describe the magnitude, spatial dimensions, and significance of the bioaccumulation problem relative to other environmental and societal problems.

The information needed to answer this question is the representative, average concentration of contaminants in sport fish indicator species in each lake for an adequately large sampling of lakes.

Management Question 2
Should a specific lake be considered for inclusion on the 303(d) List due to bioaccumulation of contaminants in sport fish?

Answering this question is critical to determining the need for 303(d) listing and cleanup actions to reduce contaminant exposure in specific water bodies. Total Maximum Daily Load evaluations (TMDLs) are required for water bodies placed on the 303(d) list. This is the principal regulatory mechanism being used by the State Water Board, the Regional Water Boards, and USEPA to establish priorities for management actions.

The State Board has established a Listing Policy for placing water bodies on the CWA Section 303(d) list. The Listing Policy establishes a standardized approach and includes California listing and de-listing factors. The fish tissue information needed to make a listing determination depends on the type of data and the pollutant. The more representative the samples are of the water body, the better. The goal in addressing Management Question 2 in this survey was to assist the Regional Boards and State Board by providing the data needed for listing decisions. Actual 303(d) listing determinations will be made by the Regional Boards using the data generated in the Lakes Survey.

Management Question 3
Should additional sampling of bioaccumulation in sport fish at a lake be conducted for the purpose of developing consumption guidelines?

Answering this question is essential as a first step in developing consumption guidelines. Consumption guidelines provide a mechanism for reducing human exposure to problematic contaminants in the near-term. The information requirements for consumption guidelines are more extensive than for 303(d) listing. OEHHA, the agency responsible for issuing consumption guidelines in California, needs samples representing at least nine or more fish from a variety of species abundant in a water body in order to issue guidance. It is useful to have information not only on the species with high concentrations, but also the species with low concentrations so anglers and other consumers of wild fish can be encouraged to target the low species.

Overall Approach

The overall approach taken to answer these three questions was to perform a statewide screening study of bioaccumulation in sport fish. The highest priority for SWAMP in the short term is to answer Management Questions 1 and 2. Answering these questions will provide a basis for decision-makers to understand the scope of the bioaccumulation problem and will provide regulators with information needed to establish priorities for cleanup actions. In the longer term, developing consumption guidelines that inform the public on ways to reduce their exposure is also a high priority. This initial monitoring effort was a cost effective way to establish a foundation for developing consumption guidelines by identifying lakes that are candidates for additional sampling

This screening study is already leading to more detailed follow-up investigations of many water bodies that are candidates for the 303(d) List or where consumption guidelines are needed.

SECTION 2 METHODS

SAMPLING DESIGN

The sampling plan was developed to address the three management questions for the project. In 2007 and 2008, sampling was conducted at 272 fishing lakes and reservoirs across California (Figures 1a-d, Tables 1a,b). Fish were collected from lakes across the state from June through November in 2007 and 2008 (Figures 1a-d, Tables 1a,b). Cruise reports with detailed information on locations are available at: http://www.swrcb.ca.gov/water_issues/programs/swamp/docs/lakes_study/bog_07lakes_monplan.pdf.

Targeted sampling of "popular" lakes comprised the bulk of the effort (222 of 272 lakes), with a random sampling of 50 lakes. In addition to the statewide targeted sampling of popular lakes, this report also includes data obtained from a coordinated targeted sampling of lakes in Region 4 (Figures 1a,c,d). The Region 4 Water Board augmented the statewide effort with funds to provide for sampling of 22 additional lakes, including a more thorough analysis of replicate samples than was feasible in the statewide effort.

The second major emphasis of the survey was to provide an evaluation of statewide lake condition. A randomized sampling of 50 lakes from the entire population of California lakes was conducted to provide an unbiased statewide assessment, and a valuable frame of reference for interpreting bias in the targeted sampling. The Sampling Plan (Davis et al. 2007a) provides more details on the design.

TARGET SPECIES

The overall goal of this screening study was to determine whether sport fish in California lakes have concentrations of contaminants that are above thresholds for protection of human health. Therefore, the study focused on sampling of indicator species that tend to accumulate the highest concentrations of the contaminants of concern. Primary target species were selected that are popular for human consumption (e.g., rainbow trout [Oncorhynchus mykiss]), and/or are effective at documenting spatial trends in methylmercury (e.g., largemouth bass [Micropterus salmoides]) or organics (e.g., common carp [Cyprinus carpio]).

Methylmercury biomagnifies primarily through its accumulation in muscle tissue, so top predators such as largemouth bass tend to have the highest methylmercury concentrations. In contrast, organic contaminants are biomagnified through accumulation in lipid. Bottom-feeding species such as common carp and channel catfish (Ictalurus punctatus) tend to have the highest lipid concentrations in their muscle tissue, and therefore usually have the highest concentrations of organics.

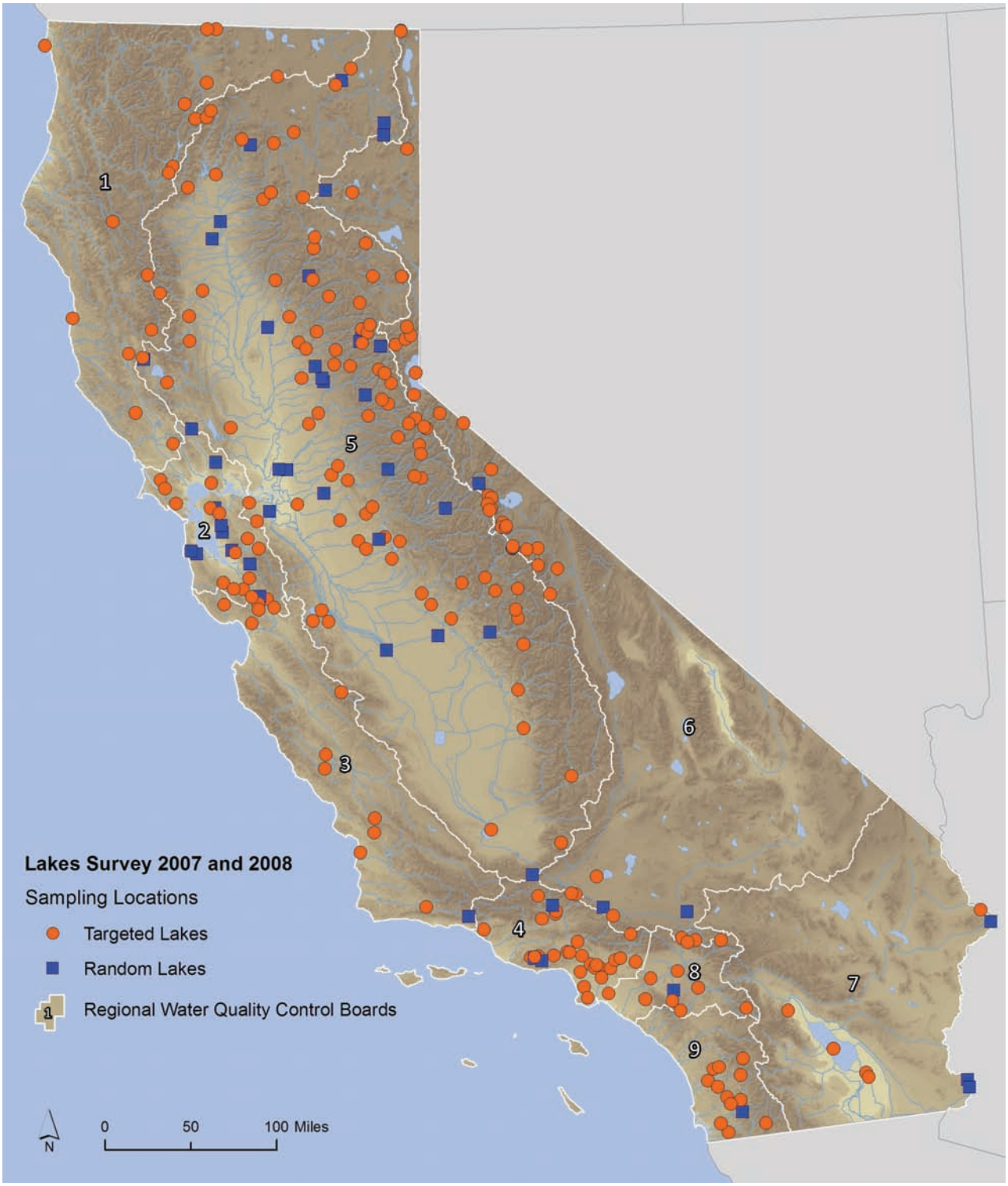

Figure 1a. Lakes sampled in the Lakes Survey. Circles represent 222 lakes that were targeted and squares represent 50 lakes sampled randomly. Lakes are sparse in large areas of Regions 1, 6, and 7.

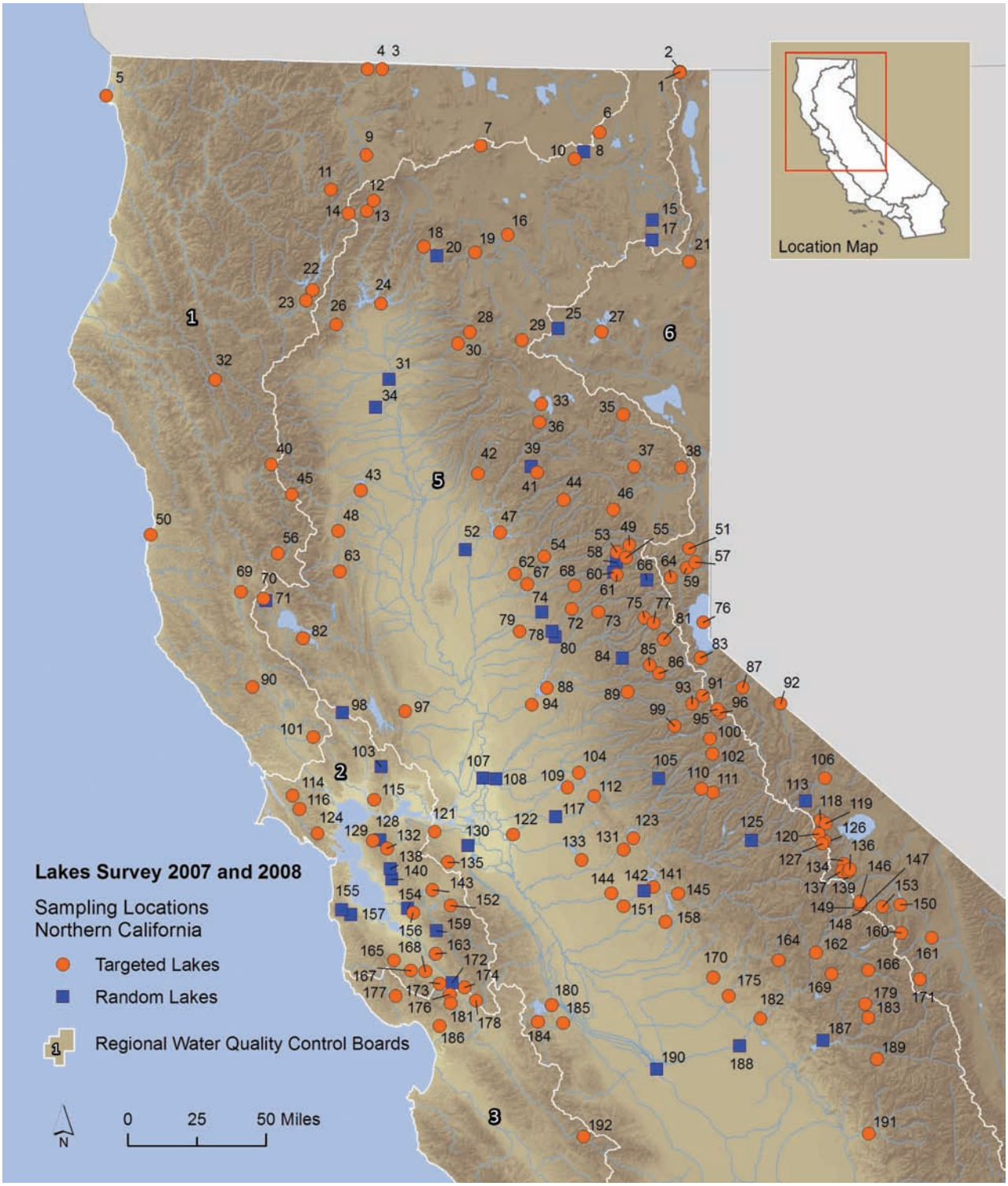

Figure 1b. Northern California lakes sampled in the Lakes Survey. Circles represent lakes that were targeted and squares represent those sampled randomly. Numbers on map relate to lake names given in Table 1. Lakes are sparse in much of Region 1.

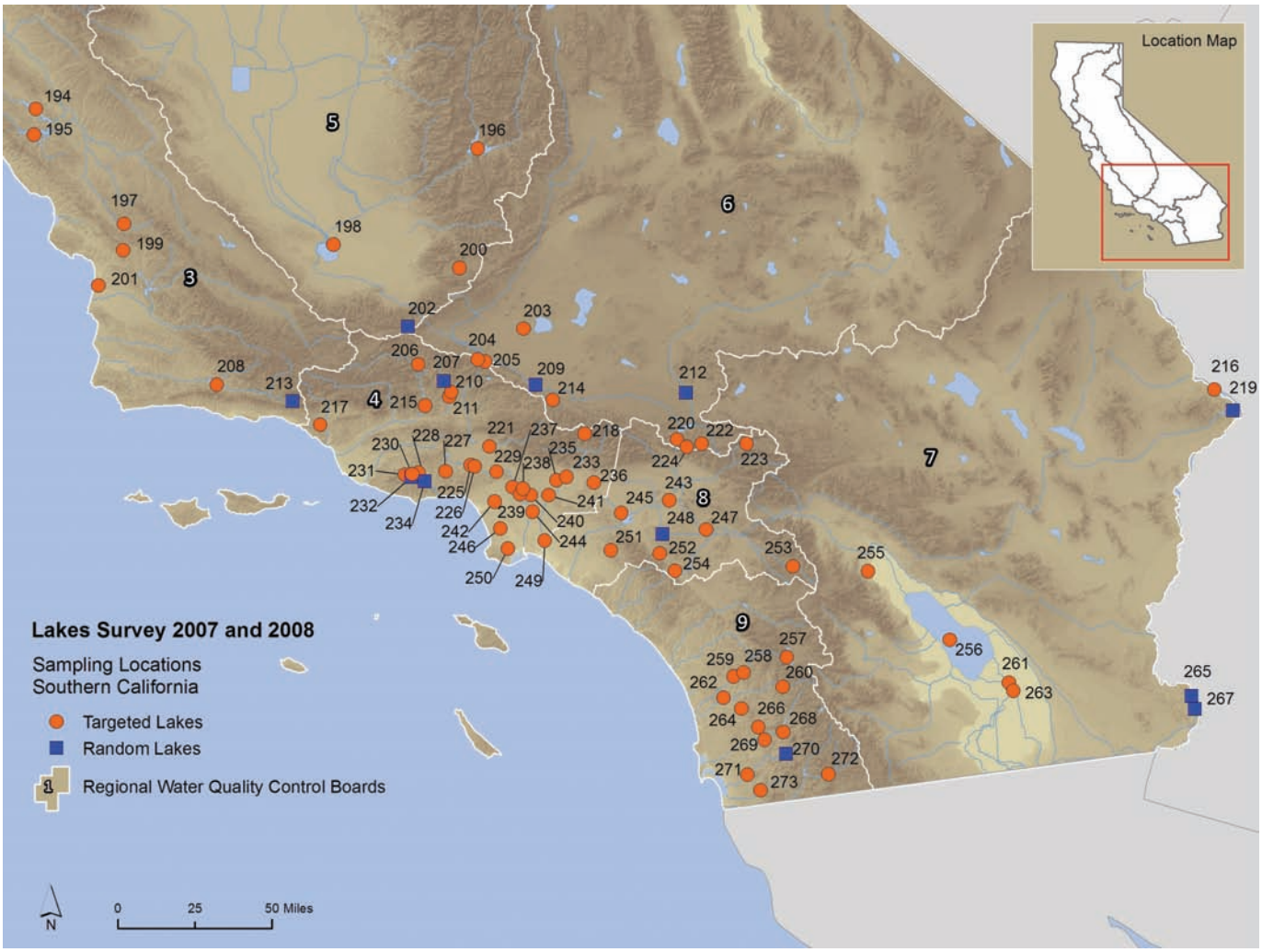

Figure 1c. Southern California lakes sampled in the Lakes Survey. Circles represent lakes that were targeted and squares represent those sampled randomly. Numbers on map relate to lake names given in Table 1. Lakes are sparse in large areas of Regions 6 and 7.

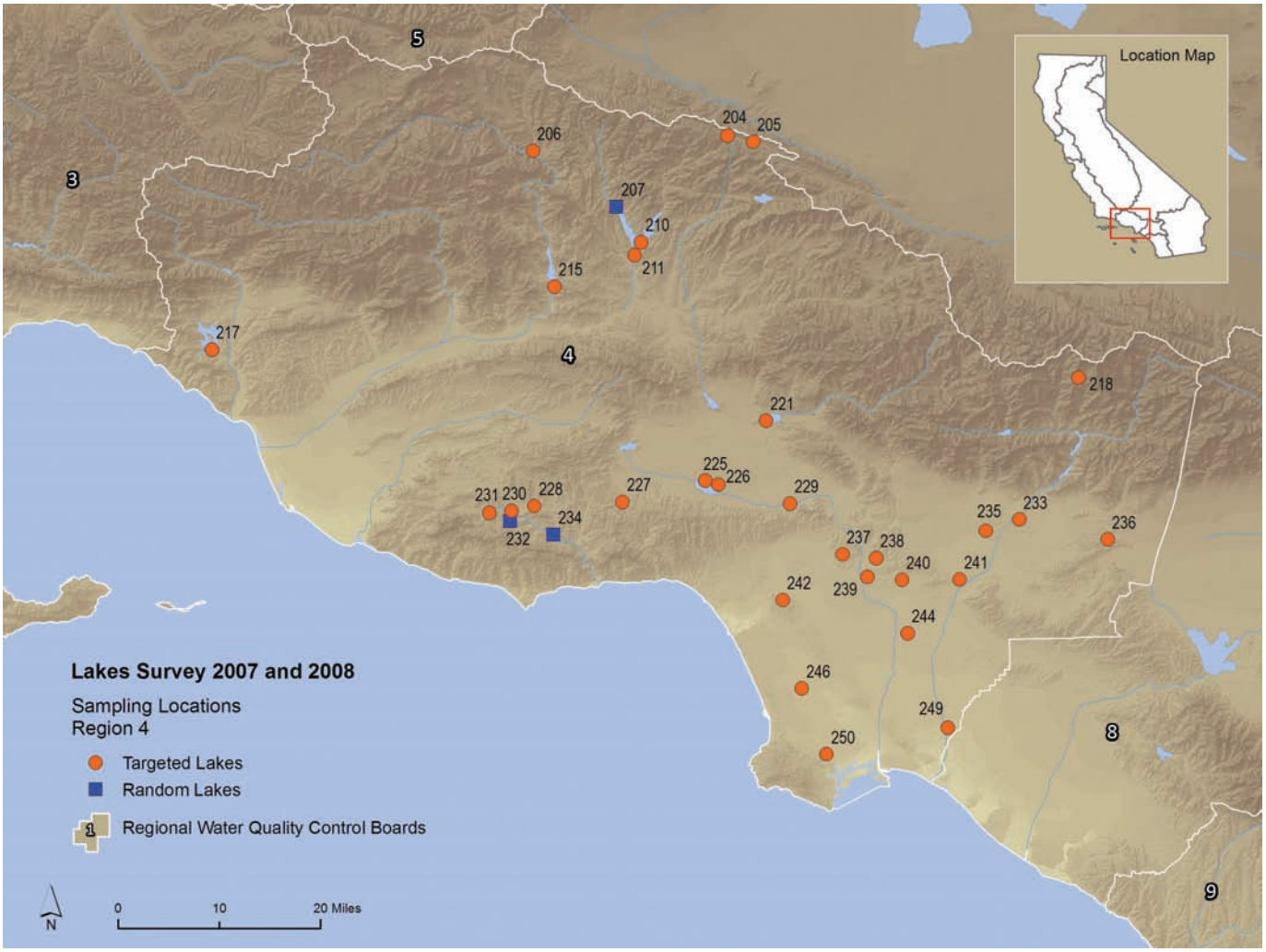

Figure 1d. Region 4 lakes sampled in the Lakes Survey. The Region 4 Water Board augmented the Survey with additional funding to sample a larger number of lakes in their Region. Circles represent lakes that were targeted and squares represent those sampled randomly. Numbers on map relate to lake names given in Table 1.

Table 1a
Lakes sampled, ordered by station number.
Note: These station numbers were assigned only for the purpose of identification on these maps. These are not related to the official station identification numbers in the database.

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
1	Cave Lake	5	X					X
2	Lily Lake	5	X					X
3	Copco Lake	1	X					X
4	Iron Gate Reservoir	1	X					X
5	Dead Lake	1	X					X
6	Reservoir C	5	X					X
7	Medicine Lake	5	X					X
8	Reservoir F	1	X				X	
9	Lake Shastina	1	X					X
10	Duncan Reservoir	5	X					X
11	Kangaroo Lake	1	X					X
12	Siskiyou Lake	5	X					X
13	Castle Lake	5	X					X
14	Gumboot Lake	5	X					X
15	West Valley Reservoir	5	X				X	
16	Big Lake	5	X					X
17	Moon Lake	5			X		X	
18	Iron Canyon Reservoir	5	X					X
19	Lake Britton	5	X					X
20	Tunnel Reservoir	5	X				X	
21	Dodge Reservoir	6	X					X
22	Trinity Lake	1				X		X
23	Lewiston Lake	1	X					X
24	Shasta Lake	5				X		X
25	Crater Lake	6	X				X	
26	Whiskeytown Lake	5			X			X
27	Eagle Lake	6				X		X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
28	North Battle Creek Reservoir	5	X					X
29	Butte Lake	5	X					X
30	McCumber Reservoir	5	X					X
31	Lake California	5	X				X	
32	Ruth Lake	1	X					X
33	Lake Almanor	5				X		X
34	Finger Lake	5	X				X	
35	Antelope Lake	5	X					X
36	Butt Valley Reservoir	5		X				X
37	Lake Davis	5			X			X
38	Frenchman Lake	5		X				X
39	Lower Bucks Lake	5	X				X	
40	Howard Lake	1	X					X
41	Bucks Lake	5		X				X
42	Paradise Lake	5	X					X
43	Black Butte Lake	5			X			X
44	Little Grass Valley Reservoir	5		X				X
45	Plaskett Lake	1	X					X
46	Gold Lake	5	X					X
47	Lake Oroville	5				X		X
48	Stony Gorge Reservoir	5		X				X
49	Jackson Meadow Reservoir	5	X					X
50	Cleone Lake	1	X					X
51	Stampede Reservoir	6			X			X
52	Thermalito Afterbay	5		X			X	
53	Bowman Lake	5	X					X
54	New Bullards Bar Reservoir	5			X			X
55	Faucherie Lake	5	X					X
56	Lake Pillsbury	1		X				X
57	Boca Reservoir	6	X					X
58	Feeley Lake	5	X				X	
59	Prosser Creek Reservoir	6	X					X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
60	Fuller Lake	5	X				X	
61	Lake Spaulding	5	X					X
62	Collins Lake	5	X					X
63	East Park Reservoir	5		X				X
64	Donner Lake	6	X					X
66	Kidd Lake	5	X				X	
67	Harry L Englebright Lak	5	X					X
68	Scotts Flat Reservoir	5	X					X
69	Lake Mendocino	1		X				X
70	Blue Lakes	5	X					X
71	Lower Blue Lake	5	X				X	
72	Rollins Reservoir	5	X					X
73	Big Reservoir	5	X					X
74	Zayak/Swan Lake	5	X				X	
75	French Meadows Reservoir	5		X				X
76	Lake Tahoe	6				X		X
77	Hell Hole Reservoir	5		X				X
78	Lake of the Pines	5	X				X	
79	Camp Far West Reservoir	5		X				X
80	Lake Combie	5	X				X	
81	Loon Lake	5	X					X
82	Clear Lake	5				X		X
83	Fallen Leaf Lake	6		X				X
84	Stump Meadow Lake	5	X				X	
85	Union Valley Reservoir	5		X				X
86	Ice House Reservoir	5	X					X
87	Indian Creek Reservoir	6	X					X
88	Folsom Lake	5			X			X
89	Jenkinson Lake	5	X					X
90	Lake Sonoma	1		X				X
91	Caples Lake	5	X					X
92	Topaz Lake	6	X					X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
93	Silver Lake	5	X					X
94	Lake Natomas	5	X					X
95	Upper Blue Lake	5	X					X
96	Lower Blue Lake (Alpine County)	5	X					X
97	Lake Berryessa	5				X		X
98	Lake Henne	2	X				X	
99	Lower Bear River Reservoir	5	X					X
100	Lake Alpine	5	X					X
101	Spring Lake	1	X					X
102	Spicer Meadow Reservoir	5	X					X
103	Lake Madigan	2	X				X	
104	Lake Amador	5	X					X
105	White Pines Lake	5	X				X	
106	Bridgeport Reservoir	6		X				X
107	Meadows Slough	5	X				X	
108	Cosumnes River	5	X				X	
109	Camanche Reservoir	5			X			X
110	Beardsley	5	X					X
111	Pinecrest	5	X					X
112	New Hogan Lake	5			X			X
113	Upper Twin Lake	6	X				X	
114	Soulejoule Lake	2	X					X
115	Lake Chabot (Vallejo)	2	X					X
116	Nicasio Lake	2	X					X
117	Unnamed Lake 2	5	X				X	
118	Virginia Lakes	6	X					X
119	Lundy Lake	6	X					X
120	Saddlebag Lake	6	X					X
121	Contra Loma Reservoir	5	X					X
122	Yosemite Lake	5	X					X
123	New Melones Lake	5		X				X
124	Bon Tempe Lake	2	X					X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
125	Hetch Hetchy Reservoir	5		X			X	
126	Ellery Lake	6	X					X
127	Tioga Lake	6	X					X
128	Briones Reservoir	2	X				X	
129	San Pablo Reservoir	2	X					X
130	Discovery Bay	5	X				X	
131	Tulloch Reservoir	5	X					X
132	Lafayette Reservoir	2	X					X
133	Woodward Reservoir	5		X				X
134	Grant Lake	6	X					X
135	Los Vaqueros Reservoir	5		X				X
136	June Lake	6	X					X
137	Silver Lake (Region 6)	6	X					X
138	Upper San Leandro Reservoir	2	X				X	
139	Gull Lake	6	X					X
140	Lake Chabot (San Leandro)	2	X				X	
141	Don Pedro Reservoir	5			X			X
142	La Grange Reservoir	5	X				X	
143	Shadow Cliffs Reservoir	2	X					X
144	Modesto Reservoir	5		X				X
145	Lake McClure	5			X			X
146	Twin Lakes	6	X					X
147	Lake Mamie	6	X					X
148	Lake Mary	6	X					X
149	Lake George	6	X					X
150	Lake Crowley	6			X			X
151	Turlock Lake	5			X			X
152	Lake del Valle	2	X					X
153	Convict Lake	6	X					X
154	Lago Los Osos	2	X				X	
155	Pilarcitos Lake	2	X				X	
156	Lake Elizabeth	2	X					X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
157	Lower Crystal Springs Reserv	2	X				X	
158	Lake McSwain	5	X					X
159	Calaveras Reservoir	2		X			X	
160	Rock Creek Lake	6	X					X
161	Pleasant Valley Reservoir	6	X					X
162	Mammoth Pool Reservoir	5	X					X
163	Lake Cunningham	2	X					X
164	Bass Lake	5	X					X
165	Stevens Creek Reservoir	2	X					X
166	Florence Lake	5	X					X
167	Lake Vasona	2	X					X
168	Almaden Lake	2	X					X
169	Huntington Lake	5		X				X
170	Eastman Lake	5		X				X
171	Lake Sabrina	6	X					X
172	Oiger Quarry Ponds	2	X				X	
173	Calero Reservoir	2	X					X
174	Anderson Lake	2	X					X
175	Hensley Lake	5		X				X
176	Chesbro Reservoir	3	X					X
177	Loch Lomond Reservoir	3	X					X
178	Coyote Lake	2	X					X
179	Courtright Reservoir	5		X				X
180	O'Neill Forebay	5		X				X
181	Uvas Reservoir	3	X					X
182	Millerton Lake	5			X			X
183	Wishon Reservoir	5	X					X
184	San Luis Reservoir	5				X		X
185	Los Banos Reservoir	5	X					X
186	Pinto Lake	3	X					X
187	Pine Flat Lake	5			X		X	
188	Unnamed Lake 1	5	X				X	

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
189	Hume Lake	5	X					X
190	Marsh in Fresno Slough	5	X				X	
191	Lake Kaweah	5		X				X
192	Hernandez Reservoir	3	X					X
193	Success Lake	5			X			X
194	Lake San Antonio	3			X			X
195	Lake Nacimiento	3			X			X
196	Isabella Lake	5			X			X
197	Santo Margarita Lake	3	X					X
198	Lake Webb	5	X					X
199	Lopez Lake	3	X					X
200	Brite Valley Lake	5	X					X
201	Little Oso Flaco Lake	3	X					X
202	Castac Lake	5	X				X	
203	Apollo Lake	6	X					X
204	Lake Hughes	4	X					X
205	Elizabeth Lake	4	X					X
206	Pyramid Lake	4		X				X
207	Elderberry Forebay	4	X				X	
208	Lake Cachuma	3			X			X
209	Palmdale Lake	6	X				X	
210	Castaic Lake	4		X				X
211	Castaic Lagoon	4	X					X
212	Spring Valley Lake	6	X				X	
213	Jameson Lake	3	X				X	
214	Little Rock Reservoir	6	X					X
215	Lake Piru	4	X					X
216	Lake Havasu	7				X		X
217	Lake Casitas	4		X				X
218	Crystal Lake	4	X					X
219	Gene Wash Reservoir	7	X				X	
220	Silverwood Lake	6	X					X

		Lake Size					Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
221	Hansen Lake	4	X					X
222	Lake Arrowhead	6	X					X
223	Big Bear Lake	8			X			X
224	Lake Gregory	6	X					X
225	Balboa Lake	4	X					X
226	Sepulveda Lake	4	X					X
227	Lake Calabasas	4	X					X
228	Lake Lindero	4	X					X
229	Toluca Lake	4	X					X
230	Westlake Lake	4	X					X
231	Lake Sherwood	4	X					X
232	Las Virgenes Reservoir	4	X				X	
233	Santa Fe Reservoir	4	X					X
234	Malibou Lake	4	X				X	
235	Peck Road Water Conservation Park	4	X					X
236	Puddingstone Reservoir	4	X					X
237	Echo Lake (Reg 4)	4	X					X
238	Lincoln Park Lake	4	X					X
239	Hollenbeck Park Lake	4	X					X
240	Belvedere Park Lake	4	X					X
241	Legg Lake	4	X					X
242	Ken Hahn Park Lake	4	X					X
243	Lake Evans	8	X					X
244	John Ford Park Lake	4	X					X
245	Prado Lake	8	X					X
246	Alondra Park Lake	4	X					X
247	Perris Reservoir	8		X				X
248	Lake Mathews	8			X		X	
249	El Dorado Lakes	4	X					X
250	Harbor Lake (Lake Machado)	4	X					X
251	Irvine Lake	8	X					X

		Lake Size					Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
252	Lee Lake/Corona Lake	8	X					X
253	Lake Hemet	8	X					X
254	Lake Elsinore	8		X				X
255	Lake Cahuilla	7	X					X
256	Salton Sea	7				X		X
257	Lake Henshaw	9		X				X
258	Lake Wohlford	9	X					X
259	Dixon Lake	9	X					X
260	Lake Sutherland	9	X					X
261	Ramer Lake	7	X					X
262	Lake Hodges	9	X					X
263	Wiest Lake	7	X					X
264	Lake Poway	9	X					X
265	Ferguson Lake	7	X				X	
266	San Vicente Reservoir	9	X					X
267	Senator Wash Reservoir	7	X				X	
268	El Capitan Lake	9		X				X
269	Lake Jennings	9	X					X
270	Loveland Reservoir	9	X				X	
271	Sweetwater Reservoir	9	X					X
272	Morena Reservoir	9	X					X
273	Lower Otay Reservoir	9	X					X

Table 1b
Lakes sampled, ordered by name.
Note: These station numbers were assigned only for the purpose of identification on these maps. These are not related to the official station identification numbers in the database.

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
168	Almaden Lake	2	X					X
246	Alondra Park Lake	4	X					X
174	Anderson Lake	2	X					X
35	Antelope Lake	5	X					X
203	Apollo Lake	6	X					X
225	Balboa Lake	4	X					X
164	Bass Lake	5	X					X
110	Beardsley	5	X					X
240	Belvedere Park Lake	4	X					X
223	Big Bear Lake	8			X			X
16	Big Lake	5	X					X
73	Big Reservoir	5	X					X
43	Black Butte Lake	5			X			X
70	Blue Lakes	5	X					X
57	Boca Reservoir	6	X					X
124	Bon Tempe Lake	2	X					X
53	Bowman Lake	5	X					X
106	Bridgeport Reservoir	6		X				X
128	Briones Reservoir	2	X				X	
200	Brite Valley Lake	5	X					X
41	Bucks Lake	5		X				X
36	Butt Valley Reservoir	5		X				X
29	Butte Lake	5	X					X
159	Calaveras Reservoir	2		X			X	
173	Calero Reservoir	2	X					X
109	Camanche Reservoir	5			X			X
79	Camp Far West Reservoir	5		X				X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
91	Caples Lake	5	X					X
202	Castac Lake	5	X				X	
211	Castaic Lagoon	4	X					X
210	Castaic Lake	4		X				X
13	Castle Lake	5	X					X
1	Cave Lake	5	X					X
176	Chesbro Reservoir	3	X					X
82	Clear Lake	5				X		X
50	Cleone Lake	1	X					X
62	Collins Lake	5	X					X
121	Contra Loma Reservoir	5	X					X
153	Convict Lake	6	X					X
3	Copco Lake	1	X					X
108	Cosumnes River	5	X				X	
179	Courtright Reservoir	5		X				X
178	Coyote Lake	2	X					X
25	Crater Lake	6	X				X	
218	Crystal Lake	4	X					X
5	Dead Lake	1	X					X
130	Discovery Bay	5	X				X	
259	Dixon Lake	9	X					X
21	Dodge Reservoir	6	X					X
141	Don Pedro Reservoir	5			X			X
64	Donner Lake	6	X					X
10	Duncan Reservoir	5	X					X
27	Eagle Lake	6				X		X
63	East Park Reservoir	5		X				X
170	Eastman Lake	5		X				X
237	Echo Lake (Reg 4)	4	X					X
268	El Capitan Lake	9		X				X
249	El Dorado Lakes	4	X					X
207	Elderberry Forebay	4	X				X	

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
205	Elizabeth Lake	4	X					X
126	Ellery Lake	6	X					X
83	Fallen Leaf Lake	6		X				X
55	Faucherie Lake	5	X					X
58	Feeley Lake	5	X				X	
265	Ferguson Lake	7	X				X	
34	Finger Lake	5	X				X	
166	Florence Lake	5	X					X
88	Folsom Lake	5			X			X
75	French Meadows Reservoir	5		X				X
38	Frenchman Lake	5		X				X
60	Fuller Lake	5	X				X	
219	Gene Wash Reservoir	7	X				X	
46	Gold Lake	5	X					X
134	Grant Lake	6	X					X
139	Gull Lake	6	X					X
14	Gumboot Lake	5	X					X
221	Hansen Lake	4	X					X
250	Harbor Lake (Lake Machado)	4	X					X
67	Harry L Englebright Lak	5	X					X
77	Hell Hole Reservoir	5		X				X
175	Hensley Lake	5		X				X
192	Hernandez Reservoir	3	X					X
125	Hetch Hetchy Reservoir	5		X			X	
239	Hollenbeck Park Lake	4	X					X
40	Howard Lake	1	X					X
189	Hume Lake	5	X					X
169	Huntington Lake	5		X				X
86	Ice House Reservoir	5	X					X
87	Indian Creek Reservoir	6	X					X
18	Iron Canyon Reservoir	5	X					X
4	Iron Gate Reservoir	1	X					X

		Lake Size					Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
251	Irvine Lake	8	X					X
196	Isabella Lake	5			X			X
49	Jackson Meadow Reservoir	5	X					X
213	Jameson Lake	3	X				X	
89	Jenkinson Lake	5	X					X
244	John Ford Park Lake	4	X					X
136	June Lake	6	X					X
11	Kangaroo Lake	1	X					X
242	Ken Hahn Park Lake	4	X					X
66	Kidd Lake	5	X				X	
142	La Grange Reservoir	5	X				X	
132	Lafayette Reservoir	2	X					X
154	Lago Los Osos	2	X				X	
33	Lake Almanor	5				X		X
100	Lake Alpine	5	X					X
104	Lake Amador	5	X					X
222	Lake Arrowhead	6	X					X
97	Lake Berryessa	5				X		X
19	Lake Britton	5	X					X
208	Lake Cachuma	3			X			X
255	Lake Cahuilla	7	X					X
227	Lake Calabasas	4	X					X
31	Lake California	5	X				X	
217	Lake Casitas	4		X				X
140	Lake Chabot (San Leandro)	2	X				X	
115	Lake Chabot (Vallejo)	2	X					X
80	Lake Combie	5	X				X	
150	Lake Crowley	6			X			X
163	Lake Cunningham	2	X					X
37	Lake Davis	5			X			X
152	Lake del Valle	2	X					X
156	Lake Elizabeth	2	X					X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
254	Lake Elsinore	8		X				X
243	Lake Evans	8	X					X
149	Lake George	6	X					X
224	Lake Gregory	6	X					X
216	Lake Havasu	7				X		X
253	Lake Hemet	8	X					X
98	Lake Henne	2	X				X	
257	Lake Henshaw	9		X				X
262	Lake Hodges	9	X					X
204	Lake Hughes	4	X					X
269	Lake Jennings	9	X					X
191	Lake Kaweah	5		X				X
228	Lake Lindero	4	X					X
103	Lake Madigan	2	X				X	
147	Lake Mamie	6	X					X
148	Lake Mary	6	X					X
248	Lake Mathews	8			X		X	
145	Lake McClure	5			X			X
158	Lake McSwain	5	X					X
69	Lake Mendocino	1		X				X
195	Lake Nacimiento	3			X			X
94	Lake Natomas	5	X					X
78	Lake of the Pines	5	X				X	
47	Lake Oroville	5				X		X
56	Lake Pillsbury	1		X				X
215	Lake Piru	4	X					X
264	Lake Poway	9	X					X
171	Lake Sabrina	6	X					X
194	Lake San Antonio	3			X			X
9	Lake Shastina	1	X					X
231	Lake Sherwood	4	X					X
90	Lake Sonoma	1		X				X

		Lake Size					Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
61	Lake Spaulding	5	X					X
260	Lake Sutherland	9	X					X
76	Lake Tahoe	6				X		X
167	Lake Vasona	2	X					X
198	Lake Webb	5	X					X
258	Lake Wohlford	9	X					X
232	Las Virgenes Reservoir	4	X				X	
252	Lee Lake/Corona Lake	8	X					X
241	Legg Lake	4	X					X
23	Lewiston Lake	1	X					X
2	Lily Lake	5	X					X
238	Lincoln Park Lake	4	X					X
44	Little Grass Valley Reservoir	5		X				X
201	Little Oso Flaco Lake	3	X					X
214	Little Rock Reservoir	6	X					X
177	Loch Lomond Reservoir	3	X					X
81	Loon Lake	5	X					X
199	Lopez Lake	3	X					X
185	Los Banos Reservoir	5	X					X
135	Los Vaqueros Reservoir	5		X				X
270	Loveland Reservoir	9	X				X	
99	Lower Bear River Reservoir	5	X					X
71	Lower Blue Lake	5	X				X	
96	Lower Blue Lake (Alpine County)	5	X					X
39	Lower Bucks Lake	5	X				X	
157	Lower Crystal Springs Reserv	2	X				X	
273	Lower Otay Reservoir	9	X					X
119	Lundy Lake	6	X					X
234	Malibou Lake	4	X				X	
162	Mammoth Pool Reservoir	5	X					X
190	Marsh in Fresno Slough	5	X				X	
30	McCumber Reservoir	5	X					X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
107	Meadows Slough	5	X				X	
7	Medicine Lake	5	X					X
182	Millerton Lake	5			X			X
144	Modesto Reservoir	5		X				X
17	Moon Lake	5			X		X	
272	Morena Reservoir	9	X					X
54	New Bullards Bar Reservoir	5			X			X
112	New Hogan Lake	5			X			X
123	New Melones Lake	5		X				X
116	Nicasio Lake	2	X					X
28	North Battle Creek Reservoir	5	X					X
172	Oiger Quarry Ponds	2	X				X	
180	O'Neill Forebay	5		X				X
209	Palmdale Lake	6	X				X	
42	Paradise Lake	5	X					X
235	Peck Road Water Conservation Park	4	X					X
247	Perris Reservoir	8		X				X
155	Pilarcitos Lake	2	X				X	
187	Pine Flat Lake	5			X		X	
111	Pinecrest	5	X					X
186	Pinto Lake	3	X					X
45	Plaskett Lake	1	X					X
161	Pleasant Valley Reservoir	6	X					X
245	Prado Lake	8	X					X
59	Prosser Creek Reservoir	6	X					X
236	Puddingstone Reservoir	4	X					X
206	Pyramid Lake	4		X				X
261	Ramer Lake	7	X					X
6	Reservoir C	5	X					X
8	Reservoir F	1	X				X	
160	Rock Creek Lake	6	X					X
72	Rollins Reservoir	5	X					X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
32	Ruth Lake	1	X					X
120	Saddlebag Lake	6	X					X
256	Salton Sea	7				X		X
184	San Luis Reservoir	5				X		X
129	San Pablo Reservoir	2	X					X
266	San Vicente Reservoir	9	X					X
233	Santa Fe Reservoir	4	X					X
197	Santo Margarita Lake	3	X					X
68	Scotts Flat Reservoir	5	X					X
267	Senator Wash Reservoir	7	X				X	
226	Sepulveda Lake	4	X					X
143	Shadow Cliffs Reservoir	2	X					X
24	Shasta Lake	5				X		X
93	Silver Lake	5	X					X
137	Silver Lake (Region 6)	6	X					X
220	Silverwood Lake	6	X					X
12	Siskiyou Lake	5	X					X
114	Soulejoule Lake	2	X					X
102	Spicer Meadow Reservoir	5	X					X
101	Spring Lake	1	X					X
212	Spring Valley Lake	6	X				X	
51	Stampede Reservoir	6			X			X
165	Stevens Creek Reservoir	2	X					X
48	Stony Gorge Reservoir	5		X				X
84	Stump Meadow Lake	5	X				X	
193	Success Lake	5			X			X
271	Sweetwater Reservoir	9	X					X
52	Thermalito Afterbay	5		X			X	
127	Tioga Lake	6	X					X
229	Toluca Lake	4	X					X
92	Topaz Lake	6	X					X
22	Trinity Lake	1				X		X

			Lake Size				Lake Selection	
Station Number	Station Name	Regional Board	Small	Medium	Large	Extra-large	Random	Targeted
131	Tulloch Reservoir	5	X					X
20	Tunnel Reservoir	5	X				X	
151	Turlock Lake	5			X			X
146	Twin Lakes	6	X					X
85	Union Valley Reservoir	5		X				X
188	Unnamed Lake 1	5	X				X	
117	Unnamed Lake 2	5	X				X	
95	Upper Blue Lake	5	X					X
138	Upper San Leandro Reservoir	2	X				X	
113	Upper Twin Lake	6	X				X	
181	Uvas Reservoir	3	X					X
118	Virginia Lakes	6	X					X
15	West Valley Reservoir	5	X				X	
230	Westlake Lake	4	X					X
26	Whiskeytown Lake	5			X			X
105	White Pines Lake	5	X				X	
263	Wiest Lake	7	X					X
183	Wishon Reservoir	5	X					X
133	Woodward Reservoir	5		X				X
122	Yosemite Lake	5	X					X
74	Zayak/Swan Lake	5	X				X	

Consequently, this study targeted two indicator species in each lake – a top predator (e.g., black bass) as a methylmercury indicator and a high lipid, bottom-feeding species (e.g., common carp or channel catfish) as an organics and selenium indicator. This approach is recommended by USEPA (2000). Some high elevation lakes only had one abundant high trophic level species (i.e., a trout species). In these cases, the one species still represented a worst-case indicator for methylmercury and organics and was sampled and analyzed for all of the pollutants on the analyte list. The species sampled most frequently were the primary target species: largemouth bass, common carp, and rainbow trout (Table 2). Other species were collected where the primary targets could not be obtained.

Black bass (including largemouth, smallmouth [*Micropterus dolomieui*], and spotted bass [*Micropterus punctulatus*]) and Sacramento pikeminnow (*Ptychocheilus grandis*) were the key methylmercury indicators. These species have a high trophic position and a strong size:methylmercury relationship. For these species, fish were sampled across a wide range of lengths and analyzed as individuals to facilitate estimation of size-standardized methylmercury concentrations. For other species methylmercury was analyzed in composites of 5 individuals.

Channel catfish and common carp were the primary targets for high lipid bottom-feeders. These species were analyzed for organics, selenium, and methylmercury. Organics and selenium were expected to be highest in these species (Davis et al. 2007b, SFEI 2008).

LOCATIONS TARGETED

Lakes and reservoirs in California vary tremendously in size, from hundreds of small ponds less than 10 ha to Lake Tahoe at 50,000 ha. For larger lakes it is necessary to sample more than one location to obtain a representative characterization of the water body. For small lakes less than 500 ha in size, one sampling location covered a significant fraction of the surface area of the lake and was considered adequate to characterize the lake. However, for larger lakes, sampling of additional locations was performed. For lakes of medium size (500 – 1000 ha), two locations were generally sampled. For lakes in the large category (1000 – 5000 ha) and extra large category (> 5000 ha), two to four locations were sampled.

ARCHIVING STRATEGY

Due to the large number of water bodies to be sampled, the relatively high cost of organics analysis, and an expectation that some of these would be below thresholds for concern, an archiving strategy was developed for composite samples of the bottom-feeder species. The strategy varied somewhat by the size of lake. The basic approach was to begin by analyzing one representative sample from each lake, and then proceed to other samples if the first sample exceeded a threshold. The threshold for this follow-up analysis was designated as 75% of the threshold for concern (Tables 3 and 4). This approach avoided expenditure of funds on organics analysis where it was not needed.

Table 2
Scientific and common names of fish species collected, the number of lakes in which they were sampled, their minimum, median, and maximum total lengths (mm), and whether they were analyzed as composites or individuals.

Species Name	Common Name	Number of Lakes Sampled	Minimum Length (mm)	Median Length (mm)	Maximum Length (mm)	Analyzed as Composites	Analyzed as Individuals
Pomoxis nigromaculatus	Black Crappie	3	225	289.5	335	x	
Lepomis macrochirus	Bluegill	2	117	134.5	165	x	
Salvelinus fontinalis	Brook Trout	2	200	263.5	308	x	
Ameiurus nebulosus	Brown Bullhead	13	149	292	417	x	
Salmo trutta	Brown Trout	12	203	347	485	x	x
Ictalurus punctatus	Channel Catfish	12	386	509	766	x	
Cyprinus carpio	Common Carp	78	290	551	886	x	x
Oncorhynchus mykiss aquilarum	Eagle Lake Trout	1	448	503.5	547	x	
Carassius auratus	Goldfish	1	309	332.5	350	x	
Mylopharodon conocephalus	Hardhead	1	140	147.5	161	x	
Lavinia exilicauda	Hitch	1	204	239.5	292	x	
Oncorhynchus nerka	Kokanee	2	326	343	359		x
Salvelinus namaycush	Lake Trout	2	356	408	460	x	x
Micropterus salmoides	Largemouth Bass	143	157	350	623	x	x
Lepomis gibbosus	Pumpkinseed	1	120	135	150	x	
Oncorhynchus mykiss	Rainbow Trout	79	140	301	598	x	x
Lepomis microlophus	Redear Sunfish	1	206	220	242	x	
Ptychocheilus grandis	Sacramento Pikeminnow	2	354	406.5	493	x	x
Catostomus occidentalis	Sacramento Sucker	15	211	431	564	x	
Micropterus dolomieu	Smallmouth Bass	10	151	309	529	x	x
Micropterus punctulatus	Spotted Bass	2	126	248	480		x
Morone saxatilis	Striped Bass	1	486	534	582	x	x
Tilapia leucosticta	Tilapia	1	253	276	299	x	

Table 3
Thresholds selected for triggering follow-up analysis of archived composite samples. Triggers were 75% of a threshold for concern (see Davis et al. 2007a). All samples were analyzed for mercury, so a threshold for follow-up analysis was not needed.

Pollutant	Threshold for Follow-up Analysis (ppb wet weight)
PCBs	22
DDTs	622
Dieldrin	18
Chlordanes	225
Selenium	2,947

Aliquots from all composites were archived whether they were analyzed or not, in case of any analytical problems or other circumstances calling for analysis or re-analysis at a later time. In addition, aliquots of some samples were selected for long-term archiving. This will provide an integrative, representative sample for each lake that can be reanalyzed in later years to confirm earlier analyses, look for new chemicals of concern, provide material for application of new analytical methods, provide material for other ecological research, and other purposes. In addition, each Regional Board identified lakes they were interested in sampling more often and establishing a baseline for trend analysis. A list of trend lakes can be found in Appendix 2. For trend lakes individual archives were retained for all species and all locations, and where sufficient tissue was present, location and lakewide archives were also retained.

Table 4
Thresholds for concern based on an assessment of human health risk from these pollutants by OEHHA (Klasing and Brodberg, 2008). All values given in ng/g (ppb). The lowest available threshold for each pollutant is in bold font. One serving is defined as 8 ounces (227 g) prior to cooking. The FCG and ATLs for mercury are for the most sensitive population (i.e., women aged 18 to 45 years and children aged 1 to 17 years).

Pollutant	Fish Contaminant Goal	Advisory Tissue Level (3 servings/week)	Advisory Tissue Level (2 servings/week)	Advisory Tissue Level (No Consumption)
Chlordanes	**5.6**	190	280	560
DDTs	**21**	520	1000	2100
Dieldrin	**0.46**	15	23	46
Mercury	220	**70**	150	440
PCBs	**3.6**	21	42	120
Selenium	7400	**2500**	4900	15000

SAMPLE PROCESSING

Dissection and compositing of muscle tissue samples were performed following USEPA guidance (USEPA 2000). All fish were dissected skin-off, and only the fillet muscle tissue was used for analysis.

CHEMICAL ANALYSIS

Nearly all (>95%) of the mercury present in fish is methylmercury (Wiener et al. 2007). Consequently, monitoring programs usually analyze total mercury as a proxy for methylmercury, as was done in this study. USEPA (2000) recommends this approach, and the conservative assumption be made that all mercury is present as methylmercury to be most protective of human health. Total mercury and selenium in muscle tissue were measured by Moss Landing Marine Laboratory (Moss Landing, CA). Detection limits for total mercury and all of the other analytes are presented in Table 5.

Trace organics in muscle tissue were measured by the California Department of Fish and Game Water Pollution Control Laboratory (Rancho Cordova, CA). PCBs are reported as the sum of 55 congeners (Table 5). Concentrations in many lakes were near or below limits of detection (Table 5). The most abundant congeners were detected in 65-69% of the 364 samples analyzed for PCBs. Frequencies of detection and reporting were lower for the less abundant PCB congeners.

QUALITY ASSURANCE

The samples were analyzed in multiple batches. QAQC analyses for SWAMP Data Quality Objectives (DQOs) (precision, accuracy, recovery, completeness, and sensitivity) were performed for each batch as required by the SWAMP BOG QAPP (Bonnema 2007). The Technical Report for this study (Davis et al. 2009) contains a complete description of the QA results.

There were 55,598 sample results for individual constituents including tissue composites, composite blind duplicates, and laboratory QA/QC samples. Overall, all data with the exception of 865 results were considered usable for the intended purpose. A 98% completeness level was attained which met the 90% project completeness goal specified in the Lakes QAPP.

ASSESSMENT THRESHOLDS

This report compared fish tissue concentrations to two types of thresholds for concern for pollutants in sport fish that were developed by OEHHA (Klasing and Brodberg 2008): Fish Contaminant Goals (FCGs) and Advisory Tissue Levels (ATLs) (Table 4).

Table 5
Analytes included in the study, detection limits, and frequencies of detection and reporting.
Frequency of detection includes all results above detection limits. Frequency of reporting includes all results that were reportable (above the detection limit and passing all QA review).

Class	Analyte	MDL	Number of Observations	Frequency of Detection (%)	Frequency of Reporting (%)
Metals/Metalloids	Mercury	0.01	3158	99%	99%
	Selenium	0.12	209	86%	86%
Cyclodienes	Dieldrin	0.42	360	29%	29%
Chlordanes	Nonachlor, cis-	0.30	360	36%	36%
	Chlordane, cis-	0.39	360	44%	33%
	Nonachlor, trans-	0.19	360	68%	59%
	Chlordane, trans-	0.44	360	41%	28%
	Oxychlordane	0.46	360	6%	6%
DDTs	DDE(o,p')	0.17	360	8%	8%
	DDE(p,p')	0.47	360	93%	92%
	DDT(o,p')	0.21	360	4%	4%
	DDT(p,p')	0.15	360	19%	19%
	DDD(o,p')	0.09	360	30%	30%
	DDD(p,p')	0.12	360	71%	71%
PCB Congeners	PCB 008	0.14	364	3%	3%
	PCB 018	0.13	364	15%	15%
	PCB 027	0.11	364	5%	5%
	PCB 028	0.16	364	27%	27%
	PCB 029	0.11	364	0%	0%
	PCB 031	0.15	364	23%	23%
	PCB 033	0.15	364	12%	12%
	PCB 044	0.15	364	32%	32%
	PCB 049	0.11	364	40%	40%
	PCB 052	0.17	364	40%	38%
	PCB 056	0.10	364	38%	23%
	PCB 060	0.11	364	29%	27%
	PCB 064	0.10	364	25%	24%
	PCB 066	0.13	364	48%	41%
	PCB 070	0.19	364	45%	35%
	PCB 074	0.12	364	38%	36%
	PCB 077	0.11	364	15%	15%
	PCB 087	0.15	364	51%	39%

Class	Analyte	MDL	Number of Observations	Frequency of Detection (%)	Frequency of Reporting (%)
PCB Congeners	PCB 095	0.18	364	54%	41%
	PCB 097	0.11	364	45%	38%
	PCB 099	0.12	364	58%	55%
	PCB 101	0.18	364	66%	54%
	PCB 105	0.15	364	40%	39%
	PCB 110	0.21	364	59%	43%
	PCB 114	0.10	364	10%	7%
	PCB 118	0.24	364	54%	49%
	PCB 126	0.11	364	2%	2%
	PCB 128	0.11	364	44%	43%
	PCB 137	0.10	364	23%	23%
	PCB 138	0.19	364	64%	63%
	PCB 141	0.11	364	36%	36%
	PCB 146	0.10	364	35%	35%
	PCB 149	0.12	364	60%	57%
	PCB 151	0.09	364	45%	45%
	PCB 153	0.18	364	69%	68%
	PCB 156	0.11	364	30%	29%
	PCB 157	0.10	364	10%	10%
	PCB 158	0.10	364	38%	37%
	PCB 169	0.10	364	6%	3%
	PCB 170	0.12	364	32%	32%
	PCB 174	0.11	364	32%	32%
	PCB 177	0.09	364	32%	32%
	PCB 180	0.10	364	65%	64%
	PCB 183	0.10	364	38%	38%
	PCB 187	0.11	364	55%	55%
	PCB 189	0.10	364	4%	4%
	PCB 194	0.10	364	30%	30%
	PCB 195	0.11	364	12%	12%
	PCB 198/199	0.09	364	14%	2%
	PCB 200	0.10	364	9%	9%
	PCB 201	0.11	364	37%	37%
	PCB 203	0.09	364	38%	38%
	PCB 206	0.11	364	26%	23%
	PCB 209	0.09	364	15%	15%

FCGs, as described by Klasing and Brodberg (2008), are "estimates of contaminant levels in fish that pose no significant health risk to humans consuming sport fish at a standard consumption rate of one serving per week (or eight ounces [before cooking] per week, or 32 g/day), prior to cooking, over a lifetime and can provide a starting point for OEHHA to assist other agencies that wish to develop fish tissue-based criteria with a goal toward pollution mitigation or elimination. FCGs prevent consumers from being exposed to more than the daily reference dose for non-carcinogens or to a risk level greater than $1x10^{-6}$ for carcinogens (not more than one additional cancer case in a population of 1,000,000 people consuming fish at the given consumption rate over a lifetime). FCGs are based solely on public health considerations without regard to economic considerations, technical feasibility, or the counterbalancing benefits of fish consumption." For organic pollutants, FCGs are lower than ATLs.

ATLs, as described by Klasing and Brodberg (2008), "while still conferring no significant health risk to individuals consuming sport fish in the quantities shown over a lifetime, were developed with the recognition that there are unique health benefits associated with fish consumption and that the advisory process should be expanded beyond a simple risk paradigm in order to best promote the overall health of the fish consumer. ATLs provide numbers of recommended fish servings that correspond to the range of contaminant concentrations found in fish and are used to provide consumption advice to prevent consumers from being exposed to more than the average daily reference dose for non-carcinogens or to a risk level greater than $1x10^{-4}$ for carcinogens (not more than one additional cancer case in a population of 10,000 people consuming fish at the given consumption rate over a lifetime). ATLs are designed to encourage consumption of fish that can be eaten in quantities likely to provide significant health benefits, while discouraging consumption of fish that, because of contaminant concentrations, should not be eaten or cannot be eaten in amounts recommended for improving overall health (eight ounces total, prior to cooking, per week). ATLs are but one component of a complex process of data evaluation and interpretation used by OEHHA in the assessment and communication of fish consumption risks. The nature of the contaminant data or omega-3 fatty acid concentrations in a given species in a water body, as well as risk communication needs, may alter strict application of ATLs when developing site-specific advisories. For example, OEHHA may recommend that consumers eat fish containing low levels of omega-3 fatty acids less often than the ATL table would suggest based solely on contaminant concentrations. OEHHA uses ATLs as a framework, along with best professional judgment, to provide fish consumption guidance on an ad hoc basis that best combines the needs for health protection and ease of communication for each site." For methylmercury and selenium, the 3 serving and 2 serving ATLs are lower than the FCGs.

Consistent with the description of ATLs above, the assessments presented in this report are not intended to represent consumption advice.

For methylmercury, results were also compared to a 0.3 ppm threshold that is being used by the State and Regional Water Boards in the current round of 303(d) listing.

DATA ANALYSIS

For individual largemouth bass, regression equations were used to estimate methylmercury concentrations (mean and 95% confidence interval) in a 350 mm (total length) largemouth bass for each lake. The 350 mm value was selected to represent the middle of the typical size distribution above the legal limit of 305 mm (12 in) for largemouth bass in California.

Candidates for 303(d) Listing

One of the objectives of this survey was to provide information that could be used in evaluating whether a given lake should be included on the 303(d) List for each pollutant. The sampling design was developed specifically to address this objective. To meet listing requirements in a cost-effective manner, all available samples were analyzed for lakes where an initial analysis of a lakewide composite sample showed that concentrations approached a threshold. This report does not, however, present an assessment for the purposes of 303(d) listing determinations. These determinations were left to the discretion of the Regional Boards.

SECTION 3 RESULTS AND DISCUSSION

In this screening study, 4,905 fish representing 23 species were collected from 272 lakes and reservoirs in California (Figure 1a-c, Tables 1a,b). A concise summary of the data for each lake is provided in Appendix 1. Excel files containing these tables are available from SFEI (contact Jay Davis, jay@sfei.org). All data collected for this study are maintained in the SWAMP database which is managed by the data management team at Moss Landing Marine Laboratories (http://swamp.mpsl.mlml.calstate.edu). The complete dataset, which will be used for 303(d) listing determinations, includes QA data (quality control samples and blind duplicates) and additional ancillary information (specific location information, fish sex, weights, etc). It is anticipated that by the fall of 2010, the complete dataset from this study will also be available on the web at http://www.ceden.org. Finally, data from this study are available on the web through the California Water Quality Monitoring Council's "My Water Quality" portal (www.CaWaterQuality.net). This site is designed to present data from the Lakes Survey and other studies in a nontechnical manner to the public, and allows mapping and viewing of summary data from each lake.

METHYLMERCURY

Comparison to Thresholds

Methylmercury is the pollutant that poses the most widespread potential health risks to consumers of fish caught from California lakes. Methylmercury was the only pollutant that frequently reached concentrations high enough that OEHHA would consider recommending no consumption of the contaminated species (0.44 ppm wet weight). This degree of contamination was quite prevalent across the state. Overall, 56 of the 272 lakes surveyed (21%) had a species with an average concentration exceeding 0.44 ppm (Table 6, Figure 2). For the random lakes, 23% had a species above 0.44 ppm (Figure 3a). The 95% confidence interval for this estimate was ±11%. Expressed on an areal basis, an estimated 18% of California lake area had fish with concentrations above 0.44 ppm (Figure 3a). For the targeted lakes, 20% had concentrations above the 0.44 ppm threshold (Figure 3b). The occurrence of these high mercury lakes showed distinct regional variation. Only 2% of the northern California trout lakes were above 0.44 ppm (Table 6). In contrast, 48% of the lower elevation lakes in northern California were above 0.44 ppm. In southern California, the overall degree of contamination was less severe than in the low elevation lakes of northern California, but the fraction of lakes above 0.44 ppm was still substantial (16%).

Table 6
Percentages of lakes in methylmercury concentration categories by region.
Concentrations in ppm. Note: Some lakes did not fall into these three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each Concentration Category					
		< 0.07	0.07-0.15	0.15-0.22	0.22 – 0.3	0.3 -0.44	>0.44
California (All Data)	272	32	13	13	7	14	21
Northern California Trout Lakes	87	71	16	6	2	2	1
Northern California Lower Elevation (<2000 ft)	82	2	5	11	12	22	48
Southern California	83	27	12	20	7	18	16

The State and Regional Boards are applying a methylmercury threshold of 0.3 ppm in fish tissue in the current round of 303(d) listing of impaired water bodies. Many lakes across the state had fish tissue concentrations above this threshold. Overall, 95 of the 272 lakes surveyed (35%) had a species with an average methylmercury concentration exceeding 0.30 ppm (Table 6, Figure 2). The occurrence of lakes with concentrations above this threshold showed distinct regional variation. Only 3% of the northern California trout lakes were above 0.30 ppm (Table 6). In contrast, 70% of the lower elevation lakes in northern California were above 0.30 ppm. In southern California, 34% of lakes were above 0.30 ppm.

Most of the lakes surveyed had some degree of methylmercury contamination. Methylmercury concentrations measured in this study were frequently higher than the lowest OEHHA threshold for methylmercury – 0.07 ppm – a concentration at which OEHHA would consider recommending consumption of less than three servings of fish per week. Overall, 68% of the 272 lakes sampled had a fish species with methylmercury concentrations above the lowest threshold for methylmercury (the 0.07 ppm three serving ATL) (Table 6, Figure 2). Most (71%) of the northern California trout lakes were below 0.07 ppm (Table 6). This was in sharp contrast to lower elevation lakes (below 2000 ft) in northern California, which had only 2% below 0.07 ppm. Concentrations in Southern California lakes were intermediate, with 27% below 0.07 ppm.

Variation Within and Among Species

As expected, relatively high methylmercury concentrations were observed in species that are high trophic position predators, including largemouth, smallmouth, and spotted bass and Sacramento pikeminnow (Table 7). For some of these species, however, the averages are based on small sample sizes and therefore are imprecise estimates. Statewide average concentrations in smallmouth and largemouth bass (0.42 and 0.41 ppm, respectively) approached OEHHA's no consumption ATL of 0.44 ppm. Other warmwater species such as common carp, channel catfish, black crappie, and bluegill had moderate methylmercury contamination.

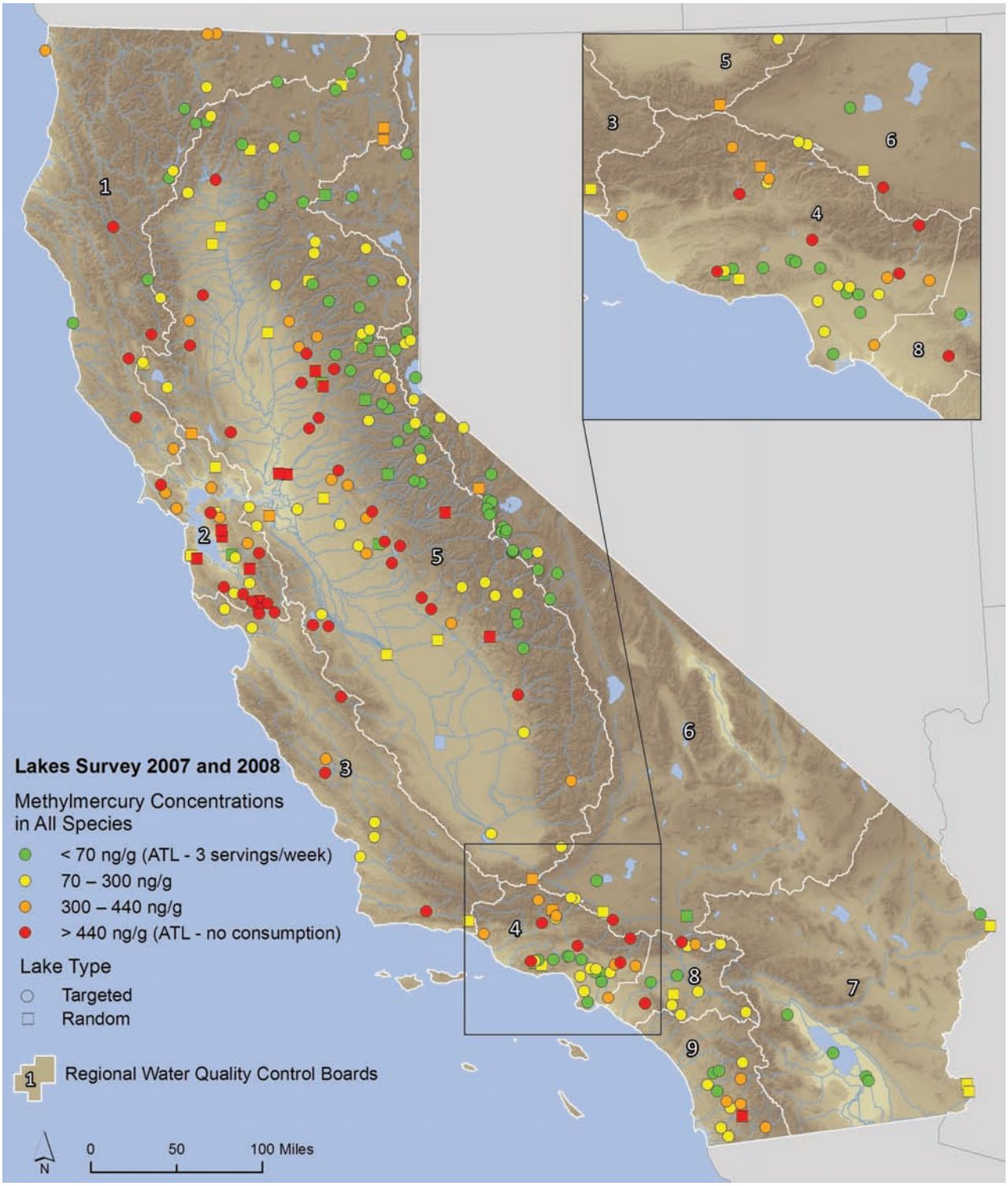

Figure 2. Spatial patterns in methylmercury concentrations (ng/g wet weight) in lakes sampled in the Lakes Survey, 2007-2008. Each point represents the highest average methylmercury concentration among the species sampled in each lake. Concentrations based on location composites and individual fish, from both targeted (circles) and random (squares) lakes.

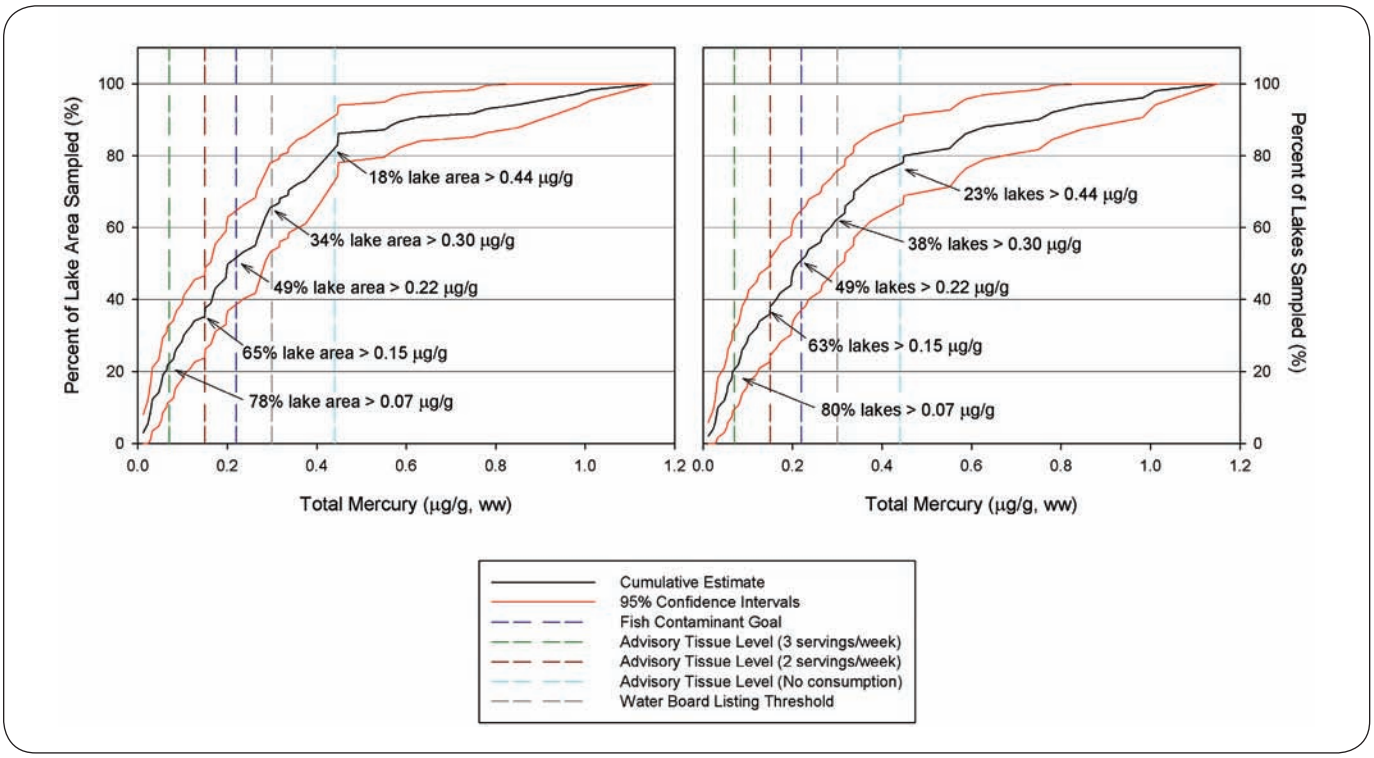

Figure 3a. Cumulative distribution function (CDF) plot for mercury in random lakes, shown as percent of lake area (left) and percent of lakes (right). Concentrations are the highest species average (ug/g wet weight) for each lake, based on location composites and individual fish at randomly sampled lakes in the Lakes Survey. Vertical lines are threshold values. Data in µg/g, or ppm.

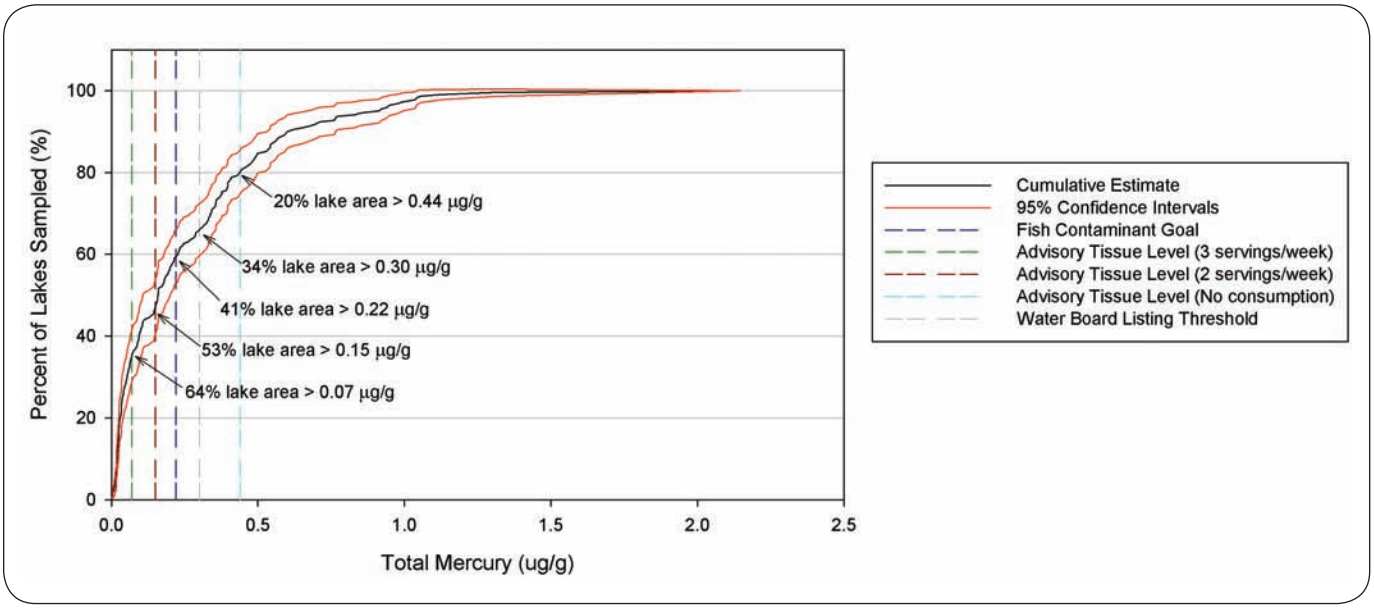

Figure 3b. Cumulative distribution function (CDF) plot for mercury at targeted lakes, shown as percent of lakes sampled. Concentrations are the highest species average (ug/g wet weight) for each lake, based on location composites and individual fish at targeted lakes in the Lakes Survey. Vertical lines are threshold values. Data in µg/g, or ppm.

Table 7

Average concentrations of mercury (ppm wet weight) in each species sampled in this survey. Averages are based on the total number of composites or estimated averages for all locations (i.e., all of the data points shown in Appendix 1). Concentrations in ppm. Averages by species are shown for the entire statewide dataset, and for each region. Almaden Lake in Region 2 had high concentrations and a large influence on the Region 2 averages for largemouth and common carp. Without the data from Almaden Lake, the average was 0.23 ppm for common carp, 0.58 ppm for largemouth bass, and 0.36 ppm for Region 2 as a whole. N=number of samples; S.E.=standard error of the mean.

Species	California			Region 1			Region 2			Region 3			Region 4			Region 5			Region 6			Region 7			Region 8			Region 9		
	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.	N	Concentration	S.E.
Black Crappie	4	0.04	0.02													1	0.08					3	0.03	0.01						
Bluegill	3	0.08	0.02				2	0.10	0.01				1	0.04																
Brook Trout	4	0.13	0.04													4	0.13	0.04												
Brown Bullhead	24	0.08	0.01	1	0.13								8	0.14	0.03	15	0.05	0												
Brown Trout	19	0.20	0.05													17	0.21	0.06	2	0.05	0									
Channel Catfish	20	0.17	0.04				7	0.12	0.04				3	0.10	0.03	6	0.36	0.10	2	0.06	0	1	0.01					1	0.05	
Common Carp	172	0.18	0.01	2	0.08	0.01	20	0.31	0.07	13	0.32	0.04	31	0.05	0.01	61	0.22	0.01	4	0.21	0.11	14	0.03	0.01	13	0.11	0.02	14	0.14	0.03
Eagle Lake Trout	4	0.06	0.01																4	0.06	0.01									
Goldfish	2	0.07	0							2	0.07	0																		
Hardhead	2	0.11	0.01	2	0.11	0.01																								
Hitch	2	0.03	0							2	0.03	0																		
Kokanee	3	0.08	0.01													1	0.10		2	0.08	0									
Lake Trout	2	0.16	0.01																2	0.16	0.01									
Largemouth Bass	199	0.41	0.02	13	0.58	0.10	22	0.65	0.09	14	0.43	0.08	26	0.31	0.04	93	0.42	0.03	5	0.41	0.14	3	0.11	0.02	8	0.15	0.05	15	0.25	0.04
Pumpkinseed	1	0.19	0										1	0.19																
Rainbow Trout	152	0.05	0	12	0.04	0.01	2	0.26	0.01	2	0.23	0.04	1	0.03		76	0.04	0	58	0.04	0				1	0.03				
Redear Sunfish	2	0.02	0										2	0.02	0															
Sac. Pikeminnow	2	0.27	0.07													2	0.27	0.07												
Sacramento Sucker	28	0.27	0.04				2	0.29	0.02	2	0.09	0				18	0.31	0.05	6	0.20	0.05									
Smallmouth Bass	22	0.42	0.06							3	1.00	0.03				19	0.33	0.05												
Spotted Bass	6	0.32	0.11													6	0.32	0.11												
Striped Bass	3	0.21	0.02																						3	0.21	0.02			
Tilapia1	4	0.01	0																			4	0.01	0						
Overall	680	0.15	0.02	30	0.19	0.03	55	0.29	0.04	38	0.31	0.03	73	0.11	0.02	319	0.22	0.05	85	0.14	0.04	25	0.04	0.01	25	0.12	0.03	30	0.15	0.03

Rainbow trout generally had low concentrations of methylmercury, with a statewide average (0.05 ppm) below the lowest OEHHA threshold (the 0.07 ppm three serving ATL).

Trout generally occupy a lower trophic position and accumulate lower concentrations of methylmercury and other pollutants, though exceptions to this pattern occur and were observed in this study (discussed further below). Another factor that probably contributes to lower observed concentrations in trout is that, in many lakes, recently planted hatchery fish are part of the catch. A previous study found that hatchery trout consistently had very low concentrations of methylmercury (rainbow trout from four hatcheries all had less than 0.023 ppm – Grenier et al. 2007).

It is important to note that resident, self-sustaining trout populations in these lakes are likely to have higher concentrations than the hatchery fish that are most readily collected. The results from Hetch Hetchy Reservoir, which has a self-sustaining population of brown trout, illustrate this point. Hetch Hetchy Reservoir was anomalous among the trout lakes with methylmercury concentrations of 0.96 and 0.54 ppm in composites of brown trout from two distinct locations (Figure 4). One other lake (Loon Lake, which also has a self-sustaining population of brown trout) also had relatively high concentrations in two composites of brown trout (0.50 and 0.30 ppm). Brown trout from the other nine lakes where they were collected generally had low concentrations (all around 0.10 ppm or less, except for one composite from Hell Hole Reservoir at 0.28 ppm).

Larger size fish from self-sustaining trout populations are particularly likely to accumulate high concentrations of methylmercury. A second factor that could contribute to the high concentrations in brown trout from Hetchy Hetchy Reservoir and Loon Lake is that brown trout are known to switch to from a diet of invertebrates to a diet of fish as they get older (Moyle 2002). The brown trout samples with high methylmercury were all above 400 mm in average length, while the samples with lower methylmercury were all below 400 mm (Figure 4).

Rainbow trout showed less variation in methylmercury concentrations than brown trout. The highest concentrations of methylmercury in rainbow trout were observed in two composites from Pilarcitos Lake in Region 2 (0.26 and 0.27 ppm). Other lakes with relatively high concentrations in rainbow trout were Jameson Lake in Region 3 (0.19 and 0.27 ppm in two composites) and Mammoth Pool Reservoir in Region 5 (0.10 and 0.22 in two composites).

Very few California lakes contain predatory fish, such as largemouth bass, with low concentrations of methylmercury (Figure 5). Only 8 of the 143 lakes where largemouth bass were sampled (6%) had average largemouth concentrations of 0.07 ppm or lower. The average (size-adjusted) concentrations observed in lakes with largemouth bass that were below the lowest OEHHA threshold were 0.07 ppm in Lake of the Pines (Region 5), 0.03 ppm in Lake Calabassas and 0.01 ppm in Toluca Lake (Region 4), 0.07 ppm in Prado Lake and 0.03 ppm in Lake Evans (Region 8), and 0.05 ppm in each of three Region 9 lakes (Dixon Lake, Lake Poway, and Lake Wohlford). These lakes stand out as having exceptionally low methylmercury contamination. These low concentrations may be due to variation in ecosystem factors such as water

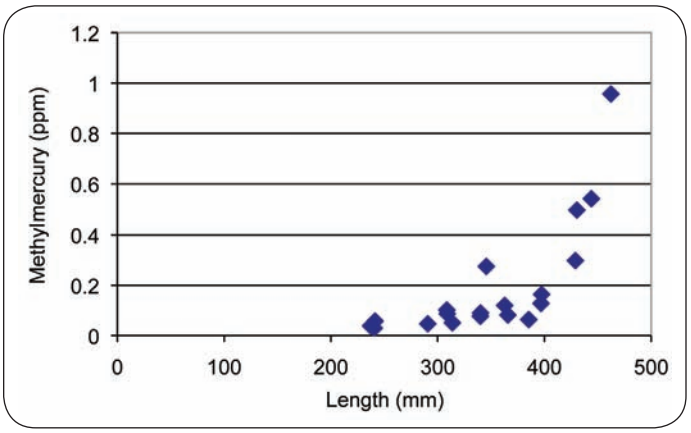

Figure 4. Methylmercury concentration (ug/g wet weight) versus average length (total) for brown trout composites. Data from 11 lakes in the Sierra Nevada.

chemistry, productivity, trophic dynamics, wetland presence, or others; or due to variation in sources, such as an absence of mining influence. The influence of these factors was explored in further detail in a companion paper (Negrey et al. 2010). The low concentrations observed at these lakes indicate that it is indeed possible for lakes in the California landscape, even those with self-sustaining populations of predators, to not have excessive bioaccumulation of methylmercury, and that a realistic management goal for at least some lakes may be to attain concentrations of this magnitude.

A much higher percentage of the low elevation lakes where predators (black bass, Sacramento pikeminnow, striped bass) were not collected had methylmercury concentrations below the 0.07 ppm threshold: 16 of 23 (70%). The species sampled at these lakes (e.g., common carp, channel catfish, black crappie, and bluegill) tend to accumulate lower concentrations of methylmercury.

Limited evaluation of correlations among species could be evaluated with this dataset (Figure 6). The largest sample size was available for largemouth bass and common carp. A fairly strong correlation was observed between these species ($R2 = 0.59$), with bass averaging 1.6 times higher concentrations than carp. Considerable variation around the regression line was observed, especially toward the higher end of the distribution of concentrations. Although sample sizes were small, concentrations in largemouth bass also appeared to have consistent relationships with Sacramento sucker, brown bullhead, and channel catfish.

Spatial Patterns

Methylmercury concentrations across the state varied at a regional scale (Table 6, Figure 2). In northern California, low concentrations were commonly observed in fish from high elevation lakes in the Sierra Nevada and Trinity Alps. The highest species averages observed in most of these lakes were below the three-serving ATL (0.07 ppm). Trout (mostly rainbow trout, but a few lakes had brown trout, brook trout, lake trout, or Eagle Lake trout) were the most commonly caught species in these lakes, and, as discussed above, tend to accumulate lower methylmercury concentrations than largemouth bass. For the 87 northern California trout lakes sampled, 71% had a maximum species average below 0.07 ppm, another 16% were between 0.07 and 0.15 ppm, and only one of these lakes (1%) had a species average above 0.44 ppm – Hetch Hetchy Reservoir with brown trout at 0.75 ppm (Table 8). Photodemethylation in the very clear water column of high-elevation lakes may be a mechanistic process that contributes to the low methylmercury concentrations in these areas.

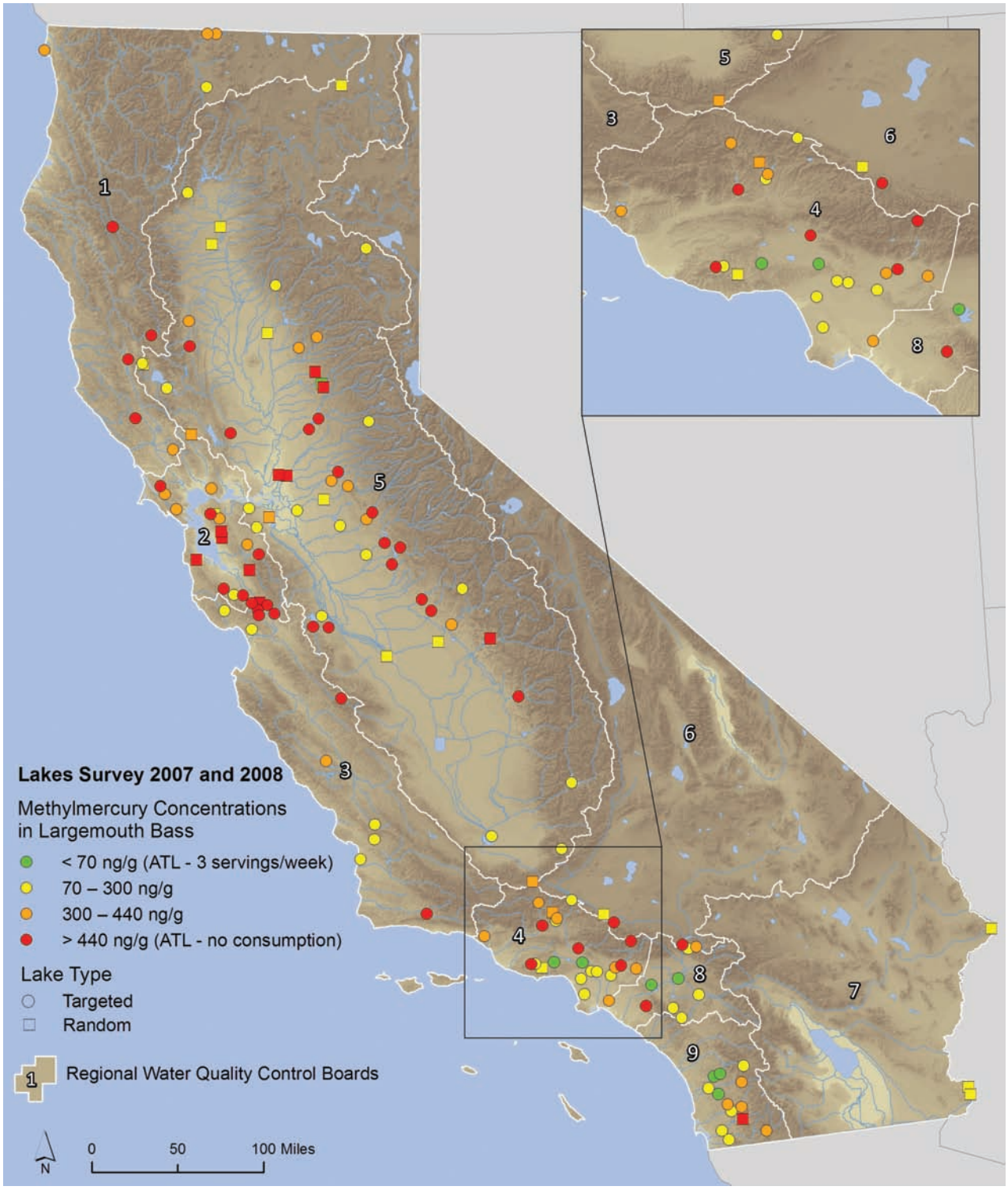

Figure 5. Spatial patterns in methylmercury concentrations (ug/g wet weight) in standard-sized (350 mm) largemouth bass at lakes sampled in the Lakes Survey, from both targeted (circles) and random (squares) lakes.

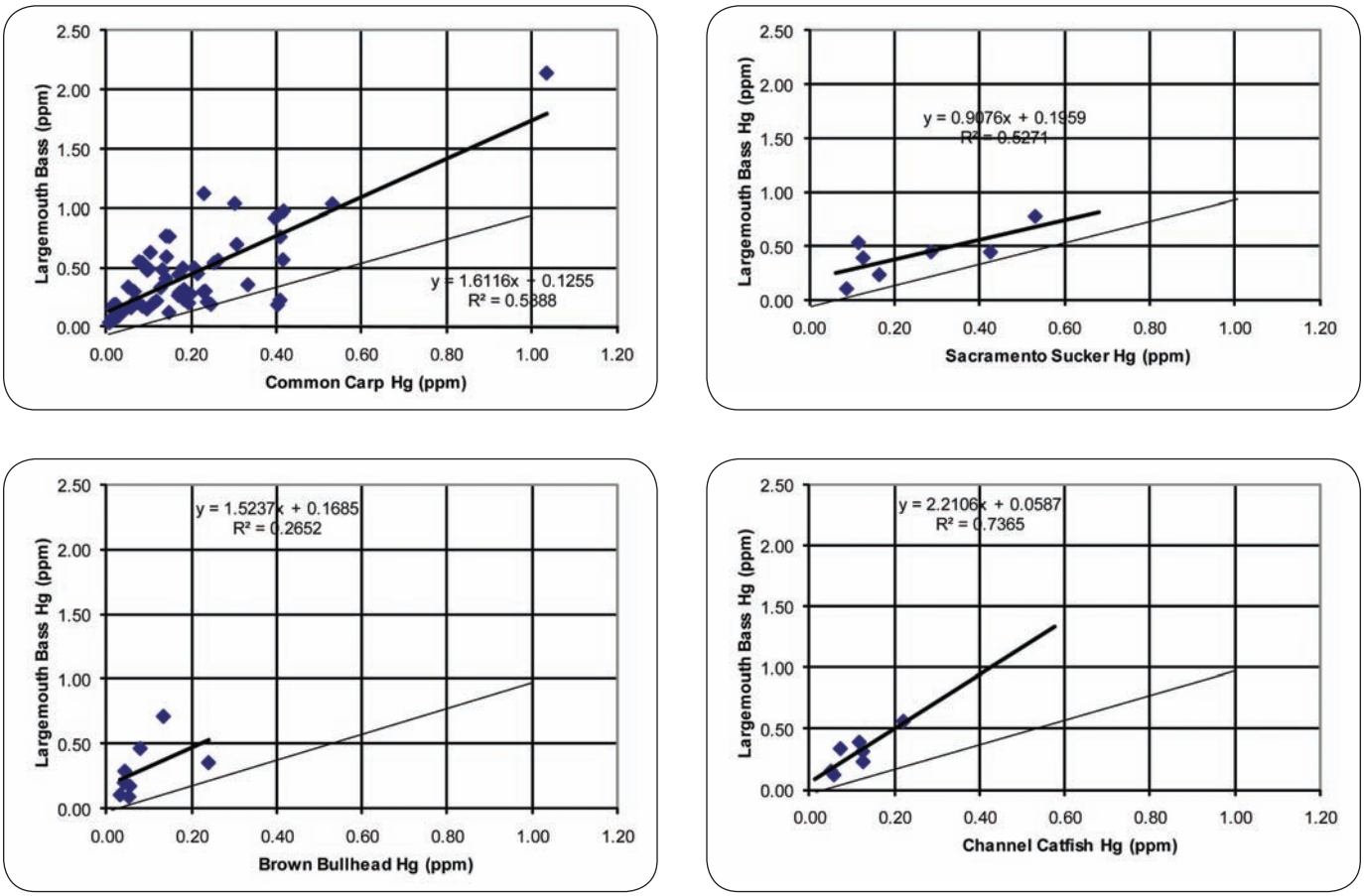

Figure 6. Correlations of methylmercury concentrations (ug/g wet weight) in largemouth bass with concentrations in other species.

In contrast to the northern California trout lakes, methylmercury concentrations in fish from lower elevation (below 2000 ft) lakes in northern California (Table 6, Figure 2) were almost always higher than the three-serving per week ATL (0.07 ppm), and frequently higher than the no consumption ATL (0.44 ppm). Of the 82 lower elevation lakes sampled in northern California, 48% had a maximum species average above 0.44 ppm, another 34% were between 0.22 and 0.44 ppm, and only two (2%) lakes in this region had a species average below 0.07 ppm. The two lakes that had a methylmercury concentration at or below 0.07 ppm were Lago Los Osos in Region 2 and Lake of the Pines in Region 5. Largemouth bass were not caught at Lago Los Osos – only channel catfish were collected. Lake of the Pines was the only lake in northern California where largemouth bass were collected that had an average concentration at a standard size of 350 mm of 0.07 ppm or lower. Interestingly, the average concentration measured at this lake was in sharp contrast to concentrations in 350 mm largemouth at two adjacent lakes: Lake Combie immediately to the south at 0.78 ppm, and Zayak/Swan Lake to the north at 0.98 ppm.

Table 8
Lakes with methylmercury above 0.44 ppm (wet weight) OEHHA threshold in average concentrations or composite samples. Data are sorted by region. Data for samples of individual fish are not included in this table.

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
1	Lake Pillsbury	Year1	medium	targeted	Largemouth Bass	350	1.34	L1	NA	11	350 mm Standard Size
1	Lake Pillsbury	Year1	medium	targeted	Largemouth Bass	350	1.29	L2	NA	11	350 mm Standard Size
1	Lake Sonoma	Year1	medium	targeted	Largemouth Bass	350	0.71	L2	NA	11	350 mm Standard Size
1	Lake Sonoma	Year1	medium	targeted	Largemouth Bass	350	0.64	L1	NA	11	350 mm Standard Size
1	Ruth Lake	Year2	small	targeted	Largemouth Bass	350	0.71	L1	NA	11	350 mm Standard Size
1	Ruth Lake	Year2	small	targeted	Brown Bullhead	323.8	0.13	L1	1	5	Location Composite
1	Lake Mendocino	Year1	medium	targeted	Largemouth Bass	350	0.55	L1	NA	11	350 mm Standard Size
1	Lake Mendocino	Year1	medium	targeted	Largemouth Bass	350	0.54	L2	NA	11	350 mm Standard Size
1	Lake Mendocino	Year1	medium	targeted	Common Carp	491.6	0.10	L2	1	5	Location Composite
1	Lake Mendocino	Year1	medium	targeted	Common Carp	479	0.07	L1	1	5	Location Composite
2	Almaden Lake	Year2	small	targeted	Largemouth Bass	350	2.15	L1	NA	11	350 mm Standard Size
2	Almaden Lake	Year2	small	targeted	Common Carp	669.4	1.05	L1	1	5	Location Composite
2	Almaden Lake	Year2	small	targeted	Common Carp	668.4	1.02	L1	2	5	Location Composite
2	Calero Reservoir	Year2	small	targeted	Largemouth Bass	350	1.05	L1	NA	16	350 mm Standard Size
2	Upper San Leandro Reservoir	Year1	small	random	Largemouth Bass	350	1.01	L1	NA	11	350 mm Standard Size
2	Anderson Lake	Year1	small	targeted	Largemouth Bass	350	0.98	L1	NA	11	350 mm Standard Size
2	Anderson Lake	Year1	small	targeted	Common Carp	501.2	0.52	L1	2	5	Location Composite
2	Anderson Lake	Year1	small	targeted	Common Carp	502.6	0.32	L1	1	5	Location Composite

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
2	Soulejoule Lake	Year1	small	targeted	Largemouth Bass	350	0.94	L1	NA	16	350 mm Standard Size
2	Calaveras Reservoir	Year1	medium	random	Largemouth Bass	350	0.86	L1	NA	11	350 mm Standard Size
2	Calaveras Reservoir	Year1	medium	random	Largemouth Bass	350	0.31	L2	NA	11	350 mm Standard Size
2	Lower Crystal Springs Reservoir	Year1	small	random	Largemouth Bass	350	0.85	L1	NA	11	350 mm Standard Size
2	Coyote Lake	Year2	small	targeted	Largemouth Bass	350	0.76	L1	NA	11	350 mm Standard Size
2	Coyote Lake	Year2	small	targeted	Common Carp	636.6	0.47	L1	1	5	Location Composite
2	Coyote Lake	Year2	small	targeted	Common Carp	633.4	0.35	L1	2	5	Location Composite
2	Stevens Creek Reservoir	Year1	small	targeted	Largemouth Bass	350	0.70	L1	NA	11	350 mm Standard Size
2	Stevens Creek Reservoir	Year1	small	targeted	Common Carp	601.4	0.32	L1	2	5	Location Composite
2	Stevens Creek Reservoir	Year1	small	targeted	Common Carp	606.4	0.29	L1	1	5	Location Composite
2	Lake Chabot (San Leandro)	Year1	small	random	Largemouth Bass	350	0.57	L1	NA	11	350 mm Standard Size
2	Lake Chabot (San Leandro)	Year1	small	targeted	Common Carp	520.8	0.54	L1	1	5	Location Composite
2	Lake Chabot (San Leandro)	Year1	small	targeted	Common Carp	520.6	0.29	L1	2	5	Location Composite
2	Lake del Valle	Year2	small	targeted	Largemouth Bass	350	0.56	L1	NA	11	350 mm Standard Size
2	Lake del Valle	Year2	small	targeted	Channel Catfish	506.8	0.32	L1	2	5	Location Composite
2	Lake del Valle	Year2	small	targeted	Channel Catfish	506.6	0.13	L1	1	5	Location Composite
2	San Pablo Reservoir	Year1	small	targeted	Largemouth Bass	350	0.48	L1	NA	11	350 mm Standard Size
2	San Pablo Reservoir	Year1	small	targeted	Common Carp	500	0.17	L1	2	4	Location Composite
2	San Pablo Reservoir	Year1	small	targeted	Common Carp	506.4	0.09	L1	1	5	Location Composite

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
2	Oiger Quarry Ponds	Year1	small	random	Largemouth Bass	350	0.45	L1	NA	11	350 mm Standard Size
2	Oiger Quarry Ponds	Year1	small	targeted	Sacramento Sucker	438.4	0.31	L1	1	5	Location Composite
2	Oiger Quarry Ponds	Year1	small	targeted	Sacramento Sucker	436.4	0.26	L1	2	5	Location Composite
3	Chesbro Reservoir	Year1	small	targeted	Largemouth Bass	350	1.04	L1	NA	11	350 mm Standard Size
3	Chesbro Reservoir	Year1	small	targeted	Common Carp	524	0.55	L1	1	5	Location Composite
3	Chesbro Reservoir	Year1	small	targeted	Common Carp	522.6	0.51	L1	2	5	Location Composite
3	Uvas Reservoir	Year1	small	targeted	Largemouth Bass	350	0.91	L1	NA	11	350 mm Standard Size
3	Hernandez Reservoir	Year2	small	targeted	Largemouth Bass	350	0.83	L1	NA	16	350 mm Standard Size
3	Lake Cachuma	Year2	large	targeted	Largemouth Bass	350	0.61	L1	NA	6	350 mm Standard Size
3	Lake Cachuma	Year2	large	targeted	Largemouth Bass	350	0.48	L2	NA	11	350 mm Standard Size
3	Lake Cachuma	Year2	large	targeted	Largemouth Bass	350	0.40	L3	NA	11	350 mm Standard Size
3	Lake Cachuma	Year2	large	targeted	Common Carp	535.8	0.20	L3	1	5	Location Composite
3	Lake Cachuma	Year2	large	targeted	Common Carp	528.6	0.18	L1	1	5	Location Composite
3	Lake Cachuma	Year2	large	targeted	Common Carp	536.6	0.16	L2	1	5	Location Composite
3	Lake Nacimiento	Year1	large	targeted	Common Carp	502.6	0.56	L2	1	5	Location Composite
3	Lake Nacimiento	Year1	large	targeted	Common Carp	510	0.50	L3	1	5	Location Composite
3	Lake Nacimiento	Year1	large	targeted	Common Carp	421.2	0.37	L1	1	5	Location Composite
4	Crystal Lake	Year1	small	targeted	Largemouth Bass	350	0.95	L1	NA	5	350 mm Standard Size
4	Crystal Lake	Year1	small	targeted	Pumpkinseed	135	0.19	L1	1	5	Location Composite
4	Santa Fe Reservoir	Year1	small	targeted	Largemouth Bass	350	0.59	L1	NA	16	350 mm Standard Size
4	Santa Fe Reservoir	Year1	small	targeted	Common Carp	531.8	0.16	L1	1	5	Location Composite
4	Santa Fe Reservoir	Year1	small	targeted	Common Carp	531.4	0.12	L1	2	5	Location Composite

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
4	Lake Sherwood	Year1	small	targeted	Largemouth Bass	350	0.54	L1	NA	16	350 mm Standard Size
4	Hansen Lake	Year1	small	targeted	Largemouth Bass	350	0.49	L1	NA	16	350 mm Standard Size
4	Hansen Lake	Year1	small	targeted	Common Carp	547.4	0.12	L1	2	5	Location Composite
4	Hansen Lake	Year1	small	targeted	Common Carp	547.8	0.08	L1	1	5	Location Composite
4	Lake Piru	Year1	small	targeted	Largemouth Bass	350	0.46	L1	NA	16	350 mm Standard Size
4	Lake Piru	Year1	small	targeted	Brown Bullhead	295.6	0.10	L1	2	5	Location Composite
4	Lake Piru	Year1	small	targeted	Brown Bullhead	296.6	0.06	L1	1	5	Location Composite
5	New Melones Lake	Year2	medium	targeted	Largemouth Bass	350	1.22	L1	NA	11	350 mm Standard Size
5	New Melones Lake	Year2	medium	targeted	Largemouth Bass	350	1.03	L2	NA	11	350 mm Standard Size
5	New Melones Lake	Year2	medium	targeted	Common Carp	587.4	0.26	L1	1	5	Location Composite
5	New Melones Lake	Year2	medium	targeted	Common Carp	544	0.20	L2	1	5	Location Composite
5	Cosumnes River	Year1	small	random	Largemouth Bass	350	1.15	L1	NA	16	350 mm Standard Size
5	New Hogan Lake	Year2	large	targeted	Largemouth Bass	350	0.51	L3	NA	11	350 mm Standard Size
5	New Hogan Lake	Year2	large	targeted	Largemouth Bass	350	0.41	L1	NA	11	350 mm Standard Size
5	New Hogan Lake	Year2	large	targeted	Largemouth Bass	350	0.37	L2	NA	11	350 mm Standard Size
5	Eastman Lake	Year2	medium	targeted	Largemouth Bass	350	1.05	L2	NA	11	350 mm Standard Size
5	Eastman Lake	Year2	medium	targeted	Largemouth Bass	350	1.03	L1	NA	11	350 mm Standard Size
5	Eastman Lake	Year2	medium	targeted	Common Carp	671.4	0.33	L1	1	5	Location Composite
5	Eastman Lake	Year2	medium	targeted	Common Carp	652.8	0.27	L2	1	5	Location Composite
5	Zayak/Swan Lake	Year1	small	random	Largemouth Bass	350	0.98	L1	NA	16	350 mm Standard Size

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	Hetch Hetchy Reservoir	Year1	medium	targeted	Brown Trout	462.3	0.96	L2	1	3	Location Composite
5	Hetch Hetchy Reservoir	Year1	medium	targeted	Brown Trout	444	0.54	L1	1	5	Location Composite
5	Hensley Lake	Year1	medium	targeted	Largemouth Bass	350	0.80	L2	NA	12	350 mm Standard Size
5	Hensley Lake	Year1	medium	targeted	Largemouth Bass	350	0.72	L1	NA	10	350 mm Standard Size
5	Hensley Lake	Year1	medium	targeted	Common Carp	469.4	0.16	L1	1	5	Location Composite
5	Hensley Lake	Year1	medium	targeted	Common Carp	480.4	0.13	L2	1	5	Location Composite
5	Shasta Lake	Year1	ex-large	targeted	Channel Catfish	592.6	0.80	L2	1	5	Location Composite
5	Shasta Lake	Year1	ex-large	targeted	Channel Catfish	681.5	0.36	L1	1	4	Location Composite
5	Lake McClure	Year1	large	targeted	Largemouth Bass	350	0.79	L2	NA	11	350 mm Standard Size
5	Lake McClure	Year1	large	targeted	Largemouth Bass	350	0.77	L3	NA	11	350 mm Standard Size
5	Lake McClure	Year1	large	targeted	Largemouth Bass	350	0.75	L1	NA	11	350 mm Standard Size
5	Lake McClure	Year1	large	targeted	Common Carp	444.8	0.17	L2	1	5	Location Composite
5	Lake McClure	Year1	large	targeted	Common Carp	425	0.13	L3	1	5	Location Composite
5	Lake McClure	Year1	large	targeted	Common Carp	413.6	0.12	L1	1	5	Location Composite
5	Lake Combie	Year1	small	random	Largemouth Bass	350	0.78	L1	NA	11	350 mm Standard Size
5	Lake Combie	Year1	small	targeted	Sacramento Sucker	443.6	0.60	L1	1	5	Location Composite
5	Lake Combie	Year1	small	targeted	Sacramento Sucker	443.2	0.46	L1	2	5	Location Composite
5	Lake Berryessa	Year2	ex-large	targeted	Largemouth Bass	350	0.77	L1	NA	11	350 mm Standard Size
5	Lake Berryessa	Year2	ex-large	targeted	Largemouth Bass	350	0.60	L4	NA	11	350 mm Standard Size
5	Lake Berryessa	Year2	ex-large	targeted	Largemouth Bass	350	0.53	L3	NA	11	350 mm Standard Size
5	Lake Berryessa	Year2	ex-large	targeted	Largemouth Bass	350	0.51	L2	NA	11	350 mm Standard Size

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	Rollins Reservoir	Year2	small	targeted	Sacramento Sucker	448.6	0.68	L1	1	5	Location Composite
5	Harry L Englebright Lake	Year2	small	targeted	Sacramento Sucker	481.4	0.66	L1	1	5	Location Composite
5	Harry L Englebright Lake	Year2	small	targeted	Sacramento Sucker	479.8	0.59	L1	2	5	Location Composite
5	Harry L Englebright Lake	Year2	small	targeted	Rainbow Trout	305.8	0.08	L1	1	5	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Largemouth Bass	350	0.62	L4	NA	11	350 mm Standard Size
5	San Luis Reservoir	Year1	ex-large	targeted	Largemouth Bass	350	0.57	L2	NA	11	350 mm Standard Size
5	San Luis Reservoir	Year1	ex-large	targeted	Largemouth Bass	350	0.57	L3	NA	11	350 mm Standard Size
5	San Luis Reservoir	Year1	ex-large	targeted	Largemouth Bass	350	0.51	L1	NA	11	350 mm Standard Size
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	767.75	0.35	L2	1	4	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	728.2	0.25	L1	1	5	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	801.4	0.19	L3	1	5	Location Composite
5	Lake Amador	Year2	small	targeted	Largemouth Bass	350	0.60	L1	NA	16	350 mm Standard Size
5	Folsom Lake	Year2	large	targeted	Largemouth Bass	350	0.59	L1	NA	11	350 mm Standard Size
5	Folsom Lake	Year2	large	targeted	Largemouth Bass	350	0.48	L2	NA	11	350 mm Standard Size
5	Folsom Lake	Year2	large	targeted	Largemouth Bass	350	0.34	L3	NA	11	350 mm Standard Size
5	Pine Flat Lake	Year1	large	random	Largemouth Bass	350	0.58	L3	NA	11	350 mm Standard Size
5	Pine Flat Lake	Year1	large	random	Largemouth Bass	350	0.55	L1	NA	11	350 mm Standard Size
5	Pine Flat Lake	Year1	large	random	Largemouth Bass	350	0.53	L2	NA	11	350 mm Standard Size
5	Pine Flat Lake	Year1	large	targeted	Common Carp	585	0.09	L1	1	5	Location Composite
5	Pine Flat Lake	Year1	large	targeted	Common Carp	590	0.07	L2	1	5	Location Composite
5	Los Banos Reservoir	Year1	small	targeted	Largemouth Bass	350	0.55	L1	NA	11	350 mm Standard Size

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	Lake Natomas	Year1	small	targeted	Largemouth Bass	350	0.54	L1	NA	11	350 mm Standard Size
5	Lake Natomas	Year1	small	targeted	Common Carp	579	0.26	L1	1	5	Location Composite
5	Lake Natomas	Year1	small	targeted	Common Carp	568.4	0.25	L1	2	5	Location Composite
5	New Bullards Bar Reservoir	Year2	large	targeted	Largemouth Bass	350	0.54	L3	NA	11	350 mm Standard Size
5	New Bullards Bar Reservoir	Year2	large	targeted	Largemouth Bass	350	0.38	L2	NA	11	350 mm Standard Size
5	New Bullards Bar Reservoir	Year2	large	targeted	Largemouth Bass	350	0.27	L1	NA	11	350 mm Standard Size
5	Lake Kaweah	Year2	medium	targeted	Largemouth Bass	350	0.54	L2	NA	11	350 mm Standard Size
5	Lake Kaweah	Year2	medium	targeted	Largemouth Bass	350	0.46	L1	NA	11	350 mm Standard Size
5	Lake Kaweah	Year2	medium	targeted	Common Carp	653.4	0.25	L1	1	5	Location Composite
5	Lake Kaweah	Year2	medium	targeted	Common Carp	684.8	0.17	L2	1	5	Location Composite
5	Lake McSwain	Year1	small	targeted	Largemouth Bass	350	0.54	L1	NA	9	350 mm Standard Size
5	Lake McSwain	Year1	small	targeted	Sacramento Sucker	406.8	0.15	L1	2	5	Location Composite
5	Lake McSwain	Year1	small	targeted	Sacramento Sucker	410.6	0.08	L1	1	5	Location Composite
5	Turlock Lake	Year1	large	targeted	Common Carp	495.4	0.52	L2	1	5	Location Composite
5	Turlock Lake	Year1	large	targeted	Common Carp	527.4	0.42	L3	1	5	Location Composite
5	Turlock Lake	Year1	large	targeted	Common Carp	489	0.28	L1	1	5	Location Composite
5	Turlock Lake	Year1	large	targeted	Largemouth Bass	350	0.24	L1	NA	11	350 mm Standard Size
5	Turlock Lake	Year1	large	targeted	Largemouth Bass	350	0.23	L2	NA	11	350 mm Standard Size
5	Turlock Lake	Year1	large	targeted	Largemouth Bass	350	0.21	L3	NA	10	350 mm Standard Size
5	East Park Reservoir	Year1	medium	targeted	Largemouth Bass	350	0.52	L2	NA	11	350 mm Standard Size
5	East Park Reservoir	Year1	medium	targeted	Largemouth Bass	350	0.39	L1	NA	11	350 mm Standard Size

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	East Park Reservoir	Year1	medium	targeted	Common Carp	451	0.25	L2	1	5	Location Composite
5	East Park Reservoir	Year1	medium	targeted	Common Carp	452.8	0.18	L1	1	5	Location Composite
5	Loon Lake	Year1	small	targeted	Brown Trout	430.4	0.50	L1	1	5	Location Composite
5	Loon Lake	Year1	small	targeted	Brown Trout	429	0.30	L1	2	5	Location Composite
5	Meadows Slough	Year1	small	targeted	Sacramento Sucker	519	0.47	L1	2	5	Location Composite
5	Meadows Slough	Year1	small	random	Largemouth Bass	350	0.45	L1	NA	11	350 mm Standard Size
5	Meadows Slough	Year1	small	targeted	Sacramento Sucker	519	0.38	L1	1	5	Location Composite
5	Don Pedro Reservoir	Year1	large	targeted	Largemouth Bass	350	0.46	L3	NA	11	350 mm Standard Size
5	Don Pedro Reservoir	Year1	large	targeted	Largemouth Bass	350	0.46	L1	NA	11	350 mm Standard Size
5	Don Pedro Reservoir	Year1	large	targeted	Largemouth Bass	350	0.40	L2	NA	11	350 mm Standard Size
5	Don Pedro Reservoir	Year1	large	targeted	Common Carp	563	0.20	L2	1	5	Location Composite
5	Don Pedro Reservoir	Year1	large	targeted	Common Carp	516.2	0.16	L3	1	5	Location Composite
5	Don Pedro Reservoir	Year1	large	targeted	Common Carp	555.8	0.15	L1	1	5	Location Composite
5	Stony Gorge Reservoir	Year1	medium	targeted	Largemouth Bass	350	0.45	L2	NA	11	350 mm Standard Size
5	Stony Gorge Reservoir	Year1	medium	targeted	Largemouth Bass	350	0.34	L1	NA	11	350 mm Standard Size
5	Stony Gorge Reservoir	Year1	medium	targeted	Sacramento Sucker	322.4	0.14	L2	1	5	Location Composite
5	Stony Gorge Reservoir	Year1	medium	targeted	Sacramento Sucker	313.4	0.11	L1	1	5	Location Composite
5	Camp Far West Reservoir	Year1	medium	targeted	Channel Catfish	418	0.44	L2	1	5	Location Composite
5	Camp Far West Reservoir	Year1	medium	targeted	Channel Catfish	458.6	0.32	L1	1	5	Location Composite
5	Isabella Lake	Year2	large	targeted	Common Carp	497.6	0.44	L2	1	5	Location Composite
5	Isabella Lake	Year2	large	targeted	Common Carp	494.6	0.41	L1	1	5	Location Composite

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppm)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	Isabella Lake	Year2	large	targeted	Common Carp	529.4	0.35	L3	1	5	Location Composite
5	Isabella Lake	Year2	large	targeted	Largemouth Bass	350	0.21	L2	NA	11	350 mm Standard Size
5	Isabella Lake	Year2	large	targeted	Largemouth Bass	350	0.19	L1	NA	11	350 mm Standard Size
5	Isabella Lake	Year2	large	targeted	Largemouth Bass	350	0.16	L3	NA	11	350 mm Standard Size
6	Little Rock Reservoir	Year2	small	targeted	Largemouth Bass	350	0.92	L1	NA	11	350 mm Standard Size
6	Little Rock Reservoir	Year2	small	targeted	Common Carp	497.4	0.43	L1	1	5	Location Composite
6	Little Rock Reservoir	Year2	small	targeted	Common Carp	497	0.37	L1	2	5	Location Composite
6	Silverwood Lake	Year1	small	targeted	Largemouth Bass	350	0.49	L1	NA	16	350 mm Standard Size
8	Irvine Lake	Year1	small	targeted	Largemouth Bass	350	0.48	L1	NA	11	350 mm Standard Size
8	Irvine Lake	Year1	small	targeted	Common Carp	596	0.11	L1	2	5	Location Composite
8	Irvine Lake	Year1	small	targeted	Common Carp	597	0.09	L1	1	5	Location Composite
9	Loveland Reservoir	Year1	small	random	Largemouth Bass	350	0.63	L1	NA	11	350 mm Standard Size
9	Loveland Reservoir	Year1	small	targeted	Common Carp	456.4	0.11	L1	2	5	Location Composite
9	Loveland Reservoir	Year1	small	targeted	Common Carp	455.6	0.09	L1	1	5	Location Composite

Although methylmercury concentrations were generally not as high in southern California, the methylmercury problem is not confined to northern California and its well-known mining regions. Most of the 83 lakes in southern California were between 0.07 and 0.44 ppm (57%), but 16% had a maximum species average above 0.44 ppm (Table 6). Average concentrations above 0.90 ppm were observed in two lakes in close proximity to each other: Crystal Lake (0.95 ppm in largemouth) and Little Rock Reservoir (0.92 ppm in largemouth). The remaining lakes (27%) in this region had a species average below 0.07 ppm (Table 6, Figure 2). Largemouth bass were collected at only seven of the 22 lakes that were below 0.07 ppm in southern California.

Implications Regarding Sources

Although identifying sources of contamination was not a primary goal of the study, this is one of the broader goals of the SWAMP. With an extensive statewide dataset, an attempt was made to determine whether the results from this study could shed some light on the relative importance of sources contributing to bioaccumulation of methylmercury uptake such as historic mining activity and atmospheric deposition. Understanding the relative importance of these and other sources has significant implications for management of the methylmercury problem in California.

Two approaches were taken to attempt to discern the importance of different sources. The first approach was quantitative – the development of a statistical model to evaluate the relative importance of many potentially important factors influencing methylmercury bioaccumulation (Negrey et al. 2010). This assessment examined watershed attributes relating to contaminant sources (mercury and gold mining, soil mercury, point sources) and other factors (e.g., watershed area, forested area, wetland area), as well as detailed information on lake attributes, making use of information generated in companion study to develop bioaccumulation factors for lakes. This quantitative assessment focused on the 17 lakes where detailed information was available.

The second approach, presented in Davis et al. (2010), was a qualitative evaluation of the fish methylmercury data in comparison to broad scale datasets on mining and geology. This qualitative effort focused on assessing the potential influence of atmospheric deposition of mercury. Considerable uncertainty surrounds this topic.

It seems certain that atmospheric deposition contributes to food web uptake to some degree. Global atmospheric transport brings a significant quantity of mercury across the Pacific Ocean. Local terrestrial sources of atmospheric mercury then add to this global background. Mercury deposited to surface waters from the atmosphere is considered to have relatively high bioavailability (Hintelmann et al. 2002).

However, the extent of the atmospheric deposition contribution to food web mercury in California's lakes and reservoirs is unclear. At one end of the spectrum is the hypothesis that atmospheric deposition alone could be sufficient to cause the degree of methylmercury bioaccumulation that is observed across California. One major body of evidence in support of this hypothesis is extensive data from other regions in North America where atmospheric deposition is clearly the driver of bioaccumulation (Wiener et al. 2006, Harris et al. 2007). In spite of the extensive mining legacy in California, the degree of food web contamination in this state does not differ greatly from that seen across the rest of the continent (discussed further below). An alternative hypothesis is that atmospheric deposition constitutes a lower level background that contributes to, but does not dominate, food web contamination, and that mining legacy or geologic mercury is the primary source of methylmercury in the food web in California's lakes and reservoirs.

The approach taken by Davis et al. (2010) to evaluate these hypotheses was to compare patterns in some of the key watershed attributes identified by Negrey et al. (2010) to fish methylmercury at a selected subset of the 272 lake dataset. The subset of lakes selected for this analysis all had largemouth bass, and included the 14 lakes with the highest bass methylmercury concentrations, the 14 lakes with the lowest concentrations, and the 17 lakes included in the quantitative analysis. It was hoped that any obvious patterns would readily emerge from a comparison of lakes with low and high methylmercury concentrations in fish.

Overall, this analysis suggested that in the active and complex geology of California it is not possible to conclusively determine whether specific watersheds are free from the possible influence of historic mining activity or mercury-enriched geology based solely on available GIS layers. In order to resolve the question of the influence of atmospheric deposition it would be necessary to perform more detailed, site-specific field work to assess the contributions of mining sediment or geology. The simplest approach would be to measure the amount of total mercury in lake sediments and see how this correlates with mercury in the food web. This approach appears promising based on Negrey et al. (2010). To reduce potential variability related to food web structure, a more definitive study would ideally examine accumulation in young-of-the-year fish (Wiener et al. 2007). Another possible approach would be to assess mercury sources through the use of mercury isotopes, which have shown some promise in identifying sources of food web mercury in San Francisco Bay (unpublished data).

Available data appear to support a general conceptual model that includes a combination of atmospheric deposition, legacy contamination from mining, and geological sources as the drivers of methylmercury bioaccumulation in California lakes and reservoirs. Methylmercury concentrations in largemouth bass of approximately 0.2 ppm in two coastal lakes situated relatively far from geologic sources of mercury but very close to the coast may be a reasonable indication of the degree of contamination attributable to long-range atmospheric transport and deposition from sources across the Pacific Ocean. Atmospheric deposition can probably lead to significantly higher or lower concentrations in aquatic food webs depending on site-specific biogeochemistry or limnology (e.g., lake productivity). Emissions from urban areas, historic mining districts, and geological sources lead to increased atmospheric deposition in inland areas adding to the background oceanic input. Mining-contaminated sediments, mercury-rich soils, and other terrestrial sources are transported into aquatic ecosystems and can also contribute to severe food web contamination, with the Guadalupe Reservoir (Tetra Tech 2005; also described in the next section) being the most extreme example. Lake biogeochemistry can also greatly dampen or increase the impact of the combined mix of sources. The end result of the interplay of these and other factors is the spatially heterogeneous patchwork of aquatic food web contamination observed in this survey.

Comparison to the National Lakes Survey

USEPA recently published results from a national probabilistic survey of contaminants in fish based on sampling conducted in 2000-2003 (Stahl et al. 2009). The results from this survey provide a national frame of

reference for the present study. Unfortunately, the data from the two surveys are not directly comparable for two major reasons. First, the USEPA survey used a similar approach with a predator and a bottom-dweller targeted at each lake. However, USEPA analyzed fillets in the predator, but whole bodies in the bottom-dweller. USEPA consequently presented results for predators and bottom-dwellers separately. Second, USEPA did not make as great an effort to control for the size of fish analyzed. The sizes of fish collected were more variable and they did not estimate concentrations at a standard size.

The national survey found that fillets of predators in 49% of the sampled population of lakes had methylmercury concentrations that exceeded the USEPA 0.3 ppm fish tissue criterion for mercury. The median methylmercury concentration in predator fillets in the national survey was 0.28 ppm (Table 9). In comparison, the median for predator fillets in this survey was much lower: 0.16 ppm. However, due to the large surface area of mountains in California, the state survey included a much higher percentage of trout lakes (44%) than the national survey (12%). The largemouth bass data from this study provide another frame of reference for comparing California to the US as a whole. The median methylmercury concentration in largemouth bass in this study was 0.34 ppm, slightly higher than the national median (0.28 ppm). Overall, although it is difficult to make a direct comparison, both the California data for predators and for largemouth bass indicate that methylmercury concentrations in California sport fish are at or below the national median.

The USEPA survey sampled 18 California lakes. Nine out of 18 (50%) of these lakes had a sample above the USEPA threshold of 0.3 ppm, similar to the national dataset as a whole. In general these data fell within the range of results from the present survey. One exception was Guadalupe Reservoir, which was sampled by USEPA but was not in the California survey. The largemouth bass composite sample from Guadalupe Reservoir had a methylmercury concentration of 6.60 ppm, the highest concentration measured in the entire country. The carp composite from Guadalupe Reservoir measured 0.52 ppm, close to the national maximum for bottom dwellers of 0.60 ppm. Exceptionally high methylmercury contamination in Guadalupe Reservoir, downstream of the historic New Almaden mercury mining district, has previously been documented (e.g., Tetra Tech 2005).

Priorities for Further Assessment

Lakes with average methylmercury concentrations of one or more species above 0.44 ppm should clearly be considered high priorities for further assessment to determine the need for consumption guidelines and management actions. Many lakes had concentrations well above the 0.44 ppm threshold (Table 8). Almaden Lake in Santa Clara County (also downstream of New Almaden) had the highest species average methylmercury concentration in this survey: 2.15 ppm in largemouth bass. Other lakes with a species average concentrations above 1 ppm included (all are in 350 mm largemouth bass unless otherwise noted): Lake Pillsbury in Region 1 (1.31 ppm); Upper San Leandro Reservoir (1.01 ppm) and Calero Reservoir (1.05 ppm) in Region 2; Cosumnes River (1.15 ppm), Lower Mokelumne River 7 (1.21 ppm in Sacramento pikeminnow), New Melones Lake (1.12 ppm), and Eastman Lake (1.04 ppm) in Region 5; and Chesbro Reservoir (1.04 ppm) and Lake Nacimiento (1.00 ppm in smallmouth bass [not size-adjusted]) in Region

3. All of these lakes above 1 ppm were in the mercury and gold mining regions in the northern part of the state. Table 8 shows the data for samples at the 61 lakes that had a species average above 0.44 ppm based on either individual or composite samples. Consumption guidelines have already been issued for 20 (33%) of these lakes, but 41 (67%) do not have guidelines.

Other priorities for further assessment to understand the sources and patterns of methylmercury contamination in California lakes are discussed in the last section of this report: Recommendations for Future Monitoring.

Table 9
Comparison of data from this study to data from the national study of contaminants in fish from lakes (Stahl et al. 2009). Data from this study for largemouth bass and predators (including all bass and trout species, as well as Sacramento pikeminnow) are compared to predator data from the national survey. All data are for muscle fillets.

		Mercury (ppm wet)	DDTs (ppb wet)	PCBs (ppb wet)
This study: largemouth bass	# of samples	199	101	101
	MEDIAN	0.34	1.9	1.1
This study: predators (181 trout, 44%)	# of samples	414	191	191
	MEDIAN	0.16	1.96	0.46
USEPA: predators (59 trout, 12%)	# of samples	486	486	486
	MEDIAN	0.28	1.5	2.2

PCBS

Comparison to Thresholds

PCBs (measured as the sum of 55 congeners) were second to methylmercury in reaching fish tissue concentrations posing potential health risks to consumers of fish caught from California lakes. However, far fewer lakes had PCB concentrations exceeding OEHHA's higher risk thresholds (Tables 4 and 10, Figure 7). Overall, only three of the 272 lakes assessed (1.1%) had a species with an average concentration high enough that OEHHA would consider recommending no consumption of the contaminated species (120 ppb). The vast majority of lakes in the survey (92%) were below the three serving ATL for PCBs (21 ppb).

The lowest threshold for PCBs was the FCG (3.6 ppb). For PCBs, 33% of the 272 lakes were above this threshold: 20% of the random lakes and 35% of the targeted lakes (Figures 8a,b). Southern California had a higher percentage of lakes with at least one sample above 3.6 ppb (60%) than lower elevation lakes in northern California (40%) and northern California trout lakes (8%) (Table 10).

The frequency distributions were different for random and targeted lakes (Figures 8a,b). This was due to the relatively extensive sampling of Region 4, the Region with the highest PCB concentrations. For the random lakes, the percentages expressed on an areal basis were very similar to those expressed on a per lake basis.

Spatial Patterns

PCB concentrations across the state varied at a regional scale (Table 10, Figure 7). Similar to the regional pattern seen for methylmercury, in northern California low concentrations were commonly observed in high elevation lakes in the Sierra Nevada and Trinity Alps. The vast majority of species averages observed in these lakes were below the FCG (3.6 ppb). For the 87 northern California lakes where trout were collected, 92% had a maximum species average below 3.6 ppb, 7% were between 3.6 and 21 ppb (the 3 serving ATL), one lake (1%) was between 21 and 42 ppb (the 2 serving ATL), and none were above 42 ppb. The highest species average measured in this region was 28 ppb in a brown trout sample from Silver Lake in Region 6.

PCB concentrations in low elevation (below 2000 ft) lakes in northern California were greater than those in the trout lakes (Table 10, Figure 7). Of the 82 low elevation lakes sampled in northern California, 60% had a maximum species average below 3.6 ppb, 29% were between 3.6 and 21 ppb, 2% were between 21 and 42 ppb, 7% were between 42 and 120 ppb, and one was above 120 ppb. The one lake with a species average above 120 ppb was Lake Vasona in Region 2, where two common carp composites had an average of 147 ppb (Table 11). The two composites measured 204 and 89 ppb. Average concentrations at two other low elevation lakes from northern California were among the highest concentrations measured in the state (Table 11): Lake Chabot in San Leandro in Region 2 (98 ppb) and San Luis Reservoir in Region 5 (85 ppb).

Table 10
Percentages of lakes in PCB concentration categories by region.
Concentrations in ppb. Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each PCB Concentration Category				
		<3.6	3.6-21	21-42	42-120	>120
California	272	67	25	3	4	1
Northern California Trout Lakes	87	92	7	1	0	0
Northern California Lower Elevation (<2000 ft)	82	60	29	2	7	1
Southern California	83	40	46	5	7	2

Southern California was the region with the highest PCB concentrations. Of the 83 lakes in southern California sampled, 40% had a maximum species average below 3.6 ppb, 46% were between 3.6 and 21 ppb, 5% were between 21 and 42 ppb, 7% were between 42 and 120 ppb, and two lakes (2%) were above 120 ppb (Table 10). Average concentrations at four lakes from southern California were among the highest concentrations measured in the state (Table 11): Pyramid Lake (238 ppb in brown bullhead), Elderberry Forebay (131 ppb in channel catfish), and Echo Lake (101 ppb in common carp) in Region 4; and Silverwood Lake (93 ppb in largemouth bass) in Region 6. Pyramid Lake and Elderberry Forebay were the two lakes in southern California exceeding the 120 ppb no consumption ATL. The PCB concentrations observed in largemouth bass in Silverwood Lake are exceptionally high for this species, and much higher than those measured in largemouth bass from Pyramid Lake where the higher lipid, bottom-feeding species (brown bullhead) reached the maximum concentrations observed in the entire dataset.

Implications Regarding Sources

The geographic distribution of PCBs measured in California sport fish provides an indication of the location and nature of the principal sources of these chemicals. A review of historic bioaccumulation monitoring of PCBs in California (Davis et al. 2007) found that high concentrations of PCBs tended to occur in areas of historic use or maintenance of electrical equipment. These areas tend to be concentrated in urban centers with high amounts of industrial activity, but also occur in scattered areas across the landscape where electrical equipment or other PCB-containing equipment was used. The many hydroelectric facilities in the state are potential sites of past or present PCB contamination.

Similar to methylmercury, significant variation exists among species in their tendency to accumulate PCBs, with high-lipid bottom-feeders like common carp, channel catfish, and brown bullhead usually accumulating the highest concentrations. Trophic position is also an important influence on biomagnification of organic contaminants, though factors leading to high concentrations in bottom-feeding species in California freshwater systems seem to predominate. Because of this interspecific variation, a map of concentrations in common carp and channel catfish provides a clearer picture of spatial variation (Figure 9).

The patchy distribution of PCBs across the state, with lakes with low concentrations observed in most areas and scattered lakes with much higher concentrations, is consistent with contamination by local sources. The Los Angeles and San Francisco Bay regions appear to be exceptions to this general pattern, with a very high prevalence of lakes above the FCG (Figure 9) that may suggest an elevated signal of regional atmospheric deposition. Other urban sources, such as urban runoff and landfill leachates may also contribute to this regional pattern.

Comparison to the National Lakes Survey

USEPA's national lakes survey did not analyze bottom-feeder fillets. Whole body and fillet samples typically exhibit very different concentrations of organics, so it is not possible to directly compare the bottom-feeder

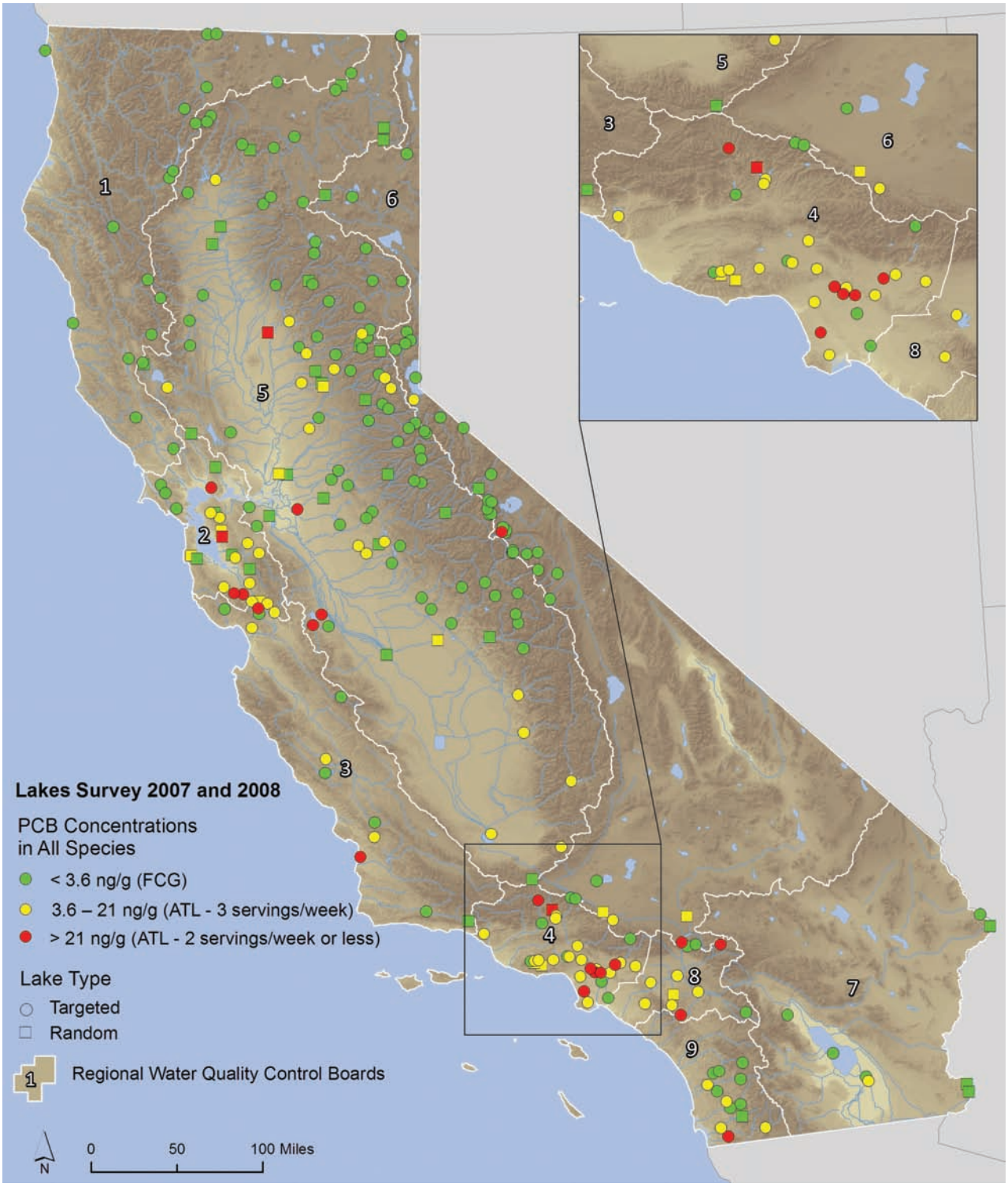

Figure 7. Spatial patterns in PCB concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Note different scale from the methylmercury maps, with the two serving ATL as the highest threshold.

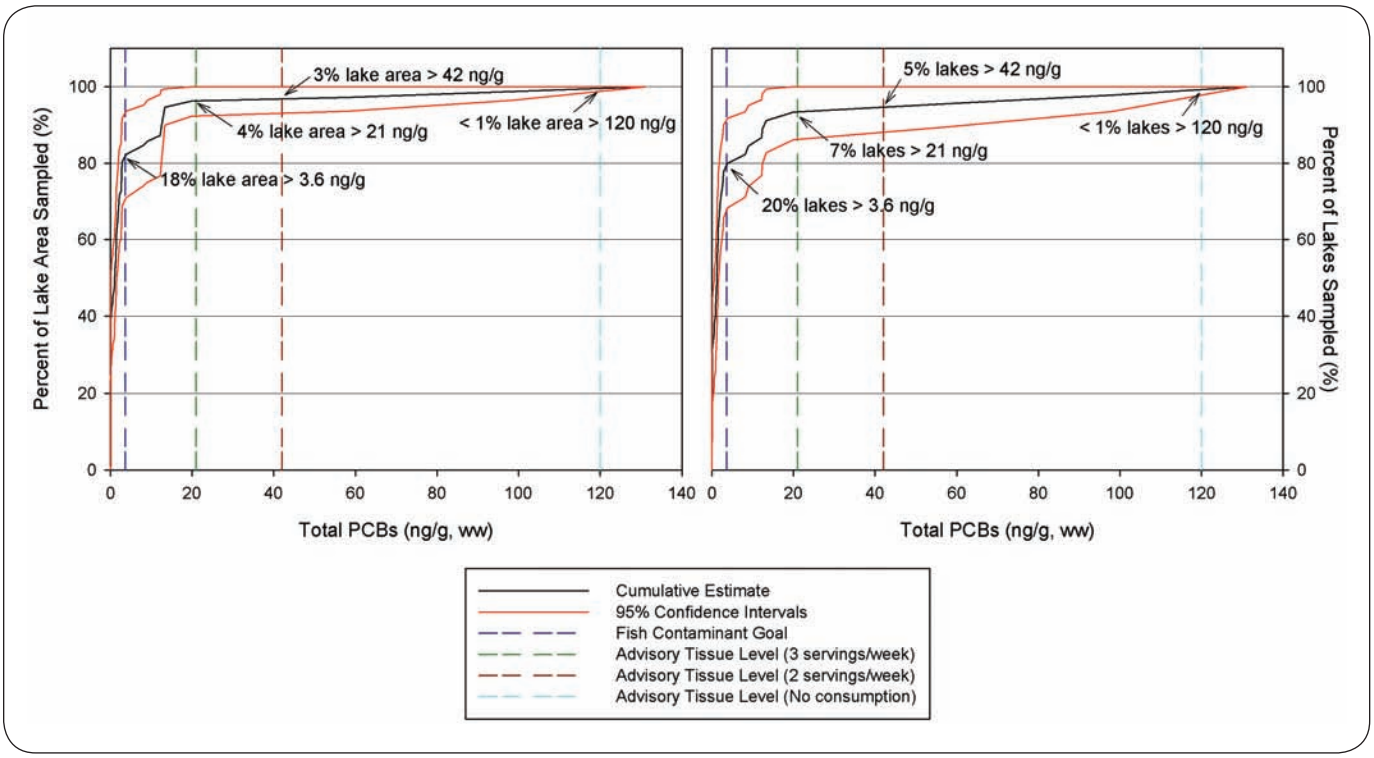

Figure 8a. Cumulative distribution function (CDF) plot for PCBs at random lakes, shown as percent of lake area (left) and percent of lakes (right). Concentrations (ng/g wet weight) are the highest species average for each lake, based on lake-wide composites at randomly sampled lakes in the Lakes Survey. Vertical lines are threshold values. Text on figure describes the percent of lake area or lakes that exceed each threshold value.

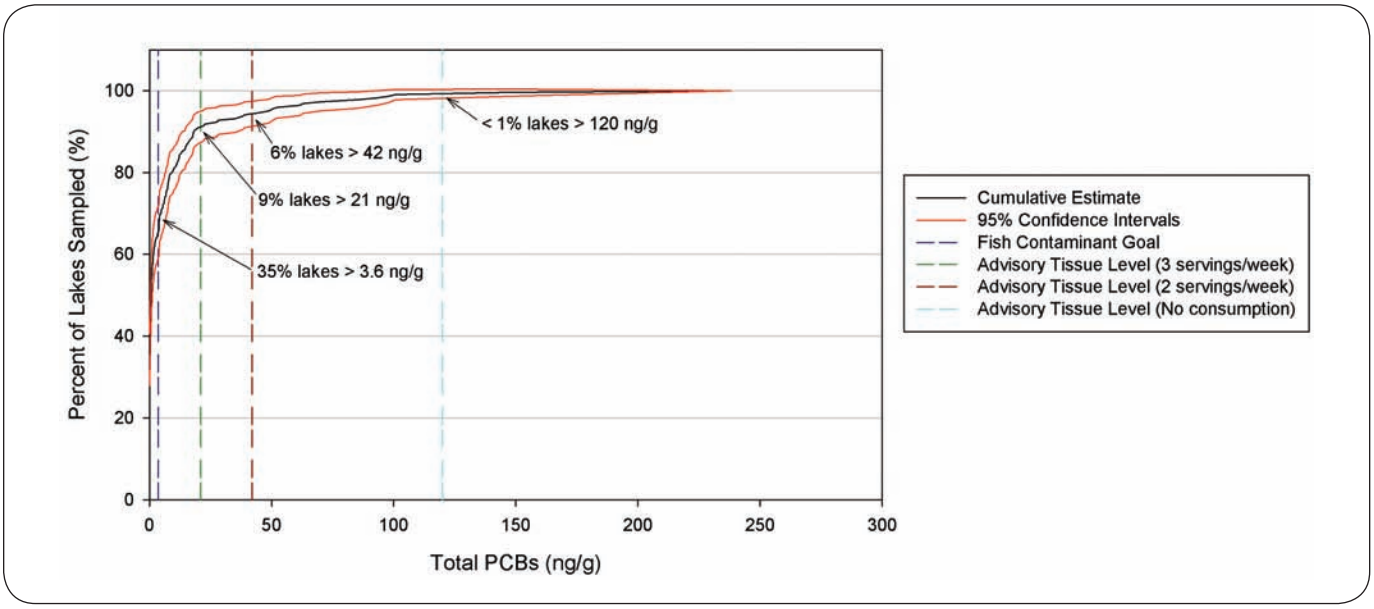

Figure 8b. Cumulative Distribution Function (CDF) plot for PCBs at targeted lakes, shown as percent of lakes sampled. Concentrations (ng/g wet weight) are the highest species average for each lake, based on lake-wide composites at targeted lakes in the Lakes Survey. Vertical lines are threshold values.

Table 11
Lakes with the highest PCB concentrations (ppb).
Data for samples of individual fish are not included in this table.

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppb)	Location Code	Composite Number	Number Fish In Sample	Sample Type
2	Lake Vasona	Year2	small	targeted	Common Carp	591	204	L1	1	5	Location Composite
2	Lake Vasona	Year2	small	targeted	Common Carp	590	89	L1	2	5	Location Composite
2	Lake Chabot (San Leandro)	Year1	small	targeted	Common Carp	521	148	L1	1	5	Location Composite
2	Lake Chabot (San Leandro)	Year1	small	targeted	Common Carp	521	48	L1	2	5	Location Composite
4	Pyramid Lake	Year1	medium	targeted	Brown Bullhead	319	416	L1	1	5	Location Composite
4	Pyramid Lake	Year1	medium	targeted	Brown Bullhead	353	195	L1; L2	NA	10	Lake-wide Composite
4	Pyramid Lake	Year1	medium	targeted	Largemouth Bass	359	66	L1; L2	NA	10	Lake-wide Composite
4	Pyramid Lake	Year1	medium	targeted	Largemouth Bass	361	66	L1	1	5	Location Composite
4	Pyramid Lake	Year1	medium	targeted	Brown Bullhead	387	60	L2	1	5	Location Composite
4	Pyramid Lake	Year1	medium	targeted	Largemouth Bass	357	35	L2	1	5	Location Composite
4	Elderberry Forebay	Year1	small	targeted	Channel Catfish	587	146	L1	2	5	Location Composite
4	Elderberry Forebay	Year1	small	targeted	Channel Catfish	594	116	L1	1	5	Location Composite
4	Elderberry Forebay	Year1	small	targeted	Largemouth Bass	350	32	L1	1	5	Location Composite
4	Elderberry Forebay	Year1	small	targeted	Largemouth Bass	347	20	L1	2	5	Location Composite
4	Echo Lake - Reg 4	Year1	small	targeted	Common Carp	501	119	L1	1	5	Location Composite
4	Echo Lake - Reg 4	Year1	small	targeted	Common Carp	498	83	L1	2	5	Location Composite
4	Echo Lake - Reg 4	Year1	small	targeted	Largemouth Bass	380	65	L1	1	5	Location Composite
4	Echo Lake - Reg 4	Year1	small	targeted	Largemouth Bass	380	31	L1	2	5	Location Composite

Regional Board	Station Name	Study Year	Lake Size	Lake Type	Common Name	Total Length Average (mm)	Result (ppb)	Location Code	Composite Number	Number Fish In Sample	Sample Type
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	801	133	L3	1	5	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	766	100	L1; L2; L3	NA	14	Lake-wide Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	728	81	L1	1	5	Location Composite
5	San Luis Reservoir	Year1	ex-large	targeted	Common Carp	768	42	L2	1	4	Location Composite
6	Silverwood Lake	Year1	small	targeted	Largemouth Bass	368	131	L1	1	5	Location Composite
6	Silverwood Lake	Year1	small	targeted	Largemouth Bass	367	55	L1	2	5	Location Composite

data in the national and California datasets. Although organics concentrations were generally lower in predator tissues, the predator fillets provide the best basis for comparing the two datasets. USEPA found that predator fillets in 16.8% of the sampled population of lakes had total PCB tissue concentrations that exceeded a 12 ppb human health risk-based threshold (Stahl et al. 2009). The median PCB concentration in predator fillets in the national survey was 2.2 ppb (Table 9). In comparison, the median for predator fillets in this survey was much lower: 0.46 ppb. However, due to the large surface area of mountains in California, the state survey included a much higher percentage of trout lakes (44%) than the national survey (12%), and trout tend to accumulate lower concentrations of PCBs than bottom-feeding warmwater species such as carp and catfish. The largemouth bass data from this study provide another frame of reference for comparing California to the US as a whole. The median PCB concentration for largemouth bass in this study was 1.1 ppb, also well below the national median of 2.2 ppb (Table 9). Both the California data for predators and for largemouth bass indicate that PCB concentrations in California sport fish are below the national median. Overall, the degree of PCB contamination of California lakes documented in this survey is relatively low compared to the rest of the country.

The USEPA survey sampled bottom dwellers in 11 California lakes. Seven out of 11 (64%) of these lakes had a sample above 12 ppb. In general these samples had higher PCB concentrations than observed in the present study. Particularly high concentrations were measured in Lake Oroville (252 ppb in common carp), Guadalupe Reservoir (103 ppb in common carp), and San Luis Reservoir (102 ppb in Sacramento sucker). This result for San Luis Reservoir was similar to results from the present study (average of 85 ppb in common carp fillets - Table 11).

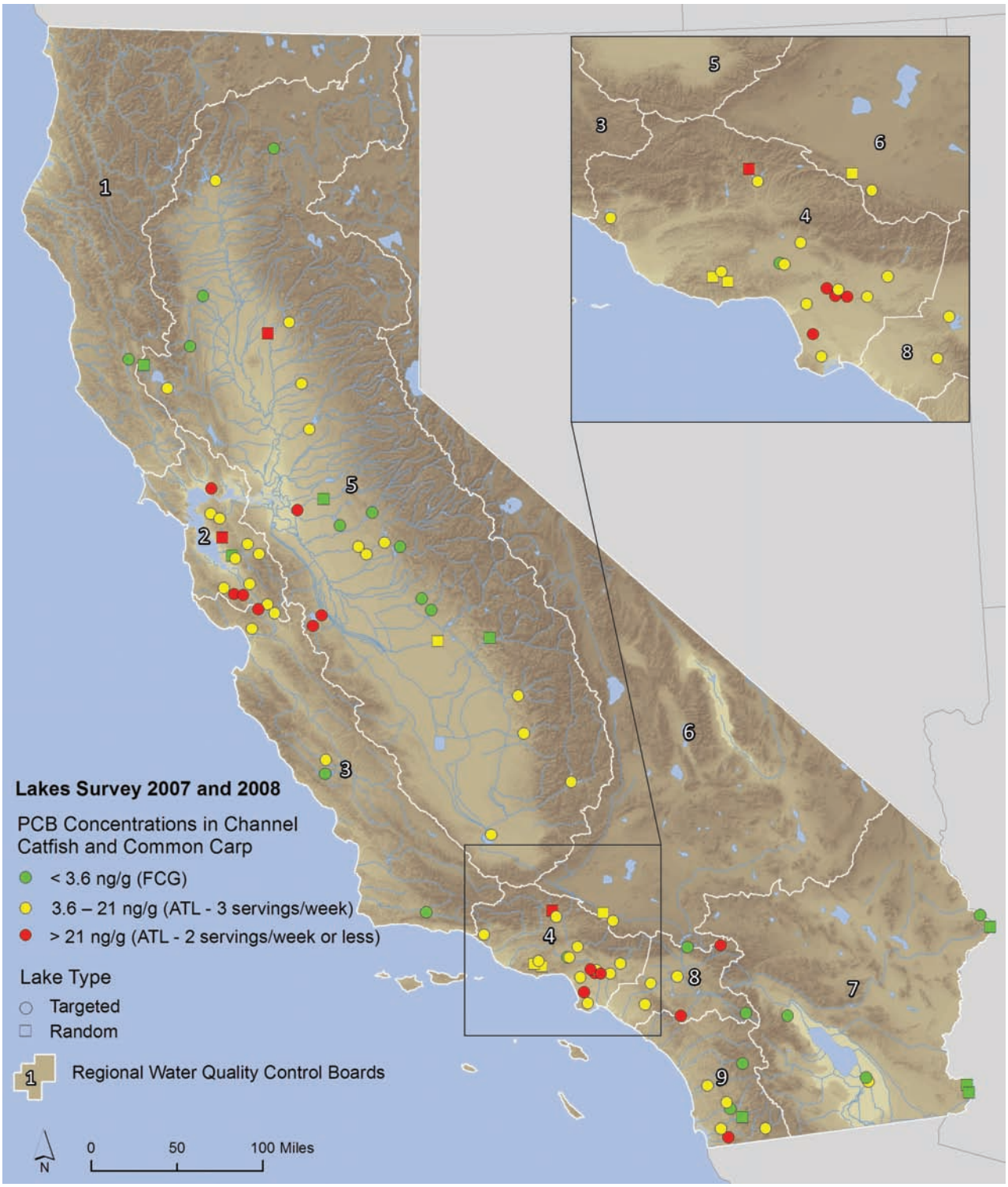

Figure 9. Spatial patterns in PCB concentrations (ng/g wet weight) in common carp and channel catfish at lakes sampled in the Lakes Survey, from both targeted (circles) and random (squares) lakes. Note that the two serving ATL is the highest threshold shown on this map.

Priorities for Further Assessment

Using the same criterion that was employed for methylmercury (i.e., exceedance of the no consumption ATL - 120 ppb for PCBs) only three lakes (in contrast to 61 for methylmercury) stand out as high priorities for further assessment to determine the need for consumption guidelines and management actions. Pyramid Lake in Region 4 had the highest species average by far for PCBs in the state (224 ppb in brown bullhead), and the highest concentration in a sample (416 ppb in a composite sample) (Table 11). Elderberry Forebay, a lake just 10 miles away from Pyramid Lake, was another lake with an average concentration exceeding 120 ppb (131 ppb in channel catfish) (Table 11). The third lake with an average above 120 ppb was Lake Vasona in Region 2 (146 ppb in common carp) (Table 11).

Other lakes with relatively high PCB concentrations included Echo Lake (average of 101 ppb in common carp), Lake Chabot (San Leandro) (average of 98 ppb in common carp), Silverwood Lake (average of 93 ppb in largemouth bass), and San Luis Reservoir (average of 85 ppb in common carp). The high concentrations in largemouth bass at Silverwood Lake suggest that this water body may warrant further investigation. Consumption guidelines have been issued for only one of these lakes: Lake Chabot (San Leandro), which has guidelines resulting from PCB contamination.

OTHER POLLUTANTS WITH THRESHOLDS

OEHHA (Klasing and Brodberg 2008) developed thresholds for four other pollutants that were analyzed in this survey: dieldrin, DDT, chlordane, and selenium. Concentrations of these pollutants infrequently exceeded any threshold, and only one highly unusual lake exceeded any no consumption ATLs (Tables 12-15). Results for these pollutants are briefly summarized below.

Table 12
Percentages of lakes in dieldrin concentration categories by region. Concentrations in ppb.
Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each Dieldrin Concentration Category				
		< .46	.46-15	15-23	23-46	>46
California	272	80	20	0	0	0
Northern California Trout Lakes	87	89	11	0	0	0
Northern California Lower Elevation (<2000 ft)	82	72	28	0	0	0
Southern California	83	73	25	0	0	1

Table 13
Percentages of lakes in DDT concentration categories by region. Concentrations in ppb.
Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each DDT Concentration Category				
		<21	21-520	520-1000	1000-2100	>2100
California	272	87	13	0	0	0
Northern California Trout Lakes	87	99	1	0	0	0
Northern California Lower Elevation (<2000 ft)	82	76	24	0	0	0
Southern California	83	82	17	0	0	1

Table 14
Percentages of lakes in chlordane concentration categories by region.
Concentrations in ppb. Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each Chlordane Concentration Category				
		<5.6	5.6-190	190-280	280-560	>560
California	272	91	9	0	0	0
Northern California Trout Lakes	87	99	1	0	0	0
Northern California Lower Elevation (<2000 ft)	82	87	13	0	0	0
Southern California	83	86	14	0	0	0

Table 15
Percentages of lakes in selenium concentration categories by region.
Concentrations in ppb. Note: Some lakes did not fall into the three regional categories.

Region	Number of Lakes	Percentage of Lakes in Each Selenium Concentration Category				
		<2500	2500-4900	4900-7400	7400-15000	15000
California	189	98	2	0	0	0
Northern California Trout Lakes	8	100	0	0	0	0
Northern California Lower Elevation (<2000 ft)	81	99	1	0	0	0
Southern California	80	96	4	0	0	0

Dieldrin

The maximum species averages for dieldrin were below the lowest threshold (the 0.46 ppb FCG) in 80% of all the lakes sampled, including 89% of the northern California trout lakes, 72% of the northern California low elevation lakes, and 73% of the southern California lakes (Table 12, Figure 10). Only one lake out of the 272 lakes sampled exceeded an ATL threshold – Little Oso Flaco Lake, which had an exceptionally high average concentration of 276 ppb based on two goldfish composites. The next highest species average measured was 6.6 ppb in common carp from San Luis Reservoir. Only Little Oso Flaco Lake appears to be a high priority for further assessment or action based on dieldrin concentrations.

Little Oso Flaco Lake is a small lake in the midst of agricultural fields and dunes 1.5 miles from the coast in San Luis Obispo County. Probably due to its proximity to agricultural fields, this lake is noteworthy for its extremely high concentrations of dieldrin, DDTs, and chlordanes. Little Oso Flaco Lake had the highest concentrations in the state for dieldrin and DDT, and one of the highest concentrations of chlordanes.

DDTs

The maximum species averages for DDTs were below the lowest threshold (the 21 ppb FCG) in 87% of all the lakes sampled, including 99% of the northern California trout lakes, 76% of the northern California lower elevation lakes, and 82% of the southern California lakes (Table 13, Figure 11). As for dieldrin, Little Oso Flaco Lake stood out as the only one of 272 lakes exceeding the no consumption ATL of 2100 ppb. DDTs in the two goldfish composites from Little Oso Flaco averaged 7490 ppb. Only one other lake had a sample exceeding the 3 serving ATL threshold for DDTs (520 ppb): Pinto Lake in Region 3, which had a concentration of 557 ppb in a common carp composite (and 290 ppb in a second carp composite). Only Little Oso Flaco Lake appears to be a high priority for further assessment of human health risks due to DDT contamination.

USEPA's national lakes survey found that predator fillets in 1.7% of the sampled population of lakes had concentrations that exceeded the 69 ppb human health risk-basedthreshold for DDT (Stahl et al. 2009). The median DDT concentration in predator fillets in the national survey was 1.5 ppb (Table 9). In comparison, the median for predator fillets in this survey was much higher: 2.0 ppb. Another factor suggesting relatively high DDT concentrations in California is that, due to the large surface area of mountains in California, the state survey included a much higher percentage of trout lakes (44%) than the national survey (12%), and trout tend to accumulate lower concentrations of DDTs than bottom-feeding warmwater species such as carp and catfish. The largemouth bass data from this study provide another frame of reference for comparing California to the US as a whole. The median DDT concentration for largemouth bass in this study was 1.9 ppb, also above the national median. Both the California data for predators and for largemouth bass indicate that DDT concentrations in California sport fish are slightly above the national median.

The maximum DDT concentration observed in the national survey was 1,761 ppb (whole body). The average concentration observed for Little Oso Flaco Lake in this study (7490 ppb in muscle) greatly exceeded all of the concentrations measured by USEPA. Overall, the degree of DDT contamination of California lakes documented in this survey is slightly elevated compared to the rest of the country.

The USEPA survey sampled bottom dwellers in 11 California lakes. Four out of 11 (36%) of these lakes had a DDT sample above 69 ppb. In general these whole body samples had higher DDT concentrations than observed in fillets in the present study. Particularly high DDT concentrations were measured in Clear Lake (154 ppb in goldfish and 106 ppb in largemouth bass), San Luis Reservoir (97 ppb in Sacramento sucker), and Guadalupe Reservoir (85 ppb in common carp). The result for San Luis Reservoir was lower than the result from the present study (average of 196 ppb in common carp), but the present study found high variance among three composites at this reservoir (324, 175, and 90 ppb). The USEPA bottom dweller result for Clear Lake was very similar to the concentration observed in common carp at Clear Lake in the present study (134 ppb).

Risks to wildlife from DDT contamination in some lakes are likely to be significant. Based on the degree of contamination observed in this survey, DDT would be expected to exceed thresholds for effects on raptor reproduction in some lakes. In addition to Little Oso Flaco Lake, Pinto Lake, San Luis Reservoir, and Clear Lake, other lakes with relatively high DDT concentrations included Sepulveda Lake (275 ppb in common carp), Perris Reservoir (193 ppb in largemouth bass), Lake del Valle (104 ppb in channel catfish), and Almaden Lake (99 ppb in common carp).

Chlordanes

The maximum species averages for chlordanes were below the lowest threshold (the 5.6 ppb FCG) in 91% of all the lakes sampled, including 99% of the northern California trout lakes, 87% of the northern California lower elevation lakes, and 86% of the southern California lakes (Table 14, Figure 12). None of the ATL thresholds were exceeded in any part of the state. The highest species average measured was 68 ppb in common carp from Almaden Lake in Region 2. The highest concentration measured in any sample was 78 ppb in a common carp composite from Lake Lindero (a second sample in Lake Lindero measured 43 ppb). Other lakes with relatively high concentrations were Lake Chabot (San Leandro) (42 ppb) and Little Oso Flaco Lake (36 ppb).

USEPA compared their predator results to a threshold of 67 ppb for chlordanes. Predator fillets in 0.3% of the national sampled population of lakes had concentrations that exceeded this threshold. Bottom-dweller concentrations (whole body) in the national survey had a median concentration of 1.65 ppb. Only one lake in the present study had a concentration (fillet) above 67 ppb (Almaden Lake). None of the lakes sampled appear to be a high priority for further assessment or action based on chlordane concentrations.

Selenium

The maximum species averages for selenium were below the lowest selenium threshold (the 3 serving ATL of 2,500 ppb) in 98% of all lakes sampled, including 100% of the northern California trout lakes, 99% of the northern California lower elevation lakes, and 96% of the southern California lakes (Table 15, Figure 13). Only Lake Cunningham (3,780 ppb) in Region 2, Ramer Lake (3,020 ppb) and Salton Sea (2,580 ppb) in Region 7, and Lake Lindero (2,790 ppb) in Region 4 exceeded the 2,500 ppb threshold. The highest concentration measured in any sample was 4,040 ppb in a common carp composite from Lake Cunningham. Only one sample (the carp composite from Lake Cunningham) exceeded a no effect threshold of 4 ppm (SFEI 2008) for effects on fish. None of the lakes sampled appear to be a high priority for further assessment or action based on selenium concentrations.

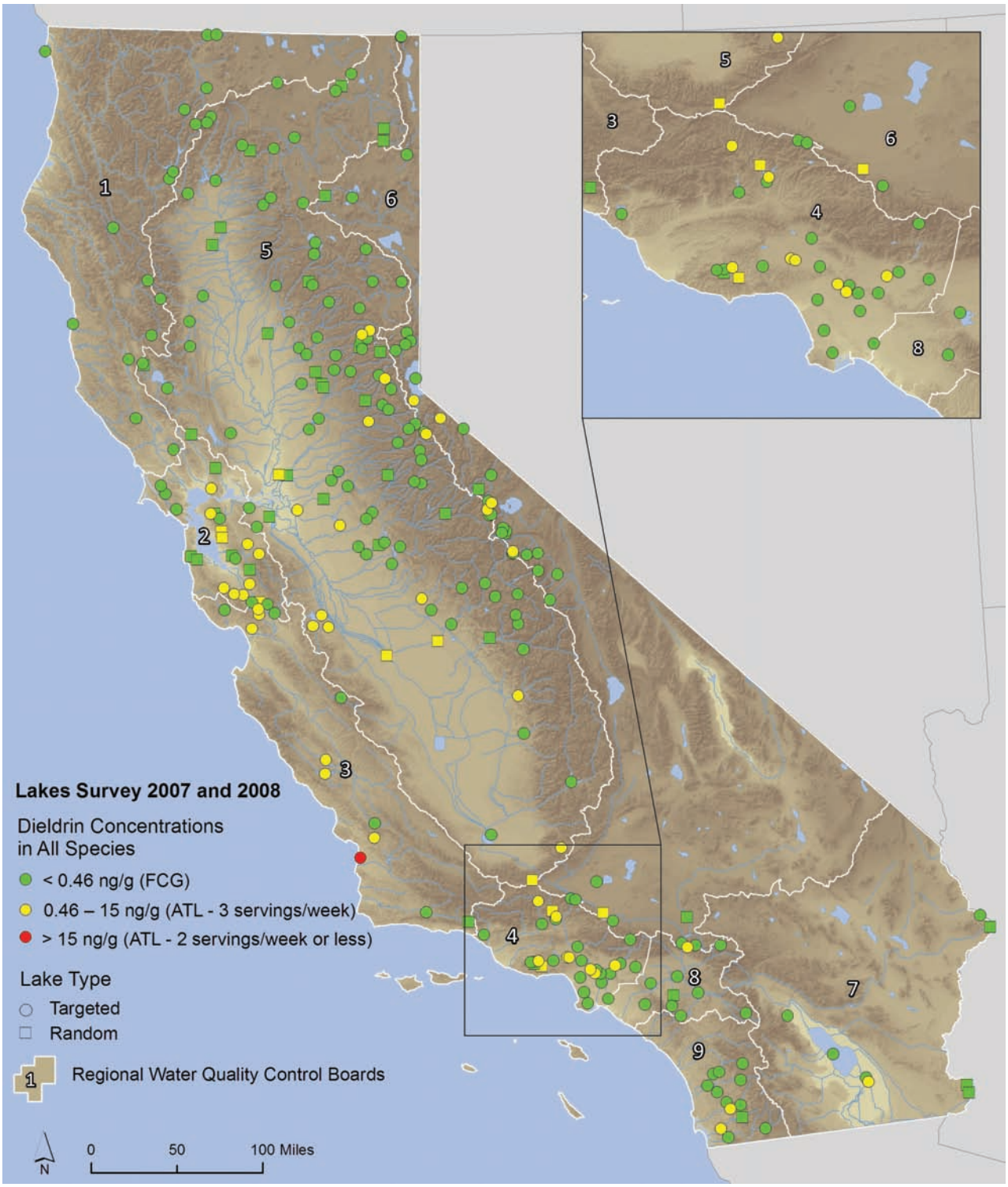

Figure 10. Spatial patterns in dieldrin concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Colors represent dieldrin concentration categories. Note that the two serving ATL is the highest threshold shown on this map.

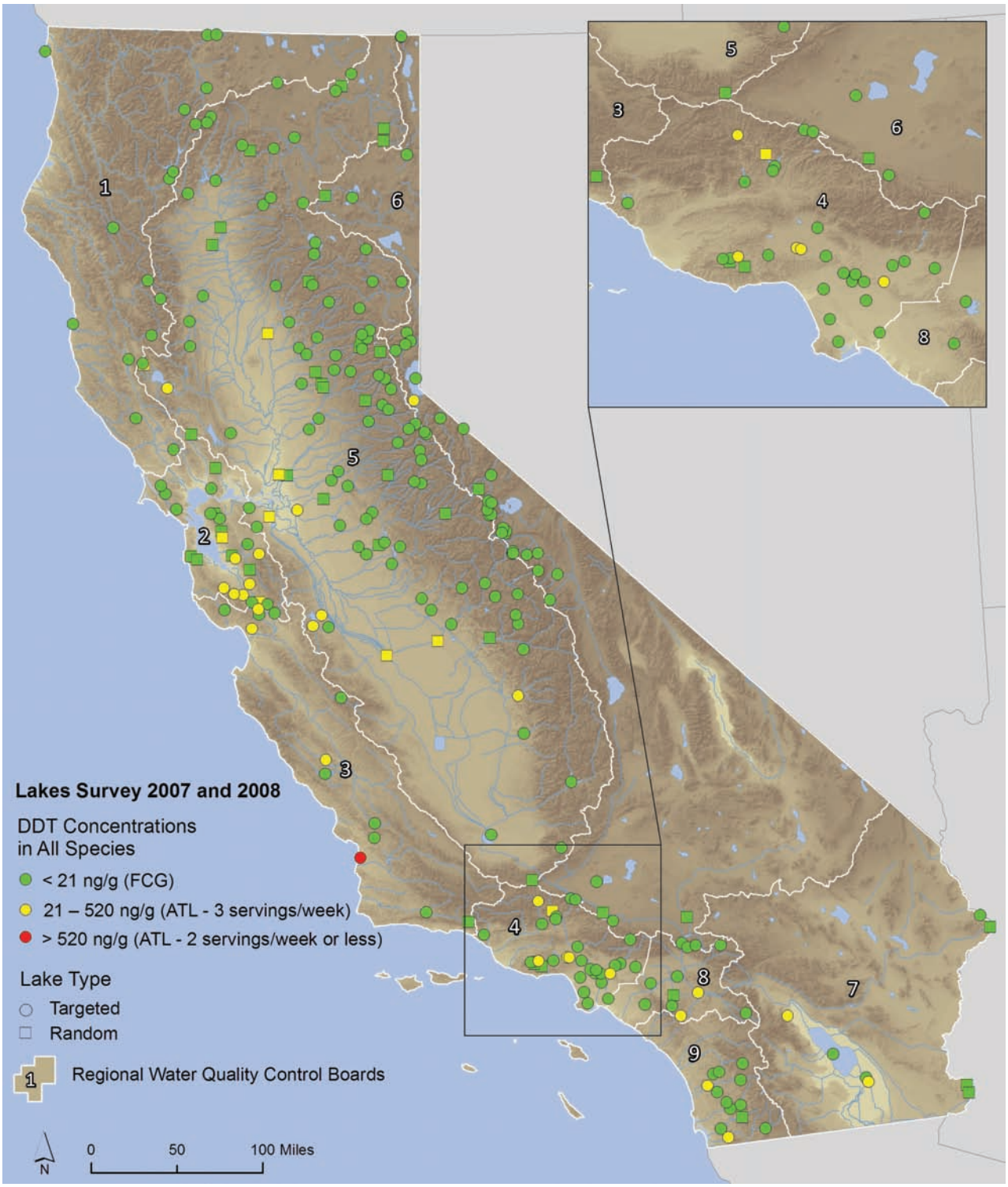

Figure 11. Spatial patterns in DDT concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Note that the two serving ATL is the highest threshold shown on this map.

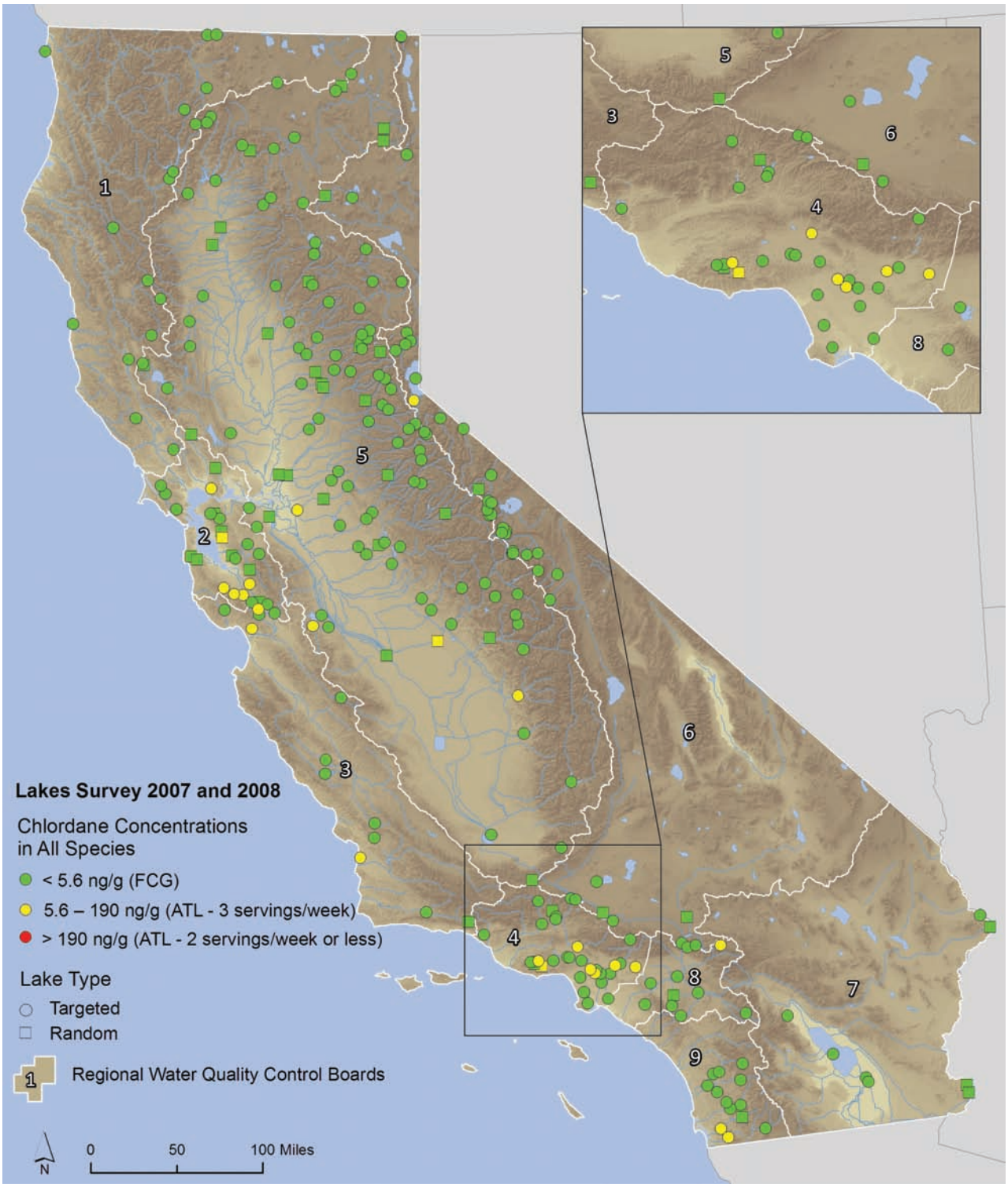

Figure 12. Spatial patterns in chlordane concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Note that the two serving ATL is the highest threshold shown on this map.

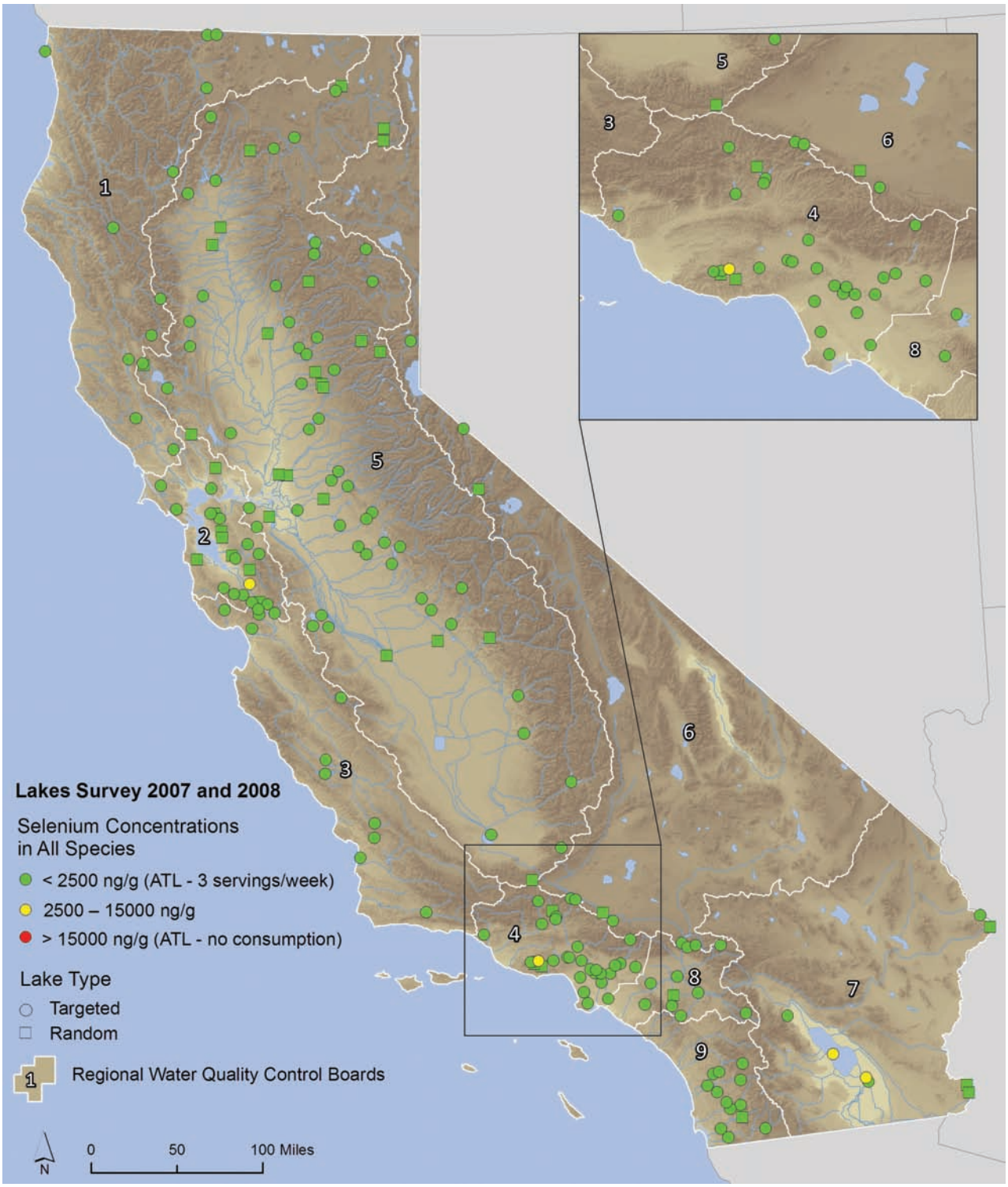

Figure 13. Spatial patterns in selenium concentrations (ng/g wet weight) at lakes sampled in the Lakes Survey. Each point represents the highest average concentration among the species sampled in each lake. Concentrations based on lake-wide and location composites, from both targeted (circles) and random (squares) lakes. Note that the two serving ATL is the highest threshold shown on this map.

SECTION 4 RECOMMENDATIONS FOR FUTURE MONITORING

The work presented in this report represents a major step forward in understanding the extent of chemical contamination in sport fish in California lakes and reservoirs, and the impact of this contamination on the fishing beneficial use. The study has shown that mercury accumulation in fish is a significant problem throughout much of the state. However, comparison to USEPA's national survey indicate that the degree of mercury contamination in California is not unusual compared to the rest of the country, in spite of the intensive mercury and gold mining that has occurred here. For other contaminants, concentrations were much lower relative to thresholds for human health concern. It should also be noted that this survey focused on the species that accumulate the highest contaminant concentrations. Concentrations in some of the other species can be expected to be substantially lower than observed for the predators and bottom-feeders evaluated in this study.

This survey has also raised many questions, and left other questions unanswered. Several areas where further study would be of great value in addressing management issues are described below. The needed studies are described below in general terms, as details should be developed through a deliberate and thoughtful group process.

1) FOLLOW-UP SAMPLING TO DEVELOP CONSUMPTION GUIDELINES AT LAKES WITH HIGHLY CONTAMINATED FISH

High priority water bodies in this regard with elevated concentrations were discussed in the mercury and PCB sections. Development of consumption guidelines requires data from a broader spectrum of species, so anglers can be directed to cleaner species if they are present (as is often the case). Obtaining the needed data typically costs approximately $20,000 per lake. Costs are greater for larger lakes. Some of this work is already underway in Regions 2 and 4, but significant additional resources would be needed to perform this follow-up work at the many lakes with concentrations above thresholds.

2) FOCUSED EVALUATIONS OF SELECTED LAKES TO IDENTIFY CONTAMINANT SOURCES

Distinguishing the relative importance of legacy contamination from mining, atmospheric deposition, and other sources is critical to effective management of methylmercury contamination. The efforts in this report and in Negrey et al. (2010) to identify sources and controlling factors for methylmercury have provided a

foundation for progress on this front, and information that can help in pursuing more refined approaches in the future. More detailed, site-specific field work could be performed to assess the contributions of different sources. Identifying and sampling lakes without mining influence could yield valuable insights. Studies that include assessment of key parameters in sediment, the food web (including lower trophic levels and trophic position), lake water, and the watersheds would have the best chance of answering source questions. Emerging tools such as mercury isotopes may be valuable in this context.

3) ASSESSMENT OF RISKS TO WILDLIFE FROM BIOACCUMULATIVE CONTAMINANTS

Although this study did not focus on risks to wildlife due to funding limitations, they are likely to be a significant concern. Exposures and risks to wildlife, including fish and fish-eating birds (Sandheinrich and Wiener 2009), are likely to be substantially higher than for humans in some instances. These risks could be assessed in a preliminary manner by estimating likely exposures based on extrapolation from the sport fish data to other species. The best approach would be to conduct monitoring targeted at addressing this question. A sampling design focusing on wildlife prey or directly on piscivorous species would be needed for an accurate assessment of exposure and risks in wildlife.

4) EMERGING CONTAMINANTS

Again due to funding limitations, this study did not evaluate emerging contaminants. Two of these contaminants, polybrominated diphenyl ethers (PBDEs) and perfluorinated compounds (PFCs), are known to accumulate in fish. Human health thresholds for these chemicals in fish are anticipated (PBDEs) or available (PFC screening values have been developed by the state of Minnesota). These and other emerging contaminants accumulate in fish and should be tracked to provide information that managers need in order to act before they become the legacy contaminants of tomorrow. In the short-term, samples archived from this study could be analyzed for these chemicals. In the longer-term, rising concerns such as these should be included in future surveys. A decreased emphasis on legacy contaminants that are on the decline in future surveys could free up funding to evaluate emerging contaminants.

5) TREND MONITORING

Lake and reservoir food webs are contaminated with mixtures of contaminants, some with declining concentrations, some rising, and some not changing appreciably. Tracking these trends is essential to effective management of water quality in these ecosystems. Large-scale processes such as climate change can influence trends. A recent study indicates that lakes in California are warming twice as fast as surface air temperatures (Schneider et al. 2009). The likely effect of this on mercury cycling is not known, but some effect on trends seems plausible. Contaminant trends in lakes are affected by a host of sources and processes operating at global (e.g., atmospheric deposition) and local scales. An effective program to monitor trends is

needed. This could include establishing long-term time series at selected locations. More thorough sampling of ancillary parameters (e.g., trophic position) would greatly enhance interpretation of these time series. It will also be valuable to repeat a broad lakes survey, but the optimal interval for this has not yet been determined.

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SWAMP
Surface Water
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Program

For more information, please contact:

Jay A. Davis
San Francisco Estuary Institute
7770 Pardee Lane
Oakland, California 94621
jay@sfei.org

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APPENDIX 1 A

Summary results of the SWAMP Lakes Survey
Data are for composites or averages at each location. Sample Type codes: C1=composite from location 1; C2=composite from location 2; LC=Lakewide Composite; 350AVE1=ANCOVA-based average for 350 mm fish at location 1; 350AVE2=ANCOVA-based average for 350 mm fish at location 2.

Regional Board	Station Name	Study Year	Common Name	Sample Type	Mercury (µg/g ww)	Dieldrin (ng/g ww)	Selenium (µg/g ww)	Sums of Chlordanes (ng/g ww)	Sums of DDTs (ng/g ww)	Sum of PCBs (ng/g ww)
1	Cleone Lake	2	Rainbow Trout	C1	0.02	0.0		0.0	2.5	0.2
1	Cleone Lake	2	Rainbow Trout	C2	0.02					
1	Copco Lake	2	Largemouth Bass	350AVE1	0.31					
1	Copco Lake	2	Largemouth Bass	C1		0.0	0.08	0.0	0.0	0.0
1	Dead Lake	2	Largemouth Bass	350AVE1	0.37					
1	Dead Lake	2	Largemouth Bass	C1		0.0	0.08	0.0	0.8	0.0
1	Howard Lake	2	Rainbow Trout	C1	0.02	0.0		0.0	2.8	0.0
1	Howard Lake	2	Rainbow Trout	C2	0.02					
1	Iron Gate Reservoir	2	Largemouth Bass	350AVE1	0.33					
1	Iron Gate Reservoir	2	Largemouth Bass	C1		0.0	0.08	0.0	0.0	1.3
1	Kangaroo Lake	2	Rainbow Trout	C1	0.03	0.0		0.0	1.0	0.0
1	Kangaroo Lake	2	Rainbow Trout	C2	0.02					
1	Lake Mendocino	1	Common Carp	C1	0.07					
1	Lake Mendocino	1	Common Carp	C2	0.10					
1	Lake Mendocino	1	Common Carp	LC		0.0	0.20	0.0	4.8	0.0
1	Lake Mendocino	1	Largemouth Bass	350AVE1	0.55					
1	Lake Mendocino	1	Largemouth Bass	350AVE2	0.54					
1	Lake Pillsbury	1	Largemouth Bass	350AVE1	1.34					
1	Lake Pillsbury	1	Largemouth Bass	350AVE2	1.29					
1	Lake Pillsbury	1	Largemouth Bass	LC		0.0	0.33	0.4	0.0	0.0

Regional Board	Station Name	Study Year	Common Name	Sample Type	Mercury (µg/g ww)	Dieldrin (ng/g ww)	Selenium (µg/g ww)	Sums of Chlordanes (ng/g ww)	Sums of DDTs (ng/g ww)	Sum of PCBs (ng/g ww)
1	Lake Shastina	2	Largemouth Bass	350AVE1	0.23					
1	Lake Shastina	2	Largemouth Bass	C1		0.0	0.08	0.0	1.0	0.4
1	Lake Sonoma	1	Largemouth Bass	350AVE1	0.64					
1	Lake Sonoma	1	Largemouth Bass	350AVE2	0.71					
1	Lake Sonoma	1	Largemouth Bass	LC		0.0	0.31	0.7	0.7	0.0
1	Lewiston Lake	2	Rainbow Trout	C1	0.04	0.0		0.0	2.5	0.3
1	Lewiston Lake	2	Rainbow Trout	C2	0.03					
1	Plaskett Lake	2	Hardhead	C1	0.12	0.0	0.08	0.0	0.0	0.0
1	Plaskett Lake	2	Hardhead	C2	0.10					
1	Reservoir F	1	Largemouth Bass	350AVE1	0.15					
1	Reservoir F	1	Largemouth Bass	C1		0.0	0.05	0.0	0.0	0.0
1	Ruth Lake	2	Brown Bullhead	C1	0.13	0.0	0.19	0.0	0.7	0.0
1	Ruth Lake	2	Largemouth Bass	350AVE1	0.71					
1	Spring Lake	1	Largemouth Bass	350AVE1	0.38					
1	Spring Lake	1	Largemouth Bass	C1		0.0	0.14	0.4	0.8	0.0
1	Trinity Lake	1	Rainbow Trout	C1	0.11					
1	Trinity Lake	1	Rainbow Trout	C2	0.11					
1	Trinity Lake	1	Rainbow Trout	C3	0.08					
1	Trinity Lake	1	Rainbow Trout	C4	0.05					
1	Trinity Lake	1	Rainbow Trout	LC		0.0	0.32	0.0	0.8	0.2
2	Almaden Lake	2	Common Carp	C1	1.05	0.9	0.35	62.2	79.0	37.3
2	Almaden Lake	2	Common Carp	C2	1.02	1.6		73.7	118.7	60.6
2	Almaden Lake	2	Largemouth Bass	350AVE1	2.15					
2	Anderson Lake	1	Common Carp	C1	0.32	0.0	0.41	5.3	11.4	10.2
2	Anderson Lake	1	Common Carp	C2	0.52					
2	Anderson Lake	1	Largemouth Bass	350AVE1	0.98					
2	Bon Tempe Lake	1	Largemouth Bass	350AVE1	0.33					
2	Bon Tempe Lake	1	Largemouth Bass	C1		0.0	0.23	0.9	0.0	0.1
2	Briones Reservoir	1	Largemouth Bass	350AVE1	0.16					
2	Briones Reservoir	1	Largemouth Bass	C1		0.0	0.34	0.2	1.0	0.9

Regional Board	Station Name	Study Year	Common Name	Sample Type	Mercury (µg/g ww)	Dieldrin (ng/g ww)	Selenium (µg/g ww)	Sums of Chlordanes (ng/g ww)	Sums of DDTs (ng/g ww)	Sum of PCBs (ng/g ww)
2	Calaveras Reservoir	1	Largemouth Bass	350AVE1	0.86					
2	Calaveras Reservoir	1	Largemouth Bass	350AVE2	0.31					
2	Calaveras Reservoir	1	Largemouth Bass	LC		0.0	0.48	0.3	1.4	0.6
2	Calero Reservoir	2	Largemouth Bass	350AVE1	1.05					
2	Calero Reservoir	2	Largemouth Bass	C1		0.0	0.62	2.0	9.5	8.1
2	Coyote Lake	2	Common Carp	C1	0.47	0.0	0.65	1.2	9.0	6.0
2	Coyote Lake	2	Common Carp	C2	0.35					
2	Coyote Lake	2	Largemouth Bass	350AVE1	0.76					
2	Lafayette Reservoir	2	Channel Catfish	C1	0.10	0.0	0.08	1.5	10.7	10.9
2	Lafayette Reservoir	2	Channel Catfish	C2	0.05					
2	Lafayette Reservoir	2	Largemouth Bass	350AVE1	0.34					
2	Lago Los Osos	1	Channel Catfish	C1	0.01	0.0	0.05	0.0	2.1	2.2
2	Lake Chabot (San Leandro)	1	Common Carp	C1	0.54	6.5	0.35	61.9	73.8	147.7
2	Lake Chabot (San Leandro)	1	Common Carp	C2	0.29	2.4		22.8	25.5	48.0
2	Lake Chabot (San Leandro)	1	Largemouth Bass	350AVE1	0.57					
2	Lake Chabot (Vallejo)	1	Common Carp	C1	0.14	1.1	2.34	27.9	16.9	30.9
2	Lake Chabot (Vallejo)	1	Common Carp	C2	0.14	1.2	0.52	19.5	10.6	25.0
2	Lake Chabot (Vallejo)	1	Largemouth Bass	350AVE1	0.41					
2	Lake Cunningham	2	Common Carp	C1	0.03	1.2	4.04	6.7	37.8	9.5
2	Lake Cunningham	2	Common Carp	C2	0.16		3.53			
2	Lake del Valle	2	Channel Catfish	C1	0.13	0.5	0.21	2.3	103.6	3.7
2	Lake del Valle	2	Channel Catfish	C2	0.32					
2	Lake del Valle	2	Largemouth Bass	350AVE1	0.56					

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2	Lake Elizabeth	2	Common Carp	C1	0.04	0.4	0.59	3.7	58.6	17.2
2	Lake Elizabeth	2	Common Carp	C2	0.26					
2	Lake Henne	1	Largemouth Bass	350AVE1	0.41					
2	Lake Henne	1	Largemouth Bass	C1		0.0	0.20	0.6	0.5	0.1
2	Lake Madigan	1	Bluegill	C1	0.09	0.0	0.35	0.0	0.0	0.0
2	Lake Madigan	1	Bluegill	C2	0.12					
2	Lake Vasona	2	Common Carp	C1	0.07	0.8	0.40	30.5	35.9	203.9
2	Lake Vasona	2	Common Carp	C2	0.04	0.7		12.5	17.7	89.4
2	Lake Vasona	2	Largemouth Bass	350AVE1	0.16					
2	Lower Crystal Springs Reservoir	1	Largemouth Bass	350AVE1	0.85					
2	Lower Crystal Springs Reservoir	1	Largemouth Bass	C1		0.4	0.41	0.3	0.7	1.2
2	Nicasio Lake	2	Largemouth Bass	350AVE1	0.40					
2	Nicasio Lake	2	Largemouth Bass	C1		0.0		0.0	0.5	0.0
2	Oiger Quarry Ponds	1	Largemouth Bass	350AVE1	0.45					
2	Oiger Quarry Ponds	1	Sacramento Sucker	C1	0.31	0.5	0.29	1.7	81.7	7.6
2	Oiger Quarry Ponds	1	Sacramento Sucker	C2	0.26					
2	Pilarcitos Lake	1	Rainbow Trout	C1	0.27	0.0		0.0	0.0	3.8
2	Pilarcitos Lake	1	Rainbow Trout	C2	0.26					
2	San Pablo Reservoir	1	Common Carp	C1	0.09	1.2	0.33	5.1	5.6	7.6
2	San Pablo Reservoir	1	Common Carp	C2	0.17					
2	San Pablo Reservoir	1	Largemouth Bass	350AVE1	0.48					

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2	Shadow Cliffs Reservoir	2	Channel Catfish	C1	0.13	0.5	0.45	0.5	14.0	12.0
2	Shadow Cliffs Reservoir	2	Channel Catfish	C2	0.11					
2	Shadow Cliffs Reservoir	2	Largemouth Bass	350AVE1	0.39					
2	Soulejoule Lake	1	Largemouth Bass	350AVE1	0.94					
2	Soulejoule Lake	1	Largemouth Bass	C1		0.0	0.23	0.0	0.0	0.0
2	Stevens Creek Reservoir	1	Common Carp	C1	0.29	0.6	1.04	24.0	31.0	22.5
2	Stevens Creek Reservoir	1	Common Carp	C2	0.32	0.8		14.1	19.8	15.6
2	Stevens Creek Reservoir	1	Largemouth Bass	350AVE1	0.70					
2	Upper San Leandro Reservoir	1	Largemouth Bass	350AVE1	1.01					
2	Upper San Leandro Reservoir	1	Largemouth Bass	C1		1.4	0.37	4.5	6.9	4.4
3	Chesbro Reservoir	1	Common Carp	C1	0.55	0.5	0.28	20.2	46.3	93.0
3	Chesbro Reservoir	1	Common Carp	C2	0.51	0.6		12.6	33.4	47.0
3	Chesbro Reservoir	1	Largemouth Bass	350AVE1	1.04					
3	Hernandez Reservoir	2	Largemouth Bass	350AVE1	0.83					
3	Hernandez Reservoir	2	Largemouth Bass	C1		0.0	0.82	0.0	0.8	0.0
3	Jameson Lake	1	Rainbow Trout	C1	0.19	0.0		0.0	0.0	0.0
3	Jameson Lake	1	Rainbow Trout	C2	0.27					
3	Lake Cachuma	2	Common Carp	C1	0.18					
3	Lake Cachuma	2	Common Carp	C2	0.16					
3	Lake Cachuma	2	Common Carp	C3	0.20					
3	Lake Cachuma	2	Common Carp	LC		0.0	1.34	0.0	1.2	0.0
3	Lake Cachuma	2	Largemouth Bass	350AVE1	0.61					
3	Lake Cachuma	2	Largemouth Bass	350AVE2	0.48					
3	Lake Cachuma	2	Largemouth Bass	350AVE3	0.40					

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3	Lake Nacimiento	1	Common Carp	C1	0.37					
3	Lake Nacimiento	1	Common Carp	C2	0.56					
3	Lake Nacimiento	1	Common Carp	C3	0.50					
3	Lake Nacimiento	1	Common Carp	LC		0.5	0.88	0.4	7.0	0.7
3	Lake Nacimiento	1	Smallmouth Bass	AVE1	1.01					
3	Lake Nacimiento	1	Smallmouth Bass	AVE2	0.94					
3	Lake Nacimiento	1	Smallmouth Bass	AVE3	1.03					
3	Lake San Antonio	1	Common Carp	C1	0.17					
3	Lake San Antonio	1	Common Carp	C2	0.30					
3	Lake San Antonio	1	Common Carp	C3	0.23					
3	Lake San Antonio	1	Common Carp	LC		1.3	1.06	1.3	23.3	3.9
3	Lake San Antonio	1	Largemouth Bass	350AVE1	0.30					
3	Lake San Antonio	1	Largemouth Bass	350AVE2	0.28					
3	Lake San Antonio	1	Largemouth Bass	350AVE3	0.32					
3	Little Oso Flaco Lake	2	Goldfish	C1	0.07	276.0	0.42	30.8	7022.4	54.0
3	Little Oso Flaco Lake	2	Goldfish	C2	0.07	277.0		41.5	7957.7	69.3
3	Little Oso Flaco Lake	2	Hitch	C1	0.03	5.6	0.47	0.0	157.6	0.4
3	Little Oso Flaco Lake	2	Hitch	C2	0.03					
3	Little Oso Flaco Lake	2	Largemouth Bass	350AVE1	0.16					
3	Loch Lomond Reservoir	2	Largemouth Bass	350AVE1	0.11					
3	Loch Lomond Reservoir	2	Largemouth Bass	C1		0.0	0.69	0.2	0.6	0.0
3	Lopez Lake	2	Largemouth Bass	350AVE1	0.10					
3	Lopez Lake	2	Sacramento Sucker	C1	0.09	0.7	0.97	1.8	11.6	5.6
3	Lopez Lake	2	Sacramento Sucker	C2	0.09					

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3	Pinto Lake	1	Common Carp	C1	0.27	6.4	0.27	19.3	556.8	9.7
3	Pinto Lake	1	Common Carp	C2	0.22	2.4		7.9	289.6	5.5
3	Pinto Lake	1	Largemouth Bass	350AVE1	0.19					
3	Santo Margarita Lake	2	Largemouth Bass	350AVE1	0.21					
3	Santo Margarita Lake	2	Largemouth Bass	C1		0.0	0.70	0.0	1.0	0.0
3	Uvas Reservoir	1	Largemouth Bass	350AVE1	0.91					
3	Uvas Reservoir	1	Largemouth Bass	C1		0.5	0.50	1.8	7.1	1.9
4	Alondra Park Lake	1	Common Carp	C1	0.05	0.0	0.35	3.4	13.2	45.4
4	Alondra Park Lake	1	Common Carp	C2	0.07	0.0		3.0	14.6	58.8
4	Alondra Park Lake	1	Largemouth Bass	350AVE1	0.20					
4	Alondra Park Lake	1	Largemouth Bass	C1		0.0		0.2	4.5	19.9
4	Alondra Park Lake	1	Largemouth Bass	C2		0.0		0.9	4.8	3.3
4	Balboa Lake	1	Common Carp	C1	0.01	0.9	1.17	0.0	34.0	1.0
4	Balboa Lake	1	Common Carp	C2	0.01	0.5		0.0	17.7	0.0
4	Belvedere Park Lake	1	Common Carp	C1	0.04	0.0	0.39	3.8	5.7	22.3
4	Castaic Lagoon	1	Largemouth Bass	350AVE1	0.18					
4	Castaic Lagoon	1	Largemouth Bass	C1		0.0	0.38	0.5	5.1	9.3
4	Castaic Lagoon	1	Largemouth Bass	C2		0.0		0.0	4.4	5.0
4	Castaic Lagoon	1	Rainbow Trout	C1	0.03	0.0	0.29	0.0	1.8	3.2
4	Castaic Lagoon	1	Redear Sunfish	C1	0.02	0.0	0.48	0.0	1.0	1.4
4	Castaic Lagoon	1	Redear Sunfish	C2	0.03	0.0		0.0	0.8	0.9
4	Castaic Lake	1	Common Carp	C1	0.25	0.6		2.1	15.5	18.8
4	Castaic Lake	1	Common Carp	C2	0.11	0.5		1.4	7.5	16.9
4	Castaic Lake	1	Common Carp	LC		0.7	0.57	2.1	10.9	16.0
4	Castaic Lake	1	Largemouth Bass	350AVE1	0.39					
4	Castaic Lake	1	Largemouth Bass	350AVE2	0.24					
4	Castaic Lake	1	Largemouth Bass	C1		0.0		0.0	8.9	7.8
4	Castaic Lake	1	Largemouth Bass	C2		0.0		0.0	7.6	12.8
4	Castaic Lake	1	Largemouth Bass	LC		0.6		1.5	11.3	16.8

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4	Crystal Lake	1	Largemouth Bass	350AVE1	0.95					
4	Crystal Lake	1	Largemouth Bass	C1		0.0	0.13	0.2	0.8	1.4
4	Crystal Lake	1	Pumpkinseed	C1	0.19	0.0	0.19	0.4	0.7	0.9
4	Echo Lake (Reg 4)	1	Common Carp	C1	0.02	1.1	0.34	18.4	23.5	119.0
4	Echo Lake (Reg 4)	1	Common Carp	C2	0.02	0.8		12.9	14.9	82.6
4	Echo Lake (Reg 4)	1	Largemouth Bass	350AVE1	0.08					
4	Echo Lake (Reg 4)	1	Largemouth Bass	C1		0.8		8.5	13.0	64.7
4	Echo Lake (Reg 4)	1	Largemouth Bass	C2		0.6		3.0	6.4	31.5
4	El Dorado Lakes	1	Largemouth Bass	350AVE1	0.36					
4	El Dorado Lakes	1	Largemouth Bass	C1		0.0	0.05	0.3	2.7	3.3
4	El Dorado Lakes	1	Largemouth Bass	C2		0.0		1.5	1.0	0.3
4	Elderberry Forebay	1	Channel Catfish	C1	0.13	1.9	0.34	3.7	33.5	116.3
4	Elderberry Forebay	1	Channel Catfish	C2	0.13	1.8		4.3	44.6	146.2
4	Elderberry Forebay	1	Largemouth Bass	350AVE1	0.32					
4	Elderberry Forebay	1	Largemouth Bass	C1		0.8		1.0	10.7	32.2
4	Elderberry Forebay	1	Largemouth Bass	C2		0.5		0.0	7.2	19.6
4	Elizabeth Lake	1	Brown Bullhead	C1	0.24	0.0	0.14	0.4	2.0	0.4
4	Elizabeth Lake	1	Brown Bullhead	C2	0.19	0.0		0.0	3.4	1.2
4	Hansen Lake	1	Common Carp	C1	0.08	0.0	0.49	6.6	8.9	6.2
4	Hansen Lake	1	Common Carp	C2	0.12	0.0		6.1	8.0	5.1
4	Hansen Lake	1	Largemouth Bass	350AVE1	0.49					
4	Hansen Lake	1	Largemouth Bass	C1		0.0		2.4	5.0	4.4
4	Hansen Lake	1	Largemouth Bass	C2		0.0		3.4	6.8	3.5
4	Harbor Lake (Lake Machado)	1	Common Carp	C1	0.01	0.0	0.44	2.3	4.7	5.0
4	Harbor Lake (Lake Machado)	1	Common Carp	C2	0.01	0.0		4.8	4.7	2.8
4	Hollenbeck Park Lake	1	Common Carp	C1	0.01	0.6	0.78	8.4	12.6	45.2
4	Hollenbeck Park Lake	1	Common Carp	C2	0.02	0.8		12.5	17.6	55.4

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4	John Ford Park Lake	1	Bluegill	C1	0.04	0.0	0.23	0.0	0.6	0.0
4	Ken Hahn Park Lake	1	Common Carp	C1	0.03	0.0	0.78	2.5	7.2	6.7
4	Ken Hahn Park Lake	1	Common Carp	C2	0.10	0.8	0.30	7.6	11.2	19.8
4	Ken Hahn Park Lake	1	Largemouth Bass	350AVE1	0.30					
4	Ken Hahn Park Lake	1	Largemouth Bass	C1		0.0		0.2	0.9	0.8
4	Ken Hahn Park Lake	1	Largemouth Bass	C2		0.0		0.0	0.7	0.6
4	Lake Calabasas	1	Largemouth Bass	350AVE1	0.03					
4	Lake Calabasas	1	Largemouth Bass	C1		0.0	0.14	0.3	5.8	25.7
4	Lake Calabasas	1	Largemouth Bass	C2		0.0		0.7	6.3	4.9
4	Lake Casitas	1	Common Carp	C1	0.13	0.0		2.2	15.0	5.1
4	Lake Casitas	1	Common Carp	C2	0.12	0.0		1.3	10.6	2.7
4	Lake Casitas	1	Common Carp	LC		0.0	1.12	1.5	10.5	
4	Lake Casitas	1	Largemouth Bass	350AVE1	0.38					
4	Lake Casitas	1	Largemouth Bass	350AVE2	0.29					
4	Lake Casitas	1	Largemouth Bass	C1		0.0		0.0	1.5	0.1
4	Lake Casitas	1	Largemouth Bass	C2		0.0		0.0	1.8	0.1
4	Lake Casitas	1	Largemouth Bass	LC		0.0		0.4	2.6	0.3
4	Lake Hughes	1	Brown Bullhead	C1	0.04	0.0	0.05	1.0	2.2	1.5
4	Lake Hughes	1	Brown Bullhead	C2	0.04	0.0		2.6	3.5	1.7
4	Lake Hughes	1	Largemouth Bass	350AVE1	0.20					
4	Lake Hughes	1	Largemouth Bass	C1		0.0		1.3	3.1	2.3
4	Lake Hughes	1	Largemouth Bass	C2		0.0		0.5	1.7	4.5
4	Lake Lindero	1	Common Carp	C1	0.01	1.8	3.24	77.6	86.2	16.2
4	Lake Lindero	1	Common Carp	C2	0.01	0.9	2.34	42.8	55.8	13.2

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4	Lake Piru	1	Brown Bullhead	C1	0.06	0.0	0.46	1.3	4.1	1.1
4	Lake Piru	1	Brown Bullhead	C2	0.10	0.0		1.3	3.3	0.4
4	Lake Piru	1	Largemouth Bass	350AVE1	0.46					
4	Lake Piru	1	Largemouth Bass	C1		0.0		0.5	4.2	1.3
4	Lake Piru	1	Largemouth Bass	C2		0.0		0.0	1.1	0.1
4	Lake Sherwood	1	Largemouth Bass	350AVE1	0.54					
4	Lake Sherwood	1	Largemouth Bass	C1		0.5	0.17	0.3	1.8	0.0
4	Lake Sherwood	1	Largemouth Bass	C2		0.0		0.0	1.5	0.0
4	Las Virgenes Reservoir	1	Channel Catfish	C1	0.05	0.0	0.16	0.9	7.8	6.7
4	Legg Lake	1	Common Carp	C1	0.01	0.0	0.38	0.3	63.7	20.2
4	Legg Lake	1	Common Carp	C2	0.02	0.0		0.0	42.3	12.0
4	Legg Lake	1	Largemouth Bass	350AVE1	0.18					
4	Legg Lake	1	Largemouth Bass	C1		0.0		1.8	72.1	23.7
4	Legg Lake	1	Largemouth Bass	C2		0.0		0.0	25.2	6.3
4	Lincoln Park Lake	1	Common Carp	C1	0.02	0.5	0.67	1.9	7.9	10.2
4	Lincoln Park Lake	1	Common Carp	C2	0.01	0.4		1.7	8.2	12.6
4	Lincoln Park Lake	1	Largemouth Bass	350AVE1	0.15					
4	Lincoln Park Lake	1	Largemouth Bass	C1		0.0		0.5	3.6	9.9
4	Lincoln Park Lake	1	Largemouth Bass	C2		0.0		0.2	1.7	5.8
4	Malibou Lake	1	Common Carp	C1	0.04	0.7	1.32	15.2	18.1	18.2
4	Malibou Lake	1	Common Carp	C2	0.03	0.7		14.7	17.2	14.4
4	Malibou Lake	1	Largemouth Bass	350AVE1	0.12					
4	Malibou Lake	1	Largemouth Bass	C1		0.7		2.3	3.0	1.6
4	Malibou Lake	1	Largemouth Bass	C2		0.0		0.0	2.0	1.0
4	Peck Road Water Conservation Park	1	Largemouth Bass	350AVE1	0.36					
4	Peck Road Water Conservation Park	1	Largemouth Bass	C1		1.0	0.34	19.2	24.4	55.3
4	Peck Road Water Conservation Park	1	Largemouth Bass	C2		0.5		8.6	9.0	22.7

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4	Puddingstone Reservoir	1	Largemouth Bass	350AVE1	0.44					
4	Puddingstone Reservoir	1	Largemouth Bass	C1		0.7	0.32	9.3	30.8	18.7
4	Puddingstone Reservoir	1	Largemouth Bass	C2		0.0		5.0	10.8	5.9
4	Pyramid Lake	1	Brown Bullhead	C1	0.29	1.3		6.9	135.4	416.1
4	Pyramid Lake	1	Brown Bullhead	C2	0.19			0.4	17.7	60.3
4	Pyramid Lake	1	Brown Bullhead	LC		0.7	0.21	2.4	86.5	194.7
4	Pyramid Lake	1	Largemouth Bass	350AVE1	0.37					
4	Pyramid Lake	1	Largemouth Bass	350AVE2	0.33					
4	Pyramid Lake	1	Largemouth Bass	C1		0.5		0.0	25.6	66.1
4	Pyramid Lake	1	Largemouth Bass	C2		0.5		0.0	13.2	34.6
4	Pyramid Lake	1	Largemouth Bass	LC		0.6		0.4	23.8	66.1
4	Santa Fe Reservoir	1	Common Carp	C1	0.16	0.0	0.17	2.2	9.4	19.1
4	Santa Fe Reservoir	1	Common Carp	C2	0.12	0.4		2.4	9.3	21.3
4	Santa Fe Reservoir	1	Largemouth Bass	350AVE1	0.59					
4	Santa Fe Reservoir	1	Largemouth Bass	C1		0.0		0.3	1.4	5.0
4	Santa Fe Reservoir	1	Largemouth Bass	C2		0.0		0.0	1.0	1.7
4	Sepulveda Lake	1	Common Carp	C1	0.01	0.7	1.08	2.8	387.1	4.1
4	Sepulveda Lake	1	Common Carp	C2	0.01	0.5		1.2	163.8	4.1
4	Toluca Lake	1	Largemouth Bass	350AVE1	0.00					
4	Toluca Lake	1	Largemouth Bass	C1		0.9	1.86	6.4	7.5	6.6
4	Toluca Lake	1	Largemouth Bass	C2		0.0		3.8	5.5	5.9
4	Westlake Lake	1	Largemouth Bass	350AVE1	0.09					
4	Westlake Lake	1	Largemouth Bass	C1		0.7	2.12	3.7	7.3	5.7
4	Westlake Lake	1	Largemouth Bass	C2		0.0		2.2	5.3	6.9
5	Antelope Lake	2	Brown Bullhead	C1	0.04	0.0	0.31	0.0	0.7	0.0
5	Antelope Lake	2	Brown Bullhead	C2	0.03					
5	Antelope Lake	2	Largemouth Bass	350AVE1	0.11					

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5	Bass Lake	2	Brown Bullhead	C1	0.05	0.0	0.08	2.5	1.8	0.0
5	Bass Lake	2	Largemouth Bass	350AVE1	0.09					
5	Beardsley	2	Rainbow Trout	C1	0.05	0.0		0.0	1.0	0.6
5	Beardsley	2	Rainbow Trout	C2	0.06					
5	Big Lake	2	Rainbow Trout	C1	0.02					
5	Big Lake	2	Sacramento Sucker	C1	0.10	0.0	0.43	0.0	1.6	0.0
5	Big Lake	2	Sacramento Sucker	C2	0.03					
5	Big Reservoir	2	Rainbow Trout	C1	0.02	0.0		0.0	3.0	0.0
5	Big Reservoir	2	Rainbow Trout	C2	0.02					
5	Black Butte Lake	2	Common Carp	C1	0.39					
5	Black Butte Lake	2	Common Carp	C2	0.31					
5	Black Butte Lake	2	Common Carp	C3	0.40					
5	Black Butte Lake	2	Common Carp	LC		0.0	0.42	0.2	1.6	0.0
5	Black Butte Lake	2	Smallmouth Bass	AVE1	0.49					
5	Black Butte Lake	2	Smallmouth Bass	AVE2	0.64					
5	Black Butte Lake	2	Smallmouth Bass	AVE3	0.45					
5	Blue Lakes	2	Largemouth Bass	350AVE1	0.16					
5	Blue Lakes	2	Largemouth Bass	C1		0.0	0.49	0.6	7.1	0.2
5	Bowman Lake	2	Brown Trout	C1	0.16	0.7		1.4	3.5	4.0
5	Bowman Lake	2	Brown Trout	C2	0.13					
5	Brite Valley Lake	2	Brown Bullhead	C1	0.04	0.5	0.08	0.3	20.9	18.1
5	Brite Valley Lake	2	Brown Bullhead	C2	0.05					
5	Brite Valley Lake	2	Largemouth Bass	350AVE1	0.29					
5	Bucks Lake	2	Rainbow Trout	C1	0.02					
5	Bucks Lake	2	Rainbow Trout	C2	0.02					
5	Bucks Lake	2	Rainbow Trout	LC		0.0		0.0	3.8	0.2
5	Butt Valley Reservoir	2	Smallmouth Bass	AVE1	0.17					
5	Butt Valley Reservoir	2	Smallmouth Bass	AVE2	0.12					

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5	Butte Lake	2	Rainbow Trout	C1	0.02	0.0		0.0	0.0	0.0
5	Camanche Reservoir	2	Largemouth Bass	350AVE1	0.38					
5	Camanche Reservoir	2	Largemouth Bass	350AVE2	0.27					
5	Camanche Reservoir	2	Largemouth Bass	350AVE3	0.33					
5	Camanche Reservoir	2	Largemouth Bass	LC		0.0	0.44	0.0	0.9	0.5
5	Camp Far West Reservoir	1	Channel Catfish	C1	0.32					
5	Camp Far West Reservoir	1	Channel Catfish	C2	0.44					
5	Camp Far West Reservoir	1	Channel Catfish	LC		0.0	0.05	1.4	5.2	4.2
5	Camp Far West Reservoir	1	Spotted Bass	AVE1	0.54					
5	Camp Far West Reservoir	1	Spotted Bass	AVE2	0.76					
5	Caples Lake	1	Brown Trout	C1	0.08	0.0		0.0	2.9	0.4
5	Caples Lake	1	Brown Trout	C2	0.12					
5	Castac Lake	1	Black Crappie	C1	0.08	0.6	0.20	0.3	3.7	0.1
5	Castac Lake	1	Largemouth Bass	350AVE1	0.32					
5	Castac Lake	1	Largemouth Bass	C1		0.0	0.05	0.3	4.7	0.1
5	Castle Lake	2	Rainbow Trout	C1	0.04	0.0		0.0	1.3	0.2
5	Castle Lake	2	Rainbow Trout	C2	0.03					
5	Cave Lake	2	Brook Trout	C1	0.18	0.0		0.0	0.0	0.0
5	Cave Lake	2	Brook Trout	C2	0.21					
5	Clear Lake	2	Common Carp	C1	0.18					
5	Clear Lake	2	Common Carp	C2	0.15					
5	Clear Lake	2	Common Carp	C3	0.28					
5	Clear Lake	2	Common Carp	C4	0.07					
5	Clear Lake	2	Common Carp	LC		0.0	0.19	4.7	133.7	13.2

Regional Board	Station Name	Study Year	Common Name	Sample Type	Mercury (µg/g ww)	Dieldrin (ng/g ww)	Selenium (µg/g ww)	Sums of Chlordanes (ng/g ww)	Sums of DDTs (ng/g ww)	Sum of PCBs (ng/g ww)
5	Clear Lake	2	Largemouth Bass	350AVE1	0.21					
5	Clear Lake	2	Largemouth Bass	350AVE2	0.30					
5	Clear Lake	2	Largemouth Bass	350AVE3	0.31					
5	Clear Lake	2	Largemouth Bass	350AVE4	0.23					
5	Collins Lake	2	Largemouth Bass	350AVE1	0.38					
5	Collins Lake	2	Largemouth Bass	C1		0.0	0.35	0.0	0.6	0.0
5	Contra Loma Reservoir	1	Largemouth Bass	350AVE1	0.20					
5	Contra Loma Reservoir	1	Largemouth Bass	C1		0.0	0.26	0.0	1.1	0.0
5	Cosumnes River	1	Largemouth Bass	350AVE1	1.15					
5	Cosumnes River	1	Largemouth Bass	C1		0.0	0.20	0.5	4.5	1.2
5	Courtright Reservoir	2	Rainbow Trout	C1	0.06					
5	Courtright Reservoir	2	Rainbow Trout	C2	0.04					
5	Courtright Reservoir	2	Rainbow Trout	LC		0.0		0.0	1.7	0.5
5	Discovery Bay	1	Largemouth Bass	350AVE1	0.36					
5	Discovery Bay	1	Largemouth Bass	C1		0.0	0.27	0.4	27.4	2.0
5	Don Pedro Reservoir	1	Common Carp	C1	0.15					
5	Don Pedro Reservoir	1	Common Carp	C2	0.20					
5	Don Pedro Reservoir	1	Common Carp	C3	0.16					
5	Don Pedro Reservoir	1	Common Carp	LC		0.0	0.50	3.1	3.2	11.3
5	Don Pedro Reservoir	1	Largemouth Bass	350AVE1	0.46					
5	Don Pedro Reservoir	1	Largemouth Bass	350AVE2	0.40					
5	Don Pedro Reservoir	1	Largemouth Bass	350AVE3	0.46					

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5	Duncan Reservoir	2	Brown Bullhead	C1	0.04	0.0	0.08	0.0	0.0	0.0
5	Duncan Reservoir	2	Brown Bullhead	C2	0.04					
5	Duncan Reservoir	2	Rainbow Trout	C1	0.04					
5	East Park Reservoir	1	Common Carp	C1	0.18					
5	East Park Reservoir	1	Common Carp	C2	0.25					
5	East Park Reservoir	1	Largemouth Bass	350AVE1	0.39					
5	East Park Reservoir	1	Largemouth Bass	350AVE2	0.52					
5	Eastman Lake	2	Common Carp	C1	0.33					
5	Eastman Lake	2	Common Carp	C2	0.27					
5	Eastman Lake	2	Common Carp	LC		0.5	0.08	2.6	9.0	0.7
5	Eastman Lake	2	Largemouth Bass	350AVE1	1.03					
5	Eastman Lake	2	Largemouth Bass	350AVE2	1.05					
5	Faucherie Lake	2	Rainbow Trout	C1	0.02	0.0		0.0	2.7	0.0
5	Faucherie Lake	2	Rainbow Trout	C2	0.02					
5	Feeley Lake	1	Brown Bullhead	C1	0.03	0.0	0.05	0.3	3.2	0.1
5	Finger Lake	1	Largemouth Bass	350AVE1	0.29					
5	Finger Lake	1	Largemouth Bass	C1		0.0	0.22	0.0	0.0	0.0
5	Florence Lake	1	Brown Trout	C1	0.09	0.0		0.0	1.1	1.8
5	Florence Lake	1	Brown Trout	C2	0.10					
5	Folsom Lake	2	Largemouth Bass	350AVE1	0.59					
5	Folsom Lake	2	Largemouth Bass	350AVE2	0.48					
5	Folsom Lake	2	Largemouth Bass	350AVE3	0.34					
5	Folsom Lake	2	Largemouth Bass	LC		0.0	0.39	0.2	8.8	0.5
5	French Meadows Reservoir	1	Rainbow Trout	C1	0.11					
5	French Meadows Reservoir	1	Rainbow Trout	C2	0.06					
5	French Meadows Reservoir	1	Rainbow Trout	LC		0.0		0.0	2.6	0.3

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5	Frenchman Lake	1	Rainbow Trout	C1	0.14					
5	Frenchman Lake	1	Rainbow Trout	C2	0.12					
5	Frenchman Lake	1	Rainbow Trout	LC		0.0		0.0	0.7	0.1
5	Fuller Lake	1	Brown Trout	C1	0.09	0.0		1.3	1.6	2.1
5	Fuller Lake	1	Brown Trout	C2	0.08					
5	Gold Lake	1	Rainbow Trout	C1	0.07	0.0		0.0	2.8	0.5
5	Gold Lake	1	Rainbow Trout	C2	0.06					
5	Gumboot Lake	1	Rainbow Trout	C1	0.03	0.0		0.0	1.1	0.8
5	Gumboot Lake	1	Rainbow Trout	C2	0.05					
5	Harry L Englebright Lak	2	Rainbow Trout	C1	0.08					
5	Harry L Englebright Lak	2	Sacramento Sucker	C1	0.66	0.0	0.35	0.4	3.5	17.6
5	Harry L Englebright Lak	2	Sacramento Sucker	C2	0.59					
5	Hell Hole Reservoir	2	Brown Trout	C1	0.05					
5	Hell Hole Reservoir	2	Brown Trout	C2	0.28					
5	Hell Hole Reservoir	2	Brown Trout	LC		0.8		1.2	1.3	9.7
5	Hensley Lake	1	Common Carp	C1	0.16					
5	Hensley Lake	1	Common Carp	C2	0.13					
5	Hensley Lake	1	Common Carp	LC		0.0	0.23	1.2	0.8	0.2
5	Hensley Lake	1	Largemouth Bass	350AVE1	0.72					
5	Hensley Lake	1	Largemouth Bass	350AVE2	0.80					
5	Hetch Hetchy Reservoir	1	Brown Trout	C1	0.54					
5	Hetch Hetchy Reservoir	1	Brown Trout	C2	0.96					
5	Hetch Hetchy Reservoir	1	Brown Trout	LC		0.0		0.2	7.0	2.6

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5	Hume Lake	2	Rainbow Trout	C1	0.02	0.0		0.2	2.1	0.9
5	Hume Lake	2	Rainbow Trout	C2	0.02					
5	Huntington Lake	2	Rainbow Trout	C1	0.04					
5	Huntington Lake	2	Rainbow Trout	C2	0.13					
5	Huntington Lake	2	Rainbow Trout	LC		0.0		0.3	2.4	1.4
5	Ice House Reservoir	2	Rainbow Trout	C1	0.03	0.0		0.0	3.3	0.0
5	Ice House Reservoir	2	Rainbow Trout	C2	0.03					
5	Iron Canyon Reservoir	2	Rainbow Trout	C1	0.06	0.0		0.0	0.0	0.0
5	Isabella Lake	2	Common Carp	C1	0.41					
5	Isabella Lake	2	Common Carp	C2	0.44					
5	Isabella Lake	2	Common Carp	C3	0.35					
5	Isabella Lake	2	Common Carp	LC		0.5	0.27	2.0	10.3	7.7
5	Isabella Lake	2	Largemouth Bass	350AVE1	0.19					
5	Isabella Lake	2	Largemouth Bass	350AVE2	0.21					
5	Isabella Lake	2	Largemouth Bass	350AVE3	0.16					
5	Jackson Meadow Reservoir	2	Rainbow Trout	C1	0.09	0.6		0.8	1.7	1.5
5	Jackson Meadow Reservoir	2	Rainbow Trout	C2	0.06					
5	Jenkinson Lake	2	Largemouth Bass	350AVE1	0.16					
5	Jenkinson Lake	2	Rainbow Trout	C1	0.03	0.5		0.2	3.5	0.0
5	Jenkinson Lake	2	Rainbow Trout	C2	0.03					
5	Jenkinson Lake	2	Smallmouth Bass	AVE1	0.29					
5	Kidd Lake	1	Brown Bullhead	C1	0.06	0.0	0.05	0.0	3.5	0.1
5	Kidd Lake	1	Brown Bullhead	C2	0.05					
5	La Grange Reservoir	1	Rainbow Trout	C1	0.02	0.0		0.2	0.7	2.8
5	La Grange Reservoir	1	Rainbow Trout	C2	0.03					

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5	Lake Almanor	2	Smallmouth Bass	AVE1	0.21					
5	Lake Almanor	2	Smallmouth Bass	AVE2	0.10					
5	Lake Almanor	2	Smallmouth Bass	AVE3	0.15					
5	Lake Almanor	2	Smallmouth Bass	AVE4	0.11					
5	Lake Almanor	2	Smallmouth Bass	LC		0.0	0.87	0.0	0.0	0.0
5	Lake Alpine	1	Rainbow Trout	C1	0.03	0.0		0.0	1.1	0.0
5	Lake Alpine	1	Rainbow Trout	C2	0.03					
5	Lake Amador	2	Largemouth Bass	350AVE1	0.60					
5	Lake Amador	2	Largemouth Bass	C1		0.0	0.33	0.3	1.0	0.2
5	Lake Berryessa	2	Largemouth Bass	350AVE1	0.77					
5	Lake Berryessa	2	Largemouth Bass	350AVE2	0.51					
5	Lake Berryessa	2	Largemouth Bass	350AVE3	0.53					
5	Lake Berryessa	2	Largemouth Bass	350AVE4	0.60					
5	Lake Berryessa	2	Largemouth Bass	LC		0.0	0.34	0.0	1.9	0.0
5	Lake Britton	2	Common Carp	C1	0.04	0.0	0.29	0.0	1.4	0.0
5	Lake Britton	2	Common Carp	C2	0.06					
5	Lake Britton	2	Smallmouth Bass	AVE1	0.18					
5	Lake California	1	Largemouth Bass	350AVE1	0.27					
5	Lake California	1	Largemouth Bass	C1		0.0	0.15	0.0	0.6	0.1
5	Lake Combie	1	Largemouth Bass	350AVE1	0.78					
5	Lake Combie	1	Sacramento Sucker	C1	0.60	0.0	0.62	0.5	8.4	12.3
5	Lake Combie	1	Sacramento Sucker	C2	0.46					
5	Lake Davis	2	Brown Bullhead	C1	0.08					
5	Lake Davis	2	Brown Bullhead	C2	0.06					
5	Lake Davis	2	Brown Bullhead	C3	0.06					
5	Lake Davis	2	Brown Bullhead	LC		0.0	0.08	0.0	1.0	0.0
5	Lake Davis	2	Rainbow Trout	C1	0.04					
5	Lake Davis	2	Rainbow Trout	C2	0.04					
5	Lake Davis	2	Rainbow Trout	C3	0.03					

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5	Lake Kaweah	2	Common Carp	C1	0.25					
5	Lake Kaweah	2	Common Carp	C2	0.17					
5	Lake Kaweah	2	Common Carp	LC		4.2	0.42	13.0	50.3	13.3
5	Lake Kaweah	2	Largemouth Bass	350AVE1	0.46					
5	Lake Kaweah	2	Largemouth Bass	350AVE2	0.54					
5	Lake McClure	1	Common Carp	C1	0.12					
5	Lake McClure	1	Common Carp	C2	0.17					
5	Lake McClure	1	Common Carp	C3	0.13					
5	Lake McClure	1	Common Carp	LC		0.0	0.37	0.0	0.0	0.0
5	Lake McClure	1	Largemouth Bass	350AVE1	0.75					
5	Lake McClure	1	Largemouth Bass	350AVE2	0.79					
5	Lake McClure	1	Largemouth Bass	350AVE3	0.77					
5	Lake McSwain	1	Largemouth Bass	350AVE1	0.54					
5	Lake McSwain	1	Sacramento Sucker	C1	0.08	0.0	0.77	2.9	2.8	2.7
5	Lake McSwain	1	Sacramento Sucker	C2	0.15					
5	Lake Natomas	1	Common Carp	C1	0.26	0.0	0.37	0.5	10.1	8.1
5	Lake Natomas	1	Common Carp	C2	0.25					
5	Lake Natomas	1	Largemouth Bass	350AVE1	0.54					
5	Lake of the Pines	1	Largemouth Bass	350AVE1	0.07					
5	Lake of the Pines	1	Largemouth Bass	C1		0.0	0.05	0.4	0.7	0.0
5	Lake Oroville	1	Common Carp	C1	0.29					
5	Lake Oroville	1	Common Carp	C2	0.22					
5	Lake Oroville	1	Common Carp	C3	0.24					
5	Lake Oroville	1	Common Carp	C4	0.31					
5	Lake Oroville	1	Common Carp	LC		0.0	0.44	0.4	5.1	6.8
5	Lake Oroville	1	Smallmouth Bass	AVE1	0.50					
5	Lake Oroville	1	Smallmouth Bass	AVE2	0.45					
5	Lake Oroville	1	Smallmouth Bass	AVE3	0.42					
5	Lake Oroville	1	Smallmouth Bass	AVE4	0.39					

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5	Lake Spaulding	2	Rainbow Trout	C1	0.02	0.0		0.0	3.0	0.0
5	Lake Spaulding	2	Rainbow Trout	C2	0.02					
5	Lake Webb	2	Common Carp	C1	0.12	0.0	0.67	0.0	8.8	3.7
5	Lake Webb	2	Common Carp	C2	0.11					
5	Lake Webb	2	Largemouth Bass	350AVE1	0.22					
5	Lily Lake	2	Rainbow Trout	C1	0.03	0.0		0.0	2.0	0.0
5	Lily Lake	2	Rainbow Trout	C2	0.05					
5	Little Grass Valley Reservoir	2	Rainbow Trout	C1	0.02					
5	Little Grass Valley Reservoir	2	Rainbow Trout	C2	0.02					
5	Little Grass Valley Reservoir	2	Rainbow Trout	LC		0.0		0.0	3.4	0.0
5	Loon Lake	1	Brown Trout	C1	0.50	0.0		0.2	7.4	4.0
5	Loon Lake	1	Brown Trout	C2	0.30					
5	Los Banos Reservoir	1	Largemouth Bass	350AVE1	0.55					
5	Los Banos Reservoir	1	Largemouth Bass	C1		0.5	0.44	0.2	3.3	0.2
5	Los Vaqueros Reservoir	2	Largemouth Bass	350AVE1	0.26					
5	Los Vaqueros Reservoir	2	Largemouth Bass	350AVE2	0.21					
5	Los Vaqueros Reservoir	2	Sacramento Sucker	C1	0.29					
5	Los Vaqueros Reservoir	2	Sacramento Sucker	C2	0.04					
5	Los Vaqueros Reservoir	2	Sacramento Sucker	LC		0.4	0.42	0.5	5.8	2.3
5	Lower Bear River Reservoir	1	Rainbow Trout	C1	0.04	0.0		0.0	3.8	1.2
5	Lower Bear River Reservoir	1	Rainbow Trout	C2	0.04					

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5	Lower Blue Lake	1	Common Carp	C1	0.26	0.0	0.22	0.5	59.3	1.1
5	Lower Blue Lake	1	Common Carp	C2	0.19					
5	Lower Blue Lake	1	Largemouth Bass	350AVE1	0.30					
5	Lower Blue Lake (Alpine County)	2	Rainbow Trout	C1	0.02	0.5		0.2	3.0	0.0
5	Lower Blue Lake (Alpine County)	2	Rainbow Trout	C2	0.02					
5	Lower Bucks Lake	1	Kokanee	AVE1	0.10					
5	Lower Bucks Lake	1	Kokanee	C1		0.0	0.05	0.6	3.7	0.1
5	Mammoth Pool Reservoir	1	Rainbow Trout	C1	0.22	0.0		1.6	1.1	0.0
5	Mammoth Pool Reservoir	1	Rainbow Trout	C2	0.10					
5	Marsh in Fresno Slough	1	Brown Bullhead	C1	0.06	0.5	0.13	0.3	22.8	2.7
5	Marsh in Fresno Slough	1	Brown Bullhead	C2	0.05					
5	Marsh in Fresno Slough	1	Largemouth Bass	350AVE1	0.17					
5	McCumber Reservoir	2	Rainbow Trout	C1	0.02	0.0		0.0	2.9	0.0
5	McCumber Reservoir	2	Rainbow Trout	C2	0.02					
5	Meadows Slough	1	Largemouth Bass	350AVE1	0.45					
5	Meadows Slough	1	Sacramento Sucker	C1	0.38	2.5	0.05	4.7	68.1	13.3
5	Meadows Slough	1	Sacramento Sucker	C2	0.47					
5	Medicine Lake	2	Brook Trout	C1	0.06	0.0		0.0	1.6	0.0
5	Medicine Lake	2	Brook Trout	C2	0.05					
5	Millerton Lake	1	Largemouth Bass	350AVE1	0.31					
5	Millerton Lake	1	Largemouth Bass	350AVE2	0.36					
5	Millerton Lake	1	Largemouth Bass	350AVE3	0.40					
5	Millerton Lake	1	Largemouth Bass	LC		0.0	0.19	0.0	0.6	0.1

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5	Modesto Reservoir	1	Common Carp	C1	0.22					
5	Modesto Reservoir	1	Common Carp	C2	0.31					
5	Modesto Reservoir	1	Common Carp	LC		0.0	0.27	3.3	8.8	7.9
5	Modesto Reservoir	1	Smallmouth Bass	AVE1	0.20					
5	Modesto Reservoir	1	Smallmouth Bass	AVE2	0.27					
5	Moon Lake	1	Sacramento Pikeminnow	AVE1	0.34					
5	Moon Lake	1	Sacramento Pikeminnow	C1		0.0	0.14	0.0	1.9	1.0
5	New Bullards Bar Reservoir	2	Largemouth Bass	350AVE1	0.27					
5	New Bullards Bar Reservoir	2	Largemouth Bass	350AVE2	0.38					
5	New Bullards Bar Reservoir	2	Largemouth Bass	350AVE3	0.54					
5	New Bullards Bar Reservoir	2	Largemouth Bass	LC		0.0	0.55	0.0	0.0	0.0
5	New Hogan Lake	2	Largemouth Bass	350AVE1	0.41					
5	New Hogan Lake	2	Largemouth Bass	350AVE2	0.37					
5	New Hogan Lake	2	Largemouth Bass	350AVE3	0.51					
5	New Hogan Lake	2	Largemouth Bass	LC		0.0	0.39	0.0	0.0	0.0
5	New Melones Lake	2	Common Carp	C1	0.26					
5	New Melones Lake	2	Common Carp	C2	0.20					
5	New Melones Lake	2	Common Carp	LC		0.0	0.46	0.4	0.0	0.4
5	New Melones Lake	2	Largemouth Bass	350AVE1	1.22					
5	New Melones Lake	2	Largemouth Bass	350AVE2	1.03					
5	North Battle Creek Reservoir	2	Brown Trout	C1	0.03	0.0		0.0	0.6	0.0
5	North Battle Creek Reservoir	2	Brown Trout	C2	0.04					

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5	O'Neill Forebay	1	Channel Catfish	C1	0.12	0.6	0.17	3.8	26.0	57.2
5	O'Neill Forebay	1	Channel Catfish	C2	0.13					67.0
5	O'Neill Forebay	1	Largemouth Bass	350AVE1	0.26					
5	O'Neill Forebay	1	Largemouth Bass	350AVE2	0.21					
5	O'Neill Forebay	1	Largemouth Bass	C2		0.0		0.0	2.9	7.8
5	Paradise Lake	2	Largemouth Bass	350AVE1	0.16					
5	Paradise Lake	2	Largemouth Bass	C1		0.0	0.40	0.0	0.7	0.0
5	Pine Flat Lake	1	Common Carp	AVE3	0.07					
5	Pine Flat Lake	1	Common Carp	C1	0.09					
5	Pine Flat Lake	1	Common Carp	C2	0.07					
5	Pine Flat Lake	1	Common Carp	LC		0.0	0.21	2.5	5.2	1.6
5	Pine Flat Lake	1	Largemouth Bass	350AVE1	0.55					
5	Pine Flat Lake	1	Largemouth Bass	350AVE2	0.53					
5	Pine Flat Lake	1	Largemouth Bass	350AVE3	0.58					
5	Pinecrest	1	Rainbow Trout	C1	0.03	0.0		0.0	0.0	0.0
5	Pinecrest	1	Rainbow Trout	C2	0.03					
5	Reservoir C	2	Rainbow Trout	C1	0.02	0.0		0.0	2.2	0.0
5	Reservoir C	2	Rainbow Trout	C2	0.01					
5	Rollins Reservoir	2	Sacramento Sucker	C1	0.68	0.0	0.43	0.4	0.1	13.5
5	Rollins Reservoir	2	Smallmouth Bass	AVE1	0.85					
5	San Luis Reservoir	1	Common Carp	C1	0.25	6.1		9.9	175.1	80.8
5	San Luis Reservoir	1	Common Carp	C2	0.35	2.5		7.5	90.0	41.7
5	San Luis Reservoir	1	Common Carp	C3	0.19	11.3		19.9	323.6	133.1
5	San Luis Reservoir	1	Common Carp	LC		6.4	0.45	16.0	219.8	99.9
5	San Luis Reservoir	1	Largemouth Bass	350AVE1	0.51					
5	San Luis Reservoir	1	Largemouth Bass	350AVE2	0.57					
5	San Luis Reservoir	1	Largemouth Bass	350AVE3	0.57					
5	San Luis Reservoir	1	Largemouth Bass	350AVE4	0.62					

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5	Scotts Flat Reservoir	2	Rainbow Trout	C1	0.03	0.0		0.0	3.2	1.2
5	Scotts Flat Reservoir	2	Rainbow Trout	C2	0.03					
5	Shasta Lake	1	Channel Catfish	C1	0.36					
5	Shasta Lake	1	Channel Catfish	C2	0.80					
5	Shasta Lake	1	Channel Catfish	LC		0.0	0.33	2.8	8.4	18.2
5	Shasta Lake	1	Spotted Bass	AVE1	0.32					
5	Shasta Lake	1	Spotted Bass	AVE2	0.18					
5	Shasta Lake	1	Spotted Bass	AVE3	0.11					
5	Shasta Lake	1	Spotted Bass	AVE4	0.03					
5	Silver Lake	2	Rainbow Trout	C1	0.05	0.0		0.0	2.1	0.0
5	Siskiyou Lake	2	Smallmouth Bass	AVE1	0.24					
5	Siskiyou Lake	2	Smallmouth Bass	C1		0.0	0.36	0.2	1.8	0.9
5	Spicer Meadow Reservoir	2	Rainbow Trout	C1	0.15	0.0		0.0	1.9	0.0
5	Spicer Meadow Reservoir	2	Rainbow Trout	C2	0.12					
5	Stony Gorge Reservoir	1	Largemouth Bass	350AVE1	0.34					
5	Stony Gorge Reservoir	1	Largemouth Bass	350AVE2	0.45					
5	Stony Gorge Reservoir	1	Sacramento Sucker	C1	0.11					
5	Stony Gorge Reservoir	1	Sacramento Sucker	C2	0.14					
5	Stony Gorge Reservoir	1	Sacramento Sucker	LC		0.0	0.38	0.0	0.5	0.0
5	Stump Meadow Lake	1	Brown Trout	C1	0.06	0.0		0.2	5.1	1.3
5	Success Lake	2	Common Carp	C1	0.26					
5	Success Lake	2	Common Carp	C2	0.27					
5	Success Lake	2	Common Carp	C3	0.16					
5	Success Lake	2	Common Carp	LC		0.0	0.16	1.7	2.1	6.7

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5	Success Lake	2	Rainbow Trout	C1	0.03					
5	Success Lake	2	Rainbow Trout	C2	0.02					
5	Success Lake	2	Rainbow Trout	C3	0.03					
5	Success Lake	2	Rainbow Trout	LC		0.0		0.0	1.7	0.0
5	Thermalito Afterbay	1	Common Carp	C1	0.23					63.1
5	Thermalito Afterbay	1	Common Carp	C2	0.24					51.0
5	Thermalito Afterbay	1	Common Carp	LC		0.0	0.15	3.2	81.5	43.8
5	Thermalito Afterbay	1	Largemouth Bass	350AVE1	0.26					
5	Thermalito Afterbay	1	Largemouth Bass	350AVE2	0.17					
5	Tulloch Reservoir	1	Largemouth Bass	350AVE1	0.37					
5	Tulloch Reservoir	1	Largemouth Bass	C1		0.0	0.44	2.2	1.3	1.1
5	Tunnel Reservoir	1	Sacramento Pikeminnow	AVE1	0.20					
5	Tunnel Reservoir	1	Sacramento Sucker	C1	0.06	0.0	0.05	0.0	1.2	0.1
5	Turlock Lake	1	Common Carp	C1	0.28					
5	Turlock Lake	1	Common Carp	C2	0.52					
5	Turlock Lake	1	Common Carp	C3	0.42					
5	Turlock Lake	1	Common Carp	LC		0.0	0.24	3.5	13.6	7.8
5	Turlock Lake	1	Largemouth Bass	350AVE1	0.24					
5	Turlock Lake	1	Largemouth Bass	350AVE2	0.23					
5	Turlock Lake	1	Largemouth Bass	350AVE3	0.21					
5	Union Valley Reservoir	2	Rainbow Trout	C1	0.03					
5	Union Valley Reservoir	2	Rainbow Trout	C2	0.02					
5	Union Valley Reservoir	2	Rainbow Trout	LC		0.0		0.0	2.0	0.0

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5	Unnamed Lake 1	1	Common Carp	C1	0.11	0.5	0.05	5.7	49.0	8.2
5	Unnamed Lake 1	1	Largemouth Bass	350AVE1	0.20					
5	Unnamed Lake 2	1	Common Carp	C1	0.19	0.0	0.05	0.2	6.3	0.8
5	Unnamed Lake 2	1	Common Carp	C2	0.20					
5	Unnamed Lake 2	1	Largemouth Bass	350AVE1	0.20					
5	Upper Blue Lake	2	Rainbow Trout	C1	0.03	0.4		0.0	3.1	0.0
5	Upper Blue Lake	2	Rainbow Trout	C2	0.02					
5	West Valley Reservoir	1	Sacramento Sucker	C1	0.34	0.0	0.05	0.4	4.4	1.6
5	West Valley Reservoir	1	Sacramento Sucker	C2	0.41					
5	Whiskeytown Lake	2	Largemouth Bass	350AVE1	0.22					
5	Whiskeytown Lake	2	Largemouth Bass	350AVE2	0.16					
5	Whiskeytown Lake	2	Largemouth Bass	350AVE3	0.16					
5	Whiskeytown Lake	2	Largemouth Bass	LC		0.0	0.57	0.0	0.0	0.0
5	White Pines Lake	1	Rainbow Trout	C1	0.03	0.0		0.0	0.0	0.1
5	White Pines Lake	1	Rainbow Trout	C2	0.03					
5	Wishon Reservoir	1	Rainbow Trout	C1	0.05	0.0		0.0	2.4	1.5
5	Wishon Reservoir	1	Rainbow Trout	C2	0.04					
5	Woodward Reservoir	1	Common Carp	C1	0.23					
5	Woodward Reservoir	1	Common Carp	C2	0.17					
5	Woodward Reservoir	1	Common Carp	LC		0.5	0.32	3.3	5.2	2.0
5	Woodward Reservoir	1	Largemouth Bass	350AVE1	0.31					
5	Woodward Reservoir	1	Largemouth Bass	350AVE2	0.25					
5	Yosemite Lake	1	Common Carp	C1	0.09	1.1	0.63	5.9	50.9	38.8
5	Yosemite Lake	1	Common Carp	C2	0.05					36.6
5	Yosemite Lake	1	Largemouth Bass	350AVE1	0.21					

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5	Zayak/Swan Lake	1	Largemouth Bass	350AVE1	0.98					
5	Zayak/Swan Lake	1	Largemouth Bass	C1		0.0	0.19	0.6	0.0	0.1
6	Apollo Lake	2	Rainbow Trout	C1	0.03	0.0		0.0	1.1	0.0
6	Apollo Lake	2	Rainbow Trout	C2	0.04					
6	Boca Reservoir	2	Rainbow Trout	C1	0.03					
6	Boca Reservoir	2	Sacramento Sucker	C1	0.10	0.0	0.08	0.0	1.1	0.0
6	Boca Reservoir	2	Sacramento Sucker	C2	0.09					
6	Bridgeport Reservoir	1	Rainbow Trout	C1	0.02					
6	Bridgeport Reservoir	1	Rainbow Trout	C2	0.02					
6	Bridgeport Reservoir	1	Rainbow Trout	LC		0.0		0.0	0.6	0.0
6	Convict Lake	2	Rainbow Trout	C1	0.02	0.0		0.0	1.5	0.0
6	Convict Lake	2	Rainbow Trout	C2	0.02					
6	Crater Lake	1	Rainbow Trout	C1	0.07	0.0		0.2	1.3	0.3
6	Crater Lake	1	Rainbow Trout	C2	0.04					
6	Dodge Reservoir	2	Rainbow Trout	C1	0.03	0.0		0.0	2.1	0.0
6	Dodge Reservoir	2	Rainbow Trout	C2	0.03					
6	Donner Lake	1	Rainbow Trout	C1	0.04	0.0		0.2	2.6	2.3
6	Donner Lake	1	Rainbow Trout	C2	0.04					
6	Eagle Lake	1	Eagle Lake Trout	C1	0.07					
6	Eagle Lake	1	Eagle Lake Trout	C2	0.06					
6	Eagle Lake	1	Eagle Lake Trout	C3	0.05					
6	Eagle Lake	1	Eagle Lake Trout	C4	0.05					
6	Eagle Lake	1	Eagle Lake Trout	LC		0.0		0.7	2.0	1.9
6	Ellery Lake	2	Rainbow Trout	C1	0.02	0.0		0.0	2.2	0.0
6	Ellery Lake	2	Rainbow Trout	C2	0.02					

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6	Fallen Leaf Lake	2	Lake Trout	C1	0.16					
6	Fallen Leaf Lake	2	Lake Trout	C2	0.15					
6	Fallen Leaf Lake	2	Lake Trout	LC		0.5		11.3	36.8	8.6
6	Grant Lake	1	Rainbow Trout	C1	0.03	0.0		0.0	3.3	0.6
6	Grant Lake	1	Rainbow Trout	C2	0.03					
6	Gull Lake	2	Rainbow Trout	C1	0.02	0.0		0.0	1.9	0.0
6	Gull Lake	2	Rainbow Trout	C2	0.02					
6	Indian Creek Reservoir	2	Rainbow Trout	C1	0.08	0.6		0.7	0.5	0.0
6	Indian Creek Reservoir	2	Rainbow Trout	C2	0.07					
6	June Lake	2	Rainbow Trout	C1	0.03	0.0		0.0	1.5	0.0
6	June Lake	2	Rainbow Trout	C2	0.04					
6	Lake Arrowhead	2	Largemouth Bass	350AVE1	0.34					
6	Lake Arrowhead	2	Largemouth Bass	C1		0.0	0.21	0.5	0.9	0.5
6	Lake Crowley	1	Rainbow Trout	C1	0.08					
6	Lake Crowley	1	Rainbow Trout	C2	0.13					
6	Lake Crowley	1	Rainbow Trout	LC		0.0		0.0	0.5	0.0
6	Lake George	1	Rainbow Trout	C1	0.03	0.0		0.0	1.8	0.4
6	Lake Gregory	2	Common Carp	C1	0.02	0.5	0.08	5.0	0.7	1.2
6	Lake Gregory	2	Common Carp	C2	0.02					
6	Lake Gregory	2	Largemouth Bass	350AVE1	0.19					
6	Lake Mamie	2	Rainbow Trout	C1	0.02	0.5		0.2	2.7	0.0
6	Lake Mamie	2	Rainbow Trout	C2	0.02					
6	Lake Mary	1	Rainbow Trout	C1	0.04	0.0		0.0	3.2	2.5
6	Lake Mary	1	Rainbow Trout	C2	0.03					
6	Lake Sabrina	2	Rainbow Trout	C1	0.03	0.0		0.0	1.1	0.0
6	Lake Sabrina	2	Rainbow Trout	C2	0.02					
6	Lake Tahoe	1	Rainbow Trout	C1	0.06					
6	Lake Tahoe	1	Rainbow Trout	C2	0.08					
6	Lake Tahoe	1	Rainbow Trout	C3	0.04					

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6	Lake Tahoe	1	Rainbow Trout	C4	0.07					
6	Lake Tahoe	1	Rainbow Trout	LC		0.0		0.4	1.3	2.3
6	Little Rock Reservoir	2	Common Carp	C1	0.43	0.0	0.33	2.9	1.3	7.5
6	Little Rock Reservoir	2	Common Carp	C2	0.37					
6	Little Rock Reservoir	2	Largemouth Bass	350AVE1	0.92					
6	Lundy Lake	2	Rainbow Trout	C1	0.06	0.9		0.7	2.4	3.2
6	Lundy Lake	2	Rainbow Trout	C2	0.05					
6	Palmdale Lake	1	Channel Catfish	C1	0.06	0.5	0.18	1.2	10.4	20.0
6	Palmdale Lake	1	Channel Catfish	C2	0.06					
6	Palmdale Lake	1	Largemouth Bass	350AVE1	0.13					
6	Pleasant Valley Reservoir	2	Rainbow Trout	C1	0.08	0.0		0.0	2.9	0.2
6	Pleasant Valley Reservoir	2	Rainbow Trout	C2	0.06					
6	Prosser Creek Reservoir	1	Rainbow Trout	C1	0.10	0.0		0.0	0.7	0.1
6	Prosser Creek Reservoir	1	Rainbow Trout	C2	0.09					
6	Rock Creek Lake	2	Rainbow Trout	C1	0.03	0.0		0.0	2.2	0.0
6	Rock Creek Lake	2	Rainbow Trout	C2	0.02					
6	Saddlebag Lake	2	Rainbow Trout	C1	0.02	0.5		0.7	2.8	0.8
6	Saddlebag Lake	2	Rainbow Trout	C2	0.03					
6	Silver Lake (Region 6)	1	Brown Trout	C1	0.05	0.0		0.0	0.8	27.8
6	Silverwood Lake	1	Largemouth Bass	350AVE1	0.49					
6	Silverwood Lake	1	Largemouth Bass	C1		0.0	0.35	1.4	13.8	131.4
6	Silverwood Lake	1	Largemouth Bass	C2		0.0		1.1	8.5	54.8
6	Spring Valley Lake	1	Rainbow Trout	C1	0.03	0.0		0.0	4.7	12.2
6	Spring Valley Lake	1	Rainbow Trout	C2	0.04					

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6	Stampede Reservoir	2	Rainbow Trout	C1	0.03					
6	Stampede Reservoir	2	Rainbow Trout	C2	0.02					
6	Stampede Reservoir	2	Rainbow Trout	C3	0.03					
6	Stampede Reservoir	2	Rainbow Trout	LC		0.0		0.0	1.8	0.0
6	Tioga Lake	2	Rainbow Trout	C1	0.03	0.0		0.0	2.6	0.2
6	Tioga Lake	2	Rainbow Trout	C2	0.02					
6	Topaz Lake	2	Rainbow Trout	C1	0.18					
6	Topaz Lake	2	Sacramento Sucker	C1	0.24	0.0	0.22	0.2	0.0	1.3
6	Topaz Lake	2	Sacramento Sucker	C2	0.12					
6	Twin Lakes	2	Rainbow Trout	C1	0.02	0.5		0.7	2.2	1.5
6	Twin Lakes	2	Rainbow Trout	C2	0.02					
6	Upper Twin Lake	1	Brown Trout	C1	0.06					
6	Upper Twin Lake	1	Sacramento Sucker	C1	0.30	0.0	0.37	0.2	2.2	0.5
6	Upper Twin Lake	1	Sacramento Sucker	C2	0.37					
6	Virginia Lakes	1	Rainbow Trout	C1	0.03	0.0		0.0	2.3	0.9
6	Virginia Lakes	1	Rainbow Trout	C2	0.03					
7	Ferguson Lake	1	Common Carp	C1	0.03	0.0	1.87	0.7	7.7	1.8
7	Ferguson Lake	1	Common Carp	C2	0.02					
7	Ferguson Lake	1	Largemouth Bass	350AVE1	0.09					
7	Gene Wash Reservoir	1	Common Carp	C1	0.02	0.0	2.67	0.0	1.6	1.3
7	Gene Wash Reservoir	1	Common Carp	C2	0.01		1.60			
7	Gene Wash Reservoir	1	Largemouth Bass	350AVE1	0.08					
7	Lake Cahuilla	1	Common Carp	C1	0.01	0.0	2.09	0.0	31.4	0.6
7	Lake Cahuilla	1	Common Carp	C2	0.01					

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7	Lake Havasu	1	Common Carp	C1	0.02		1.70			
7	Lake Havasu	1	Common Carp	C2	0.02		1.81			
7	Lake Havasu	1	Common Carp	C3	0.06		1.17			
7	Lake Havasu	1	Common Carp	C4	0.05		1.40			
7	Lake Havasu	1	Common Carp	LC		0.0	2.32	0.2	3.8	1.2
7	Ramer Lake	1	Black Crappie	C1	0.03					
7	Ramer Lake	1	Black Crappie	C2	0.04					
7	Ramer Lake	1	Common Carp	C1	0.01	0.0	3.85	0.0	13.5	0.0
7	Ramer Lake	1	Common Carp	C2	0.01		2.19			
7	Salton Sea	1	Tilapia1	C1	0.01		2.24			
7	Salton Sea	1	Tilapia1	C2	0.01		2.70			
7	Salton Sea	1	Tilapia1	C3	0.01		2.57			
7	Salton Sea	1	Tilapia1	C4	0.01		2.82			
7	Salton Sea	1	Tilapia1	LC		0.0	3.52	0.0	3.0	0.0
7	Senator Wash Reservoir	1	Common Carp	C1	0.10	0.0	2.49	0.0	5.3	1.4
7	Senator Wash Reservoir	1	Common Carp	C2	0.09		1.91			
7	Senator Wash Reservoir	1	Largemouth Bass	350AVE1	0.15					
7	Wiest Lake	1	Black Crappie	C1	0.01					
7	Wiest Lake	1	Channel Catfish	C1	0.01	0.5	0.84	0.3	48.6	4.2
8	Big Bear Lake	1	Common Carp	C1	0.19	0.5		6.5	14.7	36.8
8	Big Bear Lake	1	Common Carp	C2	0.25	0.0		7.6	19.3	37.9
8	Big Bear Lake	1	Common Carp	C3	0.21	0.0		7.9	25.5	57.9
8	Big Bear Lake	1	Common Carp	LC		0.0	0.05	6.1	18.8	51.7
8	Irvine Lake	1	Common Carp	C1	0.09	0.0	1.99	4.0	7.9	4.6
8	Irvine Lake	1	Common Carp	C2	0.11					
8	Irvine Lake	1	Largemouth Bass	350AVE1	0.48					
8	Lake Elsinore	1	Common Carp	C1	0.14	0.0		3.3	16.1	17.5
8	Lake Elsinore	1	Common Carp	C2	0.16	0.0		6.0	31.4	53.1
8	Lake Elsinore	1	Common Carp	LC		0.5	0.23	3.6	17.7	34.2

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8	Lake Elsinore	1	Largemouth Bass	350AVE1	0.12					
8	Lake Elsinore	1	Largemouth Bass	350AVE2	0.12					
8	Lake Evans	2	Common Carp	C1	0.01	0.0	0.76	0.3	12.2	4.9
8	Lake Evans	2	Common Carp	C2	0.01					
8	Lake Evans	2	Largemouth Bass	350AVE1	0.03					
8	Lake Hemet	2	Common Carp	C1	0.10	0.0	0.08	1.0	3.9	0.5
8	Lake Hemet	2	Common Carp	C2	0.12					
8	Lake Hemet	2	Rainbow Trout	C1	0.03					
8	Lake Mathews	1	Striped Bass	AVE1	0.25					
8	Lake Mathews	1	Striped Bass	AVE2	0.20					
8	Lake Mathews	1	Striped Bass	AVE3	0.19					
8	Lake Mathews	1	Striped Bass	LC		0.0	1.52	0.3	7.6	8.9
8	Lee Lake/ Corona Lake	2	Largemouth Bass	350AVE1	0.16					
8	Lee Lake/ Corona Lake	2	Largemouth Bass	C1		0.0	0.61	1.7	4.7	16.4
8	Perris Reservoir	2	Largemouth Bass	350AVE1	0.10					
8	Perris Reservoir	2	Largemouth Bass	350AVE2	0.10					
8	Perris Reservoir	2	Largemouth Bass	LC		0.0	0.56	1.3	193.1	11.8
8	Prado Lake	1	Common Carp	C1	0.02	0.0	0.31	0.3	6.6	7.1
8	Prado Lake	1	Common Carp	C2	0.02					
8	Prado Lake	1	Largemouth Bass	350AVE1	0.07					
9	Dixon Lake	2	Largemouth Bass	350AVE1	0.06					
9	Dixon Lake	2	Largemouth Bass	C1		0.0	1.01	0.0	1.1	0.8
9	El Capitan Lake	2	Largemouth Bass	350AVE1	0.36					
9	El Capitan Lake	2	Largemouth Bass	350AVE2	0.33					
9	El Capitan Lake	2	Largemouth Bass	LC		0.0	1.00	0.7	1.2	0.4
9	Lake Henshaw	2	Common Carp	C1	0.10					
9	Lake Henshaw	2	Common Carp	C2	0.07					
9	Lake Henshaw	2	Common Carp	LC		0.0	1.42	0.0	1.4	0.0

Regional Board	Station Name	Study Year	Common Name	Sample Type	Mercury (µg/g ww)	Dieldrin (ng/g ww)	Selenium (µg/g ww)	Sums of Chlordanes (ng/g ww)	Sums of DDTs (ng/g ww)	Sum of PCBs (ng/g ww)
9	Lake Henshaw	2	Largemouth Bass	350AVE1	0.19					
9	Lake Henshaw	2	Largemouth Bass	350AVE2	0.16					
9	Lake Hodges	1	Common Carp	C1	0.17	0.0	0.22	3.8	25.9	4.9
9	Lake Hodges	1	Common Carp	C2	0.17					
9	Lake Hodges	1	Largemouth Bass	350AVE1	0.29					
9	Lake Jennings	2	Channel Catfish	C1	0.05	1.3	0.19	0.3	8.6	0.8
9	Lake Jennings	2	Largemouth Bass	350AVE1	0.16					
9	Lake Poway	2	Largemouth Bass	350AVE1	0.05					
9	Lake Poway	2	Largemouth Bass	C1		0.0	1.42	0.4	1.0	0.5
9	Lake Sutherland	2	Largemouth Bass	350AVE1	0.34					
9	Lake Sutherland	2	Largemouth Bass	C1		0.0	1.22	0.3	0.5	0.0
9	Lake Wohlford	2	Largemouth Bass	350AVE1	0.05					
9	Lake Wohlford	2	Largemouth Bass	C1		0.0	0.91	0.7	2.2	0.6
9	Loveland Reservoir	1	Common Carp	C1	0.09	0.0	0.62	1.8	1.5	1.7
9	Loveland Reservoir	1	Common Carp	C2	0.11					
9	Loveland Reservoir	1	Largemouth Bass	350AVE1	0.63					
9	Lower Otay Reservoir	1	Common Carp	C1	0.05	0.6	0.49	13.1	77.0	29.2
9	Lower Otay Reservoir	1	Common Carp	C2	0.10	0.0		6.5	51.0	15.8
9	Lower Otay Reservoir	1	Largemouth Bass	350AVE1	0.20					
9	Morena Reservoir	2	Common Carp	C1	0.35	0.0	0.64	2.3	5.3	5.2
9	Morena Reservoir	2	Common Carp	C2	0.31					
9	Morena Reservoir	2	Largemouth Bass	350AVE1	0.36					
9	San Vicente Reservoir	1	Common Carp	C1	0.05	0.0	1.40	4.0	4.5	6.1
9	San Vicente Reservoir	1	Common Carp	C2	0.05					
9	San Vicente Reservoir	1	Largemouth Bass	350AVE1	0.34					

Regional Board	Station Name	Study Year	Common Name	Sample Type	Mercury (µg/g ww)	Dieldrin (ng/g ww)	Selenium (µg/g ww)	Sums of Chlordanes (ng/g ww)	Sums of DDTs (ng/g ww)	Sum of PCBs (ng/g ww)
9	Sweetwater Reservoir	1	Common Carp	C1	0.20	1.0	0.53	7.2	16.0	12.3
9	Sweetwater Reservoir	1	Common Carp	C2	0.16					
9	Sweetwater Reservoir	1	Largemouth Bass	350AVE1	0.23					

APPENDIX 2 A

List of lakes identified for trend analysis.
From Davis et al. (2007a).

Sampling Sequence	NAME	Region	County	Area (ha)	Elevation (ft)
166	Barrett	9	SAN DIEGO	50.7	1593
131	Big Bear Lake	8	SAN BERNARDINO	1102.4	6760
199	Bridgeport Reservoir	6	MONO	1058.1	6456
95	Castaic Lake	4	LOS ANGELES	923.4	1518
28	Donner Lake	6	NEVADA	331.5	5936
213	Eagle Lake	6	LASSEN	8118	5110
58	Elsinore, Lake	8	RIVERSIDE	983.6	1242
Other	Ferguson Lake	7	IMPERIAL	197.2	191
115	Lake Cahuilla	7	RIVERSIDE	48.1	22
55	Lake Casitas	4	VENTURA	699.	6519
217	Lake Chabot (San Leandro)	2	ALAMEDA	126	522
27	Lake Crowley	6	MONO	1966.9	6768
216	Lake Havasu	7	MOHAVE	7985.7	451
70	Lake Hodges	9	SAN DIEGO	165.6	277
149	Lake Mendocino	1	MENDOCINO	689.5	741
60	Lake Nacimiento	3	SAN LUIS OBISPO	2330.8	806
133	Lake Natoma	5	SACRAMENTO	196.3	129
137	Lake Pillsbury	1	LAKE	798.7	1820
179	Lake Piru	4	VENTURA	493.9	1078
164	Lake San Antonio	3	MONTEREY	2194.1	780
Other	Lake Shastina	1	SISKIYOU	363	2808
121	Lake Sonoma	1	SONOMA	962.1	452
209	Lake Trinity	1	TRINITY	6497	2374

Sampling Sequence	NAME	Region	County	Area (ha)	Elevation (ft)
80	Loon Lake	5	EL DORADO	399.2	6381
182	Lower Otay	9	SAN DIEGO	425.1	494
158	Oso Flaco Lake	3	SAN LUIS OBISPO	9.4	21
88	Pinto Lake	3	SANTA CRUZ	46.7	114
187	Prado Park Lake	8	RIVERSIDE	8.8	487
51	Puddingstone Reservoir	4	LOS ANGELES	98.4	941
75	Ramer Lake	7	IMPERIAL	62.8	174
171	Salton Sea	7	RIVERSIDE	94403.1	231
200	San Luis Reservoir	5	MERCED	5208.2	555
205	San Pablo Reservoir	2	CONTRA COSTA	317.3	318
210	Santiago Reservoir/Irvine Lake	8	ORANGE	234.6	794
18	Shasta Lake	5	SHASTA	11036.9	1077
35	Silverwood Lake	6	BERNARDINO	364.4	3375
93	Soulejule	2	MARIN	19.7	258
48	Stevens Creek Reservoir	2	SANTA CLARA	36.8	NA
46	Sweetwater Reservoir	9	SAN DIEGO	372.4	242
40	Tahoe, Lake	6	PLACER	49692.2	6231
19	Wiest Lake	7	IMPERIAL	16.8	162

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Jay A. Davis
San Francisco Estuary Institute
7770 Pardee Lane
Oakland, California 94621
jay@sfei.org

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THE RESOURCES AGENCY

DEPARTMENT OF WATER RESOURCES

EROSION CONTROL AT MALAKOFF DIGGINS STATE HISTORIC PARK

Report to the Department of Parks and Recreation Interagency Agreement 05-07-075 (DWR 163543)

CENTRAL DISTRICT

JANUARY 1987

Gordon K. Van Vleck
Secretary for Resources
The Resources Agency

George Deukmejian
Governor
State of California

David N. Kennedy
Director
Department of Water Resources

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FOREWORD

Malakoff Diggins State Historic Park is the site of one of California's largest hydraulic gold mines. During its operation between 1866 and 1900, an estimated 39 million cubic yards of rock was mined, 29 million of which were discharged as tailings to South Yuba River. Erosion of the exposed cliffs produces a significant volume of sediment. Fine grained material produced by erosion is discharged from the diggings through Hiller Tunnel to Humbug Creek and then into South Yuba River. During winter and spring, the sediment increases the turbidity of Humbug Creek and South Yuba River. Concerns have been raised about the adverse effect of turbidity and sedimentation on the fishery habitat of these two streams.

In 1976, the Central Valley Regional Water Quality Control Board ordered the Department of Parks and Recreation to study erosion and sedimentation at Malakoff Diggins State Historic Park and implement a remedial program to reduce turbid water discharge from the diggings. Since these studies were completed, the Department of Parks and Recreation has implemented several small-scale measures to mitigate the discharge of sediment-laden waters from Malakoff Diggins.

This study by the Department of Water Resources was conducted for the Department of Parks and Recreation to assess any changes in erosion and sedimentation rates or patterns in the intervening time. In addition, the suitability of various erosion control measures, including those recommended in previous reports, was evaluated. No matter what is done at Malakoff Diggins, erosion at the site will be significant for many more years to come.

James U. McDaniel
Chief; Central District

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State of California
GEORGE DEUKMEJIAN, GOVERNOR
The Resources Agency
GORDON K. VAN VLECK, Secretary for Resources

Department of Water Resources
DAVID N. KENNEDY, Director

John P. Caffrey
Deputy Director

Robert G. Potter
Deputy Director

Robert E. Whiting
Deputy Director

Salle S. Jantz
Assistant Director

Robert W. James
Chief Counsel

DIVISION OF PLANNING

Arthur C. Gooch . . . . . Chief

CENTRAL DISTRICT

James U. McDaniel . . . . . District Chief
Robert McDonell . . . . . .Supervising Engineer, WR

This report was prepared by

Eric Senter . . . . . Associate Engineering Geologist

Under the supervision of

Carl Hauge . . . . . Senior Engineering Geologist

With assistance from

Leslie Campbell . . . . . Student Assistant
Patricia Pierce . . . . . Graduate Student Assistant
Judy Hildinger . . . . . Student Assistant
Catherine Dwinnell . . . . . Student Assistant

Report produced by

Vera Padjen . . . . . Research Writer
Pamela Casselman . . . . . .Senior Word Processing Technician

Chapter 1. INTRODUCTION

Malakoff Diggins State Historic Park is the site of one of California's largest hydraulic gold mines. During its operation between 1866 and 1900, an estimated 39 million cubic yards of rock were mined, 29 million cubic yards of which were discharged as tailings to South Yuba River (Jarman, 1927). The remains of these mining operations, the main pit of the Malakoff Diggins, measures some 7,000 feet long and 3,000 feet wide. Exposed cliffs along the north, east, and west ends of the mine floor range in height from 200 feet to nearly 500 feet.

Erosion of the exposed cliffs produces a significant volume of sediment. During the winter and early spring, fine-grained material produced by erosion is discharged from the diggings through Hiller Tunnel to Humbug Creek and then into South Yuba River. The sediment degrades water quality of Humbug Creek and South Yuba River and may have an adverse impact on the fishery habitat of these two streams. Visual effects of this degradation are most obvious during winter when erosion rates are highest, and water from Humbug Creek creates a cloudy plume in South Yuba River.

In 1976, the Central Valley Regional Water Quality Control Board ordered (Order 76-258) the Department of Parks and Recreation to study erosion and sedimentation at Malakoff Diggins State Historic Park and implement a remedial program to reduce turbid water discharge from the diggings. The mandated study, conducted by Nevada County Resource Conservation District (NCRCD, 1978, 1979a, 1979b, 1980), defined problem areas in the diggings and developed a base of hydrologic data. NCRCD suggested alternatives for control of erosion and sedimentation and a proposed best management practice (1979b, 1980). The best management practice was unacceptable to the Department of Parks and Recreation because it conflicted with the major purpose for which the historic park unit was acquired. Other studies related to erosion and sedimentation have been conducted by Yuan (1979) and Peterson (1980).

In 1981, the Department of Parks and Recreation entered into a Memorandum of Understanding with the Central Valley Regional Water Quality Control Board to comply with the waste discharge requirements and to evaluate alternative management practices. Funding for this work was obtained in 1984, and the Department of Parks and Recreation contracted with the Department of Water Resources to assess any changes in erosion and sedimentation rates or patterns in the time since the NCRCD study was completed. Recommendations of previous studies to mitigate the problem have also been evaluated, along with possible solutions not previously addressed.

During the study, the Department of Water Resources has consulted with representatives of agencies having interests with the current study and those involved with past studies of the area.

Setting of the Study Area

Malakoff Diggins State Historic Park is in Nevada County, about 10 miles northeast of Nevada City (Figure 1). Diggins Creek watershed, which encompasses the Malakoff Diggins, comprises about 2 square miles of the northwestern corner of the 10-square-

mile Humbug Creek watershed (Peterson, 1980). Drainage is toward the south, to the South Yuba River.

The study area is on the southern flank of San Juan Ridge, which divides the Middle and South Yuba rivers. The topography in the vicinity of the diggings is generally gentle, with steeper slopes to the north, toward San Juan Ridge. To the south, the very steep topography of the incised South Yuba River canyon predominates. Elevations range from 2,200 feet at South Yuba River to about 4,300 feet at the summit of San Juan Ridge. The elevation of North Bloomfield, near the diggings, is about 3,200 feet.

Annual precipitation averages 60 inches, most of it falling from November through April. Temperature ranges from the 20s to 40s (°F) in the winter, with summer temperatures between the 50s to mid-90s (Yuan, 1979). This climate has given rise to the ponderosa pine forest community (California Department of Parks and Recreation, 1979).

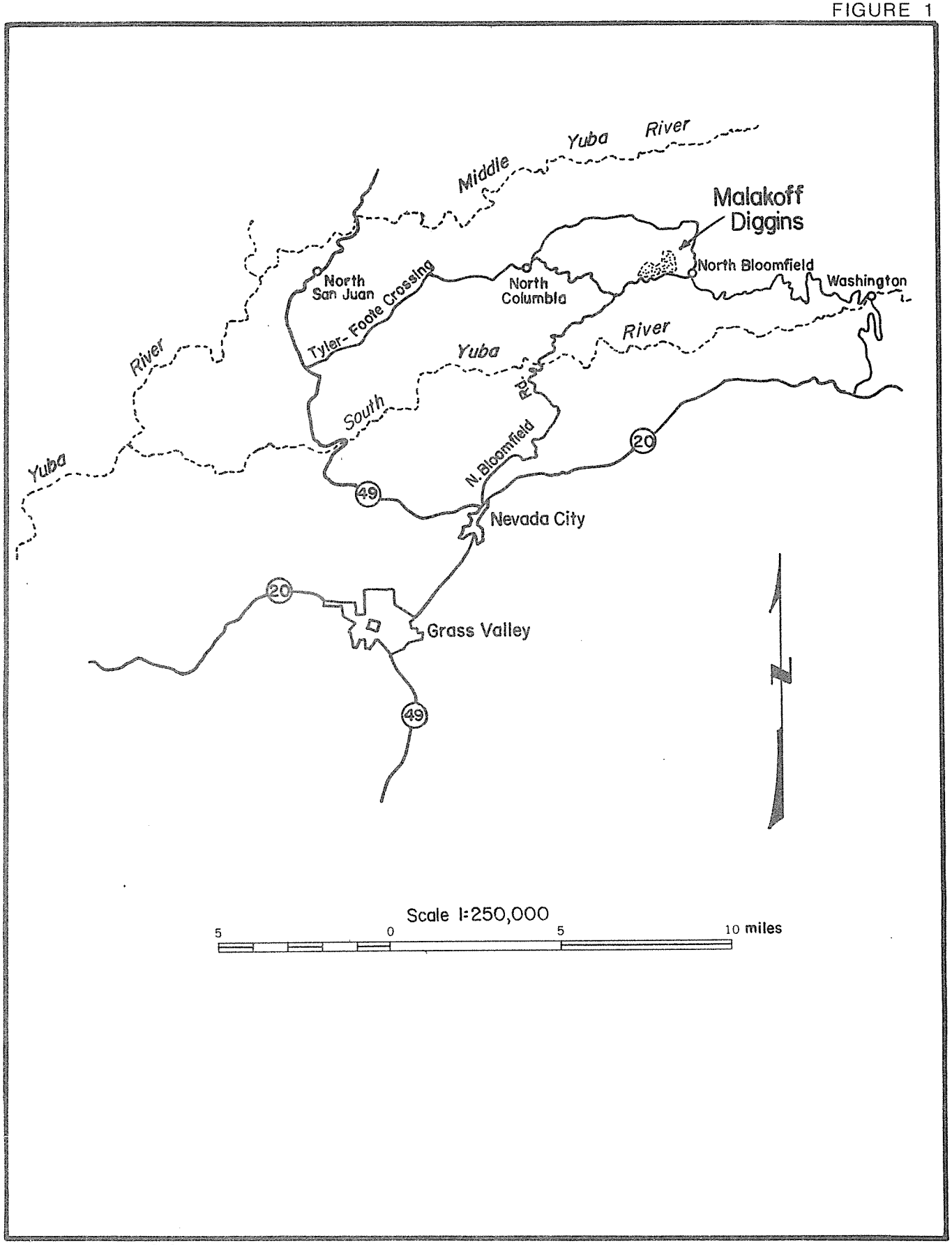
Methods of Investigation

Development of this study began with a review of studies concerning erosion and sedimentation at Malakoff Diggins. These include previous studies by Yuan (1979), the Nevada County Resource Conservation District (NCRCD 1978, 1979a, 1979b, 1980), and Peterson (1980). Hydrologic and geologic data in these studies provide the framework upon which this study is based. In addition, a literature review of topics relative to erosion and sedimentation processes and control of these processes was made.

Field work at the diggings, conducted during winter and spring 1986, consisted of reconnaissance surveys to inspect and assess field conditions and to develop plans for a surface water monitoring program. Subsequent work involved data collection at sites in and out of the diggings, including water quality and surface flow measurements.

The collected water samples were analyzed and the data compared to that generated by previous studies to determine if any decrease in sediment transport had occurred as a result of the natural establishment of vegetation within the diggings. Suspended sediment concentration, turbidity, and flow data from this and previous studies were graphed to determine relationships between these parameters. From these comparisons and field observations, alternatives for controlling erosion in the diggings were developed and evaluated.

FIGURE 1



Location Map

Chapter 2. CONCLUSIONS AND RECOMMENDATIONS

Major conclusions and recommendations reached as a result of this study are summarized below.

Conclusions

- The dominant processes by which sediment is eroded at Malakoff Diggins are rainsplash and surface flow. Landsliding, which occurs extensively in the east end of the diggings, is the dominant process of mass wasting (Peterson, 1980).

- Bare exposures of the Tertiary auriferous gravel in the cliffs of the diggings and landslide deposits at the east end of the diggings are the major sources of sediment discharged to Humbug Creek. Of the two, the landslide deposits are the largest single source of sediment (NCRCD, 1979b).

- The processes of erosion and mass wasting that occur at an accelerated rate at Malakoff Diggins are a natural induced response to topographic changes of the watershed made by hydraulic mining. This accelerated erosion has been occurring for nearly 100 years and will continue at relatively accelerated rates until a slope angle stable enough to permit soil formation and vegetation growth is reached. It will probably take hundreds or thousands of years more to reach this state under natural conditions.

- Vegetation on the mine floor is effective in trapping some of the fine-grained sediment eroded at the diggings (Peterson, 1980). Diggins Pond also traps some of the sediment eroded at the diggings. However, sediment deposition on the floor of the mine has raised it to an elevation above Hiller Tunnel inlet, and streams draining the eastern portion of the diggings now flow directly to the tunnel instead of into the pond. The ability of Diggins Pond to act as a sediment trap is, therefore, severely restricted.

- A significant volume of sand-size sediment appears to be discharged from the diggings. This indicates that a larger volume of material is discharged from Malakoff Diggins than estimated by previous studies and that the best management practice recommended by NCRCD (debris dam) may not perform according to expectations.

- Hiller Tunnel may eventually become plugged with sediment and debris that is carried by streams draining the diggings or by a catastrophic event such as landsliding. This would create a larger pond in the diggings, and probably reduce the amount of coarse sediment discharged to Humbug Creek, but could pose a safety hazard if the berm or rock unit retaining the water were suddenly breached.

- Other land uses in Humbug Creek watershed and South Yuba River watershed, including clearcut timber harvesting and other abandoned hydraulic mines, may adversely affect water quality and fishery habitats in these streams. These possible impacts have not been addressed by this or previous studies.

- The sampling technique and monitoring program used in the NCRCD study (1979a) and duplicated in this study for comparison do not adquately define the total annual runoff and annual volume of sediment discharged from Malakoff Diggins. Furthermore, data

collected by these studies are inadequate for predicting the performance of remedial alternatives.

- Due to inadequacies of the sampling technique and program, it is not possible to ascertain quantitative changes in the quality of water discharged from Malakoff Diggins since the NCRCD study (1979a). However, some qualitative observations can be made. The suspended sediment concentration and turbidity of samples collected during this study are within the range of values reported by the earlier study. Considering that this study used the same sampling techniques as the previous study, this indicates that the quality of water discharged from the diggings has not changed significantly, at least over the range of conditions sampled.

- Samples taken during the winter and spring of 1986 show that water discharged from Diggins Creek consistently caused increases of more than 10 percent in the background value for turbidity, concentration of suspended and settleable material, and electrical conductivity of Humbug Creek water. Thus, discharges from Malakoff Diggins exceed the water quality guidelines of the Central Valley Regional Water Quality Control Board (B. Newman, oral comm., 1986). Further sampling during summer and autumn is needed to determine the year-round effect of Diggins Creek on Humbug Creek. Likewise, year-round sampling at the mouth of Humbug Creek is needed to determine downstream effects of Diggins Creek on Humbug Creek and South Yuba River.

Recommendations

Based on review of previously existing data and studies concerning the Malakoff Diggins and on the data and findings of this study, several recommendations for future work can be made. Given the existing differences between water quality objectives and preserving historic aspects of the mine, a "best management practice" cannot be recommended at this time, nor is it desirable. Ultimately, the Central Valley Regional Water Quality Control Board and the Department of Parks and Recreation will have to decide what level of remedial action will be necessary to sufficiently reduce sediment discharge from the mine, while still retaining its historic quality.

Table 14 (in Chapter 7) presents a qualitative analysis of possible remedial alternatives discussed in this report and previous reports. They are discussed in more detail in Chapters 7 and 8. The following recommendations present a series of options that can be taken to effect varying levels of sediment discharge reduction, or to better define the problem so that the impacts of sediment discharge from Malakoff Diggins can be fully understood. The alternatives listed present the best course of action to achieve a given level of sediment discharge reduction, considering long-term effectiveness and associated maintenance requirements. Costs have not been estimated.

Mine Reclamation

The most effective method of eliminating the discharge of turbid water from the diggings in the shortest time possible would be to reclaim the mine. Such a program would not preserve the historic aspects of the park, and the Department of Parks and Recreation has stated that this alternative is unacceptable.

The accelerated rate at which the natural processes of erosion and mass wasting are occurring in the diggings is caused by existence of the cliffs. Until the cliffs are eroded back to a flatter configuration, conditions necessary for formation of soil and establishment of vegetation will not be met. Reclamation of the mine would bring about in a few years the slope and

soil conditions that natural processes will likely require several hundred more years to achieve. The end result is inevitable; the timing of this end result and the environmental effects sustained prior to reaching it can be controlled.

To implement this alternative, an environmental impact report would have to be prepared. In addition, an overall reclamation plan should be developed to coordinate and address pertinent topics. Specific areas of work would include:

- A detailed geotechnical and engineering study to determine the most economically feasible method of flattening the slopes with the least disruption to the upper watershed. Design of the post-reclamation slopes should account for their long-term stability, and the stability of the upper watershed slopes. Stable channels of proper capacity for streams flowing from the upper watershed would need to be included in the design, as well as erosion and sediment controls.

- Vegetation and soils studies to determine the best types of vegetation to plant. Necessary soil amendments, methods of planting, and adequate maintenance measures to ensure plant survival must also be addressed. The short-term goal of revegetation would be to establish a protective cover of fast-growing plants. A long-term plan for reforestation of the site would also need to be developed.

- Development of plans for the timing and sequence of reclamation. It may be possible to reclaim only a portion of the mine during a construction season. Design of temporary erosion and sediment controls and plans for revegetation would need to account for the possibility of phased reclamation of the mine.

- Monitoring of Diggins Creek to ascertain any changes in the sediment load resulting from corrective actions. Periodic measurements of discharge and collection of water samples by methods used in the studies conducted thus far would be adequate only for indicating gross changes in turbidity. However, if detailed information regarding annual volume of runoff and sediment discharged from the diggings is desired, then the monitoring program would have to be modified. An adequate monitoring program would include installation of a continuous flow recorder supplemented by detailed water sampling with a US-series suspended sediment sampler or other type of rated automatic sampler. Bedload sampling would also need to be included in a modified monitoring program.

Several possible adverse impacts are associated with this alternative. The most obvious are destruction of the central historic aspect of the park -- the visual impacts of the reworked cliffs and upper watershed and any erosion and sediment control structures or devices. These impacts cannot be mitigated. Other impacts include increased runoff and sediment discharge due to disruption of stable upper watershed vegetation and soils and removal of vegetation on the mine floor, instability of the post-reclamation fill slopes and upper watershed slopes, and disruption of plant and wildlife habitats on the mine floor and upper watershed. Proper design of the reclaimed slopes, with provision for erosion controls, and a strong revegetation and maintenance program would help to limit these impacts. However, as stated previously, mine reclamation would destroy the historic values of Malakoff Diggins State Historic Park and the Department of Parks and Recreation has stated that this alternative is unacceptable.

Erosion and Sediment Control Measures

Given the fact that mine reclamation is in direct opposition to the cultural and

historical values for which Malakoff Diggins State Historic Park was acquired, other alternatives for reducing turbid water discharge are available. In the short term, they will be less expensive and will present smaller magnitude impacts than mine reclamation, but their ability to effect significant reductions in the volume of sediment discharged from the diggings is much less. In addition, maintenance measures, a mandatory aspect of every alternative, will incur additional expenditures of time and money for as long as the cliffs continue to erode at their current rate.

1. Stabilizing the landsides and rehabilitating the areas of gullying in the east and northeast portion of the diggings are the two most important "limited action" alternatives for reducing sediment discharge from the diggings. In 1979, the Nevada County Resource Conservation District showed that the largest volume of sediment is derived from these sources; continued instability and gullying indicate this is still true.

   Determination of the most economical and effective means of stabilization of the slump requires a detailed geotechnical investigation. It will probably necessitate reworking or removal of some of the slump material and installation of some type of dewatering devices such as horizontal drains.

   Rehabilitation of some of the gullies will require earthwork. Erosion and enlargement of others may be controlled through use of check dams, inorganic riprap, or vegetation. The specific method of treatment of each area of gullying needs to be examined in more detail. The main objective of rehabilitating the gullies is to provide a slope across which surface water may be conveyed without causing erosion.

2. As a minimum step toward reducing the discharge of sediment to Humbug Creek, planting of vegetation and enhancing deposition of sediment by some other mechanical means should be considered.

   The natural propagation of vegetation does not appear to sufficiently reduce sediment discharge. By extending the vegetation to the east end of the mine floor and to the north and west margins of the pond, the volume of sediment deposited in the diggings could be increased. Vegetation should also be established on exposed clay beds, on debris flow deposits, and in gullies at the east end of the mine floor. Contour wattling techniques may increase the effectiveness of the vegetation to reduce erosion and encourage sediment deposition.

   Prior to planting vegetation, a specialist should be consulted to determine types of plants best suited to conditions in the east end of the mine floor and in the clay bed and debris flow area at the east end of the diggings. Maintenance needs of the vegetation should be addressed at that time.

   Sediment discharge could be further reduced by use of barriers such as filter berms, sand bags, or hay bales. The low cost and relative ease of installation and maintenance of hay bales makes them especially suitable for use at Malakoff Diggins. The bales could be installed in and near the channels of Streams 3 and 4 in the east end of the mine floor to block and divert the flows, thus lessening their velocities and increasing the possibility of sediment deposition. Several of the smaller intermittent streams draining the area to the north and west of Diggins Pond and at the east end of the diggings could also benefit from installation of hay bales.

This method of sediment control is generally a temporary measure while permanent erosion control measures are being taken. Hay bales will not function on a permanent basis. Proper anchoring and maintenance of hay bale barriers will be necessary to ensure their continued effectiveness. Possible problems include erosion beneath the bales, detachment or destruction of the bales, shifting of stream channels away from their installed location, and burial of the bales by sediment deposition. In addition, the hay bales will eventually decompose and will have to be replaced.

Elements of this recommendation are funded in the Department of Parks and Recreation 1986/1987 budget. Work is to begin during the second half of 1986 (Sydney Brown, DPR, 1986, oral comm.)

Sediment Discharge Monitoring

To more accurately determine total run-off and volume of sediment discharged from Malakoff Diggins, a continuous flow recorder and automatic water sampler should be installed at or near Hiller Tunnel outlet. The automatic sampler should be rated by comparison with samples taken with a US-series suspended sediment sampler. Bedload sampling should also be conducted. Consideration should also be given to establishing a continuous monitoring program on Humbug Creek above Diggins Creek and at the mouth of Humbug Creek. The detailed information collected at these two stations and Hiller Tunnel would provide a more accurate foundation on which to judge the impact of sediment discharge from Malakoff Diggins, as well as to evaluate the effectiveness of remedial erosion control alternatives.

Environmental Effects Assessment

It may be appropriate to conduct studies of the South Yuba River watershed to assess the quality of fishery habitats and the possible effects of sediment discharge from Malakoff Diggins. The purposes of such studies should be to identify major contributors of sediment to the South Yuba River and to prescribe an appropriate level of sediment reduction from the diggings, if this sediment is shown to have a direct and measurable negative effect on the fishery habitat.

Chapter 3. GEOLOGY, SOILS AND HYDROLOGY

This chapter summarizes the geology, soils, and hydrology of the Malakoff Diggins area. Detailed descriptions of these topics have been prepared by Peterson (1980), Yuan (1979), and Nevada County Resource Conservation District (1978, 1979a, 1979b, 1980).

Geology

Bedrock in the Malakoff Diggins area is Paleozoic-aged metamorphosed igneous and sedimentary rocks. These are unconformably overlain by undeformed fluvial sedimentary rocks, termed the auriferous gravel (Whitney, 1880), which are of Eocene age. Mio-Pliocene volcanic breccia and conglomerate (mudflows) overlie the auriferous gravel.

Extensive Quaternary colluvial deposits mantle the lower slopes of San Juan Ridge north and east of the diggings. Within the diggings, erosion of the mine walls has resulted in numerous landslides and alluvial deposits. Figure 2 shows the geology of a portion of the Humbug Creek watershed. (Map symbols are explained on page 12.)

As Figure 2 shows, exposures of the Paleozoic metamorphic rocks and Tertiary volcanic rocks are limited in the vicinity of the diggings. They are not considered to contribute significant quantities of sediment to Humbug Creek (Peterson, 1980). The predominant rock types exposed near the Malakoff Diggins pit are the auriferous gravel, Quaternary colluvium, and Holocene deposits associated with hydraulic mining.

The auriferous gravel, the major rock type in the diggings, represents fluvial deposits of the ancestral Yuba River. It is composed of cobbles and pebbles of quartzite, phyllite, quartz, slate, and lesser amounts of other rock types. At Malakoff Diggins, the lower half of the unit contains nearly equal amounts of sandstone and conglomerate, with higher proportions of sand and clay up-section. Clay beds occur throughout the auriferous gravel, but are more common higher in the section. The clay beds range in thickness from 3 to 33 feet (Peterson, 1980). The predominant clay mineral is kaolin (Yuan, 1979). The auriferous gravel is generally poorly consolidated. Bare exposures of the rock unit are subject to erosion and mass wasting.

Quaternary colluvium occurs north and upslope of the diggings. The colluvium is derived mostly from the Tertiary volcanic rocks that cap San Juan Ridge, but it also contains some material derived from the auriferous gravel. Thickness of the unit ranges from 3 to 30 feet (Peterson, 1980).

Excavation of the mine and subsequent erosion of the poorly consolidated auriferous gravel have led to the formation of numerous alluvial deposits within the diggings and along Humbug Creek. Within the diggings, the deposits include alluvial fans that have formed at the base of the mine walls. The fans are especially large at the mouths of the larger gullies entering the pit. They are composed of cobble, pebble, and sand-sized material, and grade into finer-grained alluvium of the mine floor.

The alluvium consists of a number of small-scale fluvial deposits including point bars, terraces, and floodplain deposits. The deposits are formed by numerous braided streams whose channels shift over the floor of the mine during periods of high runoff. The alluvium is composed predominantly of sand-sized

material, with lenses of pebble gravel and clay. The grain size of the alluvial deposits grades gradually finer toward Hiller Tunnel, where silt and clay-sized deposits predominate.

Terrace deposits composed of material derived from mining operations are present in places along the banks of Diggins Creek and along Humbug Creek below the confluence of Diggins Creek. At the confluence of Humbug Creek and South Yuba River, some of the deposits are 65 feet thick; however, they are generally less than 10 feet thick along Diggins and Humbug creeks (Peterson, 1980).

Landslide deposits of various types are present throughout the diggings, but are extensive in the northeast and east portions of the diggings. Landsliding, which has occurred mostly as a response to oversteepening of the natural slopes by hydraulic mining, is discussed in more detail in Chapter 5.

Soils

Principal soil series in the Malakoff Diggins watershed are the Aiken, Cohasset, Horseshoe, Iron Mountain, Josephine, and McCarthy (Brittan, 1975). Physical properties and descriptions of these soils are given in Table 1. Figure 3 shows the distribution of the soils in the Diggins Creek watershed.

Characteristics of each soil type are strongly influenced by the underlying parent material from which they are derived, and other factors including climate, organic influences, time, and topography. The erodibility of each of these soil types must be considered when choosing and implementing a sediment control alternative. The major soil types in the Malakoff Diggins watershed have erodibility and runoff characteristics that may lead to surface erosion that influences the rate of enlargement of the rim of the pit (Peterson, 1980). At present, however, most of the sediment discharged from the diggings is derived from erosion of the auriferous gravel exposed in the cliffs and from landslide deposits (NCRCD, 1979a, 1979b; Peterson, 1980).

EXPLANATION FOR GEOLOGIC MAP
(Figure 2)

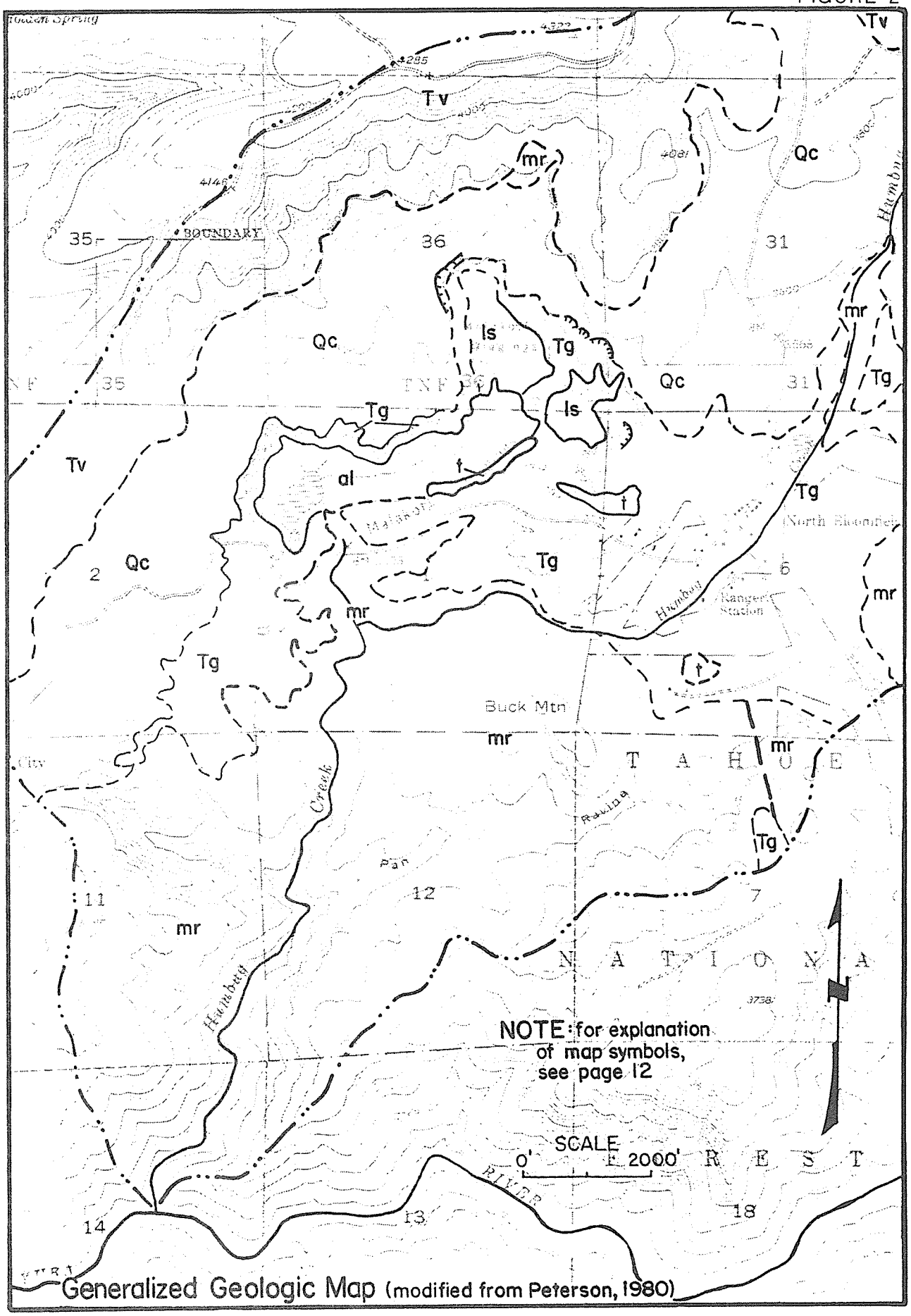
Rock Units

al	Alluvium
t	Tailings
Qc	Colluvium
Tv	Andesitic volcanics
Tg	Auriferous gravel
mr	Metamorphic rocks

Symbols

ls	Landslide
	Lithologic contact, dashed where approximately located
	Fault, dashed where approximately located
	Limit of mapped area

FIGURE 2



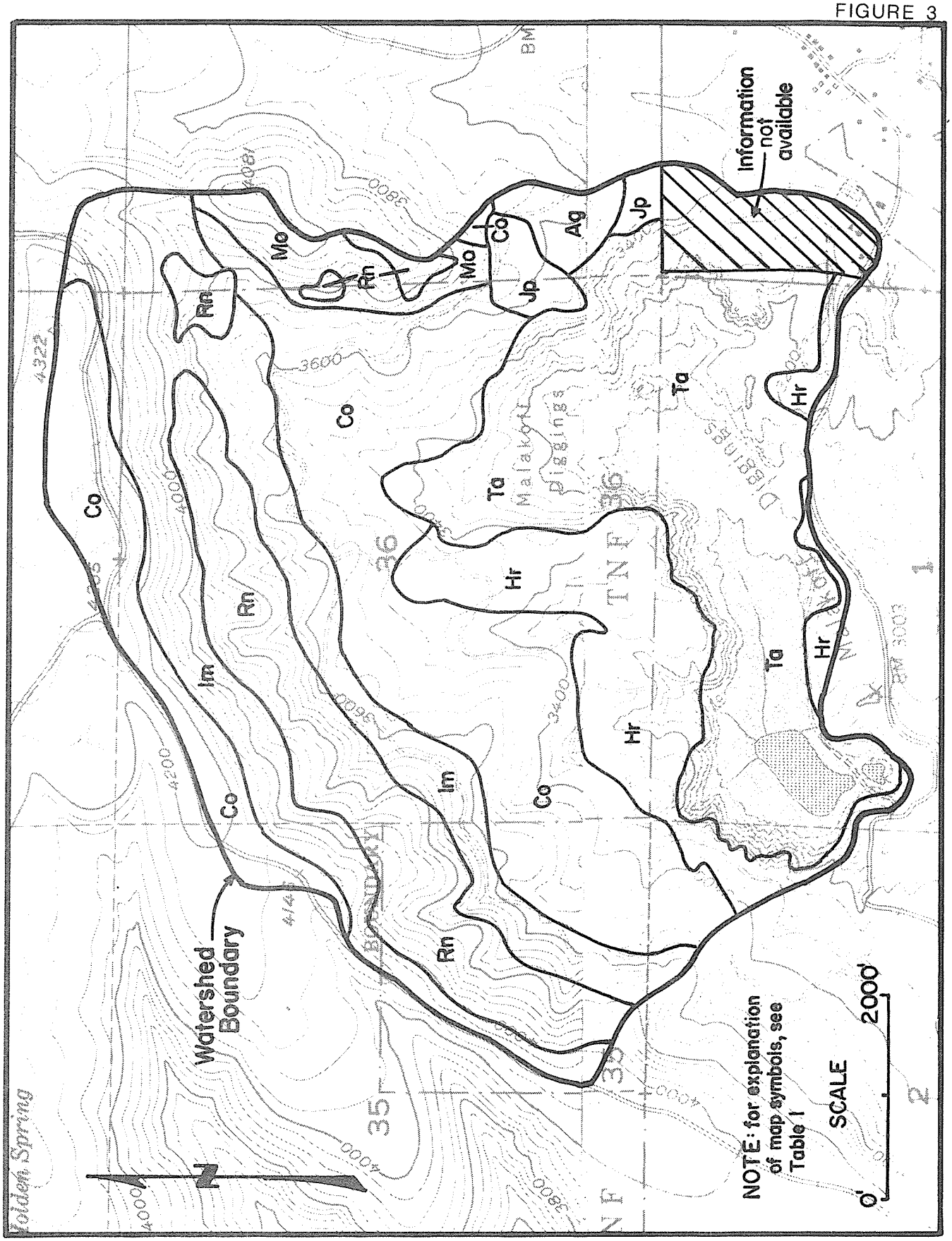
Generalized Geologic Map (modified from Peterson, 1980)

Table 1
DESCRIPTION OF SOIL PROPERTIES IN THE MALAKOFF DIGGINS WATERSHED*

Soil Series and Name	Map Symbol	Parent Material	Slope (%)	Depth (meters)	Runoff Potential	Erosion Hazard
Aiken Series:						
Aiken Cobbly Loam	Ag	Andesite tuff and conglomerate	2 to 30	1.6	Slow to medium	Slight to moderate
Cohasset Series:						
Cohasset Cobbly Loam	Co	Andesite breccia and colluvium	5 to 30	2.4	Medium to rapid	Slight to moderate
			30 to 50	1.1 to 1.5	Rapid	Moderate to high
Horseshoe Series:						
Horseshoe Gravelly Loam	Hr	Auriferous gravel	9 to 15	1.5	Medium	Moderate
			15 to 30	1.5	Medium to rapid	Moderate to high
Iron Mountain Series:						
Iron Mountain Cobbly Loam	Im	Andesite breccia	2 to 50	0.4	Medium to rapid	Moderate to high
Josephine Series:						
Josephine Cobbly Loam	Jp	Slate and shale	5 to 30	1.0 to 1.8	Medium	Slight to moderate
McCarthy Series:						
McCarthy Cobbly Loam	Mo	Andesite conglomerate	15 to 50	0.5 to 0.8	Medium to rapid	Moderate to high
Rockland	Rn		30 to 50	Variable	Medium to rapid	Slight to moderate
Tailings	Ta		0 to >50	Variable	Slow to rapid	Moderate to high

*From Brittan (1975).

FIGURE 3



Generalized Soils Map (modified from Brittan, 1975)

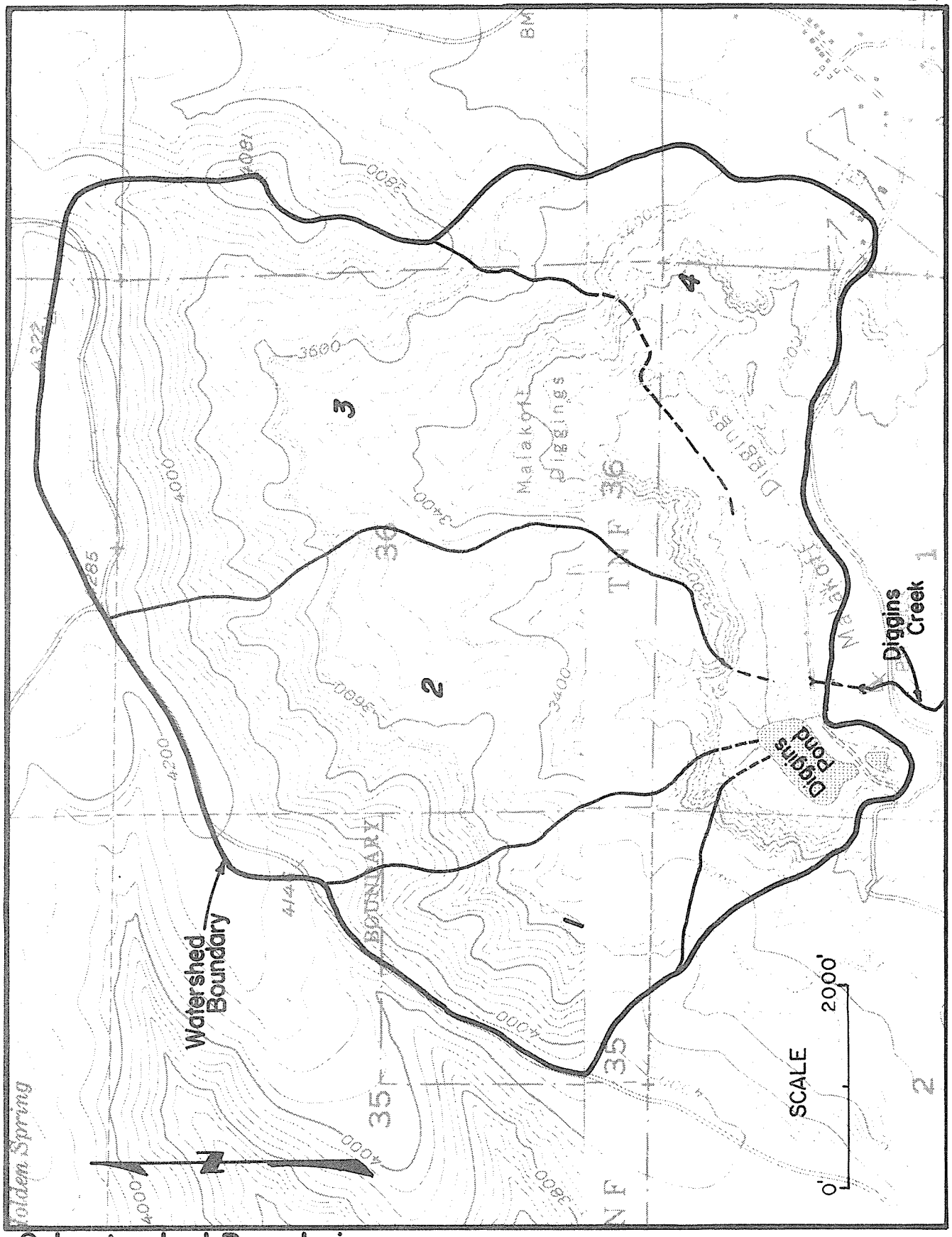
Hydrology

The watershed encompassing Malakoff Diggins comprises about 1,216 acres (19 percent) of the Humbug Creek watershed, which is about 6,400 acres in area (Peterson, 1980; NCRCD, 1978). The Nevada County Resource Conservation District (1978) divided the watershed into four subwatersheds and numbered the major stream draining each (Figure 4) (NCRCD, 1978). The NCRCD subdivisions and nomenclature are used in this report, with the exception of the boundary between subwatersheds 3 and 4 at the east end of the diggings. Here, the shifting of the braided streams back and forth across the mine floor constantly changes the location of this boundary.

Annual precipitation at Malakoff Diggins averages 60 inches, as measured at the nearby meteorological station at North Bloomfield. The area receives a few feet of snowfall each year, but it generally melts within a few days or weeks. There generally is no spring runoff of snowmelt. Table 2 shows precipitation at the North Bloomfield station. The data are also presented in Figure 5, which shows that 86 percent of the precipitation falls from November through April.

Because no permanent gaging station exists on Diggins Creek or Humbug Creek, accurate annual runoff data are not available. An indirect method of determining this value is given by the U. S. Soil Conservation Service (SCS, 1975). This method was used by Nevada County Resource Conservation District (1979b, 1980) in its estimate of an average annual runoff of 3,000 acre-feet. It is adequate for general determinations, but it is not accurate enough for predicting the effect of conservation practices (SCS, 1975, p. 2-53). To adequately define annual discharge and develop rainfall/runoff relationships, it is necessary to gauge a stream continuously over a period of several years. Until such a record can be established, estimates of runoff are subject to significant errors. Likewise, erosion control alternatives that are based on these estimates may not perform according to expectation.

FIGURE 4



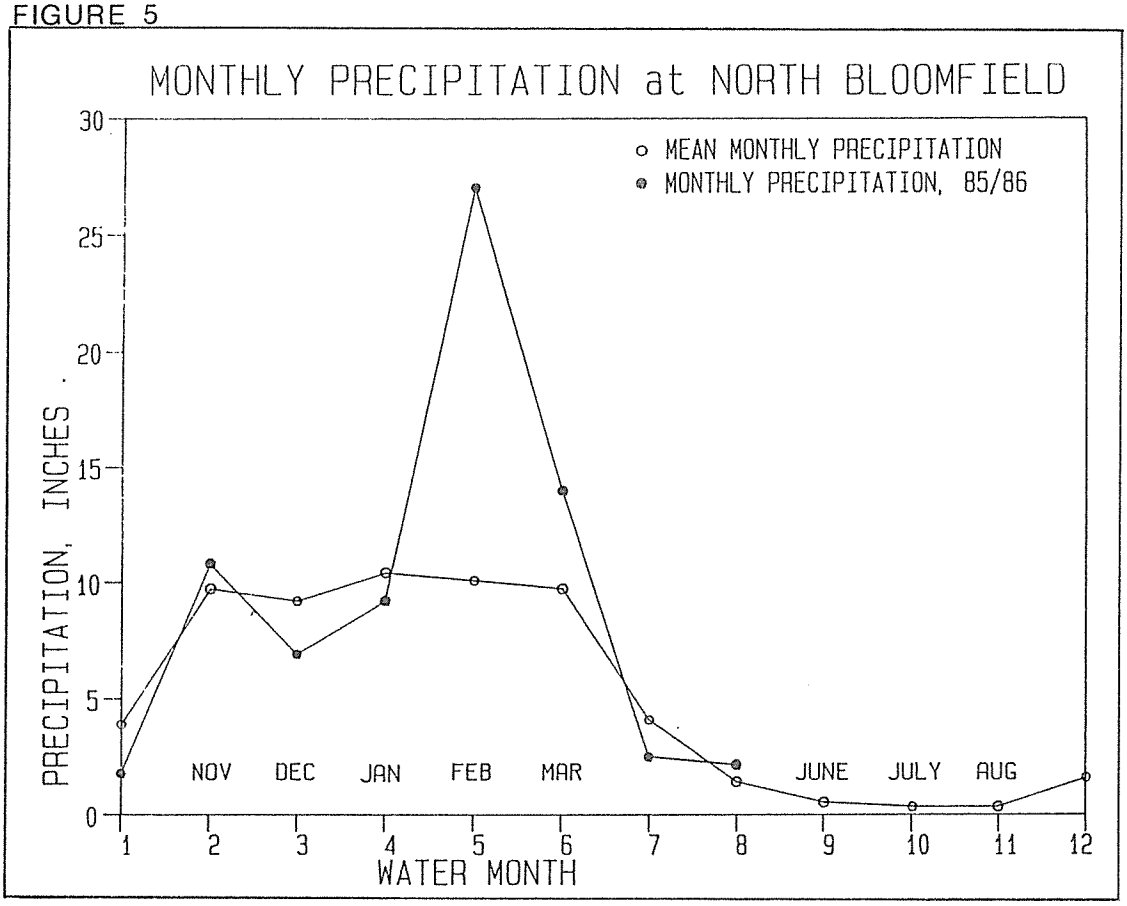
Subwatershed Boundaries

Table 2
PRECIPITATION AT NORTH BLOOMFIELD, CA
ELEVATION 3280'

MONTH	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	MONTHLY AVERAGE
JANUARY	6.3	4.9	19.4	10.2	6.1	1.1	4.2	23.5	(12.8)	14.2	12.0	8.6	12.30	**	**	9.23	10.35
FEBRUARY	1.1	6.9	13.2	6.2	12.0	6.1	4.0	9.9	13.5	16.3	4.0	8.6	16.40	**	4.60	27.06	9.99
MARCH	9.6	3.1	5.9	16.1	14.3	1.8	2.5	12.2	6.7	4.6	8.8	13.9	(21.90)	**	9.10	13.95	9.63
APRIL	2.4	5.7	0.7	3.4	5.3	2.9	1.2	7.9	3.5	3.3	1.5	11.5	9.10	**	1.20	2.43	4.14
MAY	3.1	0.9	1.3	0.2	(1.5)	0.0	3.5	0.8	2.1	3.7	(1.1)	0.3	1.20	**	0.20	2.17	1.47
JUNE	1.0	1.3	0.0	0.3	(0.8)	0.2	0.0	0.4	0.0	0.9	(0.0)	2.7	0.60	**	0.30		0.61
JULY	0.0	0.0	(0.2)	3.1	(0.2)	0.0	0.1	0.0	0.2	0.7	0.0	0.1	0.20	**	0.10		0.35
AUGUST	0.0	0.0	0.3	0.1	(1.9)	2.1	0.5	0.0	0.1	0.2	0.0	0.1	(0.30)	**	0.10		0.41
SEPTEMBER	1.1	2.6	1.5	0.0	0.2	(1.1)	1.0	4.0	0.1	0.0	1.4	3.4	(3.00)	**	1.80		1.51
OCTOBER	0.8	4.1	5.0	2.7	8.3	0.6	0.3	0.0	5.0	1.2	7.2	8.1	(6.50)	4.00	1.70		3.96
NOVEMBER	(5.4)	11.2	23.9	2.7	3.7	(2.1)	5.1	5.3	5.6	2.3	15.4	11.5	(19.90)	11.60	10.72		9.74
DECEMBER	12.3	8.0	9.5	6.2	2.9	0.4	13.1	2.9	11.2	6.0	16.9	11.6	(21.20)	**	6.92		9.22
TOTAL	43.1	48.7	80.9	51.2	57.2	18.4	35.5	66.9	60.8	53.4	68.3	80.4	112.60			ANN. AVE.*	59.80

*EXCLUDES YEARS WITH INCOMPLETE DATA
**NO RECORDS AVAILABLE
NOTE: WINTER 1985/1986 DATA COLLECTED BY PRIVATE OBSERVER AT NORTH BLOOMFIELD,
ALL OTHER DATA FROM U.S. DEPARTMENT OF COMMERCE; () INDICATES SOME DATA ESTIMATED.

FIGURE 5



Chapter 4. WATERSHED CHARACTERISTICS

The Malakoff Diggins watershed can be subdivided into three physiographic units: the upper watershed, the cliffs, and the mine floor (Figure 6). A similar subdivision was made by Nevada County Resource Conservation District (1979a). These three units are linked by a network of streams that flow across them and eventually merge at Hiller Tunnel to form Diggins Creek. The characteristics of the streams change as they cross from one physiographic unit to another. The combined influence of these effects ultimately determines the quality of water discharged to Humbug Creek. This section discusses the physiographic units and the characteristics of streams draining them.

Upper Watershed

The upper watershed of Malakoff Diggins consists of those areas to the north of the diggings that were not affected by mining activity. Although it was not mined, significant impacts to the upper watershed did occur, as it was heavily logged by the miners and other residents of North Bloomfield. The area is now typically well vegetated by second-growth ponderosa pine forest and an understory of dense brush. Upper watershed slopes underlain by auriferous gravel and colluvium typically have a slope of 0 to 30 percent.

Nevada County Resource Conservation District (1979a) observed that streams draining the upper watershed ran clear, even during intense storms and high runoff. This indicates that the area is stable and erosion now is relatively minor. It also demonstrates that, given the proper circumstances of slope, soil moisture, and nutrition, vegetation can be established and can effectively prevent erosion of the watershed.

Cliffs

Cliff areas, which represent the walls of the hydraulic mine, are present along west, north, and east margins of the diggings. Height of the cliffs ranges from 200 feet in the west to nearly 500 feet at the east end of the diggings. The cliffs are continuous except for a small segment where drainage 2 enters the pit and at the northeast corner of the diggings where landsliding has modified the topography. Areas of active gullying, landsliding, and recent landslide deposits are included in the cliff physiographic unit.

Since cessation of mining operations, the cliffs have eroded from their original near-vertical configuration to various angles of inclination. Yuan (1979) studied this retreat and calculated erosion rates of 0.79 to 11.42 inches per year for cliffs along the north-central margin of the mine. Qualitative observations in the landslide area at the east end of the diggings indicate that erosion rates there exceed Yuan's estimates for erosion of the north cliffs, at least periodically. The base of the cliffs has been buried by talus, alluvial fans, and other deposits accumulated from various erosional processes. Vegetation has established itself on these deposits at the base, but is sparse or nonexistent on the steep cliff faces.

Observations by NCRCD (1979a) indicated that streams draining the upper watershed entrained sediment and eroded the cliffs. With the exception of drainage 2, the streams are visibly more turbid at the base of the cliffs than when they enter the mine from the upper watershed. The NCRCD (1979a) data show cliff areas contribute a substantial portion of the sediment discharged from the diggings.

Mine Floor

The mine floor is a broad, gently inclined, alluvial plain within an east-west trough that once was the working floor of the hydraulic pit. It measures about 5,000 feet long and 1,000 feet wide.

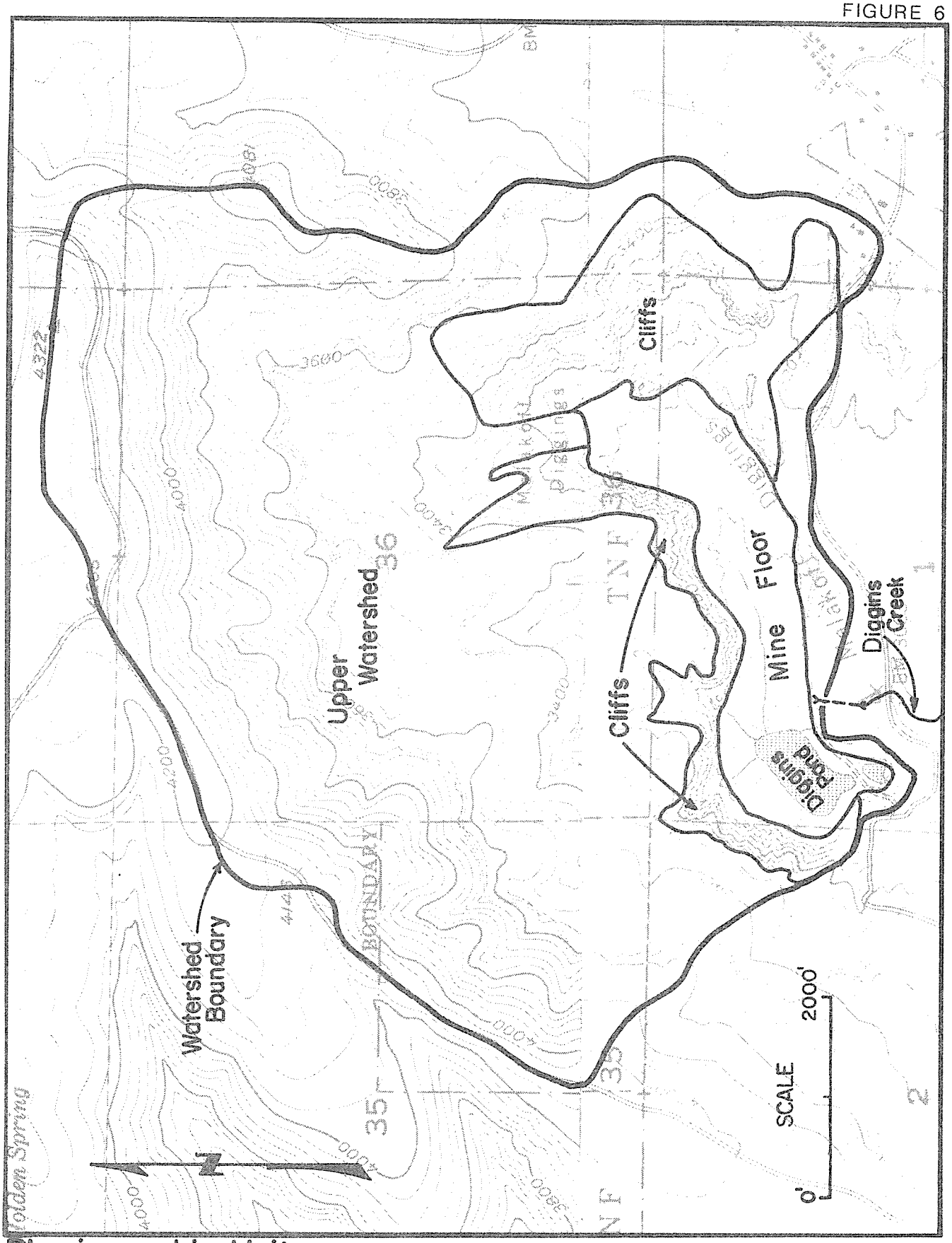
A dense stand of willows and alders has established itself in the western two-thirds of the mine floor. The eastern one-third is sparsely vegetated; however, vegetation appears to be slowly spreading into this portion of the mine floor. Conifers and brush are present on the steeper alluvial fans and talus along the margins of the mine floor.

Streams from the upper watershed drain into the mine and flow toward Hiller Tunnel, where they merge to form Diggins Creek (Figure 6). Streams 1 and 2 enter the mine on the north end of the diggings and flow into the northeast corner of a small pond (Diggins Pond). Stream 3 enters the mine at the northeast corner of the diggings and flows along the north side of the mine floor, eventually working its way southwestward through the stand of dense vegetation to Hiller Tunnel. After emerging from springs in landslide deposits near the east rim of the diggings, Stream 4 flows westward along the south side of the mine floor toward Hiller Tunnel. Neither Stream 3 nor Stream 4 flows directly into Diggins Pond.

Subsequent to flowing into the mine, Stream 4 is braided over its entire length and tends to shift back and forth across the floor of the mine throughout the winter months. Stream 3 is confined to a relatively well defined channel near the base of the cliffs as it first flows into the mine. It becomes braided as it flows into the area of dense vegetation in the western portion of the mine floor. The channel location of Stream 3 provides geomorphic evidence that streams draining the eastern end of the mine floor (subwatershed 4) deposit relatively larger volumes of sediment. The alluvial fans from these streams appear to have displaced Stream 3 to its position near the base of the cliffs. The difference in channel morphology between the streams is probably related to a higher sediment load and lower discharge for Stream 4. Since Stream 4 has a smaller drainage area and an apparently larger sediment load, it is less able to carry the load supplied to it, resulting in a braided stream. Stream 3 has a larger watershed, more runoff, and is better able to carry the sediment supplied to it; thus, it is less likely to braid.

As they enter the mine, the gradient of all the streams decreases, and they deposit some of their sediment load. Mostly sand-size and larger sediment is deposited, but some fine-size material is also deposited. The mine floor is also the depositional area for scree and landslide debris derived from mass wasting of the cliff areas. Over the years, sediment deposition in the mine has gradually reduced the size of Diggins Pond, which at one time was a much larger lake behind a dam built to impound tailings (refer to Figure 7, in Chapter 5). In fact, so much deposition has occurred in the mine that the elevation of the alluvium surrounding Hiller Tunnel is now higher than the tunnel inlet, and Streams 3 and 4 usually flow directly into the tunnel. This increases the possibility that Hiller Tunnel may become plugged by debris at some time in the future. Futhermore, because the streams no longer flow directly into Diggins Pond, its ability to act as a sediment trap is severely limited. The active deposition occurring on the mine floor and the braided, shifting nature of Streams 3 and 4 are factors to be considered when evaluating sediment control alternatives.

FIGURE 6



Physiographic Units

Chapter 5. NATURAL PROCESSES AT WORK IN THE DIGGINGS

The problems of erosion, mass wasting, and sediment depositon and discharge at Malakoff Diggins are a response to alterations of the natural environment caused by hydraulic mining in the late 1800s. These processes occur to some degree on all exposed surfaces of the earth, but the combination of geology and physiography at Malakoff has accentuated their effects. To develop effective erosion and sediment controls, it is necessary to understand how and where these processes take place in the diggings. This chapter presents this information and estimates of the rate at which these processes occur.

Erosion and Mass Wasting

The Nevada County Resource Conservation District (1979a, 1979b) demonstrated that the vast majority of sediment transported by Humbug Creek is derived from bare exposures of auriferous gravel and landslide deposits in Malakoff Diggins. This sediment enters the stream by erosion and mass wasting of the cliffs. The most important process of mass wasting that contributes sediment to Diggins Creek is landsliding. The predominant processes by which material is eroded at the diggings are rainsplash and surface flow (Yuan, 1979; Peterson, 1980). Growth of needle ice and disintegration of clay by desiccation were found by Peterson to contribute a relatively minor volume of sediment to Humbug Creek, and, as such, are not addressed in this study.

Peterson (1980) observed that certain rock types display specific characteristics of erosion and mass wasting. Erosion due to rainsplash and surface flow occurs most extensively on coarse sediment such as pebbly sandstone and conglomerate. Landsliding is most commonly associated with clay interbeds in the gravel.

Landslides

Landslides of various sizes and morphologies are present throughout the diggings. Along the north and west cliffs, slides composed of blocks of sandstone and conglomerate 3 to 6 feet deep occur on slopes greater than 60 degrees. Small slumps are associated with continuous clay beds in this portion of the mine (Peterson, 1980).

About one-third of the land surface in the eastern portion of the diggings is composed of landslide deposits. The largest of these, located in the northeast corner, now supports trees, indicating it is relatively stable. However, scarps at the head of the slide indicate that continued movement is likely.

There are also numerous landslide deposits along the cliffs at the east and southeast end of the mine. Peterson (1980) mapped landslides in this area and determined that they are derived from two specific sources. Recent mudflows can be traced to the first source, a nearly horizontal silty clay bed at elevation 3,300 feet. Older mudflows in the area are probably derived from the same source. Although the older mudflows are vegetated, they have been dissected by gullies and are an important source of sediment.

The second source is a clay bed at elevation 3,520 feet. Failure of this clay bed has caused the development of a complex landslide at the rim of the diggings. The complex landslide consists of a slump that grades downslope into mud flows. The slump is increasing in size by upslope migration of its headscarps. The mud flow deposits are derived from sloughing of the slump toe, which coincides with the edge of the cliffs. During the winter of 1986, as much as 3 feet of cliff retreat per day

25 feet of the top of the cliffs (Peterson, 1980).

Extensive gullying of landslide deposits is occurring in the eastern end of the mine. Several densely gullied cliff areas are also present, especially along the north and east walls of the mine, where they resemble badlands (Yuan, 1979).

The pebbly sandstones and conglomerates of the auriferous gravel are most susceptible to the effects of rainsplash and surface flow; whereas clay beds and cobble conglomerates are generally less dissected by rills (Peterson, 1980). This difference probably is a result of the cohesion of in-place clay particles. Cobble conglomerates may be resistant due to the mass of the clasts, partial cementation, relatively higher permeability, or a combination of these factors.

Previous studies at Malakoff Diggins have used a variety of approaches to estimate the rate of sediment erosion of the cliffs and landslide area. These estimates are summarized in Table 4. The table shows that a wide variability of rate of erosion exists in the diggins. Peterson's (1980) erosion plot data indicate that erosion takes place sporadically throughout the diggings; longer periods of observation at more control points are necessary to better define erosion rates in the diggings.

Sediment Deposition

Sediment dislodged by raindrops and entrained by surface flow is carried from the cliffs and landslide deposits toward Hiller Tunnel. A large portion of the coarse sediment is deposited in alluvial fans, in braided stream deposits on the mine floor, or in the pond as the streams flow through the pit, but most of the silt and clay-size material is eventually discharged from the diggings.

Deposition of sediment occurs as a response to reduced stream velocity. Reduction of velocity in the diggings is most dependent on the channel gradient; however, other factors also influence stream velocity, including channel roughness, water depth, and obstructions to flow such as vegetation or standing water. The gradient of the mine floor is gentle enough to cause deposition of a good portion of sand-size and larger sediment, but the velocity of streams flowing through the diggings is not decreased enough to result in deposition of significant volumes of fine material.

The size distribution of sediments deposited in the diggings were analyzed by Nevada County Resource Conservation District (1979b) and Peterson (1980), whose data are presented in Table 5. The analyses show most deposited sediment is sand-size or larger. However, the amount of clay-size sediment deposited dramatically increases with proximity to Hiller Tunnel.

Sediment deposition appears to be actively occurring in nearly all portions of the mine floor, as evidenced by the burial of trees and brush. Within the stand of vegetation at the west end of the diggings, new accumulations of sediment can be distinguished from sediment deposited in previous years based on differences in color and plant growth.

The diminution of Diggins Pond over time is further evidence of sediment deposition. Aerial photographs taken between 1952 and 1981 were studied to determine sediment deposition and vegetative growth patterns on the mine floor. Figure 7 presents the analyses of these photos. Sources of the photos are given in Table 6. Study of the 1952 photos shows that the pond extended about 600 feet east of Hiller Tunnel and only sparse, low vegetation existed on the mine floor. By 1962, the pond extended to only 100 feet east of Hiller Tunnel,

Table 4
ESTIMATES OF EROSION, DEPOSITION, AND DISCHARGE

Erosion

Study	Method	Rate of Erosion	Remarks
Yuan (1979)	Comparision of historic photographs of cliffs	13,100 to 55,600 yd^3/yr 30,000 yd^3/yr average	Estimate accounts only for erosion of cliffs; maximum possible error of 55 percent
Peterson (1980)	a) Erosion plots on cliffs	0 to 30,700 yd^3/yr, 8,500 yd^3/yr average	Results of four recovered plots for a 5-month period during the winter of 1979-1980; estimate applies only to cliff erosion
	b) Calculation utilizing sediment concentration data of NCRCD (1979a) for streams draining landslide deposits	480 to 29,600 yd^3/yr, 15,000 yd^3/yr average	Assumes 100 percent runoff of precipitation on landslide deposits in the eastern end of the diggings
Total Annual Erosion		13,580 to 86,300 yd^3/yr, 49,940 yd^3/yr average	

Deposition

Study	Method	Rate of Deposition	Remarks
Peterson (1980)	a) Historical Records: Comparison of Hammon Engineering Co. (1917) map and 1980 survey	62,100 yd^3/yr	Estimate relies on accuracy of 1917 map and Peterson's calculation of the shape of the basin in which sediment was deposited
	b) Geophysical Survey: 1. Basin volume less impounded sediment (8.41 x 106 m^3 from Jarman, 1927) 2. Basin volume less 20 m high debris dam	 6,500 yd^3/yr 115,000 yd^3/yr	Estimates rely on accuracy of Jarman's (1927) estimate of mined debris, height of the debris dam and the accuracy of Peterson's geophysical survey
	c) Estimated deposition of silt and clay in the vegetation	1,160 yd^3/yr	

Discharge

Study	Method	Rate of Discharge	Remarks
Cranmer Engineering, Inc. (1979)	Extrapolation of data collected during 1 storm event, 3/14-15/79	6,000 yd^3/yr	Based on samples of suspended load only, bed load ignored; data collected during latter part of winter when transport rates are lower
Peterson (1980)	Calculation of the percentage of clay in the total amount of sediment eroded annually, less the volume of clay deposited in the vegetation.	12,300 yd^3/yr to 21,500 yd^3/yr	Bed load transported out of diggings ignored; estimate assumes no clay deposition in areas other than the vegetation

Table 5
PARTICLE SIZE ANALYSIS*

Study	Sample	Granules	Coarse Sand	Medium Sand	Fine Sand	Silt and Clay	Comments
Peterson (1980)	1	8.6	48.3	24.7	15.6	2.8	Samples 1-4 taken at a depth of 0.3 m.
	2	25.1	40.0	19.4	14.0	1.5	
	3	4.6	50.4	27.9	16.4	0.7	
	4	11.6	45.2	19.5	21.1	2.6	
	5	3.4	32.5	26.7	26.0	11.4	Core sample of the surficial 0.6 m of sediment
	6					over 98	From a surficial layer of silty clay 8 cm thick
	7	5.2	24.3	14.1	45.2	11.2	Sediment underlying sample 6.
NCRCD (1979b)	A			99.0		1.0	Sample taken 50 yards below the slump area
	B			95.9		4.1	Sample taken midway between sample A and Hiller Tunnel inlet

*Values given as weight percent of sample.

Sample Localities

●4 Peterson, 1980

A NCRCD, 1979b (approximate location)

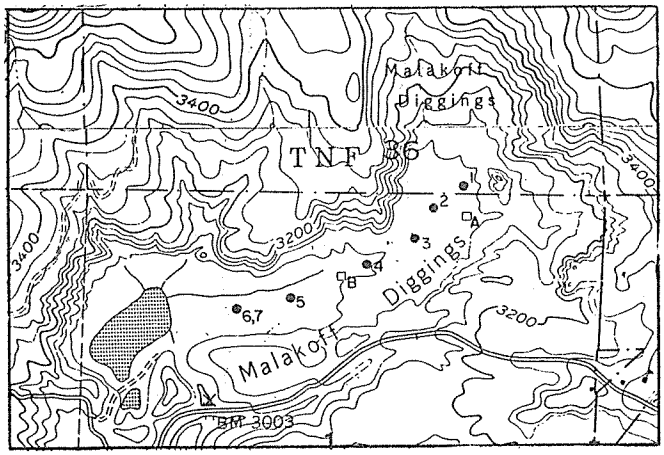
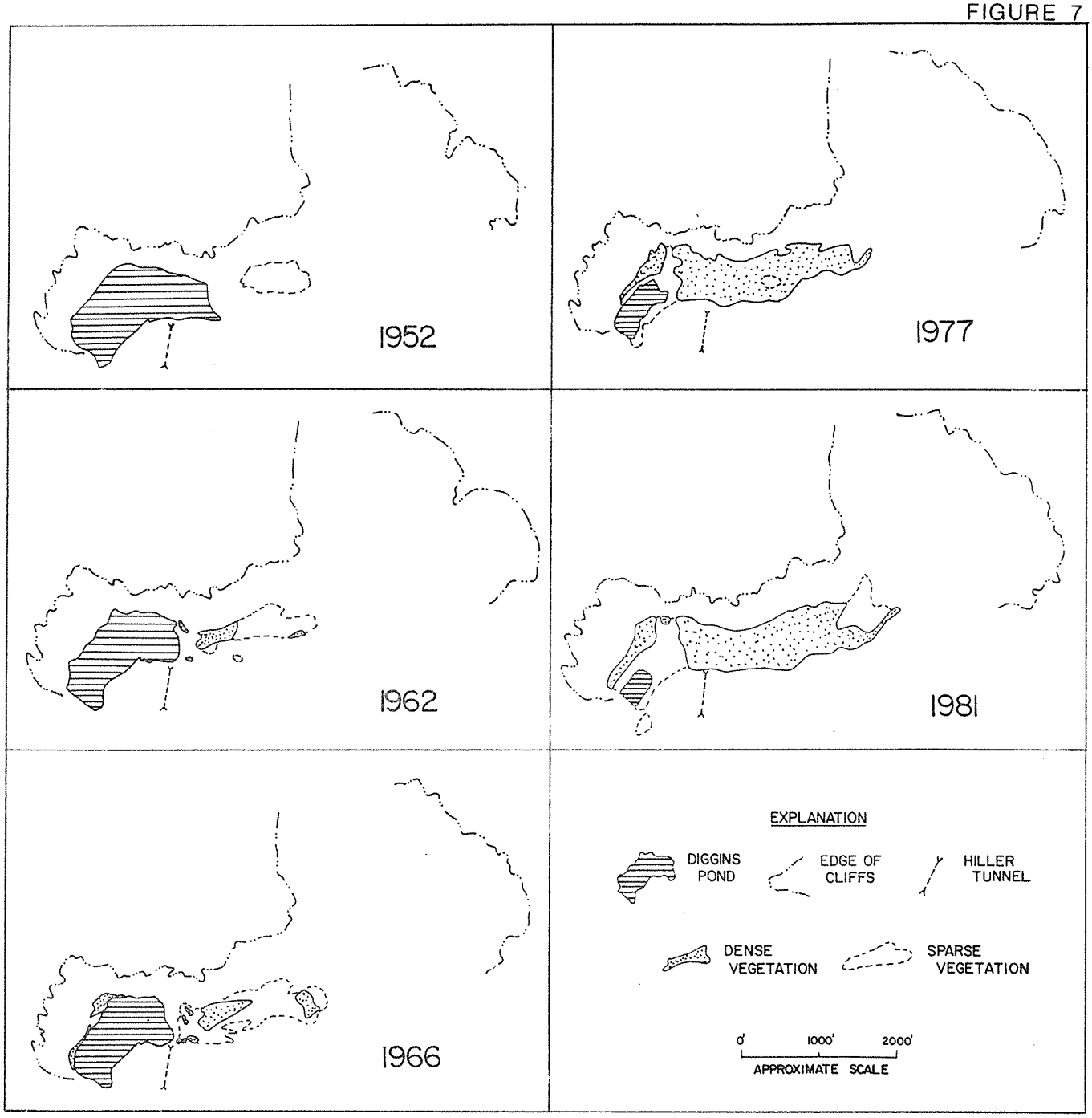


FIGURE 7



Changes in Pond Size and Vegetation Density, 1952-1981

Table 6
SUMMARY OF AERIAL PHOTO SOURCES

Date	Flight Line	Source	Original Scale (Approx)
7/20/52	DRG-7K-149	Dept. of Parks and Recreation; Dept. of Water Resources	1:20,000
8/1/62	Nev 4-236	Dept. of Parks and Recreation	1:20,000
6/15/66	BP-J 2-4	Dept. of Parks and Recreation	1:15,000
9/8/77	USDA 977-156	Dept. of Water Resources	1:24,000
4/5/81	ALL-CH-42-18	Dept. of Forestry	1:24,000

and areas of dense vegetation were established, especially along the north half of the pit. In 1966, deposition of sediment in the mine had filled Diggins Pond to a point roughly coincident with Hiller Tunnel, and by 1977, the pond was confined to the area west of Hiller Tunnel and dense vegetation covered the entire width of the mine floor. It was during this interval that streams draining the diggings probably began flowing freely across the mine floor, directly into Hiller Tunnel. This also marked the point in time at which the ability of Diggins Pond to trap sand-size sediment began to be severely restricted, and this larger sediment was discharged from the mine. The 1981 aerial photos show a continued decrease in the size of the pond and increased growth of vegetation.

Analysis of the aerial photos, combined with Peterson's particle size analysis of deposited sediments, indicates that the vegetation is effective in trapping some of the fine-grained sediment eroded at the diggings. When Diggins Pond was larger, it received runoff from all four of the larger streams draining the Malakoff Diggins watershed and probably acted as a settling basin for both coarse- and fine-grained material. Streams 3 and 4 now flow directly to Hiller Tunnel, and the pond now receives runoff indirectly from Streams 1 and 2; thus, it does not significantly reduce the amount of sediment discharged from the diggings.

At present, Hiller Tunnel is the only point through which runoff from the Malakoff Diggins watershed exits the mine. The tunnel is now kept open by the flushing action of these streams. There is a possibility, though remote, that it may become plugged in the future by the sediment and debris that these streams carry or by some catastrophe (e.g., landsliding). If this were to occur, a larger pond would once again form in the mine, creating a more effective sediment trap. However, such an occurrence might also present a hazard if sudden breaching of the retaining dike or rock unit were to occur.

Peterson (1980) used several methods to estimate the rate of sediment deposition in the diggings. His results are presented in Table 4. A wide variability in the estimates exists because they rely on comparison of 1980 conditions with those reported in the early 1900s. Inaccuracies in the earlier reports could significantly alter Peterson's results.

Sediment Discharge

Sediment not deposited in the diggings is discharged through Hiller Tunnel to Diggins Creek and eventually to the South Yuba River. The Nevada County Resource Conservation District (1979b) stated that 99.9 percent of the sediment discharged at Hiller Tunnel is silt and clay and that virtually all settleable matter is retained in the diggings. However, during the winter of 1986, the channel substrate of Diggins Creek con-

tained a significant amount of sand-size material, indicating that both coarse- and fine-size material are transported out of the diggings. The fact that sediments now fill the mine to an elevation above Hiller Tunnel outlet indicates that sand-size and larger sediment is probably discharged from the diggings by runoff that accompanies most large winter storms, if not more frequently. Such discharge of coarse sediment probably began when the pit level reached the elevation of Hiller Tunnel inlet.

If precise estimates of the total volume of sediment eroded and deposited in the diggings were possible, then the difference in these two values could be assumed to represent the annual discharge of sediment from the diggings. However, estimates of sediment erosion and deposition vary widely, and this type of comparison is not possible.

Peterson (1980) and Cranmer Engineering, Inc. (1979) used other methods to estimate the amount of sediment discharged from the diggings. These estimates are also presented in Table 4. Both methods depend on extrapolating water sample data that reflect only the suspended load; the bedload is not considered. Thus, the estimates are probably lower than the amount of sediment actually transported out of the diggings.

To adequately define the amount of sediment being discharged from Malakoff Diggins, continuous discharge and sediment sampling are necessary. Sampling must include determination of the total amount of sediment transported as bedload.

Chapter 6. DATA COLLECTION AND EVALUATION

A main objective of this study was to determine if the quality of water discharged from the diggings and its effect on Humbug Creek had changed significantly since the Nevada County Resource Conservation District study was conducted in 1979. To make this determination, water samples and discharge measurements were taken at Hiller Tunnel outlet and at the confluence of Diggins Creek with Humbug Creek. In addition, water samples were taken at the confluence of Humbug Creek with South Yuba River. The monitoring sites are shown on Figure 8. Table 7 shows the type of data collected at each site.

This study originally was to have included an evaluation of water quality changes of streams within the diggings; however, due to inadequacies of the sampling method and to sample analysis costs, the size of the monitoring program was reduced. Results are presented in this chapter.

Methods and Equipment

The methods and equipment used to acquire data for this study are presented below. With the exceptions noted, the method of data collection conforms with that described in the National Handbook of Recommended Methods for Water Data Acquisition (USGS, 1978). Water samples were analyzed by the DWR Bryte Laboratory according to Standard Methods for the Examination of Water and Wastewater (American Public Health Assoc., 1980).

Discharge

Flow depth and velocity measurements were taken by wading. Velocity was measured with a Swoffer Model 2100-L electronic current meter and a Price-type (rotating element) pygmy current meter. Velocity measurements were made using the six-tenths depth method because no depths greater than 2.5 feet were encountered.

Efforts to measure discharge were hindered by extremes of flow velocity. Measurements could not be made on one occasion because the velocity was too high to permit safe access. Later season measurements were affected by too slow or too shallow flows. At these times, velocity measurements were made at the surface of the water, and the result multiplied by 0.85 to determine mean velocity of a vertical. This method of measuring velocity is subject to a 10 to 25 percent error (USGS, 1978).

At Station 9-4, discharge measurements in some verticals are subject to inaccuracy because the fine-grained substrate would not support the weight of the flowmeter, allowing it to sink. The presence of the meter also caused local erosion of the streambed in some verticals. The error introduced by these factors is estimated to be 5 to 10 percent of total discharge. A bifurcation of the flow downstream, and obstructions in the creekbed upstream precluded measuring discharge at a different location.

Water Quality

This study duplicated the water sample collection method used by Nevada County Resource Conservation District (1979a) so that comparable data could be developed. Samples were collected at each monitoring site by orienting half-gallon plastic bottles with the mouth directed upstream, and the bottle

parallel to the direction of flow. The samples were taken at a single point at the surface in the swiftest portion of the flow. They were then analyzed for suspended solids, settleable solids, turbidity, and electrical conductivity. Samples were stored in a dark refrigerator for one to five weeks prior to analysis.

Several possible errors are introduced by the sampling method used in this study. They chiefly involve settleable solids and suspended sediment concentration and suspended sediment yield calculations. First, one point in the stream is sampled, and the data are assumed to represent the entire flow section. Because of this, lateral and vertical changes in sediment concentration are not accounted for. The streams are small and turbulent flow predominates, which tends to lessen the sediment concentration variation. However, visual observations of the streams indicate that sediment concentrations and turbidity are not always constant or evenly distributed in all portions of the flow.

Second, the sampling method does not adequately assess the portion of total load transported as bedload. Observations of stream-bottom material at Stations 7-1, 9-4, and 11-4 during 1986 indicate that a substantial portion is comprised of sand-size particles. It is unlikely that this size of material is derived from sources outside the diggings in the amounts observed. Bedload sampling is needed to more accurately determine the volume of material sand-size and larger discharged from the diggings.

A third source of error is introduced by the sampling process itself. An ideal sampler should not appreciably disturb the flow of the stream it is sampling; the method used in this study and the NCRCD study does not meet this requirement. During sampling it appeared that the bottles caused a deceleration of streamflow velocity. According to U. S. Inter-Agency Reports (1941A, 1952), this deceleration would result in the sediment concentration of the samples being greater than the actual value. Determining the variation of the water quality of the natural stream with the water quality of samples taken at each monitoring site was beyond the scope of this study.

Table 7
MONITORING SITES

Site*	Location	Date Collected
7-1	Hiller Tunnel Outlet	Water Quality, Discharge
9-4	Diggins Creek above Humbug Creek	Water Quality, Discharge
10-4	Humbug Creek above Diggins Creek	Water Quality, Discharge
11-4	Humbug Creek below Diggins Creek	Water Quality, Discharge
12-3	Humbug Creek above South Yuba River	Water Quality
13-3	South Yuba River above Humbug Creek	Water Quality
14-3	South Yuba River below Humbug Creek	Water Quality

*Site designation and location corresponds with that of NCRCD (1979a).

Fourth, data collected by this study and the NCRCD study provide only a partial record of the total discharge of water and sediment from the diggings. Discharge and sediment concentration and their relationship to each other can vary radically during the course of a single storm and over a period of weeks during the winter. This change in relationship between discharge and suspended sediment concentration, called hysteresis, is demonstrated by Figure 9, which presents data collected by NCRCD during two storms in the winter of 1979. For measurements taken February 13 and 14, 1979, Figure 9 shows that, at a given discharge, the sediment yield can vary by as much as an order of magnitude

FIGURE 8

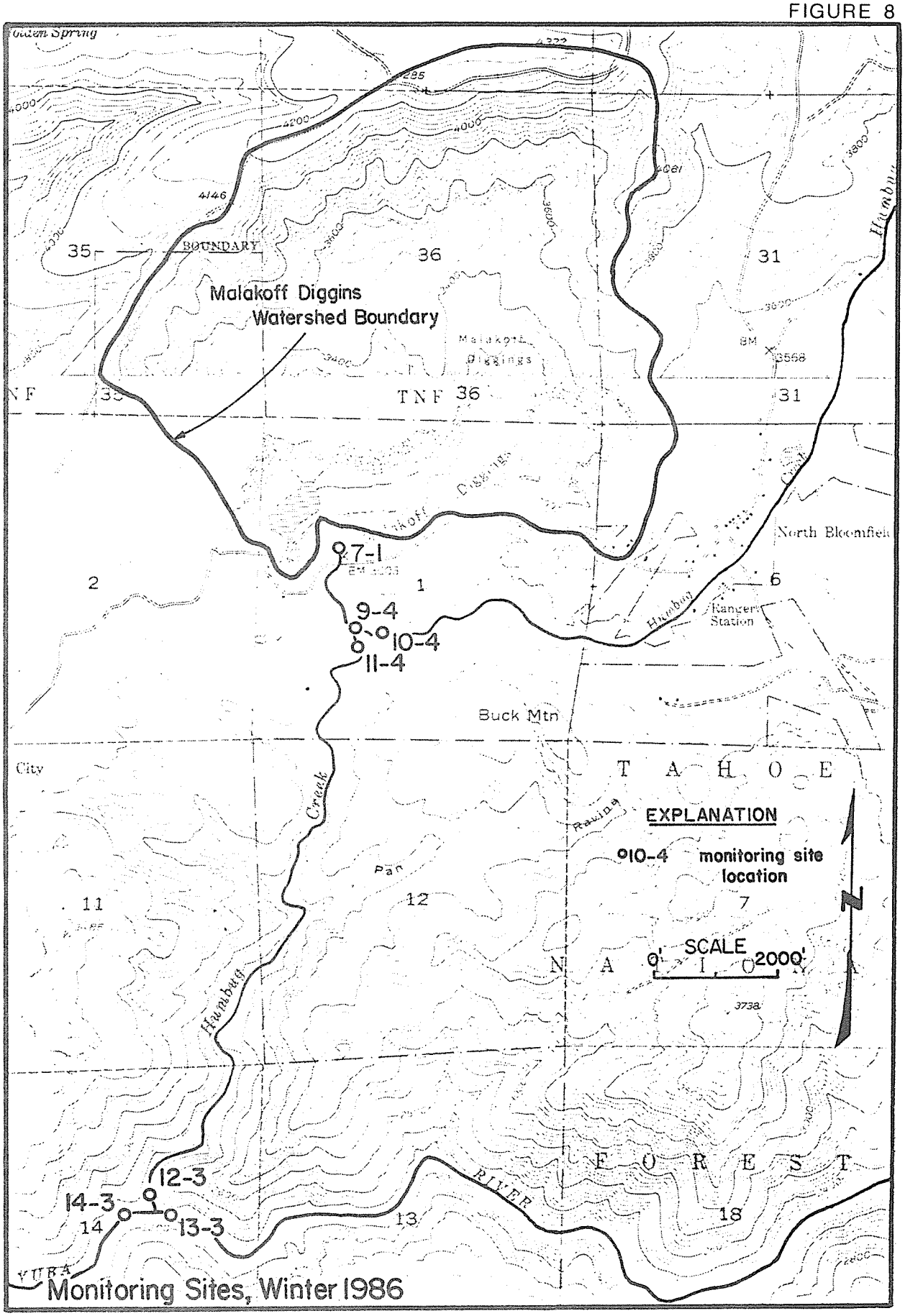
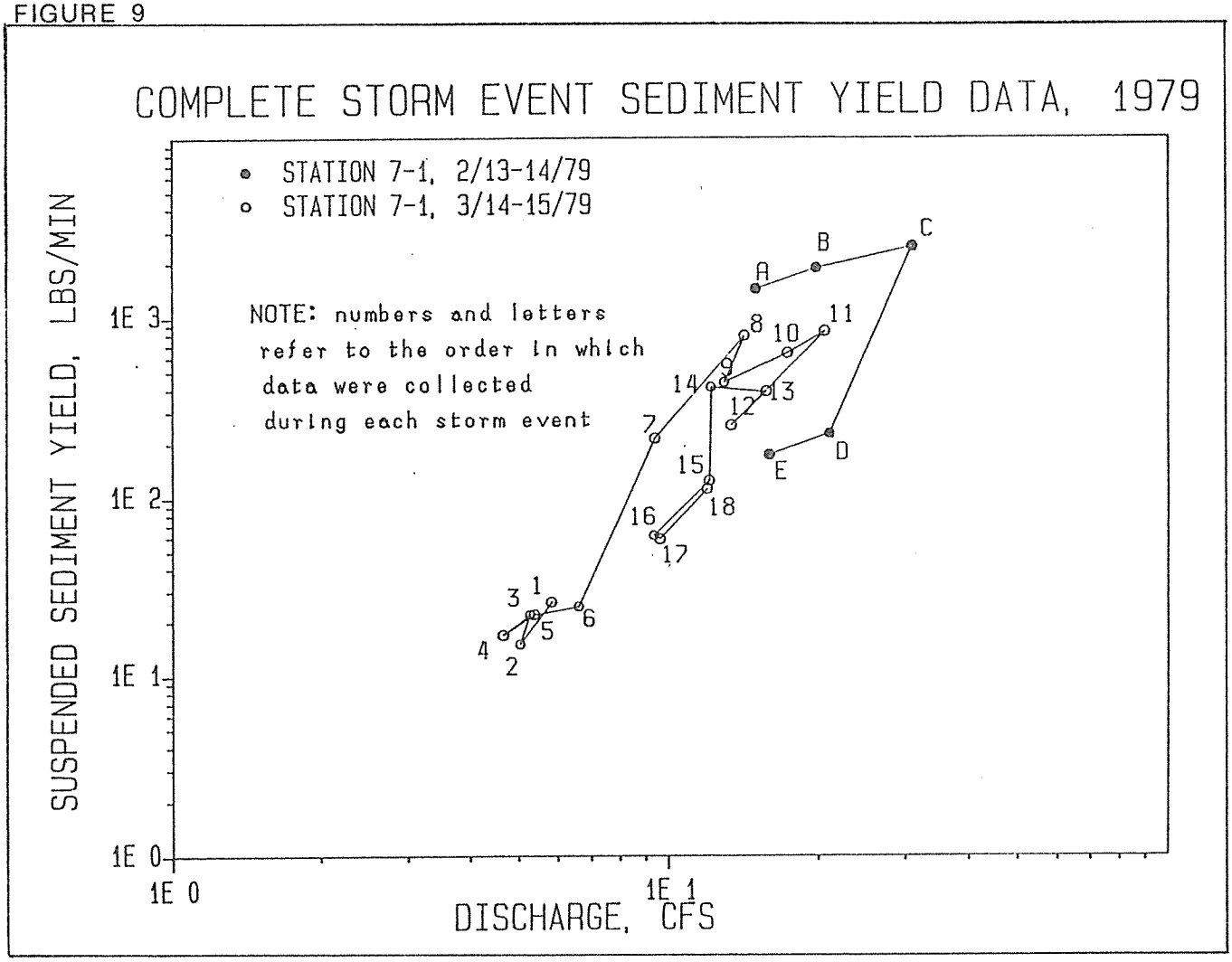

Malakoff Diggins
Watershed Boundary
BOUNDARY
35
36
31
TNF
North Bloomfield
Ranger Station
Buck Mtn
TAHOE
NATIONAL FOREST
EXPLANATION
monitoring site location
SCALE
0'
2000'
7-1
9-4
10-4
11-4
12-3
13-3
14-3
Monitoring Sites, Winter 1986

FIGURE 9



in a period of 24 hours. The peak discharge for a storm one month later, March 14 and 15, 1979, was nearly as high as that for the earlier storm, but the highest sediment yield was 2 to 3 times lower. Given these observations, noncontinuous sediment sampling and discharge measurements are not adequate to define the annual yield of sediment from Malakoff Diggins. Land-use decisions based on interpretation of these data are likely to meet with limited success. Future water sampling should not employ the method used in the previous study and duplicated in this study for comparative purposes.

Analysis and Interpretation

Despite the limitations noted above, data accumulated by this study were analyzed and compared on a site-by-site basis with the data collected by Nevada County Resource Conservation District (1979a). Where appropriate data were available, the suspended sediment yield at each station was calculated. Scatter diagrams of various water quality parameters were constructed to help determine any correlation between them and to assist in making comparisons with the earlier data. The graphed parameters are as follows:

- Suspended sediment concentration versus discharge
- Suspended sediment yield versus discharge
- Turbidity versus discharge
- Turbidity versus suspended sediment concentration
- Settleable solids versus discharge
- Settleable solids versus suspended sediment concentration
- Electrical conductivity versus discharge

Despite the hysteresis mentioned previously, suspended sediment concentration and turbidity are generally dependent on flow. Turbidity and suspended sediment concentration increases are also closely related. Electrical conductivity appears to be flow diluted.

Though there appears to be good correlation between some of these parameters, discharge-concentration relationships were not established because of the sampling program weaknesses. Continuous sampling with a rated sampler may better define discharge-concentration relationships; however, this must be confirmed by future samplings.

The relationship of settleable solids to discharge and suspended sediment concentration is less well defined. With increasing discharge (and suspended sediment concentration), settleable solids volume increases; however, NCRCD data (1979a) show high settleable solids volume at low discharges. This relationship may be a reflection of the inadequacy of the sampling technique. As discharge decreases, streamflows are more shallow and the sample is taken closer to the streambed. The higher settleable solids volume may be a reflection only of the higher concentration of this material closer to the streambed, or it may arise as a result of disturbance caused during sampling.

Data from this study were also compared to the Regional Water Quality Control Board (RWQCB) Objectives for Inland Surface Waters (Table 8). The standards

Table 8

WATER QUALITY OBJECTIVES*

Sediment

The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses.

Settleable Material

Waters shall not contain substances in concentrations that result in the deposition of material that causes nuisance or adversely affects beneficial uses.

Suspended Material

Waters shall not contain suspended material in concentrations that cause nuisance or adversely affect beneficial uses.

Turbidity

Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses.

Increases in turbidity attributable to controllable water quality factors shall not exceed the following limits:

- Where natural turbidity is between 0 and 50 Jackson Turbidity Units (JTU), increases shall not exceed 20 percent.
- Where natural turbidity is between 50 and 100 JTU, increases shall not exceed 10 JTU.
- Where natural turbidity is greater than 100 JTU, increases shall not exceed 10 percent.

Electrical Conductivity

The 25°C electrical conductivity shall not exceed 150 micromhos/cm (90 percentile) in well-mixed waters of the Feather River.

*From "Water Quality Control Plan Report for the Sacramento River Basin (5A)", California State Water Resources Control Board (1975).

for sediment, suspended material, and settleable material are qualitative in nature and thus are subject to varying degrees of interpretation. The electrical conductivity standard applies to the Feather River, a considerable distance away; electrical conductivity usually decreases with proximity to headwaters of streams. As a general guideline, discharges that cause a change of more than 10 percent in the background value of a particular water quality constituent are considered excessive (B. Newman, RWQCB, oral comm., 1986). For the purpose of this analysis, it is assumed that the condition of Humbug Creek above its confluence with Diggins Creek represents the local standard to which data should be compared. Determining the actual effects of discharges from Malakoff Diggins on the aquatic environment of Humbug Creek and the South Yuba River was beyond the scope of this study.

Results

Following are results of the monitoring program and data analysis at each site.

Hiller Tunnel Outlet

Station 7-1, Hiller Tunnel outlet, is the site for which the NCRCD (1979a) collected the largest quantity of information. Because Hiller Tunnel is constructed in bedrock, it is less likely to have undergone significant changes in configuration, thus flow and sediment transport patterns should be similar. Samples taken at this site would hypothetically give the best indication of how conditions may have changed since 1979.

Data collected during this study and those of the NCRCD (1979a) study are presented in Table 9. Five discharge measurements were made during the winter of 1986, ranging from 1.15 to 29 cubic feet per second. The higher reading is based on velocity measurements taken at the surface of the stream. Such surface sampling is subject to a 10 to 25 percent error (USGS, 1978). The range of suspended sediment concentrations of water samples is 477 to 12,000 mg/L, corresponding to turbidities of 250 and 6,400 nephelometric turbidity units (NTU). These values are within the range and magnitude of values obtained during the NCRCD (1979a) study.

Figures 10 through 16 are plots of the data collected by this study and the NCRCD (1979a) study. The plots show that, within the range of conditions sampled, very few changes have occurred in the time between the two studies. The majority of data obtained by NCRCD and this study are similar.

In all samples collected at Station 7-1, levels of settleable material, suspended material, and turbidity, and electrical conductivity are significantly higher than at Humbug Creek above Diggins Creek. The effects of Diggins Creek on Humbug Creek are discussed below.

Table 9

MALAKOFF DIGGINS WATER QUALITY DATA
STATION 7-1

DATE	TIME	SUSPENDED SOLIDS (MG/L)	SETTLEABLE SOLIDS (ML/L)	TURBIDITY (NTU)	ELECTRICAL CONDUCTIVITY (MMHOS/CM)	DISCHARGE (CFS)	SUSPENDED SED. YIELD (LBS/MIN)
02/28/86	1240	1680.00	1.10	960.00	77.00	7.24	45.61
02/28/86	1340	1620.00	1.50	585.00	44.00	7.24	43.98
02/28/86	1342	1710.00	1.30	760.00	77.00	7.24	46.43
03/07/86	1530	12300.00	9.00	6400.00	56.00	29.00 *	1337.63
03/28/86	1430	1400.00	0.60	540.00	77.00	3.91	20.53
03/28/86	1450	1430.00	0.70	570.00	76.00	3.91	20.97
03/28/86	1550	1490.00	0.70	560.00	76.00	3.91	21.85
04/06/86	1450	1330.00	0.90	560.00	107.00	2.63	13.12
04/06/86	1450	1300.00	0.80	500.00	108.00	2.63	12.82
04/06/86	1555	1180.00	0.50	500.00	105.00	2.63	11.64
04/18/86	1405	477.00	0.20	250.00	98.00	1.15	2.06
11/14/78		6.00	0.10	2.20	325.00		NO DATA
11/20/78	1430	533.00	0.40	460.00	223.00	0.76	1.52
11/21/78	1200	379.00	0.60	340.00	176.00	1.51	2.15
11/22/78	1515	53.00	0.30	58.00	161.00	1.11	0.22
11/29/78	1030					0.33	NO DATA
12/01/78	1030	12300.00	1.20	8000.00	116.00	3.39	156.36
12/04/78	1600					0.60	NO DATA
12/06/78	1400					0.35	NO DATA
12/19/78	1000	37.00	0.50	32.00	201.00	0.99	0.14
12/20/78	1305					0.64	NO DATA
12/21/78	1015					0.38	NO DATA
12/26/78	1415					0.45	NO DATA
12/27/78	1411					0.44	NO DATA
01/02/79	1455					0.24	NO DATA
01/04/79	0100					0.27	NO DATA
01/04/79	0130					0.24	NO DATA
01/04/79	0200					0.24	NO DATA
01/04/79	0230					0.29	NO DATA
01/04/79	0300					0.25	NO DATA
01/04/79	0330					0.27	NO DATA
01/04/79	0400					0.28	NO DATA
01/04/79	0430					0.25	NO DATA
01/04/79	0500	8.00	0.10	4.00	198.00		NO DATA
01/05/79	1430					0.61	NO DATA
01/08/79	0930					0.87	NO DATA
01/08/79	1315	1060.00	0.70	640.00	158.00		NO DATA
01/08/79	1635	30720.00	0.10	18000.00	97.00	7.34	845.57
01/10/79	1045					0.87	NO DATA
01/10/79	1515	1500.00	1.20	1000.00	202.00	0.88	4.95
01/10/79	1600					1.07	NO DATA
01/11/79	1050	11135.00	3.90	6250.00	63.00		NO DATA
01/12/79	1200	842.00	0.10	820.00	108.00	7.03	22.20
01/12/79	1240					6.16	NO DATA
01/14/79	1030	931.00	<0.1	940.00	88.00	4.84	16.90
01/15/79	1127	3950.00	1.50	2700.00	70.00	18.59	275.36
01/16/79	1110	818.00	<0.1	825.00	91.00	5.55	17.02
01/17/79	1135	962.00	0.10	780.00	112.00	5.49	19.81
01/17/79	1600					4.10	NO DATA
01/19/79	1500	706.00	0.20	500.00	131.00	2.90	7.68

DATE	TIME	SUSPENDED SOLIDS (MG/L)	SETTLEABLE SOLIDS (ML/L)	TURBIDITY (NTU)	ELECTRICAL CONDUCTIVITY (MMHOS/CM)	DISCHARGE (CFS)	SUSPENDED SED. YIELD (LBS/MIN)
01/26/79	1100	146.00	<0.1	155.00	122.00		NO DATA
01/29/79	1300					0.94	NO DATA
01/29/79	1330					0.80	NO DATA
02/06/79	1130					1.38	NO DATA
02/09/79	1430					0.95	NO DATA
02/12/79	1530	548.00	0.10	330.00	147.00	0.76	1.56
02/13/79	1000	26100.00	5.00	16000.00	78.00	14.89	1457.36
02/13/79	1100					15.10	NO DATA
02/13/79	1200	25510.00	4.00	15000.00	66.00	19.72	1886.46
02/13/79	1300					25.10	NO DATA
02/13/79	1400	21250.00	17.00	12750.00	61.00	30.93	2464.73
02/14/79	1000	2860.00	1.00	1950.00	65.00	21.01	225.33
02/14/79	1200	2880.00	1.00	1980.00	69.00	15.85	171.18
02/14/79	1300					18.89	NO DATA
02/16/79	1100	932.00	0.40	775.00	75.00		NO DATA
02/18/79	1105					4.85	NO DATA
02/18/79	1249	4210.00	2.20	2650.00	83.00	9.20	145.25
02/18/79	1408	5500.00	2.00	3200.00	80.00	8.30	171.19
02/19/79	1100	7300.00	2.80	4350.00	70.00		NO DATA
02/20/79	1545	19300.00	18.00	10000.00	62.00		NO DATA
02/21/79	1130	2090.00	1.00	1500.00	73.00	10.32	80.88
02/21/79	1345	2170.00	0.70	1550.00	63.00	10.49	85.36
02/23/79	1145	690.00	0.30	555.00	85.00	6.50	16.82
02/23/79	1345	1075.00	0.40	725.00	80.00	7.82	31.52
02/26/79	1150	7270.00	3.50	4250.00	59.00	13.88	378.40
02/26/79	1340					14.63	NO DATA
02/28/79	1100	8070.00	3.80	4450.00	71.00	10.68	323.20
02/28/79	1300	10550.00	7.00	5500.00	66.00	12.48	493.74
03/06/79	1145	1880.00	1.20	875.00	66.00	14.12	99.55
03/08/79	1100	1750.00	1.40	775.00	59.00	13.33	87.48
03/14/79	1155	1185.00	0.70	650.00	78.00	5.83	25.91
03/14/79	1800	795.00	0.30	420.00	79.00	5.01	14.94
03/14/79	1945	1130.00	0.50	600.00	79.00	5.25	22.25
03/14/79	2130	960.00	0.70	450.00	82.00	4.64	16.70
03/14/79	2315	1070.00	0.60	500.00	80.00	5.40	21.67
03/15/79	0135	985.00	0.70	440.00	85.00	6.58	24.30
03/15/79	0320	6210.00	4.50	1650.00	102.00	9.36	217.97
03/15/79	0510	14865.00	13.00	4600.00	80.00	14.13	787.66
03/15/79	0700	9030.00	4.10	4500.00	73.00	12.93	437.84
03/15/79	0840	9675.00	5.50	4500.00	64.00	17.37	630.21
03/15/79	1030	10480.00	5.00	5300.00	63.00	20.55	807.62
03/15/79	1215	4950.00	2.90	2650.00	70.00	13.34	247.62
03/15/79	1345	6430.00	3.00	3800.00	67.00	15.67	377.84
03/15/79	1545	9100.00	3.70	5300.00	77.00	12.15	414.62
03/15/79	1736	2760.00	1.10	1700.00	70.00	12.03	124.51
03/15/79	1905	1800.00	1.00	1100.00	70.00	9.32	62.91
03/15/79	1950	1630.00	0.90	1025.00	72.00	9.57	58.50
03/15/79	2245	2550.00	0.90	1450.00	73.00	11.89	113.70
03/21/79	1230	1355.00	0.50	800.00	81.00	5.24	26.63
03/26/79	1315	2155.00	2.10	950.00	114.00	6.57	53.09
03/27/79	1400	22150.00	14.00	9500.00	54.00		NO DATA
04/05/79	1530					2.90	NO DATA
04/10/79	1100	397.00	0.20	300.00	83.00	3.48	5.18
04/24/79	1000	707.00	0.20	575.00	102.00		NO DATA

NOTE: 1986 DATA BY DWR; 1978-1979 DATA FROM NCRCD (1979a)

* ESTIMATED VALUE BASED ON VELOCITY MEASUREMENTS AT SURFACE OF STREAM

FIGURE 10

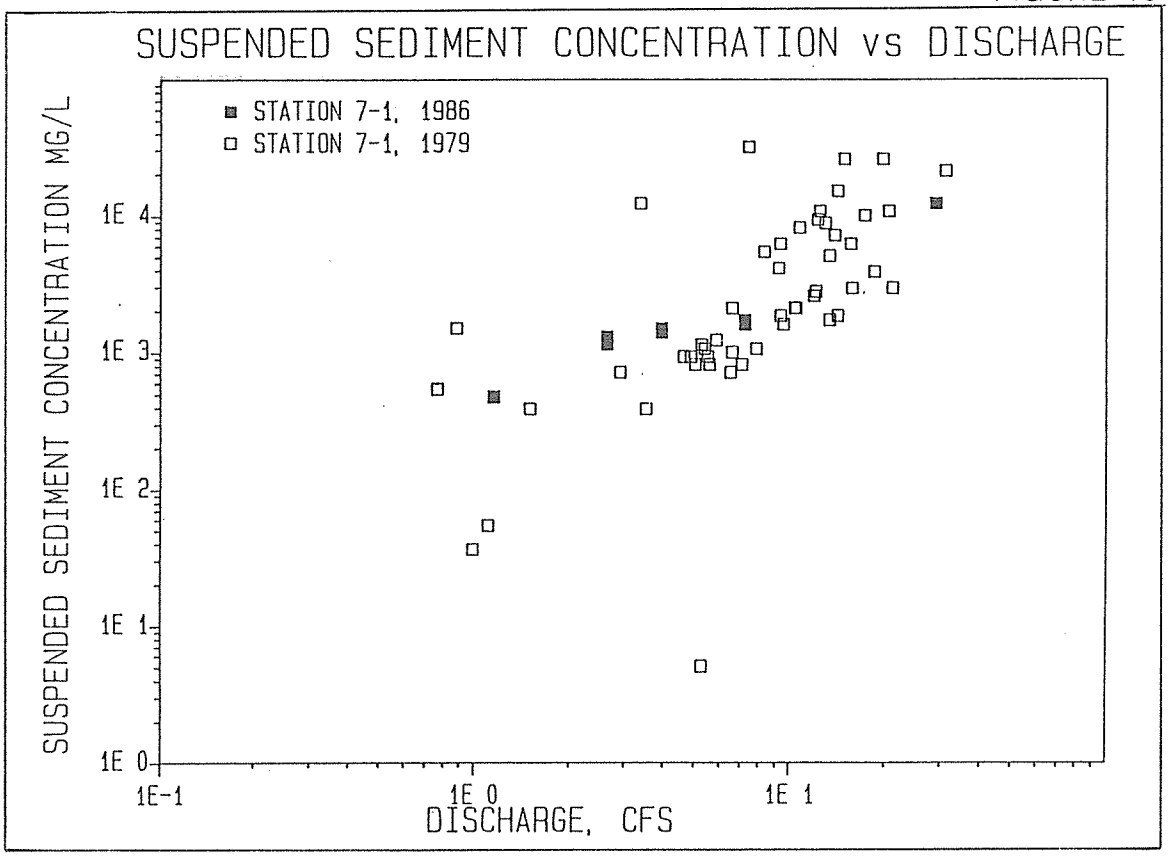


FIGURE 11

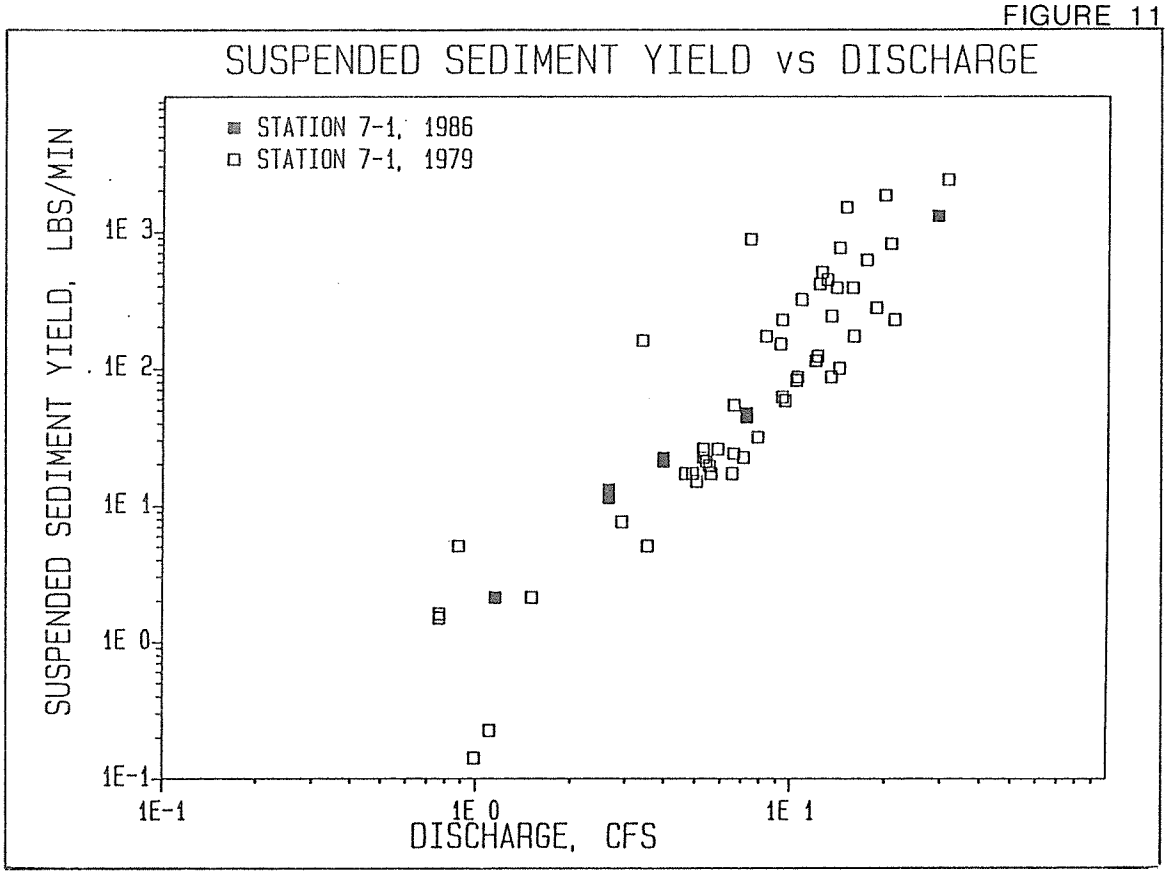


FIGURE 12

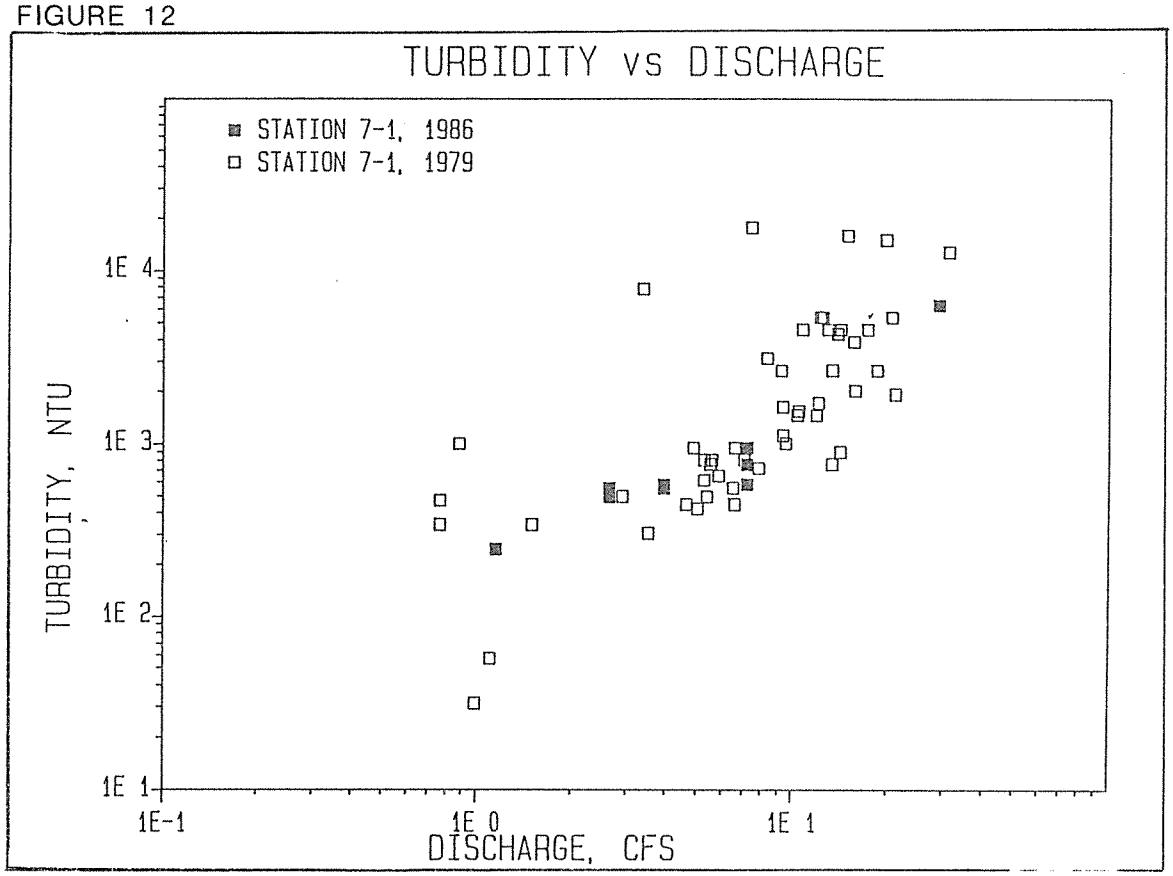


FIGURE 13

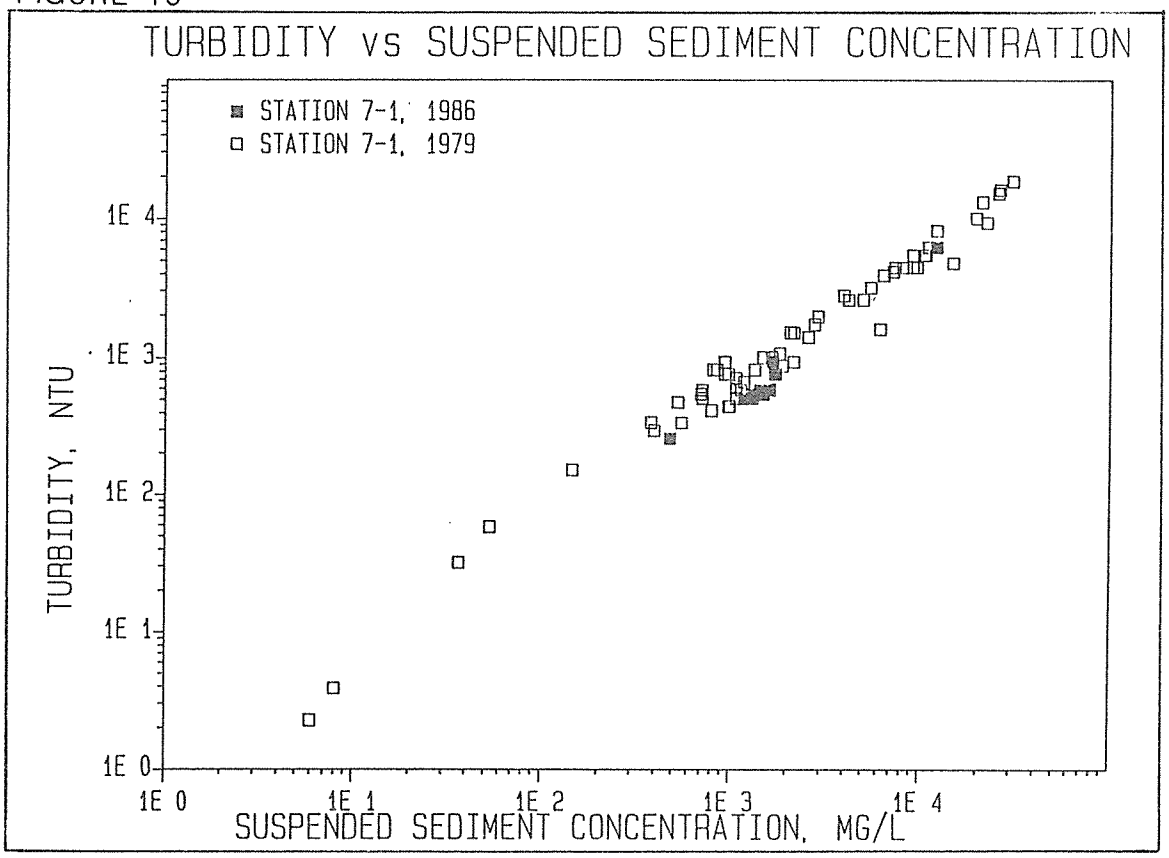


FIGURE 14

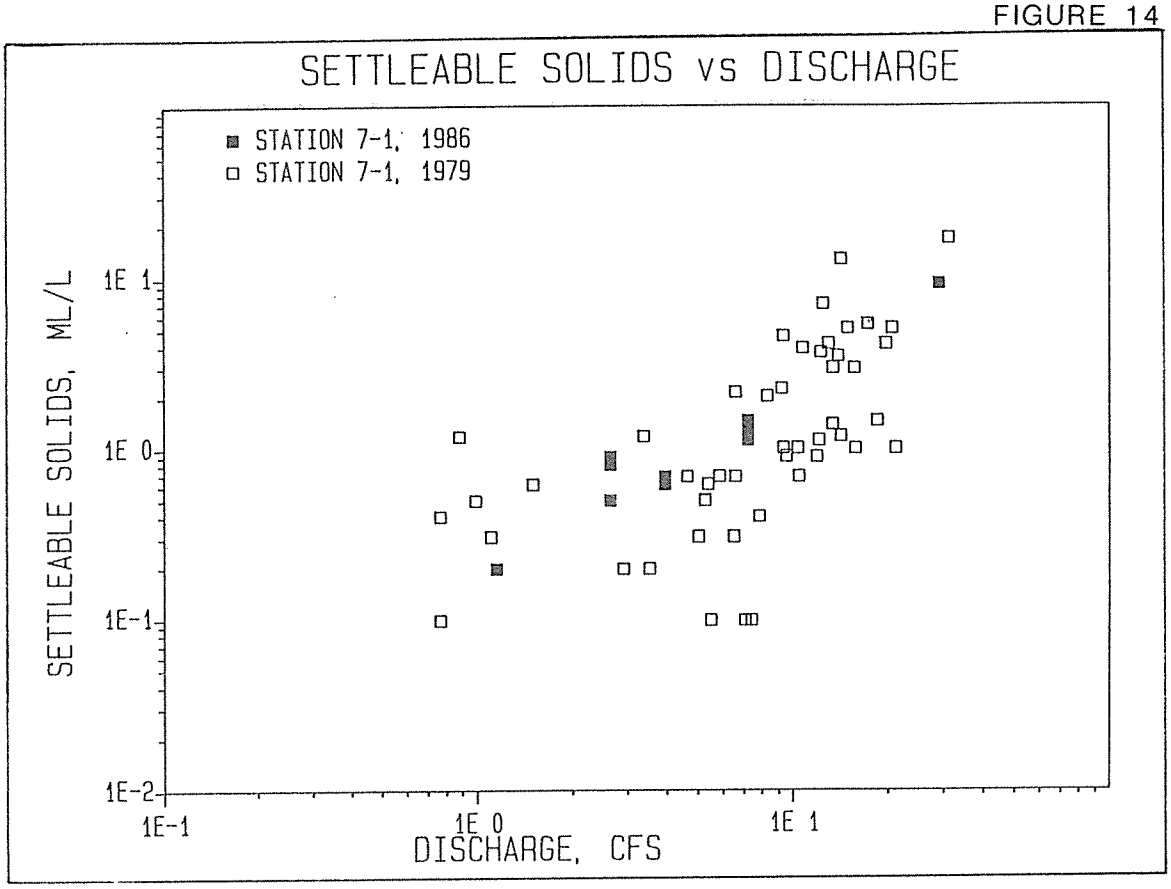


FIGURE 15

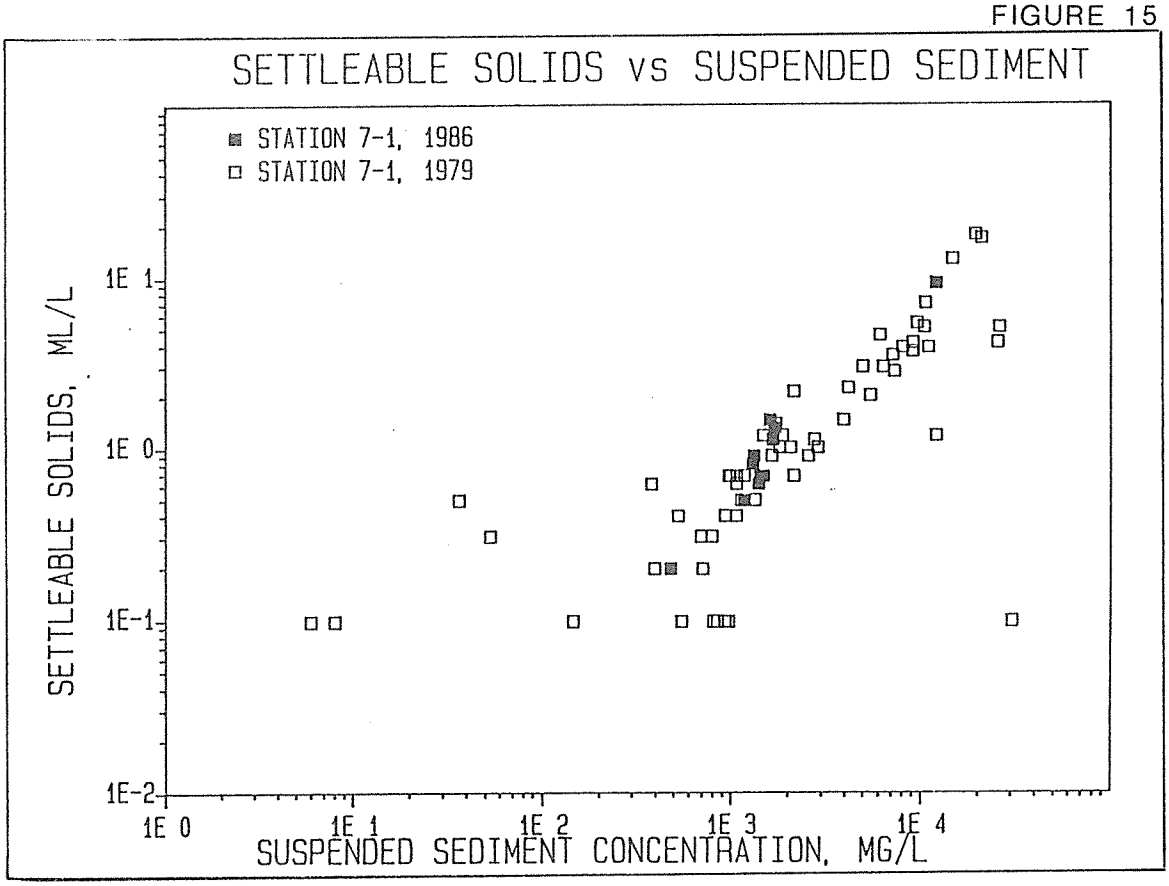
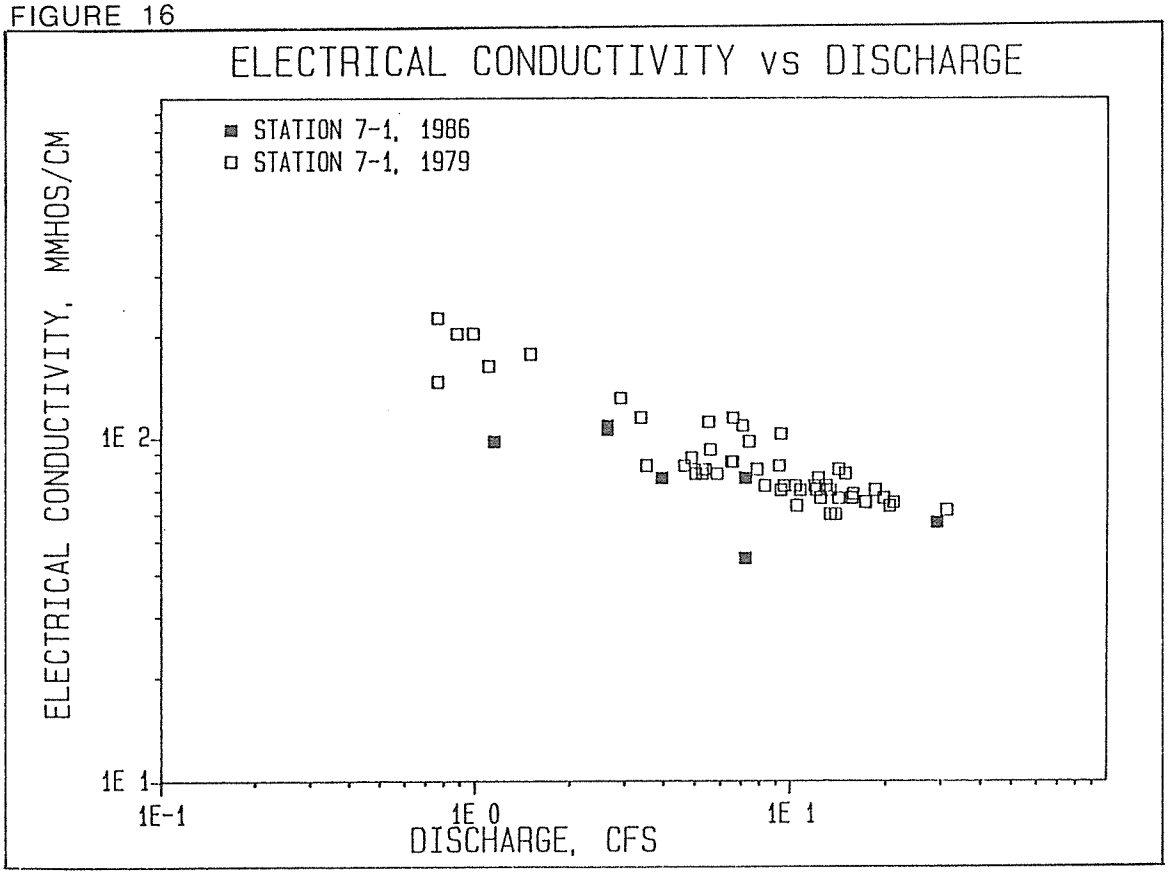


FIGURE 16


ELECTRICAL CONDUCTIVITY vs DISCHARGE
STATION 7-1, 1986
STATION 7-1, 1979
ELECTRICAL CONDUCTIVITY, MMHOS/CM
1E 2
1E 1
1E-1
1E 0
1E 1
DISCHARGE, CFS

Diggins Creek/Humbug Creek Confluence

Stations 9-4, 10-4, and 11-4 were monitored to determine the effect of water discharged from Diggins Creek on Humbug Creek. The location of Station 9-4 was moved upstream about 150 feet from the site sampled by NCRCD (1979a) because a bifurcation of Diggins Creek separated the flow of the creek upstream of the NCRCD site. Station 10-4 was located using map information, because no permanent markings of the site existed. Station 11-4 was moved about 30 feet downstream from the site monitored by NCRCD (1979a), because there were fewer obstructions in the channel, thus providing a more uniform distribution of flow across the channel. Details of the data at each station are discussed below.

Station 9-4. Data were collected at Station 9-4 four times during the winter of 1986. The station monitors changes in water quality between Hiller Tunnel and the mouth of Diggins Creek. These data and NCRCD (1979a) data are presented in Table 10.

Given the small number of samples and the possible sources of sampling error noted previously, it is possible only to approximate changes in sediment transport rates between 1979 and 1986. Figures 17 through 23 present the data in graphical form. The figures show that the water quality of samples collected during this study are similar to those of the NCRCD (1979a) study. The data in Table 10 show that few changes in water quality or discharge occur between Station 7-1 (Hiller Tunnel outlet) and Station 9-4.

Table 10

MALAKOFF DIGGINS WATER QUALITY DATA
STATION 9-4

DATE	TIME	SUSPENDED SOLIDS (MG/L)	SETTLEABLE SOLIDS (ML/L)	TURBIDITY (NTU)	ELECTRICAL CONDUCTIVITY (MMHOS/CM)	DISCHARGE (CFS)	SUSPENDED SED. YIELD (LBS/MIN)
03/07/86	1320	12000.00	14.00	6500.00	64.00	*	NO DATA
03/28/86	1310	1500.00	0.60	560.00	74.00	4.17	23.46
04/06/86	1350	943.00	0.40	544.00	94.00	2.96	10.47
04/18/86	1238	475.00	0.10	250.00	101.00	1.85	3.30
.							
12/06/78	1432	9.00	0.10	7.10	156.00	0.17	0.01
12/15/78						0.04	NO DATA
12/19/78	1233	47.00	0.40	37.00	192.00	0.79	0.14
12/29/79						0.02	NO DATA
01/05/79						0.20	NO DATA
01/10/79	1230	24.00	0.70	76.00	177.00	0.98	0.09
01/16/79	1240	1110.00	0.10	940.00	84.00	7.85	32.68
02/06/79	1300	493.00	0.10	350.00	133.00	1.09	2.02
02/20/79	1300	3250.00	1.10	1950.00	60.00	19.86	242.04
03/27/79	1100	6900.00	3.70	3350.00	41.00		NO DATA
04/05/79						4.39	NO DATA
04/10/79	1300	334.00	0.10	275.00	81.00	3.27	4.10

NOTE: 1986 DATA BY DWR; 1978-1979 DATA FROM NCRCD (1979a)

* MEASUREMENT NOT TAKEN DUE TO UNSAFE FLOW CONDITIONS

FIGURE 17

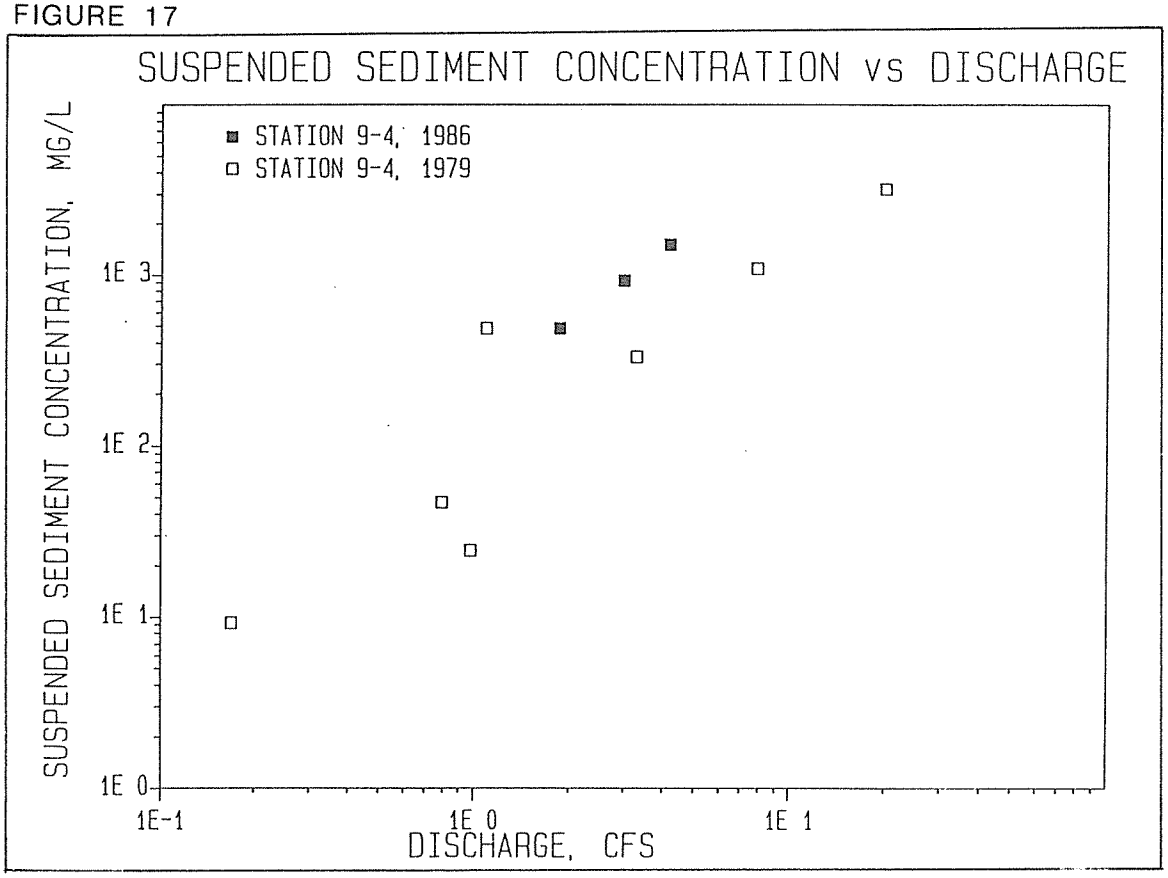


FIGURE 18

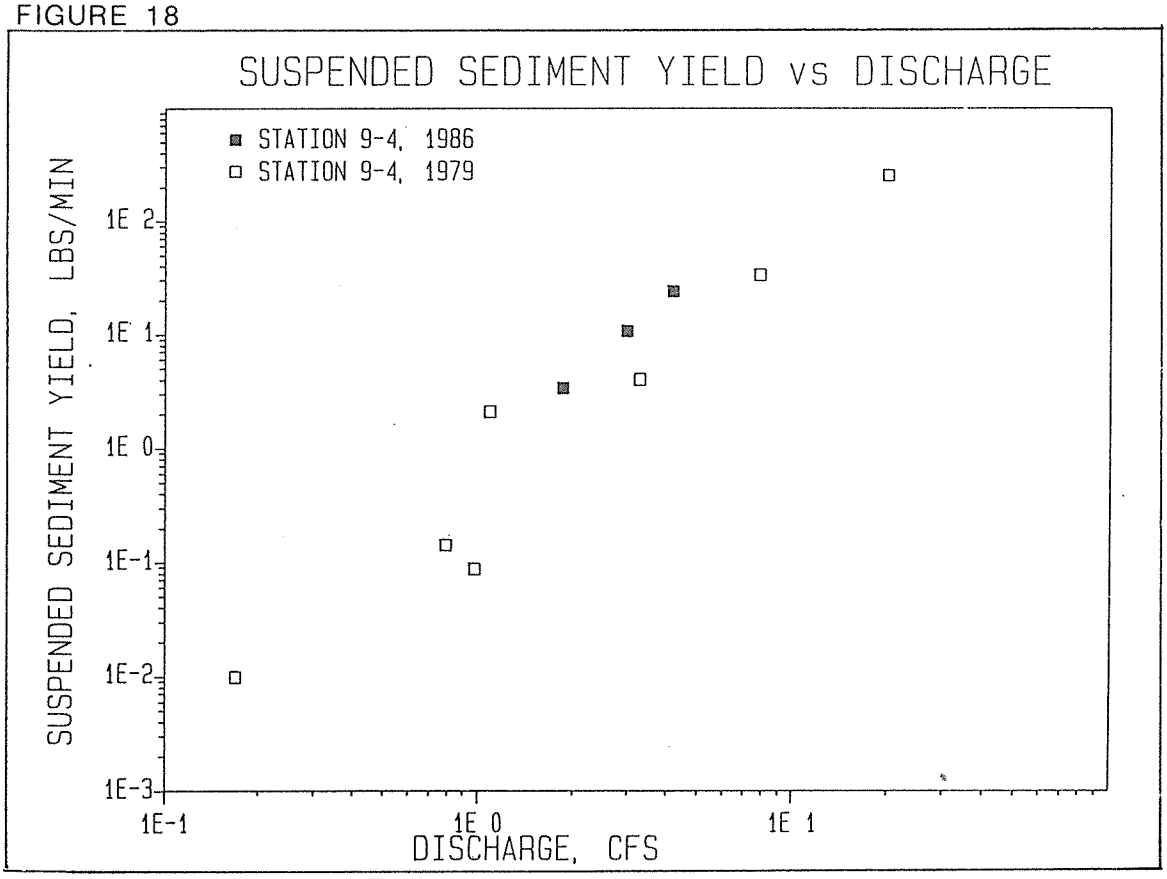


FIGURE 19

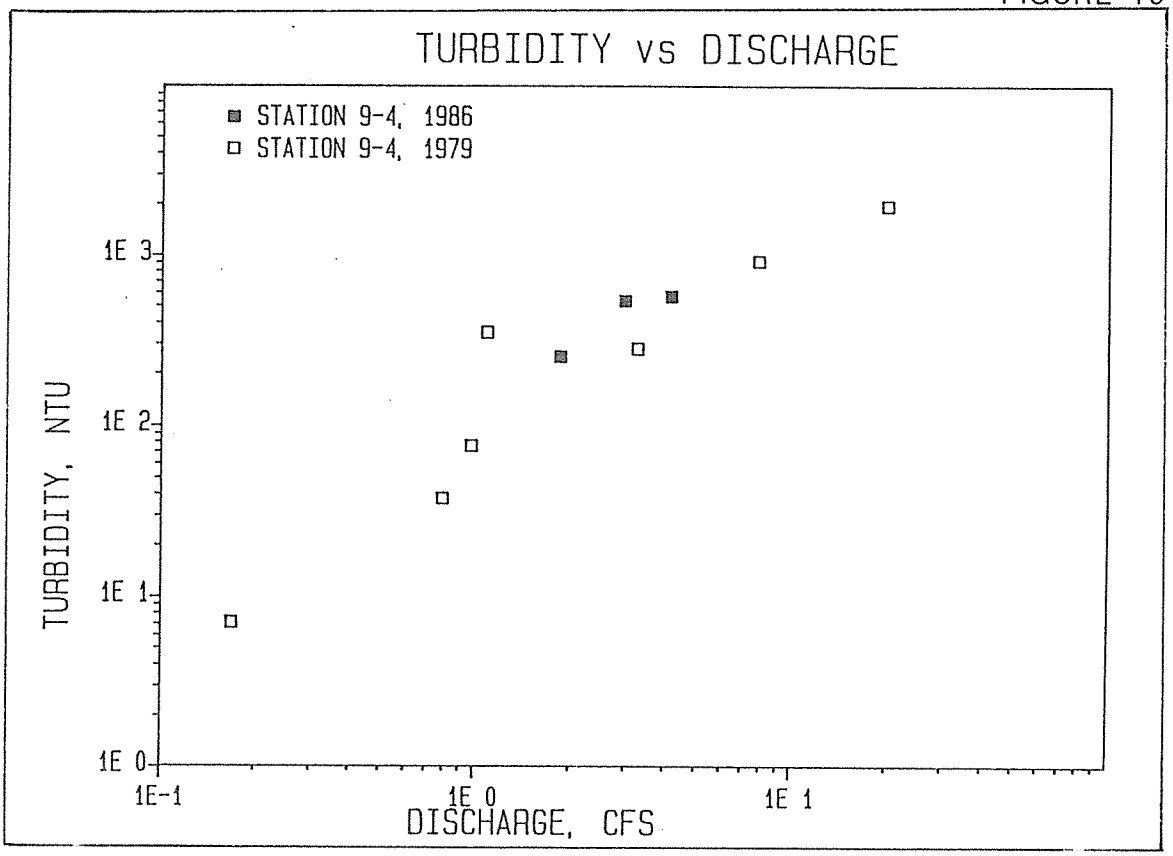


FIGURE 20

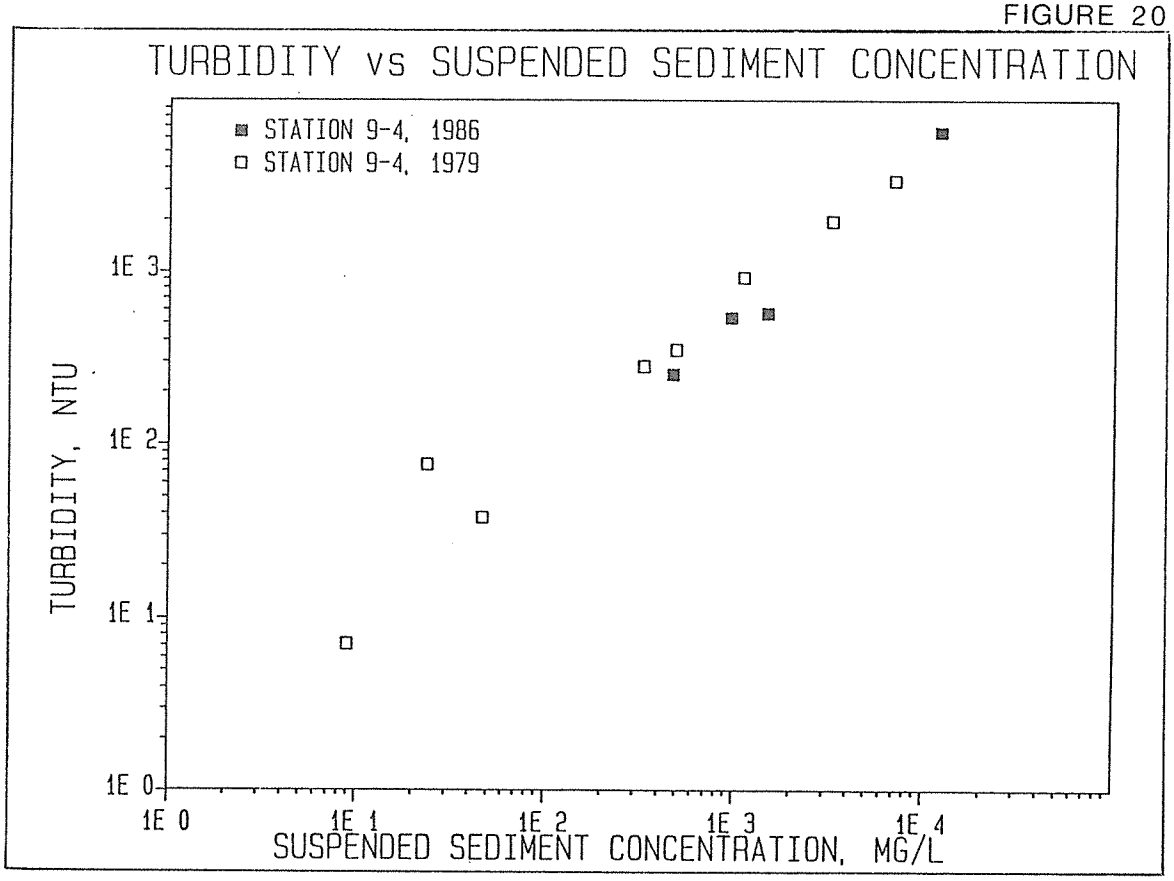


FIGURE 21

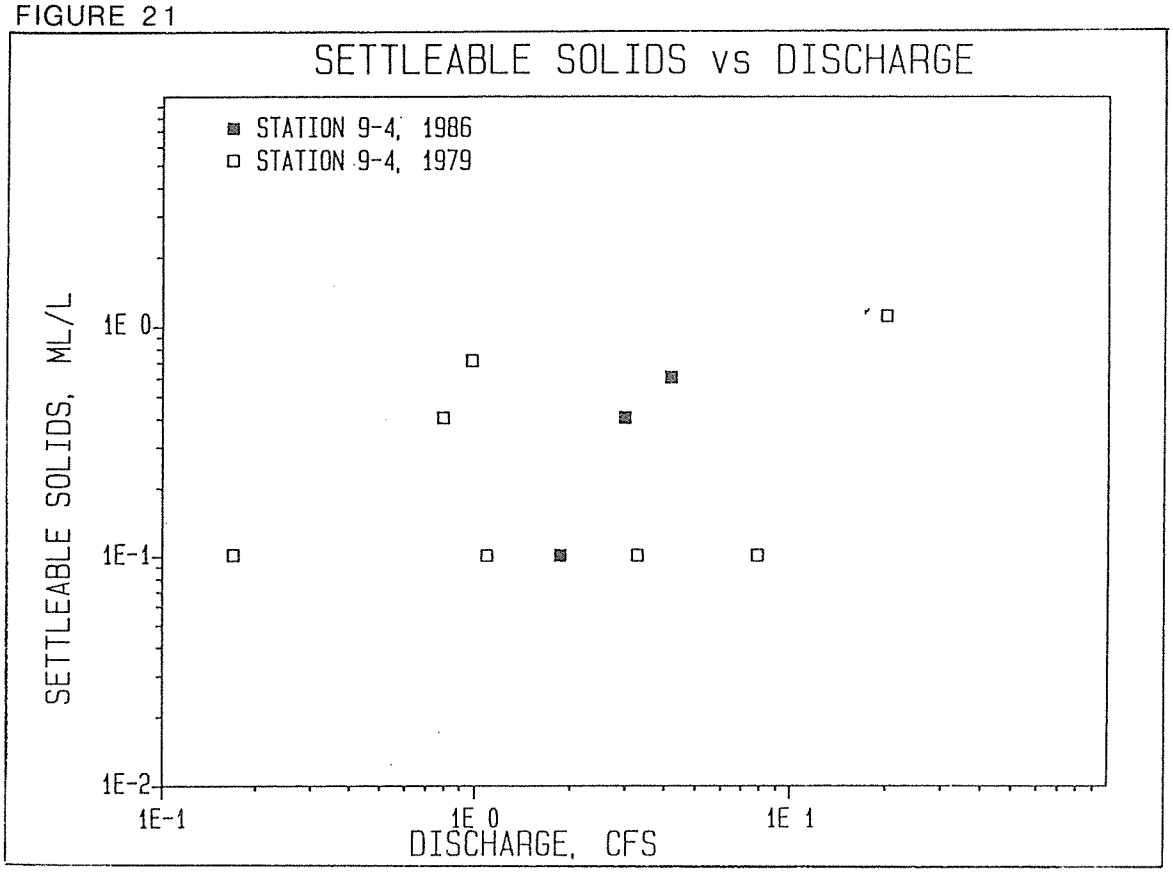


FIGURE 22

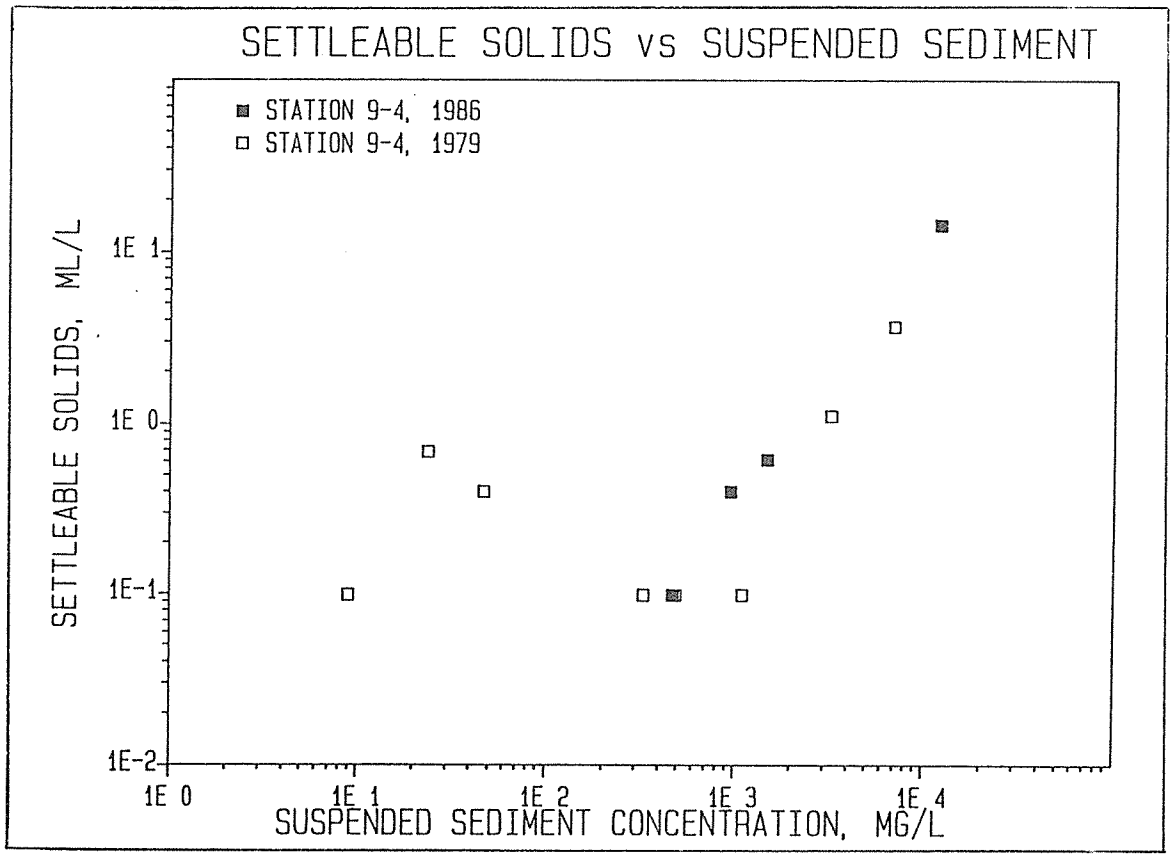
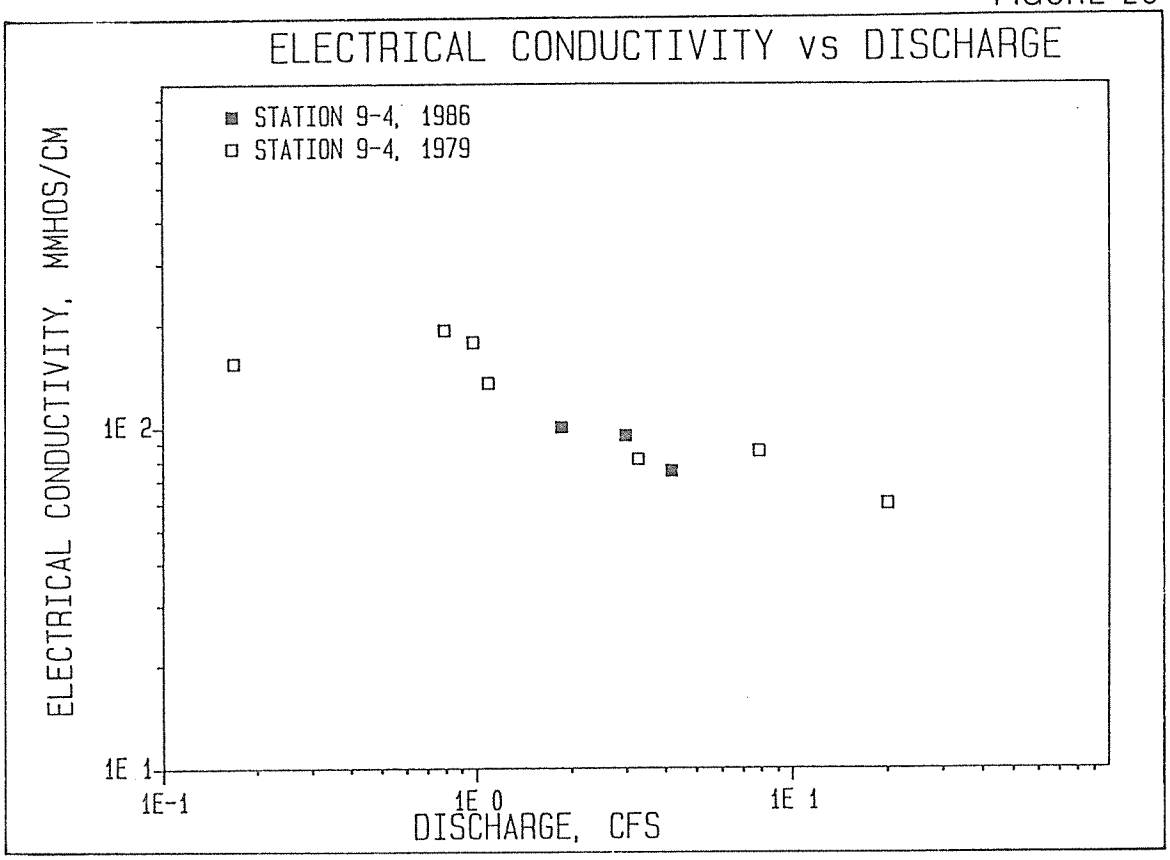


FIGURE 23



As with Station 7-1, all samples show significantly higher levels of settleable material, suspended material, turbidity, and electrical conductivity than Humbug Creek above Diggins Creek.

Station 10-4. Measurements at Station 10-4 provide baseline data that help determine the degree to which Humbug Creek is affected by Diggins Creek. Data were collected at this site five times during this study. Table 11 presents these data and the NCRCD (1979a) data; they are shown graphically in Figures 24 through 30. Water samples taken at Station 10-4 during the latter part of the sampling program contained no detectable settleable solids; these data are, therefore, excluded from Figures 28 and 29.

Levels of the key water quality parameters of suspended sediment, settleable solids, turbidity, and electrical conductivity are significantly lower than those of Diggins Creek. Figures 24 and 26 show a slight decrease in suspended sediment concentration and turbidity at a given discharge; however, there are not enough data to adequately substantiate any changes. The condition of Diggins Creek above its confluence with Humbug Creek is used as the reference standard for comparing the Regional Water Quality Control Board's guidelines for water quality.

Table 11
MALAKOFF DIGGINS WATER QUALITY DATA
STATION 10-4

DATE	TIME	SUSPENDED SOLIDS (MG/L)	SETTLEABLE SOLIDS (ML/L)	TURBIDITY (NTU)	ELECTRICAL CONDUCTIVITY (MMHOS/CM)	DISCHARGE (CFS)	SUSPENDED SED. YIELD (LBS/MIN)
02/28/86	1430	13.00	0.10	6.00	38.00	24.61	1.20
03/07/86	1630	73.00	0.20	22.00	37.00	*	NO DATA
03/28/86	1220	2.00	0.00	1.00	42.00	27.52	0.21
04/06/86	1255	3.00	0.00	2.00	47.00	17.14	0.19
04/18/86	1155	1.00	0.00	1.00	53.00	10.40	0.04
11/20/78		110.00	0.30	50.00	86.00	1.95	0.80
11/22/78						1.75	NO DATA
11/29/78						0.34	NO DATA
12/06/78	1511	0.50	0.10	0.40	156.00	0.64	0.00
12/15/78						0.50	NO DATA
12/19/78	1300	1.00	0.10	0.70	133.00	1.27	0.00
12/29/78						0.85	NO DATA
01/05/79						0.69	NO DATA
01/10/79	1315	3.00	0.10	1.00	108.00	2.26	0.03
01/16/79	1320	2.00	0.10	2.90	69.00	6.04	0.05
02/06/79	1330	1.00	0.10	0.70	81.00	2.90	0.01
02/20/79	1400	15.00	0.10	11.00	51.00	20.09	1.13
03/27/79	1200	32.00	0.20	19.00	35.00		NO DATA
04/05/79						24.35	NO DATA
04/10/79	1330	3.00	0.10	0.30	35.00	23.50	0.26

NOTE: 1986 DATA BY DWR; 1978-1979 DATA FROM NCRCD (1979a)
* MEASUREMENT NOT TAKEN DUE TO UNSAFE FLOW CONDITIONS

FIGURE 24

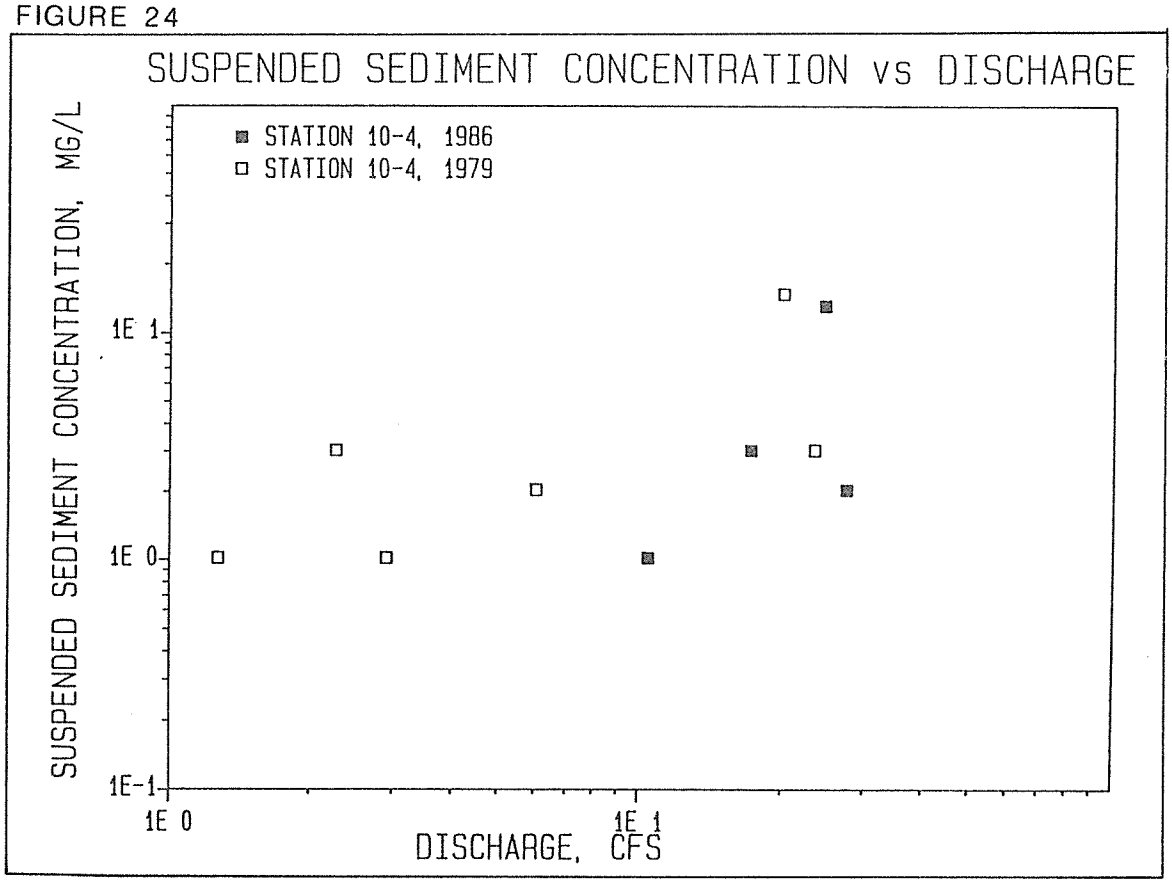


FIGURE 25

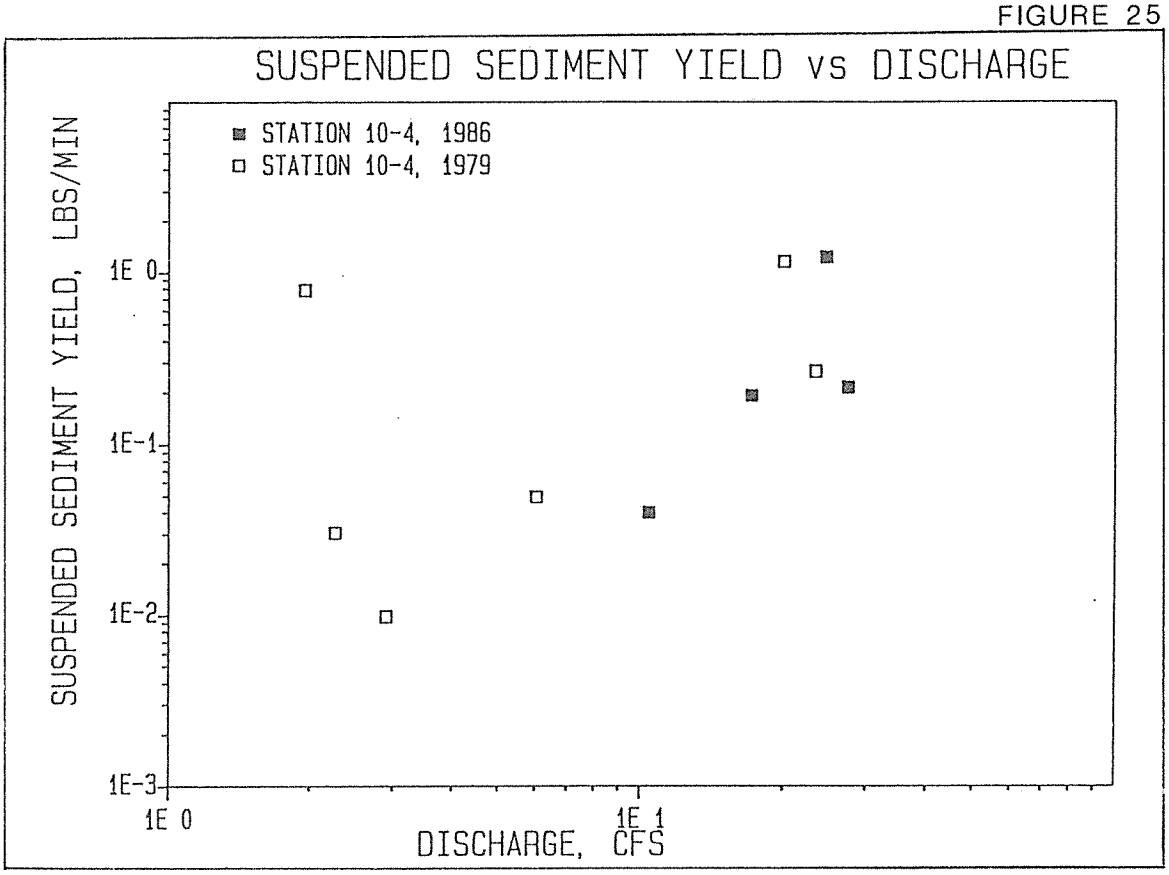


FIGURE 26

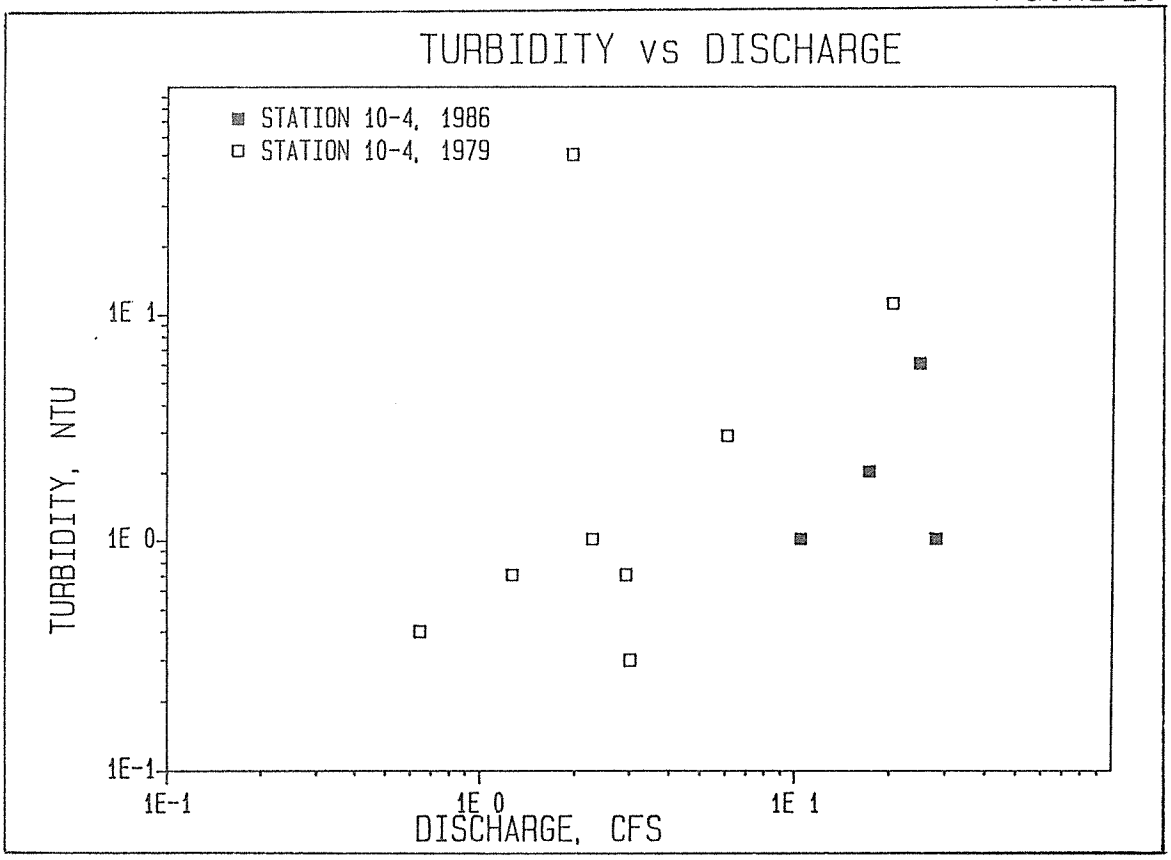


FIGURE 27

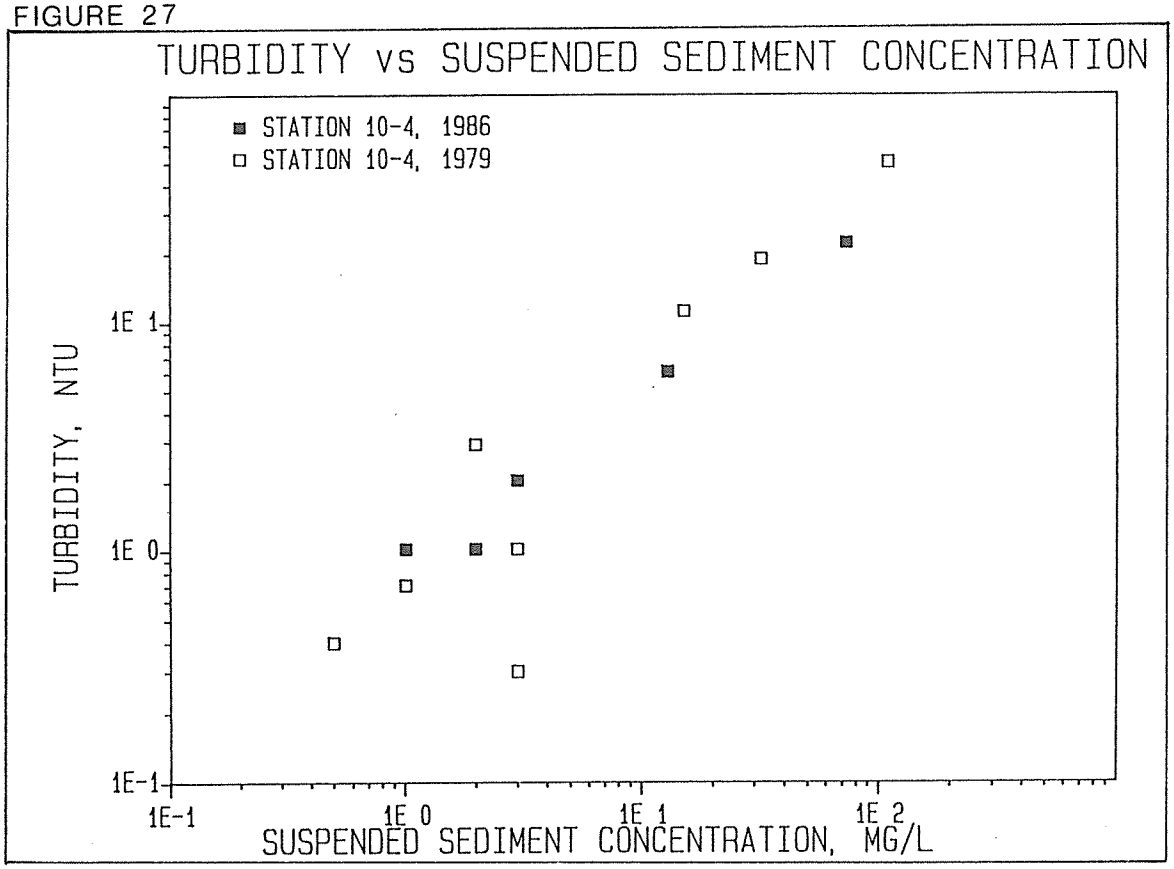


FIGURE 28

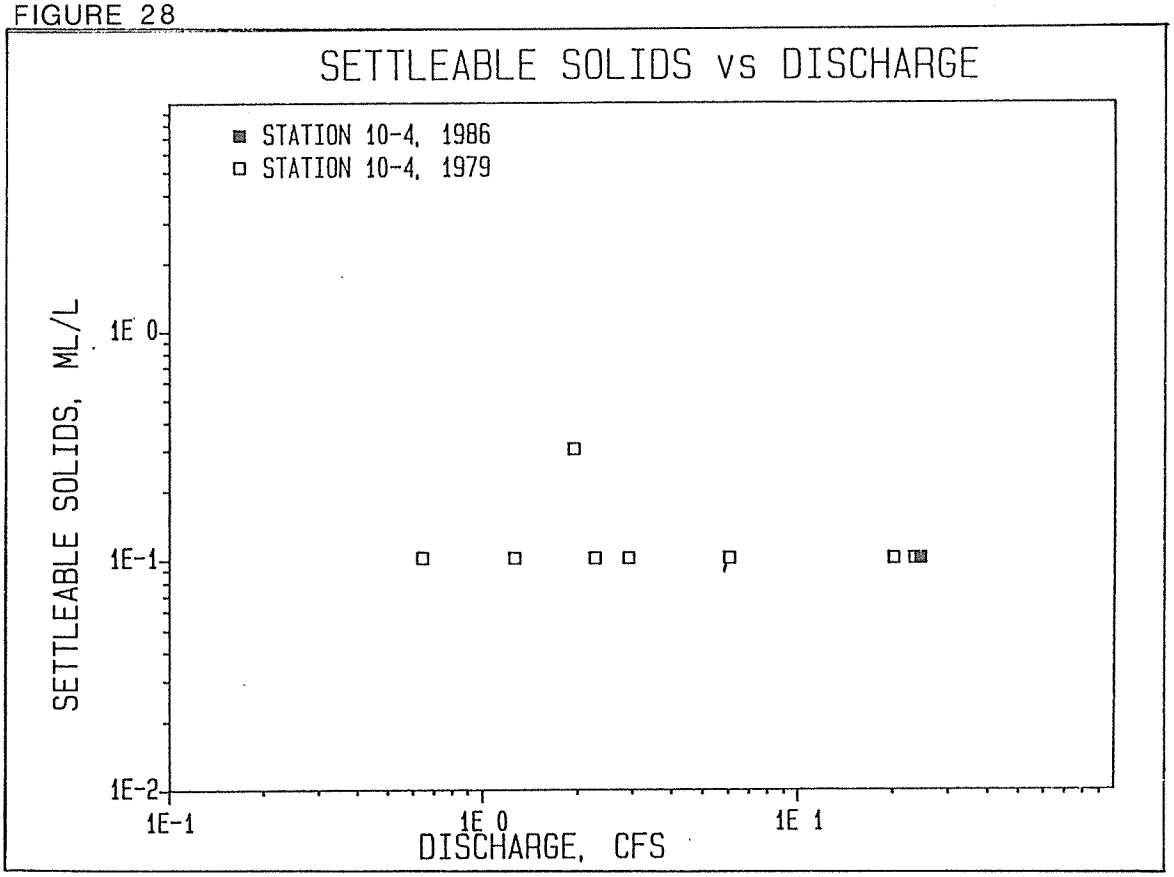


FIGURE 29

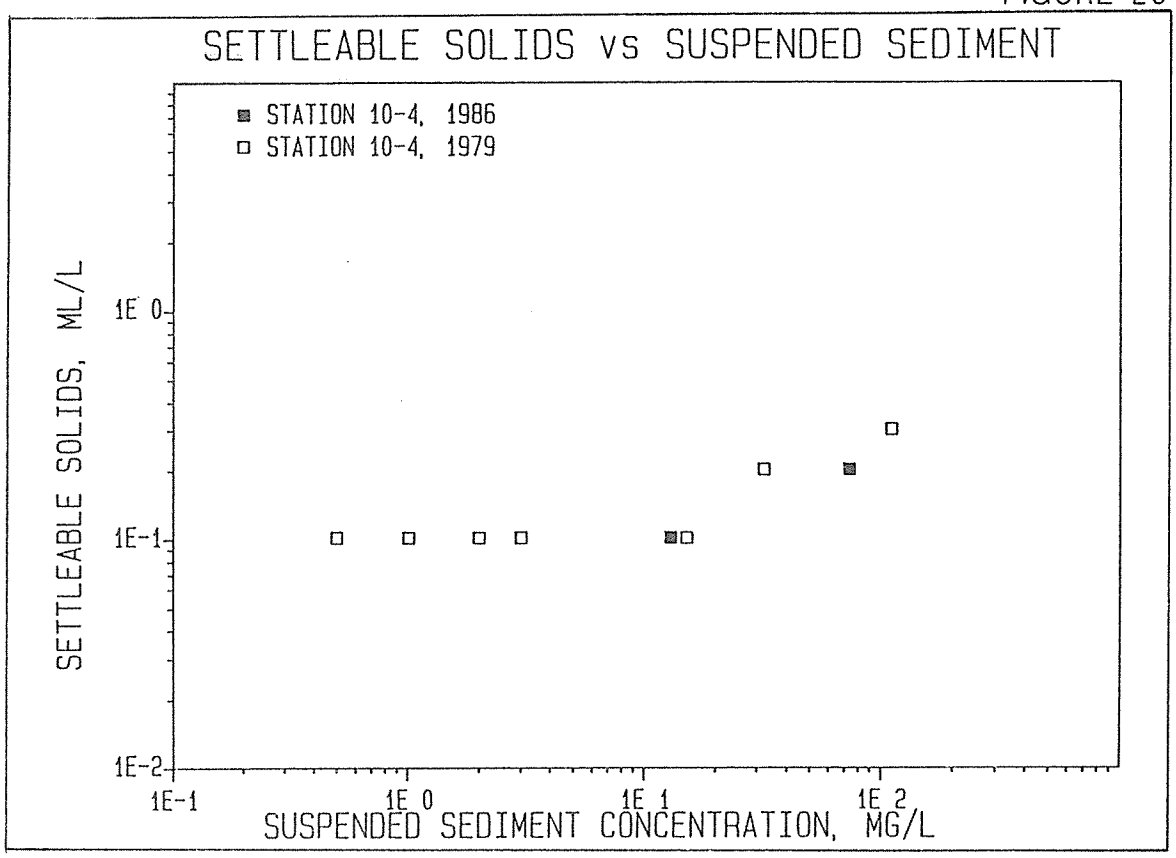
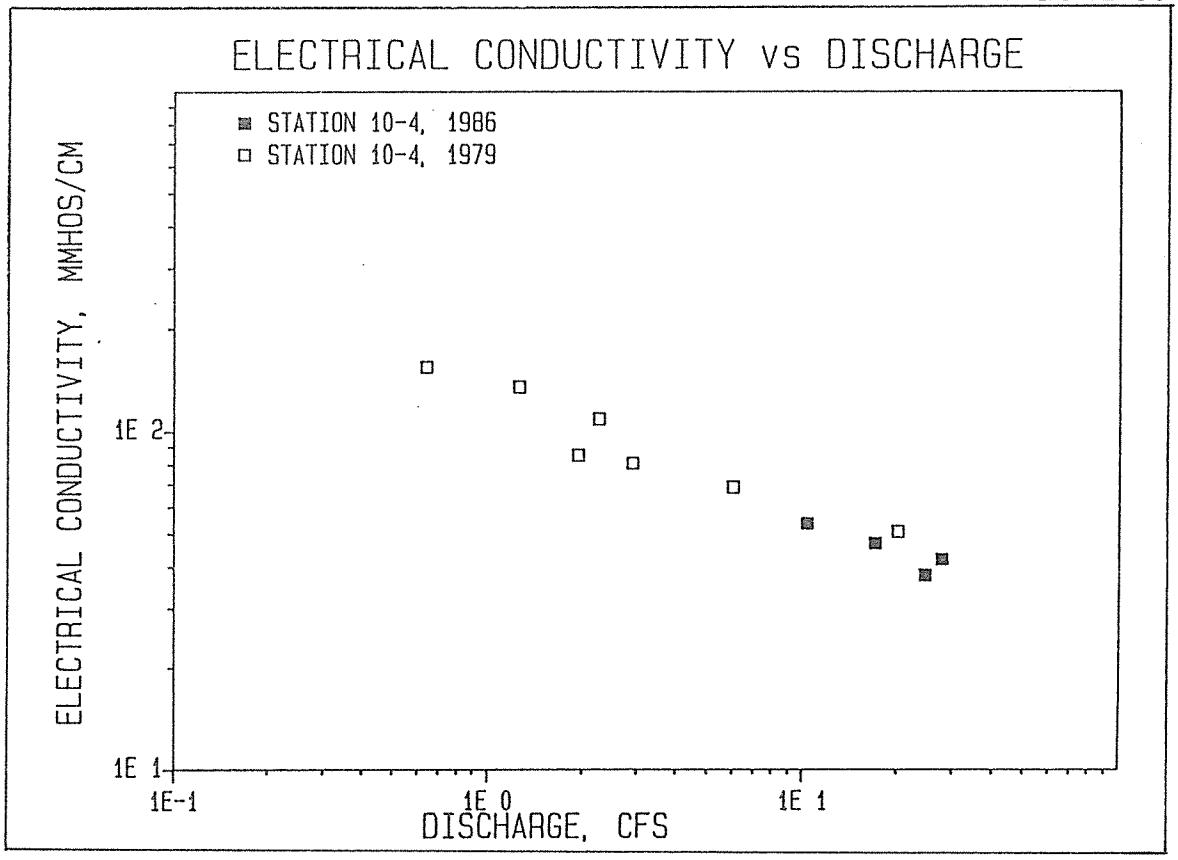


FIGURE 30



Station 11-4. The effects of Diggins Creek on Humbug Creek were monitored by measurements at Station 11-4. Samples were taken at this site five times during this study; the data are presented in Table 12. Figures 31 through 37 are graphical representations of the data. Data for February 28, 1986, when compared to other data collected at this site, appear to be inconsistent. The discharge measurement appears to be the source of this error.

Comparisons of data collected at Station 11-4 with data collected at Stations 9-4 and 10-4 show that dilution of sediment-laden Diggins Creek water occurs; however, levels of suspended material, settleable material, and turbidity are still far above the RWQCB 10 percent limit of degradation. During this study, discharges from Diggins Creek increased the electrical conductivity of Humbug Creek by about 10 to 15 percent. NCRCD (1979a) data indicate that the dilution effect may be diminished as Humbug Creek flows recede. Sampling should be conducted in the summer and autumn months to ascertain whether or not this occurs, and what effect it may have on the South Yuba River.

Relative to 1979 data, levels of suspended sediment and turbidity at a given discharge at Station 11-4 appear to have diminished slightly. However, too few samples were taken at this site to substantiate any changes. The origin of this possible reduction is uncertain, but may be related to relocation of the station. It may also result from improved water quality and/or increased discharge volume of Humbug Creek above Diggins Creek, or be a reflection of sampling error. Given the observations of suspended sediment concentration and turbidity at Station 7-1 (Figures 10 and 12), Station 9-4 (Figures 17 and 19) and Station 10-4 (Figures 24 and 26), it is doubtful that the apparent water quality improvement at Station 11-4 is related to a reduction of sediment discharge from Malakoff Diggins. Diggins Creek still significantly impacts Humbug Creek.

Table 12
MALAKOFF DIGGINS WATER QUALITY DATA
STATION 11-4

DATE	TIME	SUSPENDED SOLIDS (MG/L)	SETTLEABLE SOLIDS (ML/L)	TURBIDITY (NTU)	ELECTRICAL CONDUCTIVITY (MMHOS/CM)	DISCHARGE (CFS)	SUSPENDED SED. YIELD (LBS/MIN)
02/28/86	1600	182.00	0.10	84.00	77.00	43.85	29.93
03/07/86	1315	6240.00	7.50	2800.00	53.00	*	NO DATA
03/28/86	1100	277.00	0.10	160.00	47.00	33.95	35.27
04/06/86	1140	128.00	0.10	70.00	54.00	22.08	10.60
04/18/86	1055	70.00	0.00	40.00	62.00	12.74	3.34
11/20/78		2100.00	0.05	1800.00	124.00	2.91	22.92
11/22/78		34.00	0.10	34.00	136.00	3.73	0.48
11/29/78						0.45	NO DATA
12/06/78	1537	3.00	0.10	3.10	156.00	0.61	0.01
12/15/78						0.31	NO DATA
12/19/78	1320	21.00	0.30	19.00	157.00	1.72	0.14
12/29/78						1.14	NO DATA
01/05/79						0.61	NO DATA
01/10/79	1415	73.00	0.30	46.00	156.00	3.10	0.85
01/16/79	1345	802.00	0.20	560.00	72.00	16.79	50.50
02/06/79	1400	144.00	0.10	105.00	103.00	3.74	2.02
02/20/79	1445	6600.00	3.00	3500.00	47.00	39.95	988.76
03/27/79	1235	1800.00	1.20	1000.00	37.00		NO DATA
04/05/79						27.69	NO DATA
04/10/79	1410	37.00	0.20	25.00	40.00	26.66	3.70

NOTE: 1986 DATA BY DWR; 1978-1979 DATA FROM NCRCD (1979a)
* MEASUREMENT NOT TAKEN DUE TO UNSAFE FLOW CONDITIONS

FIGURE 31

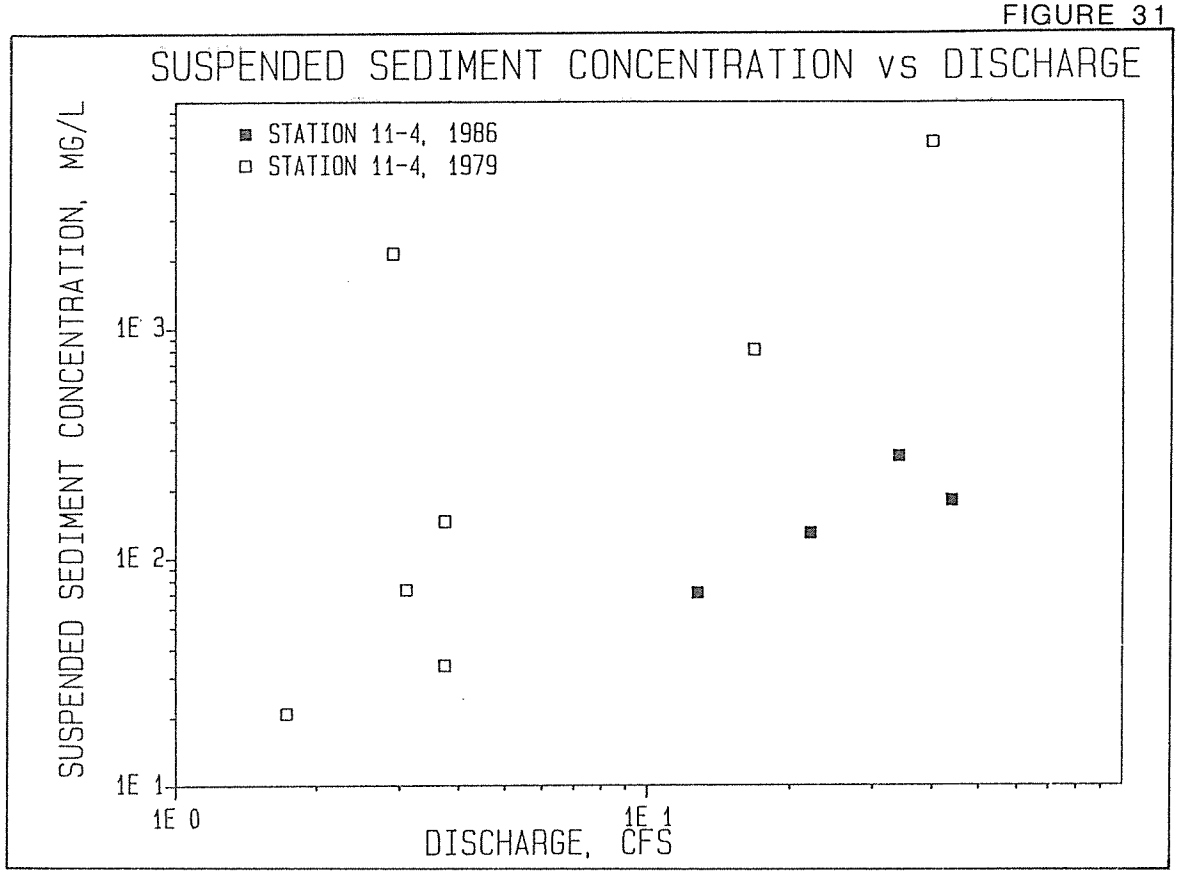


FIGURE 32

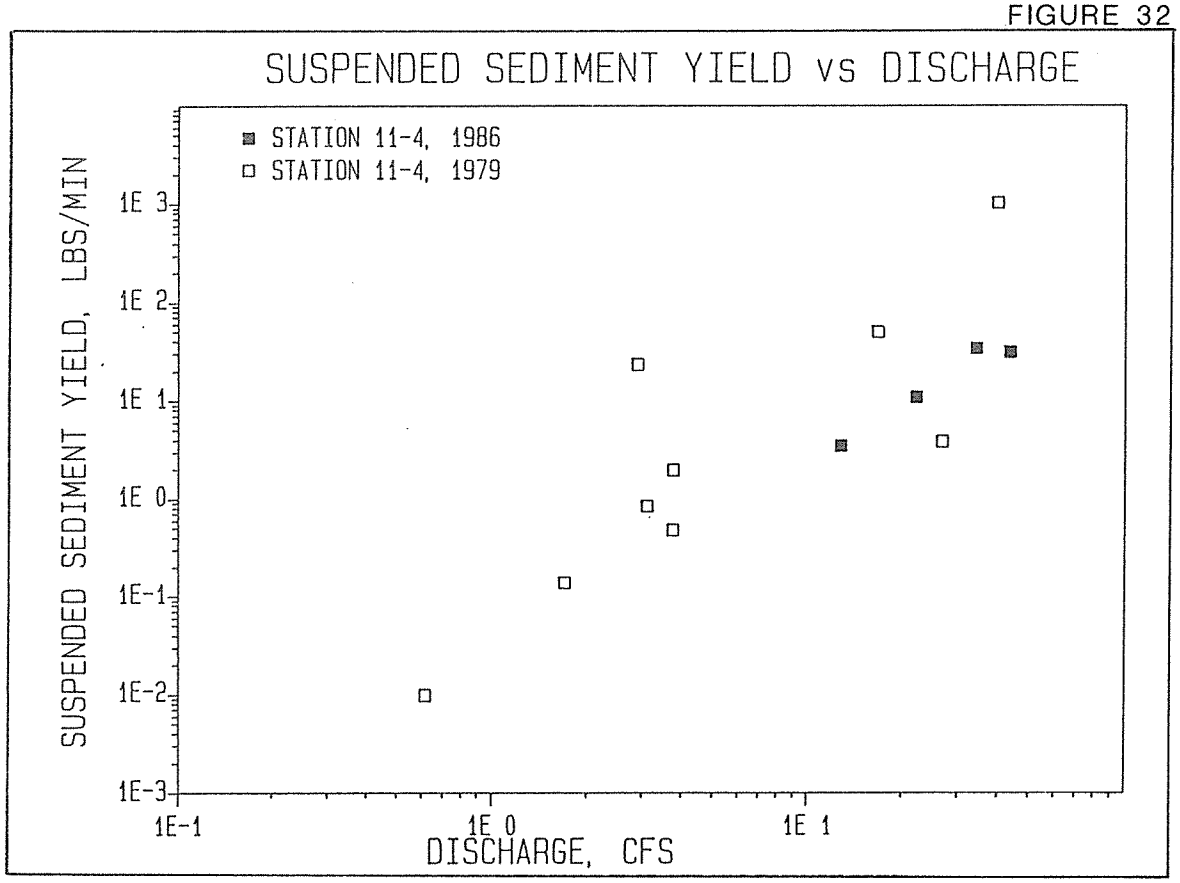


FIGURE 33

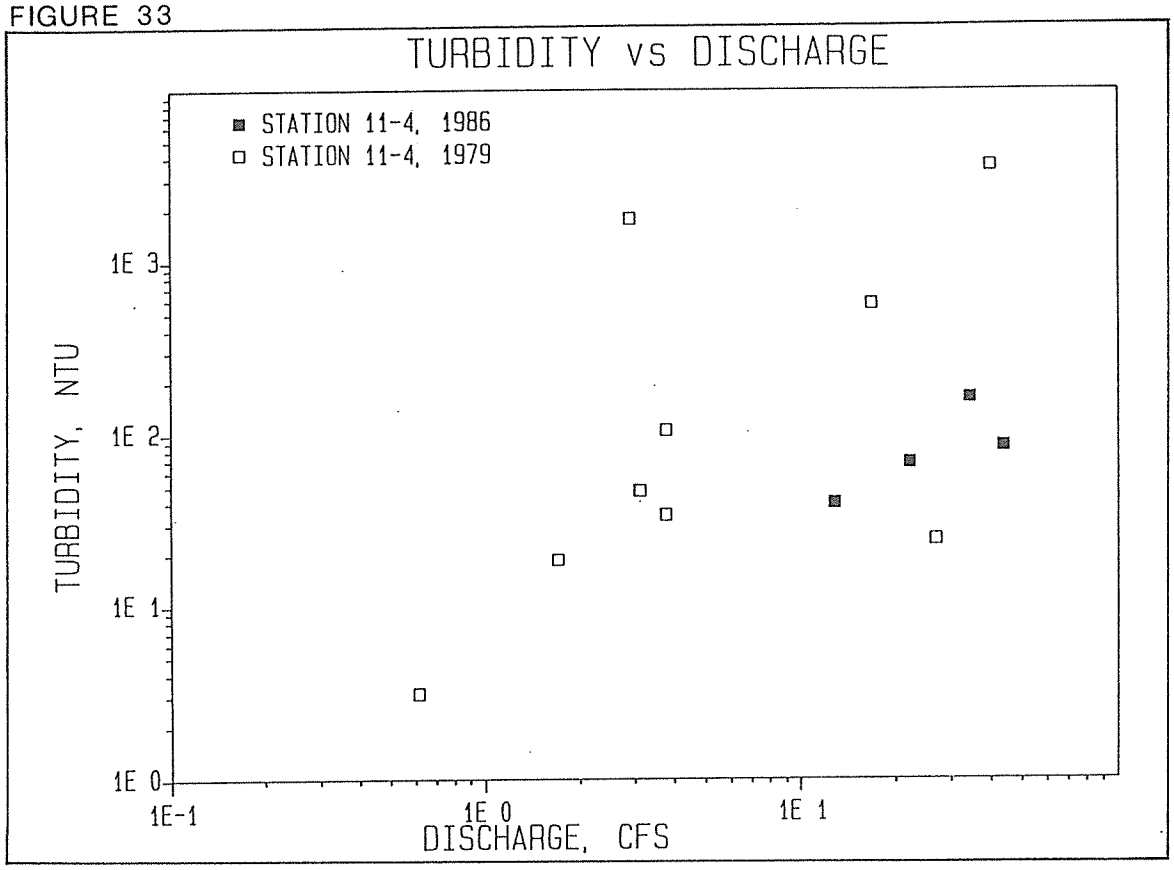


FIGURE 34

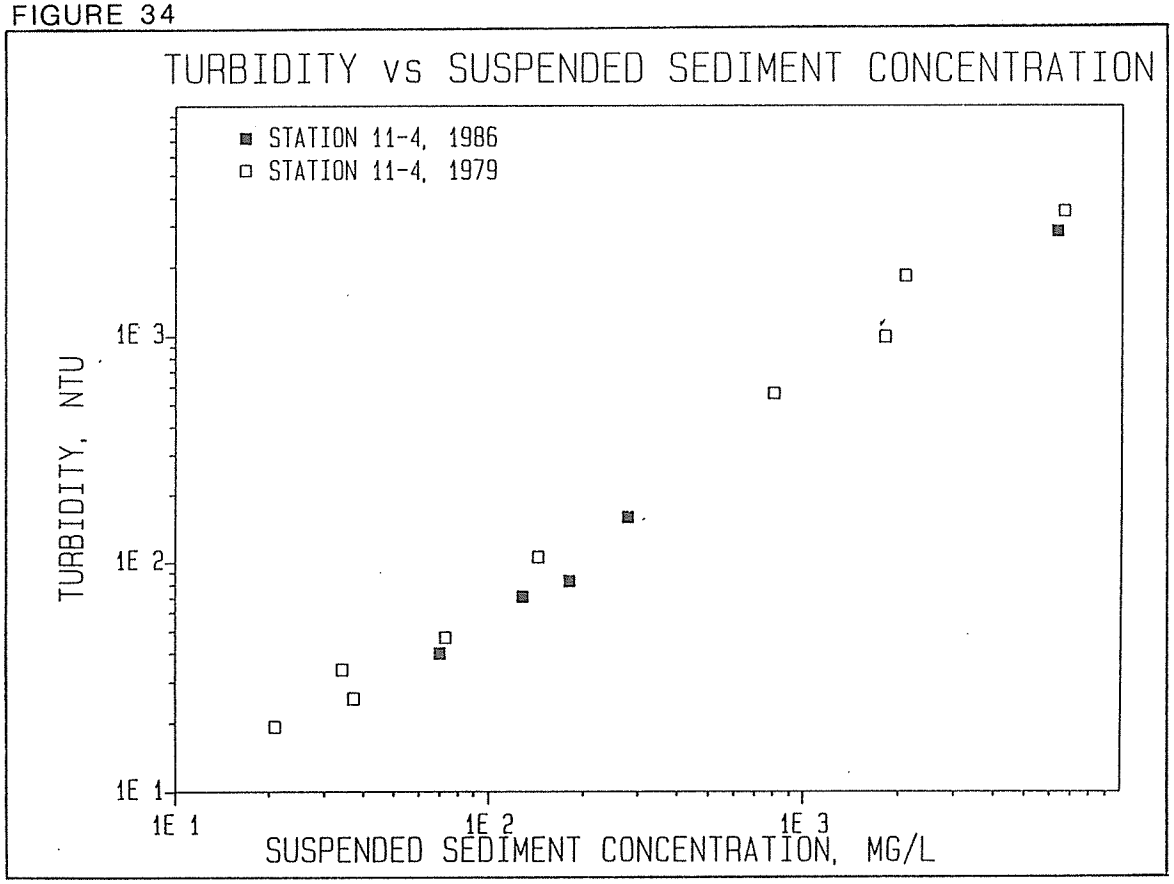


FIGURE 35

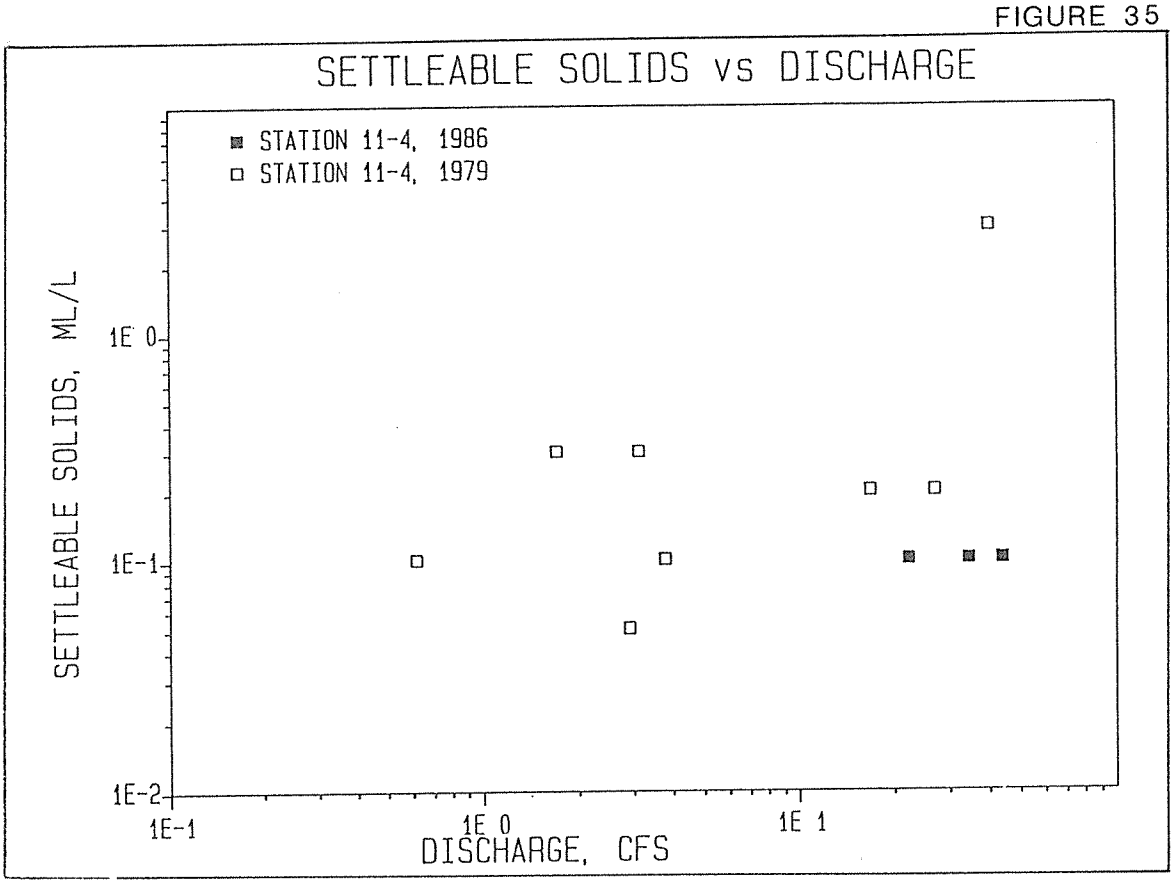


FIGURE 36

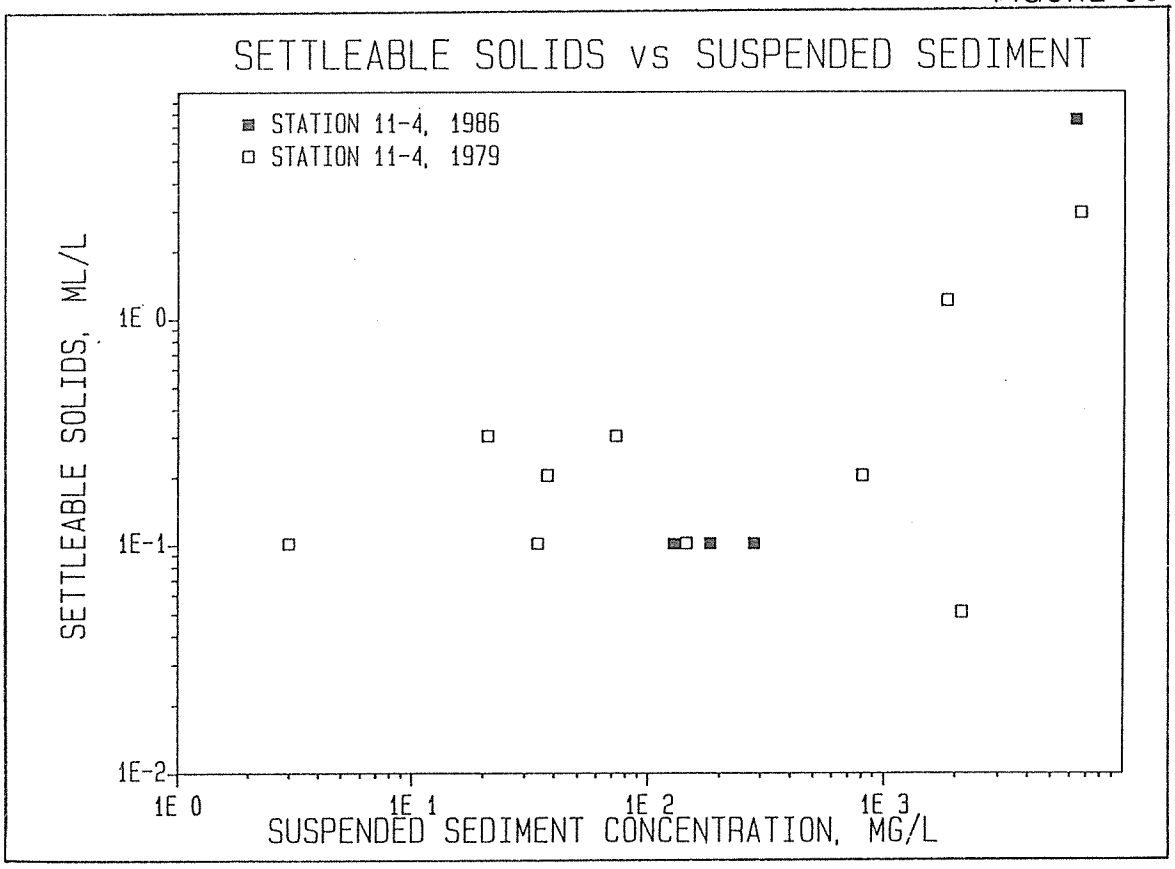
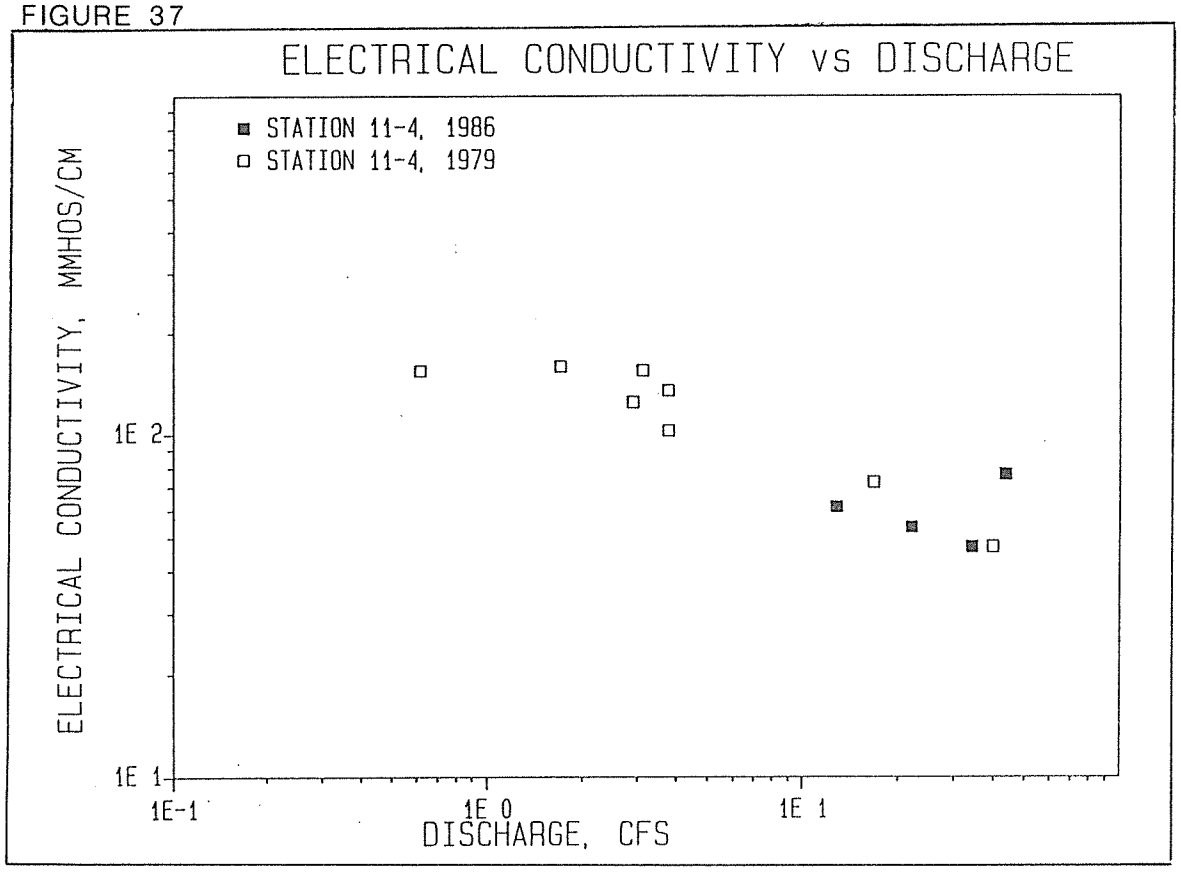


FIGURE 37



Humbug Creek/South Yuba River Confluence

Water samples were collected at Stations 12-3, 13-3, and 14-3 on one occasion to provide a comparison of existing conditions with the Regional Water Quality Control Board guidelines. The data are shown in Table 13. The sites were sampled at the beginning of a rainstorm, prior to peak runoff, so the data represent winter normal flow conditions.

Flows of the South Yuba River appear to substantially dilute the levels of all sampled parameters in water derived from Humbug Creek; however, RWQCB guidelines for turbidity and suspended material are still exceeded (using Station 13-3 as the reference standard).

Between the Humbug Creek/Diggins Creek confluence and the mouth of Humbug Creek, suspended sediment and settleable solids concentrations and turbidity are diluted. A direct comparison between these data should not be made, however, because the samples were taken at different times during runoff from the storm. The sample at Station 12-3 was taken prior to the onset of significant runoff, whereas the sample at Station 11-4 was taken after precipitation from the storm had resulted in increased runoff. Since continuous monitoring data is not available at either site, it is difficult to ascertain at what point on the storm hydrograph each of these samples were taken. Continuous monitoring at both of these sites is needed to determine the magnitude of dilution between Stations 11-4 and 12-3 and to

determine the volume of sediment discharged to the South Yuba River.

The majority of sediment in Humbug Creek sampled at Station 12-3 is presumably derived from Malakoff Diggins. However, clearcut timber harvesting within the Humbug Creek watershed has occurred in the past few years. It is possible that this land use may contribute to the overall turbidity and sediment load of the creek. The extent of any such effect was not assessed in this study. Timber harvesting outside the Humbug Creek watershed may also contribute sediment to the South Yuba River. Additional sources of sediment and turbidity include road building, other construction activity, and other abandoned mining operations.

A complete inventory of possible sediment sources and their relative effect on South Yuba River has not been made to date. An understanding of each of these is essential to prescribe an appropriate level of sediment discharge reduction from Malakoff Diggins. Studies of the South Yuba River watershed to assess the adequacy of its fishery habitat and the effects of the sediment sources on these habitats should be conducted.

Table 13

MALAKOFF DIGGINS WATER QUALITY DATA
HUMBUG CREEK/SOUTH YUBA RIVER CONFLUENCE

STATION	DATE	TIME	SUSPENDED SOLIDS (MG/L)	SETTLEABLE SOLIDS (ML/L)	TURBIDITY (NTU)	ELECTRICAL CONDUCTIVITY (MMHOS/CM)
12-3	03/07/86	1130	636.00	0.60	230.00	66.00
13-3	03/07/86	1115	7.00	0.10	1.00	31.00
14-3	03/07/86	1145	42.00	0.10	13.00	33.00
12-3	02/19/79	1012	632.00	0.20	460.00	59.00
	03/23/79		380.00	0.10	240.00	56.00
	03/27/79	1255	5200.00	2.50	2750.00	40.00
13-3	02/19/79	1005	1.50	<.1	1.90	71.00
	03/23/79	1300	1.00	<.1	0.60	59.00
	03/27/79	1245	41.00	0.20	25.00	47.00
14-3	02/19/79	1006	84.00	0.10	70.00	71.00
	03/23/79	1300	34.00	0.20	17.00	58.00
	03/27/79	1305	856.00	0.60	500.00	45.00

NOTE: 1986 DATA BY DWR; 1978-1979 DATA FROM NCRCD (1979a)

Chapter 7. METHODS FOR REDUCING SEDIMENT DISCHARGE FROM THE DIGGINGS

Measures to reduce the amount of sediment discharged to Humbug Creek must take into consideration the natural processes occurring in the diggings. As detailed in Chapter 5, these processes include landsliding, rainsplash and surface flow, and sediment deposition. Previous studies (NCRCD, 1979b, 1980; Peterson, 1980) have suggested a number of alternatives aimed at controlling these processes; however, the studies did not address all the impacts, effects, or conditions that could result from specific alternatives. This chapter discusses the suggested remedial measures and the impacts not previously addressed. Additional alternatives for controlling sediment discharge are also presented. Table 14 summarizes the items discussed in this chapter.

In the following discussion, remedial alternatives are discussed independently. In practice, several of the methods discussed will have to be implemented to reduce sediment discharge from the diggings. The use of vegetation is an important element of any remedial program.

Table 14
SUMMARY OF METHODS TO REDUCE SEDIMENT DISCHARGE

Method	Evaluation														
	Esthetic Impacts			Maintenance Needs			Effectiveness			Initial Costs			Long-Term Costs		
	High	Mod	Low	High	Mod	Low	High	Mod	Low	High	Mod	Low	High	Mod	Low
Landslide Stabilization															
Dewatering															
Spring Development		x		x					x		x			x	
Horizontal Drains		x		x				x			x			x	
Dewatering Wells	x			x				x		x			x		
Vegetative Plantings			x		x				x			x			x
Earthwork	x				x		x			x---x					x
Erosion Control															
Downspouts	x			x				x		x			x		
Diversion Ditches			x	x				x		x				x	
Gully Rehabilitation	x---x				x			x			x			x	
Slope Protection															
Vegetation		x			x			x			x---x			x---x	
Surface Covers	x			x				x		x			x		
Sediment Deposition Control															
Sediment Traps															
Vegetation Filter			x		x				x			x			x
Filter Berms	x			x					x		x			x	
Filter Fences	x			x					x		x			x	
Barriers	x			x					x		x---x			x	
Sediment Detention Basin	x			x			x---x			x			x		
Mine Reclamation	x				x		x			x					x

Methods of Landslide Stabilization

Stabilization of the slump and other landslide deposits in the eastern portion of the diggings is a remedial alternative suggested by both Nevada County Resource Conservation District (1980) and Peterson (1980). Such action could significantly reduce sediment discharge, as these landslide deposits are the chief sources of sediment in watershed areas 3 and 4. The methods of landslide stabilization suggested by Peterson (1980) and NCRCD (1979b) are presented below. Most of the methods relate to the slump. It should be recognized that landslide stabilization can be difficult and expensive; detailed geotechnical analyses of the landslides should be undertaken prior to implementing any of the methods discussed.

Dewatering

Several methods of dewatering the slump were suggested by NCRCD (1979b). These include spring development, horizontal drains, dewatering wells, and vegetative plantings. Dewatering the slump would remove the weight of the water on the slope and alleviate high pore-water pressures that may exist so that the shear strength of the slide mass is increased.

Spring Development. Spring development is intended to reduce the weight of material on the slump by collecting the natural spring effluent and carrying the water away from the slump by conduit pipe (NCRCD, 1979b). If implemented, it would be necessary to discharge water collected by the pipes at stable areas away from the slide.

This alternative may be physically ineffective in reducing instability because the present natural drainage of the slump by springs has a limited effect on its stability. In addition, the conduit pipes would have to be periodically cleaned of debris, and continued instability of the slump could damage them. Frequent and continual maintenance would be required.

Horizontal Drains. Perforated pipe installed horizontally in the slump would provide a more efficient means of slope drainage than natural springs. The drains would be most effective if they intercepted the subsurface water at the upper boundary of the clay at elevation 3,520 feet, thereby reducing the possibility of its saturation (Peterson, 1980). To reduce the erosional effects of outflow from the drains, a collection system would have to be installed, and the collected effluent would have to be discharged at a stable site.

Installation of the drains may be extremely difficult, especially in the cliff area at the toe of the slump. Once installed, the horizontal drains and effluent collection system would require maintenance to unclog and resecure the pipes. Continued movement of the slump could damage the drains and render them ineffective. The drains may also present adverse esthetic impacts.

Dewatering Wells. Reducing surcharge of the slope could be achieved by drilling wells and pumping out the ground water. The water produced from the wells would have to be transported away from the slump and discharged at a stable site. The effectiveness of this method would depend on the permeability of the slope material. Relatively impermeable slope material would require more wells for effective drainage and, therefore, higher capital costs as well as higher operation and maintenance costs. In addition, the saturated condition of the slide material could prevent access of drilling equipment to the site.

The cost of operation and maintenance includes pumping the water, cleaning the wells and discharge pipes, and maintaining the water discharge sites. Movement of the slump after emplacement of the dewatering wells would probably shear

well casings, requiring frequent replacement and incurring additional costs. The wells will also create esthetic impacts.

Vegetative Plantings. The NCRCD (1979b) suggested that vegetation with high transpiration rates could be planted to aid in the removal of ground water in the slump. The root structure of the plants would also help to maintain the stability of some of the landslide deposits and landslide-prone clay beds at elevation 3,300 feet (Peterson, 1980).

The most obvious drawback to this method is that evapotranspiration is lowest during the cool, wet season when it is most needed. Other constraints to establishing vegetation include the soil moisture and chemistry necessary to support the vegetation, and disturbing existing vegetation.

Earthwork

The slump and surrounding area could be reshaped to facilitate planned drainage and possibly shift the weight of water away from critical areas. This practice would also foster the vegetative plantings alternative by providing a more workable landscape (NCRCD, 1979b). However, grading would result in removal of some vegetation, and the increased area of bare soil would encourage runoff and erosion. The particular method used in grading (e.g., contour grading versus grading parallel to slope) may also increase runoff and erosion. Esthetic impacts could arise from grading the slope.

Another means of stabilizing the slump is to remove and/or recompact the slide material. Long-term benefits would be gained from this action, as it would serve to remove one of the major sources of sediment in the Malakoff Diggins watershed. Stabilization of the reworked slopes could be further enhanced by installation of a buttress (e.g., riprap, retaining wall) and some type of dewatering device. This method of stabilization in effect represents a partial reclamation of the mine, a subject discussed in more detail in Chapter 8. Stabilizing the slide in this manner would have the same adverse impacts as discussed above, though the magnitude of the impacts would probably be higher.

Methods of Erosion Control

Reducing the effects of rainsplash and surface flow on the bare cliffs and landslide deposits in the diggings is one of the most important yet most difficult actions to be taken to limit sediment discharge to Humbug Creek. The extreme steepness of the cliffs and the impacts of many types of remedial alternatives on the cultural and historical resources of the park severely limit the possible courses that can be taken. Following is a discussion of some of the possibilities for controlling erosion.

Downspouts

Downspouts are intended to intercept upper watershed flows in selected drainages and convey them through bare cliff areas, thereby reducing the effects of erosion by the surface flows. The discharge sites proposed by Peterson (1980) and the Nevada County Resource Conservation District (1979b) would require energy dissipators to prevent erosion of sediments deposited on the mine floor. Installation of energy dissipators would increase the estimated cost of this alternative. Other costs would be incurred for design and construction of appropriate intake structures, which were not explicitly discussed by NCRCD (1979b). Additional problems include maintenance costs, possible damage by mass movements, and esthetic impacts (NCRCD, 1979b).

Diversion Ditches

Diversion ditches constructed in the upper watershed, as suggested by NCRCD (1979b), would intercept runoff and divert it away from the cliffs and the mine floor. This alternative includes construction of ditches designed to intercept runoff from the western and the eastern portions of the upper watershed, individually or in combination.

Several problems related to implementation and maintenance of this alternative could arise. The west end diversion ditch is proposed to be constructed at about the 3,400-foot elevation contour, the east end diversion ditch is proposed to be constructed at about the 3,600-foot elevation contour. However, many portions of the upper watershed are not accessible at these elevations. Therefore, access roads for constructing and maintaining the ditches would be required. Maintenance of the ditches and the access roads would incur additional costs in the future.

Construction and maintenance of the ditches by hand labor could reduce the area of disturbance and the potential for erosion. However, costs associated with construction and maintaining up to 14,000 lineal feet of ditches (Cranmer Engineering, Inc., 1979) could prove to be prohibitive.

Runoff collected by the ditches would be directed around the diggings and into existing natural drainages. Erosion could occur if measures are not taken to stabilize the ditches' discharge sites and to protect the drainages into which the runoff is diverted. The possible erosion and adverse esthetic impacts caused by disturbing stable soils and drainages could exceed the limited benefits of this alternative.

In addition, construction of the east end ditch would not significantly reduce the volume of runoff from drainage 4, which is the major source of sediment in the diggings. As noted previously, most of the runoff in this subwatershed is derived from springs near the rim of the cliffs or from precipitation that falls downslope from the proposed ditch location.

Gully Rehabilitation

Severe gullying of landslide deposits in the northeast corner and east end of the diggings contributes a significant percentage of the sediment discharged to Humbug Creek (NCRCD, 1979b). Rehabilitating the gullies by grading or filling them and establishing vegetation could substantially reduce the amount of erosion that occurs by surface flow and rainsplash.

This type of restoration would require the use of heavy equipment, which may have difficulty in gaining access to gullied areas. Borrow areas for filling the gullies, as suggested by Peterson (1980), would create an adverse visual impact. Visual impacts due to the earthwork necessary to accomplish rehabilitation would also occur.

Alternatively, rehabilitation of the gullies could be accomplished by constructing check dams in some of the gullies. Check dams would avoid the earth disturbance caused by heavy equipment, but they would require more maintenance and upgrading over time. Also, their immediate effect on reducing erosion would be less than filling or grading the gullies. Establishing vegetation on the gully walls is an important aspect of this method of rehabilitation. Each check dam would require some type of energy dissipator to prevent erosion of the channel below it.

Slope Protection

Slope protection encompasses methods directed at preventing or lessening the effects of rainsplash and surface flow.

These methods include establishing vegetation on bare slopes or protecting the slopes with a natural or artificial cover, such as jute mesh or mulch blankets. The extreme steepness and irregular surfaces of the cliffs precludes the practical implementation of these alternatives in many areas of the diggings. In addition, instability of the slopes diminishes the potential effectiveness of establishing vegetation. However, several stable to meta-stable areas of low to moderate gradient do exist in the diggings. These areas include the lower cliffs and heads of alluvial fans, the walls of some gullies in the northeast and east end of the mine, and the nearly horizontal clay bed at elevation 3,300 feet in the eastern end of the mine.

Vegetation. The critical role of vegetation as a form of slope protection is to intercept and absorb the kinetic energy of rainfall. Establishing vegetation would be most practical on the horizontal clay bed at elevation 3,300 feet at the east end of the diggings. Landslide deposits with moderate slopes in this area may also benefit from planting vegetation. Planting using contour wattling techniques on the steeper of these slopes may decrease erosion.

Before implementing this alternative, soil conditions in this part of the diggings must be studied to ensure that nutritive and moisture requirements of vegetation are met. Similar evaluations of other bare areas around the diggings must be conducted before implementing this alternative.

Surface Covers. Surface covers also absorb rainfall energy and reduce erosion due to sheetwash and surface flow. They can be expensive to purchase and install and are highly visible; however, their ability to protect newly seeded or planted bare slopes should not be overlooked. It may be necessary to use some type of artificial cover or mulch on the slopes, at least temporarily, to promote establishment of vegetation. Types of covers that could be used are straw mulch, hydromulching, various mulch nets and blankets including Excelsior blankets, plastic netting, and jute mesh, or geotextile fabrics. Difficulty of installation (and higher costs) can be expected because of the steepness and inaccessibility of slopes in the diggings.

Methods of Controlling Sediment Deposition

Sediment eroded from the walls of the diggings is being deposited on the mine floor, as evidenced by the burial of vegetation and the diminution of the pond. However, at present, not enough sediment is deposited in the pit to adequately reduce the turbidity and sediment load of water discharged to Diggins Creek. If measures were taken to increase the amount of sediment deposition in the diggings, then the amount of sediment discharged from the diggings might be reduced to an acceptable level. Possible methods for accomplishing this are sediment traps and sediment detention basins.

Sediment Traps

Sediment traps are a passive method of controlling sediment deposition. They act as filters of sediment-laden water, allowing water to pass through the trap while retaining some of the sediment it carries. They can be constructed of either natural or artificial material. Types of sediment traps include vegetative filter strips, filter berms, filter fences, and sandbag or hay bale barriers. With the exception of vegetation, the other sediment trap methods reviewed here are generally used only as temporary measures.

Vegetative Filter Strips. Use of vegetation is successful in promoting sediment deposition; however, it is more often and more effectively used to pro-

tect slopes to prevent erosion. In its proposed application, vegetation would act to stabilize the mine floor as well as to filter turbid runoff.

The stand of willows and alders that has become established in the western end of the pit over the last 25 to 30 years is effective in trapping some of the clay-size and larger sediment. Hypothetically, extending the vegetation eastward into unvegetated areas would result in more fine-grained sediment deposition. However, the willows and alders have grown and become established at a faster pace in a westward direction. This may indicate that soil moisture or nutritive requirements for this type of vegetation are not met in the east end of the mine floor. It may also be a reflection of slower upstream propagation of vegetation from established areas, or of distance from the seed source. Burial of seeds by active sediment deposition could also account for the relatively sparse vegetation in this portion of the diggings. Soils analyses should be performed to determine the reasons for this difference. It may be necessary to introduce different species of vegetation that can survive under existing conditions at the east end of the mine floor.

In addition to the possible soil moisture and chemistry problems, several other potential problems exist. These include disturbance of existing vegetation, maintenance costs, and esthetic impacts created by establishing and propagating new vegetation. Also, the active deposition of sediment in the diggings could bury the plantings before they could become established.

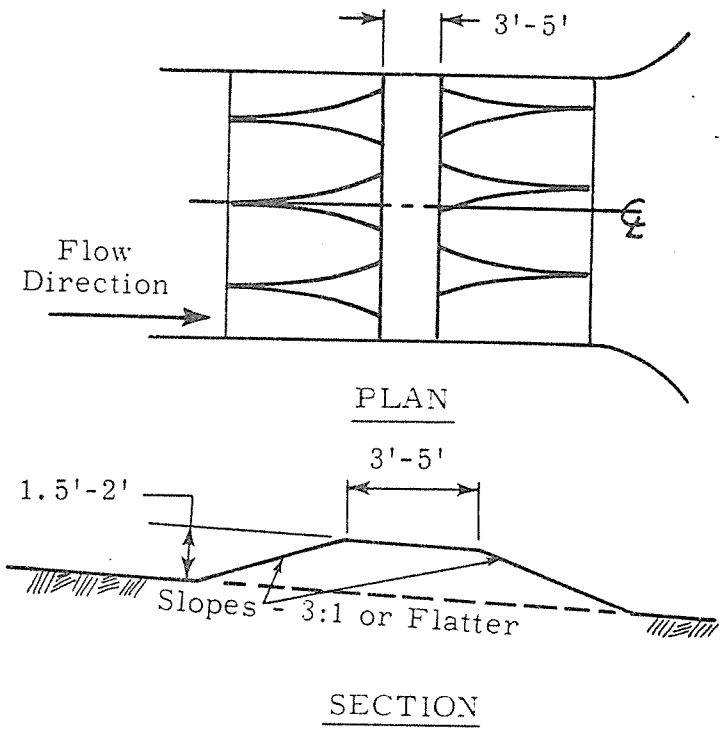
Filter Berms. Filter berms consist of small ridges of gravel or crushed rock constructed perpendicular to the direction of flow. Figure 38 shows a cross section and typical specifications of a filter berm. Spacing of the berms depends on the slope and sediment load of the stream. In the diggins, the most appropriate location for construction of filter berms is in the east end of the mine floor, near the heads of the alluvial fans. Ample material suitable for construction of the berms is available in the diggings in the form of mine tailings; however, disturbing these tailings is not in keeping with the goals of preserving cultural and historic aspects of the park. Costs related to maintaining the filter berms and the esthetic impact they present are also negative aspects of this alternative.

Filter Fences. Filter fences consist of an artificial filter fabric attached to a welded wire or cyclone fence constructed perpendicular to the direction of flow (Figure 39). Filter fences are more expensive to construct than filter berms or barriers, and they have the same maintenance and esthetic disadvantages. However, less space is disturbed during their construction than is disturbed with filter berms or barriers. This increases their suitability for installation in vegetated areas of the mine floor. Within the vegetation, the esthetic impacts of the filter fences would be substantially decreased.

Barriers. Barriers constructed of hay bales or sandbags would trap sediment in a manner similar to that of the filtering methods previously discussed, although they are less permeable than the filters. Hay bales must, therefore, be anchored to the ground with fence posts or rebar to prevent them from being washed away and to prevent runoff from flowing freely under them.

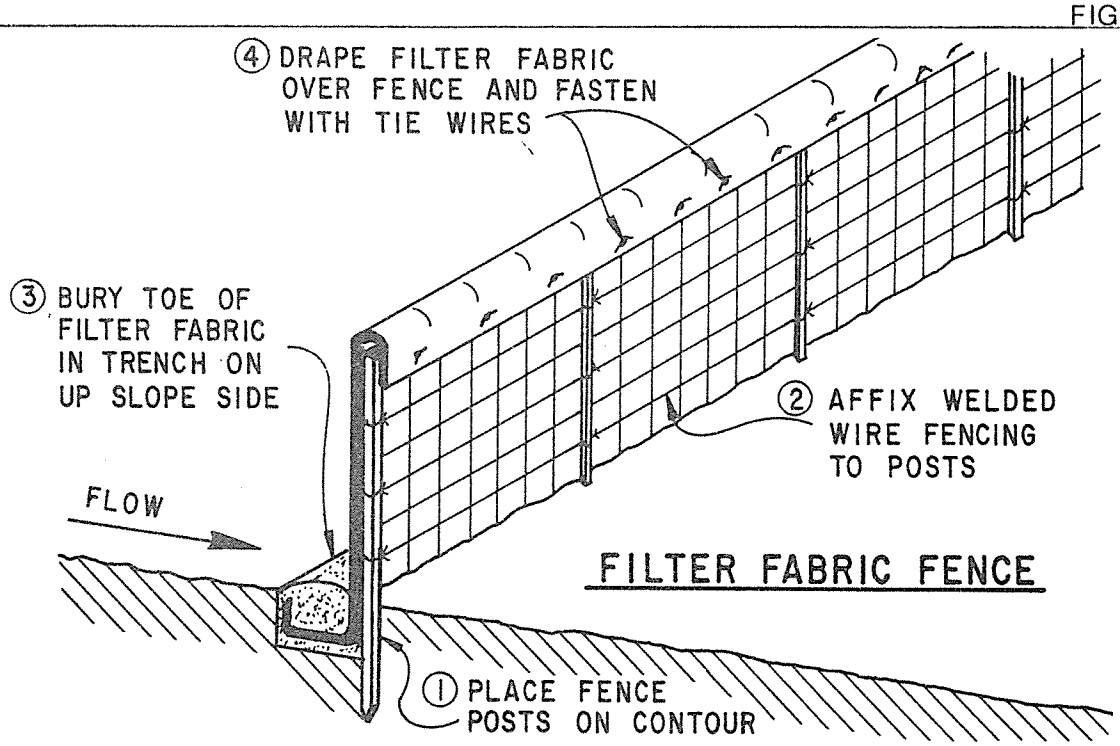
The sandbag or hay bale barriers would probably be more effective and more easily installed along the base of the cliffs to the north and west of Diggins Pond where the problems of flotation and undercutting would be less. As with the other filtering methods, the effort and cost of maintaining these structures diminishes their usefulness. In addition to general esthetic impacts associated with construction of the barriers, loose straw derived from the breakdown of the hay bales also presents a potential adverse esthetic impact.

FIGURE 38



Typical filter berm design (modified from USEPA, 1972)

FIGURE 39



Typical filter fence design (from Ca. State Water Resources Control Board, 1978)

Sediment Detention Basin

The method of sediment control recommended by Nevada County Resource Conservation District (1979b, 1980) as the most effective was construction of a settling basin at the diggings. This alternative is intended to increase the storage capacity of the existing basin in order to hold the average annual winter runoff of 3,000 acre-feet per year by constructing a 40-foot-high debris dam and two saddle dams near Hiller Tunnel (Figure 40). According to NCRCD (1979b), this would allow deposition of all settleable solids and about half the suspended solids, resulting in a 75 to 85 percent reduction of the total sediment produced by the Malakoff watershed. Several potential problems associated with implementing this alternative were not addressed by the NCRCD study.

The design capacity of the debris dam is based only on an estimate of annual runoff; there are no historical records of measurements to support this estimate. Errors in the estimate could limit the effectiveness of the basin.

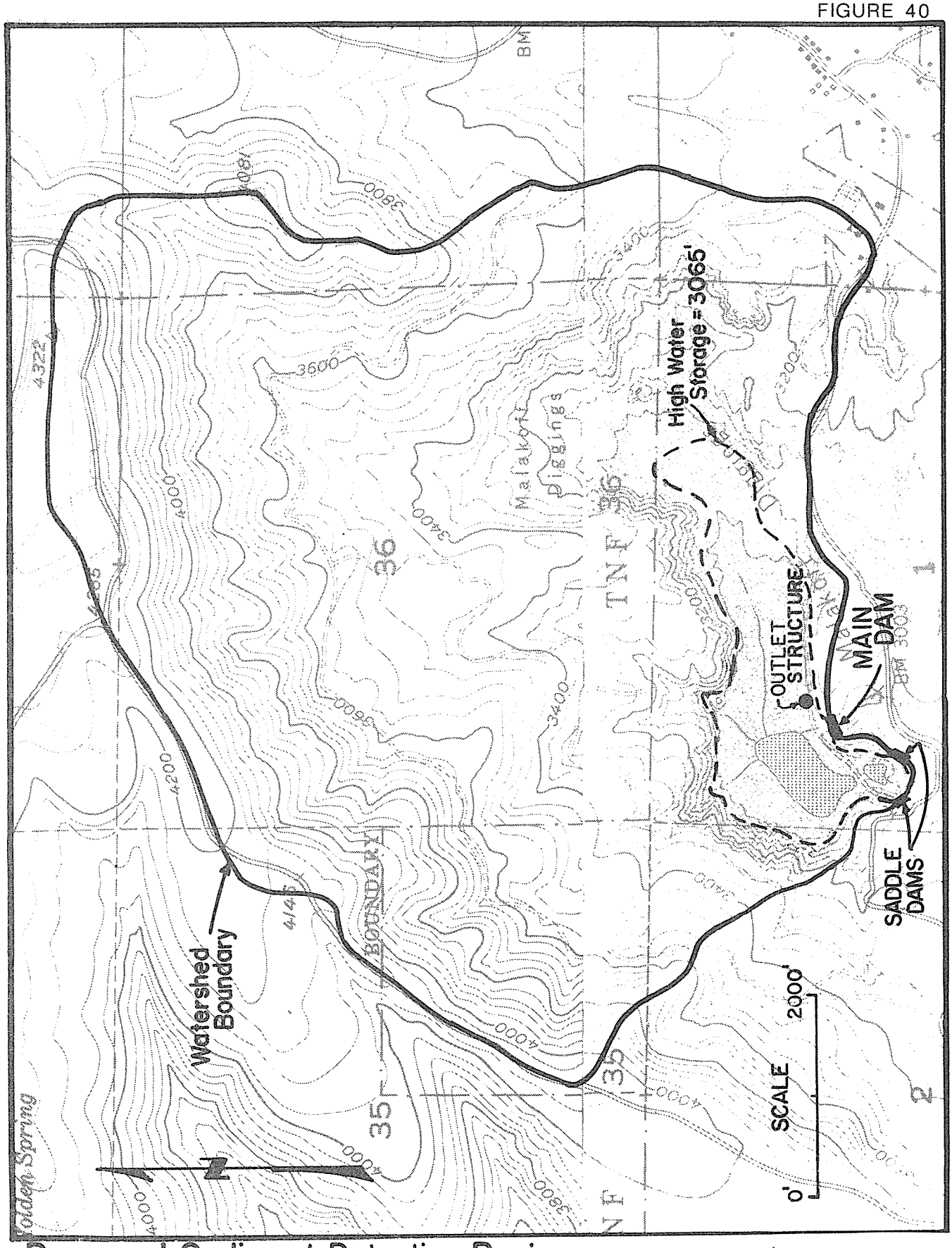
NCRCD (1979b) estimated that about half the suspended sediment would be retained by the basin; however, settling rates for clay-size particles could be strongly influenced by water chemistry. Chemical treatment of the runoff to encourage settling of the fines has not yet been thoroughly investigated. The remaining sediment that is not deposited would be released with most of the water during summer. At this time, there would be less water in the South Yuba River to dilute the turbid water released from the sediment basin. This practice would raise the possibility of the South Yuba River remaining turbid year-round: turbidity from the general watershed in winter; turbidity from Malakoff Diggins in summer.

There is a greatly increased potential for slope instability due to long-term saturation of the base of the cliffs by the impounded water and by undercutting of the cliffs by wave action. This problem was recognized by Peterson (1980, p. 74). Mass movements due to these circumstances would significantly reduce the storage capacity of the reservoir. The dam would no longer be able to retain the annual runoff, and the reservoir would have to be cleaned more often to maintain sediment storage capacity. Storage capacity would also be reduced by inundation or removal of vegetation and top soil that previously trapped sediment. Reservoir storage capacity and estimates of life expectancy could be too optimistic if these factors are not considered.

Even without considering reduced capacity due to landslides and vegetation removal, the reservoir would begin to fill with sediment. The estimated life expectancy of the reservoir is 28 years (Cramner Engineering, Inc., 1979). During this time 133,000 cubic yards of sediment would be deposited behind the dam. This estimate is based on sediment discharged from the diggings, and does not account for active deposition already occurring in the diggings. If Peterson's (1980) estimates of sediment deposition are included (6,500 to 115,000 cubic yards per year), the reservoir life expectancy will be reduced by 55 percent (resulting in a 12-year life) to 95 percent (resulting in a 1.1-year life). These are gross estimates and are subject to significant error because it was assumed that all of the sediment would be deposited in the reservoir behind the debris dam. In actuality, some of the sediment would be deposited in the alluvial fans nearer the cliffs before it reached the reservoir. However, these estimates of reservoir life expectancy do show the potential problems associated with construction of a debris dam.

At some point after construction (1.1 to 28 years), about 133,000 cubic yards of sediment deposited behind the dam would have to be removed because water storage capacity would be reduced to improperly

FIGURE 40



Proposed Sediment Detention Basin (after NCRCD, 1979a)

functioning or unsafe levels. The sediment would have to be disposed of in a manner that would prevent its return to the sediment basin or into downstream areas during subsequent runoff. Costs incurred by dredging operations and transporting the material to an acceptable disposal site may be prohibitive and should be carefully analyzed before implementation of this alternative.

Other drawbacks concern operation and maintenance of the dam and the outlet structure, which will incur additional costs over time. Damage to the outlet structure and emergency spillway during periods of especially high runoff is a real possibility.

Finally, the debris dam alternative is undesirable because it is only treating a symptom of the problem; it is not a solution. While it may intercept part of the sediment transported by streams in the mine, it does not remove the source of sediment, nor does it reduce the causes of erosion. With this alternative, the factors discussed above will be pertinent issues and problems for several hundred more years.

Chapter 8. MINE RECLAMATION

The processes that occur in Malakoff Diggins that ultimately lead to the discharge of turbid, sediment-laden water to Humbug Creek are a natural response to topographic changes caused by hydraulic mining. In Chapter 7, alternatives for controlling sediment discharge were discussed independently. However, few of the alternatives discussed in this study and previous studies actually address the long-term problem of erosion of the cliffs and how to solve it. If the ultimate goal of the erosion control program is to reduce sediment discharge to a level of insignificance, then permanent reclamation of the mine is the only possible alternative.

Mine reclamation is a broad subject that involves a wide variety of disciplines. Within each of these disciplines, a considerable volume of literature has been devoted to reclaiming mined lands. An overview of the process of reclaiming the diggings is presented below; however, conditions there must be analyzed thoroughly before undertaking such a project.

Briefly, the steps necessary to reclaim Malakoff Diggins are to reduce the cliffs to relatively flattened slopes, provide a soil medium suitable for plant growth, and establish a vegetation planting and maintenance program. Erosion and mass wasting of the slopes is gradually reducing their steepness, as the heads of the cliffs retreat into the upper watershed and alluvial fan deposition buries the base of the cliffs. However, these are slow processes. The mine has been abandoned for nearly 100 years, yet the cliffs are still too steep to allow formation of soils and establishment of vegetation. Generally, the steepest slope for vegetative and soil stability is considered to be 2:1 (horizontal to vertical) (USEPA, 1972). This slope angle agrees with that set by Nevada County Planning Department use permit requirements for reclamation plans of proposed auriferous gravel mines near Malakoff Diggins.

Establishing 2:1 slopes at Malakoff Diggins would be difficult due to the height of the cliffs. Assuming a balanced cut and fill operation for 200-foot-high vertical cliffs over a length of 10,000 feet, some 3,700,000 cubic yards of material would have to be moved. Working this volume of material would disrupt a large area of the upper watershed and the natural drainages and vegetation established there. Erosion control measures discussed earlier would have to be used to control erosion of the newly constructed slopes.

After flattening the slopes, they would have to be revegetated to stabilize and protect them. The first step is to provide a suitable growth medium. The newly created slopes would not constitute an edaphic soil, but it is probable that the proper constituents to provide a suitable growth medium structure are available. Treatment of the slopes to provide the proper soil chemistry and pH for plant growth would be necessary.

The general procedure of revegetation is to establish herbaceous plants (forbs and grasses) first. They provide the best cover and soil protection in the shortest time. Woody plants (bushes, shrubs, trees) are planted a few years after herbaceous plants to encourage reforestation. Both plantings would require soil amendments and possibly irrigation, but the ultimate goal is an established population of plants that will survive with no maintenance.

This discussion is brief, because a detailed account of procedures necessary to reclaim the diggings is beyond the scope of this study. There are numerous possibilities available with regard to flattening the slopes and establishing vegetation. Likewise, there are numerous adverse impacts associated with implementing this alternative.

The most obvious impact is the destruction of the major features for which the park was acquired. The hydraulic pit and the cliffs left by mining are integral parts of the park; reclaiming the mine would necessarily alter its character and diminish its value as an historic and cultural resource.

Other impacts include increased sediment discharge for several years due to the disturbance and exposure of stable slopes and soils in the upper watershed, and the effects on the environment of increased erosion and sedimentation. Erosion and sediment control structures would have to be installed and maintained. It is also possible that disturbing the colluvium that underlies a large portion of the upper watershed could induce landsliding. The reclaimed fill slopes might also be subject to instability. Proper design and construction practices should help to reduce the possibility of these occurrences.

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CONVERSION FACTORS

Quantity	To Convert from Metric Unit	To Customary Unit	Multiply Metric Unit By	To Convert to Metric Unit Multiply Customary Unit By
Length	millimetres (mm)	inches (in)	0.03937	25.4
	centimetres (cm) for snow depth	inches (in)	0.3937	2.54
	metres (m)	feet (ft)	3.2808	0.3048
	kilometres (km)	miles (mi)	0.62139	1.6093
Area	square millimetres (mm^2)	square inches (in^2)	0.00155	645.16
	square metres (m^2)	square feet (ft^2)	10.764	0.092903
	hectares (ha)	acres (ac)	2.4710	0.40469
	square kilometres (km^2)	square miles (mi^2)	0.3861	2.590
Volume	litres (L)	gallons (gal)	0.26417	3.7854
	megalitres	million gallons (10^6 gal)	0.26417	3.7854
	cubic metres (m^3)	cubic feet (ft^3)	35.315	0.028317
	cubic metres (m^3)	cubic yards (yd^3)	1.308	0.76455
	cubic dekametres (dam^3)	acre-feet (ac-ft)	0.8107	1.2335
Flow	cubic metres per second (m^3/s)	cubic feet per second (ft^3/s)	35.315	0.028317
	litres per minute (L/min)	gallons per minute (gal/min)	0.26417	3.7854
	litres per day (L/day)	gallons per day (gal/day)	0.26417	3.7854
	megalitres per day (ML/day)	million gallons per day (mgd)	0.26417	3.7854
	cubic dekametres per day (dam^3/day)	acre-feet per day (ac-ft/day)	0.8107	1.2335
Mass	kilograms (kg)	pounds (lb)	2.2046	0.45359
	megagrams (Mg)	tons (short, 2,000 lb)	1.1023	0.90718
Velocity	metres per second (m/s)	feet per second (ft/s)	3.2808	0.3048
Power	kilowatts (kW)	horsepower (hp)	1.3405	0.746
Pressure	kilopascals (kPa)	pounds per square inch (psi)	0.14505	6.8948
	kilopascals (kPa)	feet head of water	0.33456	2.989
Specific Capacity	litres per minute per metre drawdown	gallons per minute per foot drawdown	0.08052	12.419
Concentration	milligrams per litre (mg/L)	parts per million (ppm)	1.0	1.0
Electrical Conductivity	microsiemens per centimetre (uS/cm)	micromhos per centimetre	1.0	1.0
Temperature	degrees Celsius (°C)	degrees Fahrenheit (°F)	(1.8 × °C)+32	(°F−32)/1.8

State of California
DEPARTMENT OF WATER RESOURCES
CENTRAL DISTRICT
3251 S Street
P. O. Box 160088
Sacramento, Calif. 95816–0088

DRAFT

MERCURY MASS BALANCE FOR THE FRESHWATER SACRAMENTO-SAN JOAQUIN BAY-DELTA ESTUARY (TASK 1A)

CHRIS FOE

AUGUST 2002

ABSTRACT

The main objective of the study (Task 1A) was to calculate a mercury budget for the Bay-Delta Estuary by combining an estimate of the load entering from the Central Valley and exiting to both San Francisco Bay and to southern California with an estimate of mercury flux to and from Delta sediment (Task 4A, Dr Gary Gill). A secondary objective was to estimate the importance of mercury from wet atmospheric deposition in the Central Valley on the Estuary mass balance budget.

Two major sources of raw total mercury were measured in the Bay-Delta Estuary. The first was the Sacramento River and accounted for 161-kg during the 18-month study. Most of this mercury was transported during winter storms. The second was erosion of mercury contaminated sediment from Suisun Bay. This material is likely transported mostly during summer. The precise amount of material being eroded from the Bay is not known but may be about 278-kg or similar to what was exported during the study from the Central Valley. Mercury from Suisun Bay is transported both up and down estuary.

The Delta is a net sink for raw methyl mercury. The Sacramento River was the major river source and accounted for 60-85 percent of the total load on a monthly basis. Loads were highest in winter and spring (January to May). This was because both flow and raw methyl mercury concentrations (0.08-0.34 ng/l) were greatest then. The average river loading for the study period was about 10 gm-day^{-1}. Average flux from sediment was estimated at about 6 gm-day^{-1} (Task 4A). A precise estimate of the export rate is more difficult as methyl mercury concentrations in 30 percent of the export measurements were below detection. However, the average methyl mercury export rate from the Delta was estimated at about 6 gm-day^{-1}. Most of this material went to San Francisco Bay. The difference between the sum of all inputs (16 gm-day^{-1}) and exports (6 gm-day^{-1}) is 10 gm-day^{-1}. This is the best estimate of the methyl mercury loss rate in the Estuary. Mechanisms responsible for the loss are not yet known.

Direct deposition of mercury from rain on surface water in the Delta was not significant. Wet deposition was estimated at about 618-gm or 0.2 percent of the total mercury load to the Delta during the 18-month study. The rate may increase in wet years to about 2.8-kg of mercury. Indirect wet deposition and runoff from the Central Valley are more uncertain but may be more significant. The estimate of the annual contribution from indirect deposition ranges from a low of 25-kg to a high of 74-kg-yr^{-1} or 23-69 percent of the total incoming mercury budget from the Central Valley for water year 2001. Uncertainties in the calculation of indirect loads are discussed.

INTRODUCTION

The Sacramento-San Joaquin Bay-Delta Estuary is a significant natural resource. It is the largest estuary on the West Coast of North America draining over forty percent of the State of California. The Delta, or freshwater side of the Estuary, comprises about 1,800 km of channels and has about 400 square km of open surface water. It is a source of drinking water for 22 million Californians and is home to 230 birds, 45 mammals and 52 species of fish (Department of Water Resources, 1995). Nine million people live around its shore. The Delta supports a recreational striped bass, salmon, sturgeon, and large mouth bass fishery. Subsistence and sports fishermen also take other less desirable fin and shellfish species.

Control of mine waste is a modern legacy of early California history. Extensive deposits of mercury were discovered in the California Coast Range in the nineteenth century (Pemberton, 1983). The mines were of national importance accounting for about ninety percent (100 million kg) of the mercury mined in the United States between 1850 and 1980. The cinnibar ore was crushed and roasted on site to produce elemental mercury and the waste rock left to erode into surface water.

Gold was discovered in California in 1848. It was mined by placing sluice boxes in streams and adding elemental mercury to amalgamate the precious metal. One billion cubic meters of mercury contaminated sediment was released into Central Valley creeks and rivers by hydraulic gold mining (San Francisco Estuary Project, 1994). The result was widespread sediment mercury contamination in streams and rivers in the Sierra Nevada and downstream in the Bay-Delta Estuary.

Mercury is a potent human and wildlife neurotoxin with fetuses and the very young being most at risk (White *et al*., 1995). The principal route of exposure is through consumption of mercury contaminated fish. In 1971 a human health advisory was issued for the Bay-Delta Estuary advising pregnant women and children not to consume striped bass. The advisory was again released in 1993 upon review of more data. Elevated mercury concentration in fish tissue and in water samples collected during storm events led the State of California to place the Delta on its Clean Water Act 303(d) list of impaired water.

Methyl mercury is the neurologically important form of the element and is produced by sulfate reducing bacteria in anoxic sediment. A positive correlation exists in the Bay-Delta Estuary between total and methyl mercury sediment concentration (Heim *et al.*, 2002). This observation has led to the hypothesis that bulk mercury sediment levels in the Delta may be one factor influencing sediment methyl mercury production and aqueous concentrations.

Primary hypotheses of the CALFED grant[1] were that the main source of methyl and total mercury in the Bay-Delta Estuary was from river inputs and from *in situ* estuary sediment

[1] CALFED grant entitled "An Assessment of Ecological and Human Health Impacts of Mercury in the Bay-Delta Watershed".

production and that aqueous methyl mercury concentrations determine biotic tissue levels. If correct, then the control of methyl mercury in estuarine biota would necessitate a good understanding of the temporal and spatial pattern of methyl and total mercury inputs and sinks. The main objective of this study (Task 1A) was to estimate the magnitude of the loads of mercury entering the Bay-Delta Estuary from the Central Valley and exiting to San Francisco Bay and Southern California. These results were combined with the amount of mercury fluxing to and from sediment (Task 4A) to calculate a methyl and total mercury budget for the Delta.

Method and Materials

Sample Collection

Water was collected monthly between March 2000 and October 2001 from all the major freshwater sources to the Bay-Delta (Sacramento, San Joaquin, Mokelumne and Consumnes Rivers and Prospect Slough) and from all its major export sites (Delta Mendota Canal, State Water Project and X2) for mercury analysis (Figure 1). The Delta Mendota Canal (DMC) and State Water Project (SWP) are the major man-made conveyances transporting water out of the Delta to central and southern California. X2 is defined as the location in the Estuary with 2-o/oo bottom salinity. Surface salinity at X2 is usually about 0.5-o/oo. The location of X2 moves hourly as a function of both tidal cycle and freshwater inflow. Samples were collected at X2 to estimate mercury exports to San Francisco Bay[2].

Water samples were collected using the ultra clean sampling techniques. Briefly, each sample was collected in double-bagged 4-liter amber glass bottles that had previously been rinsed three times in ambient water. Samples were place on ice and aliquots decanted from the same bottle for total suspended solids (TSS), raw and filtered total and methyl mercury. All samples were filtered in the field within 8 hours of collection. Preservative was added within 3 days of collection at the analytical laboratory. Raw and filtered total mercury was analyzed at the California Department of Fish and Game's Moss Landing Marine Laboratory using EPA method 1631 (revision B) while raw and filtered methyl mercury was determined by Battelle Marine Sciences Laboratory (Battelle, 2000). TSS was analyzed at Sierra Foothill Laboratory using EPA method 160.2.

Water samples were collected as subsurface grabs. In shallow streams they were taken by wading into the middle of the creek, facing upward, and collecting the sample after all turbidity had dispersed. When samples were collected by boat, the vessel was anchored and allowed to swing into the wind. The depth of water was determined with a fathometer and the sample collected by lowering the sampling bailer to within several feet of the bottom and slowly pulling back to the surface. Finally, samples were taken from bridges by lowering the bailer off the center of the bridge taking care to collect the sample without hitting the bottom.

About 30 percent of the water moving through the Bay-Delta in summer is diverted to Delta Islands for agriculture. About a third of the diverted flow is returned in island main drains to Delta channels. Water samples were taken from five representative delta island main drains (Staten, Empire, Lower and Upper Jones, and Twitchell Islands, Figure 1) in June and July of 2000 to ascertain whether the islands were a net source or sink for

[2] Selection of X2 as the location to calculate mercury export from the freshwater Delta was somewhat arbitrary. This salinity was chosen as 2 to 3-0/00 salinity is the normal osmotic tolerance of freshwater organisms and the primary goal of the project was to estimate mercury loads to the habitat of these organisms.

methyl mercury. All samples were taken from actively pumped main drains within a quarter mile of the pump house.

Loads

Bulk mercury loads (kg) were estimated by multiplying water volume (acre-feet) by mercury concentration (ng/l):

$$(\text{Hg concentration})(\text{Water volume})(1.235 \text{ X } 10^{-6})$$

If mercury concentrations were below the ability of the laboratory to quantify, then half the detection limit was employed. This was only a problem with the methyl mercury analysis. The methyl mercury detection limit in 2000 and 2001 was 0.022 and 0.011 ng/l, respectively.

Net mercury production on Delta Islands was estimated by subtracting the amount of mercury exported from the islands from the amount of mercury diverted onto them as irrigation water. Exports were estimated by multiplying the average mercury concentration of return flows from islands in June and July by return flow volumes. Return flows were obtained from the Department of Water Resources Delta Island Consumption Use Model (personal communication, Suits). The amount of mercury imported to the islands was estimated by taking the average mercury concentration of the Sacramento River and of the State Water Project and multiplying this by the estimated volume of water diverted onto them.

Flow at main river and export sites is from the U.S. Geological Survey and the California Department of Water Resources. The web address for obtaining each flow is listed in Appendix A with a more detailed description of the location of the sampling site.

Atmospheric Deposition

Mercury loading from precipitation on surface water in the Delta (direct deposition) and from runoff of mercury contaminated rain falling in the Central Valley (indirect deposition) was estimated. Purpose of the calculations was to determine the proportion of fluvial input that might be attributed to atmospheric deposition.

Direct deposition was estimated by multiplying the average mercury concentration in rainwater in San Francisco Bay by the average rainfall total for the Cities of Sacramento and Stockton and by the surface area of the Delta. The average mercury concentration in rainfall in San Francisco Bay (8 ng/l) was from Tsai (2001). The rainfall totals for the Cities of Sacramento and Stockton were from the California Department of Water Resources snow survey web site (2002). Finally, the surface area of the Yolo Bypass and of the Delta was estimated at 254 and 127 km^2 (personal communication, Stephenson).

Indirect deposition was estimated by surveying rainfall patterns in the Central Valley below all major dams and selecting 10 weather stations that appeared to represent the

general precipitation pattern of each region. Rainfall totals for a wet (1999) and dry (2001) water year in each sub basin were multiplied by the associated area, the mercury concentration in precipitation in San Francisco Bay and a high and low runoff coefficient. Precipitation was again from the California Department of Water Resources snow survey web site. The area of each sub watershed was estimated from watershed mapping program **XXX.** Runoff coefficients are an estimate of the fraction of mercury deposited in a watershed that is subsequently carried into surface water. A low (10 percent) and high (30 percent) runoff coefficient was selected to evaluate the effect of indirect deposition on the mercury budget of the Delta.

Quality Assurance/Quality Control Program.

About 15 percent of all mercury analyses were for quality assurance and quality control purposes. The program had both a field and a laboratory component.

Field The field component consisted of the collection of blanks and field duplicates. On 18 occasions field blanks were collected. The procedure consisted of randomly selecting one site and carrying laboratory water of known low mercury concentration into the field and processing it thereafter in a manner identical to the field sample. The results were compared with laboratory detection limits for total and methyl mercury to ascertain whether field contamination occurred. Also, on 24 occasions duplicate field samples were simultaneously taken at randomly selected sites. The difference in TSS and mercury concentration between the paired samples was used to assess field variability.

Laboratory The quality assurance/quality control program at the California Department of Fish and Game Moss Landing Marine Laboratory and at Battelle Marine Sciences Laboratory consisted of both amendments to and replicate analysis of the same sample. At each laboratory a known amount of mercury was spiked into a randomly selected field sample and the percent recovery measured[3]. Similarly, replicate analysis of randomly selected field samples[4] was undertaken and the percent difference between the two analyses noted. The purpose of the amendments and of the replicate measurements was to ascertain the accuracy and precision of the analyses.

[3] 44 amendments for total and 88 amendments for methyl mercury
[4] 45 measurements for total and 54 measurements for methyl mercury

Results and Discussion

Quality assurance/Quality control program

The program consisted of a field and laboratory component. The field portion consisted of the analysis of blanks and field duplicates. Analysis of field blanks demonstrated sporadic contamination[5] (Table 1, Appendix B) which was subsequently traced to the reuse of both Teflon tubing and four liter glass sample collection bottles. The problem disappeared when new bottles and tubing was used with each set of samples. The contamination should not have unduly affected the accuracy of the mass balance loading rates, with the possible exception of May 2002, as the concentration of the contaminated samples was only about 20 percent of the concentration in the lowest field value. A blank sample collected on May 2000 contained 0.098-ng/l methyl mercury or about 70 percent of the smallest field value measured on the occasion.

Field duplicates were collected on 18 occasions to assess the repeatability of the measurements (Table 2, Appendix B). The mean relative percent difference[6] for raw and filtered total mercury was 11 and 17 percent, respectively, while a similar measure for raw and filtered methyl mercury was 9 and 26 percent. Analysis of filtered methyl mercury laboratory duplicates demonstrates a similar variability (34 percent; Table 3, Appendix A) suggesting that much of the methyl mercury field variability may arise during laboratory analysis.

The laboratory portion of the quality assurance/quality control program consisted of the analysis of laboratory duplicates and amendments. The mean relative percent difference of laboratory duplicates for raw and filtered total mercury and raw and filtered methyl mercury was 7, 11, 11, and 34 percent, respectively[7] (Table 3, Appendix B). On 30 to 50 occasions a known amount of mercury was spiked into a randomly selected field sample and the percent recovery calculated to assess accuracy. The mean percent recovery for raw and filtered methyl mercury spikes was 100.3 and 99.4 percent, respectively (Table 4, Appendix B) while for raw and filtered total mercury it was 108 and 106 percent, respectively (Table 5, Appendix B).

In conclusion, results from the quality assurance/quality control program suggest, with the possible exception of the filtered methyl mercury data, that the values are of sufficient quality to be used in the calculation of a mercury budget for the Bay-Delta Estuary. Conclusions from the filtered methyl mercury data should be viewed with caution.

Bay-Delta Budget

Raw field data, including mercury concentrations and water discharge rates, are summarized by month for each major import and export site in the Bay-Delta in

[5] 12 of 67 analyses for total mercury and 4 of 67 analyses for methyl mercury.
[6] High minus low value divided by the average of the high and low value.
[7] The number of samples reanalyzed for raw and filtered total mercury and raw and filtered methyl mercury was 22, 23, 37 and 17, respectively.

Appendix C. This information has been used to construct monthly water, sediment, total and methyl mercury budgets for the estuary.

Water Budget

This study was conducted during a relatively dry period. Summer flows were normal but winter precipitation was low enough to be largely contained by valley reservoirs resulting in little winter storm runoff except during March 2000. Discharge during the year and a half study was about 27.2 million acre-feet (Table 1). The water budget was balanced to within 1.5 percent[8].

The Sacramento River was the major source of water and accounted for about 75 percent of all metered flow (Table 1). Most of the water in winter and spring was exported to San Francisco Bay (X2) while in summer and fall the State and Federal Pumps (SWP and DMC) exported a large fraction to southern California.

Figure 2 illustrates net water movements in the estuary during the study period. As mentioned previously, the Sacramento River is the major water source while the primary sinks are San Francisco Bay and the State and Federal pumps in the South Delta near Tracy. Net water flow is down the Sacramento River to San Francisco Bay and through a series of interconnecting channels to the State and Federal Pumps near Clifton Court Forebay. Smaller tributaries such as the Mokelumne, Consumnes and San Joaquin Rivers and Prospect Slough are less important in the water budget but do control water quality in their drainage and immediately downstream in the delta. A combination of tidal mixing and dilution rapidly reduce the influence of each water-mass once in the tidal prism.

Suspended Sediment Budget

The Sacramento River was the major source of sediment to the Delta and accounted for 880 thousand metric tons or 62 percent of the total load (Table 2). Prospect Slough, a storm conveyance system receiving runoff from the coast range and from the upper Sacramento Basin, transported a relatively large amount of sediment (241 thousand metric tons) during March 2000, the only month when it had significant flow (Table 1). In wet years the Slough can transport as much sediment in a few months as the entire Sacramento River does in an entire year (Foe and Croyle, 1998). The other two major sources of water to the estuary, the San Joaquin and Mokelumne-Consumnes Rivers, only contributed about 18 percent of the sediment load.

The area downstream of X2 (leading to San Francisco Bay) appeared to be the major sink for sediment. Load calculations suggest that 93 percent of all the sediment leaving the Delta moved past X2. Interestingly, the freshwater side of the estuary appeared to be exporting about 50 percent more sediment than was delivered to it. Exports were greater than imports in 11 of 18 months with an estimated net loss of about 775 thousand metric tons. Losses tended to be greatest when flows were largest and X2 was located in the

[8] Estimated water exports exceeded imports by 394,000 acre-feet. Some of this difference may result from the fact that within Delta precipitation was not included in the water budget.

channel off Suisun bay[9]. Spatially, this suggests that most of the erosion may occur there.

Hydraulic gold mining deposited massive amounts of sediment in the San Francisco Bay-Delta Estuary. Bathymetric surveys conducted between 1867 and 1887, the time period of most active hydraulic mining, reveal that about 60 million cubic meters of mercury contaminated sediment was deposited in Suisun Bay alone (Cappiella *et al*., 2001). Results from the latest bathymetric survey suggest that about 60 percent of the surface area of Suisun Bay was eroding between 1942 and 1990 with an average loss of one million cubic meters of sediment per year[10, 11]. This is equivalent to an erosion rate of 528.6 thousand metric tons of sediment per year[12] or about 60 percent of the annual erosion rate from the Central Valley (Table 2). Unfortunately, no information exists on present erosion in Suisun Bay.

A turbidity maximum is often located in the shipping channel off Suisun Bay if salinity is greater than half a part per thousand (Arthur and Ball, 1978; Schoellhamer, 2001). Much of the water in Suisun Bay is less than 2-m deep. Data collected by the U.S. Geological Survey suggest that the turbidity maximum is primarily produced by wind induced waves which resuspend shallow water sediment allowing tidal currents to carry the material to deeper channels where it can be transported away (Schoellhamer, 1996; Schoellhamer and Bureau, 1998). X2 was located in the shipping channel off Suisun Bay during much of this study and water samples collected here must contain material eroding from the Bay. Erosion from Suisun Bay likely accounts for this studies finding of a net loss of sediment from the Delta (Table 2). Continuous U.S. Geological Survey optical back scatter measurements at Martinez and at Mallard Island (Figure 1) consistently demonstrate higher concentrations of suspended matter at the downstream site suggesting that most of the eroding material is being transported to San Francisco Bay (Schoellhamer, 1996). However, gravitational circulation may move some mercury-contaminated sediment, like it does salinity, landward of X2 into the freshwater side of the estuary.

Total Mercury Budget

A primary objective of this study was to develop a mercury budget for the estuary. A positive correlation exists between total and methyl mercury concentration in surficial sediment in the estuary (Weim *et al*., 2002). This suggests that bulk mercury concentration in sediment may be one factor influencing microbial production of methyl mercury and concentrations in aquatic organisms.

The Sacramento River was the principal source of raw and filtered total mercury in the study (Table 3 and 4). The River is calculated to have transported 162-kg of total mercury or 58 percent of all imports. Most of the material entered the Estuary in winter

[9] Months of March, April, May and July 2000 and February and March 2001 (Table 1 and 2).
[10] The levee for lower Sherman Island broke during this time and Sherman Lake is also eroding.
[11] -1.2 cm/yr
[12] A cubic meter of sediment weighs 528.6-kg (personal communication, Schoellhamer).

storm runoff (January through March). About 15 percent of the entire load (24-kg) were in a filter passing form. Prospect Slough, which receives storm runoff from mercury mines in Putah and Cache Creeks as well as flow from the upper Sacramento Basin, transported the largest amount of mercury of any of the river systems in single month (70-kg in March 2000). This emphasizes the potential importance of contributions from Prospect Slough in wet years.

A positive correlation was observed on the Sacramento River at Greene Landing between raw total mercury concentration and flow (Figure 3, $P<0.002$). A similar relationship was also observed in 1993-94 at low flow (Foe and Croyle, 1998). However, no correlation existed at high flow in the winter of 1994-95. It was hypothesized that the change in the relationship resulted from a change in the origin of the water mass. At low flow water primarily originates from Shasta and Oroville Dams in the upper Sacramento and Feather River basins. In contrast, in winter the source of the water at Greene Landing is mostly storm runoff from the lower American River. Storm water from the upper Sacramento and Feather Rivers is routed down the Yolo Bypass.

A positive correlation was observed between raw total mercury concentration and TSS at both Greene Landing and at X2 (Figure 4). The slope of the relationship at Greene Landing (0.14 ng-gm^{-1}) was half that of X2 (0.32 ng-gm^{-1}). The two slopes are statistically different ($P<0.001$, t-test). Slope in Figure 4 is a measure of mercury enrichment on particles collected at the site. The enrichment factor for Greene Landing is similar to values previously measured for the upper Sacramento Valley during low flow conditions but somewhat less than the 0.2-ppm that occurs during high flow (Foe 1995). The enrichment factor for X2 is similar to TSS concentrations reported 20 miles downstream in San Pablo and North Bay (0.33-ppm), subembayments of San Francisco Bay (Schoellhamer, 1996). A pattern of increasing bulk surficial mercury sediment concentrations has also been reported as one travels westward in the Delta to San Francisco Bay. Slotton *et al* (2002) and Weim *et al* (2002) report that sediment mercury concentrations in the Sacramento River and in the Delta range between 0.15 and 0.20-ppm while concentrations in Suisun Bay are 0.30 to 0.35-ppm. Hornberger *et al* (1999) report that the mercury concentration of sieved surficial sediment (<0.64-µm) in a core from Grizzly Bay, a subembayment of Suisun Bay, was 0.3-ppm but increased to 0.95-ppm at a depth of 30-cm. The mercury enriched zone persisted to about 80 cm before declining to a background concentration of 0.05 to 0.08-ppm. The increased mercury concentration at 30-cm was ascribed to deposition of mercury contaminated gold tailings.

A pattern of increasing particle mercury enrichment with increasing salinity is not commonly reported for estuaries. Particulate mercury concentrations decreased with increasing salinity in the Gironde and Scheldt Estuaries (Cossa and Noel 1987; Leermakers *et al*. 1995). The decrease is ascribed to degradation and solubilization of particulate organic matter for which mercury has a high affinity.

A possible explanation for both the increase in mercury concentrations on suspended particles at X2 and the increase in bulk sediment concentrations westward in the estuary is erosion of mercury-enriched particles from shallow water in Suisun Bay and

subsequent transport into the shipping channel by tidal currents. If sediment erosion rates in Suisun Bay are still a million cubic meters per year, then this is equivalent to the release of about 185-kg of mercury per year or 278-kg for the year and a half study[13]. Most of this material is probably moved seaward with net freshwater outflow. The net loss of mercury from the estuary reported in Table 3 may, at least in part, result from erosion of mercury contaminated sediment from Suisun Bay. The data also suggest that suspended and surficial sediment mercury concentrations in San Francisco Bay (0.33-ppm) are the result of present and historical erosion from Suisun Bay (0.35-ppm). Mercury contaminated sediment from the Central Valley (0.15-0.20 ppm) dilutes concentrations in Suisun and San Francisco Bays.

Three transects across the freshwater side of the estuary and up the lower Sacramento River were conducted in 2001 to ascertain whether gravitational circulation might also transport mercury enriched particles landward of Suisun Bay (Table 5). The location of X2 was upstream of Suisun Bay during each of the 3 cruises and mercury enriched particles, similar to concentrations measured off Suisun Bay, were consistently observed at or above the confluence of the Sacramento and San Joaquin Rivers. Brannon Island[14] was the most upstream site sampled with concentrations similar to Suisun Bay. Mercury enriched particles can be transported from the confluence of the Sacramento and San Joaquin Rivers, like salinity, toward the State and Federal pumps and deposit along the way in the Central Delta (Figure 2). Therefore, Suisun Bay is likely a major source of mercury for both the Delta and for San Francisco Bay.

In conclusion, two major sources of raw total mercury were measured in the Bay-Delta Estuary. The first was the Sacramento River and accounted for about 161-kg during the study period (Table 3). Most of this mercury was transported during winter storms. The second was erosion of mercury contaminated sediment from Suisun Bay. Work by Schoellhamer (1996) and Schoellhamer and Bureau (1998) suggest that most of this material is likely transported in summer. The precise amount of material being eroded during the study period from Suisun Bay is not known but may be similar (278-kg) to exports from the Central Valley (Table 3). Mercury from Suisun Bay is transported both up and down estuary.

Monomethyl Mercury Budget

A major objective of the CALFED grant was to develop a monomethyl mercury budget for the Delta. Methyl mercury tissue concentration in several important game and forage fish were correlated with clam tissue concentrations in the estuary and methyl mercury uptake in clams was positively related to aqueous methyl mercury divided by the square of the chlorophyll concentration (Foe *et al*., 2002). The biotic findings emphasize the importance of understanding the source and fate of aqueous methyl mercury. The primary source of methyl mercury in the Delta is hypothesized to be from river inputs and from *in situ* sediment production. The main goal of this study (Task 1A) was to measure river loads while Dr Gill of Texas A & M was to estimate sediment flux (Task

[13] (10^6 meters^3/yr)(528.6 kg/meters^3)(0.35 ppm)
[14] About 15 miles above Suisun Bay

4B). The two sets of results were to be combined to develop a “first cut” methyl mercury mass balance estimate for the Delta.

The Sacramento River was the major riverine source of methyl mercury to the estuary (Table 6). The only exception was in March 2000 when the Yolo Bypass was flooded and Prospect Slough became the major source of organic mercury. In all other months the Sacramento River accounted for 60-85 percent of the total load. The load of raw methyl mercury was highest in winter and spring (January to May). This was because both flow and raw methyl mercury concentrations (0.08-0.34 ng/l) were largest then (Table 3 and Appendix C). Aqueous raw methyl mercury concentrations averaged half this during the rest of the year (about 0.08 ng/l). The dissolved methyl mercury fraction in the Sacramento River at Greene Landing was above detection (0.022 ng/l) in 11 of 17 measurements and averaged about 45 percent of the unfiltered value.

Monthly raw methyl mercury loads for the San Joaquin, Mokelumne-Consumnes and Prospect Slough are presented in Table 6. Loads from each appear higher in winter and in early spring. However, this was the result of increased flow not higher aqueous concentrations (Appendix C). There was no apparent seasonal methyl mercury concentration pattern in any waterway except the Sacramento River. Finally, average methyl mercury concentrations in Prospect Slough (0.26 ng/l) were higher than in the Sacramento River (0.12 ng/l, $P<0.01$, Kruskall-Wallis) but similar to values in the San Joaquin (0.16 ng/l) and Mokelumne-Consumne (0.17 ng/l).

Raw methyl mercury was positively correlated with TSS at both the Sacramento River at Greene Landing and at X2 (Figure 5). The relationship was stronger at X2 ($P<0.005$) than at Greene Landing ($P<0.03$) but whether this is an artifact of the small sample size ($N=18$ for both correlations) is not known.

Methyl mercury export rates are difficult to accurately quantify as thirty percent (16/54) of the concentration measurements at export sites were below detection (Table 6). Twelve of these occurred in the first summer (June-October). As a result, the detection limit was halved in the second year and only three values were below detection. These occurred in August and September when concentrations on the Sacramento River are low. The major export was to San Francisco Bay (X2). On average 86 percent of the methyl mercury leaving the system was transported past X2.

No dissolved methyl mercury mass balance budget was attempted as one third of all measurements (44/123) were below detection. Also, the relative percent difference of duplicate laboratory and field samples was 26-37 percent (Table 2 and 3 of Appendix B) making accurate estimates of dissolved methyl mercury loads problematical. However, dissolved data was collected with each sample and the information is included in Appendix C.

Water samples collected from Delta Island main drains suggest that the islands are net exporters of raw methyl mercury. There are about three-quarters of a million acres of

Delta Islands under agricultural production. Water is diverted onto the islands for irrigation (Figure 6a) and the unused portion returned to Delta waterways via a series of main drains (Figure 6b). Many of the islands are predominately peat, a substance that Gill *et al*. (2002) and Weim *et al*. (2002) have shown to be a good substrate for methyl mercury production. Methyl mercury samples were collected from five main drains in June and July 2000 to ascertain whether the islands were a net source or sink for mercury. Mercury concentrations were variable but quite high when compared to concentrations in the channels surrounding the islands and from which irrigation water is diverted and unused water returned (Appendix C). Concentrations averaged 0.35 ng/l in June and July. This translates to a net production rate of 17 to 35-gm per month or 10-25 percent of river load in the two-month period. Island loads, while substantial, were beyond the ability of this project to characterize further. The concentrations are sufficiently high though, to warrant evaluation of tissue concentrations in piscivorous wildlife predominately feeding in Delta Island drains.

A major finding of the CALFED grant was that the Delta is a net sink for raw methyl mercury. The load of methyl mercury entering the Delta is the sum of the loads from the Rivers and from *in situ* sediment production. Losses from the system are the sum of the exports to the State and Federal Pumps and to San Francisco (X2). The difference between the sum of known inputs and exports is a measure of the uncertainty of the measurements and of the importance of other unknown processes in the Delta. The estimate of river loads are likely quite accurate. The measurements were all above detection, except for two occasions on the Mokelumne River, a minor input to the Delta. Also, river concentrations appear similar over time and differences in replicate measurements at the same place and time were low[15] (Table 2, Appendix B). The average river loading for the study period was about 10 gm-day^{-1} (Table 6, Figure 7). In contrast, while it is clear that exports were less than imports[16], a precise estimate of the export rate is more difficult as methyl mercury concentrations in 30 percent of the measurements were below detection. The average methyl mercury export rate from the Delta was estimated at about 6 gm-day^{-1} (Table 6, Figure 7). *In situ* methyl mercury production from the sediment was variable and likely higher in summer than winter (Gill *et al*., 2002). Average sediment flux for the Delta and Suisun Bay was estimated at about 6 gm-day^{-1} (Figure 7). The difference between the sum of all inputs (16 gm-day^{-1}) and exports (6 gm-day^{-1}) is 10 gm-day^{-1}. This residual is our present best estimate of the rate of methyl mercury loss in the Delta. The process(es) contributing to the loss are not known but are a focus of a new CALFED grant (Gill *et al*. (2001).

A special study was conducted in the summer of 2001 to ascertain the location where the decrease in methyl mercury concentration occurred. Three transects were run down the Sacramento River and out toward Suisun Bay, the water path from the main source to the main sink of methyl mercury. The largest drop in concentration occurred on all three cruises in the vicinity or immediately downstream of Rio Vista (Table 5). The drop in concentration was between 30 and 60 percent. There are several possible explanations. First, electrical conductivity also began to increase in the vicinity of Rio Vista and the

[15] Average relative percent difference was 9 percent (N=24, Table 2, Appendix b)
[16] Calculated exports were less than imports on seventeen of eighteen occasions (Table 6)

decrease in methyl mercury may be related to the increase in salinity. Second, the Sacramento River joins the Deep water Ship Channel a mile upstream of Rio Vista. At this point the River abruptly changes from being narrow and shallow (<10 ft) to wide and deep (35 ft). Increased channel cross-section results in an increase in water residence time and a decrease in travel time. As a result there need not be any new mercury removal process at work below Rio Vista but just more time per river mile for processes that may already be occurring above the City.

Atmospheric Deposition

Mercury loads from direct wet deposition on surface water of the Delta and from indirect deposition and runoff to the Delta from the Central Valley was estimated. The purpose of the calculation was to provide a provisional evaluation of the importance of each in the mercury budget of the Estuary.

Mercury loading from rain falling on surface water in the Delta was not significant. Direct deposition was estimated for the 18-month study at about 618-gm or 0.2 percent[17] of the total Delta load. The value was calculated by multiplying precipitation totals by the surface area of the Delta and the mercury content of the rain. The most variable of the three values is the rainfall total and the surface area of the estuary. This study was mostly conducted during a dry period. Precipitation in wet years may be up to 50 percent greater and this often occurs when the Sacramento River is at flood stage and the Yolo Bypass is flooded. The Bypass increases the size of the Delta by a factor of three. Therefore, direct loading in wet years may increase by a factor of 4.5 and result in an atmospheric contribution of about 2.8-kg of mercury.

Mercury load estimates from indirect deposition and runoff from the Central Valley are more uncertain but appear important in the overall budget of the Delta. The annual contribution from indirect wet loads range from a low of 25-kg to a high of 74-kg or 23 to 69 percent of the total mercury budget for water year 2001[18] (Table 7). The major uncertainty in the calculation of indirect loads is the concentration of mercury in rainfall and the appropriate runoff coefficient to use. Mercury concentrations in rain in San Francisco Bay were used. However, concentrations in rain at Covelo California, a national mercury deposition measurement site about 150 miles north of San Francisco Bay in the Coast Range, are half those of the Bay area. Also, inputs from dry deposition were not included in the present estimate. Tsai (2001) estimated that about 4.5 times more mercury was being deposited on an annual basis in dry than in wet deposition in San Francisco Bay. CALFED has awarded a grant to Texas A & M to measure wet and dry mercury deposition in the Central Valley. The study should commence in 2003.

The second major uncertainty factor in estimating the transfer of atmospheric loads from the Central Valley to the Delta is in determining an appropriate runoff coefficient. Runoff coefficients are a function of meteorology, land use characteristics, slope, size

[17] 0.618/278.5 kg mercury or 0.2 percent.
[18] Low estimate was calculated as 24.5/107.9 or 23 percent while high estimate was 74/107.9 or 69 percent of the total Delta budget.

and soil characteristics of the watershed (Tsiros, 1999). Dolan *et al* (1993) estimated that roughly 10 percent of the mercury falling in the Lake Superior watershed entered the lake. Quemerais *et al* (1993) determined that about 12 percent of the atmospheric mercury deposited in the St. Lawrence River watershed ran off. Mason *et al* (1994) estimated that about 30 percent of atmospheric deposition was reaching Swedish and mid continental American lakes in overland flow. Tsai (2001) used a runoff coefficient of 32 percent for San Francisco Bay. This study employed a range of runoff coefficients from 10 to 30 percent.

Variations in annual precipitation did not strongly affect the estimate of mercury loads from the Central Valley. Precipitation totals for a wet and dry year are included in Table 7 and 8. Little difference in rainfall was noted between the two water year types suggesting that this is unlikely to be a major source of variation in the mercury loads estimates.

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Table 1. Water mass balance (thousand acre-feet) for the Bay-Delta Estuary between March 2000 and Sept 2001. The budget does not include within Delta precipitation. Negative import-export values indicate that the estuary is exporting more water than is entering it.

IMPORTS						EXPORTS					
Date	Sac River	San Joaquin River	Mokelume Consumnes Rivers	Prospect Sl	Total Imports	**DMC**	**SWP**	**X2**	Delta Is	**Total Exports**	***Imports-Exports***
Mar-00	3,594	758	178	2,057	6,589	207	340	6,358		6,907	-317
Apr-00	1,583	323	68	28	2,004	131	181	1,686		1,998	6
May-00	1,254	299	74	7	1,635	77	105	1,439	125	1,747	-111
Jun-00	975	175	51	3	1,205	180	260	588	180	1,210	-5
Jul-00	1,285	120	40	3	1,449	265	359	604	233	1,461	-12
Aug-00	1,080	129	25	2	1,238	269	385	397	144	1,197	41
Sep-00	900	137	23	3	1,065	252	386	294	88	1,021	43
Oct-00	732	172	16	6	928	257	306	356	56	976	-48
Dec-00	856	135	23	3	1,019	238	291	428	39	997	21
Jan-01	1,072	150	26	18	1,269	168	240	968		1,377	-107
Feb-01	1,175	176	37	72	1,462	195	260	1,031		1,486	-24
Mar-01	1,532	218	45	147	1,944	115	360	1,426		1,902	42
Apr-01	743	182	39	5	970	129	98	735		963	**7**
May-01	574	223	28	3	829	52	33	612	125	824	5
Jun-01	742	96	6	2	847	178	8	484	180	852	-4
Jul-01	923	86	5	3	1,017	253	216	310	233	1,013	4
Aug-01	820	82	4	4	910	253	248	215	144	860	4
Sep-01	746	81	4	1	834	242	212	275	88	818	16
TOTAL	**20,595**	**3,552**	**701**	**2,373**	**27,222**	**3,469**	**4,295**	**18,212**	**1,639**	**27,617**	**-394**

Table 2. Sediment mass balance (thousand metric tons) for the Bay-Delta Estuary between March 2000 and September 2001. Negative import-export values indicate that the estuary is exporting more sediment than is being delivered to it.

	IMPORTS					EXPORTS				
Date	Sacramento River	San Joaquin River	Mokelume-Consumnes River	Prospect Slough	Total Imports	**DMC**	**SWP**	**X2**	**Total Exports**	***Imports-Exports***
Mar-00	182.0	45.0	4.0	241.1	472.0	4.1	2.3	855.9	862.3	-390.2
Apr-00	74.3	22.4	1.3	2.8	100.7	1.5	4.9	349.8	356.2	-255.5
May-00	24.8	28.9	1.1	1.0	55.7	3.4	2.6	255.9	262.0	-206.3
Jun-00	18.1	16.9	0.5	0.6	36.1	2.9	1.5	43.6	48.1	-12.0
Jul-00	26.4	10.0	0.3	0.7	37.3	4.6	2.5	68.6	75.7	-38.4
Aug-00	26.7	13.6	0.5	0.3	41.1	9.3	5.7	13.3	28.3	12.8
Sep-00	18.9	7.8	0.2	0.3	27.3	9.7	2.9	13.1	25.6	1.7
Oct-00	15.4	10.4	0.6	0.3	26.8	8.3	4.2	12.3	24.8	2.0
Dec-00	19.0	3.4	0.2	0.2	22.8	4.1	4.0	16.9	25.0	-2.2
Jan-01	221.3	11.0	0.6	4.5	237.4	3.1	2.1	46.6	51.8	185.5
Feb-01	117.6	19.4	1.4	22.4	160.8	4.6	3.5	93.0	101.1	59.7
Mar-01	30.3	13.5	0.7	11.5	55.9	2.4	3.6	153.3	159.3	-103.4
Apr-01	27.5	8.6	0.5	0.4	37.0	1.9	0.5	39.1	41.5	-4.5
May-01	14.9	14.3	0.3	0.9	30.4	1.2	0.3	25.7	27.2	3.2
Jun-01	19.2	8.8	0.2	0.5	28.7	6.4	0.0	35.3	41.7	-13.0
Jul-01	14.8	5.9	0.1	0.9	21.8	6.9	15.8	10.3	33.0	-11.2
Aug-01	21.3	4.6	0.1	0.5	26.4	5.0	1.6	12.2	18.8	7.6
Sep-01	7.6	3.6	0.1	0.1	11.4	7.2	1.8	13.9	23.0	-11.6
TOTAL	**880.0**	**248.1**	**12.6**	**289.0**	**1429.6**	**86.6**	**59.8**	**2058.9**	**2205.3**	**-775.7**

Table 3. Raw total mercury mass balance (kg) for the Bay-Delta Estuary between March 2000 and September 2001. Negative import-export values indicate that the estuary is exporting more total mercury than is entering it.

	IMPORTS					EXPORTS				
Date	Sacramento River	San Joaquin River	Mokelume-Consumnes River	Prospect Slough	Total Imports	**DMC**	**SWP**	**X2**	**Total Exports**	***Imports-Exports***
Mar-00	39.20	8.03	1.49	70.50	119.2	1.07	1.16	279.54	281.8	-162.5
Apr-00	12.88	4.60	0.64	0.74	18.9	0.43	1.60	102.44	104.5	-85.6
May-00	5.20	2.75	0.48	0.19	8.6	0.57	0.49	87.45	88.5	-79.9
Jun-00	4.05	1.82	0.27	0.13	6.3	0.59	0.71	13.89	15.2	-8.9
Jul-00	4.86	1.07	0.17	0.14	6.2	0.89	0.85	19.32	21.1	-14.8
Aug-00	4.58	2.03	0.16	0.07	6.8	1.50	1.04	4.77	7.3	-0.5
Sep-00	3.38	1.06	0.08	0.07	4.6	1.33	0.82	3.62	5.8	-1.2
Oct-00	3.41	1.53	0.13	0.11	5.2	1.27	0.94	3.41	5.6	-0.4
Dec-00	3.17	0.52	0.08	0.06	3.8	0.72		4.78	5.5	-1.7
Jan-01	30.33	1.32	0.29	0.62	32.6	0.65	0.49	14.94	16.1	16.5
Feb-01	21.12	2.29	0.00	0.00	23.4	0.98	0.79	19.99	21.8	1.7
Mar-01	6.47	2.31	0.24	2.13	11.1	0.63	1.52	42.28	44.4	-33.3
Apr-01	4.15	1.60	0.29	0.13	6.2	0.33	0.27	10.06	10.7	-4.5
May-01	2.57	2.28	0.21	0.21	5.3	0.22	0.11	7.72	8.1	-2.8
Jun-01	4.09	1.19	0.06	0.13	5.5	0.77	0.00	6.58	7.3	-1.9
Jul-01	4.91	0.58	0.04	0.20	5.7	0.89	1.85	1.51	4.3	1.5
Aug-01	5.64	0.63	0.02	0.13	6.4	0.90	0.48	2.65	4.0	2.4
Sep-01	1.96	0.61	0.03	0.03	2.6	1.28	0.54	4.11	5.9	-3.3
TOTAL	**161.98**	**36.21**	**4.69**	**75.59**	**278.5**	**15.00**	**13.67**	**629.07**	**657.7**	**-379.3**

Table 4. Filterable total mercury mass balance (Kg) for the Bay-Delta Estuary between March 2000 and September 2001. Negative import-export values indicate that the estuary is exporting more dissolved mercury than is entering it.

	IMPORTS					EXPORTS				
Date	Sacramento River	San Joaquin River	Mokelume-Consumnes River	Prospect Slough	Total Imports	**DMC**	**SWP**	**X2**	**Total Exports**	***Imports-Exports***
Mar-00	4.88	1.24	0.26	3.45	9.83	0.42	0.75	12.09	13.26	-3.43
Apr-00	2.33	0.51	0.12	0.05	3.01	0.18	0.30	2.21	2.69	0.31
May-00	1.15	0.27	0.09	0.01	1.52	0.07	0.11	1.03	1.21	0.31
Jun-00	0.70	0.16	0.06	0.01	0.92	0.16	0.26	0.44	0.86	0.06
Jul-00	1.06	0.20	0.05	0.01	1.32	0.21	0.36	0.60	1.18	0.14
Aug-00	0.85	0.12	0.04	0.01	1.02	0.29	0.83	0.28	1.40	-0.38
Sep-00	0.67	0.13	0.02	0.00	0.82	0.00	0.28	0.22	0.50	0.32
Oct-00	1.16	0.65	0.03	0.01	1.85	0.23	0.28	0.24	0.76	1.09
Dec-00	0.40	0.10	0.02	0.00	0.52	0.12	0.19	0.21	0.52	0.00
Jan-01	3.38	0.17	0.08	0.03	3.66	0.15	0.20	0.62	0.97	2.68
Feb-01	3.72	0.21	0.25	0.31	4.49	0.22	0.24	1.06	1.52	2.97
Mar-01	1.42	0.21	0.06	0.14	1.83	0.26	0.73	3.22	4.21	-2.39
Apr-01	0.53	0.09	0.07	0.00	0.69	0.13	0.11	0.46	0.71	-0.02
May-01	0.35	0.14	0.05	0.01	0.55	0.07	0.04	0.23	0.34	0.21
Jun-01	0.14	0.03	0.01	0.00	0.18	0.02	0.00	0.26	0.28	-0.10
Jul-01	0.32	0.05	0.01	0.00	0.38	0.18	0.10	0.10	0.38	0.00
Aug-01	0.69	0.18	0.00	0.01	0.88	0.14	0.11	0.10	0.35	0.53
Sep-01	0.41	0.11	0.01	0.00	0.53	0.14	0.10	0.13	0.37	0.16
TOTAL	**24.16**	**4.553**	**1.23**	**4.053**	**33.99**	**3.00**	**5.01**	**23.50**	**31.52**	**2.47**

Table 5. Change in water quality seaward in the Sacramento River during the summer of 2001.

Station	Date	River Mile	Chlor (µg/l)	Phaeo (µg/l)	TSS (mg/l)	Sp. Cond (mS)	Raw THg (ng/l)	Filtered THg (ng/l)	Raw MMHg (ng/l)	Filtered MMHg (ng/l)	THg/TSS (ppm)	MMHg/Chlor^2 (ng/µg^2)
Freeport	29 May	120	5.06	5.28	14.0	177	2.39	0.50	0.09	0.04	0.17	0.09
Greene Landing	29 May		6.12	6.16	21.0	192	3.63	0.5	0.10	0.03	0.17	0.10
Walnut Grove	29 May		4.7	4.63	13.0	180	2.19	0.44	0.10	0.03	0.17	0.10
Rio Vista	29 May		4.47	4.5	26.0	245	5.87	0.68	0.06	0.02	0.23	0.06
Brannon Is (X1)	29 May		3.12	4.42	37.0		13.00	0.93	0.05	0.01	0.35	0.05
Grizzly Bay (X3)	29 May		2.49	2.87	34.0	5723	10.20	0.31	0.04	0.01	0.30	0.04
Grizzly Bay (X5)	29 May		1.39	2.21	24.0	8421	6.53	0.37	0.05	0.01	0.27	0.05
Freeport	26 June	120	2.79	1.86	14.0	151	2.55	0.41	0.07	0.04	0.18	0.07
Green Landing	26 June		2.99	2.79	21.0	145	4.46	0.15	0.09	0.01	0.21	0.09
Walnut Grove	26 June		3.18	2.69	22.0	155	4.71	0.38	0.08	0.03	0.21	0.08
Rio Vista	26 June		3.63	3.61	32.0	310	6.90	0.71	0.06	0.02	0.22	0.06
Brannon Is (X1)	26 June		3.04	4.12	47.0	1800	9.21	0.42	0.03	0.02	0.20	0.03
Sherman Is (X3)	26 June		1.83	3.74	34.0	5400	11.00	0.43	0.04	0.01	0.32	0.04
Freeport	31 July	120	2.93	2.50	19.0	136	1.21	0.21	0.06	0.03	0.06	0.06
Greens Landing	31 July		2.77	2.18	13.0	159	1.31	0.28	0.11	0.02	0.10	0.11
Walnut Grove	31 July		2.89	1.72	14.0	172	1.34	0.21	0.06	0.01	0.10	0.06
Rio Vista	31 July		4.67	3.02	30.0	179	4.69	0.28	0.06	0.03	0.16	0.06
Sherman Is (X1)	31 July		3.04	3.61	31.0		11.10	0.45	0.04	0.01	0.36	0.04
Pittsburg (X2)	31 July		2.14	2.38	11.0		3.95	0.26	0.04	0.01	0.36	0.01

Table 6. Raw methyl mercury mass balance (gm) for the Bay-Delta Estuary between March 2000 and September 2001. Positive import-export values indicate that the estuary is importing more methyl mercury than is leaving it. Values with an asterisk were calculated from a water concentration that was below detection. Half the detection limit was used in calculating loads. The detection limit was 0.022 and 0.011 ng/l in 2000 and 2001, respectively.

	IMPORTS					EXPORTS				
Date	Sacramento River	San Joaquin River	Mokelume-Consumnes River	Prospect Slough	Total	**DMC**	**SWP**	**X2**	**Total**	***Imports-Exports***
Mar-00	657.0	153.6	37.8	1280.3	2128.7	39.2	58.5	1601.8	1699.5	429.1
Apr-00	228.7	58.7	23.8	14.0	325.3	1.8*	10.5	170.5	182.8	142.5
May-00	520.4	49.6	23.1	2.9	596.0	16.4	18.7	428.4	463.4	132.6
Jun-00	86.2	47.7	7.2	1.0	142.1	16.5	3.5*	79.3	99.3	42.8
Jul-00	82.5	17.6	0.5*	0.8	101.4	3.6*	4.9*	8.2*	16.7	84.8
Aug-00	146.8	22.4	4.9	0.6	174.7	3.7*	5.2*	5.4*	14.3	160.4
Sep-00	57.2	16.8	0.3*	0.4	74.7	3.4*	27.7	8.5	39.6	35.1
Oct-00	77.0	33.6	2.7	1.1	114.5	3.5*	4.2*	4.8*	12.5	102.0
Dec-00	94.2	17.1	2.8	1.1	115.2	18.5	18.0	31.5	68.0	47.2
Jan-01	323.3	44.5	8.2	9.6	385.6	29.9	33.6	113.0	176.5	209.1
Feb-01	256.2	39.3	15.0	36.9	347.4	2.7	24.7	84.9	112.2	235.2
Mar-01	159.1	48.1	10.5	59.2	276.7	13.2	24.5	290.7	328.4	-51.6
Apr-01	103.8	21.1	9.8	0.9	135.5	3.8	7.1	6.4*	17.3	118.2
May-01	69.9	33.6	6.2	1.1	110.8	3.6	2.1	30.9	36.6	74.1
Jun-01	80.5	30.5	1.7	0.7	113.3	13.4	0.0	22.1	35.5	77.9
Jul-01	123.1	15.6	1.0	1.2	141.0	20.2	5.7	26.9	52.8	88.2
Aug-01	72.1	19.7	0.3	0.6	92.8	9.9	2.1*	14.4	26.4	66.3
Sep-01	87.9	16.5	1.0	0.2	105.6	2.1*	8.4	2.4*	12.9	92.7
TOTAL	**3226.0**	**686.0**	**156.7**	**1412.6**	**5481.3**	**205.3**	**259.5**	**2929.9**	**3394.7**	**2086.6**

Table 7. Low and high estimate of mercury runoff (kg/yr) from wet deposition in the Central Valley during a wet (1999) and dry (2001) water year.

WET WATER YEAR			DRY WATER YEAR		
RAINFALL DEPOSIT[1/]	LOW RUNOFF ESTIMATE[2/]	HIGH RUNOFF ESTIMATE[2/]	RAINFALL DEPOSIT[1/]	LOW RUNOFF ESTIMATE[2/]	HIGH RUNOFF ESTIMATE[2/]
(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)	(kg/yr)
261	26	78	245	25	74

[1/] From table 8.
[2/] Low and high runoff coefficient were 10 and 30 %, respectively.

Table 8. Estimate of mercury deposition (kg/year) in the Central Valley watershed below all major reservoirs during a wet (1999) and dry (2001) water-year. Average mercury concentration in precipitation is assumed to be similar to San Franscisco Bay (8.0 ng/l, Tsai, 2001). Precipitation is from Department of Water Resources California Cooperative Snow Surveys.

		WET YEAR		DRY YEAR	
Location	AREA	PRECIPITATION	MERCURY DEPOSITON	PRECIPITATION	MERCURY DEPOSITON
	(km^2)	(cm)	(kg/yr)	(cm)	(kg/yr)
Shasta Dam (SHO)	9,638	142.8	110.1	110.9	85.5
Stony Gorge(STG)	3,885	39.5	12.3	47.8	14.9
Englebright (ENG)	1,251	81.2	8.1	59.6	6.0
McClure (EXC)	2,547	42.2	8.6	42.8	8.7
Los Banos LSB)	10,581	17.9	15.1	22.6	19.1
Stockton (STK)	8,657	38.3	26.5	35.4	24.5
Folsom (FLD)	4,553	51.4	18.7	43.0	15.7
Capay (CPY)	2,135	44.5	7.6	58.3	10.0
Orland (ORL)	8,836	42.7	30.2	46.2	32.6
Sacramento (SCR)	7,914	38.0	24.1	44.4	28.1
Total	59,997		261.4		245.0

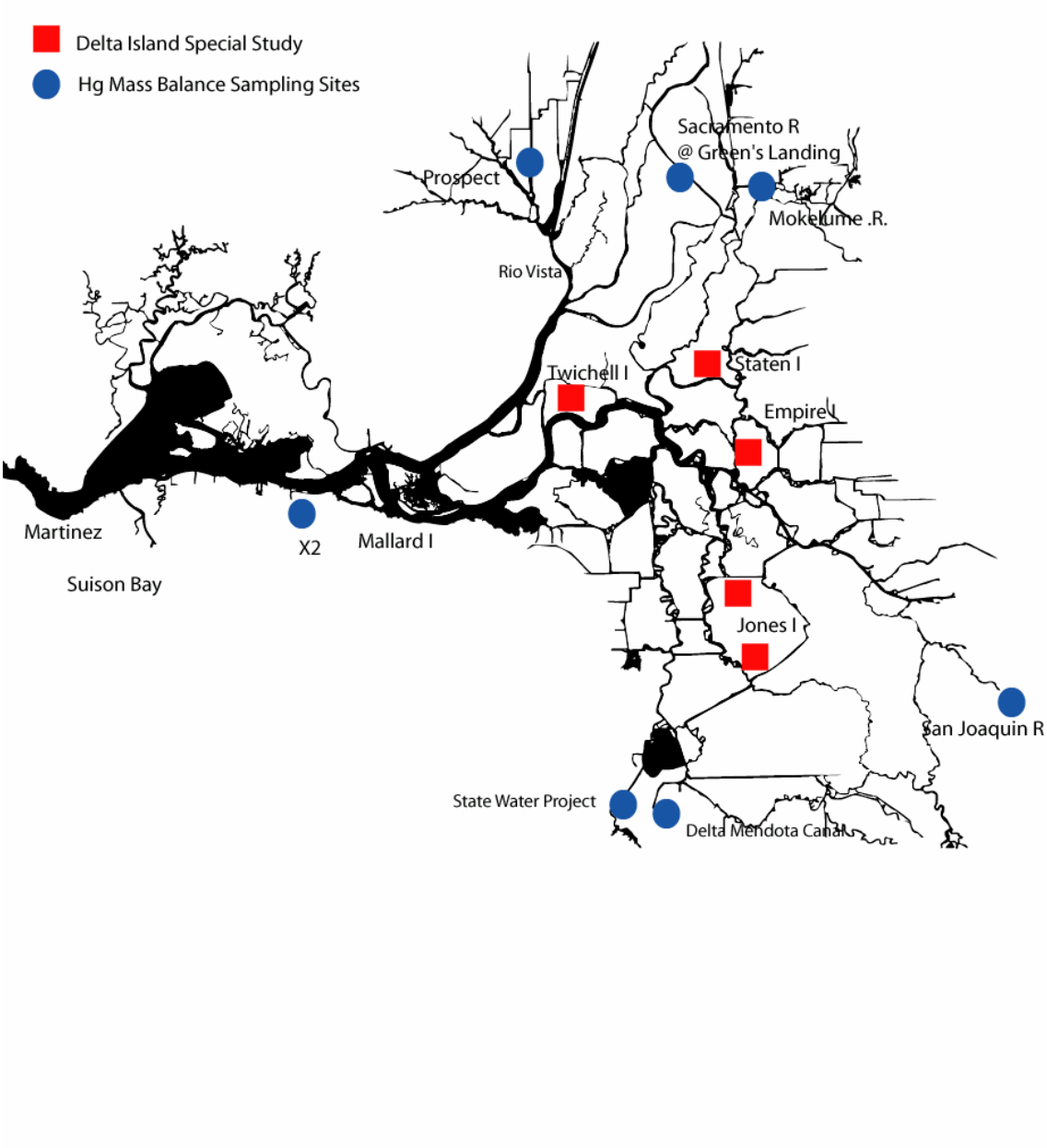


Figure 1. Map of mass balance study sites in the Sacramento-San Joaquin Bay-Delta Estuary.

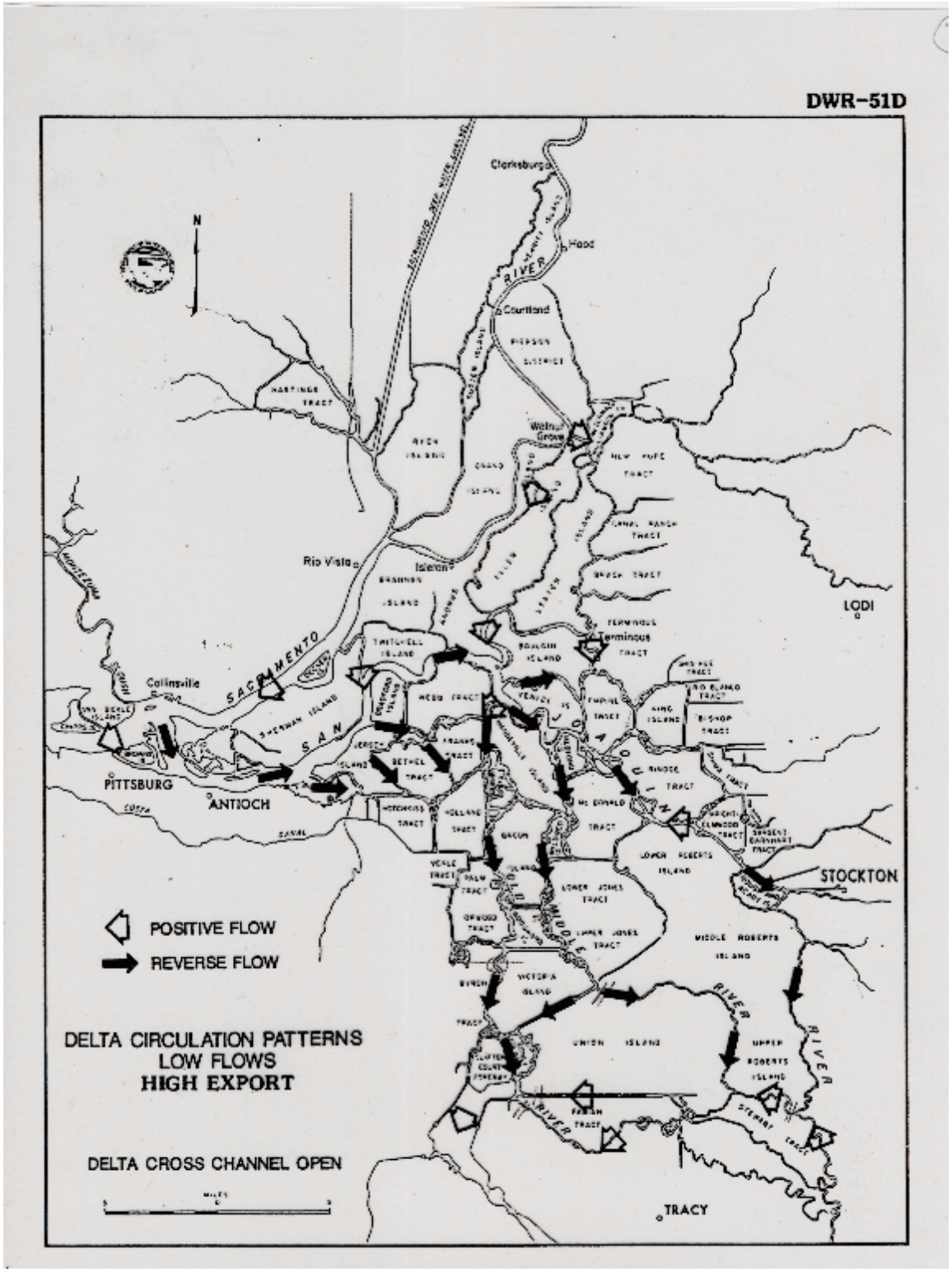


Figure 2. Typical water circulation patterns in the Delta during study. Arrows indicate net water movement. (From Department of Water Resources exhibit 51D to State Water Resources Control Board hearings on Bay-Delta Estuary, 1991).

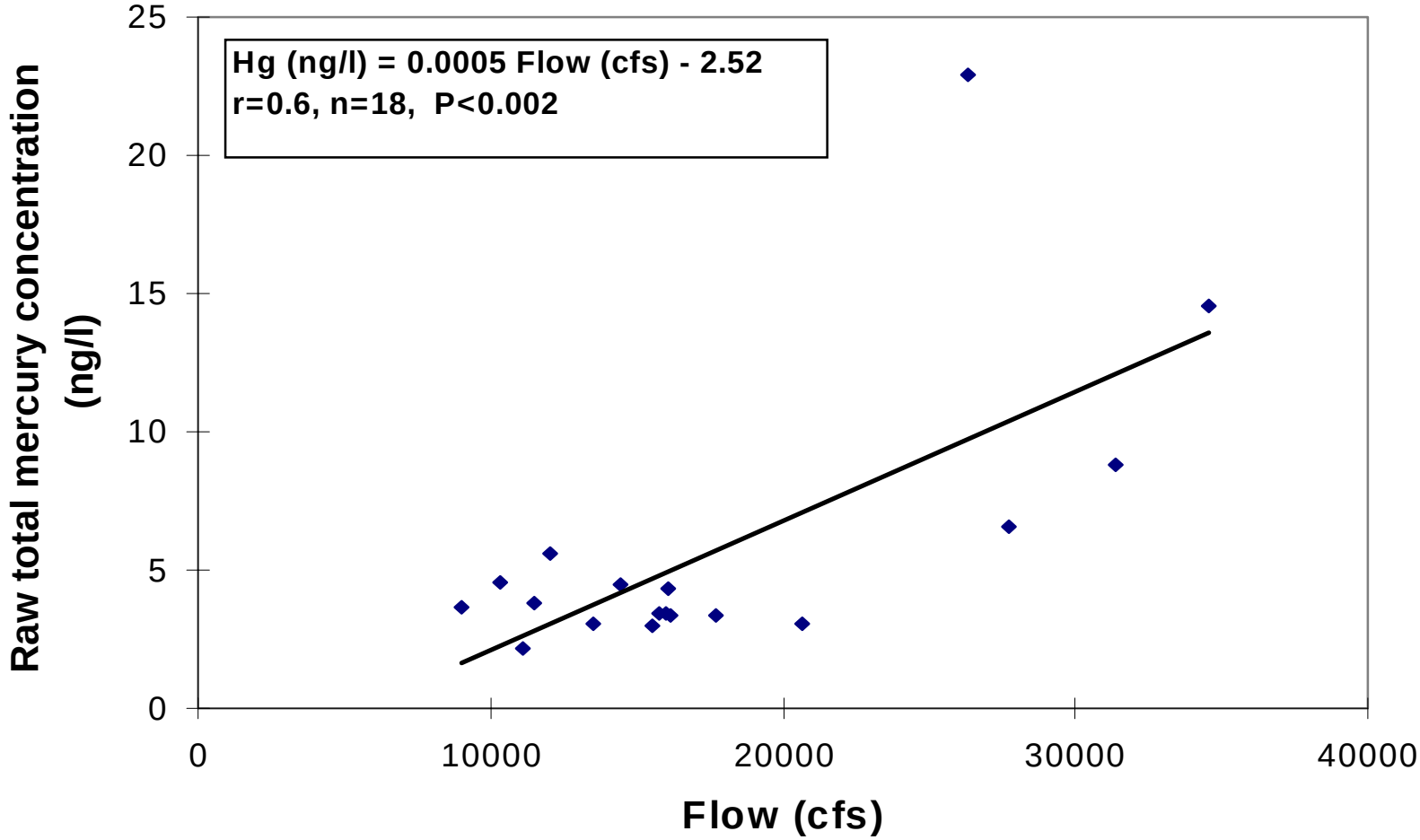


Figure 3. Correlation between raw total mercury concentration at Greene Landing on the Sacramento River and flow at Freeport in 2000 and 2001.

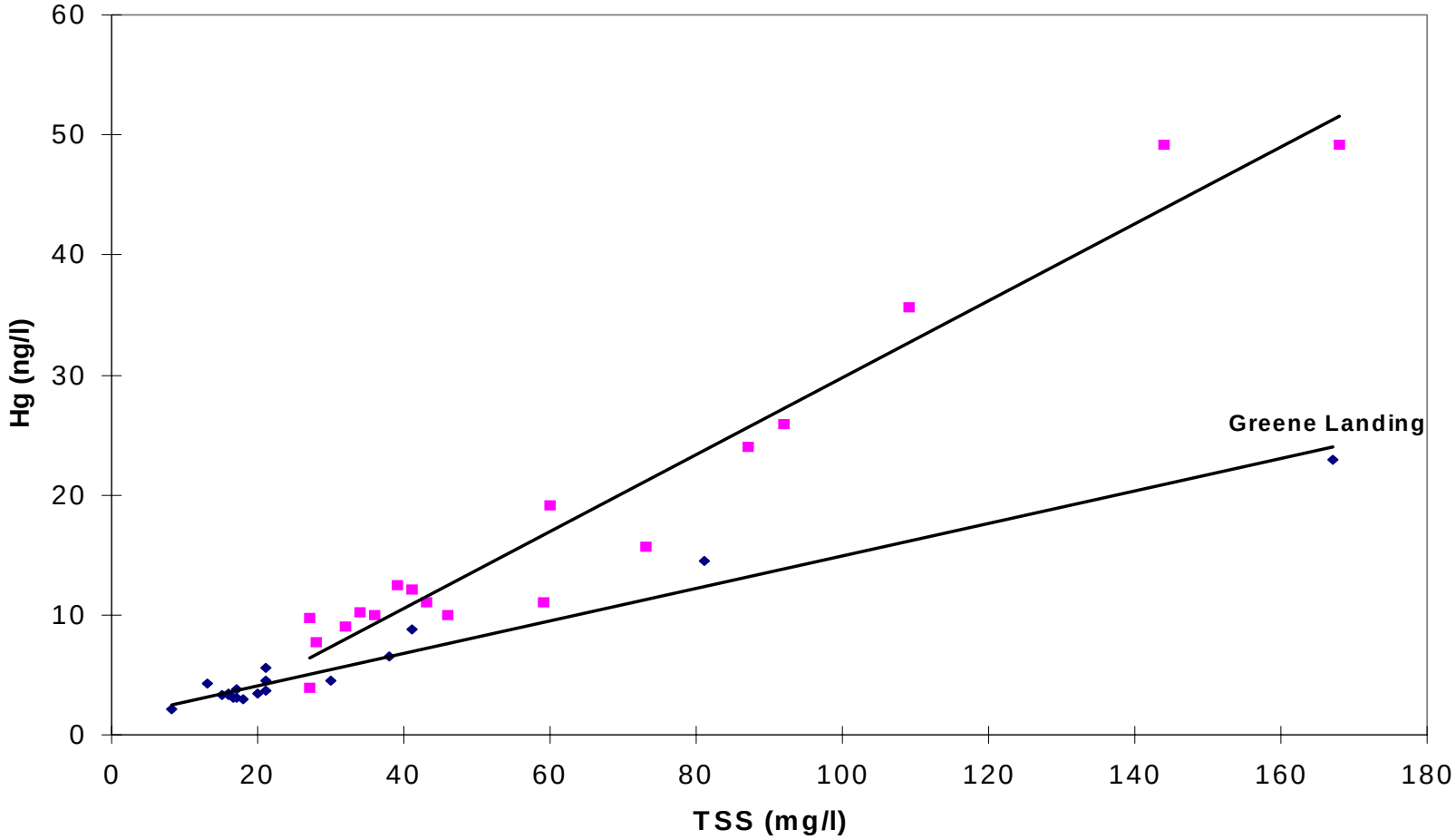


Figure 4. Correlation between raw total mercury (ng/l) and TSS (mg/l) for the Sacramento River at Greene Landing and for X2. Diamonds are Greene Landing while squares are X2.

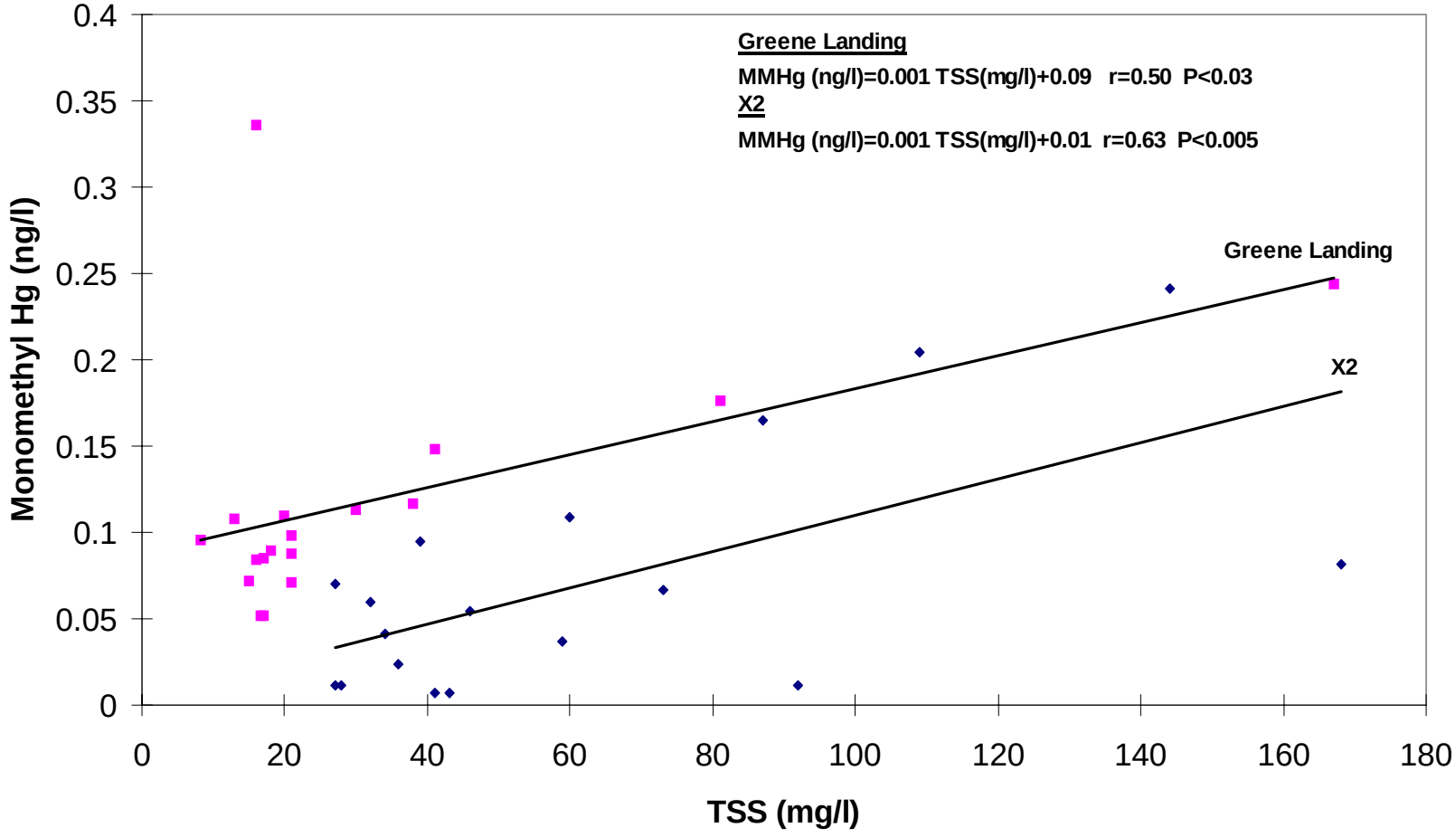


Figure 5. Correlation of raw methyl mercury (ng/L) and TSS (mg/L) for the Sacramento River at Greene Landing and for X2. Squares are Greene Landing while diamonds are X2.

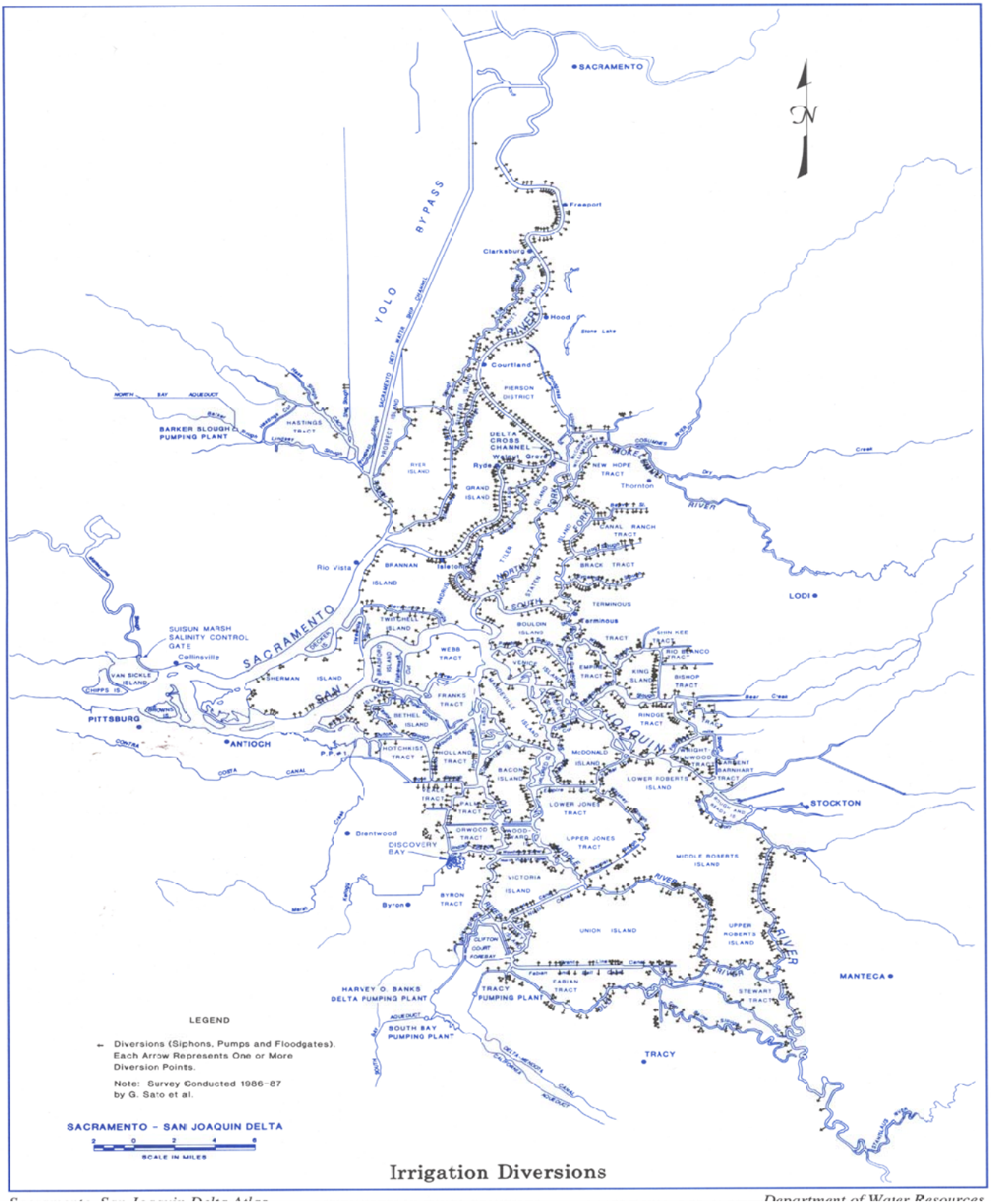


Figure 6a. Map of Delta Island irrigation diversion points. (From Department of Water Resources Sacramento-San Joaquin Delta Water Atlas.)

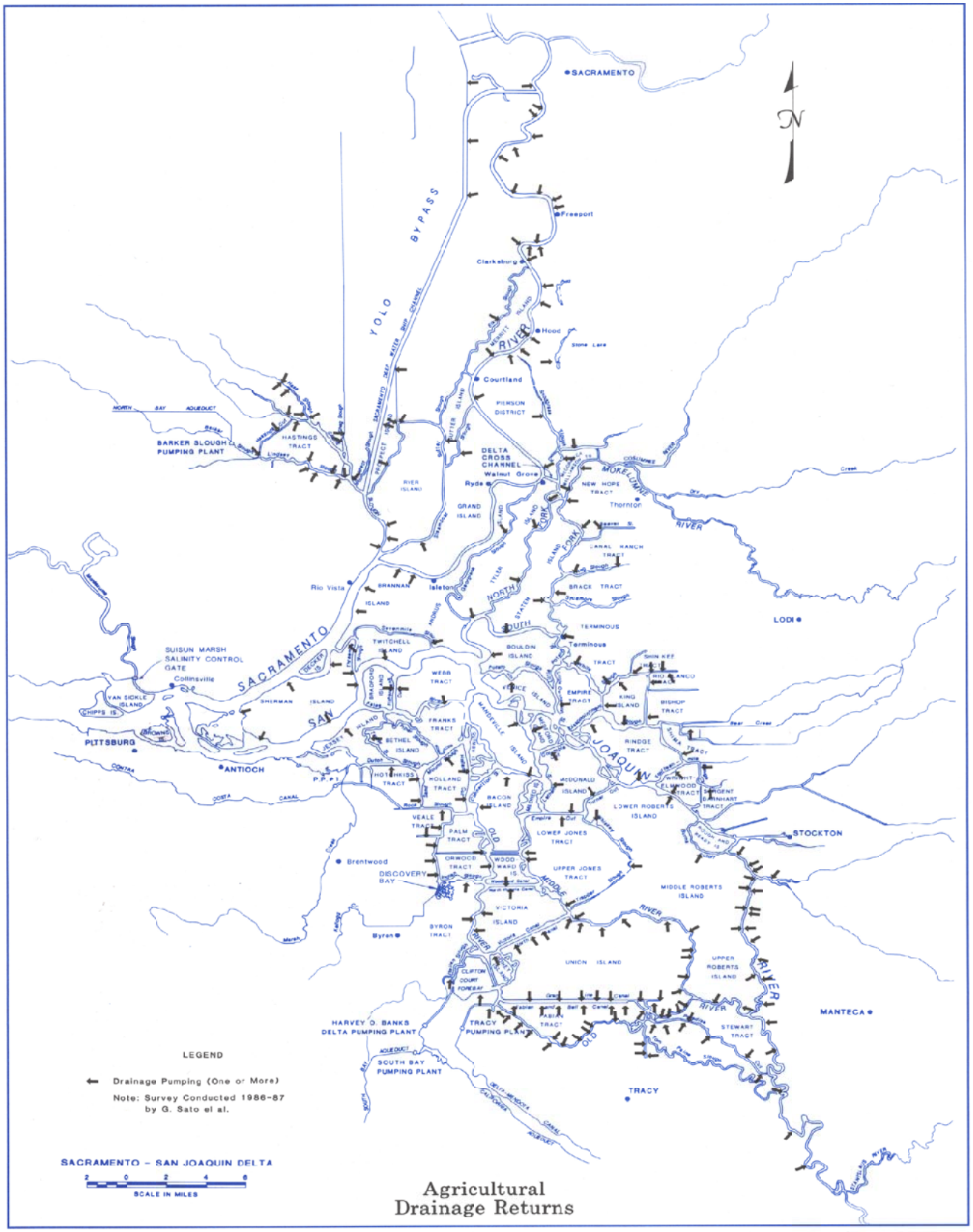


Figure 6b. Map of Delta Island irrigation return points. (From Department of Water Resources Sacramento-San Joaquin Delta Water Atlas).

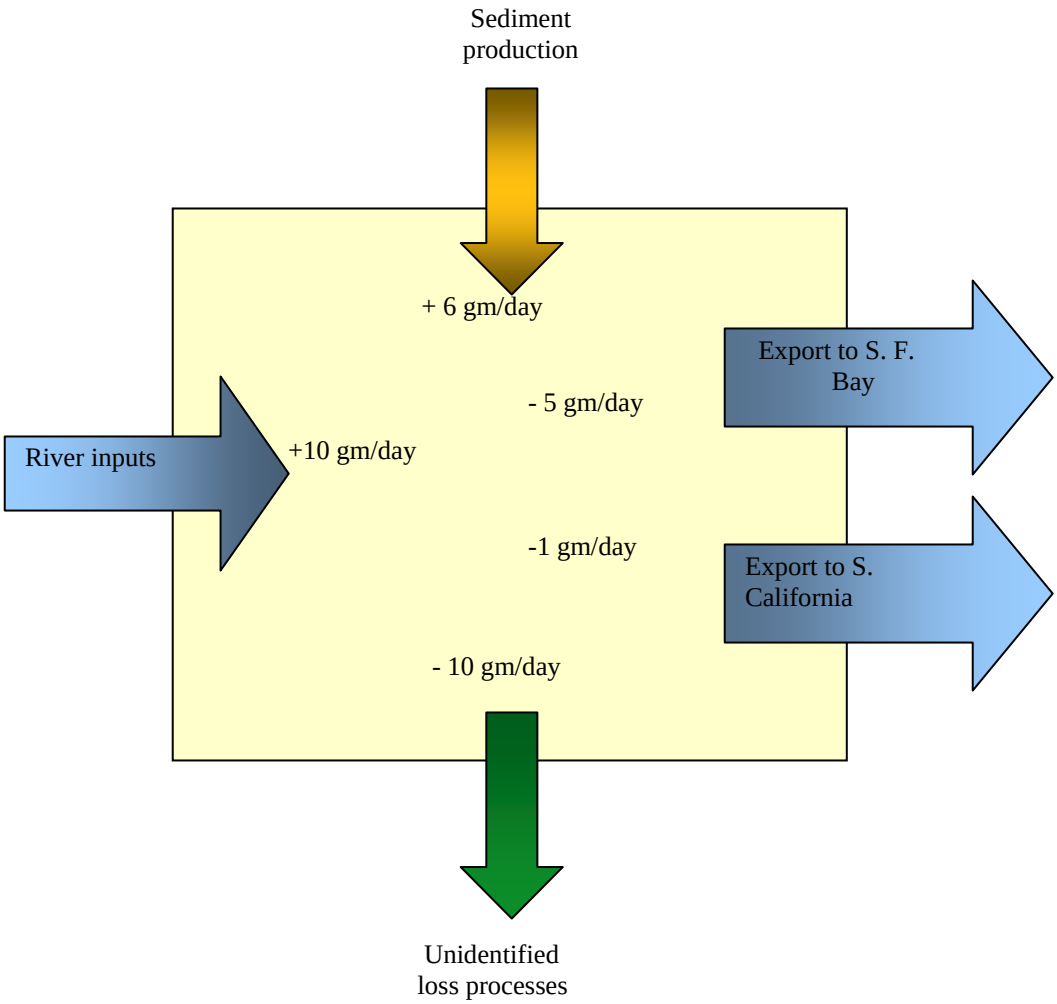
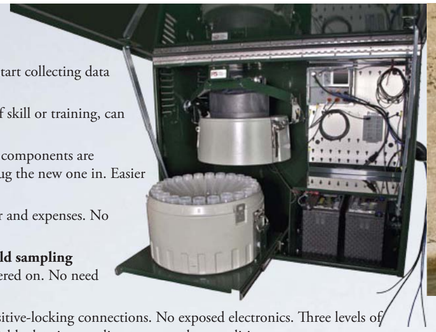
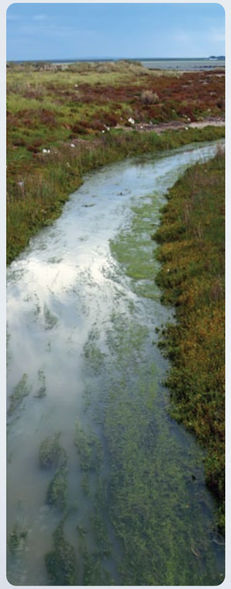


Figure 7. Cartoon of methyl mercury flux rates in the Bay-Delta Estuary. River input and export rates to the San Francisco Bay are from this report while sediment production is from Gill *et, al*., 2002. The rate of unidentified loss processes was determined by subtracting the measured river and sediment input from export to San Francisco Bay.

Key Benefits of SedEvent



- **Simplicity. A complete, turn-key system.** Install it and start collecting data immediately.
- **No programming required.** Any technician, regardless of skill or training, can be successful operating and maintaining the system.
- **No complex wiring.** Color-coded, keyed connectors. All components are interchangeable and field swappable—just disconnect, plug the new one in. Easier maintenance, greater reliability.
- **Minimal maintenance.** Reduced site visits, reduced labor and expenses. No guessing of when to carry out site visits.
- **Built-in, customizable, event-driven, turbidity threshold sampling algorithm** is ready to go as soon as the datalogger is powered on. No need to program, no need to hire expensive consultants.
- **Extreme ruggedness.** Watertight, corrosion-resistant, positive-locking connections. No exposed electronics. Three levels of lightning protection. Even a waterproof touchscreen. Reliable data in any climate or weather condition.
- **Accurate calculation of sediment loads.** Accuracy that just can't be achieved with manual grab sampling or even continuous turbidity monitoring.
- **Reduced lab analysis costs.** An autosampler without a threshold sampling algorithm takes many non-event samples that yield no sediment. SedEvent takes only the samples that count.
- **One-stop support.** A fully integrated system from a single supplier offers a single source for obtaining support and service.



The Evolution of Sediment Monitoring

1 Manual Grab Sampling	2 Continuous instream monitoring	3 Automated grab sampling	4 Event-driven automated grab sampling
• occasional or regular frequency • attempts to correlate SSC with discharge ✓ obtains actual water samples that can be analyzed in the lab for sediment content ✗ spatial and temporal coverage typically very limited ✗ poor correlation of discharge to SSC ✗ obtaining samples can be dangerous and is costly (labor) ✗ can miss >90% of information	• sensors and datalogger deployed full-time in-situ • one or multiple parameters are continually measured and recorded ✓ low cost after equipment purchased—no manual samples needed ✓ better temporal coverage ✗ without water samples taken, cannot establish correlation to SSC	• automated sampler with simple programming to grab water samples at timed intervals • stage sensor or turbidity sensor for continuous measurement of threshold trigger ✓ obtains water samples and continuous turbidity measurement ✗ low probability of samples taken in storm events (when turbidity is high) ✗ frequent site visits required to obtain samples and reset sampler — costly ✗ high water analysis cost, yet little valuable information ✗ poor correlation to SSC	• automated sampler triggered by rising and falling turbidity thresholds measured by instream turbidity sensor through a programmed datalogger ✓ obtains water samples and continuous turbidity measurement ✓ samples obtained all provide useful information—no over or under sampling ✓ lab handling costs kept to minimum ✓ site visits needed only when all sample bottles are full—labor costs kept to minimum

About FTS

FTS is in the business of **remote data collection**. We design and manufacture extremely rugged systems, dataloggers, DCPs and sensors for **hydrology and hydromet monitoring**. One of our areas of focus is **continuous instream turbidity and sediment monitoring**.

We've developed the world's first fully integrated turbidity event-triggered grab sampling system that can determine sediment and nutrient loads significantly more accurately than with traditional methods. It provides **the best method of characterizing impairments**, ensuring sound decisions affecting public safety are made and best management practices are implemented and effective.

Our technology is engineered specifically for **harsh environments** in **remote locations**, so it has to operate continually, reliably, for long periods of time, with minimal maintenance requirements.

We don't just manufacture equipment, we constantly innovate advanced environmental monitoring technology. And because **we understand our customers and their goals**, we produce solutions that have a direct impact on ease-of-use. Our customers have told us that tremendous power and flexibility should not come at the expense of simplicity.

It simply works. In *any* environment.

"We purchased the SedEvent turbidity threshold sampling system over 4 years ago and have had nearly flawless performance. The equipment is reliable, rugged, and designed with the end user in mind. This is literally a "turn-key" system that allows my field staff to concentrate on the field work, rather than troubleshooting the electronics."

William Ehinger Ph.D., Washington State Dept. of Ecology

1065 Henry Eng Place
Victoria, BC, CANADA V9B 6B2

1123 Fir Ave., Suite C
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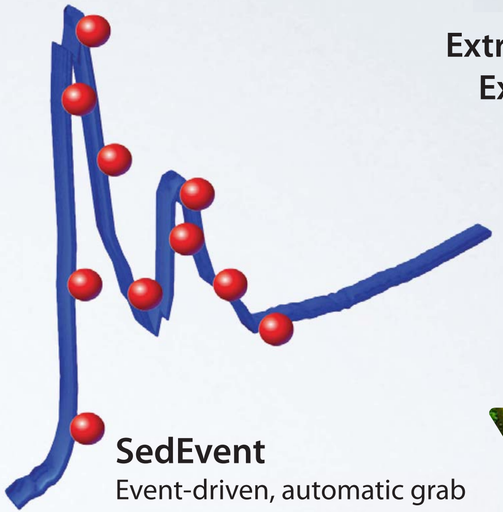
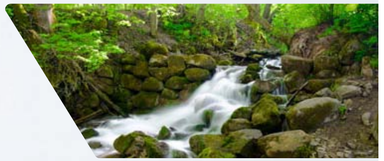
FTS

Extreme environments.
Extreme ruggedness.
Extremely simple.



SedEvent

Event-driven, automatic grab sampling system

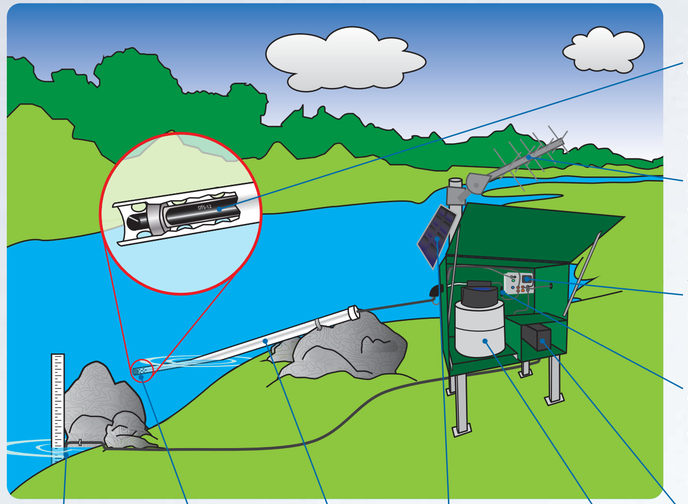


Turbidity Threshold Sampling for the Rest of Us.

Finally, a simple way to accurately determine suspended sediment and nutrient loads.

We didn't invent the concept of Turbidity Threshold Sampling (that distinction goes to Rand Eads and Jack Lewis of the USDA Forest Service). But we did invent the concept of a turn-key system that uses this effective method of intelligent, automated grab sampling that requires **no programming and minimal reliance on consultants** to install and maintain.

SedEvent™: What is it?



DTS-12 digital turbidity sensor secured in Aluminum carousel accurately monitors turbidity.

Optional Yagi antenna permits hourly communication of system status via GOES satellite (other telemetry available).

Axiom™ H2 DCP is the brain of the system.

ISCO interface provides an SDI connection from pump sampler to datalogger.

Spillproof, leak-proof, freezeproof, 12V starved electrolyte photo-voltaic battery.

Submerged stage sensor (pressure transducer or bubbler).

Perforated and cut away end maintains good flow and protects sensor from debris.

4" PVC or ABS plastic pipe conduit optimizes DTS-12 installation.

Solar panel recharges batteries for long-term remote deployment.

ISCO 3700 or 6712 portable autosampler, controlled by the DCP.

In efforts to manage and mitigate the environmental impact of suspended sediment the **Clean Water Act** introduced TMDLs (total maximum daily loads), calculations of the maximum amount of suspended sediment and other contaminants for a given waterbody.

While suspended sediment concentration (SSC) cannot be directly measured accurately or reliably, turbidity has been shown to be an excellent *surrogate* for SSC. Turbidity is caused by suspended particulate matter such as clay, silt, algae, organic and inorganic chemicals and acids like fertilizers, and microscopic organisms like harmful bacteria. These contents give water its cloudy or turbid appearance, and **turbidity in natural waters is recognized as an important indicator of natural health.**

Measuring suspended sediment concentrations used to be labor-intensive, costly, inaccurate and impractical. **SedEvent not only makes it possible and practical, it makes it simple.**

The ability to collect useful data about sediment transport and other pollutants closely coupled to SSC (such as nutrients, e-coli, phosphates and nitrates) is dependent on the timing and frequency of manual grab samples during run-off events. Most sediment and pollutant is transported during a small number of storm events which are infrequent and unpredictable. When they do occur, trained personnel or the proper equipment may not be available to collect grab samples. **Manual grab sampling schemes are also labor-intensive, inefficient, dangerous and costly (and aren't done 24/7/365).**

An automated pump sampler can eliminate the need to sample manually, but for the expense of a rechargeable power system, the autosampler, and possibly a datalogger and a typical turbidity probe (which is often "noisy" and can trigger many unnecessary samples), you're no better off. The primary limiting factor is the number of sample bottles. By the time the autosampler is full, the probability that any sample will have been taken during the critical point of a storm event is low. Expensive lab analysis costs are likely wasted.

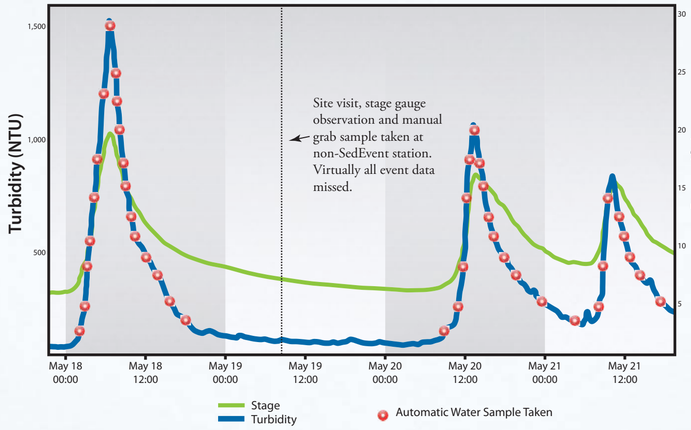
Neither method provides adequate information to make credible suspended sediment load estimates.

The **logged turbidity data** coupled with actual lab analysis of suspended sediment **at specific thresholds**, allows turbidity to be correlated to SSC and sediment loads to be computed.

With an automated pump sampler driven by the DTS-12 digital turbidity sensor and controlled by the Axiom H2 datalogger, you **obtain a better understanding of the water's quality, while taking a minimum number of samples, reducing site visits and saving lab analysis costs.**

The graph below illustrates three rain-driven events and the associated data recorded by a SedEvent system. The DTS-12 digital turbidity sensor monitors the turbidity of the water constantly. All measurements are recorded in the Axiom datalogger, which controls the attached automated pump sampler to take samples when it detects a rise or fall in turbidity at configurable thresholds.

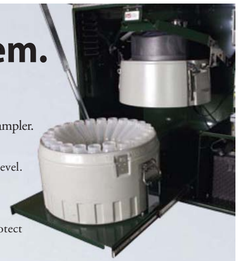
The result is a series of water samples, intelligently taken—only during an event, when the water's turbidity is high. Site visits are required only when the pump sampler is at capacity (which can be determined remotely via optional telemetry or scheduled for after known storm activity), and lab analysis costs are minimized as every sample counts.



By contrast, a manual grab sample taken during a scheduled site visit and gauge observation on May 19 at 10:00am would miss all three events, yielding a sample with a low SSC.

The only complete, turn-key system.

If you need to measure SSC, we need to talk.

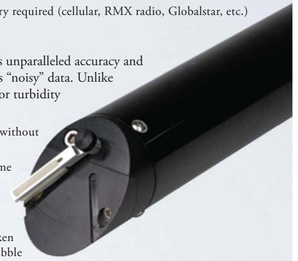


FTS's unique SedEvent enclosure is designed specifically for water quality stations utilizing an ISCO pump sampler.

- Rain canopy door swings up and locks open keeping you dry during operation and maintenance.
- Keyway mounting plate for secure, tool-less vertical mounting of datalogger and other components at eye level.
- Unique lid lift and carousel drawer provide one-handed access to sample bottles.
- Heavy-duty keyed lockbox latches keep equipment secure.
- Heavy-gauge, marine grade, powder-coated, welded aluminum shell and stainless steel hardware protect equipment from mother nature and vandals.

The Axiom™ H2 datalogger was the **first to offer an integrated waterproof touchscreen** to provide a simple, graphical interface to all logged data, scripts, configurations, sensor and power conditions and diagnosis tools. It eliminates the need for field laptops and cables, and includes **full support for event-triggered programming, without the need to program**. Power and flexibility, without sacrificing simplicity.

- Built-in threshold sampling functionality that can be set up to initiate triggers based on any measured time series data point. Invoking this feature and customizing thresholds and sampling logic is done using a simple graphical interface on the integrated color touchscreen, without the need to do any programming whatsoever. All you do is enter the threshold values. If your trigger measurement is turbidity, just use the built-in set of thresholds—there's nothing more to do.
- The Axiom will automatically log the bottle sample number taken at each threshold.
- Four independent SDI ports double the reliability when using many sensors in a complex hydromet station.
- Integrated GOES transmitter, and plug-and-play connections to any other telemetry required (cellular, RMX radio, Globalstar, etc.)

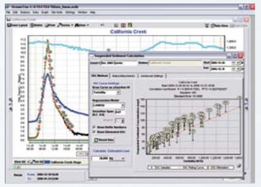


The DTS-12 is the **World's Best Instream Turbidity Sensor™**. A proprietary design provides unparalleled accuracy and extremely low maintenance. Unlike analog sensors and even other digital sensors it eliminates "noisy" data. Unlike multisondes the DTS-12 does only one task, but does it extremely well. It's the ideal sensor for turbidity threshold sampling.

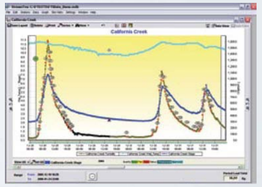
- Unique bidirectional, self-cleaning wiper keeps optic face clean so the sensor can stay submerged without maintenance for 12 months in many locations.
- Unique non-degrading laser diode-based light source provides unparalleled stability and extreme accuracy with less than 2% annual drift.
- Angled sensor head and an optimized viewing volume delivers equal sensitivity over the entire dynamic range of 0 to 1,600 NTU.
- Integrated microprocessor performs real-time statistical data analysis on 100 measurements taken over 5 seconds. This insures that only reliable data is output, by compensating for debris and bubble spikes, and eliminates the need to perform complex datalogger programming to attempt similar analysis.

All the heavy lifting of the data collected from your SedEvent station is handled off-site in StreamTrac™, our water quality monitoring data management and analysis platform.

- StreamTrac automates the collection of remote data from one or multiple sites. If you don't use telemetry, simply download data directly from the Axiom datalogger to a USB memory stick, then upload directly into StreamTrac.
- Powerful graphing tools can plot an unlimited number of datapoints, and combine multiple time series' on the same graph. This makes it easy to compare different data sets, spot trends, make correlations.
- Sediment load totals by event or by period.



- Pump sample bottle mapping, dynamically linked to graph and rating analysis tools.
- Sediment and discharge rating curves, multiple regression models.
- Alarms via email triggered when specified data conditions are met.



- Analysis is available in seconds simply by picking time frame graphically.
- Powerful data correction tools.
- Auditing of edited data and preservation of RAW data.

Biotic and Abiotic Factors Affecting Native Stream Fishes in the South Yuba River, Nevada County, California

By

MARK FREEMAN GARD
B.S. (Massachusetts Institute of Technology) 1983
M.S. (University of California, Berkeley) 1984

DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Ecology

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA

DAVIS

Approved:

Peter B Moyle

Joseph C. Cohen

Don C Erman

Committee in Charge

1994

Biotic and Abiotic Factors Affecting
Native Stream Fishes in the South Yuba River,
Nevada County, California

Mark Freeman Gard

ABSTRACT - The South Yuba River has a depleted native fish fauna, with five of the expected nine native fish species absent because of past human abuse of the system. Construction of a downstream dam excluded two native anadromous species, Pacific lamprey (*Lampetra tridentata*) and chinook salmon (*Oncorhynchus tshawytscha*) from the South Yuba River, while historic (late 1800s) sediment loadings, during the operation of a hydraulic mining site, were probably responsible for the extirpation of three native fish species, riffle sculpin (*Cottus gulosus*), California roach (*Hesperoleucus symmetricus*) and speckled dace (*Rhinichthys osculus*) from the South Yuba River. I examined the fluvial geomorphology, substrate particle size distribution, aquatic macroinvertebrates, and fish microhabitat use and abundance in the South Yuba River and tributaries to examine the effects of present sediment loadings, predation and competition by introduced smallmouth bass (*Micropterus dolomieui*), and elevated water temperatures. Present sediment loadings do not affect fluvial geomorphology, salmonid spawning gravels, aquatic macroinvertebrate populations, or fish survival and reproduction, but have reduced fish growth rates. Smallmouth bass predation is the most likely cause of reduced populations of Sacramento squawfish (*Ptychocheilus grandis*) and hardhead

(*Mylopharodon conocephalus*), and the limited distribution of California roach, restricted to one tributary. Based on the results of microhabitat experiments, competition with juvenile smallmouth bass does not appear to contribute to predation by adult smallmouth bass on juvenile squawfish. Predation by native Sacramento squawfish is reduced by prey behaviors, including greater use of cover and shifts to shallower depths and lower velocities by juvenile squawfish, and by segregation of microhabitat use by species and size class. High water temperatures are the most likely factor affecting the current distribution of rainbow trout (*Oncorhynchus mykiss*). The South Yuba River native fish assemblage can be partially restored through a combination of increased summer flows (to decrease water temperatures), reintroduction of missing species, monitoring, and management of tributaries. Reductions of sediment loads and control of introduced species do not appear to be necessary at this time for conservation of the South Yuba River native fish assemblage.

ACKNOWLEDGEMENTS

Funding for this work was provided by the California Department of Parks and Recreation, the Pacific Gas and Electric Company via the University of California Wildlands Resources Center, the Marin Rod and Gun Club, and two Jastro-Shields Research Fellowships. The field work could not have been conducted without the help of a number of individuals, especially Michael Marchetti, Noah Moyle and Andrew Hill. Drafts of portions of this dissertation were reviewed by Professors Joe Cech and Don Erman and members of the Fisheries Ecology Research Collective. Finally, I would like to acknowledge the tremendous support that I have received from my major professor, Peter Moyle, and my wife, Lindy Rodgers.

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Effects of Sediment Loads on the Fish, Invertebrates and Fluvial Geomorphology of a Sierra Nevada River, California

MARK F. GARD

Abstract - I examined the effects of sediment loadings from an abandoned hydraulic mining site on the fluvial geomorphology, substrate particle size distribution, aquatic macroinvertebrates, and fish growth, survival and reproduction in the South Yuba River (Nevada County) California. The effects of the sediment loadings, which are transported to the South Yuba River via Humbug Creek, were investigated by comparing data from sites on the South Yuba River upstream and downstream of Humbug Creek. The study did not find any deleterious effects of sediment loadings on fish survival and reproduction (based on snorkel survey data), fluvial geomorphology, or aquatic macroinvertebrate populations. In addition, the lack of a significant difference in the percentage of 0.30 to 3.35 mm material in the substrate samples suggests that sediment loads are not affecting trout spawning gravels. In contrast, Sacramento squawfish (*Ptychocheilus grandis*) growth appears to be affected by both water temperatures and sediment loadings. Downstream of Humbug Creek, growth during the first year was significantly faster, based on calculated standard lengths at the age-one annulus, but condition factor was significantly lower than above Humbug Creek.

Between 1853 and 1884, hydraulic mining for gold resulted in the transport and deposition of millions of m^3 of sediment in central California rivers, destroying fisheries and filling in stream beds (McPhee 1993). One of the most devastated drainages was the South Yuba River (Nevada County), as a result of hydraulic mining at Malakoff Diggins, with the deposition of up to 30 m of sediment at some locations (Palmer and Vileisis 1993). This former hydraulic mining site, with colorful "badlands," is now protected as part of Malakoff Diggins State Historic Park.

Sediments eroded from Malakoff Diggins are still transported to the South Yuba River, via Humbug Creek. Suspended sediments concentrations in the South Yuba River at Jones Bar (Figure 1) have been as high as 1000 mg/L in the last few decades (U.S. Geological Survey (USGS) 1967-74). Although these levels are low in comparison to those during hydraulic mining, the California Department of Fish and Game has expressed concern that they are depressing fish populations in the river, especially rainbow trout (*Oncorhynchus mykiss*) (Sandy Harrison, State Parks, personal communication).

The main purpose of this study was to determine the effects of recent, chronic sedimentation on the fishes and invertebrates of the river, to help determine what corrective actions were needed at Malakoff Diggins. A secondary purpose was to determine if there were native fish species that could be restored to the system, that were

missing from the South Yuba River as a result of sediment loadings during hydraulic mining. The objectives of this study were to assess the current degree of deposition of fine sediments from Malakoff Diggins in the South Yuba River, and to assess the effects of sediment loadings from Malakoff Diggins on: 1) fluvial geomorphology; 2) aquatic macroinvertebrates; 3) fish survival and reproduction; and 4) Sacramento squawfish (*Ptychocheilus grandis*) growth. Effects of sediment loadings on fluvial geomorphology are indicative of changes in fish habitat, such as changes in pool to riffle ratios and sedimentation of pools. Sacramento squawfish were chosen for investigations of effects of sediment loadings on fish growth because they are the numerically dominant fish species in most of the study area.

Effects of sediment loads on aquatic life can be due to sediment either suspended in the water column or deposited onto the substrate. While the concentrations and duration of suspended sediments seen in the South Yuba River in the last few decades are too low to cause direct fish mortality, they can cause a variety of sublethal effects on fish; these include: 1) decreases in growth rates, condition factor, and feeding rates; 2) increased physiological stress; and 3) various behavioral reactions, including avoidance and alarm (Newcombe and MacDonald 1991). For example, McLeay et al. (1987) found that suspended sediment levels as low as 100 mg/L can affect fish growth and feeding responses.

Turbidity resulting from suspended sediments can reduce the primary productivity of streams by reducing periphyton growth. Deposition of fine sediment can: 1) change the composition of aquatic macroinvertebrate assemblages (Wiederholm 1984, Harvey 1986); 2) decrease the abundance of benthic fishes, such as sculpins, by reducing available microhabitat (Harvey 1986); and 3) reduce the survival of salmonid embryos by entrapment and by reducing the permeability of spawning gravels, leading to decreases in the transport rate of water and dissolved oxygen to the developing embryos (Chapman 1988).

Study Area

The South Yuba River is located on the western slope of the Sierra Nevada, in the Sacramento River basin. The South Yuba River is 102 km long, with a mean gradient of 10.4%, and drains approximately 900 km^2 (Palmer and Vileisis 1993). The study area, flowing though a narrow canyon, comprised the lowermost 38 km of the South Yuba River (165-701 m above sea level), from Missouri Bar to Bridgeport (Figure 1), where the South Yuba River enters Englebright Reservoir. Mean monthly South Yuba River flows at Jones Bar (Figure 1), in the study area, during 1940-1949 and 1959-1992 ranged from 1 m^3/s in August and September to 23 m^3/s in May (USGS 1942-92). Flows are highly regulated as a result of twenty upstream reservoirs (Palmer and Vileisis 1993).

Three native fish species, Sacramento squawfish, Sacramento sucker (*Catostomus occidentalis*), and rainbow

trout, are found throughout the study area. These are the only fish species found in Reaches 1 (above Humbug Creek) and 2 (Humbug Creek to Purdon Crossing) (Figure 1). Introduced species, primarily smallmouth bass (*Micropterus dolomieui*) and several sunfish species, are found almost exclusively in the lower 5 km of the study area (Reach 4), while an additional native species, hardhead (*Mylopharodon conocephalus*), is found in the lower 15 km of the study area (Reaches 3 [Hoyt Crossing to above smallmouth bass distribution] and 4 [within smallmouth bass distribution], Figure 1). The study area was split into four reaches to distinguish between the effects of sediment and the effects of changes in species composition (the addition of hardhead and smallmouth bass to the fish assemblage found in Reaches 1 and 2).

Methods

Fluvial geomorphology

The actual stream profile of the South Yuba River was determined by measuring the distance along the South Yuba River on USGS quadrangle maps (scale 1:24,000) (USGS 1948a, 1948b, 1949) to each elevation isocline, and then plotting the resulting distances against elevations. The underlying rock types along the South Yuba River were determined from Jennings (1977). The above data were then used to see if actual channel slopes were significantly different for different underlying rock types (ANOVA and Fischer's protected LSD, SAS Institute Inc. 1982).

A plausible equilibrium profile for the South Yuba River was computed and plotted using the following criteria: 1) same elevations as the actual stream profile at the ends of the study section; and 2) a continual decrease in the channel slope going downstream through the study area. The actual stream profile was visually examined for deviations from the equilibrium profile, including the presence of knick points (Morisawa 1968), where there is an abrupt change in channel slope. I inferred whether two faults (at elevations of approximately 300 and 600 m), sediment sources (Malakoff Diggins via Humbug Creek), and sediment sinks (a former impoundment created by Excelsior Dam, Figure 1) cause deviations from an equilibrium profile by seeing if the channel slope changed in response to each of these factors.

Suspended sediments

I investigated whether suspended sediment concentrations at Jones Bar (data from USGS 1967-74) could be predicted using Jones Bar (Figure 1) flows (data from USGS 1967-74) and two categories of rainfall (less than and greater than 1.2 cm) in the previous 48 h at North Bloomfield, located in the Humbug Creek watershed (data from National Oceanic and Atmospheric Administration 1967-74) (multiple regression, Wilkinson 1990). Preliminary analysis resulted in the selection of the above two categories of rainfall, versus other possible categories, as best explaining the variation in suspended sediment

concentrations measured by USGS (1967-74). In addition, the median particle size (at 50% of the cumulative weight) was calculated for the suspended sediment samples for which the USGS (1967-74) had determined the particle size distribution.

Substrate

Thirty-three grab samples of substrate (12 from upstream of Humbug Creek and 21 from downstream of Humbug Creek) were collected in July and August of 1991 from the finest-substrate areas of South Yuba River pools to see if deposition of sediments from Malakoff Diggins was altering the substrate of the South Yuba River. The samples were processed by drying them for 24 h at 60 °C, passing the samples through a series of soil sieves (sized 0.30, 0.60, 1.00, 2.36 and 3.35 mm), and weighing the portion of substrate that was retained on each sieve, and the portion which passed through the finest sieve.

Lisle and Lewis (1992) state that particles with a diameter of 0.25 to 4 mm are the predominant sizes that infiltrate salmonid spawning gravels, because these particles are large enough to be transported in contact with the stream bed and small enough to enter the spawning gravel interstices. Chapman (1988) notes that larger particles (0.5 mm) in this size range seal the surface of spawning gravels, while smaller particles (0.2 mm) in this size range infiltrate into the spawning gravels. Accordingly, I tested the effects of Humbug Creek sediment loads on rainbow trout

spawning gravels by determining whether the percent (by weight) of substrate between 0.30 and 3.35 mm was significantly different for samples upstream and downstream of Humbug Creek (percentages were arc-sine transformed, t-test, SAS Institute Inc. 1990).

Because the main concern of sediment deposition is the effect of sand and smaller particles, only material smaller than 3.35 mm were included in the subsequent analysis. This procedure also reduced the average of the coefficient of variation for the cumulative percentage of each size class from 0.33 to 0.28, making it easier to detect potential differences in substrate caused by deposition of sediments from Malakoff Diggins. The percentage of weight passed through the finest sieve (% < 0.15 mm), and retained by each soil sieve, was calculated. The cumulative percent weight versus Φ ($- \log_2$ [particle diameter {mm}]) was then plotted to determine the median particle size (at 50% of the cumulative weight) and the quartile deviation (QD_Φ) (the average of the values of Φ at 25% and 75% of the cumulative weight; a measure of the variability of the particle size distribution) (Krumbein 1939). These data were then used to determine if there was a significant effect of sediment loads from Malakoff Diggins on the median particle size and QD_Φ (Mann-Whitney U test, Steel and Torrie 1980), and on the percent material < 0.15 mm (percentages were arc-sine transformed, t-test, SAS Institute Inc. 1982).

Invertebrates

In July and August 1991, 36 macroinvertebrate samples were collected, using a kick screen, from South Yuba River riffles. Eight samples were collected from three riffles upstream of Humbug Creek, while 24 samples were collected from nine riffles downstream of Humbug Creek; two to five samples were collected from each riffle. The kick screen was constructed of window screening measuring approximately 1 m^2, and an area of approximately 1 m^2 was kicked for each sample. The organisms were removed from the kick screen with tweezers, preserved in 70% ethyl alcohol, and returned to the laboratory for identification and enumeration. Organisms were identified to family, genus or species and assigned to functional groups using the keys of Wiggins (1977), Usinger (1956), Pennak (1989) and Merritt and Cummins (1984). The functional groups (Merritt and Cummins 1984) used were shredders, collector-gatherers, collector-filterers, scrapers and predators. Shredders feed on coarse organic matter, collectors feed on fine organic matter, scrapers feed on periphyton, and predators feed on other macroinvertebrates. Collector-filterers filter fine organic matter from the water column, while collector-gatherers gather it from the substrate. Average water column velocity was measured using an electronic velocity meter (Marsh McBirney, Model 201), water column depth was measured using a depth rod, and median particle size was visually estimated (to the nearest 5 cm) at each of the sample locations.

I first tested whether or not the number of aquatic macroinvertebrates was significantly different for South Yuba River sites upstream and downstream of Humbug Creek (Mann-Whitney U test, Wilkinson 1990). However, the lack of a uniform area for kick screen samples presumably increased the within-treatment variance, potentially obscuring the effects of sediment loadings from Malakoff Diggins. Accordingly, the following measures, which would be more independent of sampling area, were also used: the percentage of organisms in each functional group, and two measures of diversity - the inverse of the Simpson Index (SI^{-1}) and the Shannon Diversity Index (H′), calculated as follows (Ludwig and Reynolds 1988):

$$SI^{-1} = \left(\sum_{i=1}^{n} p_i^2 \right)^{-1}$$

$$H' = -\sum_{i=1}^{n} p_i \cdot \log_{10}(p_i)$$

where p_i is the proportion of organisms in each taxon (i) of the total taxa (n). For taxa which fell in more than one functional group, the organisms were split equally between the functional groups, so that individuals were not counted twice.

Before examining the effects of sediment loads, the following confounding factors were evaluated: 1) the relationship between the abundance of specific macroinvertebrate taxa and physical variables (depth, velocity and substrate particle size) (Hynes 1970, Minshall

1981, Statzner 1981, Erman and Erman 1984); and 2) increased variability of the above measures due to small numbers of organisms in each sample. Using only samples with more than 50 organisms, I evaluated the relationship between the macroinvertebrate measures and the physical variables (simple linear regression, Wilkinson 1990). In addition, I determined if there were significant differences among the twelve riffles sampled for the three physical variables (one-way ANOVA, SAS Institute Inc. 1982).

The sample results within each riffle were then pooled. Data transformations for the macroinvertebrate measures were selected which yielded distributions closest to normal, based on the linearity of the transformation options in normal probability plots. Finally, I tested whether there was a significant difference between the values of the macroinvertebrate measures for the 3 pooled samples upstream and the 9 pooled samples downstream of Humbug Creek (t-test, SAS Institute Inc. 1982).

Fish

Sampling was conducted on the South Yuba River at one site above Humbug Creek (Missouri Bar); one site within 300 m, above and below, Humbug Creek; and seven sites below Humbug Creek (Illinois Crossing, Edwards Crossing, Purdon Crossing, Hoyt Crossing, Jones Bar and Bridgeport) (Figure 1). The sites were divided into sampling units with uniform habitat types (pool, run, riffle or glide). In 1991 through 1993, fish abundance was estimated in pools and runs

(maximum depth greater than 1 m) using snorkel surveys, where two or three people swam upstream and counted the number of fish (enumerated by species and size class). In addition, for each pool or run, pool length and three to six pool widths were measured, maximum pool depth (numeric value) was visually estimated (within 0.5 m), and turbidity was visually assessed (as high or low). The average pool width of each pool or run was calculated as the mean of the measurements of pool width.

In 1991 and 1992, fish were collected from riffles and glides by electrofishing. Fish were captured from pools and runs with seines, gill nets and minnow traps. All fishes captured were identified, and their weights and standard lengths (SL) recorded. Some of the fish (primarily Sacramento squawfish less than 150 mm SL) were preserved in formalin, and the remaining fish released. Scales were removed from Sacramento squawfish greater than 150 mm SL from the area under the tip of the left pectoral fin. In the laboratory, scales from smaller preserved squawfish were also removed. All scales were mounted between two glass slides and viewed on a scale reader (23 X magnification). The age at capture (to the nearest year) and the length of the squawfish at each annulus (year) were determined from unregenerated scales, using the methods of Tesch (1971). The age at capture of young-of-year (YOY) and age-one squawfish was validated by a comparison with length-frequency histograms. The age at capture of older squawfish

was independently verified by reading some of the scales by two people.

Seven measures were used to assess the effects of sediment from Malakoff Diggins on the South Yuba River fish assemblage: 1) the number of fish per pool or run; 2) the biomass of fish per pool or run; 3) the number of YOY per pool or run; 4) the percentage of YOY per pool or run; 5) the proportion of Sacramento squawfish and hardhead in different size classes; 6) the condition factor of individual squawfish; and 7) the standard length of squawfish at the age one annulus. The first five measures were calculated using snorkel survey data. Biomass estimates were calculated using the number of fish per species and size class and estimated individual weights (Gard 1994a). The number of YOY was estimated as the number of fish in the smallest size class for each species: < 100 mm for rainbow trout and sunfish, and < 50 mm for all other species. Condition factor, a measure of the fitness of fish, was calculated as follows (Moyle and Cech 1982):

$$\text{Condition Factor} = \frac{\text{weight (g)} \times 100{,}000}{\text{standard length}^3\ (\text{mm}^3)}$$

Transformations of the first four measures above were selected which yielded distributions closest to normal, based on the linearity of the transformation options in normal probability plots. I then determined which of five pool dimensions (length, average width, maximum depth, surface area and volume) explained the largest percentage of

the variation in each of these measures (simple linear regression, Wilkinson 1990). For snorkel survey measures that did not have a significant linear relationship with any of the pool dimensions, the effects of above/below Humbug and year, plus the interaction of these two factors, were investigated (two-way ANOVA, Wilkinson 1990). For the other snorkel survey measures, the effects of the following three independent variables, plus all interactions, were tested (general linear model, Wilkinson 1990): 1) the four reaches (Figure 1); 2) year; and 3) the corresponding pool dimension. The analysis was carried out in a step-wise process, with factors and interactions with *P*-values greater than 0.05 eliminated at each step.

I tested whether the size class structure of squawfish and hardhead (the proportion of squawfish and hardhead in four different size classes (<50 mm, 50-150 mm, 150-250 mm, > 250 mm)) was significantly different for the following comparisons: 1) Reach 1 and Reach 2; 2) Reach 2 and Reach 3; and 3) Reach 3 and Reach 4 (excluding uppermost one or two pools) (Pearson's test for association, Steel and Torrie 1980).

The effects of sediment loads from Malakoff Diggins on squawfish growth were investigated by comparing the calculated standard length of squawfish at the age one annulus (during the winter) upstream and downstream of Humbug Creek (t-test, SAS Institute Inc. 1982). A transformation for condition factor values was selected

which yielded a distribution closest to normal, based on the linearity of the transformation options in normal probability plots. The effects of above/below Humbug and fish standard length on condition factor were then examined (multiple linear regression, Wilkinson 1990).

Results

Fluvial geomorphology

The actual stream profile of the South Yuba River deviates substantially from an equilibrium profile (Figure 1). Symptomatic of this deviation is the presence of a knick point 1 km downstream of Edwards Crossing. Channel slopes of the South Yuba River within the study area vary from 0.3% to 7.9%. The channel slopes are virtually the same upstream (1.14%) and downstream (1.26%) of the major sediment source (Malakoff Diggins via Humbug Creek); upstream (2.06%) and downstream (1.58%) of the former sediment sink (Excelsior Dam); and upstream (1.58% and 0.54%, respectively) and downstream (1.89% and 0.51%, respectively) of the faults crossing the South Yuba River, at elevations of 300 m and 600 m, within the study reach. Channel slopes were significantly different for different rock types ($P = 0.0175$), with mean channel slopes ranging from 1.0% for metasedimentary rocks to 2.3% for granite.

Suspended Sediments

Suspended sediment concentrations (Figure 2, mg/L) at Jones Bar can be predicted using daily average Jones Bar flows (m^3/s) and two categories of rainfall in the previous

48 h at North Bloomfield ($R^2 = 0.77$, $P < 0.001$):

for rainfall < 1.2 cm: susp. sed. = 0.918 x flow

for rainfall > 1.2 cm: susp. sed. = 4.24 x flow

The median particle sizes of suspended sediments, computed from the USGS's (1967-74) particle size distribution data, were relatively small (Table 1).

Substrate

The percentage of substrate between 0.30 and 3.35 mm did not vary significantly with above/below Humbug ($P = 0.17$). Although there was a statistically significant difference in median particle size and QD_4 ($P < 0.05$) for upstream and downstream of Humbug Creek, with larger mean values downstream of Humbug Creek, the percentage of material < 0.15 mm did not show an effect of sediment loadings from Malakoff Diggins (Table 2).

Invertebrates

The samples had a total of 2,595 organisms from 40 taxa (Gard 1994a). However, six taxa (*Hydropsyche* sp., *Baetis* sp., *Calineuria californica*, *Ironodes lepidus*, Simuliidae, and *Rhyacophila* sp.) represented almost 75% of the organisms collected. In addition to the macroinvertebrates in the kick screen samples, I found signal crayfish (*Pacifastacus leniusculus*) (at Missouri Bar ~~and Bridgeport),~~ and freshwater mussels (*Margaritifera falcata*) (in one pool in the South Yuba at Humbug Creek).

There was no significant effect of sediment loads from Malakoff Diggins on the number of macroinvertebrates per

sample (P = 0.782). Average counts were 71 organisms per upstream sample and 69 organisms per downstream sample.

There was a significant positive relationship between the percentage of scrapers and depth (r^2 = 0.26, P = 0.018), and a significant inverse relationship between the percentage of predators and substrate median particle size (r^2 = 0.238, P = 0.029). There were no significant differences among the twelve riffles sampled for depth (P = 0.43), velocity (P = 0.65) or substrate median particle size (P = 0.30).

The pooled samples had at least 91 organisms per pooled sample. Data for the inverse of the Simpson Index were square-root transformed, while data for the Shannon Diversity Index, and the percent collectors, shredders and predators were arc-sine transformed. There were no statistically significant differences for indices upstream and downstream of Humbug Creek for any of the macroinvertebrate measures (Table 3).

Fish

A total of 150 pools and runs were snorkel-surveyed in 1991, 1992 and 1993. Biomass and number of YOY were square-root transformed, number of fish were $\log_{10}$ transformed, and percent YOY were arc-sine transformed. Pool length explained the highest proportion of variation of the number of fish and number of YOY (r^2 = 0.126 and 0.028, respectively), and pool volume explained the highest proportion of variation of biomass (r^2 = 0.127). All three

regressions were significant at $P = 0.05$.

There were significant effects of the four reaches, pool volume and the interaction of these two factors ($P < 0.001$) on fish biomass, but no significant effects of year or interactions involving year. The mean values for Reaches 1 and 2 were not significantly different (Table 4); therefore, there were no significant effect of sediment loads from Malakoff Diggins on fish biomass.

There were significant effects of the four reaches ($P < 0.001$), pool length ($P < 0.001$), the interaction of location and pool length ($P = 0.001$), and the interaction of year and location ($P = 0.01$) on the number of fish. There was a significant positive effect of sediment releases from Malakoff Diggins (Table 4). Since there was a significant interaction of year and the four reaches, I looked at the simple effects, within each year, of Reaches 1 and 2, pool length and the interaction of pool length and Reaches 1 and 2 (general linear model, Wilkinson 1990). This analysis indicated that there was not a significant difference in the number of fish above and below Humbug Creek for 1991 ($P = 0.519$) or for 1992 ($P = 0.141$), but that there was a significant difference for 1993 ($P < 0.001$), with more fish downstream of Humbug Creek.

There were significant effects of the four reaches ($P = 0.004$), pool length ($P = 0.044$), the interaction of the four reaches and length ($P = 0.003$) and the interaction of the four reaches and year ($P < 0.001$) on the number of YOY.

There was no significant effect of sediment loads from Malakoff Diggins on the number of YOY (Table 4).

There was no significant relationship between the percent YOY and any of the five pool dimensions ($P > 0.05$, simple linear regression, Wilkinson 1990). There was no significant effect of above/below Humbug, year, or the interaction of above/below Humbug and year on the percent YOY ($P > 0.15$, two-way ANOVA, Wilkinson 1990). Similarly, there was no significant effect of above/below Humbug, taken alone, on the percent YOY ($P = 0.42$, t-test, Wilkinson 1990). The overall percentage of YOY was 64%.

The size class structure of squawfish or hardhead (Figure 3) was significantly different for all three comparisons ($P < 0.01$). However, the effect of Malakoff Diggins (C = 24.5) was smaller than the effects of changes in the fish assemblage composition (C = 2136 and C = 140).

Squawfish downstream of Humbug Creek ($N = 65$) had a significantly greater mean standard length at the age one annulus (during the winter) (64 mm) than squawfish upstream of Humbug Creek (58 mm, $N = 39$, $P = 0.0004$). There were significant effects of fish standard length ($P = 0.045$), above/below Humbug ($P = 0.003$), and the interaction of standard length and above/below Humbug ($P = 0.021$) on condition factor ($\log_e$ transformed), with an overall R^2 of 0.107 ($N = 218$). The regression equations from this analysis were:

Upstream of Humbug: $\log_e (CF + 1) = 1.0316 - 0.0019 \times SL$

Downstream of Humbug: $\log_e (CF + 1) = 0.8522 - 0.00022 \times SL$, where CF = condition factor and SL = standard length. Squawfish upstream of Humbug Creek had consistently higher condition factor values than squawfish downstream of Humbug Creek.

Discussion

Fluvial Geomorphology

Faults, sediment sources, and sediment sinks do not appear to be affecting the South Yuba River stream profile, based on the lack of changes in channel slope. Rather, the rock types underlying the South Yuba River appear to be the major factor affecting channel slopes, and thus the stream profile. The lack of any effect of Malakoff Diggins sediment loads is probably due to: 1) current sediment loads being relatively low; and 2) high flow events, during the last 100 years, eroding sediments deposited in the stream channel during hydraulic mining in the late 1800s.

Suspended sediments

Since most of the material in suspended transport has a median particle size less than 0.062 mm (Table 1), it would not be likely to settle out of the water column, especially during high flows, until it reaches Englebright Reservoir. Supporting this conclusion are observations that Englebright Reservoir is turbid during heavy rains (California Department of Fish and Game files). In addition, the average concentration of suspended sediment measured just downstream of Humbug Creek, 254 mg/L (Table 5) (California

Department of Water Resources (CDWR) 1987), is probably not significantly greater than the average predicted concentrations for those dates at Jones Bar (171 mg/L; calculated using the relationships of suspended sediment concentrations with flow and rainfall), given the errors associated with the multiple regression.

Humbug Creek is a substantial contributor of sediment for the South Yuba River (Table 5). Based on the relationship of suspended sediment concentrations with flows and rainfall, loadings of sediment flushing down Humbug Creek appear to be associated with rainfall events; for the period 1985-92, there were an average of 47 d per year with greater than 1.2 cm of rainfall at North Bloomfield in the previous 48 h (National Oceanic and Atmospheric Administration 1985-92). Based on data from CDWR (1987), erosion from the former hydraulic mining pit at Malakoff Diggins State Park contributes most of the sediment loading to Humbug Creek.

The rest of the sediment loading to Humbug Creek is presumably from natural erosion, and erosion from timber harvests and road construction. In addition, sediments derived from these other erosion sources in the remainder of the South Yuba River watershed probably account for most of the sediment in the South Yuba River that does not come out of Humbug Creek; however, I was not able to quantify amounts from these sources. Recreational suction dredge mining in the South Yuba riverbed mainly resuspends sediments from the

above sources, and may therefore be a source of suspended sediments during low flow periods.

However, Harvey (1986) found that the effects of suction dredge mining on aquatic organisms, principally due to the deposition of sand and gravel, were very localized. In addition, turbidity resulting from suction dredge operations is much less than the turbidity from Malakoff Diggins. Specifically, my field observations indicated that the Secchi depth approximately 30 m downstream of suction dredge operations was a minimum of 1 m, while the Secchi depth in the South Yuba River approximately 30 m downstream of Humbug Creek on August 15, 1991, with 1.2 cm of rainfall at North Bloomfield in the previous 48 h, was less than 1 cm; the Secchi depth in the South Yuba River 30 m upstream of Humbug Creek on this date was greater than 3 m. Similarly, Harvey (1986) found that the turbidity just downstream of suction dredges averaged 5 nephelometric turbidity units (NTU); whereas, the average turbidity of CDWR (1987) samples from the South Yuba River downstream of Humbug Creek was 33 NTU. Thus, the effects of suction dredge operations on my substrate samples from upstream of Humbug Creek probably did not mask effects of sediment loads from Malakoff Diggins.

Substrate

Since the sediment load from Malakoff Diggins is largely material < 0.15 mm (Table 1), the lack of difference in percent material < 0.15 mm supports the conclusion that

most of the sediment from Malakoff Diggins moves through the South Yuba River to Englebright Reservoir, rather than being deposited in South Yuba River pools. In addition, since 0.30 to 3.35 mm material has the greatest impact on trout spawning gravels, sediment loads from Malakoff Diggins are probably not affecting rainbow trout reproduction.

Invertebrates

Since there was not a significant difference between riffles for the three physical variables, I was able to control for the effects of these variables by pooling the sample results within each riffle. This procedure also increased the number of organisms within each pooled sample sufficiently to control for the other confounding factor (variability due to low numbers of organisms per sample).

Given that the mean numbers of macroinvertebrates per sample upstream and downstream of Humbug Creek were within three percent of each other, a decrease in within-treatment variability by using other types of samplers, rather than a kick screen, would probably not have altered my results of no significant effect of sediment loads from Malakoff Diggins on the number of macroinvertebrates per sample. Sumner and Smith's (1939) macroinvertebrate samples from the South Yuba River showed a much larger decrease (17%) in numbers downstream of sediment sources, although the statistical significance of this decrease is not given. Specifically, Sumner and Smith (1939) found an average of 592 organisms/m^2 in twelve samples from areas downstream of

major sediment sources, while four samples upstream of sediment sources had an average of 710 organisms/m^2. The difference in macroinvertebrate numbers between Sumner and Smith (1939) (592-710 organisms/m^2) and this study (69-71 organisms/kick screen sample) is likely due to the different sampling method (Surber sampler) used by Sumner and Smith, since I sampled approximately 1 m^2 with each kick screen sample. The larger decrease (17%) in Sumner and Smith's data, compared to this study (3%), may indicate that suspended sediment concentrations in the South Yuba River have decreased since the 1930's. This is consistent with the much larger difference in macroinvertebrate numbers (37%) found by Sumner and Smith (1939) for Yuba tributaries with sedimentation as compared to Yuba tributaries without sedimentation, since tributaries carrying sediment would be expected to have much higher suspended sediment concentrations than the South Yuba River, due to dilution; Sumner and Smith found an average of 2217 organisms/m^2 in 50 samples from Yuba tributaries with no sedimentation, while 20 samples from Yuba tributaries with sedimentation had only 1399 organisms/m^2.

I expected that the samples from the South Yuba River upstream of Humbug Creek would have higher diversity index values and a higher percentage of collector-filterers and scrapers. Various kinds of disturbances, including sediment loadings, can result in lower diversity of macroinvertebrate communities (Reger and Kevern 1981, Newbold et al. 1980).

In addition, collector-filterers can be directly adversely affected by sediment clogging their filtering apparatus, while scrapers can be indirectly affected by turbidity reducing growth of periphyton. The lack of any significant differences in the proportion of functional groups between upstream and downstream of Humbug Creek may indicate either that the limited duration and intensity of suspended sediment loadings are not affecting invertebrate populations, or that invertebrate populations downstream of Humbug Creek were able to rebound due to recolonization in the two-plus months between the end of the rainy season and my sampling during mid-summer. The former explanation is consistent with the data presented in Newcombe and MacDonald (1991), while the latter explanation is consistent with Harvey's (1986) findings that macroinvertebrates had completely recolonized areas below suction dredge mining areas within 45 d after the cessation of suction dredge mining.

Fish

Speckled dace (*Rhinichthys osculus*), riffle sculpin (*Cottus gulosus*) and California roach (*Hesperoleucus symmetricus*), which would be part of the expected native fish assemblage in a foothills Sierra stream (Moyle 1976), such as the South Yuba River, may have been extirpated from the South Yuba River by the tremendous sediment loads from hydraulic mining in the late 1800s. These species are the smallest of the native fish species, and would thus have

been most vulnerable to the effects of these historic sediment loads. In contrast, adult squawfish, hardhead, Sacramento sucker and rainbow trout could have moved far enough upstream in the South Yuba River, or into the Yuba River above its confluence with the South Yuba River, to avoid impacts of historic sediment loads. Based on the current fish species present in tributaries of the South Yuba (Gard 1994b), Kentucky Ravine (at Bridgeport) probably served as a refuge from the effects of historic sediment loads for California roach, while the other tributaries were likely only refuges for rainbow trout and suckers, possibly due to their low temperatures and/or high gradients.

Since the difference in the number of fish upstream and downstream of Humbug Creek was only seen in one of three years and did not indicate a negative effect of Humbug Creek, sediment loads from Malakoff Diggins are not adversely affecting the number of fish presently in the South Yuba River. In addition, differences in the size class structure of squawfish and hardhead upstream and downstream of Humbug Creek are small, compared with the effects of changes in fish assemblage composition. The above, together with the lack of differences upstream and downstream of Humbug Creek for fish biomass and the percentage of YOY, leads to the conclusion that sediment loads from Malakoff Diggins are not adversely affecting fish survival. In addition, the lack of difference in the number of YOY upstream and downstream of Humbug Creek leads to the

conclusion that sediment loads from Malakoff Diggins are not adversely affecting fish reproduction.

The larger age-one annulus standard length for squawfish downstream of Humbug Creek could either be due to squawfish spawning earlier downstream or to young-of-year squawfish downstream growing faster during the summer (when turbidity levels are low) as a result of higher temperatures. Fish tend to grow fastest near their preferred temperature (Jobling 1981). The preferred temperature for squawfish of 26 °C (Knight 1985) is closer to the average summer temperatures at Highway 49 and Jones Bar (20.6 - 25 °C) than to the average summer temperatures at Missouri Bar (18.8 - 22.6 °C) (Gard 1994b). In addition, YOY squawfish were much smaller in the summer of 1993, as compared to 1992, reflecting colder water temperatures, as a result of higher flows, in 1993. In contrast, lower condition factor values for squawfish downstream of Humbug Creek may be due to turbidity from Malakoff Diggins suspended sediment loads decreasing feeding rates during winter and spring. Thus, growth rates of Sacramento squawfish appear to be affected by both turbidity, caused by sediment loads from Malakoff Diggins, and water temperatures. However, a third factor also appears to be influencing squawfish growth rates in the South Yuba River, since, as compared to other rivers (Brown 1990), squawfish in the South Yuba River grow much slower (Gard 1994a). This third factor may be low productivity, since preliminary

water quality sampling (Gard, unpublished data) indicates that nutrient levels in the South Yuba River may be lower than in many other similar California rivers (Gard 1994a).

Conclusions

The limited effects of current sediment loadings on the South Yuba River seen in this study are consistent with: 1) the relatively low concentrations of suspended sediments (less than 1000 mg/L); 2) the limited duration of loadings (approximately 47 d per year); and 3) limited sediment deposition, due to both the small particle size of the sediment and the discharges of sediment primarily during high flow periods. Overall, this study demonstrates that sediment inputs from historic hydraulic mining sites are no longer having major effects on the fauna of the South Yuba River. Other alterations to the river, especially upstream water diversions, are presumably more important because they change water temperature and flow regime (Gard 1994b). For example, high water temperatures appear to be the main factor limiting rainbow trout populations in the South Yuba River (Gard 1994b). The system has recovered enough, however, so that reintroduction of missing native fishes is warranted (Gard 1994b).

Acknowledgements

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Table 2. Substrate sample characteristics of pools (mean ± SE). Differences in median particle size and QD_{ϕ} evaluated by Mann-Whitney U tests. Difference in percent material < 0.15 mm evaluated using t-test and arc-sine data transformation.

Measure	Upstream of Humbug Creek	Dowstream from Humbug Creek	p value
Median Particle Size (mm)	1.44 ± 0.063	2.068 ± 0.059	.004
QD_{ϕ}	0.535 ± 0.019	0.638 ± 0.02	<.001
Percent < 0.15 mm	0.26% ± 0.04%	0.40% ± 0.12%	.35
Sample Size	12	21	

Table 3. Characteristics of macroinvertebrate samples collected from the South Yuba River, upstream and downstream of Humbug Creek, with kick screens (mean ± SE). H′ = Shannon Diversity Index. SH^{-1} = Inverse of the Simpson Index. Percentages given for functional groups are the percent abundance represented by the functional groups in the total sample. Comparisons of Shannon Diversity Index and functional group data using t-tests and arc-sine data transformation. Comparison of the inverse Simpson Index using t-test and square-root data transformation.

Measure	Upstream of Humbug Creek	Downstream from Humbug Creek	p value
H′	0.910 ± 0.036	0.901 ± 0.026	.79
SI^{-1}	5.374 ± 0.588	5.42 ± 0.262	.929
% Scrapers	14.9% ± 5.1%	16.8% ± 1.8%	.651
% Collector-filterers	38.5% ± 5.6%	44.6% ± 4.2%	.464
% Collector-gatherers	20.3% ± 5.4%	16.1% ± 1.2%	.259
% Shredders	5.1% ± 1%	2.4% ± 0.9%	.105
% Predators	21.2% ± 6.2%	20.1% ± 2.9%	.857
Sample Size	3	9	

Table 4. Effects of location on snorkel survey measures. Data in table are means for each measure and reach. See Figure 1 for location of reaches. Units of biomass are g fish/pool or run. Means connected by horizontal lines are not significantly different at $P = 0.05$ (general linear model, Wilkinson 1990).

Measure	Reach 3	Reach 4	Reach 2	Reach 1
Biomass	6,823	6,557	2,958	3,453
Number of Fish	200	144	102	64
Number of YOY	152	104	47	28

Table 5. Humbug Creek confluence suspended sediment data. This data shows that the Malakoff Diggins historic hydraulic mining site (the primary sediment source in the Humbug Creek basin) is a substantial source of sediment loads to the South Yuba River. Data from CDWR (1987).

	Suspended Sediment Concentration (mg/L)		
Date	S. Yuba Upstream	Humbug Creek	S. Yuba Downstream
3/7/86	7	636	42
2/19/79	1.5	632	84
3/23/79	1	380	34
3/27/79	41	5,200	856
Average	13	1,712	254

Figure Legends

Figure 1. South Yuba River stream profile. Source of elevation and distance data: USGS (1948a, 1948b, 1949). Source of data on rock types: Jennings (1977). Equilibrium profile computed using the following criteria: 1) same elevations as the actual stream profile at the ends of the study area; and 2) a continual decrease in the channel slope going downstream through the study area. Macroinvertebrate and fish sampling sites shown at top of figure.

Figure 2. Suspended solids frequency distribution, Jones Bar, Water Years 1967-74. Data from USGS (1967-74).

Figure 3. Size class distribution of squawfish and hardhead. Computed using all snorkel survey data. Size of fish is standard length. See Figure 1 for location of reaches. Difference between Reach 1 and 2 reflects effect of sediment loadings from Malakoff Diggins. Differences between Reaches 2, 3 and 4 reflect effects of changes in species composition of South Yuba River fish assemblage.

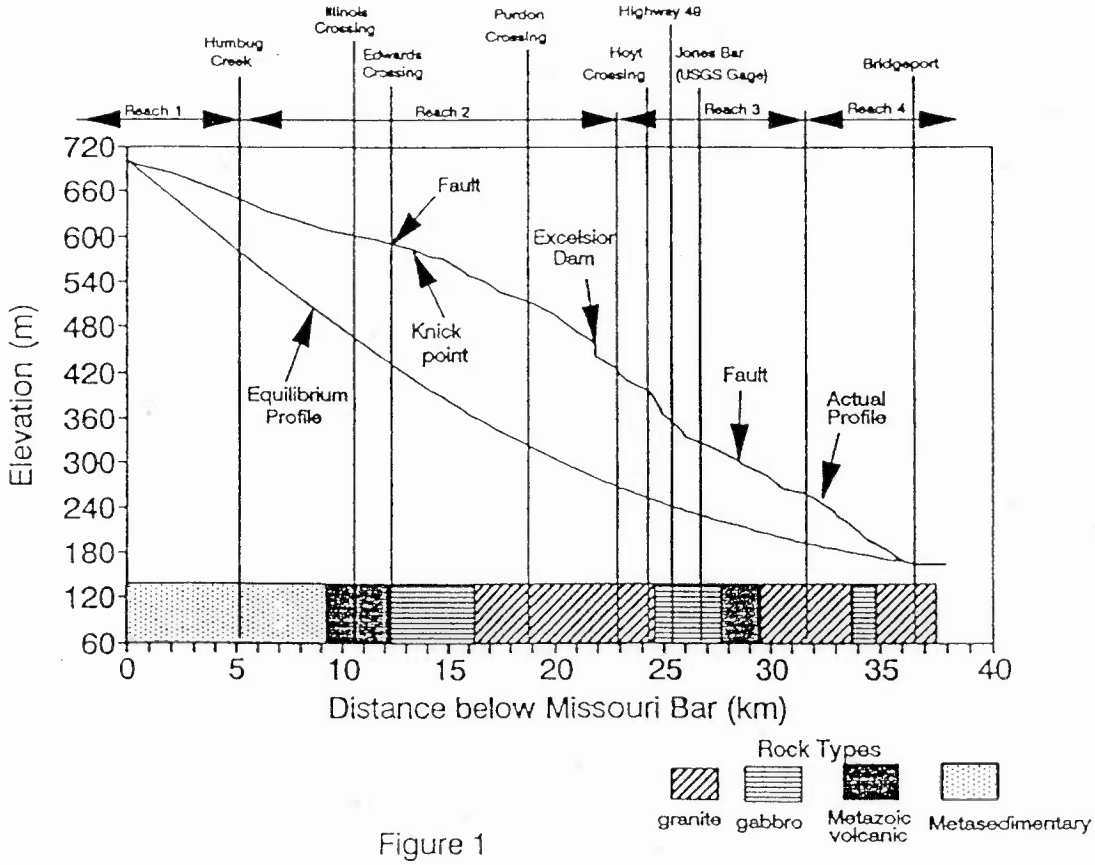
Humbug Creek
Illinois Crossing
Edwards Crossing
Purdon Crossing
Hoyt Crossing
Highway 49
Jones Bar (USGS Gage)
Bridgeport
Reach 1
Reach 2
Reach 3
Reach 4
Fault
Excelsior Dam
Knick point
Equilibrium Profile
Fault
Actual Profile
Elevation (m)
720
660
600
540
480
420
360
300
240
180
120
60
0
5
10
15
20
25
30
35
40
Distance below Missouri Bar (km)
Rock Types
granite
gabbro
Metazoic volcanic
Metasedimentary

Figure 1

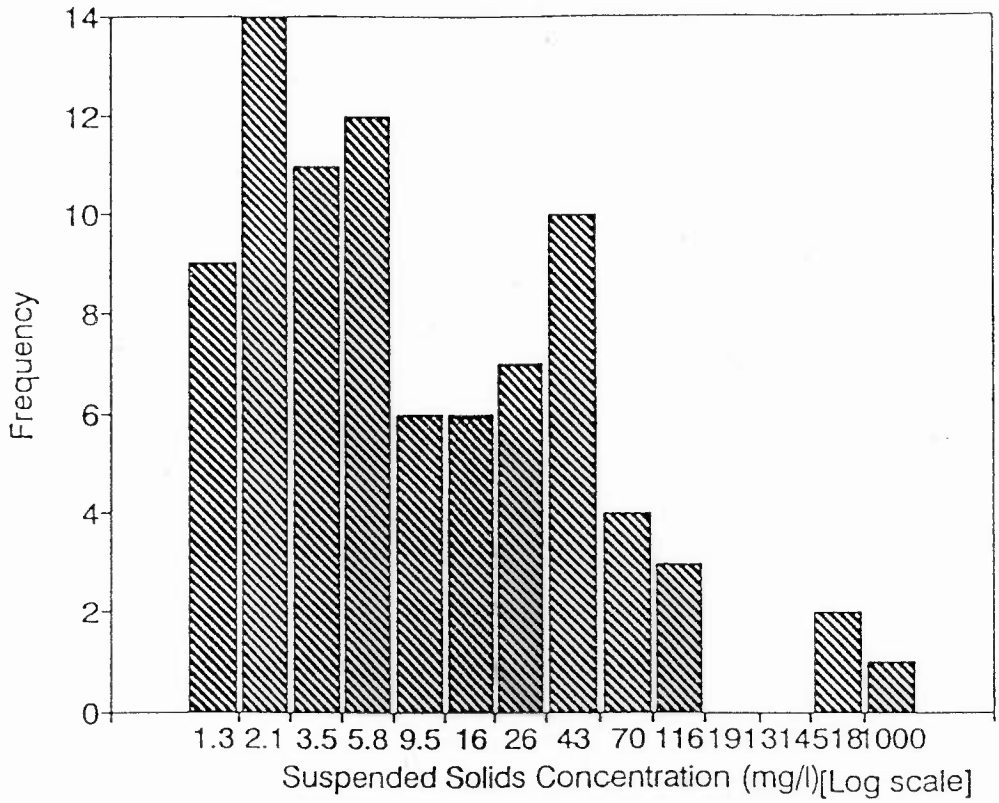
14
12
10
8
6
4
2
0
Frequency
1.3 2.1 3.5 5.8 9.5 16 26 43 70 116 191 314 518 1000
Suspended Solids Concentration (mg/l)[Log scale]

Figure 2

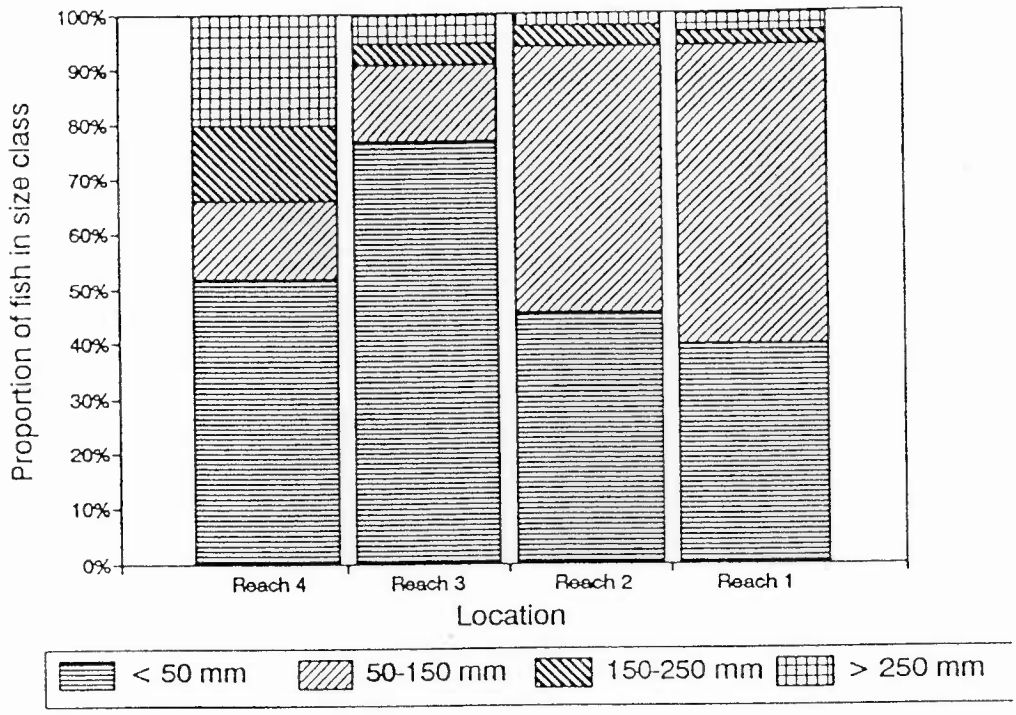
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Proportion of fish in size class
Reach 4
Reach 3
Reach 2
Reach 1
Location
< 50 mm
50-150 mm
150-250 mm
> 250 mm

Figure 3

INTERACTIONS BETWEEN AN INTRODUCED PISCIVORE AND A NATIVE PISCIVORE IN A CALIFORNIA STREAM

MARK F. GARD

Abstract. I studied microhabitat use and abundance of fish species in the South Yuba River (Nevada County, California) to examine the effects of biotic interactions between introduced smallmouth bass (*Micropterus dolomieui*) and native Sacramento squawfish (*Ptychocheilus grandis*). When smallmouth bass were absent, juvenile squawfish exhibited behaviors which decrease their risk of predation, including: 1) greater use of cover, as compared with large squawfish; and 2) shifts to shallower depths, lower velocities, and more cover use, reducing microhabitat overlap, in the presence of large squawfish. Predation by smallmouth bass appears to be the most likely cause of decreases in native cyprinids, given the disproportionate decrease in smaller size classes of native cyprinids within the distribution of smallmouth bass. Based on the results of microhabitat experiments, competition with juvenile smallmouth bass does not appear to contribute to predation by adult smallmouth bass on native cyprinids. The main factors that appear to favor smallmouth bass, with regard to interspecific predation interactions with squawfish, are: 1) the smaller size of smallmouth bass at the onset of piscivory; 2) the greater use of cover by juvenile smallmouth bass; and 3) lower microhabitat overlaps of juvenile smallmouth bass with piscivores.

Key words: intraguild predation; introduced species;

squawfish; smallmouth bass; stream fishes; microhabitat shifts; community structure.

Key phrases: causes of decline of native fish species; behaviors which decrease risk of predation; role of competition in increasing predation risk; effects of reintroduction of native species; cover as a limiting resource; segregation of microhabitat use; piscivores as a biological barrier; decreases in microhabitat overlap to reduce predation risk.

INTRODUCTION

Introduced fishes, particularly piscivores, are one of the principal causes of the severe decline of the native fish fauna of California (Moyle and Williams 1990). In particular, predation by introduced smallmouth bass has been implicated in the decline of native fishes in several California streams (Brown and Moyle in press, G. Sato, *unpublished data*), as well as in South African streams (Gore et al. 1991). Predation by adult smallmouth bass has been shown to cause substantial reductions of prey fish numbers in experimental studies (McNeely et al. 1990, Rahel and Stein 1988), while predation by juvenile smallmouth bass has significant adverse effects on larval fish numbers, based on diet (Johnson and Dropkin 1992) and larval fish census (Harvey 1991) studies. In addition, juvenile smallmouth bass could contribute to predation of native fish by forcing them into deeper waters and out of cover, making them more vulnerable to predation by large smallmouth bass.

The South Yuba River, located in Nevada County, California, was chosen as a study site because of the California Department of Parks and Recreation's interest in: 1) enhancing populations of existing native fish species; and 2) restoring populations of native fish species which were extirpated as a result of hydraulic mining in the late 1800s. Predation by smallmouth bass was thought to be a potential impediment to such conservation efforts. Smallmouth bass are ecologically similar to Sacramento squawfish, the most abundant native fish species in the South Yuba River, and the dominant native piscivore in California streams: both species tend to be found in pool and run habitats in larger rivers, feed primarily on aquatic macroinvertebrates as juveniles, and switch to piscivory as adults (Moyle 1976). In addition, both species feed with the greatest intensity in the morning (Brown 1990, Kwak et al. 1992). Diet studies indicate that larger squawfish (greater than 150 mm) feed on a wide variety of fish species, including conspecifics (Brown 1990, Moyle et al., 1979, *unpublished report*: Preliminary Study of Feeding Habits of Sacramento Squawfish (*Ptychocheilus grandis*)), while smallmouth bass in Englebright Reservoir, at the terminus of the South Yuba River, feed to some extent on immature squawfish (U.S. Army Corps of Engineers, 1991, *unpublished report*: Draft Fish and Wildlife Management Plan for Englebright Lake).

The marked effect of introduced fish on native fish species has been attributed to high levels of predation and competition, as a result of the relatively brief time that they have been in sympatry. Sacramento squawfish predation has been implicated as the cause of sharp population declines have been seen for threespine stickleback (*Gasterosteus aculeatus*) populations in coastal California streams following the introduction of squawfish (Brown and Moyle 1991, Smith 1982); threespine stickleback have been in sympatry with squawfish for less than 100 years. In the Great Lakes region, competition for drift food sources was identified as the cause of shifts in the downstream distance of brown trout (*Salmo trutta*), when it was in sympatry with coho salmon (*Oncorhynchus kisutch*); both species were introduced into this region in the last 100 years (Fausch and White 1986).

In contrast, the addition of piscivorous fish species to a fish assemblage may have little effect on fish species which have been in sympatry with the introduced species for a long period. For example, California roach (*Lavinia symmetricus*) and rainbow trout (*Oncorhynchus mykiss*), which have been sympatric with squawfish for a long time, have been relatively unaffected by squawfish introductions (Brown and Moyle 1991). Based on field (Brown and Moyle 1991) and experimental (Brown and Brasher in press) studies of microhabitat use, these species reduce squawfish predation by shifts in microhabitat use to shallower waters when in

sympatry with squawfish, relative to their microhabitat use in allopatry. Similarly, Schlosser (1987, 1988) found that several species of cyprinids, as well as juvenile smallmouth bass and white suckers (*Catostomus commersoni*), shifted to shallower habitats in the presence of adult smallmouth bass. Fraser and Cerri (1981) found that small fish avoided portions of the stream channel where predators were present, but that this effect was reduced with greater cover.

Other studies indicate limited competition between native California stream fishes, based on the relatively high degree of microhabitat segregation of species in sympatry (Baltz and Moyle 1984, Moyle and Vondracek 1985). Similarly, Brown (1991) was not able to demonstrate competition between several sculpin species, despite experimental results showing allopatric interspecific differences in microhabitat use of depth and substrate. Limited competition among California stream fish species may be due to microhabitat shifts, or to fish densities being too low for space to be a limiting resource, as a result of environmental variation restricting population densities (Baltz and Moyle 1993).

Intraguild predation (IGP) has been proposed as an important process regulating aquatic communities (Polis and Holt 1992, Polis et al. 1989). Most of the investigations of fish assemblages have focused on asymmetrical age-structured IGP with qualitative diet shifts (Polis et al. 1989); these studies have found that a prey species can

limit the population size of its predator by outcompeting juveniles of its predator (Persson and Greenberg 1990, Werner and Gilliam 1984, Johannes and Larkin 1961). Interactions between smallmouth bass and squawfish, however, can be classified as symmetrical IGP (Polis et al. 1989), since they are mutual predators of one another (U.S. Fish and Wildlife Service, Columbia River Field Station, Cook, Washington, 1992, *unpublished data on northern squawfish and smallmouth bass and their prey*). Trophic loops generated by symmetrical IGP can result in numerous indirect effects; for example, a reduction in the density of piscivorous squawfish, as a result of smallmouth bass predation limiting squawfish recruitment, would reduce interspecific competition with adult smallmouth bass and interspecific predation upon juvenile smallmouth bass.

The goals of this study were to: 1) investigate how patterns of microhabitat use allow native fish species and size classes to coexist; 2) evaluate what effect the reintroduction of native fish species would have on the species already present; 3) determine to what extent smallmouth bass are affecting the distribution and abundance of native fishes; 4) to determine the relative importance of predation, and competition between juveniles, in causing the decline of squawfish populations in the presence of smallmouth bass; and 5) evaluate whether cover is a limiting resource for juvenile fish.

METHODS

Study Area

Field studies were conducted on the South Yuba River and its tributaries during the summers of 1991, 1992 and 1993. The South Yuba River is located on the western slope of the Sierra Nevada, in the Sacramento River basin. The South Yuba River is 102 km long, with a mean gradient of 10.4%, and drains approximately 900 km^2 (Palmer and Vileisis 1993). The study area, flowing through a narrow canyon, comprised the lowermost 38 km of the South Yuba River (165-701 m above sea level), from Missouri Bar to Bridgeport (Fig. 1), where the South Yuba River enters Englebright Reservoir. Mean monthly South Yuba River flows in the study area from 1940 to 1949 and from 1959 to the present ranged from 1.06 m^3/s in August and September to 23.3 m^3/s in May (USGS 1942-92). Flows are highly regulated as a result of twenty upstream reservoirs (Palmer and Vileisis 1993). Channel slopes of the South Yuba River within the study area vary from 0.3 to 7.9% (Gard 1994a).

Three native fish species, Sacramento squawfish, Sacramento sucker (*Catostomus occidentalis*), and rainbow trout, are found throughout the study area. An additional native species, hardhead (*Mylopharodon conocephalus*), is found in the lower 15 km of the study area (Reaches 3 and 4, Fig. 1), while introduced species, primarily smallmouth bass, are found almost exclusively in the lower 5 km of the study area (Reach 4). One additional native species,

California roach, was only found in Kentucky Ravine, a tributary which enters the South Yuba River just upstream of Englebright Reservoir (Fig. 1).

Field studies

The South Yuba River was sampled at one site within the distribution of smallmouth bass (Bridgeport), an additional three sites within the distribution of hardhead (Jones Bar, Highway 49, and Hoyt Crossing), and five sites upstream of the distribution of these species (Purdon Crossing, Edwards Crossing, Illinois Crossing, Humbug Creek and Missouri Bar) (Fig. 1). The sites were divided into sections with uniform habitat types (pool, run, riffle or glide).

In 1991 and 1992, the fish species composition of riffle and glide sections were determined by electrofishing. The fish species composition of Kentucky Ravine was determined in 1992 and 1993 by electrofishing.

Snorkel surveys

The abundance of fish species in sections with a maximum depth greater than 1 m (pools and runs) was estimated using snorkel surveys, where two or three people would swim upstream and count the number of fish of each species in each of two to four size classes. In addition, for each section, pool length and three to six pool widths were measured, the maximum pool depth, percent shade and substrate composition were visually estimated, and the quality and type of cover present were visually assessed. The measurements of pool widths were used to calculate the

average pool width.

Effects of changes in fish species composition (specifically the addition of hardhead and smallmouth bass to the fish assemblage present in Reaches 1 and 2) were assessed by the following measures derived from the snorkel survey data: 1) the number of fish per section; 2) the biomass of fish per section; 3) the number of young-of-year (YOY) per section; and 4) the proportion of Sacramento squawfish and hardhead in different size classes. Details of this analysis are given in Gard (1994a).

Microhabitat measurements

In 1992, snorkel surveys were followed by microhabitat use observations at all sites except Missouri Bar and Humbug Creek. Microhabitat observations were made at Bridgeport, Purdon Crossing, Edwards Crossing, and Illinois Crossing in 1993. Observations on each group of fish, made while snorkeling upstream, consisted of: 1) fish species; 2) number of individuals; 3) visual estimate of fish standard length (SL); 4) measurement of focal depth (the distance from the substrate to the fish) and water column depth using a depth rod; 5) measurement of focal velocity (water velocity at the fish) and average water column velocity using an electronic velocity meter; and 6) visual observation of the type of substrate under the fish and the type of cover (if any) within 1 m of the fish. The average water column velocity was estimated as the velocity at 0.6 of the water column depth for depths less than 0.75 m or as

the average of the velocity at 0.8 and 0.2 of the water column depth for depths greater than 0.75 m. Substrates were classified as either aquatic vegetation or into six groups ranging in particle size from bedrock to silt. In observations of mixed substrate, the prevalent class was used. Two other variables, relative depth (focal depth divided by water column depth) and relative velocity (focal velocity divided by average water column velocity), were calculated using the above variables. If the average water column velocity was zero, the relative velocity was set at one.

Microhabitat use analysis

Using all of the microhabitat observations from 1992 and 1993, I selected transformations of the above microhabitat variables which yielded distributions closest to normal, based on the linearity of the transformation options, in normal probability plots. The six depth/velocity variables were reduced to two factors (factor analysis, SAS Institute Inc. 1982), with the factor scores weighted by the number of fish for each measurement.

Size classes of squawfish and smallmouth bass were chosen for use in subsequent analyses by selecting the largest r^2 values, using the above two factors, for different size classes (ANOVA, Wilkinson 1990) and for continuous values of SL (simple linear regression, Wilkinson 1990). Fifty percent probability ellipses were determined for each size class, plus other native species, based on the mean and standard deviation of the scores for the two

factors for each size class and species.

Quantitative measures of the depth/velocity microhabitat overlaps between species and size classes of squawfish and smallmouth bass were computed as the percentage of cases misclassified in a linear discriminant analysis of the six depth and velocity variables (Wilkinson 1990). Overlaps in substrate and cover were calculated using Schoener's (1970) formula:

$$S = 1 - 0.5(\Sigma \, |P_{x,i} - P_{y,i}| \,),$$

where $P_{x,i}$ and $P_{y,i}$ are the proportions of the total resource (i.e., cover or substrate) use of species x and y composed of resource i (i.e., type of cover or substrate).

Differences in microhabitat use between years for squawfish and smallmouth bass were examined for the two depth and velocity factors (t-test, SAS Institute Inc. 1982). For depth and velocity factors where there were significant differences between years, differences between size classes of squawfish and smallmouth bass were tested using a two-way ANOVA with independent variables year and size class, plus the interaction of year and size class (Wilkinson 1990). I then determined which means were significantly different (least-square means technique, SAS Institute Inc. 1982). For the remaining factors, differences between size classes were evaluated using t-tests (SAS Institute Inc. 1982).

Squawfish microhabitat use

The percentage of all squawfish using different substrate types in each pool at Purdon, Edward and Illinois

Crossings was compared to the percent substrate available in each pool (percentages were arc-sine transformed, paired-sample t-tests, Wilkinson 1990). In addition, I determined if the proportion of all squawfish using cover at Purdon, Edwards and Illinois Crossing was independent of the amount of cover available (classified as good, fair or poor) (Pearson's test for association, Steel and Torrie 1980). Differences in cover use between different size classes of squawfish were evaluated (Pearson's test for association, Steel and Torrie 1980).

Effects of squawfish predation

Effects of squawfish predation were examined by looking for differences in small squawfish microhabitat use from pool to pool at Purdon, Edwards and Illinois Crossings in response to the presence or number of large (> 150 mm SL) squawfish (squawfish become piscivorous at around 150 mm SL (Brown 1990, Moyle et al. 1979)). Preliminary analysis eliminated large squawfish density as a third factor, since the relationship between the number of large squawfish and pool length, surface area and volume were not significant at $P = .05$ (simple linear regression, Wilkinson 1990).

The size of small squawfish used in this analysis was selected by using the mean SL of large squawfish, from the microhabitat data, in an equation which relates the SL of squawfish predators to the SL of their prey; this equation was derived from measured predator and prey SLs (U.S. Fish and Wildlife Service, Columbia River Field Station, Cook, Washington, 1992, *unpublished diet data on northern*

squawfish and smallmouth bass and their prey). To develop this predator-prey relationship, as well as a relationship for smallmouth bass predation, I first determined which prey species were not significantly different from squawfish and centrarchids at $P = .05$, for the ratio of prey SL to predator SL (ANOVA and Fischer's protected LSD, SAS Institute Inc. 1982). The means of these prey species' SL were calculated for 5 to 10 cm increments of predator SLs, for each predator species. These means were then used to determine the relationships between prey SL and predator SL (simple linear regression, Wilkinson 1990).

The average values of the transformed depth and velocity variables for small squawfish in each pool were calculated, weighted by the number of fish per observation. The percentage of small squawfish using cover for each pool was also calculated (percentages were arc-sine transformed). The above seven variables were reduced to two factors (factor analysis, SAS Institute Inc. 1982), with the factor scores weighted by the number of small squawfish in each pool. The effects of squawfish predation were then tested by examining the effects of large squawfish presence and absence (t-tests, Wilkinson 1990), and the effects of large squawfish numbers (simple linear regression, Wilkinson 1990) on the scores of the two factors.

Competition experiments

The experiments used squawfish (SL 36 to 80 mm) and smallmouth bass (SL 42 to 55 mm) to test for decreases in use of cover by small squawfish due to competition with

smallmouth bass. Squawfish used in the experiments were caught in Bear Creek, Colusa County, by seining, while smallmouth bass were caught from Kentucky Ravine by electrofishing and from the South Yuba River at Bridgeport by seining.

Two tanks were set up indoors with two compartments, one with cover (36 plastic aquatic plants), and one without cover. Each compartment had a water depth of 26 cm, a width of 55 cm and a length of 49 cm. Water flow rates through the two tanks were 31 to 58 cm^3/s, resulting in average water velocities of 0.02 to 0.04 cm/s in the tanks. Each compartment was covered with painted wooden covers to prevent fish from jumping out of the tanks, while light was let into the compartments through perforated vertical partitions at the far end of each compartment. Water temperatures were 25 to 25.5 °C. The light regime was 12 h of light, starting at 0700, and 12 h of dark.

A total of 36 experiments (18 in each tank) were run, with each trial lasting 24 to 27 h. Approximately half of the trials had cover in the upstream compartment, while the other experiments had cover in the downstream compartment. Four treatments, with nine replicates each, were used: 1) ten squawfish; 2) ten squawfish and ten smallmouth bass; 3) eighteen squawfish; and 4) eighteen squawfish and eighteen smallmouth bass. The densities of fish used in the experiments fell within the range of densities of juvenile squawfish and smallmouth bass seen in the South Yuba River. Squawfish were withdrawn for use in each trial from a

holding tank containing approximately 200 squawfish. Initial conditions of the experiments (placement of the species) were randomized by flipping a coin. The maximum and minimum SL of each species, for each compartment, was determined before and after each trial. A divider between the two compartments was removed at the beginning of the experiments and replaced at the end, after which the number of fish in each compartment was counted.

The response variables were the mid-point of the range of SL of squawfish and smallmouth bass, and the percent of squawfish and smallmouth bass using cover in each compartment at the end of each trial (percentages were arc-sine transformed). The significance of differences in the mid-point of the range of SL for cover and no cover compartments were determined for each species (Wilcoxon signed-rank test, Wilkinson 1990). I then looked at the effect of fish density on the percent smallmouth bass and squawfish using cover, and the effect of the presence of smallmouth bass on the percent squawfish using cover (general linear model, Wilkinson 1990), while adding, one at a time, the following confounding variables to the model: 1) initial location of smallmouth bass (upstream and downstream); 2) initial location of squawfish (upstream and downstream); 3) location of cover (upstream and downstream); 4) tank effect; and 5) number of hours between lights going on and the end of the experiment. Confounding factors with $P > .05$ were eliminated.

RESULTS

Distribution

Sacramento squawfish was by far the most abundant fish species at and above Purdon Crossing. Squawfish and hardhead were common above Starvation Bar (Fig. 1). Smallmouth bass was the most abundant fish species in pools downstream of Starvation Bar (Fig. 2). In addition, young-of-year smallmouth bass were the only fish found in riffles at Bridgeport. Young-of-year smallmouth bass were also captured in Kentucky Ravine.

Available habitat

The 73 sections that were snorkel surveyed had an average width of 16.5 m, an average length of 79 m, and an average maximum depth of 2.8 m. Cover was poor in 10, fair in 39, and good in 24 of these sections. Most sections had large rock cover, while many sections had aquatic vegetation, woody debris and surface turbulence cover. Most of the snorkeled sections were fairly unshaded, with around 10% shading.

Snorkel survey

Based on a total of 150 snorkel-surveys during 1991-93 of the above 73 sections, the overall percentage of YOY of all species observed was 64%. Analysis of the snorkel survey data (Gard 1994a) suggests that the addition of hardhead to the fish assemblage has significant positive effects on fish biomass, the number of fish and the number of YOY, based on the statistically significant differences in these snorkel survey measures for Reaches 2 and 3 ($P <$

.05, general linear model and means separation, Wilkinson 1990). Specifically, the mean values of biomass, number of fish and number of YOY in Reach 2 were, respectively, 2,958 g/section, 102 fish/section, and 47 YOY/section, while the mean values of these parameters for Reach 3 were 6,823 g/section, 200 fish/section and 152 YOY/section. In contrast, the addition of smallmouth bass to the fish assemblage had no significant effect on fish biomass or the number of YOY ($P > .05$), and a significant negative effect on the number of YOY ($P < .05$), based on a comparison of these measures for Reaches 3 and 4. Specifically, the mean values of biomass, number of fish and number of YOY in Reach 4 were, respectively, 6,557 g/section, 144 fish/section, and 104 YOY/section.

The size class structure of squawfish and hardhead (Gard 1994b) was significantly different for Reaches 2, 3 and 4 ($P < .01$, Pearson's test for association, Steel and Torrie 1980); the largest difference was due to the addition of hardhead ($C = 2136$), compared to the addition of smallmouth bass ($C = 140$). In addition, there is an increase in the proportion of fish in the smallest size class with the addition of hardhead, while there is an increase in the proportion of squawfish and hardhead in the two largest size classes with the addition of smallmouth bass (Gard 1994b).

Microhabitat use

A total of 1,156 observations of 6,928 fish were made, for an average of 6 fish per observation. Total depth, and

average water column and focal velocities were square-root transformed, focal depth was log transformed, and relative depth was arc-sine transformed. The two factors derived from these microhabitat variables explain 67% of the total variance of the six variables, with the first factor (velocity) most strongly correlated with focal and average water column velocity, and the second factor (depth) most strongly positively correlated with focal and relative depths, but strongly negatively correlated with relative velocity (Table 1).

Three size classes for squawfish (≤ 50 mm, 51-149 mm and ≥ 150 mm; hereafter referred to as small, medium and large) and two size classes for smallmouth bass (≤ 50 mm and > 50 mm; hereafter referred to as small and large), were selected for further analysis. The r^2 values for the squawfish and smallmouth bass size classes were, respectively, 0.041 and 0.136 for the depth factor and 0.359 and 0.272 for the velocity factor ($P < .001$ for all four ANOVA). Figures 3 and 4 show 50 percent probability ellipses that characterize the depth/velocity factors associated with these size classes, as well as for other native species for which I made microhabitat measurements. The 50% probability ellipse for hardhead ≥ 150 mm SL, not shown in Fig. 3, almost completely overlaps the 50% probability ellipse for large squawfish. Notable in these figures is the low overlap in depth and velocity microhabitat use among native species, compared to the much higher overlap between smallmouth bass and squawfish. The

quantitative estimates of microhabitat overlaps between species and size classes of squawfish and smallmouth bass are shown in Table 2.

There was a significant difference between 1992 and 1993 for squawfish for both the velocity and depth factors ($P < .001$) and for smallmouth bass for the depth factor ($P = .047$), but no significant difference between years for smallmouth bass for the velocity factor ($P = .44$). For squawfish, there were significant effects of year and size class ($P < .001$) for both the velocity and depth factors; while the interaction of year and size class was significant for the velocity factor ($P < .001$), it was not significant for the depth factor ($P = .82$). Large squawfish were at significantly greater depths than squawfish less than 150 mm SL, within each year (Table 3). All three size classes were significantly different from each other within each year for the velocity factor (Table 4).

For smallmouth bass, there were significant effects of year ($P = .03$) and size class ($P < .001$) on the depth factor, but no significant interaction ($P = .51$). Large smallmouth bass were consistently found in significantly deeper waters than small smallmouth bass (Table 5). In addition, large smallmouth bass had a significantly greater ($P < .001$) mean velocity factor score (0.3) than small smallmouth bass (- 0.21).

Cover was used by 80% of smallmouth bass, with little difference between large and small smallmouth bass. Cover was used much less (< 60%) by squawfish. Large rocks were

the most common type of cover used by both squawfish and smallmouth bass (Gard 1994b).

Squawfish microhabitat use

While there were statistically significant differences between the mean percent squawfish using substrate types and the mean percent available for bedrock, boulder and silt (Gard 1994b), these differences are probably not truly significant, given that errors in my estimation of the percentage of substrate types available in each pool (± 10%) were greater than the mean differences between use and availability for the above substrate types.

Squawfish use of cover was not independent of cover availability ($P < .01$), with squawfish using cover more when more cover was available. Specifically, 57% of squawfish in pools with good and fair cover were observed using cover, while 41% of squawfish in pools with poor cover were observed using cover. The proportion of squawfish using cover at Purdon, Edwards and Illinois Crossing was significantly different for the three size classes of squawfish ($P < .01$), with 55% of squawfish less than 150 mm SL using cover, and only 32% of large squawfish using cover.

Effects of squawfish predation

The mean prey size of squawfish can be predicted using the equation: Prey SL = 13.94 + 0.2 x Predator SL (r^2 = 0.54); while the mean prey size of smallmouth bass can be predicted using the equation: Prey SL = 16.65 + 0.2 x Predator SL (r^2 = 0.87, data from U.S. Fish and Wildlife Service, Columbia River Field Station, Cook, Washington,

1992, *unpublished data on northern squawfish and smallmouth bass and their prey*, graphs of relationships in Gard 1994b). Based on the microhabitat data, the average SL for large squawfish was 275 mm; using the equation given above for squawfish, the mean prey size for a 275 mm squawfish would be 69 mm SL. Accordingly, I looked at the response of squawfish less than 70 mm SL to the presence or number of large squawfish.

The two factors for small squawfish microhabitat use explain 69% of the total variance of the seven variables. The first factor (depth) is strongly correlated with total, focal and relative depths, while the second factor (velocity/cover) is strong positively correlated with average and focal velocities and strongly negatively correlated with the percent squawfish using cover (Table 6).

The mean value of the velocity/cover factor score for the eight pools lacking large squawfish (0.131) was significantly greater (P = .01) than for the 26 pools that held large squawfish were present (-0.048). When one outlier pool without large squawfish was eliminated, the mean value of the depth factor score for the seven remaining pools lacking large squawfish (0.108) was significantly greater (P = .02) than the 26 pools containing large squawfish (-0.03, t-test, SAS Institute Inc. 1982). The elimination of this outlier is justified, since the value for this pool was based on only two observations. In contrast, the mean number of observations/pool for squawfish less than 70 mm SL was 6.4. There was no significant

relationship between the scores of the above two factors and the number of large squawfish ($P > .89$).

Competition experiments

There was no significant relationship between the fish's use of cover and SL for either squawfish ($P = .80$) or smallmouth bass ($P = .18$). This result is not inconsistent with the field microhabitat data, given the narrow range of sizes used in the experiments. Accordingly, SL was not used as a factor in further analysis. All of the confounding factors had a p value greater than 0.05 in the full model, and thus were not used in further analysis. There was no significant effect of fish density on the percentage of smallmouth bass using cover ($P = .17$, t-test, SAS Institute Inc. 1982). Neither fish density, smallmouth bass presence, nor their interaction had a significant effect on the percent squawfish using cover ($P > .5$, two-way ANOVA, Wilkinson 1990). Similarly, the mean percentage of squawfish using cover in the presence of smallmouth bass (74%) was not significantly different ($P = .53$, t-test, SAS Institute Inc. 1990) from the percentage of squawfish using cover in the absence of smallmouth bass (79%). Finally, there was no significant effect ($P = .69$, ANOVA, Wilkinson 1990) of fish density (10, 18-20, 36 fish) on the percentage of squawfish using cover.

DISCUSSION

I conclude from this study that: 1) segregation of microhabitat use by size class and species, and shifts of juvenile squawfish to shallower and slower velocity waters

in the presence of large squawfish, allow native fish species and size classes to coexist; 2) the increases in fish numbers and biomass observed with the addition of hardhead to the native fish assemblage indicate that the reintroduction of native species would not be likely to have an adverse effect on the native species already present; 3) predation by smallmouth bass is the most likely cause of reductions in abundance of squawfish and hardhead, by limiting recruitment of these species, and the limited distribution of California roach; 4) competition between juvenile smallmouth bass and juvenile squawfish does not play a major role in enhancing the predation; and 5) cover is not a limiting resource for juvenile fish in the South Yuba River.

Coexistence of native species

Intraspecific predation risk is reduced by different size classes of both squawfish and smallmouth bass being segregated by depth and/or velocity microhabitat use; similar patterns were reported for smallmouth bass by Sechnick et al. (1986), and for other species by Baltz and Moyle (1984) and Moyle and Vondracek (1985). In contrast, substrate does not appear to be an important microhabitat variable for squawfish, since they seem to be using substrate types in proportion to their occurrence. The relatively low overlap between native species, with most of the available space in the microhabitat phase-plane occupied (Fig. 3) is consistent with these species having had a sympatric distribution for a long period. Similar patterns

of ecological segregation of species and sizes classes of native fish assemblages have been seen in other California streams (Alley and Li 1977, Baltz and Moyle 1984, Moyle and Vondracek 1985, Moyle et al. 1982).

Squawfish less than 70 mm SL use cover more and are in lower velocities and shallower depths when squawfish predators are present. The greater use of cover by small squawfish would directly reduce predation risk, while their shift to lower velocities and shallower depths would further reduce microhabitat overlap with large squawfish, and thus lower predation risk. The microhabitat shifts of juvenile squawfish seen in this study in response to risk of intraspecific predation are similar to the microhabitat shifts of juvenile smallmouth bass observed by Schlosser (1987) in response to risk of intraspecific predation, and microhabitat shifts observed by Rahel and Stein (1988), Brown and Moyle (1991), Brown and Brasher (in press) and Schlosser (1987, 1988) in response to interspecific predation. Further, the shift in use of cover in this study is consistent with the role of cover seen in Fraser and Cerri's (1981) experiments. The difference in cover use between size classes of squawfish is consistent with the fact that squawfish less than 150 mm SL are at greatest risk of predation by large squawfish (Gard 1994b), and thus would be expected to use cover more to reduce their risk of predation. The lack of any significant relationships between small squawfish microhabitat use and large squawfish numbers indicates that the presence, rather than number, of

squawfish predators, is controlling the microhabitat shift of small squawfish. This is consistent with behavioral observations that large squawfish move throughout individual pools, making one squawfish as much of a perceived predation risk as 20 squawfish.

Reintroduction of native species

Based on the effects seen in this study of the addition of hardhead to the native fish assemblage, reintroduction of other native fish species would not be likely to have an adverse effect on the native fishes already present. The increases in biomass, number of fish and number of YOY with the addition of hardhead to the native fish assemblage can be attributed to the lack of competition of hardhead with the other native species, as a result of having had sympatric distributions for a long period of time. Competition of hardhead with rainbow trout and suckers is precluded by partitioning of space in the stream, with respect to depth and velocity, while competition with squawfish is precluded by partitioning of food resources. Specifically, large squawfish are largely piscivorous, while hardhead ≥ 150 mm SL feed largely on large invertebrates and aquatic plants (Moyle 1976). The increase in the percentage of the smallest size class of squawfish and hardhead (YOY) with the addition of hardhead is likely due to the greater fecundity and earlier age of maturity, and thus greater reproductive potential, of hardhead, as compared to squawfish (Moyle 1976).

Smallmouth bass predation

Young-of-year squawfish and hardhead are almost entirely absent in Reach 4, presumably due to predation by smallmouth bass. Specifically, the mean number of YOY squawfish and hardhead within the distribution of smallmouth bass, excluding the farthest upstream one or two pools, was 6 fish/pool, resulting in the decrease in all YOY fish seen with the addition of smallmouth bass to the fish assemblage. I attribute the high densities (> 100 fish/pool) of small squawfish and hardhead in the one or two pools furthest upstream in the distribution of smallmouth bass to upstream supplies of these fish, carried in by river flow, exceeding the predation capacity of the smallmouth bass in these pools.

Although California roach (maximum SL 90 mm) were probably originally eliminated from the South Yuba River in the late 1800's by sediment loads from hydraulic mining (Gard 1994a), the present distribution of roach, restricted to Kentucky Ravine, is probably due to smallmouth bass in the South Yuba River acting as a biological barrier. Kentucky Ravine provides roach and young-of-year suckers a refuge from predation by smallmouth bass because the shallow depths exclude larger, piscivorous smallmouth bass. Specifically, the minimum size of predatory smallmouth bass for the size range of native fish found in Kentucky Ravine (> 30 mm) would be 60 to 80 mm SL (Gard 1994b); the mean total depth for smallmouth bass of this size range from the microhabitat data (60 cm) was greater than the maximum depth

found in Kentucky Ravine (54 cm). The role of smallmouth bass predation is also supported by my field observations that signal crayfish (*Pacifastacus leniusculus*), another important component of the diet of adult smallmouth bass (Moyle 1976), were common in Kentucky Ravine but rare in the South Yuba River at Bridgeport.

The increase in the proportion of the two largest size classes of hardhead and squawfish with the addition of smallmouth bass can be attributed to selective predation by smallmouth bass on the other two smaller size classes. Smallmouth bass predation appears the most likely cause for the absence of YOY squawfish and hardhead in two pools at Bridgeport on September 16, 1993, given the presence of 40-50 squawfish and hardhead less than 50 mm SL in each of these pools on July 29 and 30, 1993. There is some overlap between the microhabitat use of young-of-year squawfish and piscivorous smallmouth bass, allowing predation to occur (Table 2). This overlap would likely be higher during predation by large smallmouth bass, since Kwak et al. (1992) found that large smallmouth bass shift to shallower and lower velocity waters when they feed. In addition, since the overlaps between large smallmouth and small squawfish for depth/velocity (14.6%), cover (74.2%) and substrate (87.2%) are greater than the respective overlaps between large squawfish and small smallmouth (8.4%, 51.7% and 61.1%), squawfish would be more vulnerable to interspecific predation than smallmouth bass when the two species are together, as at Bridgeport.

rather than moving upstream from Reach 4.

If the above suspected barrier to upstream migration of introduced centrarchids is effective, actions to reduce or extirpate these species from the South Yuba River are probably not warranted. In addition, such actions would probably not be successful due to the populations of these species in Englebright Reservoir (Gard 1994*a*). Elimination of these introduced species may also be an unrealistic goal because the disturbed nature of Class III waters, such as the South Yuba, tends to result in introduced species being integral parts of the biotic community (Moyle & Sato 1991). Thus, a reasonable goal would be to protect the portions of the South Yuba River above Starvation Bar for conservation of native species, while leaving the Bridgeport area as a recreational resource based on fishing for smallmouth bass.

Monitoring of the distribution and abundance of fish species, via snorkel surveys and electrofishing, is important in evaluating the effectiveness of and altering other management actions. At a minimum, annual snorkel surveys from Starvation Bar to Bridgeport would show whether or not the upper end of the distribution of smallmouth bass had extended upstream, potentially requiring additional controls, while annual electrofishing of Kentucky Ravine would show whether or not introduced species were having adverse effects on California roach populations, potentially requiring installation of fish barriers in Kentucky Ravine near its confluence with the South Yuba River and

eradication of introduced fish from Kentucky Ravine.

Tributaries: South Yuba River tributaries play vital roles in sustaining native fish populations by providing a refuge from predation for California roach (Gard 1994c) and temperature refugia and juvenile rearing habitat for rainbow trout. As such, the conservation of native fishes in the South Yuba River would be enhanced by protecting the biotic integrity of these tributaries through either the acquisition of land adjacent to these tributaries or conservation easements for such land. The elimination of introduced fish species from impoundments on South Yuba River tributaries, through draining or the use of rotenone, would also enhance the conservation of native fish in these tributaries. Despite its low rank (Table 4), Kentucky Ravine should have the highest priority for protection, since it is the only place where I found California roach in the South Yuba River watershed. Owl and Rush Creeks are the next most important tributaries, since they can serve as temperature refugia for rainbow trout when water temperatures in the lower portions of the South Yuba River exceed 28 °C; this probably explains why these tributaries have the highest densities of rainbow trout. Missouri Canyon and Spring Creek would have the next highest priority, while the other tributaries would have a relatively low priority with regards to the conservation of native fish.

Although large Sacramento squawfish do prey on small squawfish and hardhead, their effect is not as pronounced as the effect of smallmouth bass predation, in that YOY squawfish and hardhead are relatively abundant in Reaches 1, 2 and 3 (an average of 79 fish/pool). This can be partially attributed to the fact that squawfish do not become piscivorous until they are 150 mm SL, while smallmouth bass can become piscivorous at 50 mm SL (Moyle 1976). Based on the 1992 and 1993 snorkel surveys and the above information, the average density of piscivorous fish in Reach 4 (22 fish/100 m) was much higher than the average density of piscivorous fish in Reaches 1, 2 and 3 (7 fish/100 m). Predation rates presumably would be lower, and thus numbers of young-of-year squawfish and hardhead greater, with lower predator densities. Predation rates in Reach 4 may be further elevated by predation of larval native fish by juvenile smallmouth bass (Harvey 1991, Johnson and Dropkin 1992). Lower activity levels of adult smallmouth bass, as compared to adult squawfish, could inhibit microhabitat shifts of small squawfish, leaving them more vulnerable to predation by smallmouth bass; similarly, Harvey et al. (1988) attributed differences in triggering microhabitat shifts of juvenile cyprinids to the low activity levels of smallmouth bass, as compared to the more active largemouth bass (*Micropterus salmoides*).

Accordingly, smallmouth bass predation probably is responsible for the absence of California roach in the South Yuba River, and the low abundance of Sacramento squawfish

and hardhead in Reach 4 (13 fish/pool, as compared with 125 fish/pool in Reaches 1, 2 and 3) by limiting recruitment. In fact, given the absence of roach in the South Yuba River, the presence of large squawfish and hardhead in Reach 4 is probably due to larger individuals moving downstream from Reach 3, rather than from recruitment in Reach 4. As a result of smallmouth bass predation, there is a substitution of smallmouth bass for native fish, as seen by the lack of change in biomass or number of fish with the addition of smallmouth bass to the fish assemblage. This pattern, as well as the relatively high microhabitat overlap between squawfish and smallmouth bass (Fig. 4), is consistent with the relatively short period of time that smallmouth bass have been in sympatry with the native South Yuba River fish species.

Smallmouth bass competition

Based on the results of the microhabitat experiments, small smallmouth bass do not make small cyprinids more at risk of predation. The experiments were consistent with the field measurements, in that overall the percentage of fish using cover was less for small squawfish (76%) than for small smallmouth bass (90%). Further, since the compartments with and without cover were the same size, and since the above percentages are greater than 50%, both species show a preference for cover, although smallmouth bass have a higher preference for cover.

Cover as a limiting resource

The lack of competition shown in these experiments, as compared with the results of Fausch and White (1986), may indicate that cover is not a limiting resource, given the current densities of juvenile fish in the South Yuba River. Previous studies indicate that space (including cover) is not a limiting resource in California streams because of low population densities (Baltz and Moyle 1993); fish densities in the South Yuba River are relatively low, compared to other California streams (Gard 1994b). Low fish population densities in other California rivers have been attributed to extreme variations in flow (Baltz and Moyle 1993). This factor is probably not responsible for low fish densities in the South Yuba River, since its flows are highly regulated; rather, low fish densities may be due in large part to low productivity; preliminary water quality sampling (Gard unpublished data) indicates that nutrient levels in the South Yuba River may be lower than most similar California rivers.

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Table 1. Correlations of microhabitat depth and velocity variables with derived factors (factor analysis). Factor analysis was conducted using microhabitat data from all observations, with factors weighted by the number of fish per observation.

Variable	Factor 1 (Velocity)	Factor 2 (Depth)
Total Depth	0.58	0.32
Focal Depth	0.60	0.68
Relative Depth	0.08	0.72
Average Velocity	0.87	0.06
Focal Velocity	0.89	- 0.30
Relative Velocity	0.12	- 0.74

Table 2. Quantitative estimates of microhabitat overlap between different size classes (mm SL) of squawfish (SQ) and smallmouth bass (SMB). Depth/velocity overlaps were computed as the percentage of cases misclassified using a linear discriminant analysis of the six depth and velocity microhabitat variables. Overlaps in substrate and cover were computed using Schoener's (1970) formula.

Species/Size Classes	Inter[1]	Depth/Vel	Cover	Substrate
SQ ≤ 50, SQ ≥ 150	p	28.3%	81.4%	71.4%
SQ 51-149, SQ ≥ 150	p	7.1%	81.0%	80.2%
SMB ≤ 50, SMB > 50	p	17.1%	84.0%	78.0%
SQ ≤ 50, SMB ≤ 50	c	32.1%	70.3%	78.4%
SQ 51-149, SMB ≤ 50	c	16.1%	69.3%	63.0%
SQ ≥ 150, SMB ≤ 50	p	8.4%	51.7%	61.1%
SQ < 50, SMB > 50	p	14.6%	74.2%	87.2%
SQ 51-149, SMB > 50	p/c	32.0%	76.8%	83.5%
SQ ≥ 150, SMB > 50	c	26.4%	59.5%	76.4%

[1] Type of interaction: p = predation, c = competition

Table 3. Mean values of depth factor for each year and size class of Sacramento squawfish. Values with the same letter are not significantly different at $P = .05$ (general linear model and least-square means separation technique). Results show that, within each year, squawfish ≥ 150 mm SL were in significantly deeper water than squawfish < 150 mm SL.

	Year	
Size Class (SL, mm)	1992	1993
≥ 150	.243 a	.144 a,b
51-149	.135 b	.019 c
≤ 50	.113 b	- .030 c

Table 4. Mean values of velocity factor for each year and size class of Sacramento squawfish. Values with the same letter are not significantly different at $P = .05$ (general linear model and least-square means separation technique). Results show that, within each year, velocities were significantly different for all three size classes of squawfish, with large squawfish at the fastest velocities.

	Year	
Size Class (SL, mm)	1992	1993
≥ 150	.3495 b	.6041 a
51-149	.0709 c	.3499 b
≤ 50	- .2276 d	- .2563 d

Table 5. Mean values of depth factor for each year and size class of smallmouth bass. Values with the same letter are not significantly different at $P = .05$ (general linear model and least-square means separation technique). Results show that, within each year, large smallmouth bass were consistently in significantly deeper waters than small smallmouth bass.

	Year	
Size Class (SL, mm)	1992	1993
> 50	.244 b	.417 a
≤ 50	- .057 c	.038 c

Table 6. Correlations of microhabitat depth, cover and velocity variables for squawfish less than 70 mm SL with derived factors (factor analysis). The analysis only used data from pools at Edwards, Purdon and Illinois Crossing (Fig. 1) where squawfish less than 70 mm SL were present (*n* = 34). The microhabitat data used in the factor analysis were the average values for each pool of the six depth and velocity variables, weighted by the number of squawfish per observation; and the percentage of squawfish using cover in each pool. The factor analysis used a weighting factor of the number of squawfish less than 70 mm in each pool.

Variable	Factor 1 (Depth)	Factor 2 (Vel/Cover)
Total Depth	0.90	0.02
Focal Depth	0.96	0.07
Relative Depth	0.62	0.20
Average Velocity	0.07	0.95
Focal Velocity	0.23	0.93
Relative Velocity	- 0.56	- 0.21
Percent Cover Use	- 0.13	- 0.69

Figure Legends

Fig. 1. Map of South Yuba River sampling locations, reaches used in analysis of snorkel survey data, and distribution/abundance of fish species. Definition of abundance categories: common is > 30 percent of fish present in pool; few is < 10 percent of fish present in pool.

Fig. 2. Plot of smallmouth bass (expressed as percentage of fish seen in snorkel survey) versus distance upstream from Englebright Reservoir, at the downstream end of the study area. Line shows result of simple linear regression (Wilkinson 1990) of percent smallmouth bass versus distance upstream of Englebright Reservoir, using only data from within the distribution of smallmouth bass (up to 5 km above Englebright Reservoir).

Fig. 3. Plot (Phase plane diagram) of size classes of native fish species in two-dimensional factor score space. Ellipses show 50 percent probabilities of depth and velocity microhabitat use for rainbow trout (RT), and size classes (mm SL) of Sacramento squawfish (SQ) and Sacramento sucker (SU). Ellipses were computed based on the mean (at the center of ellipse) and standard deviation of factor scores for each species and size class.

Fig. 4. Plot (Phase plane diagram) of size classes (mm SL) of Sacramento squawfish (SQ) and smallmouth bass (SMB) in two-dimensional factor score space. Ellipses show 50 percent probabilities of depth and velocity microhabitat use, and were computed based on the mean (at the center of ellipse) and standard deviation of factor scores for each species and size class.

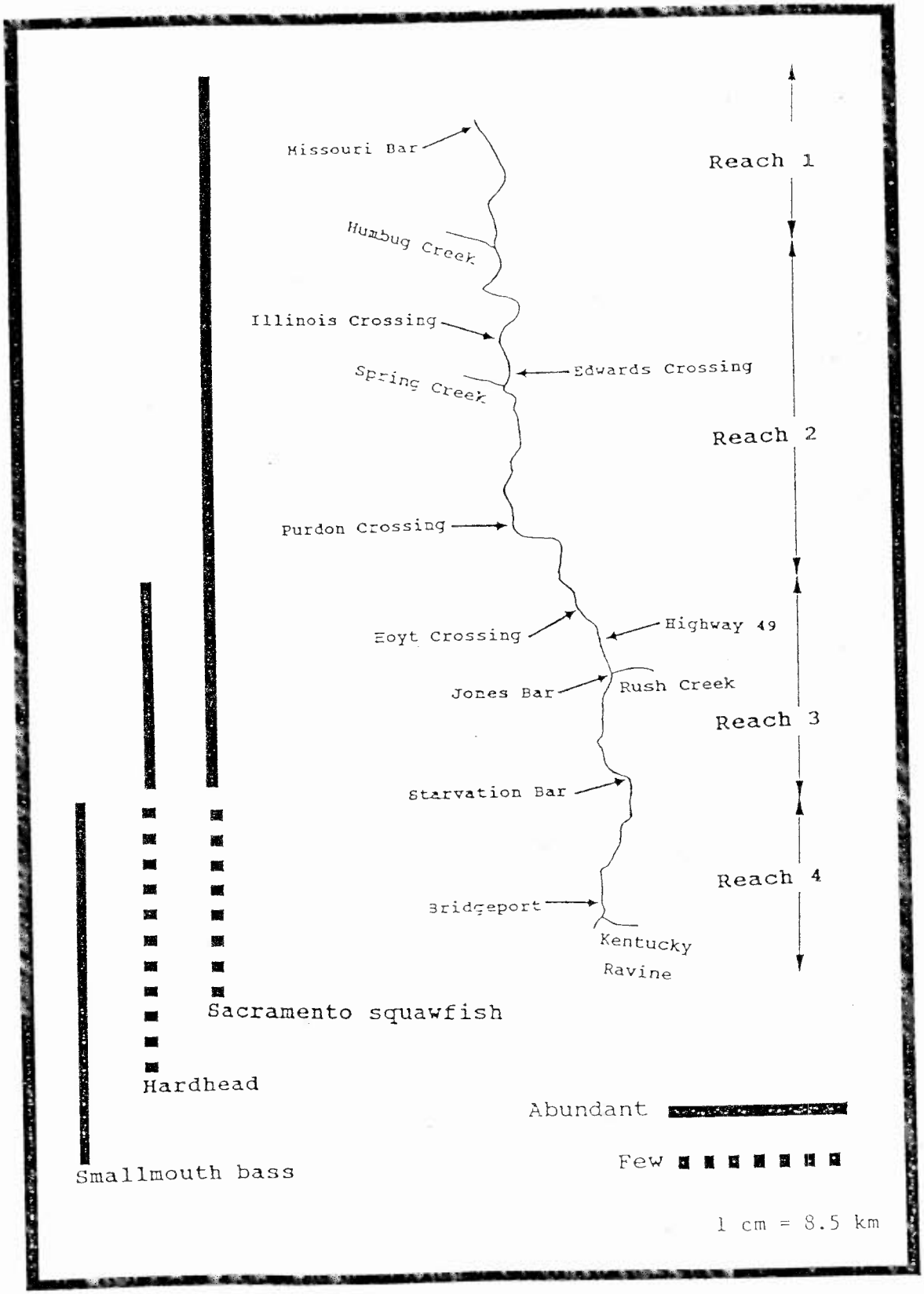
Missouri Bar
Humbug Creek
Illinois Crossing
Spring Creek
Edwards Crossing
Purdon Crossing
Eoyt Crossing
Highway 49
Jones Bar
Rush Creek
Starvation Bar
Bridgeport
Kentucky Ravine
Reach 1
Reach 2
Reach 3
Reach 4
Sacramento squawfish
Hardhead
Smallmouth bass
Abundant
Few
1 cm = 8.5 km

Figure 1

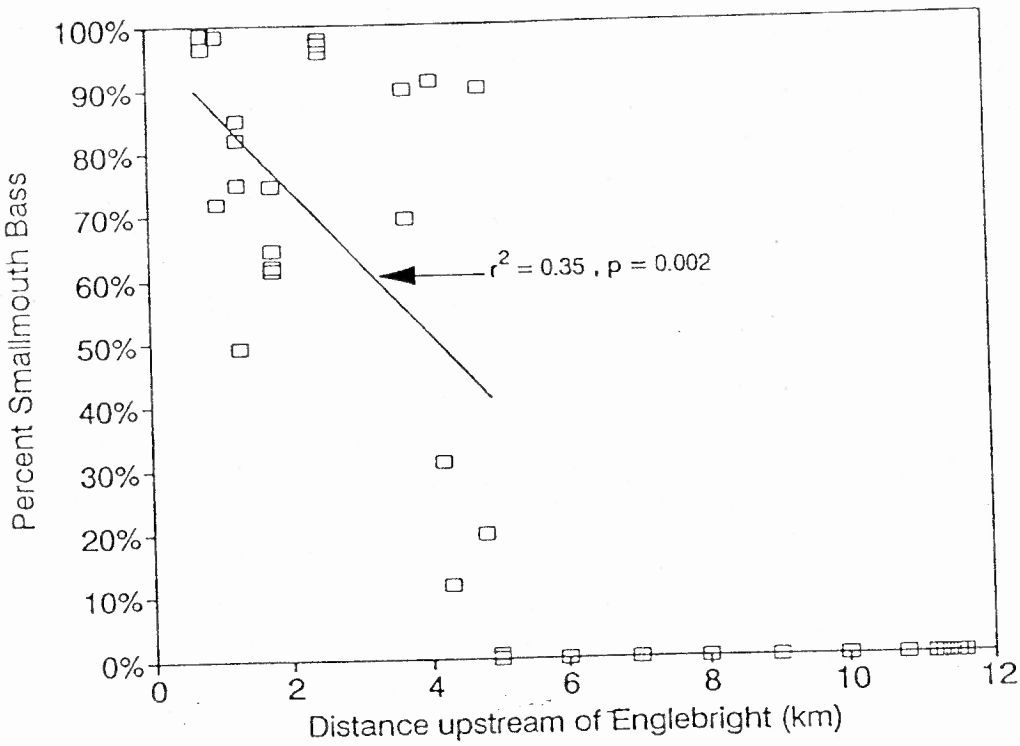
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Smallmouth Bass
$r^2 = 0.35$, $p = 0.002$
0
2
4
6
8
10
12
Distance upstream of Englebright (km)

Figure 2

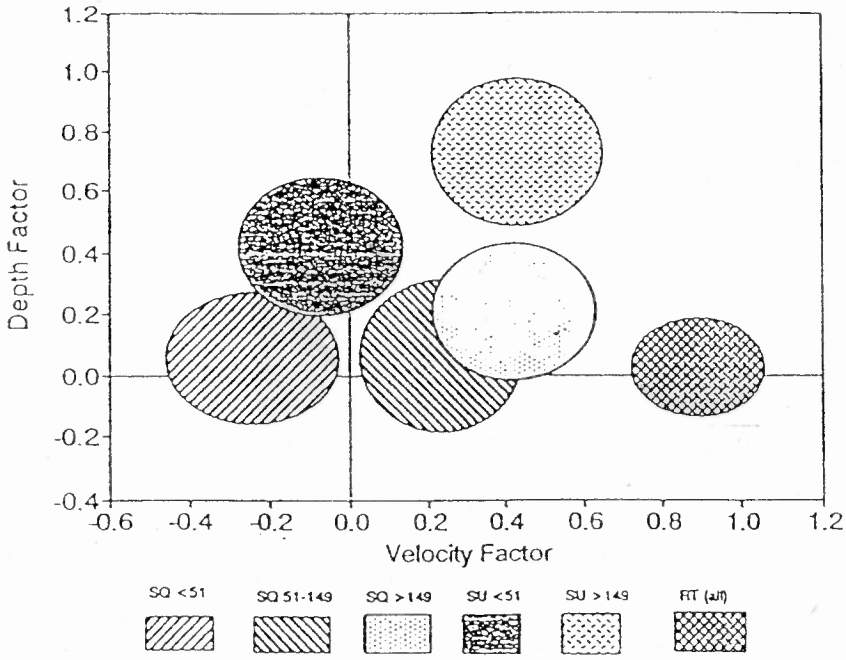
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
Depth Factor
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Velocity Factor
SQ <51
SQ 51-149
SQ >149
SU <51
SU >149
RT (all)

Figure 3

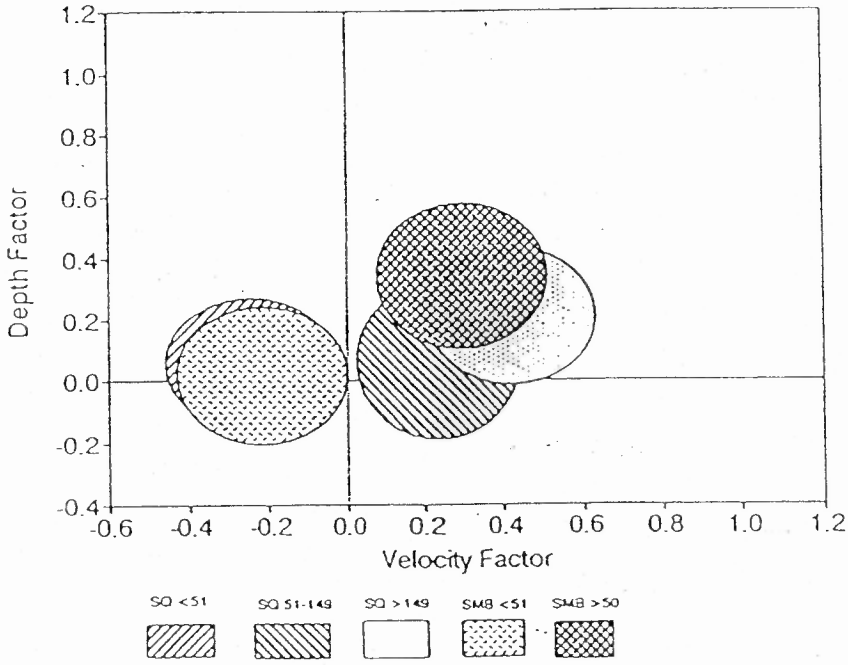
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
Depth Factor
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Velocity Factor
SQ <51
SQ 51-149
SQ >149
SMB <51
SMB >50

Figure 4

Restoration of a California Stream Native Fish Assemblage

Mark F. Gard

ABSTRACT - The South Yuba River has a depleted native fish fauna, with five of the expected nine native fish species absent because of past human abuse of the system. Anadromous Pacific lamprey (*Lampetra tridentata*) and chinook salmon (*Oncorhynchus tshawytscha*) are excluded by a downstream barrier. Three smaller native species, riffle sculpin (*Cottus gulosus*), California roach (*Hesperoleucus symmetricus*) and speckled dace (*Rhinichthys osculus*), were probably extirpated from the South Yuba River by the effects of hydraulic mining in the late 1800's. Current suspended sediment loads, together with water temperature and possibly nutrient concentrations, reduce Sacramento squawfish (*Ptychocheilus grandis*) growth rates. Roach appear to be prevented from reinvading the South Yuba River due to predation by introduced smallmouth bass (*Micropterus dolomieui*). Smallmouth bass also presumably limit the abundance of Sacramento squawfish and hardhead (*Mylopharodon conocephalus*) due to predation on young-of-year fish. High water temperatures are the most likely factor affecting the current distribution of rainbow trout (*Oncorhynchus mykiss*). Due to lower temperatures, perennial tributaries to the South Yuba River are important juvenile trout rearing habitat. The fish community of the South Yuba River can be partially restored through a combination of reintroductions and increased flows.

Introduction

There has been a severe decline of the native fish fauna of California, largely due to water diversions, watershed degradation, and introduction of exotic species (Moyle & Williams 1990). This trend is epitomized by the South Yuba River, which has been subject to many types of human abuses, including: 1) current and historical sediment loadings as a result of hydraulic mining at Malakoff Diggins in the late 1800s; 2) elevated water temperatures due to flow regulation; 3) predation and competition by introduced fish species; and 4) blockage of anadromous fish passage due to downstream dam construction. The expected native fish assemblage in a Sierra foothill stream, such as the South Yuba River, would be rainbow trout, Sacramento squawfish, hardhead, Sacramento sucker (*Catostomus occidentalis*), California roach, speckled dace, Pacific lamprey, chinook salmon and riffle sculpin (Moyle 1976). Anadromous Pacific lamprey and chinook salmon were present in the 1920s and 1930s (Gard 1994*a*), but are now excluded by Englebright Dam, located downstream of the South Yuba River and constructed in 1939-40.

Management objectives for the South Yuba River are to maintain/restore the native fish community, and to improve the habitat for these species (T.L. Taylor, California State Department of Parks and Recreation (State Parks), *personal communication*). However, evaluating the feasibility of restoring the native fish community requires knowledge of

the causes of extinction, of factors limiting the existing fish populations, and of the suitability of the habitat for reintroductions.

The goals of this study were to: 1) determine which native fish species, plus any introduced species, are present in the South Yuba River and its tributaries; 2) ascertain the distribution and abundance of these species; 3) discern what factors are limiting the distribution and abundance, or causing the absence, of these species; and 4) evaluate how various management options would aid in the conservation of native fish in the South Yuba River watershed.

Study Area

Field studies were conducted on the South Yuba River and its tributaries during the summers of 1991, 1992 and 1993. The South Yuba River is located on the western slope of the Sierra Nevada, in the Sacramento River basin. The South Yuba River is 102 km long, with a mean gradient of 10.4%, and drains approximately 900 km^2 (Palmer & Vileisis 1993). The study area, located near Nevada City, comprised the lowermost 38 km of the South Yuba River (165-701 m above sea level), from Missouri Bar to Bridgeport (Figure 1), where the South Yuba River enters Englebright Reservoir. Channel slopes of the South Yuba River within the study area vary from 0.3% to 7.9% (Gard 1994*b*). Mean daily maximum water temperatures at Jones Bar (Figure 1) for 1967-1979 ranged from 5 °C in December and January to 24 °C in July

(Figure 2) (U.S. Geological Survey (USGS) 1967-79).

Much of the South Yuba River watershed above Humbug Creek (Figure 1) is part of Tahoe National Forest, administered by the U.S. Forest Service. State Parks manages two areas within the South Yuba River watershed: Malakoff Diggins State Historic Park, in the Humbug Creek drainage, and the South Yuba Recreation Area, which is partially owned by State Parks, and partially managed by State Parks on behalf of the U.S. Bureau of Land Management (BLM). State Parks began acquisition at Malakoff Diggins in 1964 (Taylor 1987), is currently acquiring additional land along the South Yuba River, and plans to obtain ownership of the BLM's portion of the South Yuba Recreation Area in the future (S. Harrison, State Parks, *personal communication*).

Mean monthly South Yuba River flows in the study area for 1940-1949 and 1959-1992 ranged from 1.06 m^3/s in August and September to 23.3 m^3/s in May (USGS 1942-92). Flows during my field studies in 1991 and 1992 were around 0.85 m^3/s, while flows during my field studies in 1993 averaged 2.2 m^3/s (USGS 1991-93). The mean annual peak flow at Jones Bar from 1966 to 1992 is 220.6 m^3/s, while the maximum flow for the period of record was 1,520 m^3/s, on December 22, 1964 (USGS 1966-92).

Flows in the South Yuba River are highly regulated as a result of 20 upstream reservoirs (Gard 1994a) with a combined capacity of approximately 28,100 ha-m, which is equivalent to nine months of average flows at Jones Bar

(USGS 1991, California Department of Fish & Game (CDFG) files, Palmer & Vileisis 1993). Most of the upstream reservoirs, including Lake Spaulding (Figure 3), are operated by the Pacific Gas and Electric Company (PG&E) for power generation. In addition, PG&E diverts substantial quantities of water out of the South Yuba River basin. PG&E's out-of-basin diversions, for the period of 1966 to 1991, averaged 14.7 m^3/s to the Bear River via the Drum Canal and 2.6 m^3/s to Deer Creek via the South Yuba Canal, while 2.3 m^3/s of flows were diverted into the South Yuba River basin from the Middle Yuba River basin (Figure 3) (USGS 1966-91). Thus, for this period, net diversions out of the South Yuba River basin averaged 15 m^3/s, versus average yearly flows at Jones Bar of 12 m^3/s (USGS 1966-91). PG&E is required to maintain a minimum of 0.14 m^3/s in the South Yuba River at Lang's Crossing, just below the diversion points (CDFG files). Monthly average South Yuba River flows at Lang's Crossing were less than 0.14 m^3/s for nine out of 300 months for 1967 to 1991 (USGS 1967-91). Several other reservoirs, including Bowman Lake on Canyon Creek (Figure 3), a major tributary of the South Yuba River, are operated by the Nevada Irrigation District, for irrigation of approximately 11,300 ha and domestic water supply for 57,000 people (Palmer & Vileisis 1993).

With the exception of Canyon Creek, all of the tributaries of the South Yuba River below Spaulding Reservoir are unregulated. Contributions of these

tributaries to Jones Bar flows can be substantial, especially during low flow months (Gard 1994*a*, USGS 1967-91). Tributaries within the study area include Missouri Canyon, Humbug Creek, Spring Creek, Rock Creek, Rush Creek, Owl Creek, French Corral Creek and Kentucky Ravine (Figure 1). French Corral Creek has intermittent flows, with isolated pools remaining during the summer, while Humbug, Spring, Rock, Owl and Rush Creeks, Missouri Canyon and Kentucky Ravine have perennial flows. There are small impoundments on Rock Creek, Kentucky Ravine and Owl Creek.

Currently, there are no diversions within the study area. However, prior to 1966 there was a major diversion ($\geq$ 1.1 m^3/s) at the Excelsior Dam, approximately 1.6 km upstream of Hoyt Crossing (Figure 1), resulting in dewatering of the stream channel for 1 km downstream in 1937 (CDFG files).

Methods

Water Temperature: I investigated whether monthly mean water temperatures (USGS 1967-79) for July and August (the months with elevated water temperatures) could be predicted using monthly average flows at Jones Bar (USGS 1967-79) and monthly mean air temperatures in Nevada City (National Oceanic and Atmospheric Administration 1967-79) (multiple regression, Wilkinson 1990). Water temperatures were measured at Highway 49 and Missouri Bar during the summer of 1991, at Jones Bar during the summer of 1992, and at Jones Bar and Missouri Bar during the summer of 1993 (Figure 1),

using Peabody Ryan Model "J" continuously-recording thermographs. In addition, one-time measurements of water temperatures were taken at each site sampled on the South Yuba River (Figure 1) plus tributaries and Englebright Reservoir (Gard 1994a).

Fish Distribution and Relative Abundance: The South Yuba River was sampled at nine sites: Bridgeport, Jones Bar, Highway 49, Hoyt Crossing, Purdon Crossing, Edwards Crossing, Illinois Crossing, Humbug Creek and Missouri Bar (Figure 1). The sites were divided into sections with uniform habitat types (pool, run, riffle or glide).

The fish species composition of riffle and glide sections were determined by electrofishing. The abundance of fish species in sections with a maximum depth greater than 1 m (pools and runs) was estimated for the above sites using snorkel surveys, where two or three people would swim upstream and count the number of fish of each species in each of two to four size classes. Snorkel surveys were also performed between Jones Bar and Bridgeport in 1992, between Starvation Bar (5 km above Bridgeport) and Bridgeport in 1993, and above Hoyt Crossing in 1992. Estimates of fish density were computed using the above snorkel survey data and measurements of pool lengths.

Tributaries: The species composition of tributaries of the South Yuba River was determined in 1991 and 1992 by electrofishing. Specifically, Spring Creek, Missouri Bar and Humbug Creek were sampled in 1991, and Rush Creek and

Kentucky Ravine were sampled in 1992. Fish caught were identified, and their standard length, and in some cases their weight, measured.

In 1993, the species composition and the total number and biomass of fish was determined for the tributaries sampled in 1991 or 1992, plus French Corral, Rock and Owl Creeks, using the Leslie catch per unit effort method (Van Den Avyle 1993). After selecting a representative section of the tributary, generally around 50 m in length, near its confluence with the South Yuba River, block nets were placed at the top and bottom of the section. Three passes were then made through the section with electrofishing equipment. At the end of each pass, each fish caught was identified, its standard length and weight measured, and then was released outside of the section. Afterwards, the length, several widths (used to calculate the average width), and maximum depth of each section were measured, and the percentage of habitat types (run, riffle, cascade and pool) and substrate types within each section visually estimated.

Effort for each pass was defined as the number of minutes spent electrofishing, while catch was the total number or weight of fish caught in the pass. The total biomass and number of fish in each section was estimated as the value of the cumulative catch corresponding to a value of zero for catch per unit effort (simple linear regression, Wilkinson 1990). For tributaries where the regression was not statistically significant for the biomass estimate, the

biomass for each species was estimated by multiplying the calculated number of fish by the average weight of the fish caught for that species. The following variables were selected to use in ranking the tributaries: 1) biomass of rainbow trout; 2) number of rainbow trout; 3) biomass of native fish; and 4) number of native fish. I then decided whether to normalize these variables by the following section dimensions based on the statistical significance of their relationship (simple linear regression, Wilkinson 1990): 1) length; 2) surface area; and 3) volume. The tributaries were then ranked, based on the score of the first principal component found using these four fish variables (Wilkinson 1990).

Results

Water Temperature: Variations in July and August monthly mean water temperatures (°C) at Jones Bar can be predicted using monthly average flows (m^3/s) at Jones Bar and monthly mean air temperatures (°C) in Nevada City via the following equation ($r^2 = 0.722$, $p < 0.0001$, $n = 23$):

Water Temp = 8.37 - 0.21 x Flow + 0.766 x Air Temp

The thermograph data indicated that, even as far upstream as Missouri Bar, water temperatures can get as high as 26.5 °C (Table 1). In addition, water temperatures in 1993 were cooler than in 1991 and 1992. The one-time measurements of water temperatures indicate that, during periods of high water temperatures in the South Yuba River (greater than 20 °C), most of the tributaries are substantially cooler than

adjacent portions of the South Yuba River (Gard 1994*a*). In addition, Englebright Reservoir, at a depth of 1.5 m, was 6 °C cooler than the South Yuba River at Bridgeport on August 5, 1992.

Fish Distribution and Relative Abundance: The following native fish species were found in the South Yuba River and/or its tributaries: rainbow trout, Sacramento squawfish, Sacramento sucker, hardhead, and California roach. In addition, the following introduced fish species were observed: smallmouth bass, green sunfish (*Lepomis cyanellus*), bluegill (*Lepomis macrochirus*), brown bullhead (*Ictalurus nebulosus*), brown trout (*Salmo trutta*) and carp (*Cyprinus carpio*).

Rainbow trout were most abundant in the South Yuba River in Reach 1 (Figure 1), and were much more abundant at all locations in the South Yuba River in 1993 than in 1991 and 1992 (Figure 4). For example, I observed 16 rainbow trout below Starvation Bar in 1993, while I did not see any rainbow trout below Jones Bar in 1992. The few rainbow trout found in the South Yuba River in Reaches 2, 3 and 4 in the summers of 1991 and 1992 were adults, and were generally near colder-water tributaries or below a waterfall (where dissolved oxygen concentrations would be high). Rainbow trout also move upstream from Englebright Reservoir to Bridgeport in the winter (Gard, *unpublished data*). Since brown trout were stocked in Englebright Reservoir as recently as 1984 (Gard 1994*a*), they may also move upstream

to Bridgeport in the winter.

Sacramento sucker adults were found throughout the South Yuba River, but in fairly low numbers (an average of one to two large individuals [around 350 mm SL] per snorkeled section). Juvenile suckers [100 to 250 mm SL] were typically the only fish found in riffle and shallow run habitats in Reaches 1, 2 and 3, while young-of-year suckers were usually found in shallow areas of pools in the South Yuba River. Sacramento squawfish were found in the South Yuba River throughout the study area, and were by far the most abundant fish species in the South Yuba River in Reaches 1 and 2 (Figure 1). Hardhead were found in the South Yuba River in Reaches 3 and 4 (Figure 1). Smallmouth bass were only found in the South Yuba River in Reach 4, along with most individuals of other introduced fish species. Smallmouth bass were the most abundant fish species in pools in Reach 4 (Gard 1994*c*), and young-of-year smallmouth bass were the only fish found in riffles at Bridgeport. Occasional individuals of other introduced fish species were observed farther upstream (Table 2).

Most of the tributaries had primarily juvenile rainbow trout, with low numbers of juveniles of introduced fish species and other native species present in some tributaries (Table 2). In contrast, an isolated pool in French Corral Creek only had green sunfish and bluegill, and the fish species composition of Kentucky Ravine was largely introduced and native warm-water fishes (Table 2).

California roach were only found in Kentucky Ravine; roach were much more abundant in 1993 than in 1992. Based on length-frequency histograms (Gard 1994*a*), most of the rainbow trout in tributaries were young-of-year, although some of the tributaries (Table 2) had some larger rainbow trout (up to 192 mm SL).

Ranking of Tributaries: For most of the tributaries, there was a good fit of the data to the expected linear relationship between catch per unit effort and cumulative biomass or numbers for the three-pass electrofishing sampling (Table 3); all of the regressions were statistically significant, with the exception of biomass for Owl and French Corral Creeks. Since the only section-size relationship significant at the $p = 0.05$ level was for rainbow trout biomass and section volume ($r^2 = 0.58$), the other three fish variables were not normalized for the size of the section, while rainbow trout biomass was divided by section volume. The first principle component of the four ranking criteria for South Yuba tributaries (Table 4) explained 84% of the total variance of these four criteria.

Discussion

A statewide system of aquatic habitats managed for biodiversity (Aquatic Diversity Management Areas (ADMA)) has been proposed as a means of stemming the decline of native California fish species (Moyle & Yoshiyama 1994). The South Yuba River is a good candidate for an ADMA, since most of the land along the South Yuba River is already managed by

public agencies. Factors to consider in selecting an ADMA include: 1) protection of entire drainages; 2) barriers that prevent invasion of introduced species from downstream areas; and 3) wide buffer zones to protect aquatic ecosystems from disturbances in adjacent terrestrial environments (Moyle & Yoshiyama 1994). Schlosser (1991) also stresses the importance of considering the entire drainage, through the use of landscape ecology principles, in conserving stream fishes. The South Yuba River would be classified as a Class III ADMA under Moyle & Yoshiyama's (1994) classification system, since it has been extensively and largely irreversibly modified by human activities, specifically sediment loads and flow regulation, despite its natural appearance. Moyle & Sato (1991) suggest that management of Class III preserves focus on species or habitat types, rather than ecosystems. In applying these principles to the South Yuba River, including considering the reintroduction of missing species, factors which will impede the conservation of the native fish species, as well as the feasibility of overcoming these impediments (Table 5), must first be considered.

Sediment Loads: Speckled dace, California roach, and riffle sculpin were apparantly extirpated from the South Yuba River by the tremendous sediment loads from hydraulic mining in the late 1800's. However, current sediment loads from Malakoff Diggins appear to have relatively little effect on the South Yuba River biotic community; while

squawfish growth rates appear to be adversely affected by sediment loads, based on an analysis of condition index data, there appears to be no adverse effect of current sediment loads on aquatic macroinvertebrates, and fish growth and reproduction (Gard 1994*b*). In addition, the low ranking of Humbug Creek (Table 4) is not likely to be due to effects of sediment from Malakoff Diggins State Park, given the findings of Marchetti (*Draft master's thesis,* 1994) that there were few differences in fish or macroinvertebrate numbers in Humbug Creek upstream and downstream of Malakoff Diggins. Accordingly, a reduction in sediment loads from Malakoff Diggins does not appear necessary for protection of the South Yuba River ecosystem. The limited effect of current sediment loadings is consistent with the typical concentrations of suspended sediment (less than 1000 mg/l), limited duration of loadings (approximately 47 days per year), and limited deposition of sediment, due to both the fine particle size of the sediment and the discharges of sediment primarily during high flow periods (in winter and spring) (Gard 1994*b*). However, other considerations may make reductions in sediment loadings from Malakoff Diggins necessary. For example, since it appears that most of the sediment from Malakoff Diggins is not deposited in the South Yuba River, but carried into Englebright Reservoir (Gard 1994*b*), deposition of Malakoff Diggins sediment in Englebright Reservoir, with resultant loss of water storage capacity, may be a concern.

Water Temperature and Flows: High summer water temperatures are the most likely factor limiting the distribution of rainbow trout. Water temperatures in the downstream portions of the South Yuba River in 1991 and 1992 (Table 1) nearly reached or exceeded the maximum temperature for rainbow trout of 28 °C (Moyle 1976), while the cooler water temperatures in 1993 coincided with much greater numbers of rainbow trout in the South Yuba River (Figure 4). The cooler water temperatures in 1993, as compared to 1991 and 1992 (Table 1), probably were due to the higher flows in the summer of 1993. Rainbow trout juveniles, which are more sensitive to high water temperatures, were primarily found in cooler-temperature tributaries. Rainbow trout adults in the South Yuba River downstream of Illinois Crossing in 1991 and 1992 were primarily found near where these tributaries enter the South Yuba River, where they could occupy cooler microhabitats when water temperatures get too high. Similarly, Baltz et al. (1987) found that rainbow trout in the Pit River selected microhabitats that had average water temperatures 0.8 to 2.2 °C cooler than mean available water temperatures. Alternatively, rainbow trout downstream of Starvation Bar may move into the cooler waters of Englebright Reservoir when water temperatures in the South Yuba River become too high; the water temperatures up through the dates of my observations of rainbow trout below Starvation Bar in 1993 did not exceed 26 °C.

Squawfish growth rates in the South Yuba River appear to be affected in part by water temperatures, based on an analysis of squawfish lengths at the age-one annulus; squawfish probably grow fastest at water temperatures around 26 °C (Gard 1994*b*).

State Parks could cooperate with CDFG and other interested parties to petition for increased flow releases to the South Yuba River from Spaulding Reservoir during any amendments of the Federal Energy Regulatory Commission license of this facility. This action would increase populations of rainbow trout in the South Yuba River by reducing high summer water temperatures, but could also further reduce squawfish growth rates. Given the greater trout numbers seen in 1993, as compared to 1991 and 1992, rainbow trout populations would be increased by keeping July and August monthly average daily maximum water temperatures at or below 23.6 °C (the monthly average daily maximum water temperature at Jones Bar in July and August 1993). Based on the maximum monthly average Nevada City air temperature of 22.7 °C and the equation derived above, a monthly average flow of 10.7 m^3/s at Jones Bar would satisfy this water temperature criteria. Since typical total base flows of tributaries downstream of Lake Spaulding are around 0.7 m^3/s (Gard 1993a), an increase of the minimum required flow at Lang's Crossing in July and August from the current 0.14 m^3/s to 10 m^3/s would increase rainbow trout populations in the lower portions of the South Yuba River. Air

temperatures in September through June are typically low enough to keep South Yuba water temperatures below 23.6 °C without increases in flows at Lang's Crossing. The increase in July and August flows could require, at most, an 11% decrease in net diversions of water out of the South Yuba River basin; however, modified reservoir operations, such as changes in the timing of water storage and release, could reduce the needed decrease in out-of-basin diversions.

Another approach which has been taken in establishing stream flows to support aquatic life is the in-stream flow incremental methodology (IFIM), developed by the U.S. Fish and Wildlife Service, in which both water temperatures and the amounts of microhabitat available for different species and life stages is determined for different flows (Orth & Maughan 1982). Evaluation of available microhabitat would also show whether spawning areas for trout in the South Yuba River are limited as a result of retention of gravel supplies by upstream reservoirs, and thus if artificial replenishment of spawning gravels would be appropriate.

It is possible that the level of discharge needed to keep South Yuba River water temperatures below 23.6 °C could be reduced by modifying the location of releases from Spaulding Reservoir. Currently, releases to the South Yuba River from Spaulding Reservoir during low flow periods are through the two Spaulding powerhouse intakes (A. Ruff, PG&E, *personal communication*). When Spaulding Reservoir is full, water is also discharged via an overspill. In addition,

there is a low level outlet, which has not been used in the last few years. Although temperature profiles have not been made, it is likely that Spaulding Reservoir is stratified in the summer (A. Ruff, PG&E, *personal communication*). It may be possible to lower South Yuba water temperatures and raise South Yuba River nutrient levels by discharging water to the South Yuba River from the low level outlet, or from the deeper of the two powerhouse intakes; this would be more likely to result in releases of water from the hypolimnion of Spaulding Reservoir, which would probably be colder, and would probably have higher nutrient levels, than the epilimnion. This action could also increase the productivity, and hence potentially fish densities, of the South Yuba River, since preliminary water quality sampling (Gard, *unpublished data*) indicates that nutrient levels in the South Yuba River may be lower than most similar California rivers (Gard 1994*a*).

Introduced species: Smallmouth bass predation appears to be limiting the abundance of squawfish and hardhead in the South Yuba River downstream of Starvation Bar, and restricting the distribution of California roach to Kentucky Ravine (Gard 1994*c*). Potential competitive interactions of juvenile smallmouth bass with juvenile squawfish does not appear to make squawfish more at risk of predation by adult smallmouth bass (Gard 1994*c*). The absence of native fish from French Corral Creek is probably due in part to negative effects of sunfish; in other intermittent streams with

isolated pools, sunfish have replaced California roach, which could otherwise survive the low dissolved oxygen levels and high temperatures typical of isolated pools (Moyle, *personal communication*). Although the relatively low number of native fish in Rock Creek may be due to predation by brown trout, brown trout are less of a concern than introduced centrarchids due to their low numbers.

The abundance of smallmouth bass in the South Yuba River decreases with the distance upstream from Englebright Reservoir (Gard 1994*c*), suggesting that the smallmouth bass population is maintained by immigration from Englebright Reservoir. Similarly, the percentage of introduced fish in Kentucky Ravine decreases with the distance upstream of the South Yuba River (Gard 1994*a*). The upper limit of smallmouth bass distribution in the South Yuba River in 1992, approximately 1.5 km below Starvation Bar, coincided with a possible velocity barrier (a 7 m tall cascade), suggesting that this cascade blocks smallmouth bass from moving upstream. The upper limit of their distribution in 1993 was approximately 200 m further downstream than in 1992, possibly due to the higher flows during the winter and spring of 1993, reaching 4,560 cfs, versus flows in 1992, which only reached 2,300 cfs (USGS 1992-93), pushing the upper end of the smallmouth bass distribution downstream. The individuals of introduced species found in the South Yuba River and tributaries upstream of the above barrier probably were washed down from impoundments on tributaries,

Other management actions: With the probable exception of temperature for chinook salmon, existing habitat present in the South Yuba River would be capable of satisfying the ecological characteristics of the missing native fish species. However, reintroduction of chinook salmon and Pacific lamprey to the South Yuba River would require the installation of fish passage facilities at Englebright Dam to eliminate the current barriers to migration. In addition, passage of upstream and downstream migrants through Englebright Reservoir could also be a problem. In contrast, the reintroduction of speckled dace, California roach and riffle sculpin to the South Yuba River would not require any such structures. These species should only be reintroduced upstream of Starvation Bar, since predation by smallmouth bass would likely make the reintroduction of these small-bodied species downstream of Starvation Bar unsuccessful. Reintroduction of riffle sculpin immediately below suction dredging areas could also be a problem, given the deleterious local effects of suction dredging on this species (Harvey 1986). Since these species have been sympatric with Sacramento squawfish for a relatively long period of time, they should be able to withstand squawfish predation. For example, roach in the Eel River basin were able to maintain their populations after the invasion of squawfish (Brown & Moyle 1991). In addition, since they have been sympatric with all of the native species currently present in the South Yuba River for a long period of time,

they would not be likely to have an adverse effect on the current species as a result of competition; this is supported by the increase in fish numbers and biomass in the South Yuba River currently with the addition of hardhead to the native fish assemblage at and above Purdon Crossing (Gard 1994c). In fact, the reintroduction of these species might have a beneficial effect on squawfish by serving as an additional food supply for large squawfish. Stocking programs could also extend the distribution of hardhead further upstream.

Designation of the South Yuba River as wild and/or scenic would help to conserve the native fish fauna by preventing new dams on the river (Palmer & Vileisis 1993); such dams, for either water supply or small-scale hydroelectric generation, could adversely affect native stream fish by inundation of upstream areas or dewatering of downstream areas, further increases in downstream water temperatures, isolation of tributaries, barriers to colonization, and trapping of gravel.

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Table 1. South Yuba River water temperatures (°C) during the summers of 1991-1993. See Figure 1 for sampling locations.

Location	Period of Record	Maximum Daily High	Maximum Daily Low	Mean Daily High	Mean Daily Low
Missouri Bar	7/18-9/25/91	26.5	24.3	22.6	20.3
Highway 49	7/25-9/12/91	29.1	26.6	25.0	22.6
Jones Bar	7/9-9/14/92	27.9	25.3	24.6	21.9
Missouri Bar	6/24-9/8/93	25.0	22.5	21.1	18.8
Jones Bar	6/25-9/15/93	27.1	24.8	23.1	20.6

Table 2. Abundance and distribution of fish species in the South Yuba River and tributaries. Definition of abundance categories: A = abundant (> 30 percent of fish present); F = few (< 10 percent of fish present); R = rare (< 1 percent of fish observed); N = not present. Abundance and distribution of rainbow trout and sunfish in the South Yuba River and of California Roach in Kentucky Ravine varied with year. See Figure 1 for locations of reaches for the South Yuba River.

	Rainbow Trout			Sacramento Squawfis		Sacramento Sucker		Hardhead			Green		Smallmouth Bass		Brown	Brown	
Stream	YOY	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	CA Roach	Sunfish	Bluegill	Juvenile	Adult	Bullhead	Trout	Carp
South Yuba River: Reach	F	F	F	A	A	F	F	N	N	N	N	N	N	N	N	N	N
Reach 2	R	F/R	F/R	A	A	F	F	N	N	N	N	N	N	N	N	N	N
Reach 3	N	F/R	F/R	A	A	F	F	A	A	N	R	N	N	N	R	N	N
Reach 4	N	N	F/N	R	F	R	F	R	F	N	A/F	A/F	A	A	R	N	R
Missouri Canyon	A	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Humbug Creek	A	R	N	N	N	R	N	N	N	N	N	N	N	N	N	N	N
Spring Creek	A	F	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Rock Creek	F	N	N	N	N	F	N	N	N	N	N	N	N	N	N	R	N
Rush Creek	A	F	N	N	N	F	N	N	N	N	N	N	N	N	N	N	N
Owl Creek	A	F	N	R	N	F	N	N	N	N	N	R	N	N	N	N	N
French Corral Creek	N	N	N	N	N	N	N	N	N	N	F	A	N	N	N	N	N
Kentucky Ravine	R	N	N	R	N	A	N	R	N	A/F	F	R	F	N	N	N	N

Table 3. South Yuba Tributaries - r^2 Values for Population and Biomass Estimates. All of the relationships are statistically significant at $p = 0.05$ except biomass for Owl and French Corral Creeks (simple linear regression).

Tributary Name	Biomass r^2	Population r^2
Owl Creek	0.22	0.78
Rush Creek	0.86	0.97
Missouri Canyon	0.94	0.92
Spring Creek	0.91	0.98
Humbug Creek	0.99	0.98
Rock Creek	0.90	0.98
Kentucky Ravine	0.95	0.998
French Corral Creek	0.07	0.73

Table 4. Ranking of South Yuba Tributaries. Units of rainbow trout numbers and native species numbers are number of fish. Units of rainbow trout biomass [Wt/Vol] are g/m^3. Units of native fish biomass [Wt] are g. PC Score is the score of the first principle component for the four ranking criteria (rainbow trout and native fish biomass and numbers).

	Rainbow Trout		Native Sp.		
Tributary Name	No.	Wt/vol.	No.	Wt.	PC Score
Owl Creek	138	14.5	165	1,887	3.97
Rush Creek	97	6.6	104	372	1.00
Missouri Canyon	78	3.7	78	79	0.05
Spring Creek	18	10.2	18	551	- 0.04
Humbug Creek	16	3.5	17	387	- 0.87
Rock Creek	12	3.8	19	81	- 1.11
Kentucky Ravine	1	0.7	44	246	- 1.16
French Corral Cr.	0	0.0	0	0	- 1.84

Table 5. Feasibility of potential major restoration measures to restore the South Yuba River native fish assemblage. SMB = Smallmouth Bass.

Species	Barrier to Restoration	Feasibility
Chinook Salmon	Removal of Dam	Very Low
Pacific Lamprey	Removal of Dam	Very Low
California Roach	Elimination of SMB	Low
	Reintroduction	High *
Speckled Dace	Reintroduction	High *
Riffle Sculpin	Reintroduction	High *
	Increased Flows	Moderate
Sacramento Squawfish	Elimination of SMB	Low
	Increased Flows	Moderate
	Increased Nutrients	Moderate
Sacramento Sucker	Increased Nutrients	Moderate
Rainbow Trout	Increased Flows	Moderate
Hardhead	Increased Flows	Moderate
	Increased Nutrients	Moderate
	Expansion of Range	High

* If reintroduction is upstream of Starvation Bar

Figure Legends

Figure 1. Map of South Yuba River sampling sites and tributaries.

Figure 2. Mean South Yuba River daily maximum water temperatures at Jones Bar (Figure 1) for 1967-1979. Data from USGS 1967-79.

Figure 3. Map of South Yuba River watershed.

Figure 4. Rainbow Trout density vs distance. Lines show results of simple linear regressions of rainbow trout density versus distance for 1991/92 and 1993 ($p < 0.05$).

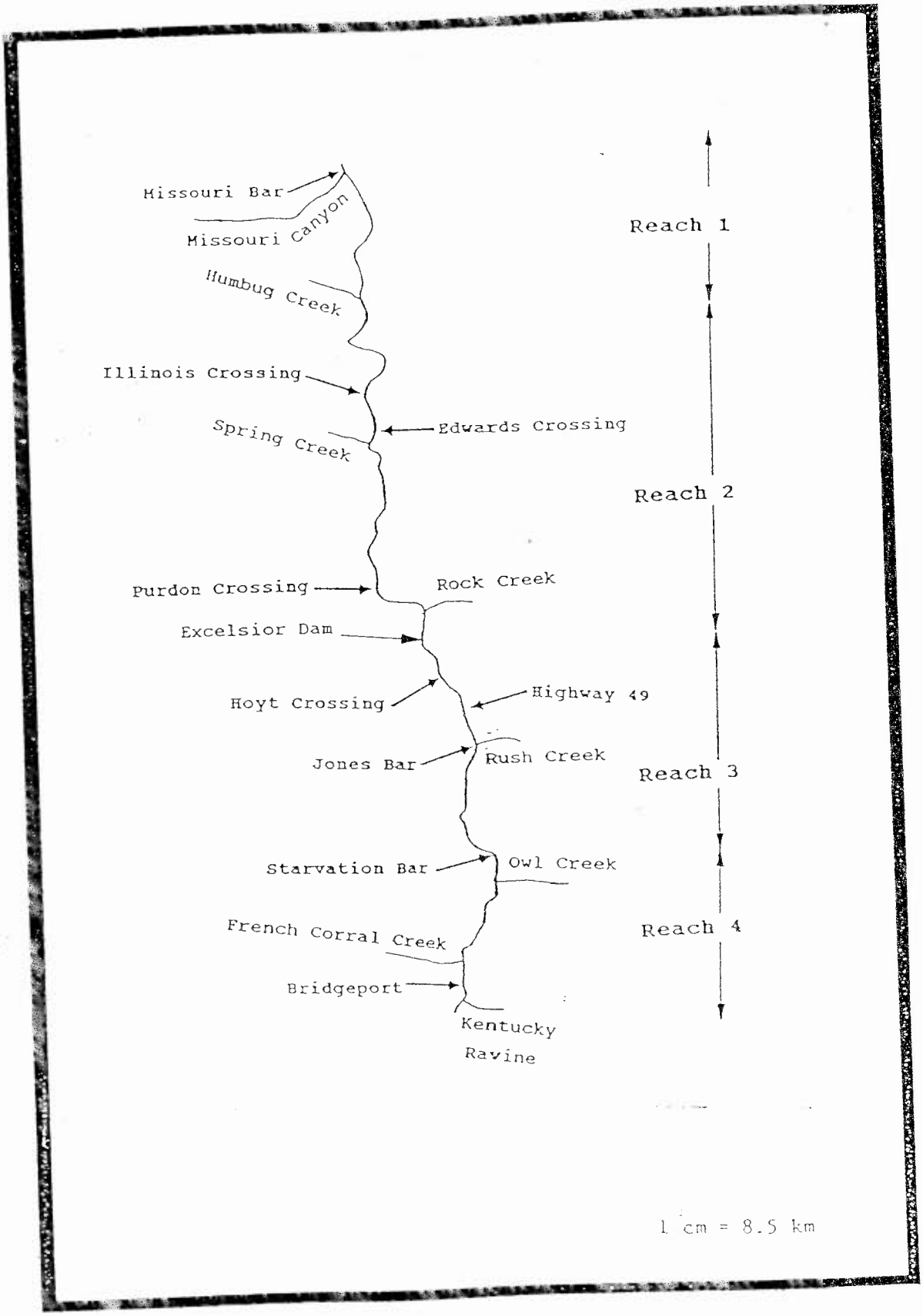

Missouri Bar
Missouri Canyon
Humbug Creek
Illinois Crossing
Spring Creek
Edwards Crossing
Purdon Crossing
Rock Creek
Excelsior Dam
Hoyt Crossing
Highway 49
Jones Bar
Rush Creek
Starvation Bar
Owl Creek
French Corral Creek
Bridgeport
Kentucky Ravine
Reach 1
Reach 2
Reach 3
Reach 4
1 cm = 8.5 km

Figure 1

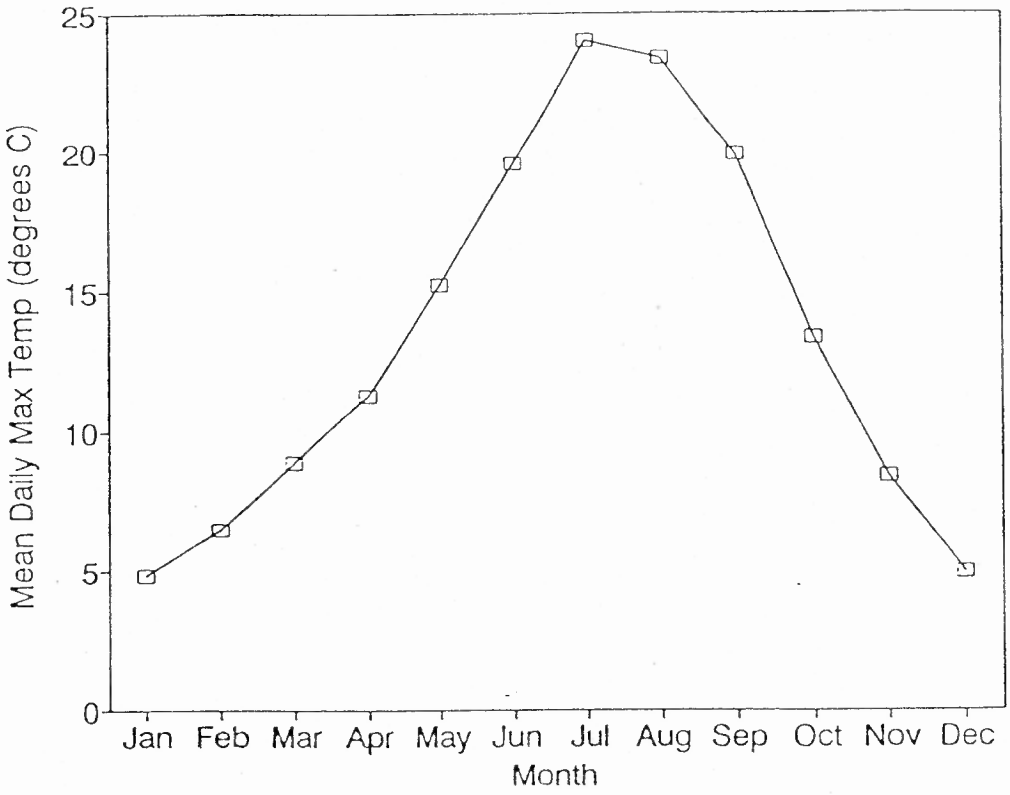

25
20
15
10
5
0
Mean Daily Max Temp (degrees C)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month

Figure 2

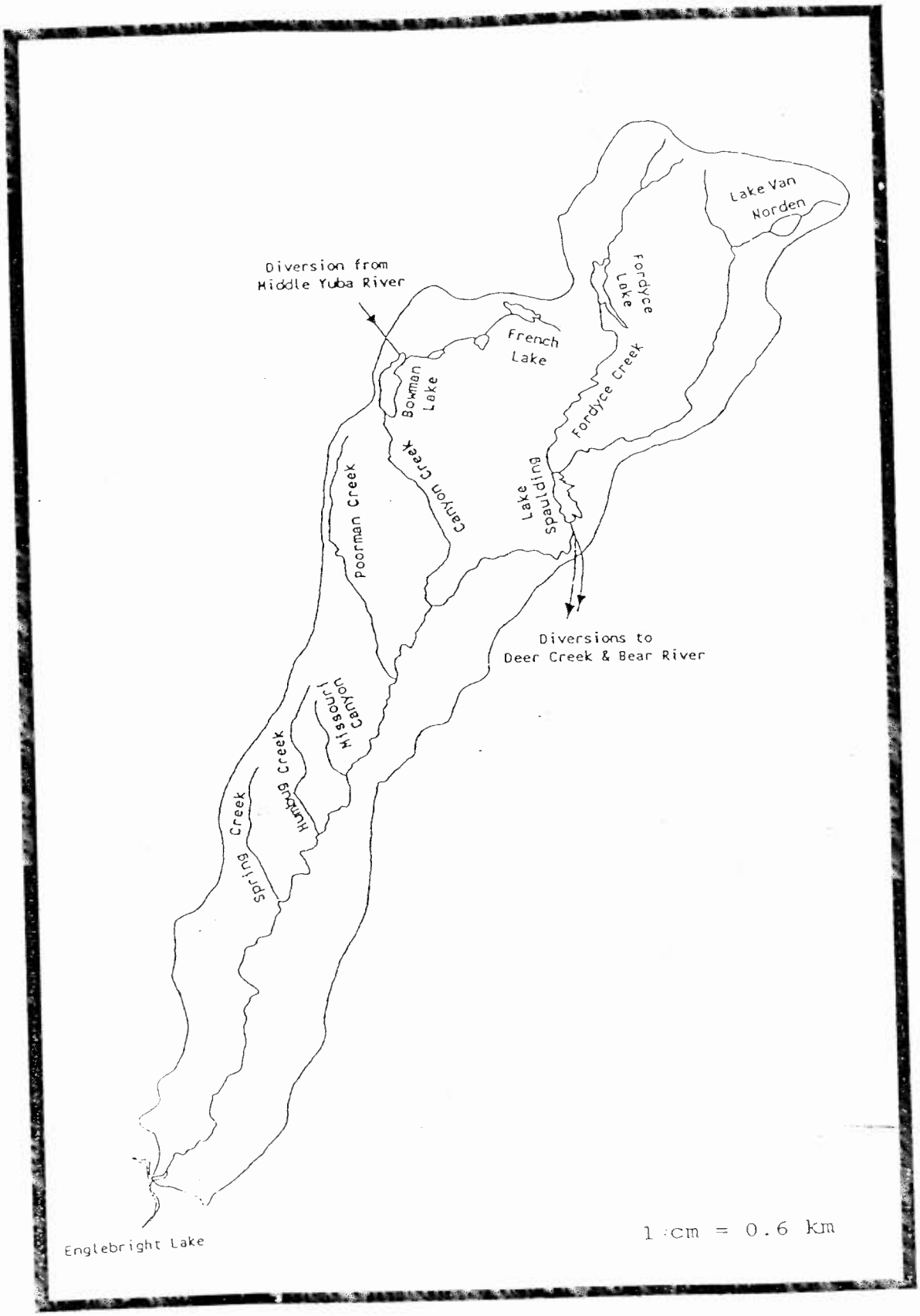

Lake Van Norden
Diversion from Middle Yuba River
Fordyce Lake
French Lake
Bowman Lake
Fordyce Creek
Canyon Creek
Poorman Creek
Lake Spaulding
Diversions to Deer Creek & Bear River
Missouri Canyon
Humbug Creek
Spring Creek
Englebright Lake
1 cm = 0.6 km

Figure 3

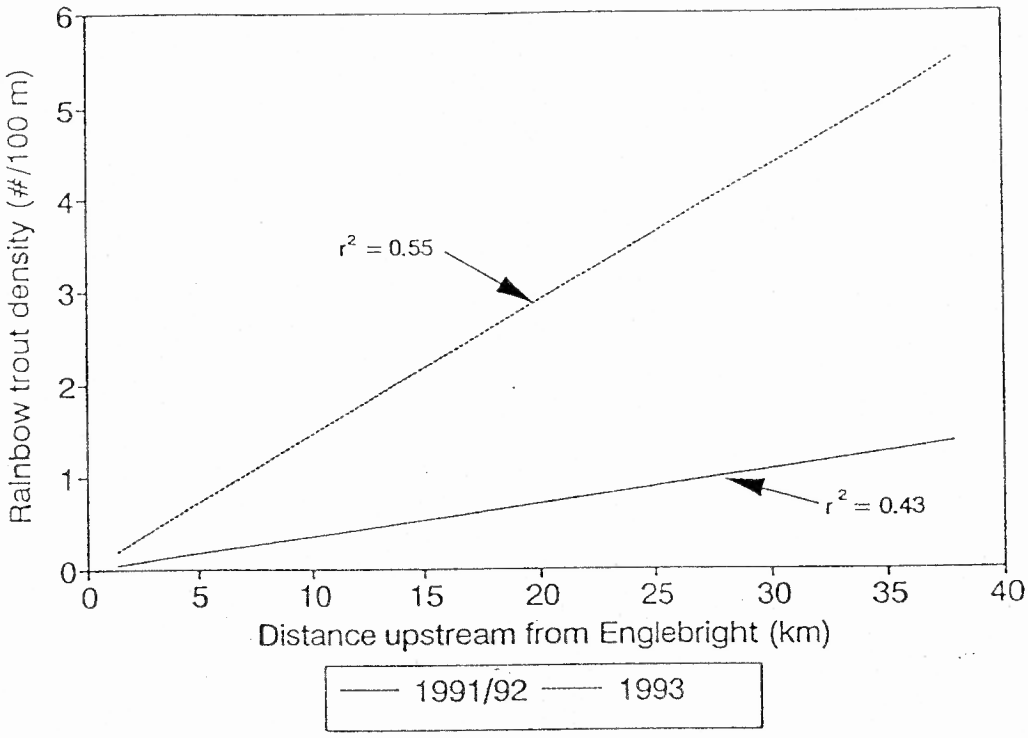
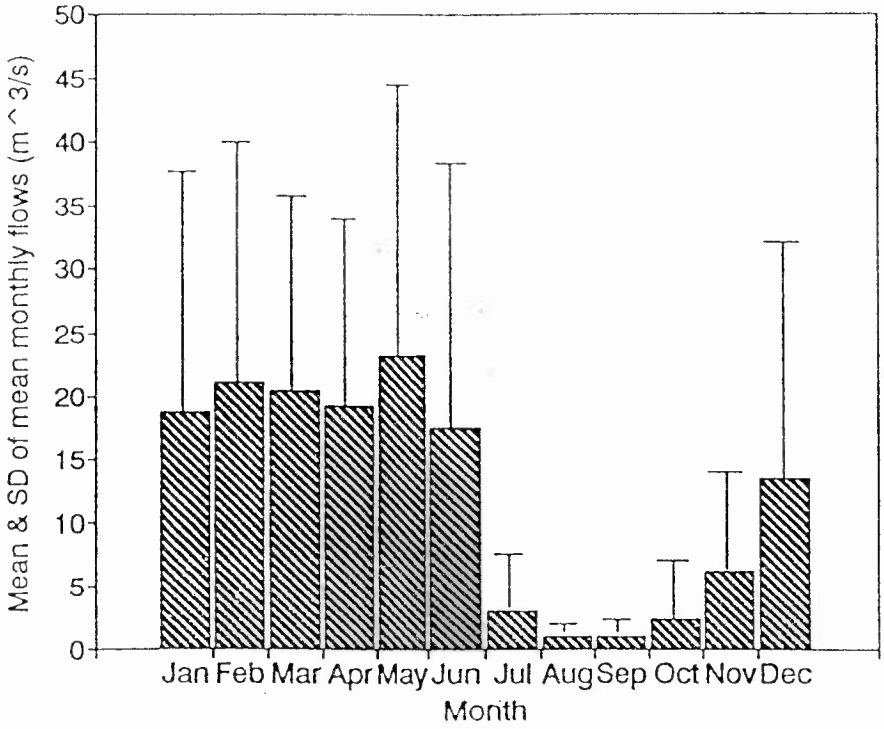
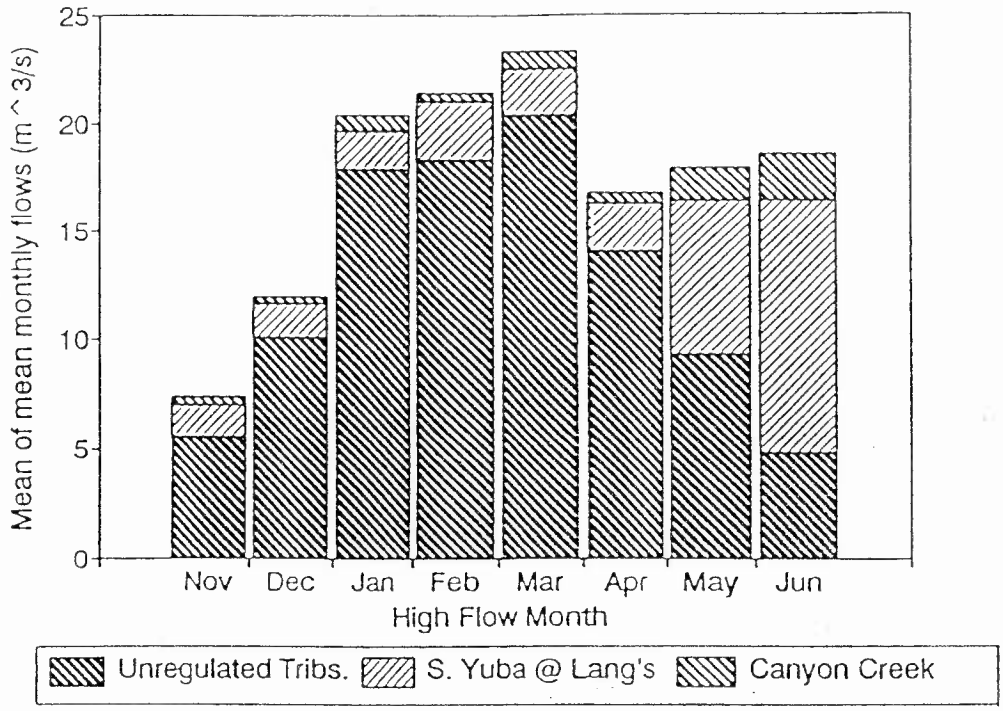

Rainbow trout density (#/100 m)
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
Distance upstream from Englebright (km)
r² = 0.55
r² = 0.43
1991/92
1993

Figure 4

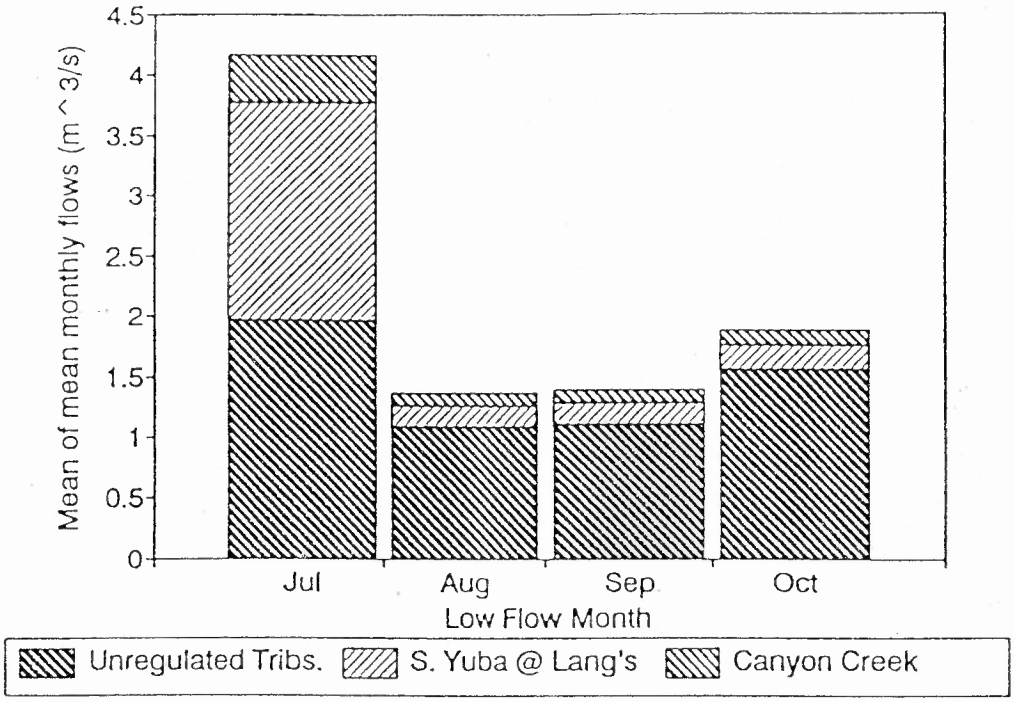
APPENDIX



South Yuba River flows at Jones Bar (Water Years 1942-49, 59-92)



Contributions to Jones Bar flows (Water Years 1967-91)



Contributions to Jones Bar flows (Water Years 1967-91)

South Yuba River Watershed Impoundments
Data from CDFG files and Palmer & Vileisis (1993)

Name	Capacity (hectare-meters)	Operated by
Lake Spaulding	9,210	PG&E
Bowman Lake	8,437	NID
Fordyce Lake	6,146	PG&E
French Lake	1,717	NID
Meadow Lake	591	PG&E
Faucherie Lake	461	NID
Sawmill Lake	373	NID
Lake Sterling	203	PG&E
Kidd Lake	184	PG&E
Jackson Lake	120	NID
Culbertson Lake	105	PG&E
White Rock Lake	71	PG&E
Lower Lindsey Lake	36	PG&E
Feeley Lake		PG&E
Rock Lake		PG&E
Blue Lake		PG&E
Rucker Lake		PG&E
Fuller Lake		PG&E
Island Lake		
Lake Angela		

South Yuba River Water Temperatures
Based on Measurements Made During
Snorkel Surveys and Microhabitat Measurements

Location	Date	Water Temperature (°C)
Bridgeport	7/31 - 8/01/91	23-29
Bridgeport	7/02 - 7/03/92	15-21
Bridgeport	8/05/92	26
Bridgeport	7/29 - 7/30/93	18-26
Edwards Crossing	8/07/91	21-24
Edwards Crossing	9/18/91	18-19
Edwards Crossing	7/22/92	23.3
Edwards Crossing	7/01/93, 8/06/93	21
Edwards Crossing	8/19 - 8/20/93	17-19
Highway 49	7/24 - 7/25/91	24-25.5
Highway 49	7/31/92	22.7
Hoyt Crossing	8/29/91	18-19
Hoyt Crossing	7/15 - 7/16/92	24-25.5
Hoyt Crossing	7/08/93	25
S Yuba at Humbug Cr.	8/14 - 8/15/91	20.5-23
Illinois Crossing	7/23/92	21.2-23.8
Illinois Crossing	8/11/93	22
Jones Bar	7/08/92	23.8
Jones Bar	6/25/93	19
Jones Bar	9/16/93	18
Missouri Bar	6/24/92	23
Missouri Bar	7/18/91	19.9-22
Missouri Bar	6/24/93	14-16.2
Purdon Crossing	8/21 - 8/22/91	20-23
Purdon Crossing	7/29 - 7/30/92	22.8-26.9
Purdon Crossing	8/12/93, 8/19/93	20
Purdon Crossing	8/26/93	20-21

Water Temperatures of South Yuba Tributaries
and Difference in Temperature Between the Tributary
and the Adjancent Portion of the South Yuba River
[A positive difference means that the tributary is colder]

Tributary	Date	Water Temp. (°C)	Temperature Difference (°C)
Kentucky Ravine	8/07/92	19	7
Kentucky Ravine	8/26/93	18	2
Spring Creek	9/18/91	13.5-15.5	3.5-4.5
Spring Creek	7/01/93	18	3
Humbug Creek	8/15/91	17.5-18	3-5
Humbug Creek	7/23/93	15	5
Rush Creek	7/08/92	19.5	4.3
Rush Creek	6/25/93	19	0
Missouri Canyon	7/17/91	15	5-7
Missouri Canyon	6/24/93	13	1
Rock Creek	9/17/93	13	5
Owl Creek	7/16/93	17	5
French Corral Creek	9/09/93	22	1

South Yuba River Thermograph Data - 1991

Date	Highway 49 High	Highway 49 Low	Missouri Bar High	Missouri Bar Low	Temperature Difference Highs	Temperature Difference Lows
7/18	—	—	23.5	20.2	—	—
7/19	—	—	22.9	21.1	—	—
7/20	—	—	23.1	20.4	—	—
7/21	—	—	23.9	20.5	—	—
7/22	—	—	24.7	21.5	—	—
7/23	—	—	24.8	21.7	—	—
7/24	—	—	24.8	21.6	—	—
7/25	27.9	23.8	24.5	21.5	3.4	2.3
7/26	27.5	24.3	25.2	21.5	2.3	2.8
7/27	28.2	25.2	25.8	22.3	2.4	2.9
7/28	28.4	25.7	26.0	23.3	2.4	2.4
7/29	29.0	26.0	26.3	23.7	2.7	2.3
7/30	29.1	26.6	26.5	24.0	2.6	2.6
7/31	28.7	26.8	26.5	24.3	2.2	2.3
8/1	27.4	25.0	25.6	23.4	1.8	1.6
8/2	26.3	24.0	24.7	22.3	1.6	1.7
8/3	25.4	23.3	23.5	21.7	1.9	1.6
8/4	25.0	23.2	23.1	21.5	1.9	1.7
8/5	25.3	23.0	23.4	20.8	1.9	2.2
8/6	25.1	22.8	23.2	21.0	1.9	1.8
8/7	24.8	22.7	22.8	20.8	2.0	1.9
8/8	24.9	22.2	23.1	20.4	1.8	1.8
8/9	25.0	22.1	23.2	20.5	1.8	1.6
8/10	25.5	22.7	23.6	21.0	1.9	1.7
8/11	25.8	23.1	23.9	21.4	1.9	1.7
8/12	25.5	23.0	23.9	21.5	1.6	1.5
8/13	25.2	23.2	23.2	21.7	2.0	1.5
8/14	26.3	24.0	23.2	21.6	3.1	2.4
8/15	25.1	24.1	23.1	21.5	2.0	2.6
8/16	25.2	22.6	23.4	20.5	1.8	2.1
8/17	25.4	23.0	23.5	21.2	1.9	1.8
8/18	25.5	23.1	23.7	21.5	1.8	1.6
8/19	24.7	23.0	23.2	21.3	1.5	1.7
8/20	24.6	22.2	23.4	20.8	1.4	1.4
8/21	25.0	22.5	23.5	20.9	1.5	1.6
8/22	25.0	22.7	23.4	20.8	1.6	1.9
8/23	25.8	22.6	23.2	20.7	2.6	1.9
8/24	24.2	22.0	22.6	20.5	1.6	1.5
8/25	23.6	21.6	22.5	20.4	1.3	1.4
8/26	23.2	21.0	21.8	19.7	1.4	1.3
8/27	22.2	20.3	21.0	19.2	1.2	1.1
8/28	21.8	19.7	20.5	18.2	1.3	1.5
8/29	22.7	20.0	20.7	18.3	2.0	1.7
8/30	23.2	20.8	21.4	18.8	1.8	2.0
8/31	23.4	21.0	21.5	19.3	1.9	1.7
9/1	23.3	20.9	21.6	19.3	1.7	1.6
9/2	23.7	21.2	21.7	19.5	2.0	1.7
9/3	24.3	22.0	22.3	20.2	2.0	1.8
9/4	24.8	22.4	22.8	20.5	2.0	1.9
9/5	24.7	22.2	22.7	20.5	2.0	1.7
9/6	24.3	22.5	22.5	20.6	1.8	1.9
9/7	24.2	22.2	22.5	20.5	1.7	1.7
9/8	24.6	22.0	22.0	20.3	2.6	1.7
9/9	22.0	20.4	20.8	19.2	1.4	1.2
9/10	21.8	20.2	20.5	18.7	1.3	1.5
9/11	21.8	19.9	20.3	18.5	1.5	1.4
9/12	—	20.0	20.2	18.2	—	1.8
9/13	—	—	20.0	17.3	—	—
9/14	—	—	20.0	18.0	—	—
9/15	—	—	20.2	18.1	—	—
9/16	—	—	20.3	18.3	—	—
9/17	—	—	20.2	18.4	—	—
9/18	—	—	20.4	18.3	—	—
9/19	—	—	20.5	18.5	—	—
9/20	—	—	20.5	18.6	—	—
9/21	—	—	20.2	18.1	—	—
9/22	—	—	19.8	18.0	—	—
9/23	—	—	19.5	17.5	—	—
9/24	—	—	19.3	17.5	—	—
9/25	—	—	—	17.5	—	—
Average	25.0	22.8	22.8	20.3	1.9	1.8

South Yuba River Thermograph Data - 1992

Date	Jones Bar High	Jones Bar Low
7/9	25	21.6
7/10	26	22.9
7/11	25	23.6
7/12	24.2	23
7/13	25.7	22.5
7/14	25.7	23.4
7/15	27.2	24.3
7/16	26.4	24.6
7/17	27.7	25.3
7/18	26.9	24.3
7/19	26.2	23.6
7/20	25.8	22.9
7/21	26	23
7/22	25.6	22.9
7/23	25	22
7/24	25	22.2
7/25	25.7	22.4
7/26	26	23
7/27	25.9	22.8
7/28	26.2	22.6
7/29	26.3	23.2
7/30	26.1	23.2
7/31	25.7	22.6
8/1	25.6	22.5
8/2	25.6	22.4
8/3	25	22.1
8/4	24.9	21.4
8/5	25	21.7
8/6	24.8	21.6
8/7	25	21.9
8/8	25.3	22.2
8/9	25.6	22.2
8/10	26.2	23
8/11	26.6	23.4
8/12	27.9	24.9
8/13	27.6	25
8/14	27.2	24.6
8/15	27.6	25.2
8/16	27.6	25
8/17	27.4	24.7
8/18	26.6	23.6
8/19	26	23.2
8/20	25.9	23
8/21	24.4	22.7
8/22	23	20.6
8/23	22.6	19.9
8/24	22.6	19.8
8/25	22.5	19.7
8/26	22.7	19.8
8/27	23	20.2
8/28	22.6	20.6
8/29	23.2	21
8/30	22.4	21
8/31	22.7	20.2
9/1	23	20.3
9/2	22.9	20.4
9/3	22	20
9/4	21.6	19.1
9/5	21.7	19.2
9/6	21.6	19.2
9/7	21.4	18.9
9/8	21.2	18.5
9/9	21.5	18.6
9/10	21.1	19.3
9/11	21.3	18.6
9/12	21.1	18.7
9/13	20.5	18.6
9/14	20.4	18.3
Average	24.6	21.9

South Yuba River Temperature Data - 1993

	Jones Bar		Missouri Bar		Temperature Difference	
Date	High	Low	High	Low	Highs	Lows
6/24	—	—	16.9	—	—	—
6/25	20.8	—	18.4	15.2	2.4	—
6/26	19.1	18.6	18.5	14.6	0.6	4
6/27	19.5	18	18.4	15.5	1.1	2.5
6/28	19.5	17.6	17.3	15.5	2.2	2.1
6/29	19.9	16.6	17.4	15	2.5	1.6
6/30	20.2	17.1	18.3	15.3	1.9	1.8
7/1	21.6	18	19.1	16.1	2.5	1.9
7/2	21.8	19	19.3	17.6	2.5	1.4
7/3	21.8	18.8	19.7	17	2.1	1.8
7/4	22.4	19	20.5	17.4	1.9	1.6
7/5	23.1	19.8	20.8	18.2	2.3	1.6
7/6	23.9	20.7	21.6	18.5	2.3	2.2
7/7	24.6	21.6	22.4	19.5	2.2	2.1
7/8	24.8	21.9	22.4	19.6	2.4	2.3
7/9	24.9	22	22.3	19.6	2.6	2.4
7/10	24.9	22	22.3	19.6	2.6	2.4
7/11	25.1	22.4	22.5	20	2.6	2.4
7/12	25	22.6	22.6	20.3	2.4	2.3
7/13	24.6	22.1	22.1	19.9	2.5	2.2
7/14	23.6	21.4	21.1	19.1	2.5	2.3
7/15	23	20.7	20.1	18.3	2.9	2.4
7/16	22.5	19.9	19.9	17.4	2.6	2.5
7/17	22.2	19.5	20	17.3	2.2	2.2
7/18	22.8	19.9	21	18.1	1.8	1.8
7/19	22.9	20.4	21.5	18.8	1.4	1.6
7/20	22	20.2	19.8	18.8	2.2	1.4
7/21	22.3	19.8	20.1	17.5	2.2	2.3
7/22	23	20.1	20.8	17.9	2.2	2.2
7/23	24.6	21.5	20.9	19	3.7	2.5
7/24	23.8	21.1	19.9	18.1	3.9	3
7/25	23.2	20.5	20.8	17.5	2.4	3
7/26	24.1	20.9	22	18.6	2.1	2.3
7/27	24.6	21.6	22.6	19.4	2	2.2
7/28	24.8	22.1	23	20	1.8	2.1
7/29	24.6	22.4	22.4	20.2	2.2	2.2
7/30	24.6	21.7	22.6	19.5	2	2.2
7/31	25.2	22	23.2	20	2	2

South Yuba River Temperature Data - 1993

Date	Jones Bar High	Jones Bar Low	Missouri Bar High	Missouri Bar Low	Temperature Difference Highs	Temperature Difference Lows
8/1	26.1	23	24	20.6	2.1	2.4
8/2	27.1	24.1	25	21.9	2.1	2.2
8/3	26.8	24.8	24.9	22.5	1.9	2.3
8/4	26.2	23.8	24.6	22	1.6	1.8
8/5	25.7	23.1	24.2	21.4	1.5	1.7
8/6	25.5	22.9	23.9	21.2	1.6	1.7
8/7	24.9	22.8	23.3	21	1.6	1.8
8/8	24.6	22	22.9	20.3	1.7	1.7
8/9	24.2	21.6	22.3	20	1.9	1.6
8/10	23.6	21.8	21.9	20.1	1.7	1.7
8/11	23.1	20.8	21.7	19.3	1.4	1.5
8/12	23	20.6	21.5	19	1.5	1.6
8/13	23.5	20.8	21.7	19.1	1.8	1.7
8/14	23.6	21.1	21.7	19.4	1.9	1.7
8/15	22.6	21.5	20	19.3	2.6	2.2
8/16	22.2	19.7	20.3	17.7	1.9	2
8/17	22.8	20.1	21	18.1	1.8	2
8/18	23	20.5	21.3	18.6	1.7	1.9
8/19	21.7	20.7	20	18.9	1.7	1.8
8/20	20.8	19.2	18.7	17.5	2.1	1.7
8/21	21.8	18.8	19.2	16.5	2.6	2.3
8/22	23.1	20.1	20.9	17.6	2.2	2.5
8/23	23.7	21	21.5	19	2.2	2
8/24	23.5	21.2	21.7	19.3	1.8	1.9
8/25	22.8	20.6	21.3	19.3	1.5	1.3
8/26	22.2	19.9	20.6	18.5	1.6	1.4
8/27	22.4	19.7	20.7	18.4	1.7	1.3
8/28	22.6	20	21	18.6	1.6	1.4
8/29	22.7	20.1	20.9	19	1.8	1.1
8/30	22.6	20.1	21	18.9	1.6	1.2
8/31	22.7	20.1	20.6	18.8	2.1	1.3
9/1	22.9	20.5	21.1	18.9	1.8	1.6
9/2	23.1	20.6	21.1	19.1	2	1.5
9/3	23.5	20.8	21.3	19.2	2.2	1.6
9/4	23.7	21.2	21.5	19.5	2.2	1.7
9/5	23.5	21.4	21.5	19.7	2	1.7
9/6	23	20.9	21.3	19.6	1.7	1.3
9/7	23	20.7	21.2	19.2	1.8	1.5
9/8	23	20.6	—	19.2	—	1.4
9/9	23.2	20.8	—	—	—	—
9/10	23.1	20.8	—	—	—	—
9/11	22.8	20.5	—	—	—	—
9/12	22.1	19.9	—	—	—	—
9/13	21	18.6	—	—	—	—
9/14	20.2	18.2	—	—	—	—
9/15	20.1	18	—	—	—	—
Average	22.3	20.2	20.4	18.3	2.0	1.9

South Yuba River Substrate Samples

Site	Section #	Sample #	% .3 mm - 3.35 mm	% < .15 mm	MPS (mm)	Quartile Deviation
Bridgeport	3	1	86.95%	0.49%	0.81	0.75
Edwards Crossing	5	1	96.29%	0.69%	0.62	0.53
Edwards Crossing	5	2	35.69%	0.18%	1.41	0.75
Edwards Crossing	6	1	41.58%	0.05%	1.37	0.60
Edwards Crossing	6	2	98.26%	0.21%	0.62	0.50
Highway 49	1	1	25.47%	0.60%	1.07	0.78
Highway 49	1	2	38.30%	0.16%	0.76	0.68
Highway 49	3	1	38.21%	0.12%	1.15	0.78
Highway 49	5	1	72.43%	0.27%	1.11	0.70
Hoyt Crossing	2	1	68.89%	0.35%	0.97	0.70
Hoyt Crossing	2	2	90.23%	2.66%	0.42	0.45
Hoyt Crossing	4	1	97.18%	0.70%	0.64	0.55
Hoyt Crossing	4	2	73.47%	0.07%	1.41	0.68
Hoyt Crossing	5	1	58.10%	0.19%	1.23	0.68
Hoyt Crossing	5	2	88.14%	0.52%	0.78	0.63
Humbug Crossing	-1	1	71.53%	0.00%	1.46	0.50
Humbug Crossing	0	1	61.17%	0.20%	1.74	0.38
Humbug Crossing	0	2	38.35%	0.18%	1.19	0.60
Humbug Crossing	3	1	89.01%	0.33%	1.23	0.55
Humbug Crossing	3	2	81.12%	0.17%	1.46	0.48
Missouri Bar	1	1	48.65%	0.33%	1.68	0.53
Missouri Bar	1	2	61.08%	0.45%	1.57	0.55
Missouri Bar	3	1	44.80%	0.22%	1.23	0.60
Missouri Bar	3	2	74.00%	0.26%	1.15	0.63
Missouri Bar	3	3	88.63%	0.23%	1.27	0.55
Missouri Bar	6	1	25.37%	0.58%	1.68	0.55
Missouri Bar	6	2	71.47%	0.20%	1.62	0.50
Purdon Crossing	1	1	52.88%	0.11%	1.23	0.68
Purdon Crossing	1	2	92.61%	0.22%	0.84	0.63
Purdon Crossing	3	1	90.10%	0.30%	0.66	0.60
Purdon Crossing	3	2	95.53%	0.18%	0.87	0.63
Purdon Crossing	8	1	72.24%	0.23%	0.81	0.58
Purdon Crossing	8	2	98.65%	0.14%	0.81	0.53

South Yuba River Macroinvertebrate Taxa in Kick Screen Samples

Order/Suborder	Family	Genus/species	Functional Group
Trichoptera:	Hydropsychidae	*Hydropsyche* sp.	Collector-filterer
	Rhyacophilidae	*Rhyacophila* sp. (2 species)	Predator, collector-gatherer, shredder
	Glossosomatidae	*Glossoma* sp.	Scraper
	Lepidostomatidae	*Lepidostoma* sp.	Shredder
	Philopotamidae	*Chimarra* sp.	Collector-filterer
	Limnelphilidae	*Discomoecus* sp.	Scraper, shredder, predator
	Polycentropodidae	*Polycentropus* sp.	Predator, collector-filterer, shredder
	Hydroptilidae	*Ochrotrichia* sp.	Collector-gatherer
	Sericostomatidae	*Gumaga* sp.	Shredder
Plecoptera:	Perlidae	*Calineuria californica*	Predator
	Perlidae	*Hesperoperla pacifica*	Predator
	Pteronarcyidae	*Pteronarcella regularis*	Predator, shredder
Megaloptera:	Corydalidae	*Orohermes crepusculus*	Predator
	Corydalidae	*Corydalus cognata*	Predator
Ephemeroptera:	Baetidae	*Baetis* sp. (2 species)	Collector-gatherer, scraper
	Oligioneuriidae	*Isonychia velma*	Collector-filterer, predator
	Heptageniidae	*Ironodes lepidus*	Scraper, collector-gatherer
	Epheremellidae	*Serratella* sp.	Collector-gatherer
	Tricorythidae	*Leptohyphes* sp.	Collector-gatherer
Coleoptera:	Psephenidae	*Psephenus* sp.	Scraper
	Elmidae	*Ordobrevia* sp.	Collector-gatherer, scraper
	Ptilodactylidae	*Stenocolus scutellaris*	Shredder
Diptera:	Tipulidae	*Antocha monticola*	Collector-gatherer
	Simuliidae	1 species	Collector-filterer
	Chironomidae		Collector-gatherer, collector-filterer
	Blephariceridae	1 species	Scraper
Zygoptera:	Coenagrionidae	*Argia* sp. (2 species)	Predator
	Calopterygidae	*Hetaerina americana*	Predator
Anisoptera:	Gomphidae	*Ophiogomphus occidentis*	Predator
	Gomphidae	*Erpetogomphus compositus*	Predator
	Cordulegastridae	*Cordulegaster dorsalis*	Predator
	Aeshnidae	*Aeshna interrupta*	Predator
	Corduliidae	*Somatochlora* sp.	Predator
Lepidoptera:	Pyralidae	*Petrophila* sp.	Scraper
Limnophila:	Physidae	*Physa* sp.	Scraper, collector-gatherer
	Planorbidae	*Gyraulus* sp.	Scraper, collector-gatherer
Oligiochaete worm			Collector-gatherer

South Yuba River Macroinvertebrate Data

Site	Bridgeport						Edwards Crossing						Hoyt Crossing					Humbug Crossing						Missouri Bar					Purdon Crossing						Highway 49		
Section Number	2	2	2	4	4	4	4	4	4	7	7	7	1	1	1	1	1	4	4	4	6	6	6	2	2	7	7	7	2	2	2	4	4	4	2	2	2
Sample Number	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	4	5	1	2	3	1	2	3	1	2	1	2	3	1	2	3	1	2	3	1	2	3
Hydropsyche sp.	17	40	3	11	6	5	79	27	8	8	1	17	16	20	6	6	45	4	40	61	19	46	18	5	1	30	36	25	33	7	27	17	56	4	0	0	6
Rhyacophila sp. 1	0	4	0	0	0	0	2	3	2	0	0	0	0	2	0	0	0	7	25	12	9	16	6	4	1	14	5	6	2	2	17	1	5	0	0	0	1
Rhyacophila sp. 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
Glossoma sp.	1	1	0	1	2	3	1	1	0	1	0	1	0	0	0	0	1	0	0	0	0	1	0	1	4	0	0	8	3	0	2	0	1	3	0	0	0
Lepidostoma sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Chimarra sp.	0	7	0	1	1	5	2	5	0	1	0	1	1	6	0	2	16	0	1	0	0	0	0	0	0	6	4	1	3	0	4	2	30	1	6	0	2
Discomoecus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	10	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Polycentropus sp.	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	3	0	0	1	2	0	0	2	0	0	0	3	6	1	0	1	0	0	0	0
Ochrotrichia sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Helicopsyche borealis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	0	3	19	0	0	0
Gumaga sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Calineuria californica	0	16	3	10	6	8	1	2	3	11	3	6	21	3	26	10	16	5	32	8	23	6	1	6	0	5	9	8	3	2	15	1	9	4	5	3	6
Hesperoperla pacifica	0	2	2	0	0	0	9	5	1	1	0	0	2	1	2	4	4	0	22	5	2	4	2	1	0	2	0	0	2	0	0	1	7	0	10	0	1
Pteronarcella regularis	0	0	0	0	0	0	2	1	0	0	0	0	0	0	2	0	2	0	0	1	0	2	0	0	0	0	0	0	1	0	0	0	2	0	1	0	1
Orohermes crepusculus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0
Corydalus cognata	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Baetis sp. 1	0	9	1	14	5	16	5	38	9	6	0	16	17	1	5	1	19	0	7	1	14	15	5	26	0	7	4	6	2	2	4	6	7	4	6	1	18
Baetis sp. 2	0	1	0	0	0	0	0	0	5	1	0	2	3	0	2	0	1	0	0	0	0	0	0	3	0	0	1	0	0	0	2	1	0	0	0	0	1
Isonychia velma	0	1	0	0	0	0	0	0	0	2	0	0	10	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	61	1	0
Ironodes lepidus	0	5	0	9	9	6	23	17	5	0	0	1	10	0	1	5	15	0	1	6	0	3	0	2	0	4	2	7	16	0	0	11	6	0	55	0	1
Serratella sp.	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	6	0	2	4	9	0	0	0	0	0	0	0	0	2
Leptohyphes sp.	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
Psephenus sp.	0	1	0	0	0	0	0	1	0	0	0	6	0	0	2	0	0	2	4	7	1	0	0	0	0	0	0	1	1	1	5	1	1	0	0	0	0
Ordobrevia sp.	0	0	0	0	0	0	0	0	1	2	0	0	0	1	2	0	1	1	2	2	1	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	1
Stenocolus scutellaris	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Antocha monticola	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
Metacnephia sp.	0	28	0	94	6	0	18	18	1	0	0	1	0	0	0	0	1	1	0	0	0	33	0	15	1	0	1	0	0	0	0	0	1	0	0	0	0
Chironomidae	3	20	0	5	0	0	0	0	1	0	0	0	1	1	2	1	3	1	0	0	0	1	0	6	0	0	9	1	0	0	0	2	1	0	0	0	0
Blephariceridae	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Argia sp. 1	0	1	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	1	2	0	0	1	0	0	0	4	0	1	0	0	0	0	1	1	1
Argia sp. 2	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Hetaerina americana	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ophiogomphus occidentis	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Erpetogomphus compositus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
Cordulegaster dorsalis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Aeshna interrupta	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Somatochlora sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Petrophila sp.	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physa sp.	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	1	4	0	0	0
Gyraulus sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oligochaete worm	0	2	1	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Total	23	141	10	147	36	51	142	117	36	39	9	57	83	38	57	29	127	27	137	108	74	147	37	78	13	73	76	79	72	30	85	44	134	42	145	6	45

South Yuba River Nutrient and Periphyton Samples 9/9/93

Site	SRP Conc (ug/l)	NO3 Conc (ug/l)	Periphyton Dry wt (gm/m2	Periphyton AFDW (gm/m2)
Edwards	3	<10	222.4	21.0
Edwards	2	<10	23.9	4.9
Edwards	3	<10	14.3	1.6
Purdon	3	12	51.9	8.0
Purdon	4	<10	31.4	4.8
Purdon	3	<10	55.5	8.0
Bridgeport	3	<10	42.1	9.0
Bridgeport	3	<10	71.4	10.5
Bridgeport	3	<10	87.8	14.1
Average	3		66.8	9.1

Conductivity of the South Yuba & Tributaries

Location/Tributary	Date	Conductivity (μmhos)
Missouri Bar	6/23/93	27
Edwards Crossing	7/01/93	40
Jones Bar	6/25/93	37
Jones Bar	9/16/93	83
Missouri Canyon	6/23/93	60
Spring Creek	7/01/93	52
Rock Creek	9/17/93	72
Rush Creek	6/25/93	202
Kentucky Ravine	8/26/93	200

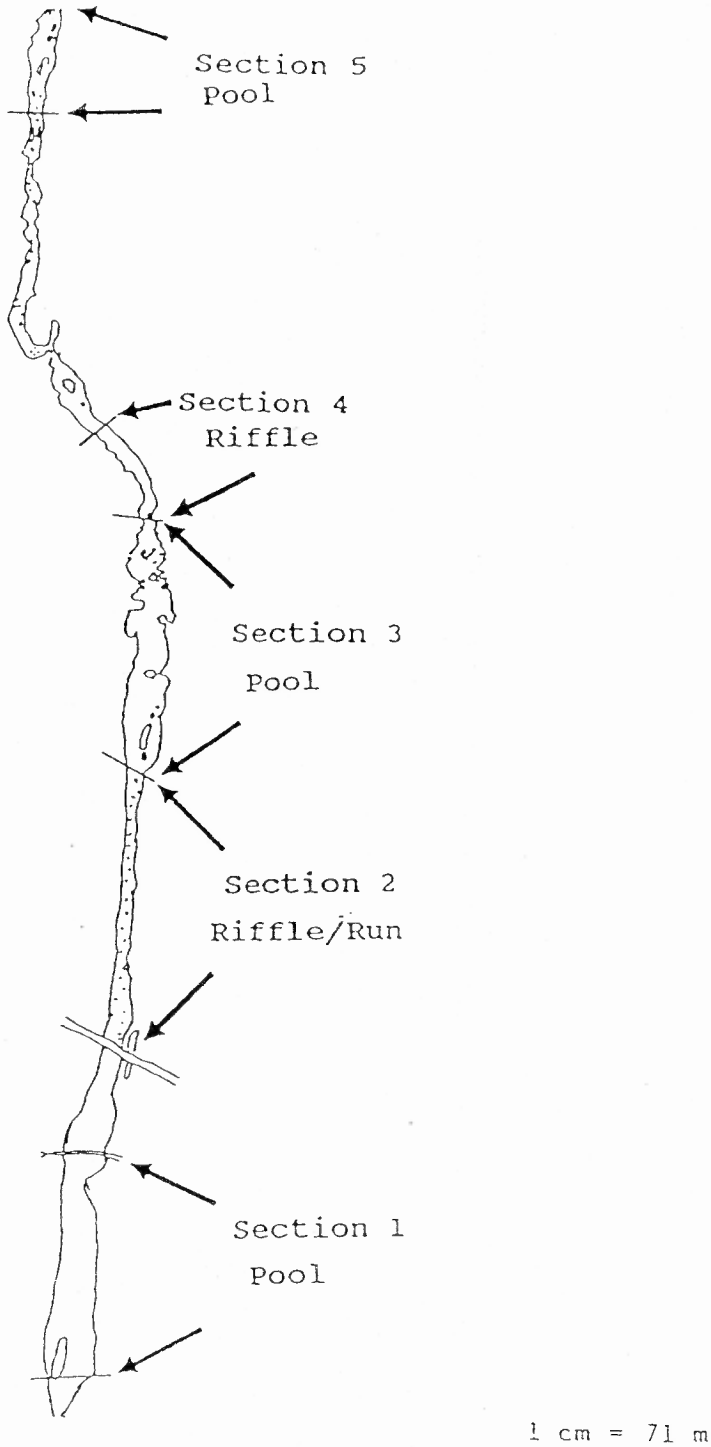
Macroinvertebrate Orders in Sumner & Smith (1939) Samples
Data from CDFG files.

Bridgeport	Highway 49	Purdon Crossing
Trichoptera	Trichoptera	Trichoptera
Ephemeroptera	Plecoptera	Ephemeroptera
Diptera		Diptera
Coleoptera		Plecoptera
Hydracarina		Coleoptera
		Hydracarina

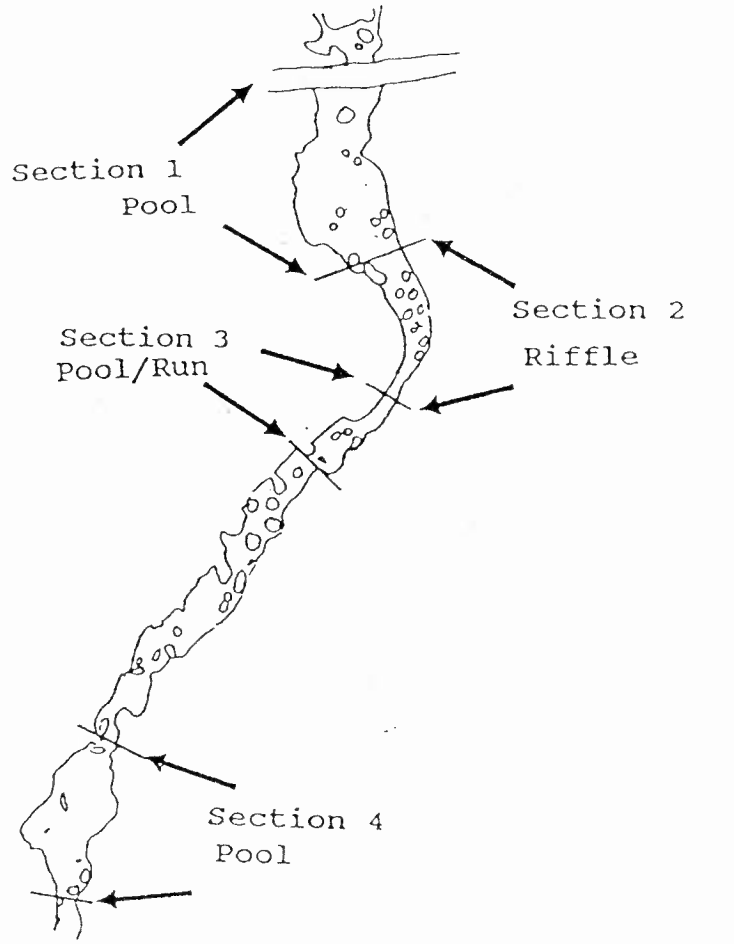
Squawfish substrate use from microhabitat data
versus availability estimates from visual estimates[1]

Substrate type	Mean % fish using	Mean % Available
Bedrock	15.1%	22.7%
Boulder	11.0%	14.3%
Cobble	25.2%	23.4%
Gravel	25.3%	20.9%
Sand	23.2%	14.7%
Silt	0.2%	3.2%

[1] Means connected by horizontal lines are not statistically significantly different at the $p = 0.05$ significance level (paired-sample t-test). $n = 37$.

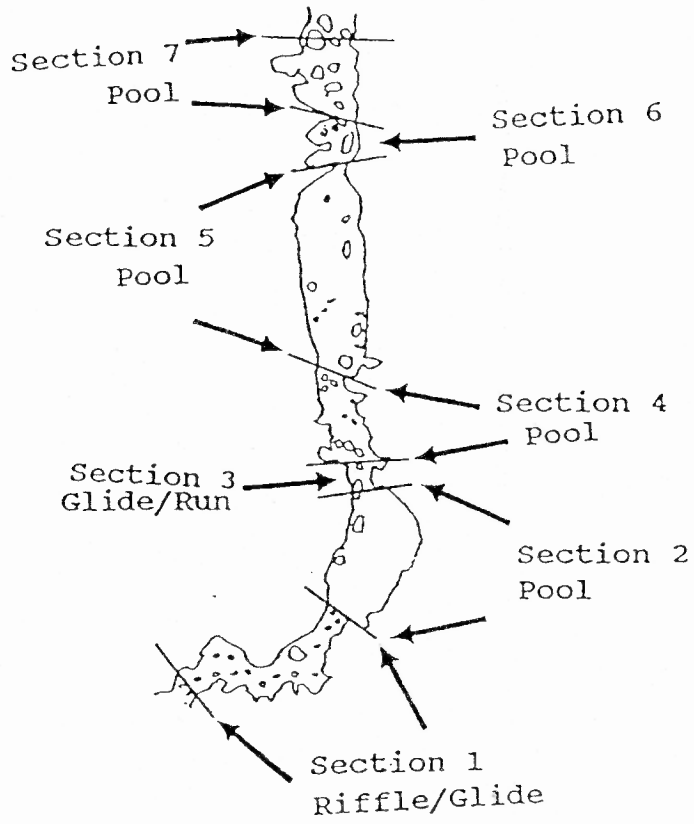

Section 5
Pool
Section 4
Riffle
Section 3
Pool
Section 2
Riffle/Run
Section 1
Pool
1 cm = 71 m

Bridgeport



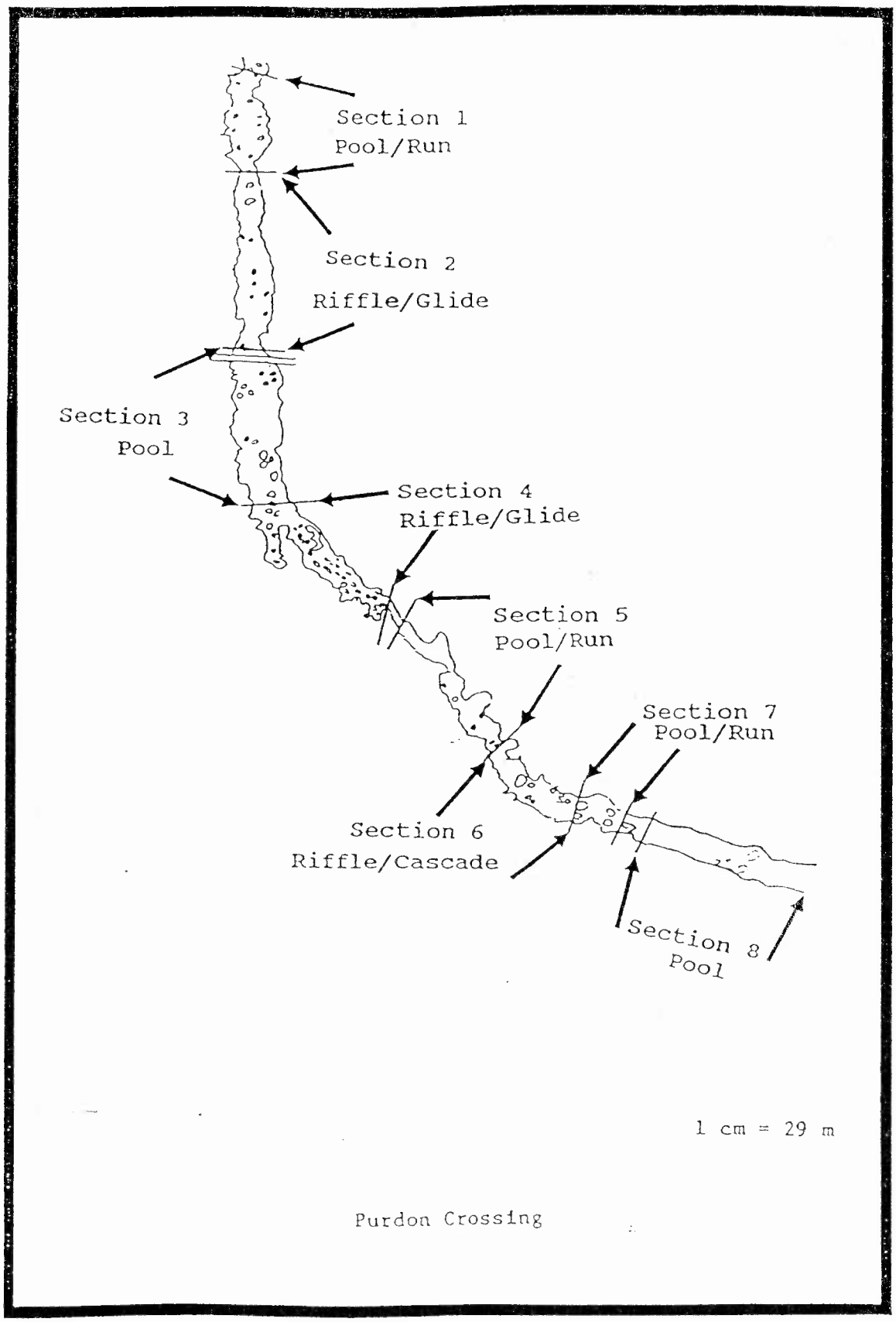
1 cm = 23 m

Highway 49

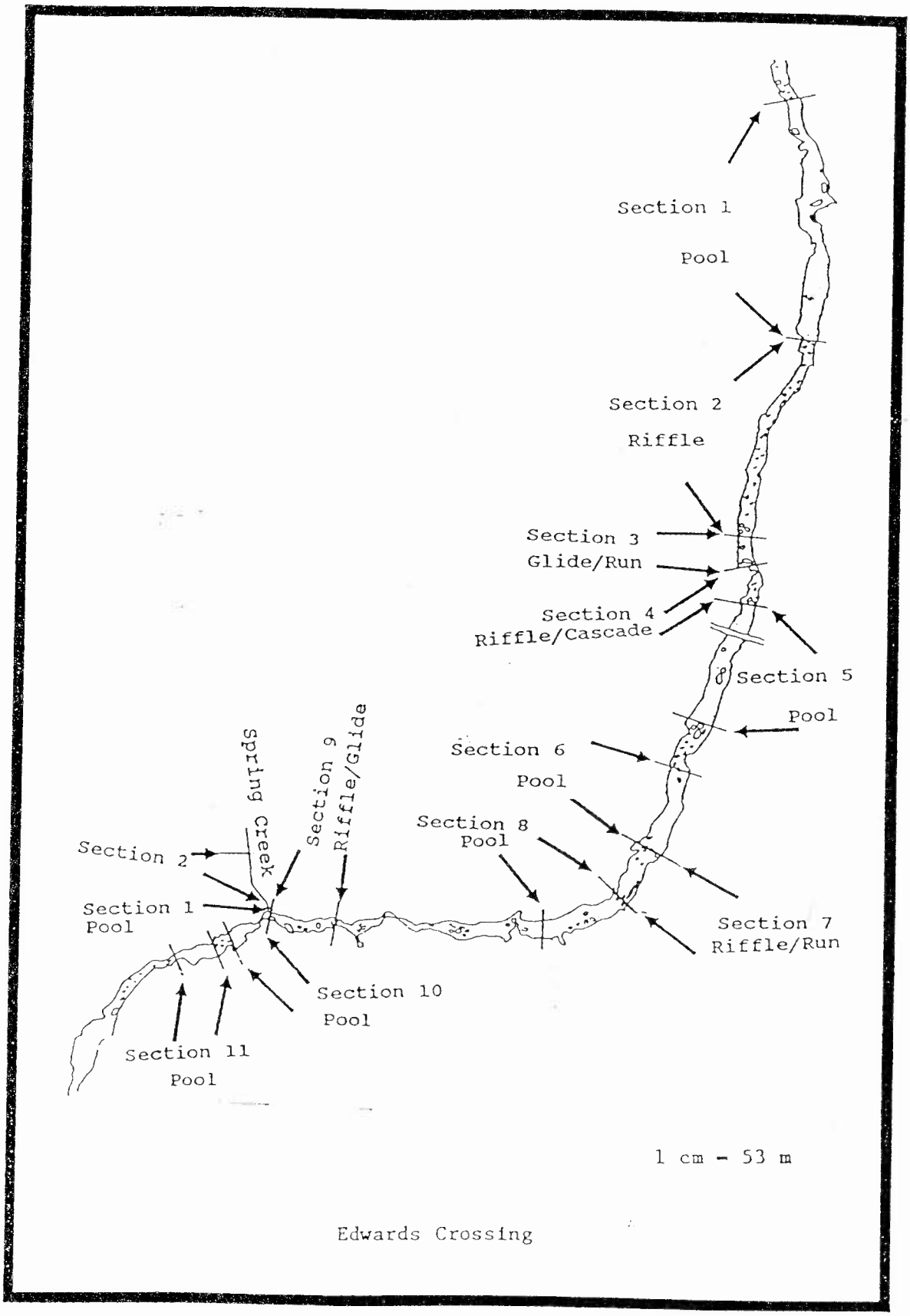


1 cm = 28 m

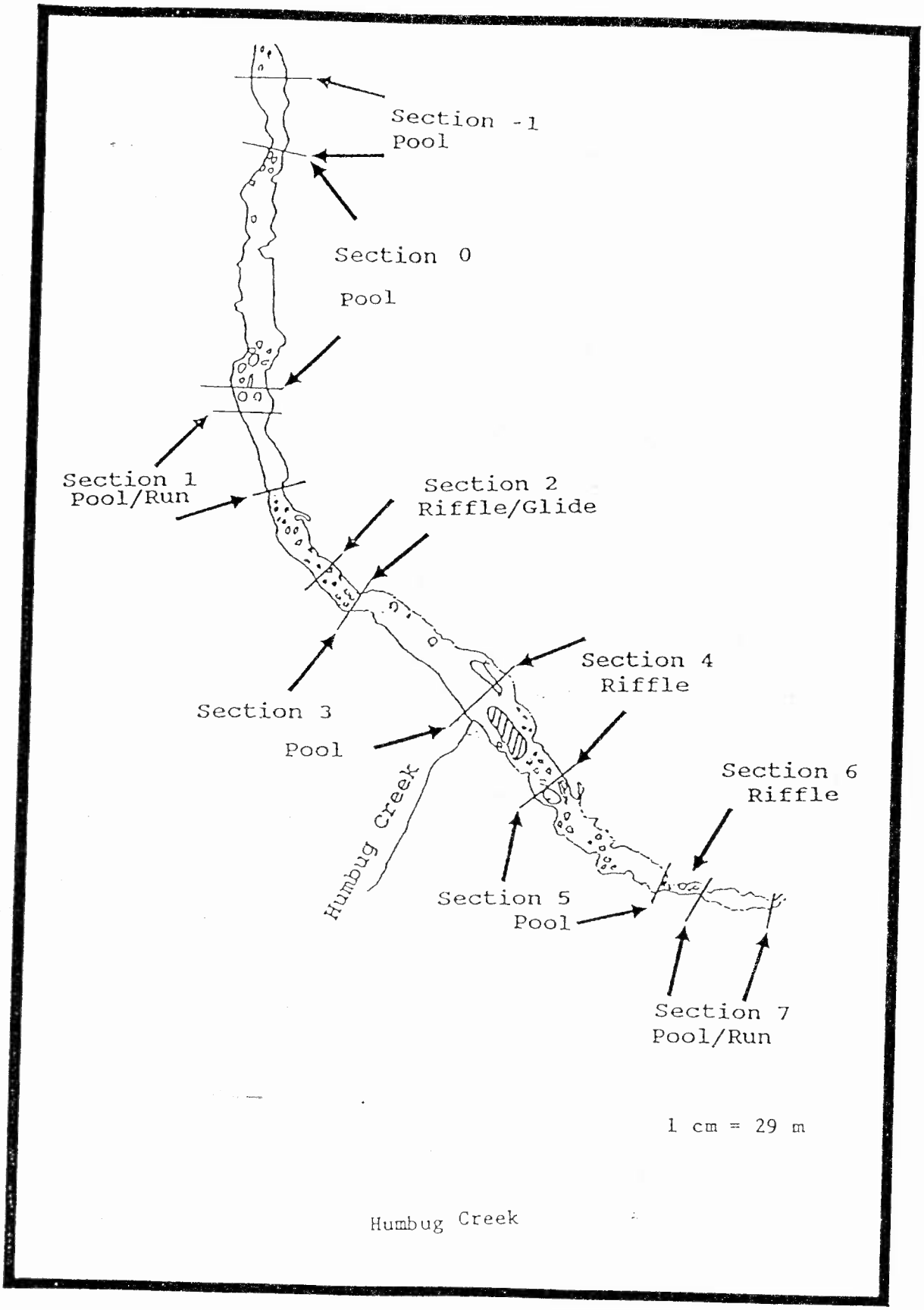
Hoyt Crossing

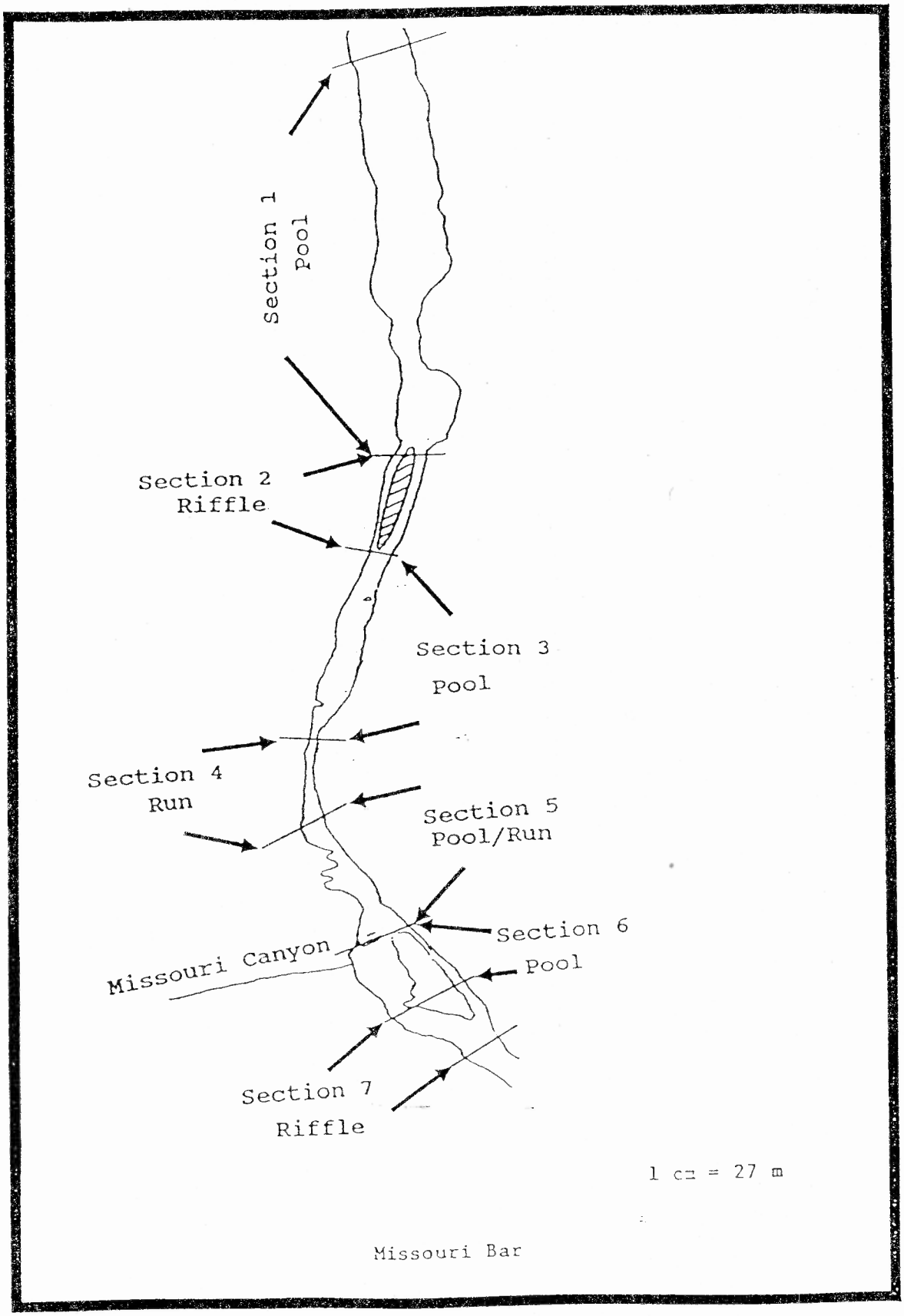


Purdon Crossing



Edwards Crossing

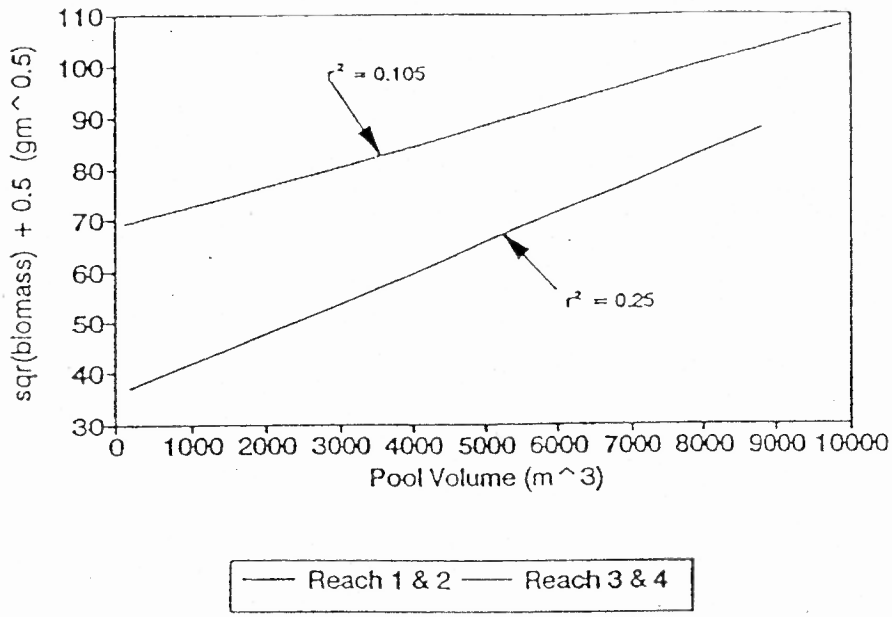

Section -1
Pool
Section 0
Pool
Section 1
Pool/Run
Section 2
Riffle/Glide
Section 3
Pool
Section 4
Riffle
Section 5
Pool
Section 6
Riffle
Section 7
Pool/Run
Humbug Creek
1 cm = 29 m
Humbug Creek


Section 1
Pool
Section 2
Riffle
Section 3
Pool
Section 4
Run
Section 5
Pool/Run
Section 6
Pool
Missouri Canyon
Section 7
Riffle
1 cm = 27 m
Missouri Bar

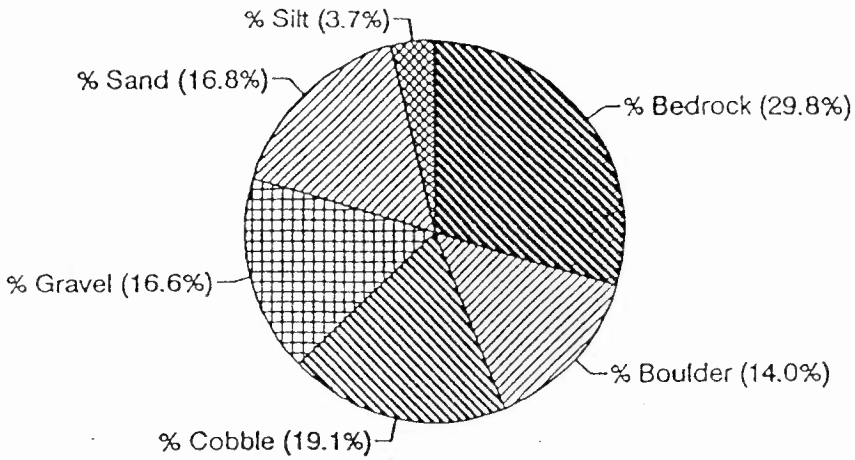
Weights Used to Calculate Fish Biomass
From Snorkel Survey Data

Species	Size class (mm)	Weight (gm)	Source
Smallmouth Bass	< 50	2.44	a
	50-150	23	b
	150-250	184	b
	50-250	77.6	b
	> 250	621	b
Sacramento squawfish	< 50	0.64	a
	50-150	13.21	a
	150-250	104	a
	> 250	426	b
Hardhead	150-250	131	a
	> 250	429	b
Squawfish/Hardhead	< 50	0.64	a
	50-150	15.82	a
	150-250	116	b
	> 250	381	b
Sacramento Sucker	< 50	0.86	a
	50-250	57.7	b
	> 250	686	b
Rainbow Trout	< 100	2.68	a
	100-200	51	b
	> 200	219	b
Bluegill/Green Sunfish	< 100	17.7	a
	> 100	66	a
Brown Bullhead	> 250	376	c
California Roach	50-150	20	d
	< 50	0.3	d
Threespine Stickleback	all	1.0	c
Spotted Bass	> 250	363	c
	150-250	100	c
	< 50	0.5	c
Brown Trout	> 200	184	c
	100-200	48	c
	< 100	2.6	c

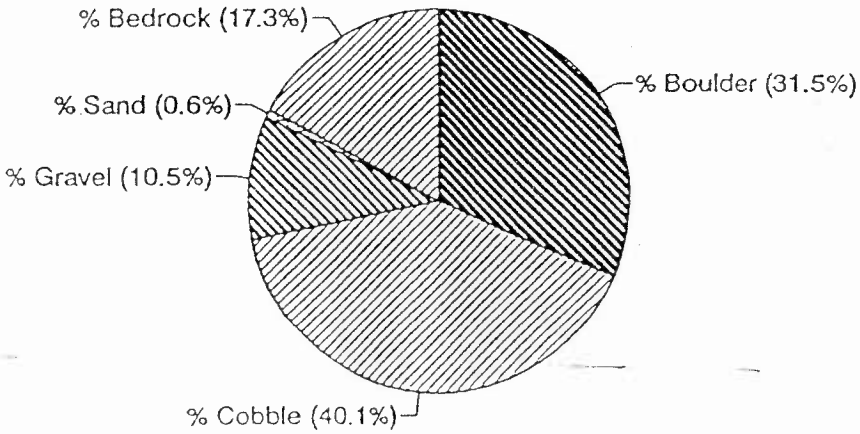
Sources:
- a - average weight of South Yuba River fish
- b - calculated from average condition index of South Yuba River fish and estimated mean standard length
- c - Carlander (1969)
- d - calculated from average condition index of Kentucky Ravine roach and estimated mean standard length



Snorkel Survey Results



Pool and Run Habitats (N=68)



Riffle and Cascade Habitats (N=8)

Substrate Composition of South Yuba River Habitats

South Yuba River - Physical Characteristics of Sites

Site name	Section #	Length	Avg. width	Max. depth	Habitat type	% bedrock	% boulder	% cobble	% gravel	% sand	% silt	Shade	Cover
Bridgeport	1	155.8	32.7	2	Pool	5	5	20	30	35	5	10%	Overall fair; aquatic macrophytes, boulders, logs
Bridgeport	10	128	15.8	3	Pool	30	10	0	50	10	0	5%	Overall fair; large rocks, surface turbulence
Bridgeport	2	260	15.3	0.5	Riffle/Run	10	25	30	20	10	5	10%	Overall good; large rocks, surface turbulence
Bridgeport	3	235	21.0	4	Pool	50	10	5	15	10	10	10%	Overall abundant; boulders, aquatic plants
Bridgeport	4	106		0.5	Riffle	10	40	30	20	0	0	10%	Overall good; surface turbulence, large rocks
Bridgeport	5	114.2	16.6	2	Pool	50	10	10	10	10	10	10%	Overall good; large rocks, overhangs
Bridgeport	D1	101	12.5	2	Pool	20	10	50	5	15	0	5%	Overall fair; large rocks, aquatic vegetation, caves
Bridgeport	D2	30	10.1	1	Run	15	15	60	5	5	0	0%	Overall good; large rocks, surface turbulence, caves
Bridgeport	D3			1	Riffle/Run								
Edwards Crossing	1	223.6	19.6	4	Pool	30	30	10	10	10	10	10%	Overall good; boulders, rocks
Edwards Crossing	10	40	8.3	2	Pool	40	10	0	30	20	0	10%	Overall fair; surface turbulence, large rocks
Edwards Crossing	11	35	11.0	3	Run	30	10	25	45	0	0	10%	Overall fair; surface turbulence, large rocks
Edwards Crossing	2	190		1	Riffle	40	25	25	5	5	0	10%	Overall fair; surface turbulence, large rocks
Edwards Crossing	3	29.2		1	Glide/Run	50	20	10	10	0	10	10%	Overall poor; large rocks
Edwards Crossing	4	38.8	8.0	0.5	Riffle/Cascade	30	40	40	0	0	0	60%	Overall very good; surface turbulence, large rocks
Edwards Crossing	5	109.3	18.0	2.1	Pool	20	20	30	20	5	5	10%	Overall good; boulders
Edwards Crossing	6	76	17.5	5	Pool	35	10	10	5	20	20	20%	Overall fair; logs, large rocks
Edwards Crossing	7	50.4	16.0	1	Riffle/Run	10	30	50	5	5	0	10%	Overall fair; surface turbulence, rocks
Edwards Crossing	8	77.6	14.3	3.5	Pool	40	5	15	20	20	0	5%	Overall fair; logs, large rocks, cave
Edwards Crossing	8A	44	14.5	2	Pool	35	15	5	35	10	0	0%	Overall fair; large rocks, caves
Edwards Crossing	9	60			Riffle/Glide								
Highway 49	1	67	20.7	3.5	Pool	50	20	10	10	0	10	20%	Overall abundant; Boulders, rock overhangs/undercuts
Highway 49	2	43.6	11.6	0.5	Riffle	0	40	40	20	0	0	10%	Overall good; surface roughness, boulders
Highway 49	3	30.6	15.0	2.5	Pool/Run	50	10	10	10	15	5	40%	Overall abundant; boulders (abundant), logs (few)
Highway 49	4	40.3	19.9	2	Pool	30	10	15	20	25	0	10%	Overall fair; boulders, turbulence at head of pool
Highway 49	U1	73	15.6	4	Pool	40	20	10	10	20	0	5%	Overall fair; large rocks, aquatic vegetation, caves
Highway 49	U2	20	11.5	3	Pool	40	0	20	20	20	0	5%	Overall fair; surface turbulence, large rocks
Highway 49	U3	36	11.5	2	Pool/Run	35	5	30	20	10	0	5%	Overall good; large rocks, surface turbulence
Highway 49	U4	60	14.0	3	Pool	40	20	20	5	15	0	5%	Overall fair; large rocks, aquatic veg, cave, woody debris
Hoyt Crossing	1			1	Riffle/Glide	10	20	50	15	5	0	15	Overall fair; surface turbulence, boulders, logs
Hoyt Crossing	2	46.9	23.6	2.5	Pool	10	0	25	5	60	0	5%	Overall poor; large rocks
Hoyt Crossing	3	9.4	16.9	1.5	Run/Glide	50	10	10	5	20	5	10%	Overall abundant; rocks, overhangs
Hoyt Crossing	4	20.4	20.4	3	Pool	35	35	10	10	10	0	5%	Overall fair; large rocks
Hoyt Crossing	5	80.6	18.3	3	Pool	20	15	20	20	20	5	10%	Overall fair; large rocks, cave
Hoyt Crossing	6	20.8	12.4	3.5	Pool	85	10	5	0	0	0	5%	Overall fair; large rocks
Hoyt Crossing	7	26.4	16.0	3	Pool	60	15	10	5	5	5	25%	Overall good; large rocks
Hoyt Crossing	D1	65	14.7	3	Pool	10	10	15	35	20	10	5%	Overall fair; large rocks
Hoyt Crossing	D2	42.5	18.3	2	Run	70	5	15	5	5	0	10%	Overall good; large rocks, caves
Humbug Crossing	-1	36	15.5	1.5	Pool	20	30	20	20	5	5	10%	Overall fair; boulders, surface turbulence at head of pool
Humbug Crossing	0	120.1	11.0	2	Pool	30	10	30	20	10	10	10%	Overall good; tree roots, rock overhangs, boulders
Humbug Crossing	1	38.9	13.7	1.5	Run/Pool	40	15	15	20	5	5	10%	Overall good; logs, large rocks, caves under rocks
Humbug Crossing	2	20	16.7	1.5	Riffle/Glide	40	30	15	10	5	0	10%	Overall good; boulders, surface roughness
Humbug Crossing	3	80	19.5	4	Pool	10	15	25	20	20	10	15%	Overall good; boulders, overhang, logs, shade from trees
Humbug Crossing	4	30.5	17.0	1	Riffle	10	10	60	20	0	0	10%	Overall good; cobbles, surface roughness
Humbug Crossing	5	73	18.1	3	Pool	30	30	15	5	10	10	10%	Overall abundant; logs, boulders, caves
Humbug Crossing	6				Riffle								
Humbug Crossing	7	35	5.3	2	Pool/Run	50	40	5	0	5	0	30%	Overall good; surface turbulence at head of pool, boulders

South Yuba River - Physical Characteristics of Sites

Site name	Section #	Length	Avg. width	Max. depth	Habitat type	% bedrock	% boulder	% cobble	% gravel	% sand	% silt	Shade	Cover
Humbug Crossing	8	50	12.0	2	Pool	25	35	35	5	0	0		
Illinois Crossing	1	100	15.5	4	Pool	5	20	15	5	50	5	5%	Overall poor; large rocks, woody debris
Illinois Crossing	2	93	19.0	4	Pool	30	5	30	30	5	0	10%	Overall poor; large rocks, aquatic vegetation
Illinois Crossing	3	120	21.6	1	Run/Glide	5	5	75	10	5	0	5%	Overall poor; large rocks, woody debris
Illinois Crossing	3A	125	22.9	1	Run/Glide	10	10	60	10	10	0	60%	Overall fair; large rocks, aquatic vegetation
Illinois Crossing	4	74	14.3	2	Run/Glide	10	5	50	20	15	0	20%	Overall poor; large rocks
Jones Bar	1	44	11.5	3	Run	10	10	65	5	10	0	5%	Overall poor; large rocks
Jones Bar	2	30	13.1	1.5	Run	65	10	10	5	10	0	10%	Overall good; large rocks, caves
Jones Bar	3	68	13.0	3	Pool	50	5	10	5	30	0	5%	Overall good; large rocks
Jones Bar	4	51	17.0	4	Pool	15	10	15	0	60	0	5%	Overall fair; large rocks
Jones Bar	5	71	24.8	4	Pool	15	15	5	5	60	0	5%	Overall fair; large rocks, aquatic vegetation
Jones Bar	6	168	16.2	4	Pool	10	10	35	25	20	0	10%	Overall poor; large rocks, aquatic vegetation
Jones Bar-Bridgeport	1	135	13.4	3	Pool/Run	30	20	40	5	5	0	5%	Overall fair; large rocks
Jones Bar-Bridgeport	2	78	11.2	3	Pool/Run	30	5	5	40	20	0	10%	Overall fair; large rocks, surface turbulence
Jones Bar-Bridgeport	3	68	12.3	3	Pool/Run	30	15	30	20	15	0	5%	Overall fair; large rocks, surface turbulence
Jones Bar-Bridgeport	4	109	16.0	3	Pool	15	15	0	35	35	0	5%	Overall poor; large rocks, surface turbulence
Jones Bar-Bridgeport	5	65	10.5	3	Pool	35	10	35	10	10	0	5%	Overall poor; large rocks, surface turbulence
Jones Bar-Bridgeport	6	100	10.7	3	Pool	40	10	20	20	10	0	0%	Overall fair; large rocks, surface turbulence
Jones Bar-Bridgeport	7	44	16.4	4	Pool	50	0	0	25	25	0	5%	Overall poor; large rocks, surface turbulence
Jones Bar-Bridgeport	8	110	16.2	5	Pool	15	25	0	35	25	0	5%	Overall fair; large rocks, surface turbulence
Missouri Bar	1	187	19.8	4.5	Pool	40	10	5	5	0	40	30%	Overall fair; large boulders
Missouri Bar	2	40		1	Riffle	10	10	70	10	0	0	50%	Overall good; overhanging trees, large rocks, surface turb.
Missouri Bar	3	80.2	22.0	3	Pool	40	10	5	5	0	40	10%	Overall fair; large rocks
Missouri Bar	4	34	13.4	1	Run	10	20	20	10	0	0	5%	Overall poor; large rocks
Missouri Bar	5	63	23.1	4	Pool/Run	40	10	10	0	40		20%	Overall fair; large rocks
Missouri Bar	6	34.5	23.3	3	Pool	0	0	40	0	60	0	10%	Overall fair; logs, overhanging trees
Missouri Bar	7	30		1	Riffle	10	60	30	0	0	0	20%	Overall good; surface roughness, boulders
Missouri Bar	8	90	23.3	4	Run	30	40	20	0	0	10	5%	Overall fair; large rocks
Missouri Bar	9	160	22.3	4	Pool	20	10	50	10	10	0	10%	Overall fair; large rocks, aquatic vegetation
Purdon Crossing	1	49.7	14.9	1.5	Pool/Run	20	20	10	20	20	10	5%	Overall fair; boulders
Purdon Crossing	2	65.8	14.5	0.5	Glide/Riffle	20	10	50	5	10	5	5%	Overall abundant; boulders, surface roughness
Purdon Crossing	3	77.4	22.4	1.5	Pool	10	15	15	45	10	5	5%	Overall fair; boulders
Purdon Crossing	4	81.4	21.1	0.5	Riffle/Glide	30	40	25	5	0	0	10%	Overall abundant; boulders, logs, surface roughness
Purdon Crossing	5	74.7	10.3	2.5	Pool/Run	40	20	5	10	10	5	5%	Overall good; boulders, overhanging rocks
Purdon Crossing	6	40.1	20.5	0.5	Riffle/Cascade	30	30	30	10	0	0	5%	Overall abundant; boulders, surface turbulence
Purdon Crossing	7	23.0	12.2	1.5	Pool/Run	20	20	20	20	20	0	10%	Overall fair; boulders, overhanging rocks
Purdon Crossing	8	84	21.9	2.5	Pool	15	15	20	25	25	0	10%	Overall fair; boulders
Purdon Crossing	U1	120	19.5	2	Pool	20	20	40	10	10	0	5%	Overall good; large rocks, aquatic vegetation, caves
Purdon Crossing	U2	148	19.5	3	Pool	10	10	25	35	20	0	5%	Overall good; large rocks, woody debris, caves
Purdon Crossing	U3	46	14.3	2	Pool/Run	30	10	25	25	10	0	5%	Overall good; large rocks
Purdon Crossing	U4	30	15.1	2	Pool/Run	30	10	15	30	15	0	5%	Overall fair; large rocks
Purdon Crossing	U5	61	14.3	1.5	Run/Glide	25	25	25	20	5	0	5%	Overall good; large rocks
Starvation Bar-Bridgeport	1	142	18.9	4	Pool	10	10	10	40	30	0		Overall fair; large rocks
Starvation Bar-Bridgeport	2	147.7	19.9	3	Pool	10	5	45	25	15	0		Overall fair; large rocks

Snorkel Survey Data - Purdon Crossing and above

			Sacramento sucker			Sacramento Squawfish					Rainbow Trout	
Site name	Section #	Date sampled	SL > 250 mm	SL 50-250 mm	SL < 50 mm	SL > 250 mm	SL 150-250 mm	SL 50-150 mm	SL < 50mm	SL > 200 mm	SL 100-200 m	SL < 100 mm
Missouri Bar	1	18-Jul-91	9	0	37	0	21	86	0	8	0	0
Missouri Bar	1	24-Jun-92	0	0	0	8	0	60	60	0	3	0
Missouri Bar	1	08-Sep-93	1	0	0	12	3	70	151	3	14	1
Missouri Bar	3	18-Jul-91	3	0	78	0	0	24	1	0	0	0
Missouri Bar	3	24-Jun-92	0	0	0	0	0	34	0	0	2	0
Missouri Bar	3	08-Sep-93	0	0	4	0	0	0	2	0	7	0
Missouri Bar	4	17-Jul-91	0	0	2	0	0	0	0	1	1	0
Missouri Bar	4	24-Jun-92	1	0	0	0	0	0	5	0	0	0
Missouri Bar	5	17-Jul-91	14	0	32	0	0	22	0	0	0	1
Missouri Bar	5	24-Jun-92	17	0	0	0	0	72	3	0	0	0
Missouri Bar	6	17-Jul-91	0	0	14	0	0	50	14	0	0	0
Missouri Bar	6	24-Jun-92	0	0	0	0	0	45	1	0	0	0
Missouri Bar	6	08-Sep-93	0	0	0	0	0	1	6	0	2	0
Missouri Bar	8	25-Jun-92	4	0	0	5	0	3	41	1	1	0
Missouri Bar	8	08-Sep-93	0	0	0	0	0	12	0	4	4	4
Missouri Bar	9	09-Sep-92	1	0	0	7	0	23	41	0	0	0
Missouri Bar	9	08-Sep-93	0	1	17	1	2	0	1	6	11	0
Purdon Crossing	1	22-Aug-91	0	1	0	5	9	63	15	0	0	0
Purdon Crossing	1	29-Jul-92	0	0	0	0	0	35	22	0	0	0
Purdon Crossing	1	12-Aug-93	1	0	1	0	4	50	0	0	0	0
Purdon Crossing	3	21-Aug-91	0	0	0	9	27	69	5	0	0	0
Purdon Crossing	3	29-Jul-92	1	0	0	0	17	10	13	0	0	0
Purdon Crossing	3	06-Aug-93	1	0	0	3	23	57	6	0	0	0
Purdon Crossing	5	22-Aug-91	0	0	0	4	30	43	26	0	0	0
Purdon Crossing	5	29-Jul-92	0	1	0	4	8	22	42	0	0	0
Purdon Crossing	5	12-Aug-93	0	0	0	0	2	87	0	0	1	0
Purdon Crossing	7	22-Aug-91	0	0	0	1	4	40	5	0	0	0
Purdon Crossing	7	29-Jul-92	0	0	0	0	0	2	24	0	1	0
Purdon Crossing	7	12-Aug-93	0	0	1	0	3	16	0	0	0	0
Purdon Crossing	8	22-Aug-91	0	0	2	4	4	113	102	0	0	0
Purdon Crossing	8	29-Jul-92	0	0	0	8	0	34	64	0	0	0
Purdon Crossing	8	12-Aug-93	0	1	0	3	1	79	6	0	0	0
Purdon Crossing	U1	30-Jul-92	0	0	0	4	0	1	60	0	0	0
Purdon Crossing	U1	19-Aug-93	0	0	1	3	3	82	6	1	0	0
Purdon Crossing	U2	30-Jul-92	1	0	0	7	1	134	96	0	0	0
Purdon Crossing	U2	26-Aug-93	5	0	2	2	4	100	20	0	0	0
Purdon Crossing	U3	26-Aug-93	0	0	1	2	0	17	50	0	1	0
Purdon Crossing	U4	26-Aug-93	1	3	0	3	4	16	21	0	0	0
Purdon Crossing	U5	26-Aug-93	0	0	0	1	1	30	31	0	0	0

Snorkel Survey Data - Purdon Crossing and above

Site name	Section #	Date sampled	Sacramento sucker BL > 250 mm	BL 50-250 mm	BL < 50 mm	Sacramento Squawfish BL > 250 mm	BL 150-250 mm	BL 50-150 mm	BL < 50mm	Rainbow Trout BL > 200 mm	BL 100-200 mm	BL < 100 mm
Edwards Crossing	1	07-Aug-01	2	1	0	7	10	246	138	0	0	0
Edwards Crossing	1	22-Jul-02	0	3	0	8	0	143	283	0	0	0
Edwards Crossing	1	10-Aug-03	1	0	13	6	0	156	107	0	3	0
Edwards Crossing	10	20-Sep-91	0	0	0	0	0	0	4	0	0	0
Edwards Crossing	10	24-Jul-92	0	0	5	1	0	21	43	0	0	0
Edwards Crossing	10	20-Aug-93	0	0	33	1	0	0	40	1	0	0
Edwards Crossing	11	20-Sep-91	0	0	0	0	0	0	0	0	0	0
Edwards Crossing	11	24-Jul-92	0	1	2	1	0	23	52	0	0	0
Edwards Crossing	11	20-Aug-93	10	0	20	1	0	43	42	0	1	0
Edwards Crossing	5	07-Aug-91	0	0	0	1	24	118	1	0	0	0
Edwards Crossing	5	22-Jul-92	0	0	0	0	0	52	38	0	0	0
Edwards Crossing	5	06-Aug-03	3	0	5	1	3	103	17	0	0	0
Edwards Crossing	6	20-Sep-91	0	0	0	2	0	7	23	0	0	0
Edwards Crossing	6	24-Jul-92	1	0	3	4	0	41	67	0	0	0
Edwards Crossing	6	20-Aug-93	1	0	5	2	0	40	66	1	0	0
Edwards Crossing	8	18-Sep-91	0	0	0	0	20	0	66	0	0	0
Edwards Crossing	8	24-Jul-92	0	3	1	0	0	29	116	0	0	0
Edwards Crossing	8	20-Aug-93	0	0	1	0	0	7	21	0	2	0
Edwards Crossing	8A	24-Jul-92	0	0	0	0	0	18	36	1	1	0
Edwards Crossing	8A	20-Aug-93	1	3	21	0	1	35	30	1	0	0
S. Yuba at Humbug Creek	-1	15-Aug-91	0	0	0	0	0	0	5	0	3	0
S. Yuba at Humbug Creek	-1	22-Jul-93	0	0	0	0	0	1	0	0	1	0
S. Yuba at Humbug Creek	0	15-Aug-91	3	0	23	0	3	0	64	1	0	0
S. Yuba at Humbug Creek	0	22-Jul-93	1	0	0	1	1	62	5	3	2	0
S. Yuba at Humbug Creek	1	15-Aug-91	2	0	3	0	0	0	41	0	0	0
S. Yuba at Humbug Creek	3	14-Aug-91	8	0	3	2	0	35	10	1	3	0
S. Yuba at Humbug Creek	3	22-Jul-93	2	0	0	1	0	20	15	3	3	0
S. Yuba at Humbug Creek	5	14-Aug-91	10	0	0	0	0	1	57	1	0	0
S. Yuba at Humbug Creek	5	22-Jul-93	1	0	0	0	0	5	34	0	5	0
S. Yuba at Humbug Creek	7	18-Aug-91	0	0	0	1	0	0	0	0	1	0
S. Yuba at Humbug Creek	7	22-Jul-93	4	0	0	0	0	15	0	0	3	0
S. Yuba at Humbug Creek	8	22-Jul-93	3	1	0	1	0	31	0	0	1	0
Illinois Crossing	1	23-Jul-92	0	0	0	4	4	141	5	1	1	0
Illinois Crossing	1	11-Aug-93	1	0	1	0	1	12	12	0	2	0
Illinois Crossing	2	23-Jul-92	0	0	0	1	0	44	13	0	0	0
Illinois Crossing	2	11-Aug-93	10	0	9	1	1	5	52	0	1	0
Illinois Crossing	3	23-Jul-92	0	0	0	2	0	9	285	0	0	0
Illinois Crossing	3	11-Aug-93	0	0	1	0	0	10	34	0	0	1
Illinois Crossing	3A	11-Aug-93	8	0	2	2	0	26	25	0	0	0
Illinois Crossing	4	23-Jul-92	1	4	0	5	5	56	110	0	0	0
Illinois Crossing	4	11-Aug-93	10	0	7	2	1	91	30	2	4	0

Snorkel Survey Data - Hoyt Crossing and below - Native Fish

			Sacramento sucker			Rainbow trout			Sacramento Squawfish + Hardhead			
Site name	Section #	Date sampled	SL >250 mm	SL 50-250 mm	SL <50 mm	SL >200 mm	SL 100-200 mm	SL <100 mm	SL >250 mm	SL 150-250 mm	SL 50-150 mm	SL <50 mm
Bridgeport	1	31-Jul-91	0	3	0	0	0	0	0	16	10	3
Bridgeport	3	31-Jul-91	1	2	0	0	0	0	13	5	0	0
Bridgeport	5	01-Aug-91	1	0	0	0	0	0	0	0	0	0
Highway 49	1	24-Jul-91	1	3	15	0	0	0	7	33	41	27
Highway 49	3	24-Jul-91	2	0	10	0	0	0	5	17	21	3
Highway 49	4	24-Jul-91	2	2	0	0	0	0	6	13	33	10
Hoyt Crossing	2	29-Aug-91	2	0	0	0	0	0	25	15	27	71
Hoyt Crossing	3	29-Aug-91	0	0	0	0	0	0	2	1	24	6
Hoyt Crossing	4	29-Aug-91	2	3	0	0	0	0	7	11	2	7
Hoyt Crossing	5	29-Aug-91	3	0	0	0	0	0	13	13	2	56
Hoyt Crossing	6	29-Aug-91	0	0	0	0	0	0	9	3	7	3
Hoyt Crossing	7	29-Aug-91	1	2	0	1	0	0	13	9	2	72

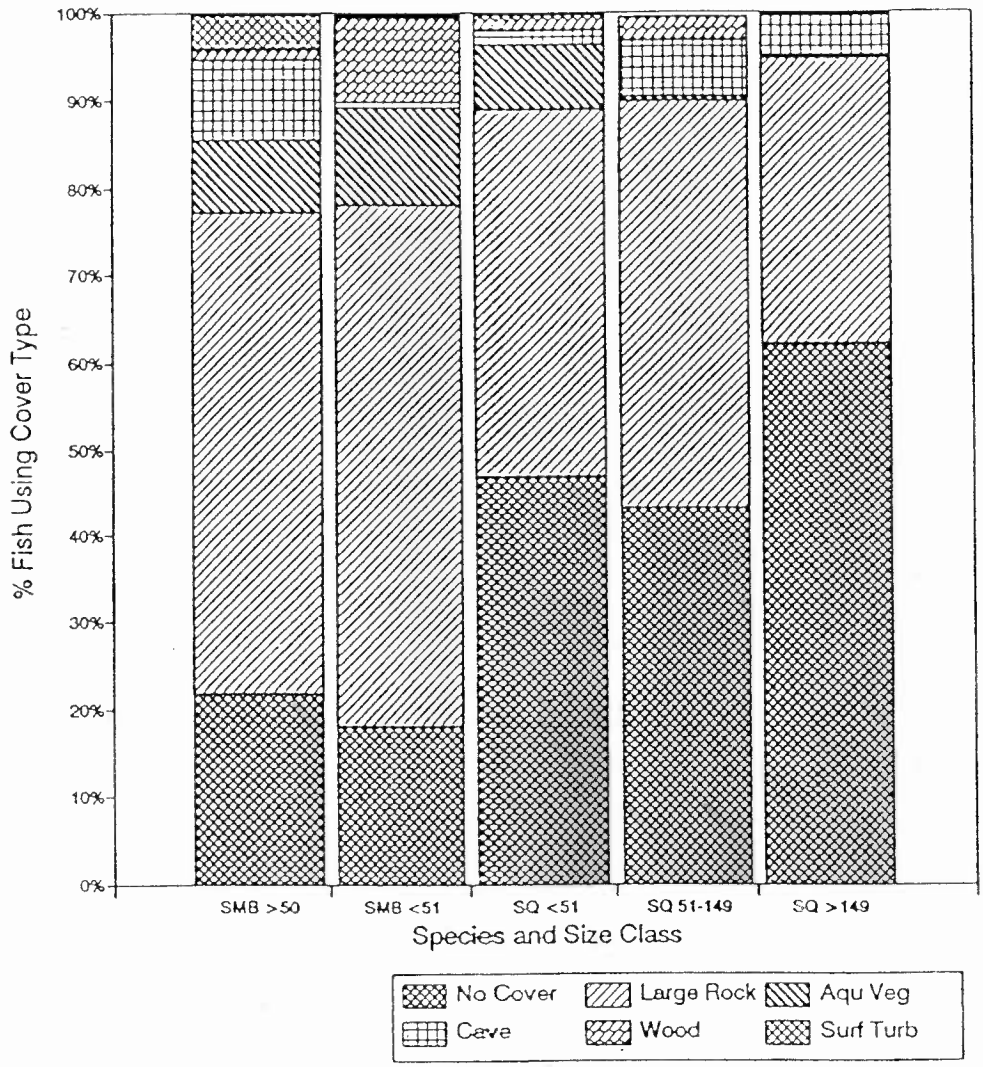
Snorkel Survey Data - Hoyt Crossing and below - Native Fish

Site name	Section #	Date sampled	Sacramento sucker SL > 250 mm	Sacramento sucker SL 50-250 mm	Sacramento sucker SL < 50 mm	Sacramento Squawfish SL > 250 mm	Sacramento Squawfish SL 150-250 mm	Rainbow trout SL > 200 mm	Rainbow trout SL 100-200 mm	Rainbow trout SL < 100 mm	Hardhead SL > 250 mm	Hardhead SL 150-250 mm	Sacramento Squawfish + Hardhead SL 50-150 mm	Sacramento Squawfish + Hardhead SL < 50 mm
Bridgeport	1	06-Aug-92	0	0	0	5	0	0	0	0	0	0	3	0
Bridgeport	1	29-Jul-93	0	0	0	0	0	1	0	0	0	0	3	40
Bridgeport	1	16-Sep-93	0	0	0	0	0	0	0	0	0	0	6	0
Bridgeport	10	13-Aug-92	0	0	0	3	0	0	0	0	0	0	0	0
Bridgeport	10	05-Aug-93	4	0	0	1	0	0	0	0	0	0	5	13
Bridgeport	3	06-Aug-92	0	0	0	4	1	0	0	0	0	0	0	3
Bridgeport	3	30-Jul-93	5	7	0	1	2	0	0	0	3	7	0	45
Bridgeport	3	16-Sep-93	3	0	0	0	0	0	0	0	8	0	0	0
Bridgeport	5	13-Aug-92	1	0	0	0	0	0	0	0	0	0	0	0
Bridgeport	5	05-Aug-93	0	0	0	0	0	0	0	0	0	0	0	0
Bridgeport	D1	06-Aug-92	0	0	0	0	0	0	0	0	0	0	0	0
Bridgeport	D1	29-Jul-93	1	3	0	0	1	0	1	0	2	0	0	0
Bridgeport	D2	06-Aug-92	0	0	0	0	0	0	0	0	0	0	1	0
Bridgeport	D2	29-Jul-93	0	0	0	0	0	0	0	1	0	0	0	0
Highway 49	U1	31-Jul-92	1	2	0	25	6	0	0	0	6	3	58	202
Highway 49	U1	08-Jul-93	2	0	0	4	4	0	0	1	5	5	61	225
Highway 49	U2	31-Jul-92	0	0	0	2	1	0	0	0	3	0	0	60
Highway 49	U2	08-Jul-93	0	0	0	1	0	0	0	0	1	0	0	25
Highway 49	U3	31-Jul-92	0	0	0	1	6	0	0	0	3	2	11	129
Highway 49	U3	08-Jul-93	0	0	0	1	3	0	1	0	2	3	0	180
Highway 49	U4	04-Sep-92	0	0	0	1	1	0	0	0	0	0	80	148
Highway 49	U4	08-Jul-93	1	0	0	2	2	0	0	0	4	7	0	218
Hoyt Crossing	2	16-Jul-92	1	0	0	4	2	0	0	0	7	4	53	156
Hoyt Crossing	2	08-Jul-93	1	0	0	3	12	0	0	0	4	6	57	2
Hoyt Crossing	3	16-Jul-92	0	0	0	1	2	0	0	0	1	0	0	45
Hoyt Crossing	3	08-Jul-93	0	0	0	0	1	0	0	0	0	0	0	3
Hoyt Crossing	4	16-Jul-92	0	0	0	2	4	0	0	0	3	0	0	90
Hoyt Crossing	4	08-Jul-93	7	2	0	1	6	0	0	0	0	2	0	0
Hoyt Crossing	5	16-Jul-92	3	0	0	14	1	0	0	0	11	0	0	207
Hoyt Crossing	5	08-Jul-93	1	0	0	2	10	1	0	0	2	17	0	1
Hoyt Crossing	6	16-Jul-92	1	0	0	4	1	0	0	0	3	1	0	20
Hoyt Crossing	6	08-Jul-93	0	0	0	0	1	0	0	0	0	2	0	0
Hoyt Crossing	7	16-Jul-92	2	0	0	3	6	1	0	0	8	0	2	170
Hoyt Crossing	7	08-Jul-93	0	1	0	1	7	0	1	0	1	4	0	171
Hoyt Crossing	D1	16-Jul-92	0	0	0	11	6	0	0	0	16	1	5	320
Hoyt Crossing	D2	16-Jul-92	0	0	0	26	3	0	0	0	6	2	0	37
Jones Bar	1	08-Jul-92	0	1	0	1	1	0	0	0	0	3	7	217
Jones Bar	1	16-Sep-93	1	0	0	4	0	0	0	0	6	5	0	0
Jones Bar	2	09-Jul-92	7	0	1	2	4	0	0	0	4	8	2	175
Jones Bar	2	16-Sep-93	4	0	0	3	1	0	0	0	6	0	0	175
Jones Bar	3	08-Jul-92	0	0	0	1	3	1	0	0	6	1	54	662
Jones Bar	3	16-Sep-93	0	0	0	3	0	0	0	0	8	5	0	3
Jones Bar	4	08-Jul-92	0	40	0	2	1	0	1	0	5	33	31	194
Jones Bar	4	16-Sep-93	1	0	0	1	1	0	0	0	0	13	0	300
Jones Bar	5	08-Jul-92	4	0	0	2	0	0	0	0	16	10	142	184
Jones Bar	5	16-Sep-93	1	0	0	4	0	0	0	0	21	15	0	400
Jones Bar	6	10-Jul-92	0	0	0	1	29	0	0	0	33	0	454	610
Jones Bar-Bridgeport	1	12-Aug-92	0	0	0	2	0	0	0	0	15	0	19	217
Jones Bar-Bridgeport	2	12-Aug-92	1	0	0	4	0	0	0	0	4	0	19	129
Jones Bar-Bridgeport	3	12-Aug-92	16	0	1	1	0	0	0	0	8	0	17	323
Jones Bar-Bridgeport	4	13-Aug-92	0	0	0	4	0	0	0	0	10	0	1	478
Jones Bar-Bridgeport	5	13-Aug-92	5	0	0	2	0	0	0	0	5	0	27	470
Jones Bar-Bridgeport	6	13-Aug-92	3	0	0	1	0	0	0	0	0	0	0	435
Jones Bar-Bridgeport	7	13-Aug-92	0	0	0	0	0	0	0	0	2	0	0	0
Jones Bar-Bridgeport	7	30-Jul-93	9	2	4	0	0	0	0	0	24	26	0	360
Jones Bar-Bridgeport	8	13-Aug-92	0	0	0	2	0	0	0	0	13	0	20	5
Starvation Bar-Bridge	1	30-Jul-93	2	2	2	2	4	0	0	0	4	5	0	520
Starvation Bar-Bridge	2	30-Jul-93	0	0	0	1	1	0	0	0	8	0	0	10

Snorkel Survey Data - Hoyt Crossing and below - Introduced Fish

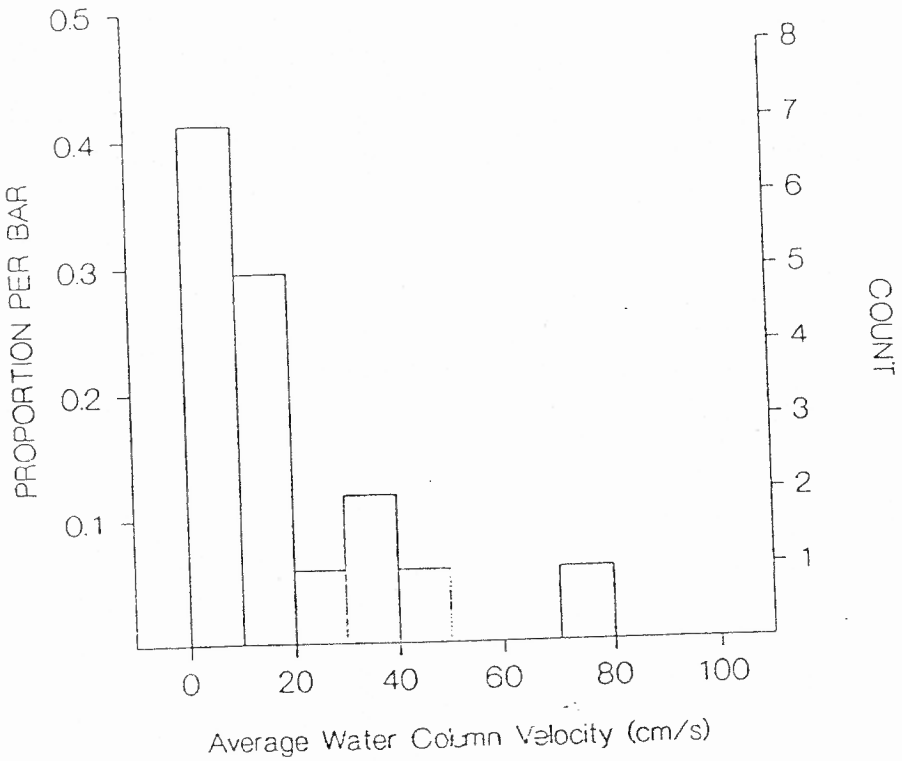
Site name	Section #	Date sampled	Smallmouth bass SL >250 mm	SL 50-250 mm	SL <50 mm	Bluegill + Green Sunfish SL >100 mm	SL <100 mm
Bridgeport	1	31-Jul-91	5	33	20	0	29
Bridgeport	3	31-Jul-91	0	51	3	3	10
Bridgeport	5	01-Aug-91	1	23	9	0	0
Highway 49	1	24-Jul-91	0	0	0	0	0
Highway 49	3	24-Jul-91	0	0	0	0	0
Highway 49	4	24-Jul-91	0	0	0	0	0
Hoyt Crossing	2	29-Aug-91	0	0	0	0	0
Hoyt Crossing	3	29-Aug-91	0	0	0	0	0
Hoyt Crossing	4	29-Aug-91	0	0	0	0	0
Hoyt Crossing	5	29-Aug-91	0	0	0	0	0
Hoyt Crossing	6	29-Aug-91	0	0	0	0	0
Hoyt Crossing	7	29-Aug-91	0	0	0	0	0

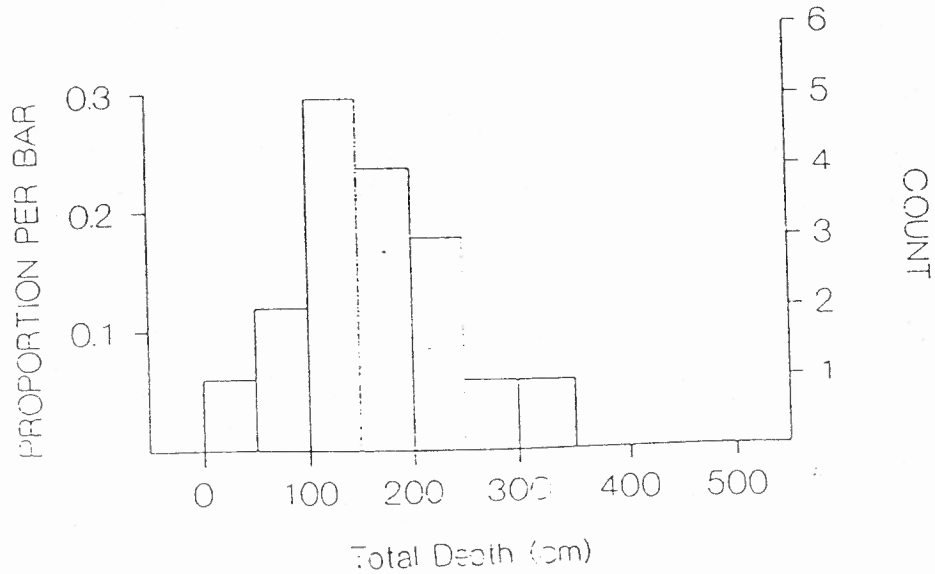
Site name	Section #	Date sampled	Smallmouth bass SL >250 mm	SL 50-150 mm	SL 150-250	SL <50 mm	Bluegill + Green Sunfish SL >100 mm	SL <100 mm	Brown bullhead SL >250 mm
Bridgeport	1	06-Aug-92	1	66	13	5	2	5	0
Bridgeport	1	29-Jul-93	2	10	10	139	3	7	0
Bridgeport	1	16-Sep-93	0	29	10	20	6	1	0
Bridgeport	10	13-Aug-92	0	28	25	0	3	0	0
Bridgeport	10	05-Aug-93	3	14	11	33	4	0	0
Bridgeport	3	06-Aug-92	0	11	2	0	0	0	0
Bridgeport	3	30-Jul-93	2	5	4	197	0	1	0
Bridgeport	3	16-Sep-93	2	6	12	0	0	0	0
Bridgeport	5	13-Aug-92	0	21	23	0	0	0	0
Bridgeport	5	05-Aug-93	1	20	9	59	3	1	0
Bridgeport	D1	05-Aug-92	6	36	12	2	1	0	0
Bridgeport	D1	29-Jul-93	3	13	7	0	1	0	0
Bridgeport	D2	05-Aug-92	0	25	2	0	0	0	0
Bridgeport	D2	29-Jul-93	0	9	2	55	0	0	0
Highway 49	U1	31-Jul-92	0	0	0	0	0	0	0
Highway 49	U1	06-Jul-93	0	0	0	0	0	0	0
Highway 49	U2	31-Jul-92	0	0	0	0	0	0	0
Highway 49	U2	06-Jul-93	0	0	0	0	0	0	0
Highway 49	U3	31-Jul-92	0	0	0	0	0	0	0
Highway 49	U3	06-Jul-93	0	0	0	0	0	0	0
Highway 49	U4	04-Sep-92	0	0	0	0	0	0	0
Highway 49	U4	06-Jul-93	0	0	0	0	0	0	0
Hoyt Crossing	2	15-Jul-92	0	0	0	0	0	0	0
Hoyt Crossing	2	06-Jul-93	0	0	0	0	0	0	0
Hoyt Crossing	3	15-Jul-92	0	0	0	0	0	0	0
Hoyt Crossing	3	06-Jul-93	0	0	0	0	0	0	0
Hoyt Crossing	4	15-Jul-92	0	0	0	0	0	0	0
Hoyt Crossing	4	06-Jul-93	0	0	0	0	0	0	0
Hoyt Crossing	5	15-Jul-92	0	0	0	0	0	0	0
Hoyt Crossing	5	06-Jul-93	0	0	0	0	0	0	0
Hoyt Crossing	6	15-Jul-92	0	0	0	0	0	0	0
Hoyt Crossing	6	06-Jul-93	0	0	0	0	0	0	0
Hoyt Crossing	7	15-Jul-92	0	0	0	0	0	0	0
Hoyt Crossing	7	06-Jul-93	0	0	0	0	0	0	0
Hoyt Crossing	D1	16-Jul-92	0	0	0	0	0	0	0
Hoyt Crossing	D2	16-Jul-92	0	0	0	0	0	0	0
Jones Bar	1	06-Jul-92	0	0	0	0	0	0	0
Jones Bar	1	16-Sep-93	0	0	0	0	0	0	0
Jones Bar	2	09-Jul-92	0	0	0	0	0	0	2
Jones Bar	2	16-Sep-93	0	0	0	0	0	0	0
Jones Bar	3	06-Jul-92	0	0	0	0	0	0	0
Jones Bar	3	16-Sep-93	0	0	0	0	0	0	0
Jones Bar	4	06-Jul-92	0	0	0	0	0	0	0
Jones Bar	4	16-Sep-93	0	0	0	0	0	0	0
Jones Bar	5	06-Jul-92	0	0	0	0	4	0	0
Jones Bar	5	16-Sep-93	0	0	0	0	0	0	0
Jones Bar	6	10-Jul-92	0	0	0	0	0	0	0
Jones Bar-Bridgeport	1	12-Aug-92	0	0	0	0	0	0	0
Jones Bar-Bridgeport	2	12-Aug-92	0	0	0	0	0	0	0
Jones Bar-Bridgeport	3	12-Aug-92	0	0	0	0	0	0	0
Jones Bar-Bridgeport	4	13-Aug-92	0	0	0	0	0	0	0
Jones Bar-Bridgeport	5	13-Aug-92	0	0	0	0	0	0	0
Jones Bar-Bridgeport	6	13-Aug-92	1	0	2	0	0	0	0
Jones Bar-Bridgeport	7	13-Aug-92	5	1	12	0	0	0	0
Jones Bar-Bridgeport	7	30-Jul-93	2	0	2	100	0	0	0
Jones Bar-Bridgeport	8	13-Aug-92	2	13	3	0	0	0	0
Starvation Bar-Bridge	1	30-Jul-93	2	2	6	62	0	0	0
Starvation Bar-Bridge	2	30-Jul-93	1	8	14	189	1	0	0



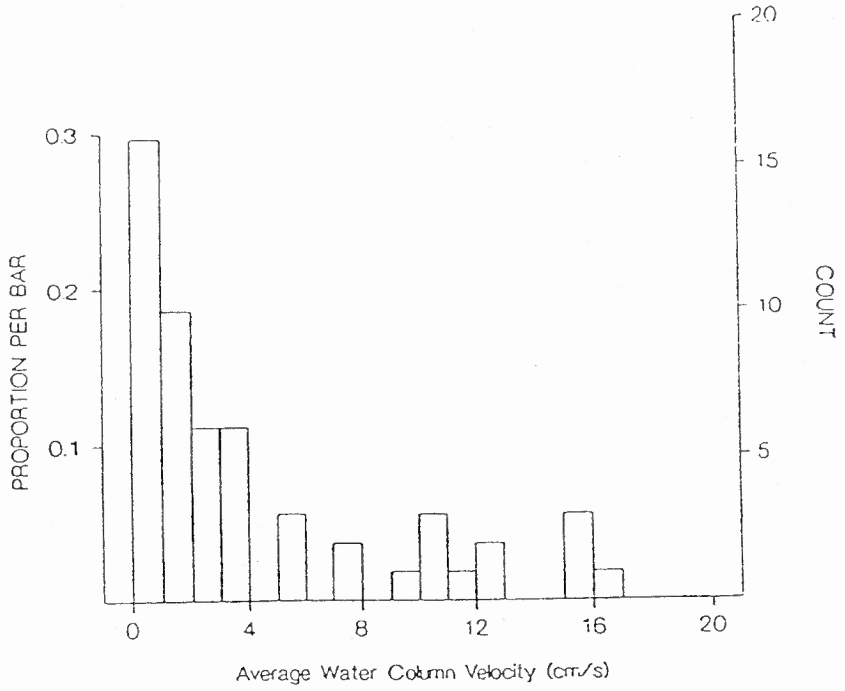
Microhabitat Use - Cover

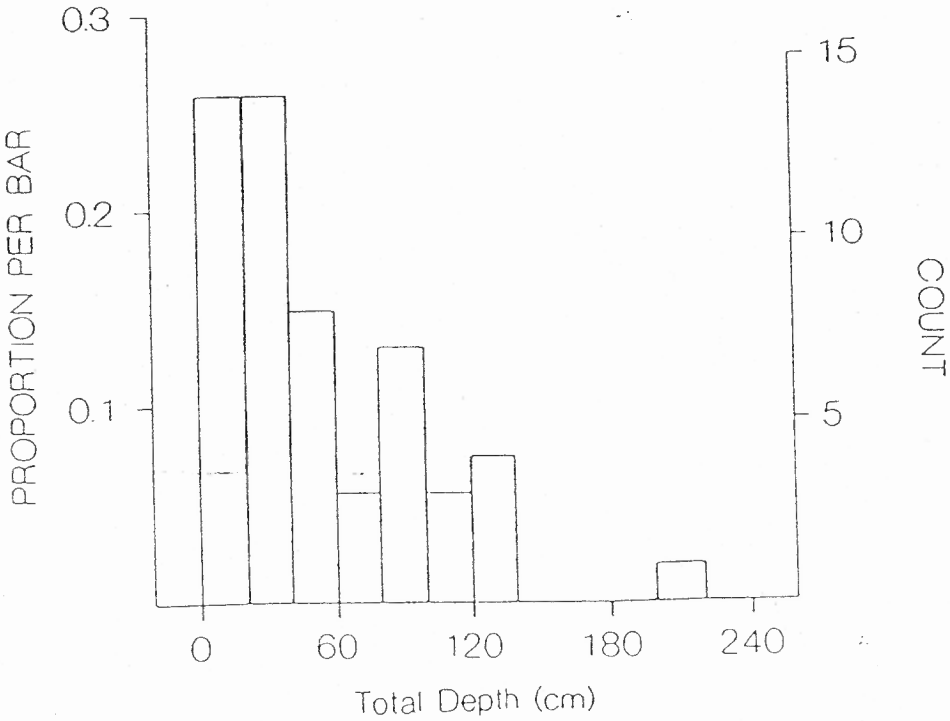
Microhabitat Use of Sacramento Sucker ≥ 150 mm SL



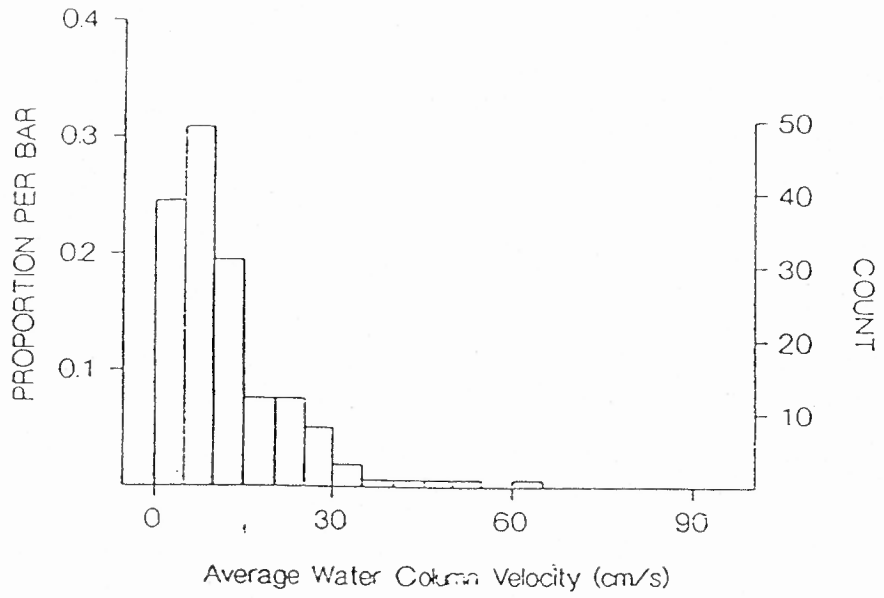


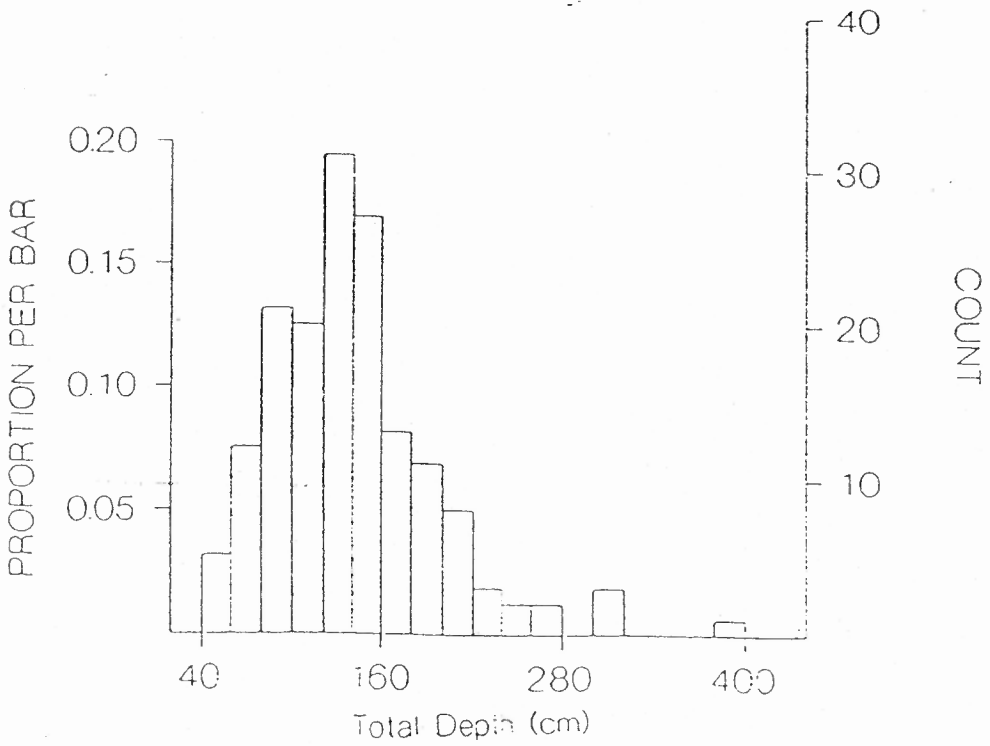
Microhabitat Use of Smallmouth Bass ≤ 50 mm SL



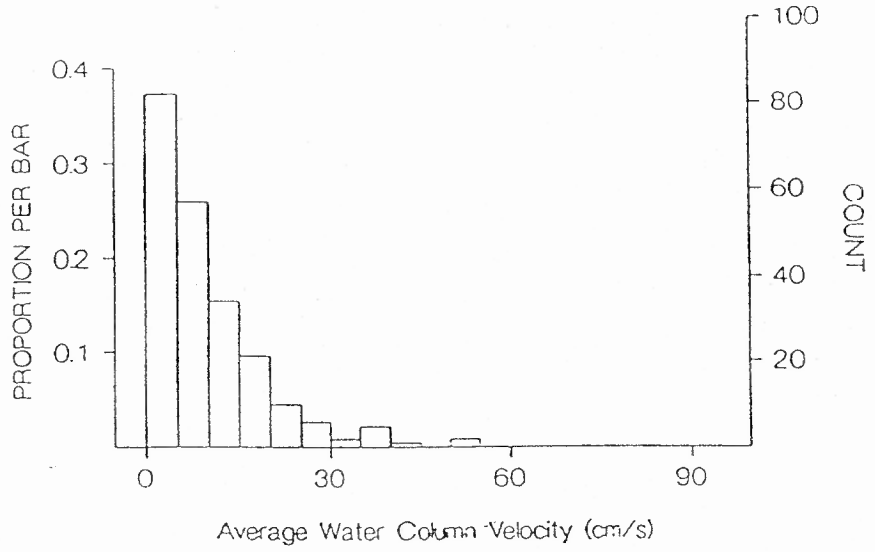


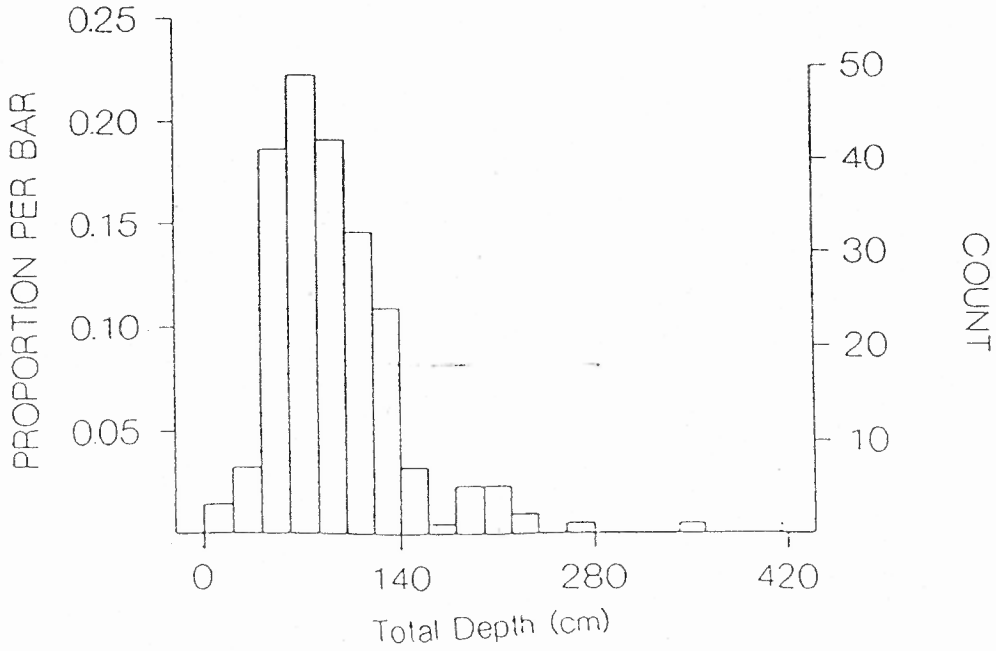
Microhabitat Use of Squawfish ≥ 150 mm SL



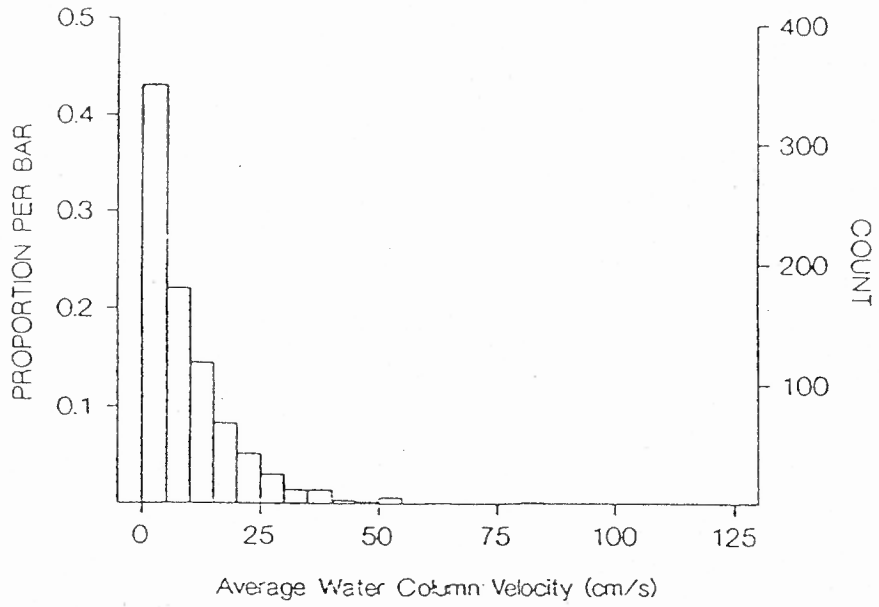


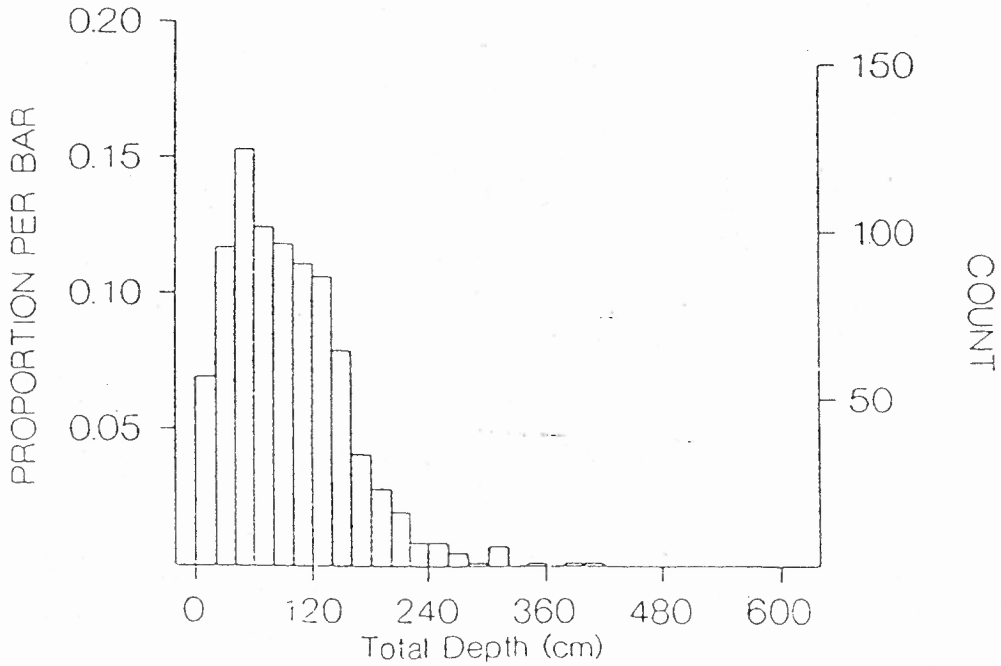
Microhabitat Use of Squawfish 51-149 mm SL



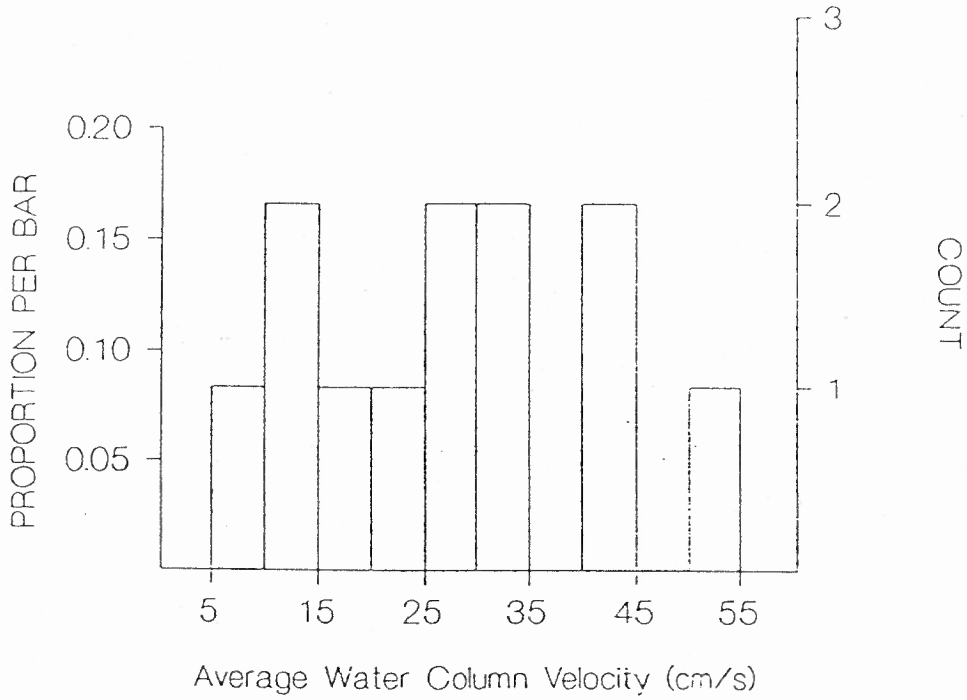


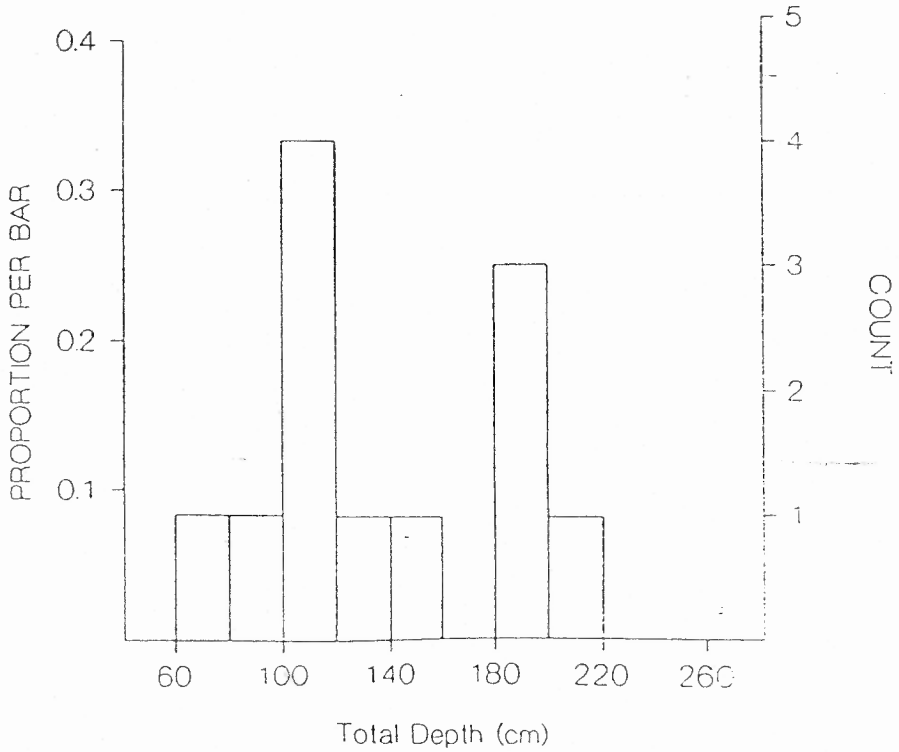
Microhabitat Use of Squawfish ≤ 50 mm SL



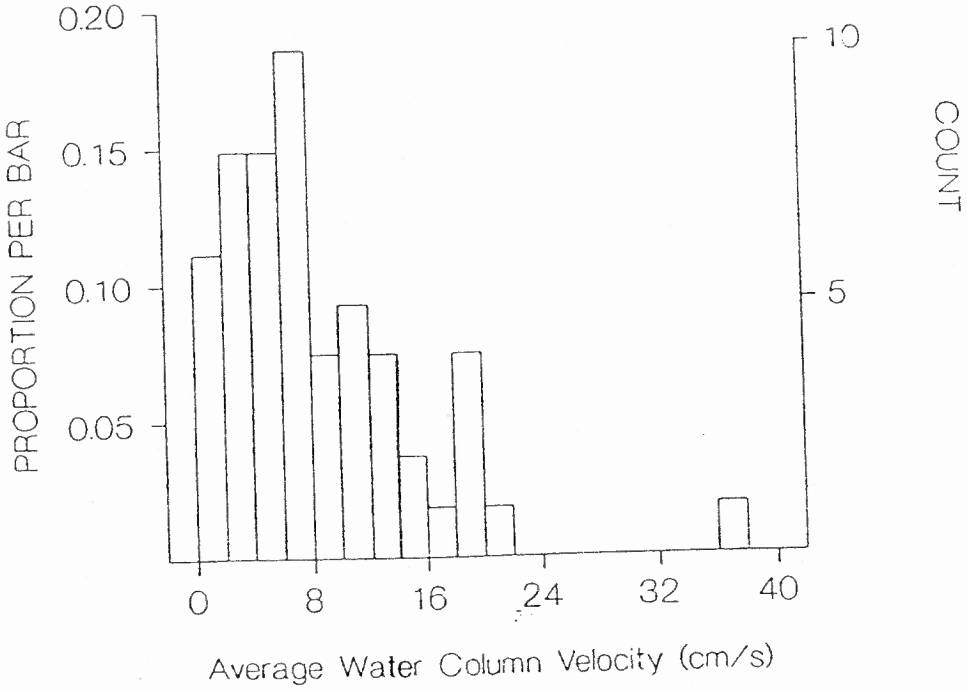


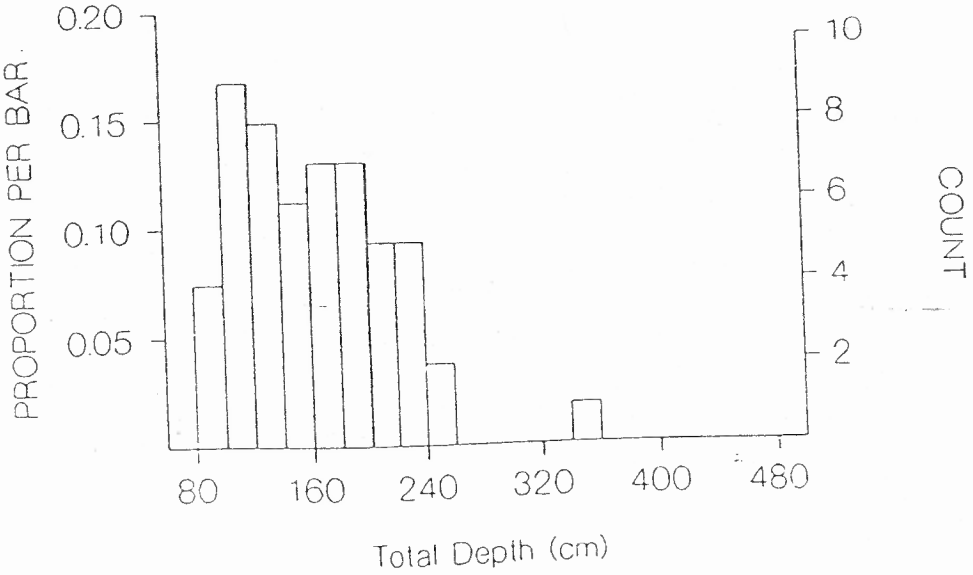
Microhabitat Use of Rainbow Trout



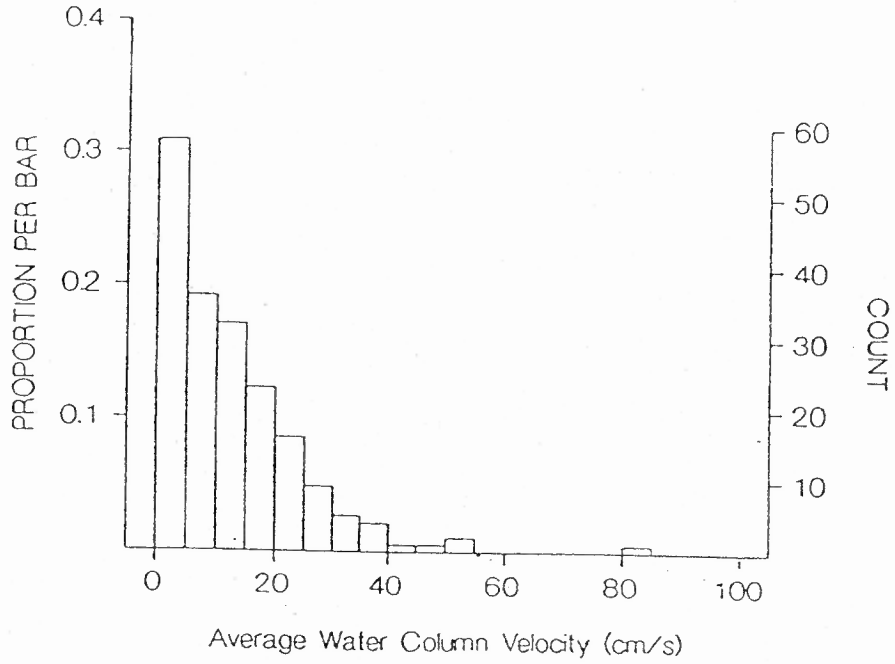


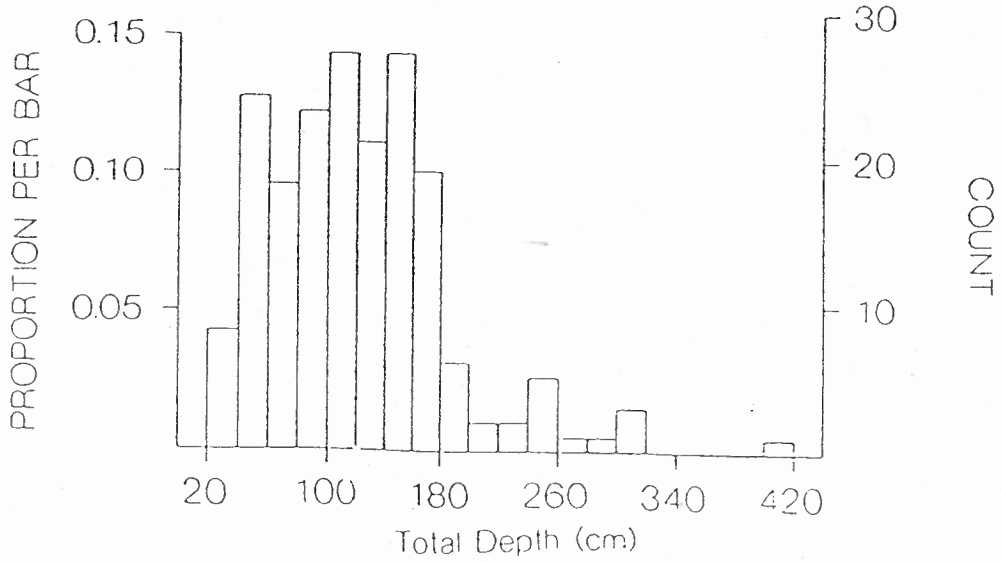
Microhabitat Use of Hardhead ≥ 150 mm SL



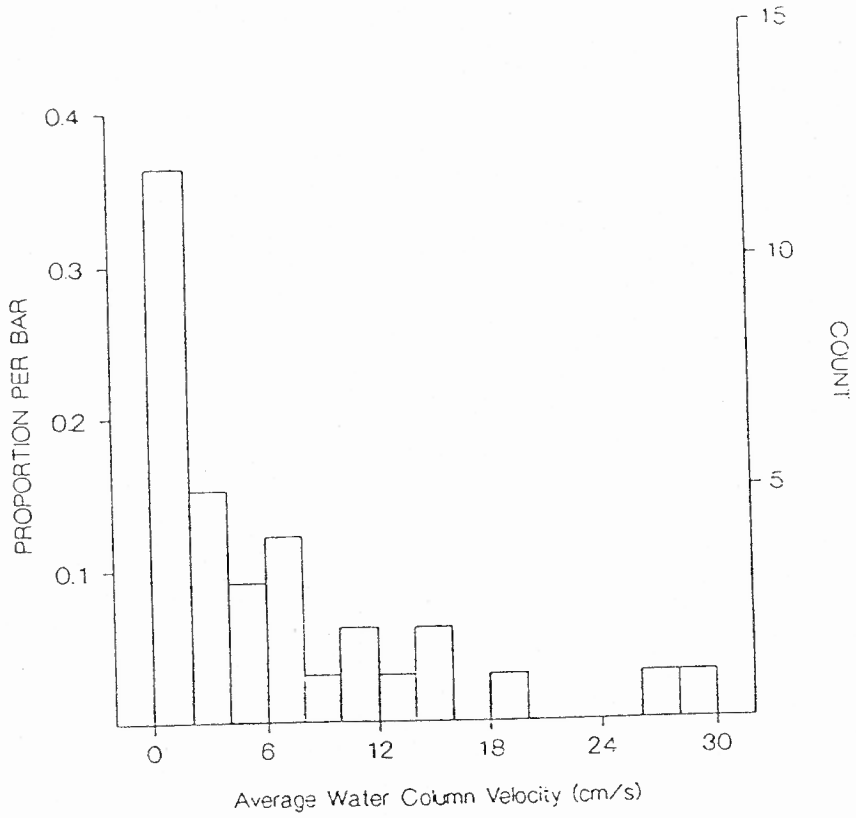


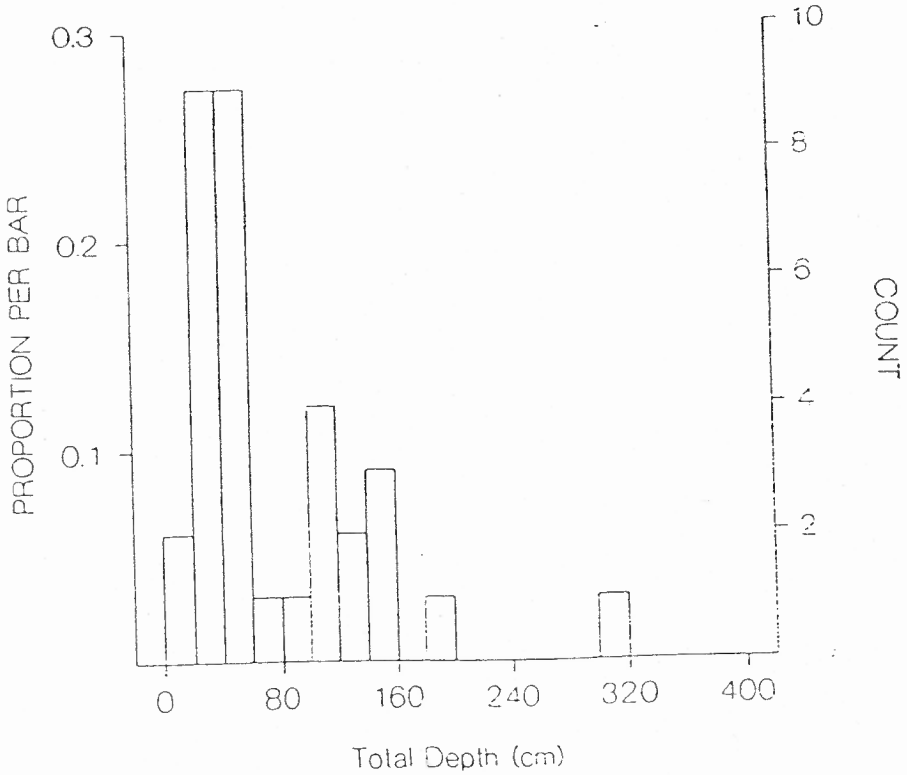
Microhabitat Use of Smallmouth Bass > 50 mm SL

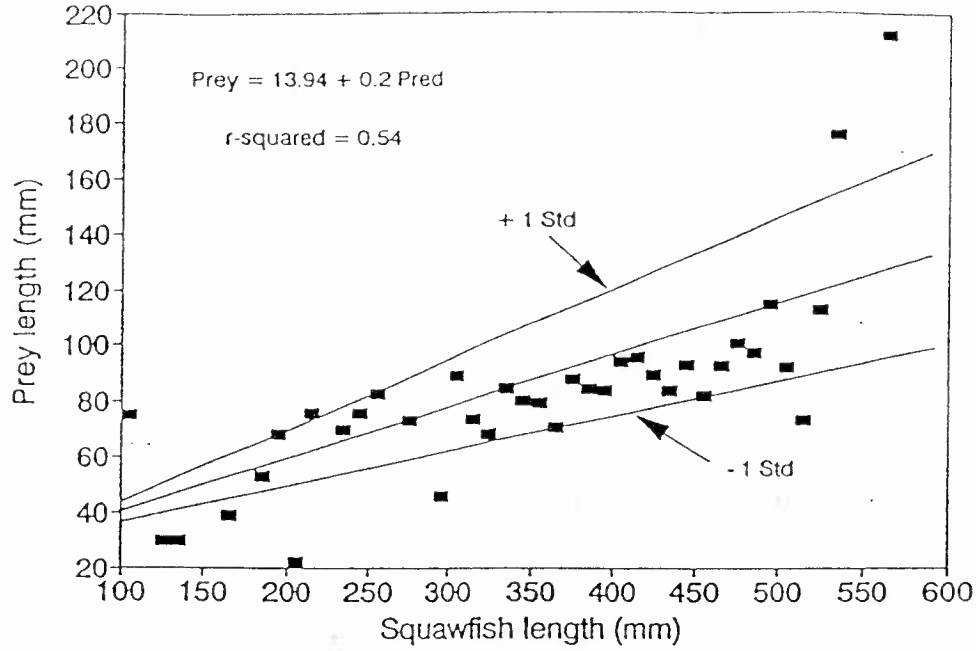




Microhabitat Use of Sacramento Sucker ≤ 50 mm SL

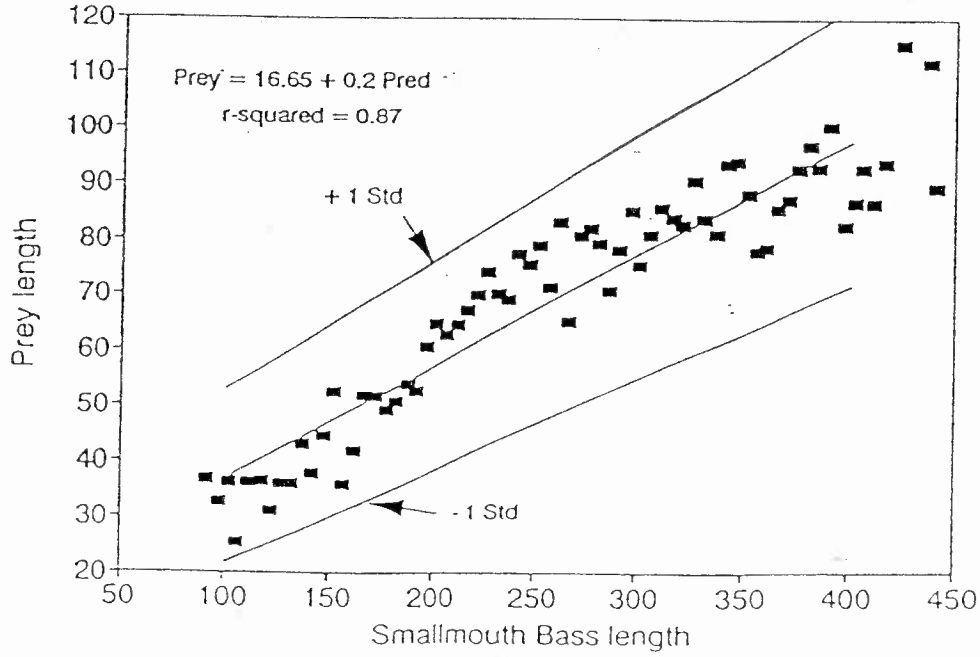






Squawfish Prey Size

Data from USFWS (1992).



Smallmouth Bass Prey Size

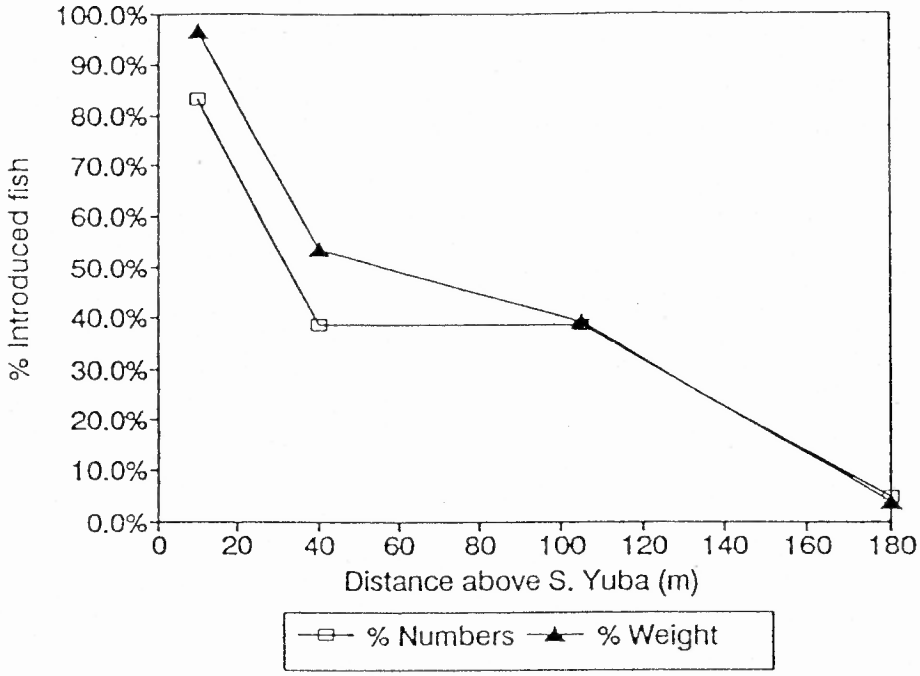
Data from USFWS (1992).

Electrofishing Data - South Yuba Tributaries

Site name	Section #	Date	Section Length	Section Avg. width	Section Max. depth	% pool	% riffle	% cascade	% run	% bedrock	% boulder	% cobble	% gravel	% sand	% silt
French Corral Creek		09-Sep-93	2	3.7	60	100%	0%	0%	0%	0%	80%	20%	0%	0%	0%
Humbug Creek		23-Jul-93	51.5	2.6	87	60%	30%	10%	0%	40%	30%	20%	5%	5%	0%
Kentucky Ravine	A	27-Aug-93	70	2.3	30	5%	70%	5%	20%	0%	10%	90%	0%	0%	0%
Kentucky Ravine	B	27-Aug-93	60	3.3	54	50%	50%	0%	0%	0%	0%	40%	20%	40%	0%
Kentucky Ravine	C	27-Aug-93	20	2.4	30	70%	30%	0%	0%	0%	0%	10%	0%	70%	20%
Missouri Canyon		24-Jun-93	50	1.6	53	40%	50%	10%	0%	20%	20%	50%	10%	0%	0%
Owl Creek		16-Jul-93	55	2.1	90	40%	45%	15%	0%	10%	35%	35%	15%	5%	0%
Rock Creek		17-Sep-93	28.6	2.7	39	75%	10%	5%	10%	10%	20%	70%	10%	0%	0%
Rush Creek	3	25-Jun-93	58	2.8	68	70%	30%	0%	0%	10%	20%	50%	15%	5%	0%
Spring Creek	2	01-Jul-93	54.2	2.1	90	30%	60%	10%	0%	45%	10%	10%	20%	15%	0%

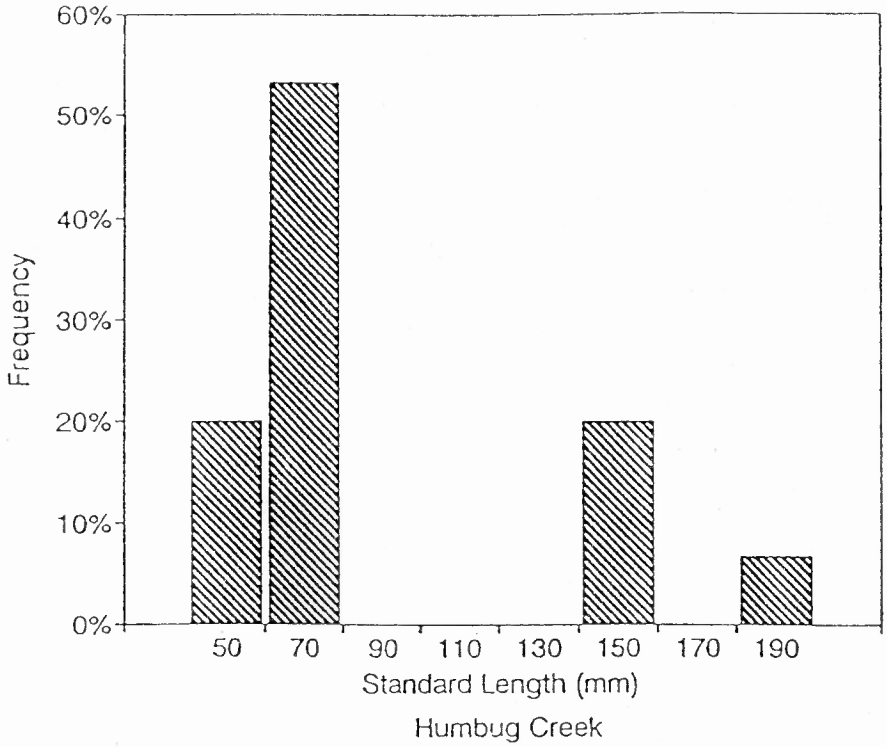
Site name	Section #	Description	Rainbow Trout Number	Rainbow Trout Weight	Sacramento Sucker Number	Sacramento Sucker Weight	Sacramento Squawfish Number	Sacramento Squawfish Weight
French Corral Creek		Isolated pool; just upstream of footbridge	0	0	0	0	0	0
Humbug Creek		Middle of section at foot bridge	16	202	1	185	0	0
Kentucky Ravine	A	Bottom end at pipe crossing	1	16.9	21	111.7	8	56.8
Kentucky Ravine	B	Upper end at pipe crossing	78	79.4	0	0	0	0
Kentucky Ravine	C	Bottom end at South Yuba River	138	768.4	25	1084.7	2	34
Missouri Canyon		Bottom end just above South Yuba river	12	57	7	24	0	0
Owl Creek		Bottom end approximately 20 m above South Yuba	97	366	7	6	0	0
Rock Creek		Bottom end approximately 100 m above South Yuba	18	550.8	0	0	0	0
Rush Creek	3	Upper end just above road crossing						
Spring Creek	2	Above 3.9 m waterfall at South Yuba river						

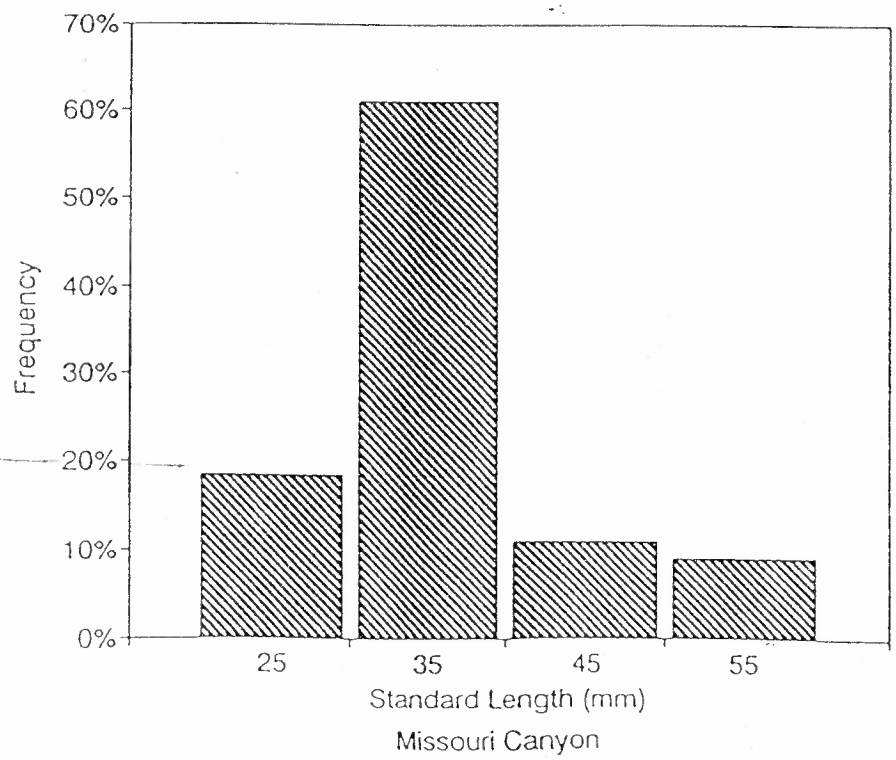
Site name	Section #	Bluegill Number	Bluegill Weight	Smallmouth Bass Number	Smallmouth Bass Weight	Hardhead Number	Hardhead Weight	Green Sunfish Number	Green Sunfish Weight	California Roach Number	California Roach Weight	Brown Trout Number	Brown Trout Weight
French Corral Creek		32	456.9	0	0	0	0	1	14.5	0	0	0	0
Humbug Creek		0	0	0	0	0	0	0	0	0	0	0	0
Kentucky Ravine	A	0	0	8	16.2	4	17.5	20	142.1	12	43.6	0	0
Missouri Canyon		0	0	0	0	0	0	0	0	0	0	0	0
Owl Creek		2	39	0	0	0	0	0	0	0	0	0	0
Rock Creek		0	0	0	0	0	0	0	0	0	0	1	94
Rush Creek	3	0	0	0	0	0	0	0	0	0	0	0	0
Spring Creek	2	0	0	0	0	0	0	0	0	0	0	0	0

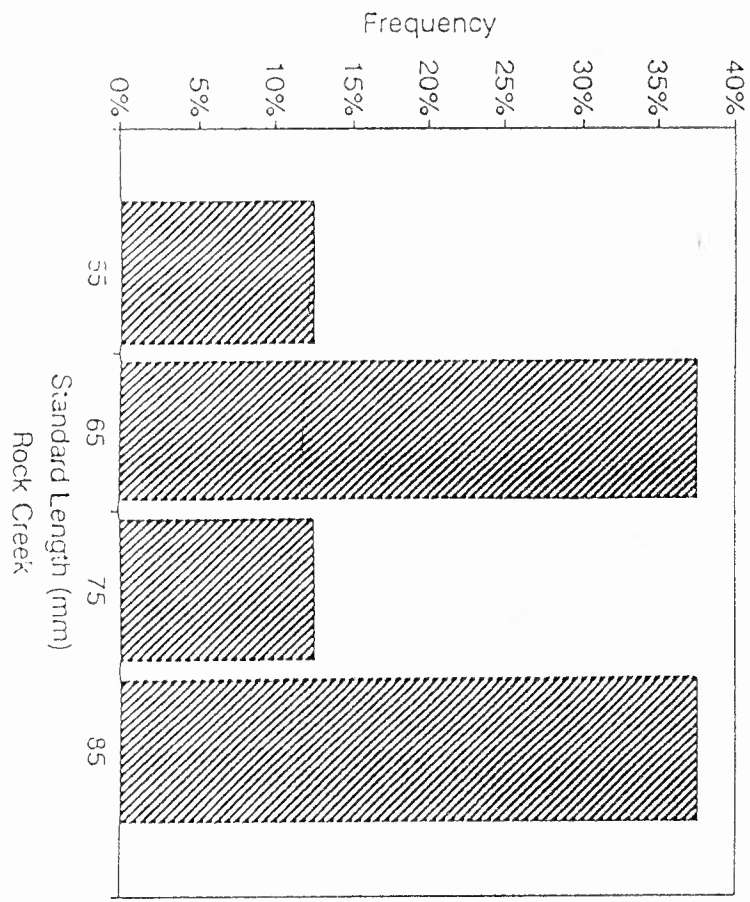


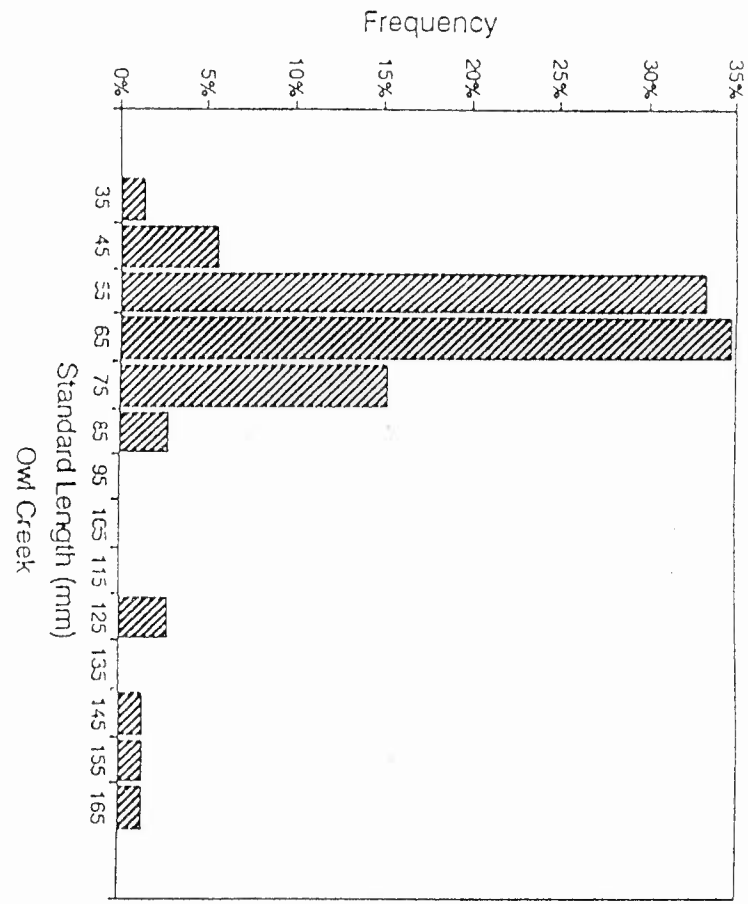
Kentucky Ravine Fish Assemblage Composition

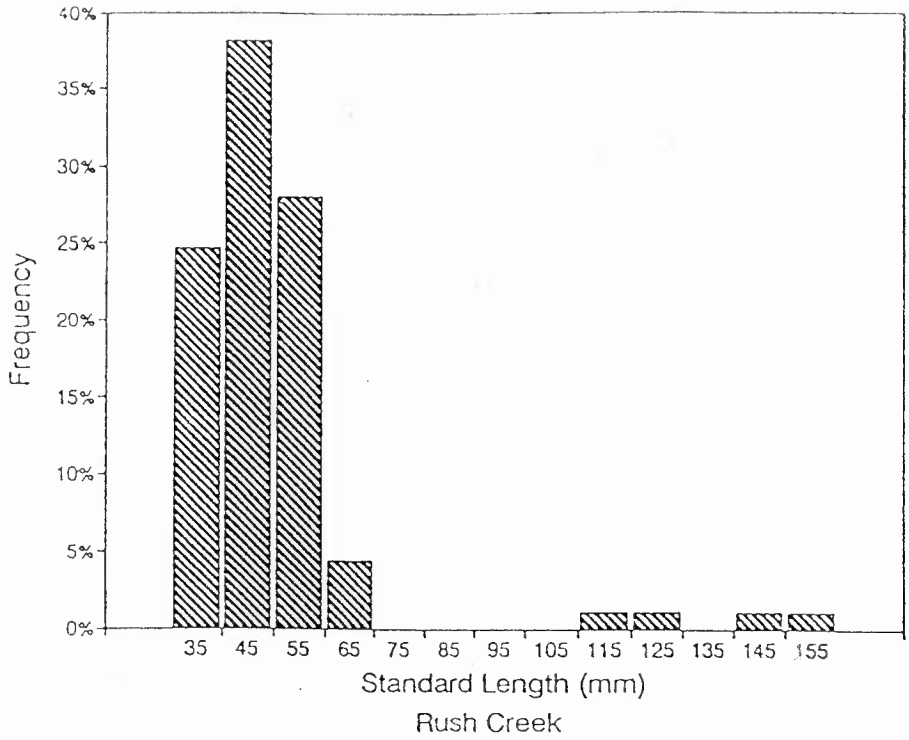
Rainbow Trout Length-Frequency Histograms
South Yuba River Tributaries

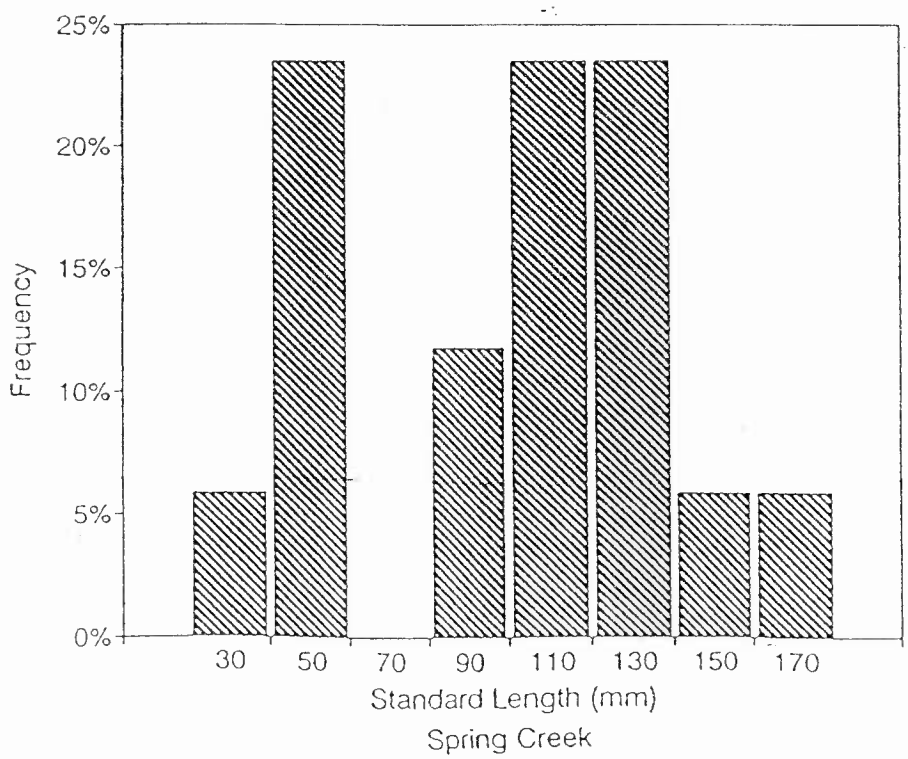





Frequency
40%
35%
30%
25%
20%
15%
10%
5%
0%
55
65
75
85
Standard Length (mm)
Rock Creek


Frequency
35%
30%
25%
20%
15%
10%
5%
0%
35
45
55
65
75
85
95
105
115
125
135
145
155
165
Standard Length (mm)
Owl Creek


40%
35%
30%
25%
20%
15%
10%
5%
0%
Frequency
35 45 55 65 75 85 95 105 115 125 135 145 155
Standard Length (mm)
Rush Creek


25%
20%
15%
10%
5%
0%
Frequency
30 50 70 90 110 130 150 170
Standard Length (mm)
Spring Creek

Comparison of South Yuba River with other California rivers. Units of squawfish standard lengths at annuli are mm.
Other rivers are ranked with regards to their nutrient levels. Data for rivers other than the South Yuba were from the references below, the U.S. EPA STORET water quality database, and unpublished data from D. Azuma, U.S. Forest Service and from P.B. Moyle.

Stream Name	Nitrate (ug/l N)	Orthophosphate (ug/l P)	Periphyton AFDW (g/m^3)	Macroinvertebrate (No./Sample)	Squawfish Standard Length at annulus: age 1	age 2	age 3	age 4	Fish Density (No./100 m)	Fish Biomass (kg/100 m)
Sacramento River @ Clarksburg	140	57			128	221	288	341		
Coyote Creek	1230	37			52	110	190	250		
Big Sulfur Creek	80	23	30	1192						
Kern River	31	20							172	10.6
Kings River	30	20							22.3	123
Middle Fork Eel River		17			73	153	190	227	2208	15.7
North Fork Feather River		16		105	54	104	168	241		
South Fork Eel River	73	15	26.7		80	144	229		1351	417
Eel River	48	14			68	142	206		426	9.0
North Fork Eel River									1587	19.0
Bear Creek		14			65	144	201	257		
Sacramento River @ Red Bluff	180	14			85	168	239	297		
North Fork Kings River	39	11		469						
Stony Creek	150	8			65	125	189	243		
Thomes Creek	100	8			69	141	208	267		
Merced River	50	< 10							36.9	511
South Fork Tuolumne River		5							391	113
Clavey River									414	898
Barnwell Creek	< 10	42	3.5							
Big Canyon Creek	< 1	35	2							
Rice Fork Eel River	< 1	14	3		61	147	224	273	54.2	11.5
South Yuba River	< 10	3	9.1	70	61	94	127	158	198	7.6

References:

Brown, L.R. 1990. Age, growth, feeding, and behavior of Sacramento squawfish (Ptychocheilus grandis) in Bear Creek, Colusa Co., California. Southwestern Naturalist 35:249-260.

Brown, L.R. and P.B. Moyle. 1991. Eel River survey: final report. Department of Wildlife and Fisheries Biology, University of California, Davis

Cepello, S.A. 1985. Benthic macroinvertebrate study. Pages VI-1 to VI-82 in L.E. McMillan, editor. Geysers-Calistoga KGRA-ARM program 1982-83 annual report. 2 volumes.

Feminella, J.W., M.E. Power and V.H. Resh. 1989. Periphyton responses to invertebrate grazing and riparian canopy in three northern California coastal streams. Freshwater Biology 22:445-457.

Hill, W.R. and A.W. Knight. 1988. Concurrent grazing effects of two stream insects on periphyton. Limnology and Oceanography 33:15-26.

Lamberti, G.A. and V.H. Resh. 1985. Comparibility of introduced tiles and natural substrates for sampling lotic bacteria, algae and macroinvertebrates. Freshwater Biology 15:21-30.

Pacific Gas and Electric. 1984. 1983 Annual progress report on water quality sampling to be filed pursuant to Article 48 of the License for the Helms Pumped Storage Project (FERC 2735).

Pacific Gas and Electric. 1986. 1984 Annual progress report on water quality sampling to be filed pursuant to Article 48 of the License for the Helms Pumped Storage Project (FERC 2735).

Power, M.E. 1990. Benthic tufts vs floating mats of algae in river food webs. Oikos 58:67-79.

HISTORIC DATA ON FISH POPULATIONS

The earliest record of fish species in the South Yuba River is a photograph of Alfrieda Knowlton holding a chinook salmon caught at Bridgeport in the mid 1920's (Michalski, pers. comm.). In addition, Greg Schiffner (pers. comm.) stated that his grandfather had caught chinook salmon in the South Yuba River near Nevada City in the early 1900's. Sumner & Smith's 1938 survey found Sacramento squawfish at Edwards Crossing, lampreys (probably Pacific lampreys) climbing over an old dam one mile above Purdon Crossing, lamprey ammocoetes (larvae) in silt above this dam, and rainbow trout in a pool in Missouri Canyon near its confluence with the South Yuba River (California Department of Fish and Game (CDFG) files).

Fish species reported in the South Yuba River watershed by the Federal Energy Regulatory Commission (1987) were rainbow, brown and brook trout, largemouth and smallmouth bass, channel catfish, brown bullhead, carp, green sunfish, hitch[1], Sacramento squawfish and hardhead. The report does not describe the distribution of species[2], but notes that Sacramento squawfish and hardhead dominated the fish community. Fish species composition reported above Hoyt Crossing by the Northwest Power Company (1983) was hardhead

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[1] Questionable identification - more likely to be California roach.

[2] Brook trout probably were only present far upstream of Missouri Bar or were misidentified, since they are restricted to cold temperatures.

(40%), Sacramento squawfish (33%), fathead minnow (20%)[3], rainbow trout (5%) and smallmouth bass (2%)[4]. The popular press reported that both rainbow and brown trout were present in the South Yuba River at Humbug Creek in the late 1960s (Sunset 1969). Abundances of fish species recorded in visual observations by Taylor (1987, 1990) in the South Yuba River at Humbug Creek and by the U.S. Forest Service (USFS) (1987) in the South Yuba River around Missouri Bar are given in Table 1.

Table 1
South Yuba River Fish Abundances (number/100 m)

Data Source	Sacramento Squawfish	Rainbow Trout	Sacramento Sucker
Taylor (1987)	16	7	6
Taylor (1990)	138	5	7
USFS (1987)	17	3	33

The only recorded stocking in the South Yuba River below Missouri Bar was 1,995 juvenile rainbow trout stocked at Edwards Crossing on July 20, 1953 (CDFG files). However, numerous species have been stocked by the CDFG in Englebright Reservoir (Table 2). Other species that have been captured in Englebright Reservoir include largemouth and smallmouth bass, warmouth, bluegill, green sunfish, white catfish, channel catfish, golden shiner, Sacramento squawfish, hardhead, carp, and California roach (U.S. Army Corps of Engineers 1991).

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[3] Questionable identification - more likely juvenile hardhead, Sacramento squawfish or Sacramento sucker.

[4] Possible misidentification.

Prior to the construction of the New Bullards Bar Reservoir, warmwater species (primarily smallmouth bass, white crappie

Table 2
Fish Stocked in Englebright Reservoir
Data from US Army COE (1991)

Species	Years stocked
Lake Trout	1965-66
Kokanee Salmon	1965-66, 77
Rainbow Trout	1971, 78-88
Brown Trout	1977, 81-84
Black Crappie	1984
White Crappie	1984
Brook Trout	1986
Alabama Spotted Bass	1986

and white catfish) were most abundant; afterwards, rainbow trout were the most common game species, although rainbow trout are sustained by stocking due to marginal upstream spawning habitat (U.S. Army Corps of Engineers 1991). Thus, Englebright Reservoir is now a cold-water fishery, with water temperatures on September 22, 1990 ranging from 14 °C at the surface to 8 °C at a depth of 30 meters (CDFG files). The most recent creel census, in 1985, recorded 97 rainbow trout, 8 brown trout, 4 smallmouth bass and 3 white crappie (CDFG files).

Knight (1985) recorded microhabitat use of fish at Bridgeport and Highway 49 in August and September of 1982 and 1983. Notable is the presence of rainbow trout at both sites (Table 3); water temperatures during his observations were around 21 °C.

Table 3
Number of Fish Observed in the South Yuba River in 1982-83
Data from Knight (1985 and unpublished).

Species	Bridgeport	Highway 49
Hardhead	16	10
Sacramento Squawfish	9	26
Sacramento Sucker	5	1
Rainbow Trout	1	1
Smallmouth Bass	34	0

The U.S. Bureau of Land Management (BLM) captured Sacramento suckers and Sacramento squawfish with electrofishing equipment as part of an aquatic life survey of the South Yuba River at Edwards Crossing (BLM 1979). Table 4 shows the fish species found by the BLM in aquatic life surveys of South Yuba River tributaries in 1979 and 1980 (BLM 1979-80). It should be noted, in comparing this data with the data in Chapter 3, that the BLM sampled Owl Creek and Rock Creek a considerable distance upstream of their confluence with the South Yuba River. The green sunfish found in Humbug Creek probably washed down from a small impoundment in Malakoff Diggins State Park.

Table 4
Fish Species Observed in South Yuba River Trubutaries
Data from BLM (1979-80).

Tributary	Year	Species
Shady Creek	1979	No fish observed
Spring Creek	1979	Rainbow trout
Spring Creek	1980	Rainbow trout
Owl Creek	1980	No fish observed
Rock Creek	1979	Rainbow trout
Humbug Creek	1979	Sacramento sucker, Green sunfish, Rainbow trout

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Sediment from hydraulic mining detained by Englebright and small dams in the Yuba basin

L. Allan James*

Geography Department, University of South Carolina, Columbia, SC 29208, USA

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Abstract

Recent initiatives to find ways to reintroduce anadromous fish to the Central Valley of California have identified the Yuba River as one of the best potential watersheds for expanding spawning habitat of spring-run chinook salmon and steelhead trout. Salmon spawning in the Yuba River would require substantial modifications or removal of Englebright Dam, a large dam (86 million m^3 capacity) built by the U.S. Army Corps of Engineers in 1941. An extensive on-going feasibility study by local, state, and federal organizations, therefore, is examining aspects of various dam-treatment scenarios that range from no action to complete dam removal.

This paper examines the extraordinary history of the watershed and resulting conditions pertinent to the feasibility of altering Englebright Dam. It seeks to accomplish four goals. First, historical geomorphic changes in the watershed are outlined that influence the physical context of the feasibility study. The Yuba watershed is centered in the hydraulic gold-mining region made famous by G.K. Gilbert (Gilbert, G.K., 1917. Hydraulic-mining débris in the Sierra Nevada. U.S. Geol. Survey Prof. Paper 105 154 pp.), and Englebright Dam was built as a *débris dam* to control the sediment from hydraulic mining. Second, recent findings of high concentrations of mercury in sediment and fish tissues in the watershed are briefly reviewed. Much mercury was applied during the 20th century. Third, historic data on 20th century hydraulic mining are presented that document numerous small dams built in the Yuba basin to detain mining sediment. Finally, field measurements of the texture and lithology of modern bed materials in the Yuba River basin are presented that demonstrate reworked sediment from mining is an important component of the modern sediment load and fine spawning gravels.

The complex anthropogenic geomorphic changes in the Yuba basin present a challenge with regards to responsible treatment of Englebright Dam. If toxic sediment is being reworked in the upper watershed, Englebright Reservoir may play an important role in protecting fish populations below in the Sacramento Valley. Where large volumes of mining sediment are stored behind small detention structures in the upper basin, they should be mapped and assayed for mercury. Stabilization or restoration options for these deposits should consider the potential role that they could play in supplying fine spawning gravel to the main channel.
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Keywords: Hydraulic gold mining sediment; Dam removal; Aquatic restoration, Sierra Nevada, California

* Tel.: +1 803 777 6117; fax: +1 803 777 4972.
E-mail address: AJames@sc.edu.

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1. Introduction

This paper examines recent geomorphic changes in the Yuba watershed that pertain to an extensive on-going study of the feasibility of altering or removing Englebright Reservoir. Basic goals of the paper are to briefly describe the Upper Yuba River Study Program and what is known about the potential for mercury toxicity of mine tailings, and to describe in detail the sedimentation history and modern sediment conditions in the basin. Emphasis of the paper is on the latter two topics. The sedimentation history is divided into a brief description of sedimentation from 19th century mining (covered in detail elsewhere) and of sediment from 20th century mining and detention dams in the basin. Previously unpublished data provide 20th century sediment production volumes from hydraulic gold mining and detention-dam storage capacities. Descriptions of modern channel-bed sediment are introduced based on previously unpublished field sampling.

The Yuba River in northern California has been recognized as a potential watershed for reintroducing anadromous fish to the Central Valley. Presently, however, Englebright Dam halts fish migrations at the lower foothills of the Sierra Nevada, so natural spawning would require treatment of Englebright Dam. Four possible dam-treatment options are presently under study: do nothing, build a record-high fish-bypass system, lower the dam, or completely remove the dam. Englebright Dam is a concrete arch dam 79 m high and 348 m long (Fig. 1). With a capacity of 86 million m^3 (70,000 ac-ft), Englebright Reservoir is large relative to most dam-removal projects (Graf et al., 2002). The dam was completed in 1941 for the explicit purpose of detaining sediment from hydraulic gold mining. Hydraulic mining produced prolific amounts of sediment in the watershed (Gilbert, 1917) and the dam was built to facilitate more hydraulic mining.

The history and geomorphic consequences of hydraulic gold mining in the Yuba watershed are relevant to the feasibility of dam removal and are a central topic of this paper. Earlier studies of geomorphic effects of massive production of mining sediment during the 19th century are reviewed. Misconceptions about the lack of persistent remobilization of this mining sediment stored in the upper basin are revisited with evidence of on-going sediment mobility. Contributions of fine gravel from this sediment may have great bearing on long-term sediment loads and toxicity downstream as well as the sustainability of salmonid spawning habitat. In addition to effects of 19th century mining and to Englebright Dam, the effects of 20th century licensed hydraulic mining are described. This period of mining has received little prior attention in the historical or scientific literature, but was accompanied by the

Fig. 1. Englebright Dam and Reservoir. Photograph by author, 2002.

construction of numerous detention structures in the Yuba basin to store mine tailings locally. These structures and associated sediment deposits should be located, tested for mercury, considered for treatment or removal, and factored into the feasibility study.

This paper does not make a recommendation for or against a particular treatment of Englebright Dam. Extensive studies are underway including analysis of cores from Englebright Reservoir to assess the sedimentology and geochemistry of reservoir sediment (Childs et al., 2003), and modeling of water and sediment transport in the watershed. A feasibility assessment would be premature until these studies are complete. Nor does this paper present results of pending and on-going scientific studies in the watershed. The relevant points made in this paper, however, have been provided to the appropriate work groups of those studies (e.g., UYRSP Tech. Review Panel, 2001).

1.1. Study area

The Yuba basin is on the western flank of the northern Sierra Nevada, California (Fig. 2). It flows out of glaciated granodiorites of the high Sierra through deep, steep-walled canyons of the Sierra foothills out to the flat Central Valley. The study area includes the Middle and South Yuba Rivers plus the lower North Yuba below Bullards Bar Dam (BBD). Most of the North Yuba River above its confluence with the Middle Yuba is excluded because New BBD

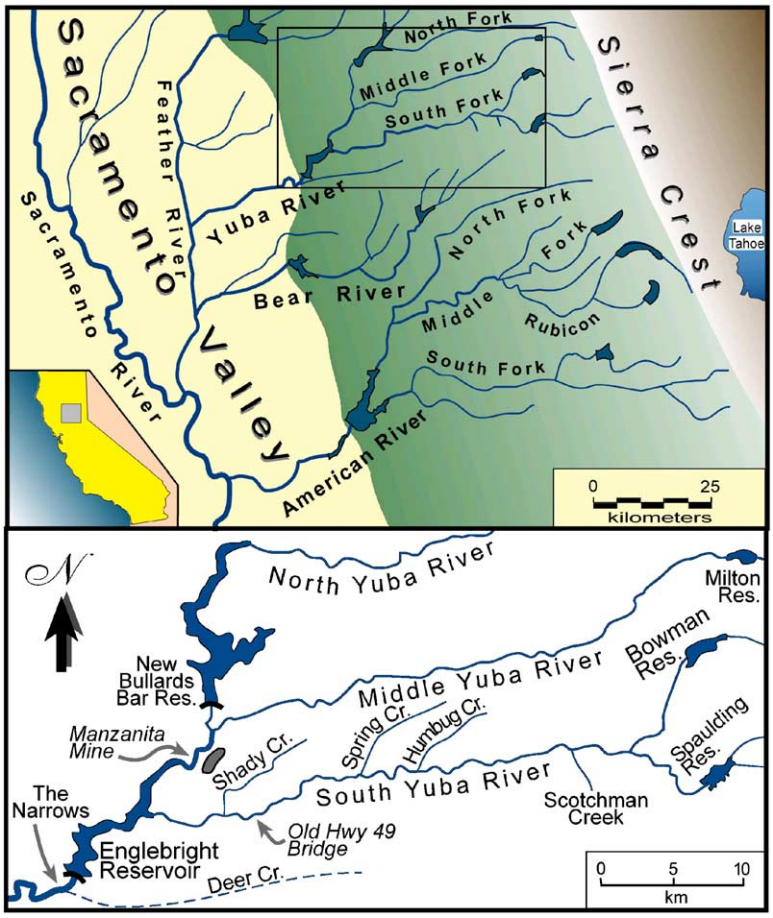

Fig. 2. Study area showing Middle and South Yuba flowing into Englebright and North Yuba into Bullards Bar.

(reservoir capacity 1.2 billion m^3) has controlled water and sediment since it was built in 1970. For the sake of simplicity, the Middle Yuba referred to in this report includes the lower North Yuba below New BBD. This is most relevant to the Manzanita Mine, a large hydraulic mine that discharged sediment to the North Yuba below its confluence with the Middle Yuba.

Geomorphically the Yuba watershed can be divided into two different drainage systems: relatively low-gradient upland tributaries with a capacity for long-term sediment storage, versus steep lower tributaries and main channels where stream powers are high, bed material is coarse, and little storage capacity exists. The upland tributary system can be further partitioned into two components: upland sediment production and in-stream sediment processes. Under natural conditions hill-slope erosion processes probably dominated sediment production, but in tributaries draining hydraulic mines vast deposits of mining sediment in the valley bottoms now dominate sediment production. Main Yuba canyons are about 300 m below the relatively flat ridge crests where the mines are located. This facilitated hydraulic mining because tailings were quickly disposed of by dumping them into the canyons below. Large floods with high stream powers remove all but the coarsest boulders from the steep, narrow canyons (Fig. 3). This removal explains the lack of long-term storage of mine tailings in the main channels while much sediment remains in the upper tributaries (Gilbert, 1917).

2. Upper Yuba River Study Program

An extensive study of the feasibility of changing Englebright Dam, known as the Upper Yuba River Study Program (UYRSP), was initiated in 1998, received funding of $6.7 million in December 2000, and continues at the time of this writing. The UYRSP is coordinated by CalFed, a cooperative effort of more than 20 State and Federal agencies working with local communities to improve the quality and reliability of water supplies in California, and to revive the San Francisco Bay–Delta ecosystem. Many projects occur within the extensive CalFed program, of which the UYRSP is but one. The ecosystem restoration objectives of CalFed—to restore ecological processes, habitats, and species diversity to the Bay–Delta ecosystem—are the primary motivation behind the UYRSP, although these objectives must be balanced with existing constraints including water supplies, flood control, recreation, and water quality.

The UYRSP is designed to encourage public participation based on a workgroup consisting of

Fig. 3. Coarse colluvial boulders in South Yuba at Highway 49 bridge. Fine sand and gravel can be sampled in interstices of boulders in pools, bars, and floodplains even at sites like this.

stakeholders in the area divided into three teams: River, Lake, and Agency teams. The first business of the Workgroup (*Phase I*) was to establish technical committees and to identify six focus areas for addressing the feasibility of introducing anadromous salmon: habitat, sediment, water quality, water supply-hydropower, flood-risk management, and economics. The project is now in *Phase II* in which the scopes of the six focus areas have been defined, data are being collected, and analysis will be conducted. Evaluations and recommendations of the various dam-treatment scenarios will take place in *Phase III* of the project planned for completion in 2007.

2.1. Goal to reintroduce chinook salmon and steelhead trout

Prior to mining in the 19th century and damming in the 20th century, the range of two species of anadromous salmon, spring-run chinook salmon (*Oncorhynchus tshawytscha*) and steelhead trout (*Oncorhynchus mykiss*), extended well beyond the present range and into the Sierra Nevada. Much of the former chinook salmon spawning habitat is no longer available because of dams in the lower foothills on all major rivers of the Central Valley. The current range of chinook salmon is largely limited to low-gradient rivers of the Central Valley that are not generally conducive to spawning. Steelhead trout ranges are potentially higher in elevation than chinook salmon but are also restricted by dams. An exception to the lack of foothill spawning habitat is found in Butte Creek where the recent removal of several dams opened up 30 km of the lower river to salmon spawning (Gleick, 2000).

Conservative estimates of the historical, pre-mining upper limits to California chinook salmon have been presented by Yoshiyama et al. (1996) where they could be established by direct evidence; especially by contemporary historical accounts. The pre-mining range of chinook salmon in the Middle and South Yuba Rivers is not known because of rapid disruptions of these rivers by intense mining operations prior to historical fish observations. The CalFed UYRSP was established to ascertain if introduction of chinook salmon and steelhead trout to the Yuba basin is biologically, environmentally, and socio-economically feasible.

3. Potential mercury toxicity of mine wastes

One of the most toxic elements commonly found in riparian environments is mercury. In the United States as of 1998, 2506 fish and wildlife consumption advisories were issued for all substances. Of these, more than 75% (1931) were for mercury (Alpers and Hunerlach, 2000). All segments of the San Francisco Bay are listed as impaired because of mercury contamination, so the State is required to establish total maximum daily loads (TMDL) for mercury that can be received by the Bay. Inorganic mercury was used extensively to extract gold, and much of it may remain in sluice boxes and mining-sediment deposits in the Yuba watershed. Local bioassays indicate high levels of mercury in fish tissues in the mining regions, especially in the South Yuba and Bear Rivers. Mercury concentrations in most game fish sampled from Englebright Reservoir were above 0.3 ppm, the screening threshold set by the Environmental Protection Agency (EPA), and in several cases approached 1.0 ppm, the Food and Drug Administration's (FDA) action level for mercury in commercial fish. A relationship has been shown between the amount of mercury in the tissues of aquatic organisms and the volume of hydraulic mining sediment produced in various watersheds (Fig. 4). Mercury levels in the Yuba and Bear River basins are clearly in need of close scrutiny.

Mercury continued to be used in 20th century hydraulic mining operations and thus may be found in

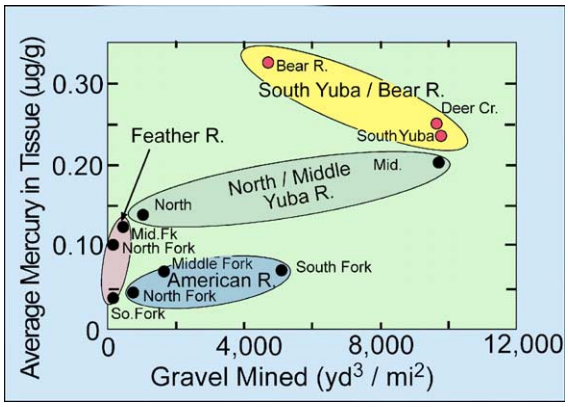

Fig. 4. Summary of mercury bioassays showing high tissue concentrations levels in South Yuba and Bear Rivers (Alpers and Hunerlach, 2000; Hunerlach et al., 1999).

relatively recent deposits as well as older, more extensive deposits of mine tailings. Mercury does not naturally occur in the Sierra Nevada in appreciable amounts but was imported from mines in the Coast Ranges. Historical production of mercury reflects the decline of hydraulic mining after the 1884 Sawyer court injunction but substantial production continued after that time (Fig. 5). Much mercury may have been used by licensed hydraulic mines in the Yuba after 1893. U.S. Geological Survey scientists recently found extremely high concentrations of mercury in tunnels draining the Polar Star and Southern Cross mines near Dutch Flat in the Bear River basin (Hunerlach et al., 1999). The Polar Star Mine was issued licenses to hydraulically mine 463,000 m^3 in 1894, 1,500,000 m^3 in 1898, and an unknown volume from 1906 to June, 1908 (Licenses #16, 193 and 737). An attempt by the author in the 1990s to repeat a photograph of the Polar Star mine taken ca. 1908 (Lindgren, 1911) proved impossible because the angle from the edge of the pit had changed; a large, high ledge on the southwest rim of the Polar Star pit had been removed after the Lindgren photograph was taken. This ledge had been over the upper Polar Star tunnel so the sediment must have been removed through the tunnel. Thus, the mercury found in the Polar Star tunnel is a product of 20th century mining. The Southern Cross mine was also issued a license to mine from 1908 to 1909 (Lic. #786). In 2000, the EPA spent approximately $1.5 million to remove mercury-contaminated sediment from abandoned sluices in tunnels draining the Polar Star and Southern Cross mines (CERCLIS, 2000).

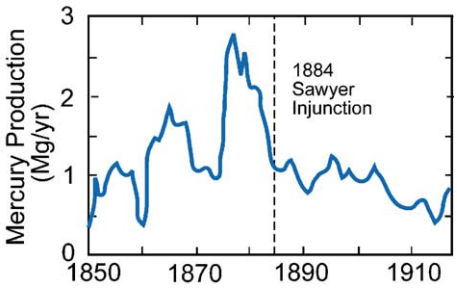

Fig. 5. Mercury production in Coast Range mines. Rapid rise and fall ~1875–1883 reflects use by hydraulic mining. Rise in mid-1890s may represent use by licensed hydraulic mines. Adapted from Alpers and Hunerlach (2000) and Hunerlach et al. (1999); based on data from Bradley (1918); assuming 34.5 kg (76 lb) per flask.

Substantial concentrations of inorganic mercury in Yuba River sediments are clearly cause for concern (May et al., 2000; Alpers and Hunerlach, 2000). Yet, work has just begun on the biological hazards of mercury in the Yuba watershed and advisories have only recently been issued (Alpers et al., 2002). The primary threat of mercury contamination arises from the potential conversion of inorganic mercury to methyl mercury, a highly toxic, organic form of mercury that accumulates in aquatic organisms and biomagnifies through aquatic food webs. Methyl mercury is hazardous to human health, and can adversely affect fish populations in quite low concentrations, particularly in early life stages (Wiener and Spry, 1996; Fjeld et al., 1998; Latif et al., 2001). The presence of mercury in a methylating environment could defeat attempts to restore salmon fisheries. The abundance of methyl mercury in the system, therefore, should be assessed along with environments conducive to mercury methylation or demethylation (UYRSP Tech Panel Report, 2001). The critical question to be addressed is the *net production* of methyl mercury (methylation minus demethylation) rather than the abundance of inorganic or total mercury (Bodaly et al., 1993; Wiener and Shields, 2000). Unfortunately, wetland environments may promote methylation and these are systems that CalFed seeks to enhance and protect in the lower Sacramento and Bay–Delta system downstream. The likelihood and consequences of introducing mercury to the lower Yuba, Feather, and Sacramento Rivers is an important component of the Englebright feasibility study.

4. Recent geomorphic and sedimentation history

Sedimentation and other geomorphic consequences of hydraulic gold mining in the Yuba basin were documented by Gilbert (1917). This section briefly reviews the early history and geomorphic results of hydraulic mining in the Yuba basin. It then examines an often overlooked period of 20th century mining and the dams and deposits associated with those activities. This is followed by descriptions of 20th century dams and mining-sediment production that were associated with hydraulic gold-mining activities in the watershed including a case study of Scotchman Creek.

4.1. Nineteenth century hydraulic mining sediment in the Yuba basin

Sediment production by hydraulic mining in California was unprecedented in the annals of mining and human impacts on the environment (Gilbert, 1917). Vast hydraulic mine pits were exhumed (Fig. 6) and sediment was released to rivers with no regard to the downstream consequences. The Yuba basin received more sediment from hydraulic mining than any other basin in the Sierra Nevada (Gilbert, 1917) and specific sediment production (volume per unit area) was second only to production in the Bear River (James, 1999). Within the Yuba basin, the South Yuba received more mining sediment than any of the other branches, and the smaller Middle Yuba basin had the highest specific production, particularly if the lower North Yuba below the Middle Yuba confluence is included (Table 1). This production represents 22 cm of denudation averaged across the entire South and Middle Yuba basins, or ~7 mm per year. Sedimentation was so devastating to flooding, agriculture, and navigation in the Sacramento Valley that an injunction was issued by Judge Lorenzo Sawyer in 1884 which may represent the first instance in United States history of an environmental enjoinder on such a lucrative industry. The history of this sedimentation episode has been well documented from both physical (Gilbert, 1917; James, 1989, 1999) and political/institutional perspectives (Kelley, 1959, 1989). Much of the sediment from this period passed down through the system (Gilbert, 1917). Yet, large volumes of sediment from 19th century hydraulic gold mining remain stored in upper tributaries of the Yuba watershed such as Scotchman Creek, Spring Creek, and Shady Creek (Fig. 7). Topographic surveys of these deposits are needed to map and inventory sediment storage.

4.2. Twentieth century hydraulic mining sediment in the Yuba basin

Most studies have ignored the persistent hydraulic gold mining that occurred after Judge Sawyer's 1884 injunction. Sadly, after a decade of judicial struggle by farmers to document the environmental destruction and halt hydraulic mining, only 9 years later Congress quietly passed legislation that allowed hydraulic mining to start back up. The Caminetti Act of 1893 legalized hydraulic mining based on a permitting system under the assumption that sediment produced by mining would be prevented from reaching navigable streams. Licenses were contingent upon provisions for the local storage of mine tailings, usually by the construction of a sediment-detention dam made of brush, logs, rock, or concrete. The permitting program was administered by the *California Debris Commission* (CDC), created by the

Fig. 6. Manzanita Mine near Sweetland ca. 1909; drains to lower North Yuba near Englebright Reservoir. Gilbert's 1909 survey found total volume mined was 37 million m^3. A California Debris Commission license for 806,000 m^3 (~2% of total volume) was issued in 1894. From Gilbert (1917; Plate 10).

Table 1
Sediment produced by hydraulic mining

	Drainage area		Volume produced (m^3 10^6)	Production/drainage area		Denudation		
	Total (km^2)	Mining (km^2)[a]		Total (mm)	Mining (mm)[a]	Total (mm/year)	Mining (mm/year)[a]	
19th c. Mining (1853–1884): (31 years)								
Mid. Yuba	510	402	109[b]	214	272	6.90	8.76	
Mid+LNY[c]	560	432	179[b]	320	415	10.32	13.4	
So. Yuba	994	475	165[b]	166	348	5.36	11.2	
Total	1554	907	344[b]	222	380	7.15	12.2	
								% 19th century production[d]
CDC 1893–1950 (conservative minimum estimate): (57 years)								
Mid. Yuba	510	402	0.81	1.6	2.0	0.028	0.035	1.16
Mid+LNY[c]	560	432	1.45	2.6	3.4	0.045	0.059	0.81
So. Yuba	994	475	3.40	3.4	7.2	0.060	0.126	2.06
Total	1554	907	4.81	3.1	5.3	0.054	0.093	1.40
So. Yuba[e]	994	475	1.70	1.7	3.6	0.030	0.063	1.03
Total[e]	1554	907	3.10	2.0	3.4	0.035	0.060	0.90

[a] Drainage area of mining districts: South Yuba below and including Scotchman Creek; Middle Yuba below Milton Reservoir.
[b] Volumes produced from Benyaurd et al. (1891) times 1.51 (Gilbert, 1917).
[c] Middle Yuba and Lower North Yuba below New Bullards Bar Dam.
[d] Licensed mining volume as % 19th century volume.
[e] Without mines licensed to dispose of tailings in Englebright Reservoir.

Caminetti Act within the War Department (now U.S. Army Corps of Engineers) (Hagwood, 1981). The CDC inspected detention structures and issued licenses for specific volumes of gravel releases based on the ability to detain sediment. Although this period of hydraulic mining began in 1893, it will be

Fig. 7. View up Shady Creek, South Yuba tributary, 1992. Large amounts of mining sediment stored in low-gradient upland tributaries, identified by sand and fine-gravel texture and white quartz. Evidence of reworking includes steep terrace scarps (long arrow) and historical features emerging from bed (old flume with square nails; short arrow at left).

referred to as *20th century mining* or *licensed mining* to distinguish it from the far more intense unregulated hydraulic mining prior to 1884 that will be referred to as *19th century mining*.

The 57-year period of 20th century mining (1893 to 1950) in the Yuba watershed lasted almost twice as long as the 31-year period (1853 to 1884) of unregulated mining. Most 20th century hydraulic mines operated briefly and produced little sediment, but some operated over extended periods, with repeated license renewals, and produced large volumes of sediment. Although the geomorphic effects of 20th century mining were subtle relative to earlier sedimentation, large sediment volumes were produced and stored near the mines, and mercury was apparently used profusely. The fate of this sediment is largely unknown, although a few known deposits are documented later in this paper. Gilbert (1917) noted evidence of recent mining in hydraulic pits of the Yuba basin in 1908, but felt that contemporary sediment production was insubstantial and inadequate to explain his initial estimates of sediment production in the Bear River that he thought were too high:

"During the surveys in 1908 it was easy to see that certain parts of the growth had sprung up, were of early date, and that other parts, still bare of vegetation, were relatively recent; but it was not practicable either to infer dates with approximate accuracy or to estimate separately the more recent work. It is believed, however, that the work subsequent to 1890 can account for only a small part of the discrepancy between the two estimates. . ." (Gilbert, 1917: 39)

Most CDC mining licenses involved the construction of detention structures that are described later. In a few cases, however, sediment was stored on the floor of an abandoned hydraulic mine pit. A notable example of pit storage is the Manzanita Mine (Fig. 6) that drains to the lower North Yuba below the Middle Yuba confluence a short distance above Englebright Reservoir. A license was granted in 1894 to store 806,000 m^3 of sediment in the floor of the former mine. The mine produced 637,000 m^3 by 1897 when the license was revoked. By 1898, an additional 142,000 m^3 was stored behind brush and earth dams and 42,000 m^3 was added to pit storage (CDC, nd). Based on a 1909 topographic survey of this mine pit, Gilbert (1917) concluded that a total of 37 million m^3 of sediment had been removed, so the licensed volume represents only about 2% of the total mined volume.

A summary of CDC records of 20th century mines and detention structures in the Yuba watershed is presented later in this paper. A summation of sediment-production volumes from CDC license data for the entire Sierra Nevada came to only 2.4% of the total sediment production from hydraulic mining (James, 1999). This represents a conservative minimum estimate because of missing records and incomplete accounting of sediment produced. Much more sediment may have been produced than the volumes reported by the CDC. While licensed mining sediment production was probably small relative to the peak rate of 19th century sediment production, the deposits influenced valley-bottom morphology and may continue to produce sediment. Furthermore, recent realizations about mercury associated with hydraulic mine tailings in the Sierra Nevada has increased the importance of locating these deposits due to their potential Hg toxicity.

4.3. History and nature of debris dams in the Yuba watershed

Three major periods of dam building can be identified that were associated with hydraulic gold mining. The earliest historic dams on main channels in the mining districts were by tailings fans associated with episodic sedimentation from 19th century hydraulic mining. A second period of dam construction ensued after 1893 with a proliferation of small sediment-detention dams built to qualify for 20th century hydraulic-mining licenses. Finally, the construction of Englebright Reservoir marks the modern period in which a large dam arrests the down-valley transport of mine tailings.

4.3.1. Tailings fans

In the early period of unregulated hydraulic mining, sediment from mining created large fans that dammed rivers and created lakes that acted as large sediment-storage repositories. These tailings fans have been documented in the Bear River including detailed contemporary accounts near Dutch Flat (James, 1988: pp. 48–50, 2004; James and Davis, 1994). A few tailings fans trapped large volumes of sediment behind valley spurs that later cut narrow

bedrock notches. These valley-spur cutoffs were created when a tailings fan forced the main channel up against the far valley wall where it ultimately incised into the spur (James, 2004). Now the cutoff spur acts as a knickpoint controlling long-profile readjustments and retarding the release of mining sediment stored upstream. Two valley-spur cutoffs have been identified in the Bear River basin: at Steephollow Crossing and above Red Dog Ford. Although spur cutoffs have not been mapped in the Yuba basin, the landform previously was not recognized and they may have gone unnoticed. Spur cutoffs would not have formed on the South or Middle Yuba main channels because of high stream powers that eroded fan toes and prevented damming. Tailings fans in tributaries could hold large sediment repositories in the Yuba basin and should be mapped as sites of potential long-term sediment supplies.

4.3.2. Debris-control dams

Early in the period of licensed mining, basic procedures for detaining sediment with small impoundments were developed. During the first decade of licensed mining, the engineering of small detention structures was rudimentary, so many of these ephemeral structures washed out within a few years. The CDC (1904) soon developed guidelines with standard design structures for two types of detention structures: brush dams and log-crib dams. The standard CDC design for brush dams advocated use of live brush at least 3 m long with large limbs bent back and long, trimmed poles 10 to 30 cm in diameter. A brush layer was applied with butts pointing downstream, poles were laid over and wired perpendicular to the brush, and a layer of gravel or small stones was applied (Fig. 8). This sequence was repeated with multiple layers of brush, poles, and gravel offset upward so the face of the dam sloped steeply downstream. A pool of water at least 0.6 m deep was to be maintained while mining proceeded. In spite of this standardization of design, these structures were ephemeral and most were breached by large floods. Nevertheless, vestiges of these structures may anchor historical terraces along valley walls in the upper basin and a map inventory is needed. A summary of CDC records of detention structures in the Yuba watershed and mining sediment production associated with them is given later.

The standard CDC (1904) design for log-crib dams specified two walls of logs connected by cross-logs notched and bolted together (Fig. 9). The bottom and sides were supposed to be founded on bed rock and the cribs filled with stone and chinked with brush, twigs, and leaves, so the dam would maintain a pool at least 0.6 m deep during mining. Few crib dams have been located in the mining districts. Most were quickly breached (Gilbert, 1917), although crib-dam remnants may store tailings throughout the region

Fig. 8. Brush dam below Murchie Mine in South Yuba basin showing butts of brush pointing downstream and poles crossing. Photographed in 1908 by Gilbert (1917; Plate 26A).

Fig. 9. Log-crib dam on Spring Creek below North Columbia mine. November 1905. From Gilbert (1917; Plate 27A). Gilbert revisited this dam in October 1908, noting that it failed in 1907.

(e.g., Scotchman Creek described later). A contemporary description of brush and log-crib dams and their ephemeral nature is provided by G.K. Gilbert:

"In the early years of the commission's control its requirements were satisfied by dams of brush or of wooden cribs loaded with stone or gravel, and it is only in recent years that concrete dams have been prescribed. In a few projects separate spillways were provided for the streams on which brush and crib dams were built, but usually the streams were allowed to cross the crests of the dams, and in all such places the storage was not permanent. After the wood of brush and cribs has decayed, and often sooner, the dams are breached and the stored débris is exposed to wash." (Gilbert, 1917: 67)

Much sediment passed through the detention structures as was shown by channel changes below dams responding in phase with the production of mining sediment in the Bear River (James, 1999). Trap efficiencies of the small dams were low, so CDC estimates of 20th century sediment production may be systematically low to the extent that tailings were transported downstream without being accounted for. The proportion of delivered sediment detained by a reservoir (trap efficiency) is a function of reservoir capacity, magnitudes of inflow, volumes and textures of sediment, density currents, reservoir-operating policy, bathymetry, and the shape, type and location of outlets (Brown and Thorp, 1947; Brune, 1953). Trap efficiencies of moderately large reservoirs are typically between 50% and 98% (Colby, 1963: 35; Brown and Thorp, 1947) but may be considerably less for small pools such as the sediment-detention dams. Based on estimated yields of sediment and surveys of reservoir bathymetry, trap efficiencies for six small, low reservoirs in the lower Schuylkill River ranged from 2.1% to 31.4% with an average of 11.9% (Yorke et al., 1985). These reservoirs had mean widths between 109 and 175 m and capacities between 540,000 m^3 and 3,900,000 m^3, and were much larger than the typical brush dams and log-crib dams of the Sierra Nevada. Sediment yield is calculated from surveys of reservoir sedimentation as the ratio of stored volumes of sediment to trap efficiency (Vanoni, 1975), so a 20% trap efficiency would indicate sediment yields five times the volume of sediment stored in the detention structure. This does not adjust for reductions in trap efficiencies as reservoirs fill (Verstraeten and Poesen, 2000). These observations suggest that only a small percentage of the sediment produced by licensed 20th century mining was detained by crib dams even if leakage through dams and failures are discounted. Since sediment-production estimates given in CDC records were usually based on reservoir filling, actual sediment production

was probably much greater than reported in CDC reports. For current planning purposes, however, the important issue is how many of these structures remain in small mining tributaries, how much sediment remains behind them, and whether or not these deposits contain mercury, acid, or other hazardous materials.

4.3.3. Englebright Dam

Englebright Dam was built in 1941 by the U.S. Army Corps of Engineers for the explicit purpose of storing hydraulic gold-mining sediment. The reservoir is narrow and 14 km long with a surface area of 330 ha. It stands in the lower foothills at an elevation of 160 m amsl and is accessible above the lower reaches only by boat. Englebright Dam supports local recreation and two minor hydropower plants, but provides negligible water storage or flood control. The dam was justified under the assumption that its cost would be recouped by hydraulic mines paying for sediment storage, but mining ceased shortly after dam construction. From 1941 to 1950, nine licenses to mine ~1.7 million m^3 of hydraulic mining sediment (2% of total reservoir capacity) were issued to mines in the South Yuba based on storage in Englebright Reservoir (Table 2). No record exists of CDC licenses in the Middle Yuba based on storage in Englebright Reservoir. In addition to the licensed volumes, reworking of sediment from earlier tailings must have delivered large volumes of sediment to the reservoir over the past 60 years. Sedimentation in the reservoir ranges from 6 to 31 m in depth and accounts for an approximately 25% loss of storage capacity (Childs et al., 2003).

4.4. CDC records of dams and sediment production

From 1893 through 1950, the CDC licensed hydraulic gold mining in the Yuba watershed and kept records of the size, nature, and location of detention structures for licensed mines. They also estimated volumes of sediment production from hydraulic mining based on inspections of fill behind dams. Existing records are sometimes conflicting and often incomplete, but they allow approximations to be made of locations and relative magnitudes of mining during this period. Although CDC records prior to 1906 were largely destroyed by the San Francisco fire, partial records of the early period are available in reports to Congress (Kidder, 1894, 1896, 1899). Later archival CDC records from 1905 to 1935 are better but also incomplete. Summaries have

Table 2
Conservative minimum volumes of 20th century sediment-detention structure storage capacities and mined volumes in the South and Middle Yuba basins

	South Yuba			Middle Yuba			Both Basins		
	N	Storage capacity, m^3	Volume mined, m^3	*N*	Capacity, m^3	Volume mined, m^3	*N*	Capacity, m^3	Volume mined, m^3
Licenses applied for	46			24			70		
Licenses refused	3			1			4		
No evidence license granted[a]	2			2			4		
Licenses granted for[b]:									
Brush dams	8	1,034,798	576,350	9	475,739	85,806	17	1,510,537	662,156
Log-crib dams	11	346,590	297,241	8	16,407	98,201	19	362,997	395,442
Concrete dams[c]	4	573,825	265,490	1	38,255	10,329	5	612,080	275,819
Earth or gravel dams	4	353,476	15,685	3	570,994	252,866	7	924,470	268,550
Pit storage	5	160,671	393,261	7	929,979	1,002,434	12	1,090,650	1,395,695
Subtotal:	32	2,469,360	1,548,027	28	2,031,374	1,449,635	60	4,500,734	2,997,662
Storage in Englebright (> 1940)	9	NA	1,667,233	0	NA	0	9	NA	1,667,233
Total with Englebright:	41		3,215,260	28		1,449,635	69		4,664,895

Source: CDC archives (n.d.); Kidder, 1894, 1896, 1899.
[a] Probably no mining at these sites. Does not include licenses known to have been refused.
[b] Includes only mines with evidence that license was granted, so the structure was built and inspected.
[c] Four licenses granted to Omega Mine for concrete dams at same site in Scotchman Creek. Fifth license for Sierra Hydraulic mine in Middle Yuba. Sixth application based on concrete dam in S. Yuba at Relief Hill refused.

been presented elsewhere of CDC records for licensed mining in the Bear and North Fork American Rivers (James, 1999). This section summarizes CDC records of 20th century mining in the South and Middle Yuba Rivers and presents a case study of licensed deliveries of mining-sediment and detention structures in Scotchman Creek.

4.4.1. Sediment production and storage capacities

Tallies of CDC license data for this study provide conservative minimum estimates of the number of hydraulic gold-mining licenses issued, the types of structures associated with the licenses, volumes of storage capacity, and sediment production associated with the structures. These results include only records for mines that were clearly located in the basin and for which the values were specified in one or more CDC documents based on licenses that were granted. The structures described were presumably built and inspected, as this was required for issuance of licenses. These values should be regarded as minimums for several reasons. First, many records throughout the period do not report dam capacities or sediment-production volumes. Storage capacities were given on only 42% of license reports and production volumes on only 39% of the reports. While many unreported values may have been associated with small or failed mine operations, the reported volumes are less than actual amounts because of lack of data for so many mines. Second, many records of licenses for the Yuba watershed are not included in this tally because they do not specify a location within the South or Middle Yuba. While they could be located in the North Yuba, lower Yuba, or Deer Creek basins, several may have been in the South or Middle Yuba basins. Twenty-six mines at unspecified locations in Yuba basin received licenses and an additional 13 unknown Yuba mines applied for licenses with an unknown outcome (no date of issue reported). Most of these licenses are from before 1906 when records are sparse. A third reason for underestimated sediment-production values stems from low trap efficiencies as described earlier. With these limitations in mind, examination of the CDC data provides a number of interesting patterns.

At least 69 licenses for hydraulic gold mining were issued from 1893 to 1948 in the South and Middle Yuba basins: 41 in the South Yuba and 28 in the Middle Yuba (Table 2). Licenses were based on a variety of sediment detention strategies, including storage in local mine pits (12), brush dams (17), log-crib dams (19), earth- or gravel-fill dams (7), concrete dams (5), and storage in Englebright Reservoir (9). The numbers indicate the number of licenses rather than the number of structures. Occasionally multiple licenses were issued for the same structure by raising a dam. For example, the concrete dam on Scotchman Creek was raised by additional concrete and by adding brush dams and other works on top as described in the next section.

The total reported storage capacity of small structures in the upper watershed was 4.5 million m^3: 2.4 million m^3 in the South Yuba and 2.0 million m^3 in the Middle Yuba. The relative importance of different types of detention structures can be estimated from the CDC records (Table 2). In a few cases, two types of detention were reported for a license, so the volume was equally apportioned to each type. For the Omega Mine on Scotchman Creek, the large capacity for an 1893 license was arbitrarily assigned 25% to a brush dam and 75% to a concrete dam. Brush dams provided the largest type of detention capacity, with pit and earth dams comprising the next largest capacities (Fig. 10A). Storage within existing hydraulic mine pits usually involved plugging tunnels or shifting sediment to a previously worked area and can be associated with wetlands that create a mercury-methylating environment. The relative importance of these methods varies substantially between the South and Middle Yuba. Pit storage was by far the dominant method in the Middle Yuba but was of little importance in the South Yuba. Most pit storage (68% of Middle Yuba and 58% of total pit storage) was in the Manzanita Mine near Sweetland (Fig. 6) where at least 637,000 m^3 of sediment was produced based on a license issued in 1894 to mine 806,000 m^3 (revoked in 1897). The license was obtained by damming tunnels that had drained the mine during 19th century operations. Without the capacity of the Manzanita Mine, pit storage was far less important. That single Manzanita Mine license represents 40% of the total known capacity of storage and 44% of the 20th century sediment produced in the Middle Yuba. The remaining sediment storage capacity and production was largely accounted for by earth-fill and brush dams (Fig. 10). In the South Yuba, a greater reliance

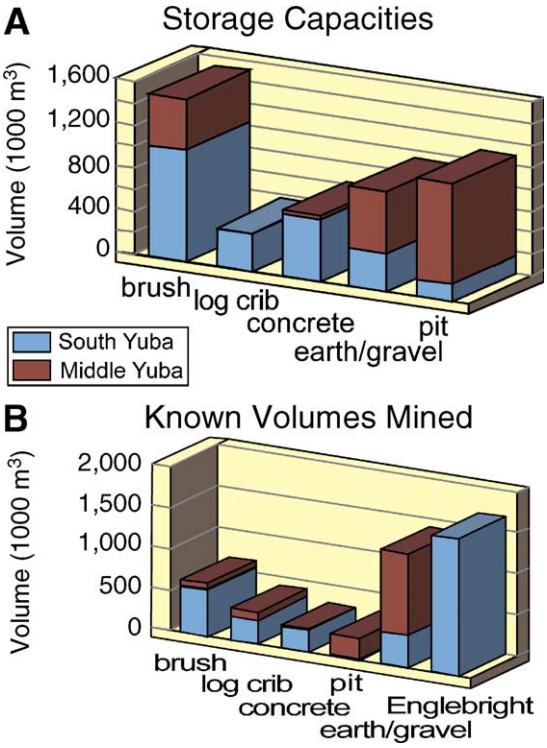

Fig. 10. Conservative minimum estimates of volumes associated with licensed hydraulic mining, 1893–1950. (A) Total dam storage capacities: South Yuba, 2.2 million m^3; Middle Yuba, 2.0 million m^3. (B) Total reported hydraulic mining sediment production: South Yuba, 3.4 million m^3 (1.7 without Englebright); Middle Yuba, 1.5 million m^3. Data from CDC archives.

was put on brush dams, the concrete dam on Scotchman Creek, log-crib dams, and earth-fill dams.

Total reported sediment produced by licensed hydraulic mining was 4.8 million m^3 including deliveries to Englebright Reservoir, with 3.2 million m^3 in the South Yuba (1.5 million m^3 without Englebright) and 1.4 million m^3 in the Middle Yuba (Table 2). Sediment produced for storage in Englebright Reservoir after 1941 was the single most-important source of sediment reported, and accounted for almost half of the reported hydraulic mining sediment produced in the South Yuba and a third of the sediment in the entire watershed (Fig. 10B). The sediment volumes for Englebright are probably complete and relatively accurate because they are based on water use, while the other volumes are probably severely underestimated. Nevertheless, a proliferation of hydraulic mining occurred in the 1940s associated with dam closure and this sediment was delivered directly to the reservoir. Recent coring of Englebright Reservoir revealed storage of ~22 million m^3 or approximately 25% of the initial reservoir capacity (Childs et al., 2003). The 1.67 million m^3 of mining sediment produced by licensed mining after 1940 for Englebright Reservoir (Table 2) represents 7.6% of the sediment now in the reservoir. This production was entirely in the South Yuba and mostly from Scotchman Creek (Table 3). Sediment production associated with other detention structures is generally less than storage capacities which may represent failure of structures before mining was complete, license revocations, or lack of reporting of mined volumes. In some cases, mined volumes are greater than reported storage capacities which probably represents unreported storage values. These estimates of licensed sediment production range between 1% and 2% of the total hydraulic mining sediment produced since 1853 (Table 1), but should be considered a conservative minimum estimate.

When these conservative values of licensed sediment production volumes are divided by drainage areas of the basins, the net denudation varies between 0.28 and 0.60 cm (Table 1). Three to six millimeters of denudation by 20th century mining is almost two orders of magnitude smaller than the exceptional 22 cm of total denudation in the Yuba basin caused by 19th century unregulated hydraulic mining. When averaged over the 57-year period of mining, denudation from 20th century, hydraulic mining ranges from 0.03 to 0.06 mm $year^{-1}$. These rates are substantial from the perspective of long-term erosion rates in large watersheds. They are an order of magnitude less than maximum regional denudation rates (~0.3 mm $year^{-1}$) and are comparable to long-term rates (0.03 to 0.06 mm $year^{-1}$) at tectonically stable Sierra Nevada granitic sites based on cosmogenic radionuclides (Riebe et al., 2001). If sediment production is averaged over the smaller areas of the mining districts, average denudation by mining is substantially higher (Table 1). At the extreme, total denudation of the entire South Yuba downstream of and including Scotchman Creek was more than a third of a meter, mostly because of unregulated 19th century mining. The conservative minimum estimates of denudation by licensed mining in the South and Middle Yuba mining districts are 7.2 and 3.4 mm, respectively;

Table 3
Dams and sediment on lower Scotchman Creek

Date	License #	Dam	Volume mined
ca. 1890	none	Log dam, 12.2 m high and 14 m long at crest; filled (Turner, 1891: 3049)	
1893	3	brush and gravel dam; rock spillway.	765,000 m^3 capacity
1904–1909	660	concrete dam; license revoked 1909.	16,100 m^3 mined
1914–1919	898	concrete dam with 12.8 m basket dam; raised 1919 +2.4 m; failed 1919.	344,000 m^3 mined
1922–1925	956	Deposited in local mine pit	2700 m^3 mined
1925–1929	978	1927: photo shows failed dam	8400 m^3 mined
1929	1007	dam raised 2.1 m; license revoked 1929	200,000 m^3 mined
1933–1941	1112	log-crib and concrete dam; license revoked 1941 (filled).	93,000 m^3 mined
1938–1939	1194	log-crib dam; license revoked 1939.	138,000 m^3 mined
1941–1943	1244	Englebright Reservoir	955,000 m^3 mined
??	1264	Englebright Reservoir	???
??	1270	Englebright Reservoir	???
1948–1950	1271	Englebright Reservoir	200,000 m^3 mined

Source: CDC records.

representing a substantial erosional event for such large areas.

4.4.2. Case study: 20th century dams and mining on Scotchman Creek

A long sequence of licensed mining took place in the Omega Mine which drains to Scotchman Creek (Table 3). This history, from CDC archives (n.d.), illustrates the complex nature of repeated dam construction, licensing, dam filling and failure, and sediment production. The sequence began with one of the first CDC licenses issued; a license in 1893 to produce 765,000 m^3 of sediment. Another license issued in 1904 for sediment discharges to a concrete dam was revoked in 1909 after 16,000 m^3 had been mined. Reasons for license revocation were not given but usually represent the filling or failure of a dam. In 1914 another license was issued to discharge sediment into a concrete dam with a 12-m-high "basket dam" addition. This dam failed in 1919 after the reservoir was filled with 344,000 m^3 of sediment but the dam was raised 2.4 m shortly afterwards. A CDC photograph shows lower Scotchman Creek in 1927 with a failed earth-fill dam (Fig. 11), but no mention is made of the failure in CDC records. In 1929, the dam was raised 2.1 m, 200,000 m^3 of sediment was mined, and

Fig. 11. Lower Scotchman Creek dam site, 1927. View downstream toward failed earth-fill dam; presumably same site as concrete dam. CDC archives.

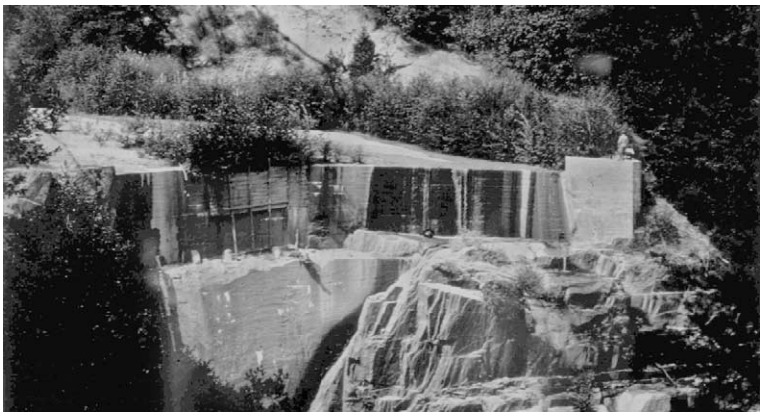

Fig. 12. Concrete gravity dam on lower Scotchman Creek showing lower section and an upper addition. Was full of sediment when photo taken, December 25, 1941. Dam intact and filled with sediment when visited occasionally since 1989. CDC archives, U.S. Army Corps of Engineers.

the license was revoked. In 1933, another license was issued for a concrete dam, and by 1941 93,000 m^3 of sediment had been mined, the dam had filled (Fig. 12), and the license was revoked.

A log-crib dam on Scotchman Creek was built in 1938 on top of tailings upstream of the concrete dam. The license was revoked in 1939 after 138,000 m^3 had been mined, presumably because the reservoir had filled. The log dam was breached by a large 1986 flood (Fig. 13) and deposits above the dam were regrading in 1989. The concrete dam downstream has remained filled with sediment, so the sediment released from the log-crib dam is being delivered downstream to Englebright Reservoir. A topographic cross-section of Scotchman Creek was surveyed in 1989 with rod, tape, and level 15 m above the concrete dam. The maximum top width of the mining sediment deposit was 58.5 m across a low mining-sediment terrace from valley wall to valley wall, and the channel bed in 1989 was only 1.5 m below this terrace.

Fig. 13. Log-crib dam on middle Scotchman Creek built in 1938. License revoked in 1939 (reservoir probably filled). Dam breached by 1986 flood and stored sediment was eroding in 1989 when photographed by author.

5. Modern river conditions

The contribution of reworked mine tailings is important to understanding future sediment loads in the basin, so the ability to identify and assess the mobility of this sediment is of great relevance. Fortunately, the texture and lithology of mining sediment are distinctive and readily allow identification of tailings and the degree to which they have been mixed (James, 1991). Field observations of channels in the Yuba basin indicate the presence of large volumes of historical sediment in terraces and channel bed materials in certain tributaries. A few of these deposits were sampled in the summer of 1989 using grid-sample counts of pebbles and bulk-sample sieving of channel materials. This section briefly describes the nature of channel-bed and low-bar samples and the patterns of mining sediment that they indicate.

5.1. Bed material textures

The Tertiary bench gravels that were mined for gold are dominated by fine gravel and sand. Mine tailings tend to be much finer-grained than the channel lag and colluvial materials common in channels lacking mining sediment. Thus, sediment from hydraulic mining tends to be relatively mobile and suitable for spawning habitat. Grid-samples (Wolman, 1954) of low-flow bed materials were collected at several sites within the South Yuba basin. Particle intermediate-axis dimensions were recorded to the nearest millimeter, and mean grain sizes were calculated by the method of moments (Table 4). Normally, fluvial bed sediment fines downstream as gradients decrease. This general pattern can be seen in the main channel (circles on Fig. 14) with two exceptions. The anomalously fine sample from the upper basin at a drainage area of 134 km^2 reflects the lack of coarse colluvium in wide valleys of the glaciated upper basin. Conversely, the anomalously coarse sample in the lower South Yuba at a drainage area of 800 km^2 is from an exceptionally narrow, steep stretch of canyon at Highway 49 where colluvial boulders dominate the channel (Fig. 15). The other four main-channel samples in the lower South Yuba, collected between Edwards Crossing and the Englebright delta, are relatively fine textured with mean grain sizes between 13 and 15 cm (Table 4).

Relatively fine sediment from mining dominates some of the tributaries in the Yuba watershed. Normally, tributaries have coarser bed materials than main channels and the textures will plot as an extension of the negatively sloped line on plots like Fig. 14. The combination of low-gradients and large amounts of fine-grained mining-sediment, however, results in the three tributary samples being substantially finer than bed sediment in the main channel. Shady Creek is clearly dominated by mining sediment and has fine, well-sorted bed material (Fig. 7). Humbug Creek conveyed tremendous volumes of mine tailings when it acted as the drain for the

Table 4
1989 bed load textures and white quartz (wtQtz) summary: grid-samples

Site	Drainage Area (km^2)	Total N	Mean mm	Mean Phi	%wtQtz total	%wtQtz ≤50 mm	N ≤50 mm
South Yuba channel							
at Cisco	134	61	222	−7.79	0.0	0.0	5
at Langs Xg	310	50	512	−9.00	2.0	0.0	1
above Scotchman Cr	532	100	228	−7.84	4.0	0.0	6
at Edwards Xg	710	100	132	−7.04	21.0	33.3	18
at Purdon Xg	745	101	149	−7.22	19.8	70.6	17
at Hwy. 49	801	60	524	−9.03	8.3	75.0	4
Bridgeport	993	50	128	−7.00	18.0	80.0	5
Bridgeport channel	993	50	150	−7.23	12.0	66.7	3
Tributaries							
Humbug Cr	16	53	77	−6.26	22.6	50.0	14
Shady Cr #10	32	100	43	−5.42	54.0	51.3	80
Shady Cr #8	38	100	27	−4.78	62.0	57.9	76

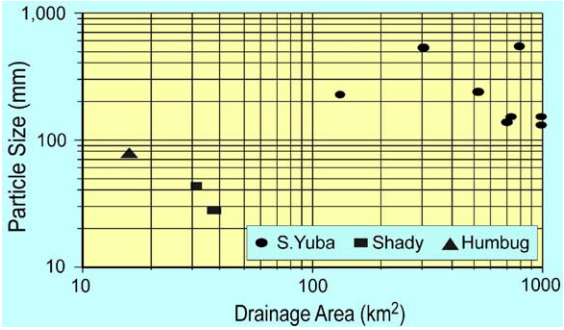

Fig. 14. Bed material textures are relatively fine in tributaries dominated by mine tailings but coarse in the South Yuba main channel that is dominated by channel lag. Grid-sample data, 1989.

Malakov Diggings. During the 1870s, a tunnel was bored beneath Humbug Creek and tailings bypassed the creek at an early date. The amount of mining sediment in the bed of Humbug Creek today is mitigated by thick vegetation stabilizing most deposits outside of the channel. Fine bed textures suggest, however, that reworked mining sediment still contributes a substantial amount of the modern bed load. This interpretation is supported by the presence of moderately high white quartz concentrations described in the next section. In short, bed material textures suggest that main channels are dominated by gravel, cobbles, colluvium, and channel lag materials but some tributaries are dominated by finer sediment from mining. Examination of the lithology of the bed materials corroborates this interpretation and indicates further that a population of relatively fine-grained mining sediment is passing through the reaches of the main channel.

5.2. Lithology of bed material

The percentage of white quartz pebbles in samples of bed material from these rivers can be a reliable indicator of the proportion of tailings from hydraulic mines that worked the auriferous Tertiary channels (James, 1991). This simple relationship with quartz facilitates field recognition of sediment from mining by its distinct white color, and allows quantitative assessments to be made of the dilution and mixing of sediment in the downstream direction. Sediment sampling was designed, therefore, to measure percentages of quartz to ascertain the relative importance of mine tailings in the stored material in and along channels at various locations within the watershed. Terrace and channel-bed materials were sampled, although only the results of bed material samples are reported here. Application of this method requires caution not to include sites that have gained quartz from roads and construction sites. Mining sediment quarried from river deposits is commonly used for aggregate, and may be introduced to watersheds where no mining occurred. Generally, such introductions are relatively minor and localized compared to sediment produced by hydraulic mining. Where possible, samples were collected above bridges to avoid contamination from roads.

Quartz pebbles were identified and recorded in the grid-samples of bed material described above during sampling. Although percent-frequency of quartz was calculated for each total sample, the more relevant statistic is the percent-frequency of quartz in pebbles no larger than 50 mm (Table 4). Sediment from mining tends to be finer than fluvial sediment from other sources, and by isolating the finer fractions of channel samples, the importance of mine tailings to the highly mobile portion of bed material can be determined.

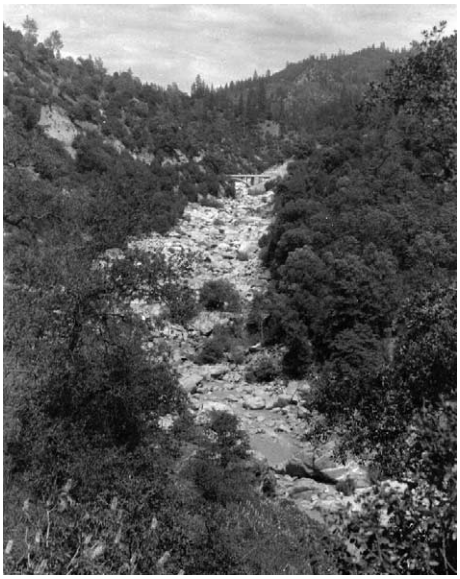

Fig. 15. View upstream on South Yuba toward Highway 49 bridge, showing dominance of coarse lag boulders in main channels. Photograph by W.D. Johnson, Jr., 1934. U.S.G.S. Field Records Library.

Above Scotchman Creek, grid-samples of main-channel bed material have few pebbles and lack white quartz pebbles. The number of pebbles and quartz concentrations increase rapidly downstream to high values that indicate a dominance of mine tailings in this fraction (Fig. 16A). This trend suggests the increasing presence of sediment from mining in the active bed load of the main South Yuba channel once it enters the mining districts. High concentrations of quartz and, therefore, sediment from mining are also present in bed materials of Shady and Humbug Creeks.

Although the size of the grid-samples range from 50 to 100 clasts, they often have too few clasts in the small pebble range to allow an unequivocal evaluation of the relationships described above (Table 4). In anticipation of this limitation, a second set of samples was collected in 1989 using an alternative method to expand the geographic range and size of quartz pebble samples. Bulk surface samples of pebbly bed material were collected from the low-flow channel bed and low bars with a folding shovel approximately to the depth of the coarsest grain size (usually < 10 cm). Each sample was air dried in the field and sieved through brass 20-cm-diameter sieves. White vein-quartz pebbles were separated in the 32–64, 16–32, and 4–8 mm fractions, and both quartz and non-quartz fractions were weighed in the field to the nearest 0.1 g using a portable digital balance. Summary data are presented here for percent white quartz (by weight) of the 16–32 mm fraction (Table 5).

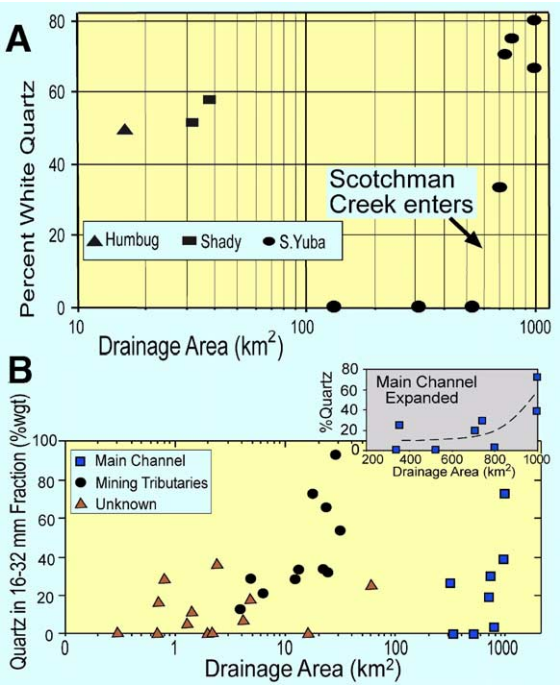

Fig. 16. Distinct lithology of sediment from hydraulic mining facilitates identification of mining. High white quartz concentrations in bed material indicate which tributaries carry mining sediment. (A) Quartz percentages of pebbles ≤50 mm from grid-samples of channel-bed material. High percentages in Shady and Humbug Creeks and lower South Yuba River indicate high contributions from reworked mining sediment. Low quartz contents above Scotchman Creek indicate little mining sediment in bed load. Sediment from mining is delivered to main South Yuba channel by Scotchman Creek. (B) Percent white quartz in the 16–32 mm fraction of sieved bulk samples. Main channel shows same pattern of increase below Scotchman Creek. Tributaries known to drain mines tend to have high quartz. Based on 1989 field data.

As expected, the percent quartz in bulk samples of bed materials of the South Yuba has a distinct spatial pattern and appears to be strongly related to the presence of sediment from hydraulic gold-mining. In agreement with the grid-samples, quartz pebbles are scarce above the mining districts but increase below Scotchman Creek (Fig. 16B). Two main-channel bulk samples above Scotchman Creek had no quartz and so little fine sediment was available at the third site that it should be disregarded. Increased quartz downstream in the main channel is interpreted as the presence of reworked sediment from mining in the fine fraction of the modern bed material. Bulk pebble samples also corroborate the presence of reworked mine tailings in the beds of tributaries draining hydraulic mines. For example, Shady and Scotchman Creeks are presumably dominated by hydraulic mining sediment because of the fine textures of bed materials and massive terraces of actively eroding mining sediment. Samples from tributaries draining known mines (round points in Fig. 16B) tend to contain high percentages of quartz, particularly the four samples from Shady Creek that all have more than 50% quartz. In contrast, the mining history of many tributaries is unknown. Several tributaries with no known hydraulic mines in the headwaters (triangles on Fig. 16B) have little or no quartz. For example, bed material sampled in Kentucky Creek near its mouth has no quartz and probably represents a lack of sediment from hydraulic

Table 5
Bed material composition in sieved pebbles (intermediate axes 16 to 32 mm)

Location	Other comments	32 mm>pebbles> 16 mm wgt (g)	% Quartz by weight			Drainage area (km^2)
			Main	Mining	Unknown	
South Yuba						
Englebright	delta	216	72.2			994.0
Bridgeport	d/s bridge	641	38.5			993.0
Hwy. 49	d/s 49	445	3.0			801.0
Purdon Crossing	u/s bridge	565	29.5			745.0
Edwards Crossing	u/s bridge	400	19.1			710.0
at Scotchman Cr	u/s confluence	194	0.0			519.0
u/s Holbrook Flat	low bar; right bank	917	0.0			340.0
Jolly Boy Mine	low bar above mine	33	26.5			320.0
Tributaries						
Kentucky Cr	u/s bridge	233			0.0	16.0
French Corral	d/s bridge	527		21.1		6.5
French Corral	at 2nd bridge	738		28.2		5.0
Lower Shady	Reader Ranch	357		52.9		32.0
Shady Cr	below old Hwy. 49	212		92.6		29.0
Shady Cr	at Wildman10	760		65.5		23.4
Shady Cr	at Whittlesey	548		72.6		18.0
Kennebec Cr	u/s N. Bloomfield Rd.	341			29.2	0.8
Humbug Cr	d/s Pan Ravine	707		31.2		24.6
Pan Ravine	~20 m u/s Humbug	523			36.9	2.4
Humbug Cr	Site2	489		32.6		22.2
Humbug Trib	Relief Hill Rd.	329		12.6		4.0
Missouri Cn	30 m u/Relief Hill Rd.	495			0.0	2.1
McKilligan Cr	u/Relief H. Rd.	555			0.0	0.7
Thimblebry Cr	15 m u/Relief Hill Rd.	106			0.0	0.3
Logan Cr	450 m u/s Relief Hill Rd.	431			0.0	2.0
Poorman Cr	40 m u/s Relief Hill Rd.	421			26.1	60.7
Washington Cr	d/Br&Trb	511			18.5	4.9
Wash Cr Trib	nr Washington	949			17.0	0.7
Washington Cr	u/s bridge	390			7.4	4.2
Scotchman Cr	in pothole d/s dam	524		32.7		13.6
Scotchman Cr	u/s logdam	784		27.8		12.5
Missouri Cn	Scotchman trib	222			5.6	1.3
Rgt bank Trib	nr Holbrook Flat	624			11.6	1.4

Sample sites: Main=main channel. Mining=tributaries with at least one hydraulic mine. Unknown=tributaries that may or may not have received tailings.

mining in the active bed load. Many tributaries, including some that drain known mines, have intermediate concentrations of quartz between 10% and 40% that suggest continued contributions of sediment from mining but with a substantial amount of sediment dilution from other sources.

The textural and lithologic data support an interpretation that at least two populations of bed material are present in many locations in the watershed. Quartz-rich sediment from mining is relatively fine and mobile while lag gravels, colluvium, and the background sediment load from non-mining areas tend to be coarser and low in quartz. Stream powers are quite high in the main channels of the South and Middle Yuba Rivers and these channels have coarse lag deposits (Fig. 3). Yet even in these locations, fine sediment stored in pools, potholes, and interstices of boulder lags represents bed load that is being transported during high flows. These materials are rich in quartz and indicate that reworking of mine tailings continues to produce a high percentage of the sediment load in the basin.

6. Discussion

The high percent quartz in the 16–32 mm fraction of bed materials in the watershed indicates substantial volumes of sediment from mining are moving through the channel system. In Shady Creek, quartz concentrations in modern bed materials are so high that little other sediment could be present and reworking of sediment from mining must be the dominant sediment source. In other tributaries, such as Kentucky Creek, no hydraulic mining occurred or, if it occurred, the deposits may now be relatively stable. In the main South Yuba channel, textures and compositions of the bed sediment vary downstream with local hydraulic conditions. Yet, even in main channels within the mining districts, most sites have substantial proportions of sediment from mining in the fine-grained fraction, indicating that reworked mine tailings are now in transit. At least two sedimentary populations are present in these main-trunk samples: coarse lag and colluvial boulders that presumably move very little during typical annual floods, and fine-grained sediment from mining that is passing through the sections.

An enduring geomorphic concept that emerged from study of these deposits is G.K. Gilbert's (1917) symmetrical sediment-wave model. In this model, channel-bed elevation changes were specifically linked to sediment loads by likening the passage of sediment to the passage of a water wave. This model has been critiqued elsewhere and a revised skewed-wave concept has been proposed on the basis of observations in the Bear and American watersheds (James, 1989, 1997, 1999). Yet, the symmetrical wave has not previously been evaluated in the Yuba River where it was largely derived. Here, too, the concept that bed elevations provide a reliable measure of sediment loads is found to be in need of revision for the same reasons. First, in many South Yuba tributaries the storage and remobilization of sediment from mining continues in contrast to predictions of the symmetrical sediment-wave model. Second, the symmetrical wave model was based on the elevations of low flows on the channel bed at sites where channel-bed scour would be encouraged; either narrow gorges (Fig. 17) or leveed channel reaches. Finally, the elevation of the channel bed is a poor surrogate for sediment loads even in unbiased locations when sedimentation has occurred beyond the inner channel. The longitudinal profiles of severely aggraded channels tend to regrade long before sediment loads return to pre-aggradation levels. After channels incise, they

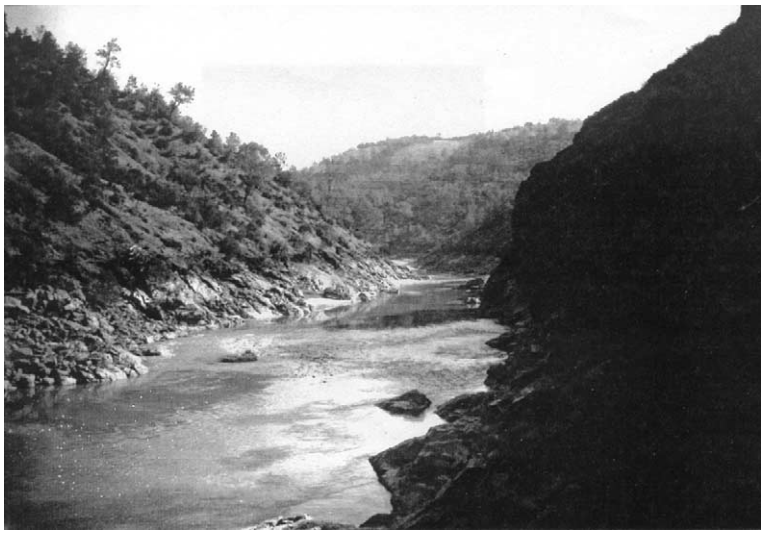

Fig. 17. View upstream on Yuba River through Englebright reservoir site "from a point 1 mile above the mouth of Deer Creek." Shows lack of sediment storage sites. Shoals in channel bed indicate on-going transport of sediment through the reach presumably dominated by contemporary or reworked sediment from mining. This site has been under water for 60 years. Photograph from U.S.G.S. Field Records Library. G.K. Gilbert collection; Photograph #3244.

continue to widen and rework sediment stored in floodplain and terrace deposits, thus maintaining elevated sediment loads. Yuba River channel beds rapidly returned to pre-mining elevations, but sediment loads have not returned to pre-mining levels. The mobility of sediment from mining is clearly indicated by the texture and lithology of bed materials throughout the mining districts. This and the obvious field evidence of sustained reworking of mine tailings in Scotchman, Spring, and Shady Creeks should not be overlooked.

Uncritical acceptance of the symmetrical-wave model would have several implications to the Englebright study. Implicit assumptions that most sediment from mining remaining in the watershed above Englebright Reservoir has been removed by erosion or permanently stored, would lead to the erroneous conclusion that the only sediment from hydraulic mining of relevance is now stored within Englebright Reservoir. Fortunately, the UYRSP has initiated a suspended-sediment monitoring program by the U.S. Geological Survey at Jones Bar that will allow first approximations to be made of fine-sediment loadings in the basin. Unfortunately, no funding exists for sampling bed load that is likely to be a major component of the total sediment load. The reservoir sediment-coring program will be crucial for determining sediment loads to Englebright Reservoir and for calibrating the sediment model being developed for the UYRSP. Given limited temporal and spatial resolutions of core data, however, uncertainty will likely require some subjective interpretations of the stratigraphic record for the last few decades. Thus, an understanding of the long-term dynamics of watershed processes over the past 62 years will be important and should consider the complex history of 19th and 20th century hydraulic mining and tailings stored in the upper tributaries.

7. Conclusions

CalFed is undertaking an elaborate, sophisticated study of the feasibility of altering or removing Englebright Dam. The potential rewards are extremely high: restoration of the salmon fishery in the Central Valley. The potential dangers are also extremely high: unleashing large volumes of possibly toxic sediment or reestablishing a salmon fishery only to find that spawning gravels are not sustainable. In addition to storage of vast volumes of sediment produced by 19th century mining, numerous small dams were built and filled with sediment after 1893. Unfortunately, neither the locations of the 20th century detention structures nor the volumes and chemistry of hydraulic gold-mining sediment they store have been mapped or inventoried. Where or how much sediment from mining remains in these tributaries is not known, and an inventory of the dams and deposits is greatly needed. Lamentably, little historic research exists on 20th century hydrologic changes in the Yuba basin. Gilbert's (1917) field observations in the Yuba watershed from 1905 to 1909 provide crucial contemporary documentation of the period but follow-up studies are needed.

The hydraulic-mining sedimentation history of the basin is complex and on-going. A pervasive modern belief in the region is that hydraulic gold mining ended in 1884 with Judge Sawyer's injunction and that the sediment from that period is now either gone or permanently stored. These assumptions are false. Field evidence shows that large volumes of tailings remain in upland tributaries, and CDC (nd) documents show that mining, dam construction, and local sediment storage was active in the Yuba watershed from 1893 to 1950. While 20th century hydraulic mining produced only a small percent of the historical sediment in the Yuba basin, construction of dams was required for the on-site retention of sediment, and the use of mercury was widespread. In some cases (e.g., Scotchman Creek), dams built during this period contain large reservoirs of mine tailings that are known to be actively eroding. Some of the dams plugged tunnels to allow storage of tailings in abandoned hydraulic mines where wetlands may now be sites of mercury methylation. For example, between 1894 and 1898 at least 679,000 m^3 of tailings were stored on the floor of the Manzanita Mine that now holds a large pond–wetland complex.

The on-going production of sediment from mine tailings is relevant to Englebright planning options through current and projected sediment loads, maintenance of salmonid spawning gravels in the upper river, and potential mercury toxicity. Field samples of bed material indicate that sediment from mining continues to move through the basin. Long-

term storage of fine-grained sediment in main channels of the South and Middle Yuba has been negligible for almost a century (Gilbert, 1917), so it has been common to underestimate long-term storage and remobilization of mine tailings in remote tributaries of the watershed. Storage is substantial in some tributaries, however, and reworking of these deposits appears to be an important source of sediment. Furthermore, these sediment deliveries may be the primary source of fine gravel essential to spawning in main channels, and as these supplies are reduced through time habitats may decline. In other words, distinguishing between background sediment characteristics and contributions from mine tailings is essential to addressing questions of habitat sustainability. More research is needed on the importance of reworked tailings to spawning gravels in main channels.

Given the rapid historical changes to sediment deliveries and the apparent importance of reworked tailings to current spawning habitats, the feasibility of changes to Englebright Dam rests not only on the impacts of releasing sediment stored in the reservoir and current sediment loadings in the watershed. Feasibility of establishing a sustainable salmon fishery may also rest on the long-term dynamics of sediment production from tailings stored in the upper watershed. These dynamics include the potential long-term decline of fine spawning-gravel supplies as tailings are depleted as well as potential impacts of episodic releases from these sources if small orphan detention dams fail. The impacts of an episodic release of tailings may come as a brief but damaging flux of fine sediment or the permanent loss of a perennial source of fine gravel that could be important to entire reaches of the main channel. Where sediment-detention structures or tailings remain in the upper watershed, the potential for dam failure or sediment depletion and the impacts should be assessed. Dam remediation or stream restoration plans should be considered to remove, repair, or maintain small, poorly maintained, orphan dams filled with tailings (e.g., the breached log-crib dam and concrete dam on Scotchman Creek). These plans should consider not only the disposal or stabilization of sediment, but also the maintenance of gradual sediment releases to sustain spawning habitat. Such decisions need to be developed and coordinated with geochemical and biological studies that integrate findings of sediment toxicity and decisions about developing salmonid fisheries that may depend on sediment releases from these sites.

Managing this sediment system would be considerably easier if sediment from hydraulic mining could be conceptualized by a simple symmetrical sediment wave; that is, if reworking of tailings stored in the upper basin could be ignored and present sediment production rates could be assumed static. Unfortunately, neither the processes nor the history of sediment production in this watershed are simple, and management options must account for complex dynamics of a changing system.

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Estimating reservoir sedimentation rates at large spatial and temporal scales: A case study of California

J. Toby Minear[1] and G. Matt Kondolf[1]

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[1] Previous reservoir sedimentation models have ignored two key factors for large spatial and temporal modeling of multiple reservoirs: trapping by upstream dams and decreasing sediment trapping as reservoirs fill. We developed a spreadsheet-based model that incorporates both factors. Using California as a case study, we used measured sedimentation rates to estimate sediment yields for distinct geomorphic regions and applied those rates to unmeasured reservoirs by region. Statewide reservoirs have likely filled with 2.1 billion m^3 of sediment to date, decreasing total reservoir capacity by 4.5%. About 200 reservoirs have likely lost more than half their initial capacity to sedimentation.

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1. Introduction

[2] Reservoir sedimentation is a serious problem in many regions with high sediment yield, particularly in, geologically active regions such as California. Small-capacity reservoirs in rapidly eroding mountain regions are most vulnerable to sedimentation problems. The costs of dealing with accumulated sediments can be prohibitively expensive and, for some dam removals, have been the greatest component of dam decommissioning costs [e.g., *U.S. Bureau of Reclamation*, 2006]. Even before reservoirs fill completely with sediment, sediment within the reservoir can reduce usable capacity, interfere with outlet works, damage turbines, and cause backwater flooding upstream [*Morris and Fan*, 1998]. Reservoirs filled with sediment may be at greater risk during earthquakes because accumulated sediment deposits are denser than water and may exert greater force against the dam during seismic shaking [*Chen and Hung*, 1993]. Reservoir sediments are also a significant global sink for carbon and other important nutrients [*Vorosmarty et al.*, 2003; *Stallard*, 1998]. In addition, the trapped sediment is not available for downstream economic and ecological benefits, such as beach replenishment [*Willis and Griggs*, 2003] or salmonid habitat, and release of sediment-starved water commonly causes bed incision in the downstream channel, which can result in downstream stream bank erosion, infrastructure damage, and drawdown of the alluvial water table [*Williams and Wolman*, 1984; *Kondolf*, 1997].

[3] In the design and maintenance of most reservoirs, little thought has been given to sustaining reservoir functions as capacity is progressively lost to sedimentation. Loss of reservoir capacity from sedimentation is difficult to offset with construction of new reservoirs because reservoirs have already been constructed at most viable sites in the developed world [*Morris and Fan*, 1998]. Maintaining reservoir capacity into the future will require that we address capacity losses from sedimentation, which requires tools to predict sedimentation rates and to identify reservoirs vulnerable to rapid sedimentation.

[4] Existing reservoir sedimentation models are not able to model large temporal or spatial scale patterns of sedimentation, primarily due to the extensive data requirements of the models. Current sedimentation models include process-based models that operate at small temporal and spatial scales and require data such as yearly or daily hydrologic records, detailed reservoir bathymetry, and sediment grain size distributions [e.g., *Ackers and Thompson*, 1987; *Sundborg*, 1992; *Lajczak*, 1996; *Tarela and Menendez*, 1999; *Rowan et al.*, 2000]. Similarly, geographic information system (GIS) based large spatial scale models estimate sedimentation on the basis of land use and/or hydrologic data [*Verstraeten et al.*, 2003; *Vorosmarty et al.*, 2003], which are lacking for most areas, particularly for historical periods. In addition, applying these process-based models without calibration can result in modeled sediment yields diverging from measured sediment yield rates by orders of magnitude [*Trimble*, 1999].

[5] Most importantly, existing reservoir sedimentation models do not account for two important factors: the effects of trapping by upstream reservoirs and changes in the rate of sediment retention, known as the trap efficiency, over time as reservoirs fill. As upstream reservoirs are built, they can reduce sediment yield to downstream reservoirs. This effect is particularly important in areas with numerous reservoirs within the same watershed, as exemplified by the 57 reservoirs on the American River and tributaries upstream of Folsom Reservoir, California (California Division of Safety of Dams (CDSD), Electronic database of dams and reservoirs in California, 2005, available at http://www.water.ca.gov/damsafety/).

[6] Temporally variable trap efficiency, the percentage of the incoming sediment trapped by a reservoir, is an important factor to include in sedimentation models when the time

[1]Department of Landscape Architecture and Environmental Planning, University of California, Berkeley, California, USA.

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Table 1. Reservoirs and Reservoir Sediment Yields by Geomorphic Region in California[a]

Geomorphic Region	Abbreviation	Number of Reservoirs: Total	Number of Reservoirs: Surveyed Reservoirs	Sediment Yield (m^3 km^{-2} yr^{-1}): Median	25% of Median	75% of Median	Minimum	Maximum	Mean	Standard Error	Median Denudation Rate (mm yr^{-1})
Coastal	C	370	23	262	160	406	19	3,419	417	142	
Central Valley	CV	18	4	89	36	234	24	277	120	55	0.032
Siskiyou	Sis	94	2	531	351	711	351	711	531	180	0.192
Peninsular	P	425	6	130	50	505	21	905	270	137	0.047
Sierra Nevada	SN	166	19	97	73	369	8	1,257	219	67	0.035
Transverse	T	127	12	519	304	986	93	5,085	919	389	0.188

Regions Without Sedimentation Data	Abbreviation	Number of Reservoirs: Total	Number of Reservoirs: Surveyed Reservoirs	Estimated Sediment Yield (m^3 km^{-2} yr^{-1})
Modoc	M	107	ND	531
Mojave Desert	MD	11	ND	97
Cascade	Cas	41	ND	531
Basin and Range	BR	17	ND	97
Colorado Desert	CD	3	ND	130
Colorado River	CR	3	ND	not used

[a]Capacity data from individual reservoirs used to determine sedimentation rates available at http://www.lib.berkeley.edu/WRCA/. We excluded the Colorado River geomorphic unit from this study because the river originates outside California and only a small portion of the state drains to the Colorado. ND indicates no reservoir sedimentation data used (either none reported or none meeting minimum standards for use in study). Estimated sediment yields are for regions with no data interpolated from nearby regions.

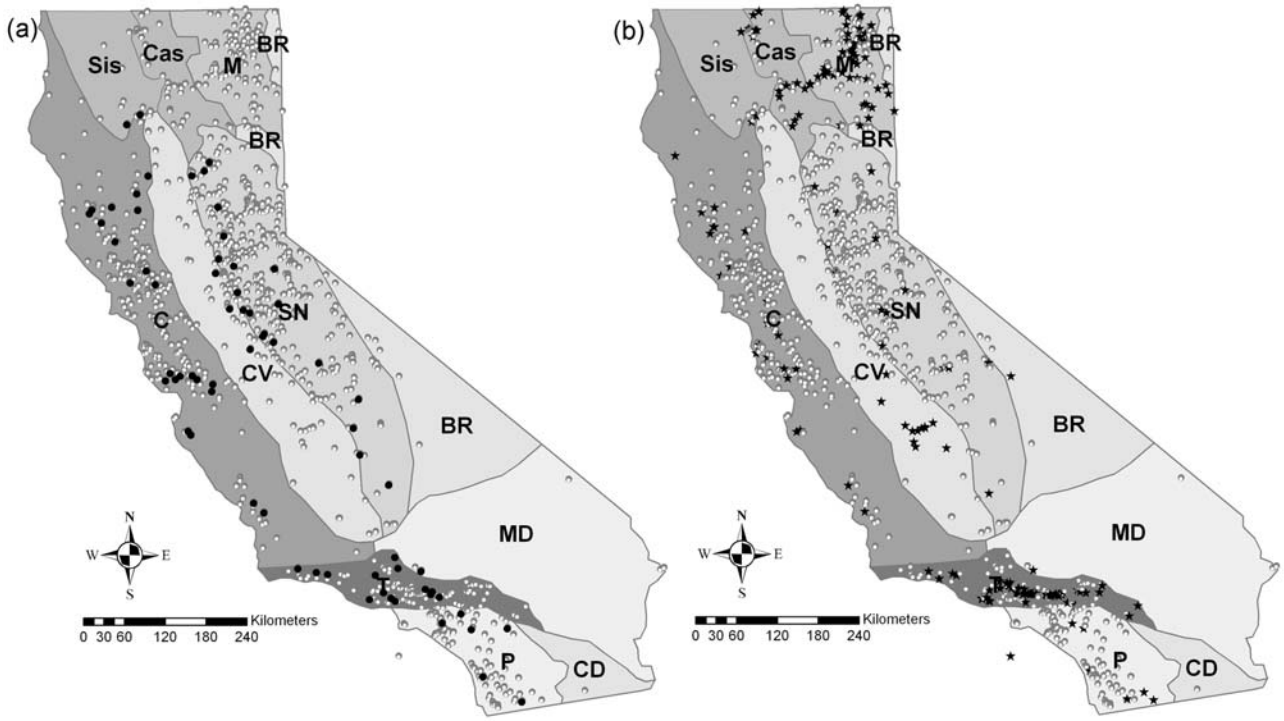

Figure 1. Reservoirs and geomorphic regions of California. (a) Reservoirs with measured sedimentation rates used in this study are shown with solid circles; others are shown with open circles. Geomorphic regions [from *CGS*, 2002] with higher median sediment yields are shown in darker shades; lower yield areas are shown in lighter shades. (b) Reservoir sedimentation predicted by the 3W model: open circles, >50% of capacity remaining; solid stars, <50% capacity due to sedimentation. The extent of the state extends from 32.50°N to 42.00°N and from 114.13°W to 124.40°W.

scale of the model is approaching the time scales at which appreciable changes occur in reservoir capacity because of reservoir sedimentation. For bed load sediment, trap efficiency is 100% (except in very small diversion or low-head navigation dams) but for suspended sediment trap efficiency varies roughly with the ratio of reservoir capacity to river inflow: large reservoirs typically approach 100% and small reservoirs are less efficient, with trap efficiency decreasing over time as sedimentation reduces capacity [*Brune*, 1953]. Previous reservoir sedimentation models have either not incorporated trap efficiency [*Dendy et al.*, 1973], thereby implicitly assuming 100% trap efficiency, or have used constant trap efficiency less than 100% [*Taylor*, 1983; *Renwick et al.*, 2005; *Vorosmarty et al.*, 2003].

[7] We developed a spreadsheet-based model that iteratively calculates sediment yield, accounting for trapping by upstream reservoirs and changing trap efficiency with time. As a case study, we applied the model to California, where a large number of the state's 1391 dams are in areas of high sediment yield. Dozens of small reservoirs in the state have already experienced significant capacity loss, and the population of reservoirs is aging: more than half are more than 50 years old, and at least 170 are more than a century old.

2. Methods

[8] Our approach consists of two parts: (1) a determination of sediment yield by geomorphic region from measured reservoir sedimentation rates and (2) the application of this sediment yield rate to unmeasured reservoirs in each region.

2.1. Determining Sediment Yield by Geomorphic Region

[9] To capture the pronounced regional variations in sediment yield, we used the geomorphic regions defined by the *California Geological Survey* (*CGS*) [2002] on the basis of similar climate, relief, geology, and vegetation (Table 1 and Figure 1a). To determine sediment yield by region, we compiled reservoir sedimentation data from *Dendy and Champion* [1973, 1978], *Federal Interagency Sedimentation Committee* (*FISC*) [1992], *Willis and Griggs* [2003], *Kondolf and Matthews* [1993], and unpublished data of B. Greimann, U.S. Bureau of Reclamation (personal communication, 2005). Remarkably few reservoirs in California have been subject to sedimentation surveys, with the number of surveys declining since the mid-20th century (Figure 2). We excluded three reservoirs (Matilija, San Clemente, and Englebright) that have been proposed for removal and have good sedimentation data to use to test our model.

[10] To locate the reservoirs, we initially assessed the Reservoir Sedimentation Information System (RESIS) [*Steffen*, 1996], which organized data from *Dendy and Champion* [1973, 1978] and *FISC* [1992] into a computerized database, later updated (as RESIS-II) with an automated location program that attempted to match coordinate data from each of the reservoirs, with approximately 75% success [*Stallard et al.*, 2001]. The RESIS-II database had inconsistencies in reported drainage areas and spelling of reservoir names [*Stallard et al.*, 2001], errors in reservoir location, and duplicate entries with conflicting data. We instead chose

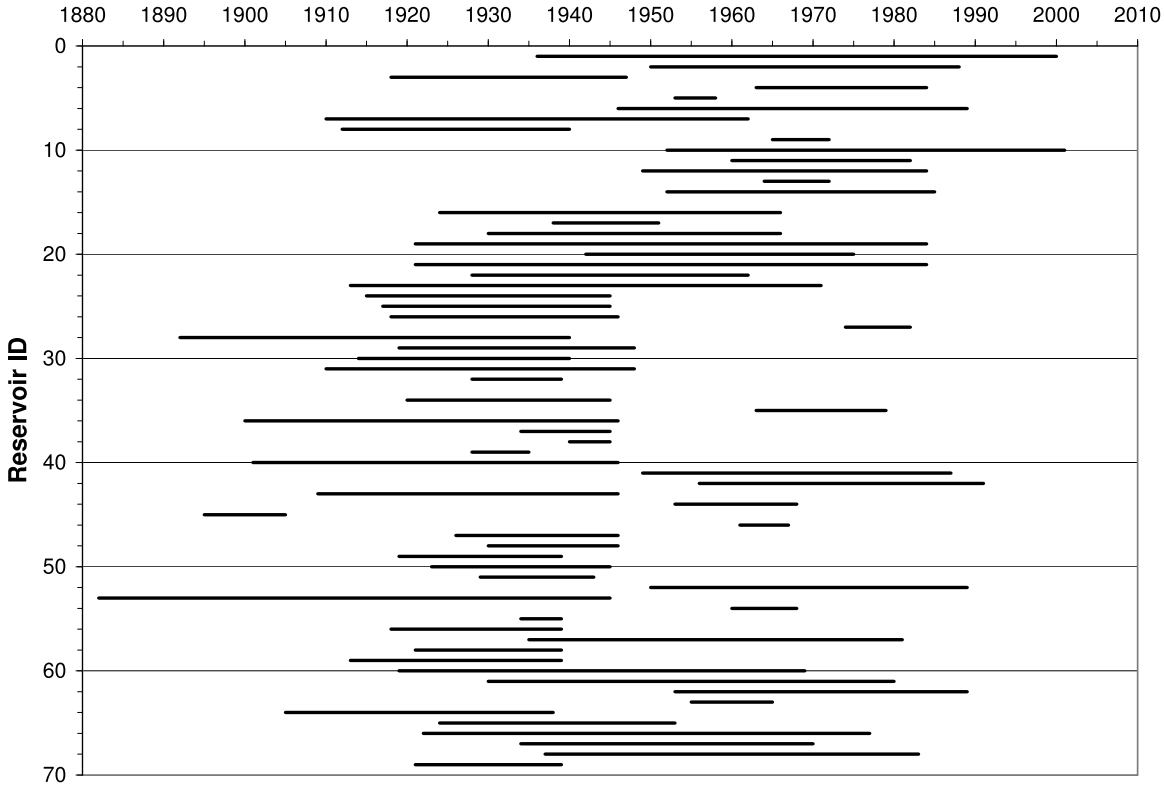

Figure 2. Period of reservoir sedimentation surveys in California. Note the sparseness of data for the latter part of the 20th century. Numbers on the *y* axis correspond to the reservoir identification numbers held on file at the University of California, Berkeley, Water Resources Center Archives.

to match the reservoir sedimentation records to the database of the CDSD, which regulates the 1391 dams in the state that exceed a threshold size of 7.7 m high and 18,500 m^3 storage capacity or 1.8 m high and 61,700 m^3 storage capacity. We initially identified 214 reservoirs with sedimentation records, from which we removed records for debris basins (89) and dry flood-control-only reservoirs (19) because they are dry most of the year and would have different trap efficiencies. We also excluded diversion dams (1) and reservoirs that lacked essential data, such as age or size (2). This left 103 reservoirs, for which we determined locations of 69 by matching the name, stream, size, and construction date to the CDSD database. The remaining 34 reservoirs were not used because we could not confidently determine their location.

[11] Using universal transverse Mercator (UTM) coordinates in the CDSD database, we plotted locations of all dams (measured and unmeasured) on a GIS map of California and compiled dendritic diagrams relating reservoirs to others upstream and downstream. Superimposing geomorphic regions of California [from *CGS*, 2002] onto the larger GIS map, we assigned each reservoir to one of the regions on the basis of its catchment's dominant geomorphic region. We deleted from our data set 189 dams in the CDSD database lacking drainage area, year completed, or UTM coordinates, leaving 1202 dams. Overlaid on a GIS layer of reservoirs and lakes, the CDSD dams typically plotted within tens of meters of where the hydrography data set displayed the appropriate lake or reservoir. There were significant differences between the CDSD and the National Inventory of Dams (NID) databases, despite the fact that the California entries in the NID were supposedly compiled from CDSD data. Hundreds of dams appeared in one but not the other database. The source of this discrepancy was not obvious.

2.2. Estimating Sediment Yield Rates by Geomorphic Region

[12] We used the following equation from *Brown* [1944] to calculate trap efficiency:

$$C_{a,t} = 1 - 1/\left[1 + (0.00021 \times K_{a,t-1}/W_a)\right], \qquad (1)$$

where $C_{a,t}$ is trap efficiency (expressed as a decimal percent) of reservoir a at time step t; $K_{a,t-1}$ is reservoir capacity (m^3) of reservoir a at time step $t - 1$, calculated by equation (5); and W_a is drainage area (km^2) of reservoir a. We used the Brown equation instead of the better known Brune curve [*Brune*, 1953] because the Brune relation requires water inflow data, which were available for only about 20% of the reservoirs.

[13] To calculate the sediment yield from a basin with a reservoir that has a sedimentation record, we constructed a coupled worksheet model to calculate the weighted watershed area (adjusted for upstream construction of reservoirs and trapping effects) for a reservoir of interest, while taking into account trap efficiency for all reservoirs in the basin and construction of upstream reservoirs. For the first worksheet, we created a set of formulas, three versions of which are shown here for each time step (a year in this case),

taking into account trap efficiency as well as upstream reservoirs:

$$A'_{a,t} = \{C_{a,t}[A_a - (A'_b + A'_c + \ldots)]\}, \quad (2)$$

$$A'_{b,t} = \{C_{b,t}[A_b - A']\}, \quad (3)$$

$$A'_{c,t} = \{C_{c,t}A_c\}. \quad (4)$$

This set of equations represents the weighted watershed area (A') for a single time step for a set of reservoirs along a single mainstream. In the equation, A' is the weighted watershed area (km^2) during the time step; C is trap efficiency (decimal), calculated from *Brown*'s [1944] equation (1); A is the drainage area (not sediment contributing area) (km^2); subscripts a, b, and c denote different reservoirs: in this case reservoir a is farthest downstream and c is upstream of b; and subscript t denotes current time step (yearly in our case). If reservoirs b and c were on separate streams and not in line with each other, the formula to use for reservoir b would be equation (4).

[14] For the first part of the study, to determine the sediment yield rates for reservoirs with measured sedimentation rates, we differentiated between two populations of reservoirs: measured and unmeasured. Since the infill rates and sediment yield are not known a priori for the unmeasured reservoirs, we used the initial trap efficiency as the single value for unmeasured reservoirs upstream of the measured reservoir of interest. For the measured reservoirs, since we had both initial and final trap efficiency, we linearly interpolated between them to determine trap efficiency for the intervening years. For the second part of the study, when we applied the sediment yield rates to calculate reservoir sedimentation in unmeasured reservoirs, we calculated trap efficiency from the *Brown* [1944] curve on a yearly basis as described in equation (1).

[15] We used the following equation to determine the volumetric sediment yield for a single measured reservoir:

$$Y = X_a / \mathrm{sum}_{(t\ \mathrm{start\ to}\ t\ \mathrm{finish})}(A'_a) \quad (5)$$

where Y is the sediment yield of the basin (m^3 km^{-2} per time step), X_a is the amount of sediment accumulated in reservoir a (m^3), $\mathrm{sum}_{(t\ \mathrm{start\ to}\ t\ \mathrm{finish})}$ is the sum over the years of the sedimentation survey from which X_a is derived, and A' is calculated from equations (2), (3), and (4) above. Here Y is a volumetric sediment yield, not sediment yield by weight, since it has not been corrected for the density of the sediment in the reservoirs.

2.3. Estimating Reservoir Sedimentation in Unmeasured Reservoirs

[16] For the second part of the study, estimating reservoir sedimentation in unmeasured reservoirs, we used the calculated volumetric sediment yield values for each geomorphic region from the first part of the study, applying the median sediment yield as well as the 25th and 75th quartiles (Table 1). For geomorphic regions lacking measured reservoirs (Modoc, Cascade, Basin and Range, and Mojave Desert), we assigned yields from nearby regions.

[17] We constructed a coupled three-worksheet (3W) model, similar to the model for estimating sediment yield, linking yearly time steps of varying trap efficiency, reservoir capacity, and reservoir sedimentation rate. For the first worksheet of the 3W model, we created a set of formulas, three of which are shown here, to calculate reservoir sedimentation in a given reservoir for each time step (a year in this case), taking into account trap efficiency as well as upstream reservoirs:

$$R_{a,t} = \{C_{a,t-1}[A_aY - (R_b + R_c + \ldots)]\}, \quad (6)$$

$$R_{b,t} = \{C_{b,t-1}[A_bY - (R_c)]\}, \quad (7)$$

$$R_{c,t} = \{C_{c,t-1}[A_cY]\}. \quad (8)$$

This set of equations represents the reservoir sedimentation R for a single time step for a set of reservoirs along a single mainstream. In the equation, R is the amount of sediment (m^3) trapped during the time step; C is trap efficiency (decimal), in this case calculated in the second worksheet from *Brown*'s [1944] equation (1); A is the reservoir's drainage area (not just the area below upstream dams) (km^2); Y is sediment yield (m^3 km^{-2} per time step); subscripts a, b, and c denote different reservoirs: in this case reservoir a is farthest downstream and c is upstream of b; and subscript t denotes current time step (yearly in our case), while subscript $t - 1$ represents the previous time step. If reservoirs b and c were on separate streams and not in line with each other, the formula to use for reservoir b would be equation (8). To determine the total amount of sediment deposited, R was summed for the period of interest.

[18] In the second worksheet, we calculated trap efficiency for each reservoir using the *Brown* [1944] curve, equation (1) in section 2.2, with the capacity term, K, calculated in the third worksheet. The third worksheet calculates the reservoir capacity to reflect the amount of sediment deposited in the reservoir during the previous time step:

$$K_t = K_{t-1} - R_t, \quad (9)$$

where K is reservoir capacity (m^3), t and $t - 1$ denote the current and previous time step, and R (m^3) is the calculated value from equations (6), (7), and (8) above.

[19] We assumed that reservoir sediments had a density of 960 kg m^{-3}, the median value from *Dendy and Champion* [1973, 1978] and *FISC* [1992], after comparing reported values of density among geomorphic regions and comparing the 3W model estimates of median yield with bedrock denudation studies using a rock density of 2650 kg m^{-3}. The linked 3W worksheets used to determine both steps of this study (estimating sediment yield from measured reservoirs and estimating reservoir sedimentation in unmeasured reservoirs) can be found in the auxiliary material for this paper.[1]

[1]Auxiliary materials are available at ftp://ftp.agu.org/apend/wr/2007wr006703.

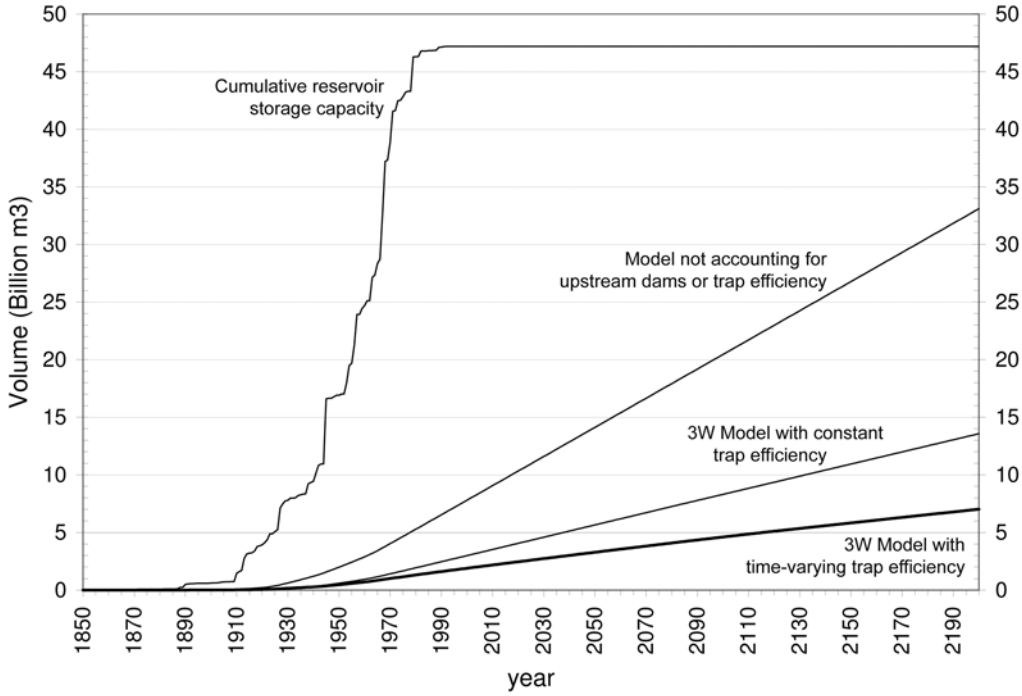

Figure 3. Cumulative reservoir capacity and estimates of reservoir sedimentation. Shown are long-term reservoir sedimentation accumulation predicted by the 3W model and predictions by simplified sedimentation models that do not account for multiple upstream dams or temporally variable trap efficiencies.

2.4. Uncertainty and Limitations of the Model

[20] Many variables influence sediment deposition within a reservoir, including flow, relative pool height, sediment supply from upstream, and sediment size and distribution, which vary regionally with geology, geomorphic delivery processes, land use history, fires, and climatic cycles. Our approach assumed that similar processes occur within geomorphic regions and that these processes are constant through time, which is a simplification necessary for computation. Thus, this model is appropriate for detecting regional trends and highlighting reservoirs potentially at risk of sedimentation but would not give accurate estimates of sedimentation within individual reservoirs.

[21] For our study, we assumed that the surface sediment samples from *Dendy and Champion* [1973, 1978] and *FISC* [1992] were representative of the sediment density found throughout each individual reservoir, but in reality sediment density can vary in a single reservoir with sample location and depth and how composite sediment density is calculated for the reservoir [e.g., *Snyder et al.*, 2006]. For the 3W model, we applied the median sediment density of 960 kg m^{-3} from *Dendy and Champion* [1973, 1978] and *FISC* [1992] (taken primarily from grab samples at the top layer of sediment) to all geomorphic regions in the study since there was little statistical evidence to support using a different value, but densities could vary among and within regions.

3. Results

[22] The median sediment yield in the state is 180 m^3 km^{-2} yr^{-1}, with the highest yield (520 m^3 km^{-2} yr^{-1}) in the Transverse Ranges and the lowest (89 m^3 km^{-2} yr^{-1}) in the Central Valley. Although compilations of sediment yield data typically show smaller yields from larger basins [*Walling*, 1983], no such trend was apparent in our small data set. Total annual sediment accumulated in California reservoirs through the year 2008 is estimated to be 2.1 billion m^3, representing a decrease of 4.5% of the state's total reservoir storage capacity of 47.2 billion m^3. Extrapolated to year 2200, the cumulative sedimentation is predicted to reach 7.1 billion m^3 (15% of statewide capacity) (Figure 3).

[23] The 3W model predicted that at present, over 120 reservoirs have capacities reduced to less than 25% of original capacity and almost 190 reservoirs have less than 50% of original capacity remaining (Figure 1b). These include not only small diversion dams and debris basins but also several moderate-sized reservoirs with well-known sedimentation problems, including San Clemente, Searsville, Jameson, Gibraltar, Matilija, and Century reservoirs.

[24] Comparing the 3W model results against sedimentation data for three well-studied reservoirs exposed some discrepancies, as should be expected when using median sediment yield. San Clemente Reservoir on the Carmel River decreased in reservoir capacity from 1.76 million m^3 in 1921 to 154,000 m^3 in 2000 [*Coastal Conservancy*, 2007], a difference of 1.62 million m^3. The 3W model predicted 1.65 million m^3 of sediment, close to the measured loss of capacity. Englebright Dam on the Yuba River was built in 1941 with an initial reservoir capacity of 86 million m^3. The 3W model estimated that Englebright

Reservoir should have 5.6 million m^3 of sediment on the basis of regional trends, but *Childs et al.* [2003] estimated the volume of sediment in the reservoir at 21.9 million m^3. This discrepancy may be explained by the fact that Englebright Dam was built as a debris basin to trap sediment from hydraulic mining upstream and much of the hydraulic mining sediment remains in tributaries continuing to move down into Englebright Reservoir [*James*, 2005]. As such, the catchment sediment yield of the Yuba River is likely much higher than elsewhere in the Sierra Nevada. Matilija Dam on Matilija Creek (Ventura River) was built in 1949 with a capacity of 8.66 million m^3, which decreased to 5.45 million m^3 in 1967 when the dam was lowered out of safety concerns arising from structural deterioration [*U.S. Bureau of Reclamation*, 2006]. Matilija Dam had approximately 615,000 m^3 (500 ac ft) of storage remaining in 1999, with the reservoir nearly full of 4.5 million m^3 of sediment trapped [*U.S. Bureau of Reclamation*, 2006]. The 3W model estimated 3.2 million m^3 of deposited sediment, or approximately 70% of the observed reservoir sedimentation.

4. Discussion

[25] When creating reservoir sedimentation models, it is important to take into account trapping by upstream reservoirs and incorporating variable trap efficiency in areas with numerous dams in the same watershed. Without taking into account upstream reservoirs, the total drainage area impounded by dams in California would appear to be 906,000 km^2 (over 2 times the area of the state). However, after correcting for reservoirs in upstream watersheds using the 3W model, the impounded drainage area drops to 186,000 km^2 (46% of the state). We compared the results of the 3W model against two simple reservoir sedimentation models, both of which did not account for trapping by upstream reservoirs and assumed either perfect trap efficiency or set trap efficiency to the static initial value. The two simpler models overpredicted reservoir sedimentation rates compared to the 3W model by 416% and 161%, respectively, up to the year 2008 (Figure 3). Without accounting for upstream dams or trap efficiency, total sedimentation in the year 2200 would be projected to be 33.1 billion m^3, or two thirds of the state's reservoir capacity, much higher than the volume projected by the 3W model (7.1 billion m^3).

[26] The 3W model as well as future reservoir sedimentation models could be improved by a statistical analysis of the *Brown* [1944] and *Brune* [1953] sediment trapping data since these curves are still recommended in standard reservoir engineering textbooks [*Vanoni*, 2006]. The Brown and Brune equations were derived by fitting the data by eye and, as such, no meaningful statistical information can be gleaned from them. We performed a brief statistical analysis during the course of this current study and found that compared to the original data, both Brown and Brune's equations produce residuals that have a trend and are not homoschedastic. An improvement of generalized trap efficiency equations would be a valuable contribution to the field. An expansion or evaluation of the quality of their data set also would be warranted. In California, a welcome addition to the current reservoir sedimentation database would be additional sedimentation surveys, particularly in geomorphic regions that have not been well studied such as the Siskiyou, Mojave Desert, and Modoc Plateau regions.

5. Conclusion

[27] Sediment accumulated in reservoirs creates costly problems for dam operation and ultimate decommissioning. Many of the dams on the landscape can be viewed as future maintenance problems, which will become more urgent as they fill with sediment and lose capacity. In addition, the carbon stored within reservoir sediments has been shown to be a significant sink of terrestrial carbon [*Stallard*, 1998]. Given that most reservoirs have not been surveyed for sedimentation, managers could benefit from a tool with which to identify at a regional level those reservoirs at higher risk of filling in the near future so that problems can be anticipated and countermeasures can be explored and implemented such as installation of upstream sediment traps, sediment pass-through, flushing, or mechanical removal.

[28] The 3W model presented here is the first such model to estimate reservoir sedimentation at a large number of reservoirs while taking into account the effect of reduced sediment input due to trapping by upstream dams, important in rivers with multiple dams. The model serves to identify reservoirs vulnerable to sedimentation problems by virtue of their size and regional sediment yields and which may be likely candidates for either removal or sediment management. Our analysis indicates that sedimentation rates are small relative to overall storage capacity statewide, but some individual reservoirs have been affected because of their small capacities and high sediment yields of their catchments. The model correctly identified several small reservoirs that have been recognized as having filled (or nearly so) with sediment and identified several others that are likely to experience such problems in the near future, which have important implications given the high costs of dredging or decommissioning such structures. While a state-level study was completed here, the 3W model could be applied equally well to individual watersheds with varying sediment yields. By anticipating which reservoirs are most vulnerable to capacity loss from sedimentation, the 3W model approach is a tool with which managers can identify reservoirs at risk and can implement countermeasures where feasible and warranted to avoid the costs of sediment-filled reservoirs.

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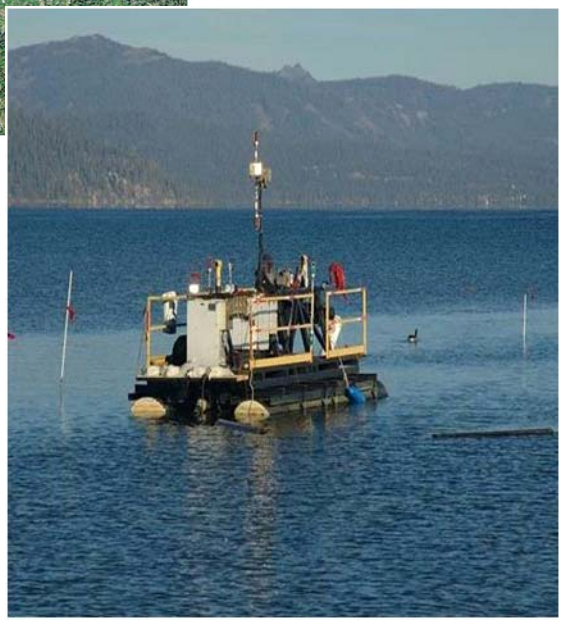
G. M. Kondolf and J. T. Minear, Department of Landscape Architecture and Environmental Planning, University of California, 202 Wurster Hall, Berkeley, CA 94720, USA. (tminear@berkeley.edu)

NEVADA IRRIGATION DISTRICT

Combie Reservoir Sediment and Mercury Removal— A Water Supply Maintenance Project

PROJECT DESCRIPTION



July 2009

COMBIE RESERVOIR SEDIMENT AND MERCURY REMOVAL

A WATER SUPPLY MAINTENANCE PROJECT – Project Description

PROJECT OVERVIEW

Most surface waters in the Sierra Nevada have been significantly and adversely impacted by historic gold mining activities, particularly the streams, rivers, and reservoirs in the Cosumnes, American, Bear and Yuba watersheds. As a result, water bodies in these regions contain elevated concentrations of mercury that are remnants of gold processing practices used over a century ago. Mercury is a water quality constituent of national concern; it is listed in California Toxics Rule by the Environmental Protection Agency. Consumption of fish from water bodies contaminated with mercury can lead to developmental delays in fetuses, infants and children.

The Nevada Irrigation District (NID) owns and operates two reservoirs on the Bear River which are 303d listed[1] for mercury: Rollins Reservoir and Combie Reservoir. For more than 30 years, NID has contracted with private aggregate mining companies to remove sediments that naturally migrate toward the reservoirs. At Combie Reservoir, dredging was used to remove sediments for more than 15 years. Dredging operations in Combie Reservoir were halted in 2003 as a result of high mercury levels found in dredge effluents, affecting NID efforts to maintain reservoir storage capacity, and potentially affecting NID's ability to supply drinking water to its customers. With the majority of California's water supply coming from rivers and reservoirs of the Sierra Nevada Mountains, the impact of such mercury contamination, may threaten water quality for many Californians, and the prevention of dredging operations threatens water supply storage over the long-term.

The Combie Reservoir Sediment and Mercury Removal Project (hereafter referred to as the Project) is a water supply maintenance project that removes sediment from Combie Reservoir while introducing an innovative recovery process to reduce elemental mercury concentrations in the Bear River watershed. It will utilize the design, construction, and operation of an innovative mercury extraction process paired with ongoing sediment removal operations to maintain reservoir storage capacity. This project will utilize a proven patented technology, the Knelson Concentrator, in a new application in order to remove elemental mercury from dredged sediments, while monitoring and studying the effects of the operation on water quality and biota. This initial project is estimated to take between three to five 5 years to complete. On-going maintenance dredging to maintain reservoir capacity is estimated to reoccur on 10 year intervals. Project benefits include; water supply reliability, water quality protection and improvement, ecosystem restoration and enhanced recreation. If this project demonstrates that mercury can be

[1] The 303(d) List of Waters reports prepared by the State Water Resources Control Board identifies streams and lakes as impaired for one or more pollutants because they do not meet one or more water quality standards. Impaired waters are identified through assessment and monitoring programs conducted by local, state and federal agencies.

removed from river sediments the process can be applied at other reservoirs throughout the Sierra Nevada. In time, there could be a beneficial effect toward remediation and reduction of mercury contamination. Such remediation efforts would also be beneficial to the California Bay-Delta.

PROJECT LOCATION

The Project location is in the northeastern section of Combie Reservoir at the Bear River inflow. Combie Reservoir straddles the Nevada-Placer County line east of the Lake of the Pines community in Nevada County and west of the Meadow Vista community in Placer County (Figure 1).

PROJECT PURPOSE

The purpose of the Project is two-fold. First, it will remove sediments accumulated in Combie Reservoir. Sediment removal will restore and maintain water storage capacity and water supply availability for NID customers in portions of Nevada County and Placer County. Secondly, the Project introduces an innovative recovery process to remove elemental mercury from settled or suspended sediments during dredging operations. The Project sponsor is NID, with the United States Geological Survey (USGS) serving as one of the primary project partners responsible for monitoring water quality and ecological parameters of interest.

PROJECT OBJECTIVES

Objective 1: ***To remove sediment in order to restore and maintain reservoir storage capacity on an as-needed basis.*** Combie Reservoir was built over 70 years ago to provide quality drinking water and irrigation supplies to the NID service area in portions of Placer and Nevada counties. NID has maintained the reservoir capacity for more than 20 years by dredging sediments that threatened to fill the reservoir from the Bear River, upstream of Combie Reservoir. Even though dredging has occurred for many years, approximately 200,000 tons of sediment has migrated past the dredging operations, entering the reservoir. The transported sediment (from the river) settled at the northeastern end of the reservoir as water velocities taper off and particulate matter settles out (of suspension) at the upper reaches of the reservoir (Figure 2).

Objective 2: ***To remove mercury associated with sediments deposited in Combie Reservoir.*** In 2003, dredging operations were halted due to elevated concentrations of mercury found in the dredge effluent. Tests confirmed that the unfiltered water sampled in accordance with State regulations exceeded 50 nanograms per liter (ng/L), which is the relevant water quality maximum acceptable contaminant level (criterion), based on the United States Environmental Protection Agency's California Toxics Rule. Since that time, ongoing sedimentation occurs at the northeastern end of Combie Reservoir coupled with elevated mercury concentrations, increasing threats to water supply capabilities and quality, as well as recreational opportunities.

Mercury is a chemical that was widely used to extract gold as part of hydraulic gold mining during the mid-to late 1800s. Mercury exists in multiple forms and high levels

are found in water bodies throughout the Sierra Nevada region. The two primary forms of mercury pertinent to this project are: elemental mercury and methylmercury.

- Elemental mercury, or quicksilver, is a form of mercury that was applied during hydraulic mining to amalgamate, or bind to, gold, making it easier to recover from the slurry.

- Methlymercury is a biologically active form of mercury found in living organisms, such as fish. Mercury is methylated[2] by bacteria in a low oxygen environment, such as at the bottom of a reservoir. Methylmercury moves up the food chain from bacteria to plankton, to macroinveratbrates, to herbivorous fish, to piscivorous (fish eating) fish, and biomagnifies[3] with each step to dangerously high levels in fish, a level that is poisonous to fish eating birds, and humans.

Common remediation techniques for methylmercury removal follow one of two approaches: 1) the reduction of elemental mercury in order to reduce the source for methylation, or 2) the interruption of the methylation process so as to limit the conversion of elemental mercury to methylmercury. The proposed Project will remove elemental mercury that is bound to the dredged sediment thereby removing the source material for methylation. Dredging may also make the northeastern end of the reservoir that is currently shallow and warm and therefore likely conducive to methelyation less conducive, because dredging will create deeper and cooler conditions. In this way the project is expected to reduce not only the source material for methylmercury (elemental mercury in the sediment) but will also change the conditions in which the methylation process currently takes place.

In order to measure the effects of removing elemental mercury and reducing methylation conditions, environmental monitoring will take place before, during, and after the dredging and mercury removal operations. This information will help fill critical data gaps in the currently limited understanding of mercury behavior in a reservoir environment, specifically, downstream transport and bioaccumulation pathways so that watershed wide benefits to mercury removal can be realized. (See project Monitoring and Adaptive Management Section.)

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[2] Methylation is a term used in the chemical sciences to denote the attachment or substitution of a methyl group on various substrates. This term is commonly used in chemistry, biochemistry, soil science and the biological sciences. Methylmercury is composed of a methyl group (CH_3-) bonded to a mercury atom; its chemical formula is CH_3Hg^+ (sometimes written as $MeHg^+$).

[3] Biomagnification, is the increase in concentration of a substance that occurs in a food chain as a consequence of food chain energetics; put simply, big fish eat lots of little fish.

Objective 3: ***To improve reservoir management and maintenance by demonstrating an efficient method of mercury removal paired with dredging operations.*** NID and its project partners propose to introduce a mercury removal component to an existing dredging operation in order to meet USEPA and State water quality standards for mercury found in water bodies. An integral component of this project is to study water quality during the dredging and mercury removal operations as a performance measure so that NID operations can be adjusted to maximize mercury removal efficiency. (See project Monitoring and Adaptive Management Section.) If this project proves successful NID will be able to pursue a proactive mercury removal program as part of a consistent and ongoing maintenance dredging operations at Combie Reservoir. The lessons learned from this project will be useful and possibly transferrable to similarly impacted reservoirs in the Sierra Nevada region.

Objective 4: ***To support local industry by marketing gravel, sand, silt, and clay material removed during dredging.*** Vast quantities of gravels naturally flowed unrestricted into streams which drain into the Bear River. Even with the court-ordered cessation of hydraulic mining in 1884, thousands of tons of hydraulic mining debris continue to be transported downstream during storm events into Rollins Reservoir and Combie Reservoir. This material is a marketable resource for the construction industry (sand and gravel), the ceramic industry (silts and clays), and landscape industry (silts and clays).

In the past, marketable materials harvested from the Combie Reservoir have been sold as road base, construction and landscape fill material from a nearby plant within the Bear River canyon owned by Chevreaux Aggregates, Inc. (Chevreaux's Meadow Vista plant). Some materials have been processed for concrete and asphalt. Recently, a construction tile manufacturer sampled and tested some of the soils for its clay tile product, with satisfactory results.

The by-products from this Project – gravel, sand, silt, and clay– will be used as raw material by local industries.

Objective 5: ***To improve recreational opportunities and boat access within Combie Reservoir.*** Currently, the recreation and boat access at the northeastern end of Combie Reservoir is limited and/or non-existent, at low water levels, due to excessive build-up of sediments that block access to a large portion of the reservoir shoreline, including many private docks. At times, sand-bars prevent boaters from traversing the upper reaches of the reservoir; this also prevents access to portions of Combie Reservoir for beach use, fishing, and other recreational activities. This project will remove sediment barriers that limit such recreational access.

PROJECT BACKGROUND

NID constructed Combie Reservoir in 1926. At full capacity it has 5,555 acre-feet of operational storage. Combie Reservoir is a source of drinking and irrigation water for numerous consumers in Placer and Nevada counties; it also provides recreational opportunities to residents of both counties. Combie Reservoir is also the primary source of water for a 12 million gallon per day (MGD) water treatment plant. Lake water is pumped to an open canal which flows to the Lake of the Pines Water Treatment Plant serving over 2000 homes, businesses and a high school in southwestern Nevada County.

Since the mid 1960s, aggregates have been removed from the upper reaches of Combie Reservoir, within a man made pond (approximately 750 feet wide by 4,000 feet in length). The pond was separated from the Bear River and the rest of Combie Reservoir by a series of dikes and berms. In the mid-1990's, or earlier, aggregates were removed from the pond using suction dredge methods; this was done to eliminate the need to lower water levels and maintain a relatively high water level for recreation purposes and power generation at the Combie North Power House (a small hydro-electric generator located at Combie Dam). In 2003 dredging operations in Combie Reservoir were halted, ultimately leading to the inception of this Project. Elevated total mercury concentrations were detected in the dredge effluent during routine sampling as part of California Regional Water Quality Control Board (CRWQCB) permit requirements. It was determined that mercury was mobilized with sand and finer particulates during dredging activities.

Previously, the USEPA gave final approval to California's 2002 Section 303(d) List of Water Quality Limited Segments. Under Section 303(d) of the 1972 Clean Water Act, states, territories and authorized tribes are required to develop a list of water quality limited segments that includes water bodies that do not meet water quality standards even after minimum required levels of pollution control technology have been installed. This law also required these jurisdictions to establish priority rankings for listed waters, as well as develop action plans known as Total Maximum Daily Loads (TMDL) in order to improve water quality. Combie Reservoir was included on the 2002 list due to the presence of mercury associated with historical gold mining practices.

It has recently been determined by the California Attorney General and the Executive Director of the California State Mining and Geology Board that dredging within a water supply reservoir does not constitute a mining activity. A 1995 California Attorney General Opinion (78 Ops. Cal. Atty. Gen. 343) established that maintaining a flood-control facility is exempt from the State Surface Mining and Reclamation Act (SMARA). In a letter dated July 30, 2008, Stephen M. Testa, Executive Officer of the California State Mining and Geology Board, confirmed that the State Attorney General Opinion applies to all maintenance activities of a water retention and flood-control facility, provided that the original contours of the water facility are not altered. As such, maintenance dredging of Combie Reservoir to be conducted as part of this Project is not subject to SMARA.

An Initial Study has been prepared for this project to meet the requirements of the California Environmental Quality Act (CEQA). The primary purpose of the Initial Study is to describe

existing environmental resources, potential environmental impacts and environmental mitigation measures that may be required for this Project. The Regional Water Quality Control Board, California Department of Fish and Game and US Army Corps of Engineers require environmental documentation in order to issue applicable permits. As such, the Initial Study is focused on providing the environmental documentation required for permitting under CEQA.

All permits for the Project will be requested by and will be issued to NID. Therefore, NID, as the public agency that intends to carry out the Project, will serve as the lead agency pursuant to CEQA. Agencies that require environmental documentation in order to issue their respective authorizations are as follows:

1. Sacramento Regional Water Quality Control Board -Waste Discharge Permit and Section 401 Certification or Waiver
2. California Department of Fish and Game -Section 1603 Stream Alteration Agreement and dredge operations
3. Placer County -Hazardous Materials Business Plan

In addition, the U.S Army Corp of Engineers has jurisdiction, but may not require a Section 404 Permit for Discharge of Dredged or Fill Material into Waters of the US. A jurisdictional determination has been requested of the U.S Army Corp of Engineers.

PROJECT FEATURES

The initial Project will occur over a three- to five- year period, during which an estimated 150,000 to 200,000 tons of material will be removed from Combie Reservoir. Periodic maintenance dredging will occur on an as needed basis on approximate 10 year intervals. Sediments will be removed using an electric dredge and mechanical centrifuge dewatering system (as manufactured by Eveready Marine Service, or equivalent). Mercury will be removed from the dredged sediments using a Knelson Concentrator (Concentrator), a centrifugal technology that is proven to effectively remove mercury and other heavy metals from sediment. The Project includes four major components, as described below and illustrated in Figures 3 and 4:

1) ***Dredging of Combie Reservoir.*** The dredge site is located in the northeastern end of the reservoir. The existing site features at Combie Reservoir provide an ideal location for implementation and demonstration of the mercury removal technology. Existing Project features include:

   a. The former dredge pond (approximately 750’ by 4,000’) where dredging occurred before operations were halted;
   b. The levee road and berms constructed to isolate the pond from the Bear River and the rest of Combie Reservoir; and
   c. Channelized flow of the Bear River around the east side of the pond where the river flows into the northeastern end of Combie Reservoir.

The Project is expected to operate for nine months per year for three- to five- years to remove the estimated 150,000 to 200,000 tons of material from the reservoir. The dredge will have an electrically operated boom with an estimated maximum reach of 20-30 feet in length, and will be capable of pulling up sediment from the bottom of Combie Reservoir at an approximate rate of 250 gallons/minute.

The dredged material will be a slurry of gravel and sand that will be pumped from the dredge through a pipe, either floating on the water or lying on the bottom of the reservoir, and laid along the levee road to the on-site Mobile Separation and Dewatering System (MSDS), located at the northeast end of the pond – refer to Figures 3, 4 and 5. The following equipment will be utilized on-site and will comprise new features of the Project:

- Eveready remote controlled all electric floating dredge with positive displacement pump on pontoons, or equivalent
- Slurry pipeline (8” to 12” diameter) with electric and control cables
- Receiving tanks and primary screens (2 tanks, about 10’ dia. x 10’ tall)
- Trash bin or dump truck (for large debris and rock)
- Electric pumps (6) and flexible distribution piping
- Secondary separation and agitated conditioning tanks (4 tanks, about 10’dia. x 10’ tall)
- Polymer storage and mixing tanks with control booth (2 containers, about 8’ x 30’x 10’ tall)
- Centrifuge with conveyor belt system (for material delivery to the Concentrator and waiting trucks)
- Two to four dump or transport trucks
- Earth containment berm
- Portable diesel generator "whisper quiet" model Duthie Power Services with an output capacity of 220KVA 480 Volt 300 amp @60 Hz., or equivalent[4]
- 100 gallon above ground diesel fuel storage tank

The above list of equipment describes the Eveready (electric) Mobile Dredge and Dewatering System, a complete set of portable equipment used to dredge, classify, and dewater aggregate material from the reservoir. This equipment will feed material directly to the Concentrator. The dewatered material will produce a liquid effluent, or centrate, resulting in a clean water return to Combie Reservoir and a solid material by-product.

The pumping activity through the pipeline will occur constantly during dredge and mercury removal activities. The dredge pump, cutter head, as well as the dewatering system motors operate through Variable Frequency Drive (VFD) controls. The flow of material will vary based on the pulp density of the slurry material and the capacity of the Concentrator. The flow will be controlled by the on-board operator using the VFD controls.

[4] In the future, NID may connect to the 3-phase, 480V power source if it extended to the Chevreaux plant

The size of the system dredge module is 10’ x 30’, and weighs approximately 15,000 lbs. The cutter head boom can be lowered to a measured depth (for dredging sediments and avoid excavating below the original contours of the reservoir). Located just behind the cutter head is a hidrostal sludge pump; this is a positive displacement pump (800- 1,000 gallons per minute) that will not clog. This combination of cutter head and hidrostal pump reduces the risk of suspended sediment or contaminant dispersal into the reservoir due to the powerful suction at the entry to the cutter head. In addition, the positioning of the hidrostal pump below the water surface provides a virtually silent operation.

The dredged materials received through the cutter head are then pumped and conveyed through a floating pipeline to a receptor or shore-based treatment process which can be located up to 4,000’ away from the dredge (even further by the use of a booster pump).

The dredged material (slurry) then passes over a vibrating screen assembly to remove large rock and debris. The screened slurry is then pumped to another vibrating screen, separating silts and clay size material from sand and rock size aggregates, if needed, where the segregated material falls into agitated conditioning tanks. The conditioned slurry is then pumped to one of the high "G" centrifuge where primary dewatering occurs and produces a thickened sludge that is conveyed to the Concentrator, for the removal of mercury. Effluent from the Concentrator is later pumped to the second high “G”[5] centrifuge, where optimal separation produces a dry cake and centrate. If required, the separation process is enhanced by injecting flocculating polymers into the conditioned slurry feed prior to entering the centrifuges. The dry cake is discharged to trucks via conveyors and the centrate is returned to the first containment chamber (of the pond).

The dry cake material will then be loaded onto large dump trucks and transported to the Chevreaux Meadow Vista processing plant, which is located on the Bear River approximately one-half mile north of the Project site – refer to Figure 3.

Water and suspended solids that leak or spill from the dewatering equipment are contained by an earthen berm and returned to the primary separating tanks (manually excavated or pumped). A series of containment chambers in the pond will provide additional spill protection – see below.

The pond was the original dredging site at the Project location before operations ceased in 2003. As described in a previous section, the pond is separated from the river by a series of berms and a levee road. As part of this Project, the pond will be divided into a series of containment chambers separated by floating log booms with turbidity curtains; the curtains will extend from the surface of the water to the bottom of the pond. Centrate will be discharged to the first containment chamber to filter the water and allow turbidity to settle, if any, and provides source water for the Concentrator. Secondary containment chambers, and more if needed, will be used to further remove any material in suspension and provide discrete areas for monitoring water quality. Only clean water will be returned to Combie Reservoir (at the south end of the pond) once the slurry/centrate has

[5] ‘G’ denotes gravitational forces at ~9.8 m/sec^2.

been processed through the Knelson Concentrator, dewatering centrifuges and turbidity curtains.

The dredge will maneuver in small isolated parts of the "Area to be Dredged" using a series of cables, pulleys and anchors– refer to Figure 3. These isolated areas will be cordoned off to boats and swimmers using safety buoys. All cables, pulleys and anchors will be positioned to avoid disturbance of riparian areas along the reservoir shore, Bear River and containment pond. There will be three anchor points for the dredge cable/pulley maneuvering system for the electric dredge. Two points will be on shore with a cable running between them and the other will be submerged. A pulley connected to a cable on the two shore mounted anchors would provide guidance for the dredge path of travel. The shore mounted anchor point(s) will be positioned on shore such that there would be minimal disturbance to riparian vegetation. When the dredge is to be re-positioned, it would be able to move without relocating the shore mounted anchors as it could merely realign its path along the pulley and cable system between the two shore-mounted anchors. In addition, the shoreline location where the slurry pipe will cross the riparian area between the reservoir and the upland levee road will be selected such that disturbance to riparian vegetation is minimized by the placement of the pipe. Given the site conditions at the proposed location, the above-ground placement of this pipe over rock or earthen portions of the levee should be possible without harming any vegetation. The dredge will be shut down periodically in order to set up and relocate the dredge to various staging areas, and to allow inspection, maintenance and water quality monitoring.

A portable diesel generator ("Whisper quiet" Duthie Power Services, 220KVA Generator 480 Volt 300 amp @ 60 Hz, or equivalent), licensed by the Air Resources Board will be brought in to run the dredge and dewatering equipment (a separate smaller generator will provide power to the concentrator and mobile office). The generator will be placed on land above the ordinary high water mark (1,602' MSL) and power cables will be connected to the mobile dredge and shore mounted dewatering system.

Small quantities of diesel fuel (less than 100 gallons) will be stored and dispensed on site, if needed for the portable generator. Storage and handling of diesel fuel will be done in accordance with Placer County Hazardous Material Business Plan requirements.

2) ***Removal of Mercury from Dredged Sediments.*** The concentrator used for this Project will have a 12-inch bowl that spins at 60-80*g* (gravitational force (~9.8 m/sec^2)) to separate mercury from the thickened sludge (from the primary centrifuge). The concentrator is a unique centrifuge that is capable of removing 85 to 95 percent of mercury from the sediments. The concentrator will operate during dredge operations and up to two hours each day after dredge operations are ended in order to process all material remaining in the tanks and centrifuges. At times, the concentrator and centrifuges may operate without the use of the dredge to re-process the dry cake, or centrate, if needed to achieve maximum efficiency. The following equipment comprises the new Project features for this component:

- Knelson Concentrator (model KC-CD12MR[MS]) or equivalent

- Mobile office and lab (approximately 8’ by 65’) with separate generator (less than 50 horsepower)

During operations of the dewatering system, a thickened sludge will be transported from the primary centrifuge to the Concentrator by a conveyor belt system. Mercury and other heavy metals will be extracted through the Concentrator as the thickened sludge mixes with water and travels through the machine. The tail water (treated effluent) from the Concentrator will be pumped into the second centrifuge for secondary dewatering.

After final dewatering, the centrate will be discharged to the first containment area, then flow through a series of containment chambers, as needed to further remove suspended particles from the centrate, before it flows into Combie Reservoir – see Water Filtration below. The centrate will be monitored to insure project effectiveness. The extracted mercury and other heavy metals (concentrate) will be collected and transported to a legal offsite disposal area as required by the Placer County Hazardous Materials Business Plan. Any recovered gold or amalgam will be transported to an accredited off-site laboratory for assay, analysis, and separation; the disposal of any separated mercury will be in accordance with county and state regulations appropriate to the location of the laboratory used. All recovered mercury will be retired and will not be resold on the open market.

3) ***Water Filtration.*** Water filtration will take place using a series of containment chambers separated by floating turbidity curtains in the pond. The containment chambers will be designed to allow water to pass through the turbidity curtain while keeping back (retaining and/or serving as a barrier to) suspended solids. Two or more curtains will be used to create three or more areas of containment in the pond. These containment areas will be monitored for effectiveness.

Water will migrate by hydraulic gradient, which will flow in one direction (south) towards the reservoir through the turbidity curtains. Clean water will be returned to Combie Reservoir at the south end of the pond through an over-control structure (such as an overflow pipe with an inverted 90-degree elbow and screened, designed to draw water from mid-depth). The over-control structure will be a monitoring site to insure water quality protection. In this way, the water will be filtered, leaving floating material and suspended material to settle out and/or remain in the pond, returning only clean water to the reservoir.

In addition to the floating turbidity curtains in the pond, a series of shallow groundwater monitoring wells will be installed along the berm separating the pond and the Bear River. This will provide added assurance that water does not filter back into the river without proper treatment and clarification, or filtered through the berm.

New Project features that comprise the water filtration component include:

- Log booms with turbidity curtains
- Overflow pipe
- Shallow groundwater monitoring wells

4) ***Transport of Marketable By-Products to Off-Site Locations.*** The Project site allows for maximum use of the aggregates that will be removed from Combie Reservoir due to its vicinity to the Chevreaux Aggregates, Inc. (Chevreaux) Meadow Vista processing plant. The plant is located only one half of a mile upstream along the Bear River. Sand, silt, clay, and gravel (dry cake) will be transported by truck from the MSDS to the Chevreaux plant for processing. If for any reason, Chevreaux does not take possession of the dry cake, it will be transported (by truck) to another aggregate plant within Placer County or Nevada County. Once processed by Chevreaux or another plant, the marketable materials will be stored on site and trucked to construction sites or other industries in the region. Non-marketable materials will be disposed of in accordance with existing state and federal regulatory permits issued to the plant operator.

5) ***Flood Plain Management***. The entire operation is located within the Bear River floodplain. The following measures will be incorporated as project features to minimize the effects associated with high water flows:
   a. All shore based and equipment processes will be located and operated above the ordinary high water mark of 1,602 feet (msl) (See Figure 4)
   b. All operations will be suspended from the period of December 1 through April 1 each year.
   c. All project features including the mobile office and concentrator, mobile equipment, on-site diesel fuel storage, portable restrooms and dredge will be removed and stored off site, above the flood plain, prior to December 1 of each year. Said features will not be returned on-site until after April 1 or after winter storms have ended, whichever is later.
   d. The MSDS and Concentrator staging areas will be restored to pre-project conditions following completion of the Project.

6) ***Days and Hours of Operation.***
   a. Dredging, dewatering and material transport
      - Monday through Saturday 7:00 a.m. to 7:00 p.m.
      - No work on federal holidays
   b. Mercury processing
      - No limitation

PROJECT MONITORING AND ADAPTIVE MANAGEMENT

The innovative nature of this project requires that monitoring be used to measure the impacts of the project on three separate accounts; 1) To inform environmental permitting specific to the Wastewater Discharge Permit (Anti-Degradation Study) 2) To measure the environmental benefits of ecosystem restoration (Environmental Monitoring) 3) To inform the dredging and mercury removal operation so that adaptive management can be used to optimize mercury removal efficiency (Operational Monitoring).

1) Anti-Degradation Study: A one year long Anti-Degradation study began in February 2009, and includes monthly and storm water sampling above and below Combie Reservoir, at the pond-reservoir interface and at the area to be dredged in the northeastern end of the reservoir. These data will be used to characterize pre project water quality

conditions. The water quality parameters being measured include general mineral and organic constituents, general physical parameters such as turbidity, and total mercury and methylmercury. This study will also include laboratory testing of the Knelson concentrator for total, methyl and reactive mercury. These data are important to be able to describe background water quality conditions and predict the water quality changes that result from the project. These data will be used to write an Anti-degradation study report which will be reviewed by the Central Valley Regional Water Quality Control Board as part of the Waste Discharge Permit.

2) Environmental Monitoring: The USGS California Water Science Center in Sacramento will design and conduct the environmental sampling and will analyze the results. The USGS Study Sampling Plan includes samples of water, sediment, and biota (fish and invertebrates) in Combie Reservoir before, during, and after project operations to determine whether concentrations of mercury and methylmercury in Combie Reservoir are reduced as a result of dredging and mercury removal. The goal of the environmental sampling is to determine the effectiveness of removing elemental mercury as a strategy to reduce methylmercury in the aquatic food chain and to characterize the form of mercury that is transported both into and out of Combie Reservoir. This environmental monitoring should lead to a better understanding of mercury transport, methylation, and bioaccumulation in the Bear River system.

3) Operational Monitoring: Water that enters and exits the dredging and mercury removal equipment will be monitored in order to maximize efficiency. The Central Valley Regional Water Quality Control Board will require water quality monitoring in order to insure that all water quality standards are achieved during operations. The sampling locations and frequency are to be determined by the Central Valley Regional Water Quality Control Board and will be described in detail in the Waste Discharge Permit. The sampling locations likely to be required by the Board include the water entering the MSDS from the dredge, effluent from the centrifuge, or centrate that discharges into the first containment chamber of the pond, and at the pond-reservoir interface. Shallow groundwater wells along the levee road that separates the Bear River from the Pond will also be monitored to determine if groundwater flow occurs between the River and the Pond. These predicted operational monitoring locations are depicted in Figure 6 Process Flow Diagram by the letter ‘M’. The precise water quality parameters and monitoring frequency will be determined by the Central Valley Regional Water Quality Control Board. The goal of the operational monitoring will be to update the dredging and mercury removal equipment use parameters through adaptive management.

A Technical Advisory Committee (TAC) will be formed to evaluate monitoring data that is collected during the life of the project. The TAC will be made up of scientists, key stakeholders, tribes, landowners, and engineering operations experts. Monitoring results will provide the TAC with information needed to optimize the degree and timing of operations and determine the effectiveness of the mercury removal process. The role of the TAC will include:

a. Reviewing monitoring data,

b. Providing quality assurance and quality control (QA/QC) of monitoring data,

c. Providing guidance on operations and engineering, and

d. Making recommendations to equipment operators.

PROJECT BENEFITS

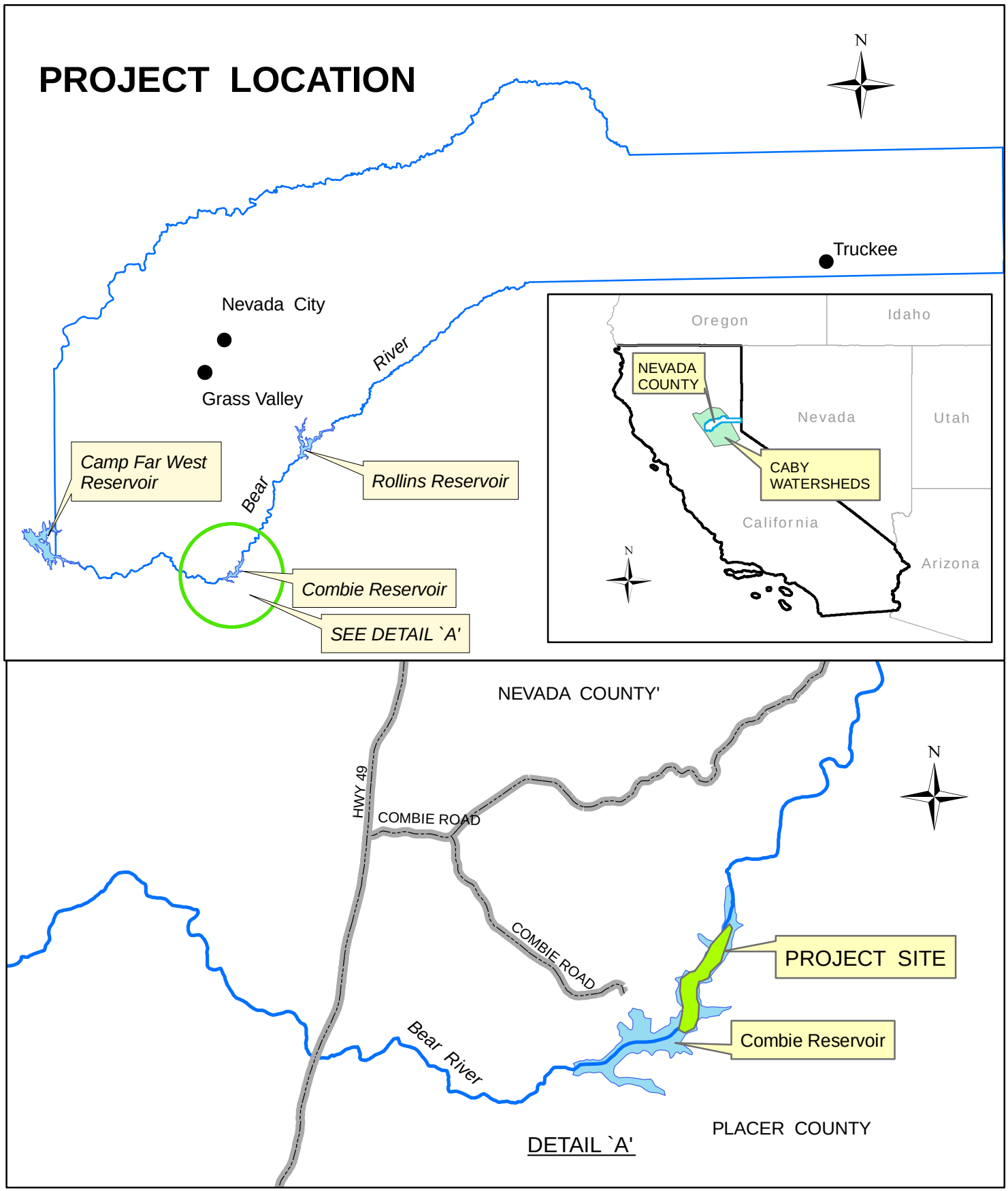
Water Supply Reliability. This project was conceived by the need to restore and maintain water storage capacity in Combie Reservoir. As a water supply reservoir, NID is responsible to its customers to maintain a reliable water supply. Periodic or on-going removal of sediments that enter the reservoir is necessary to maintain this water supply. By developing an action strategy to remove mercury in conjunction with accumulated sediments, NID will be able to maintain the needed water storage capacity in Combie Reservoir.

Removing Mercury Contamination. This project intends to develop Best Management Practices (BMPs) for restoring water storage capacity and removing legacy mercury contamination within the Sierra Nevada region. If proven to be successful in removing mercury, this strategy should provide for more reliable water supply and improved water quality for all beneficial uses within the region, as well as in downstream water bodies such as the California Bay-Delta.

Mercury Fate and Transport Research. While the main intent of the Project is to remove sediments and mercury from Combie Reservoir, because of the controlled operational environment, there are numerous research opportunities within this intent that may serve to fill critical data gaps in our understanding of mercury in and below reservoir environments. The USGS Sampling and Analysis Plan will quantify the effects of removing elemental mercury to the aquatic food chain. Specifically, this research will address the impacts of removing a known amount of elemental mercury on methylmercury levels in young of the year fishes, macroinvertabrates and other biosentinal species. Monitoring below Combie Reservoir will help fill critical data gaps regarding the form and quantity of mercury that is transported to downstream reaches, enabling improved quantification of overall tributary contributions of methylmercury to the Bay Delta. The sampling and analysis plan proposed by USGS has immeasurable benefits to mercury related studies and remediation techniques throughout California.

Recreation and Public Access. Currently, recreation activities at the northeastern end of Combie Reservoir is limited due to excessive build-up of sediments that block access to portions of the reservoir and its shoreline, including private boat docks. This project will work to remove sediment barriers that limit private boat dock access, while improving water quality and aquatic habitat.

Water Quality Protection and Improvement. This project will remove mercury from sediment deposits in Combie Reservoir. Systematic removal of mercury from the reservoir may allow for future removal of Combie Reservoir from the California 303 (d) list under the Clean Water Act.



Job Title: **COMBIE RESERVOIR SEDIMENT AND MERCURY REMOVAL PROJECT**

Date: December 2007

Drawn By: C. Holman

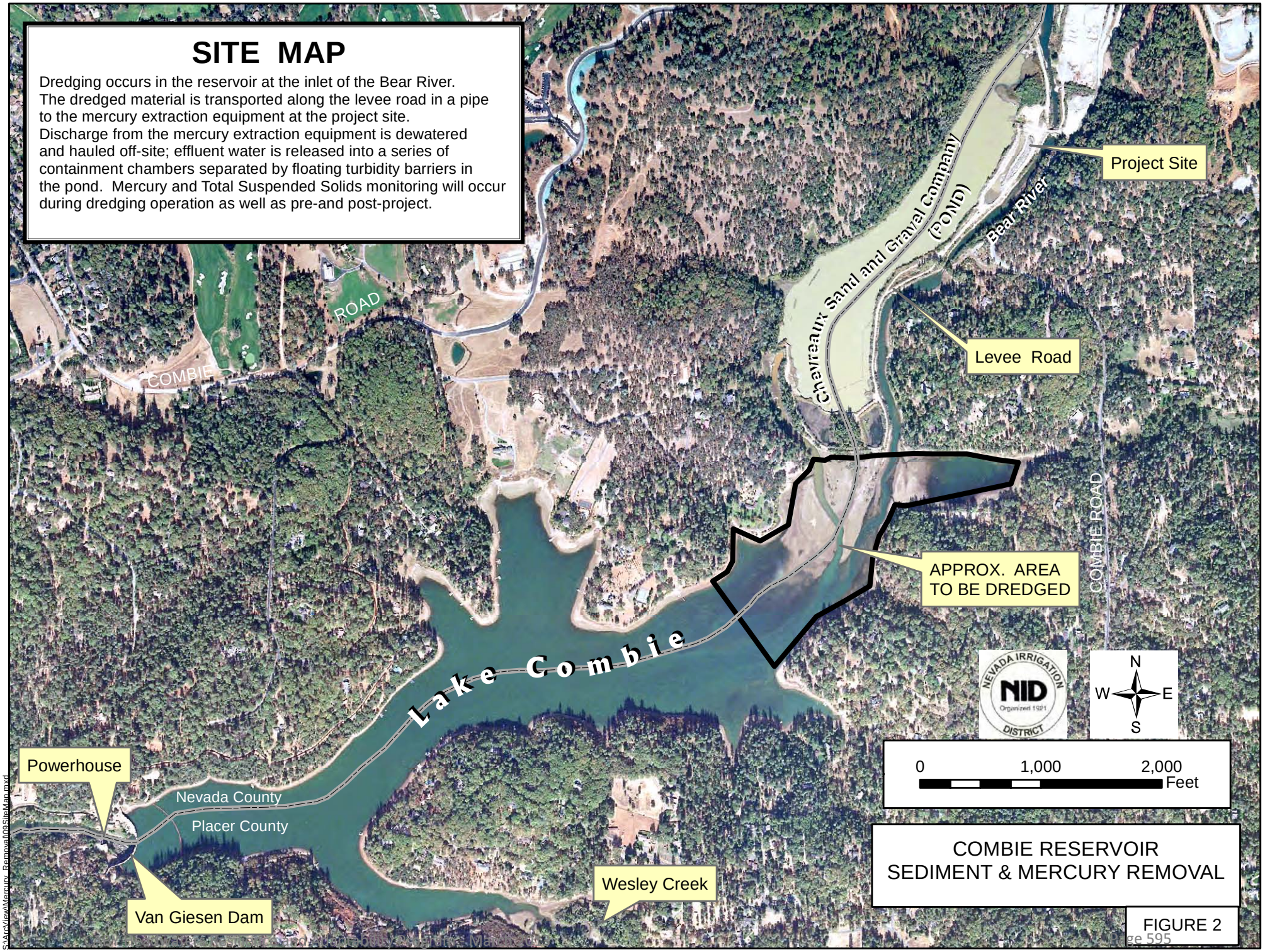
NEVADA IRRIGATION DISTRICT
NEVADA COUNTY -- PLACER COUNTY
GRASS VALLEY, CALIFORNIA

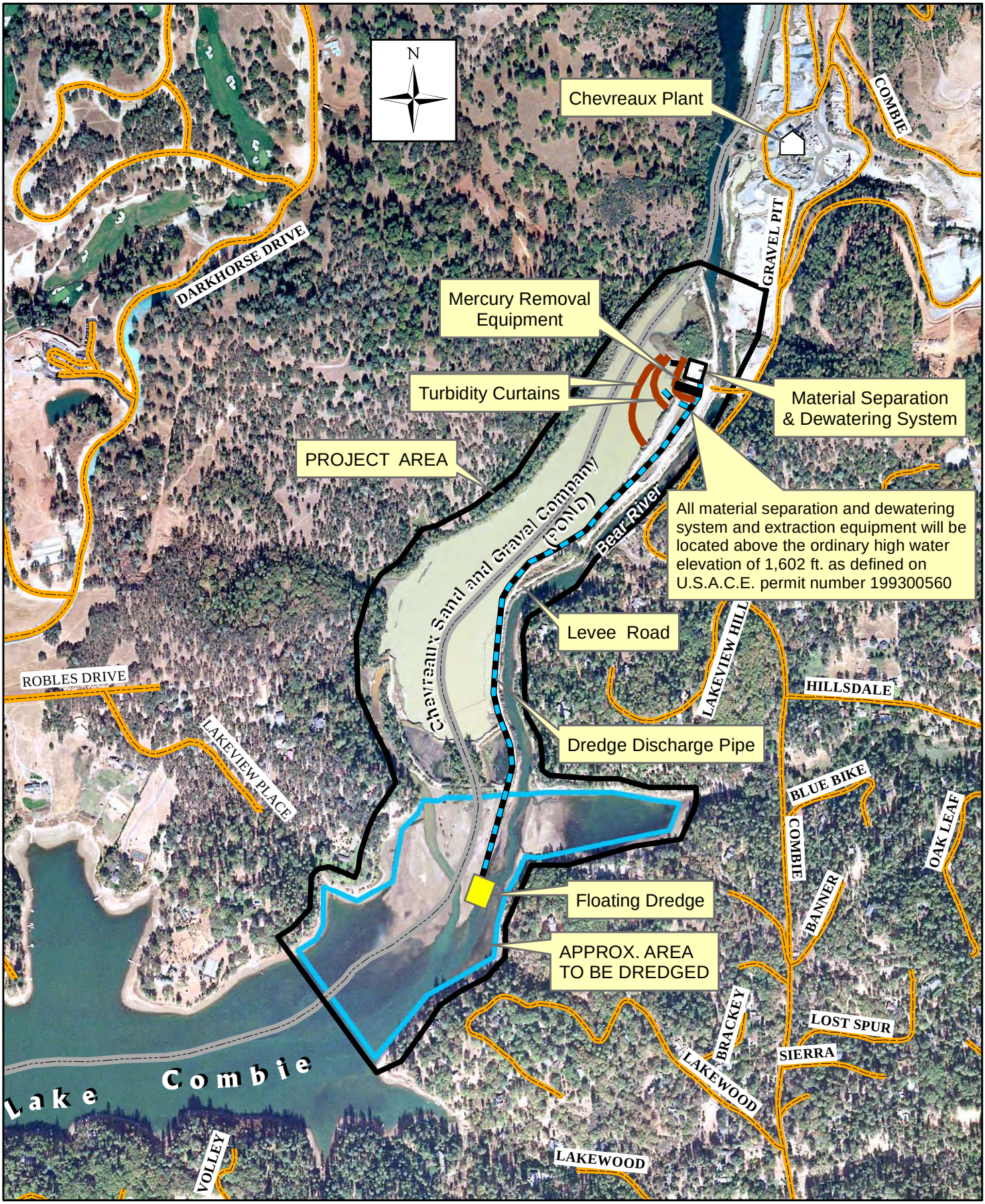
Scale: No Scale

Sheet: 1 of 1

Figure 1

S:\ArcView\Mercury Removal from Combie Loc.mxd


SITE MAP
Dredging occurs in the reservoir at the inlet of the Bear River. The dredged material is transported along the levee road in a pipe to the mercury extraction equipment at the project site. Discharge from the mercury extraction equipment is dewatered and hauled off-site; effluent water is released into a series of containment chambers separated by floating turbidity barriers in the pond. Mercury and Total Suspended Solids monitoring will occur during dredging operation as well as pre-and post-project.
Project Site
Bear River
Chevreaux Sand and Gravel Company (POND)
Levee Road
ROAD
COMBIE
COMBIE ROAD
APPROX. AREA TO BE DREDGED
Lake Combie
NEVADA IRRIGATION DISTRICT
NID
Organized 1921
N
W
E
S
0
1,000
2,000
Feet
Powerhouse
Nevada County
Placer County
Van Giesen Dam
Wesley Creek
COMBIE RESERVOIR
SEDIMENT & MERCURY REMOVAL
FIGURE 2
S:\ArcView\Mercury_Removal\09SiteMap.mxd



S:\ArcView\Mercury_Removal\09UpperPondDetails.mxd

Job Title: **COMBIE RESERVOIR SEDIMENT AND MERCURY REMOVAL PROJECT**

Date: June 2009

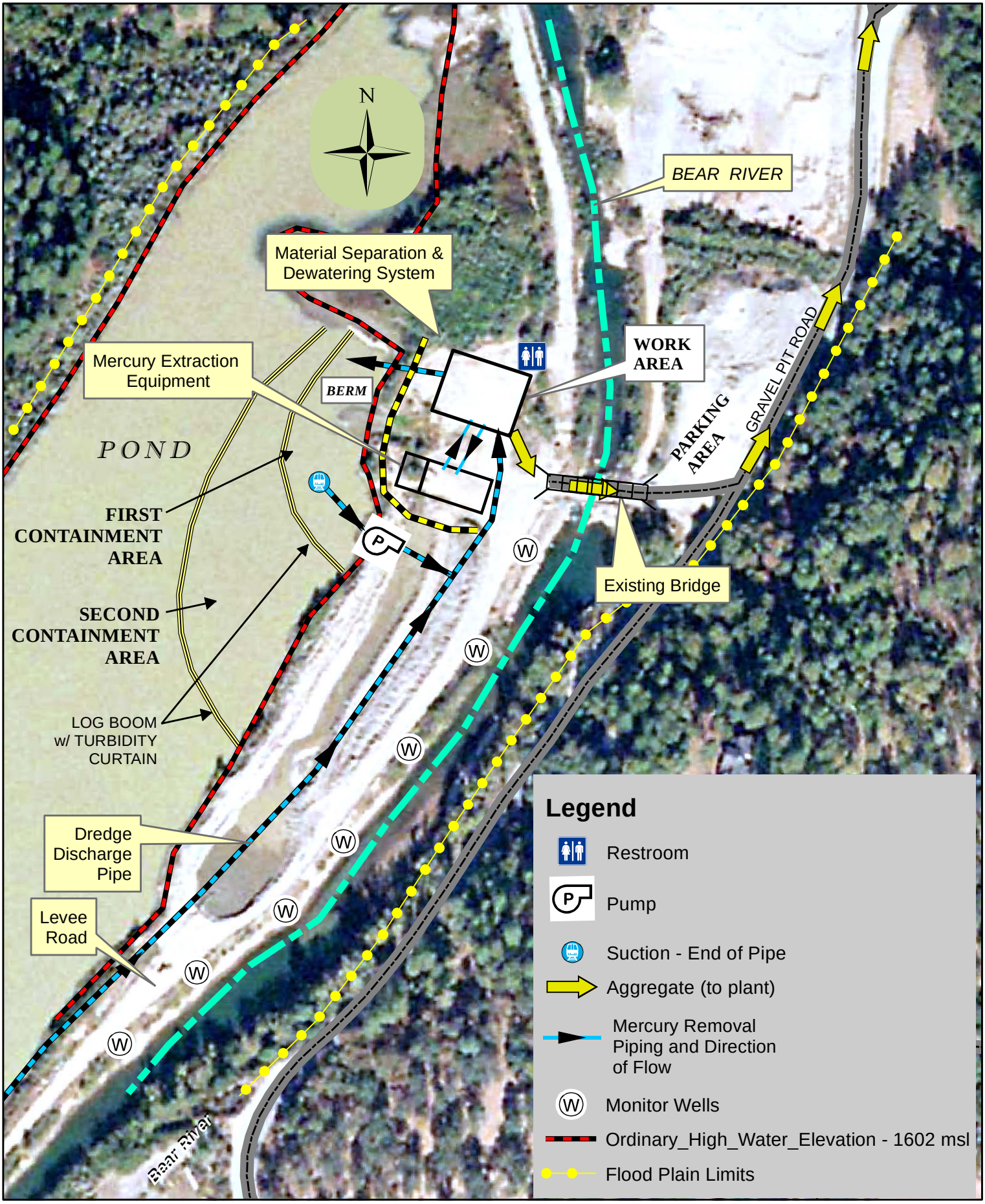
Drawn By: D. HUNT

NEVADA IRRIGATION DISTRICT
NEVADA COUNTY -- PLACER COUNTY
GRASS VALLEY, CALIFORNIA

Scale: no scale

Sheet: 3 of 6

Figure 3



S:\ArcView\Mercury_Removal/09UpperPondArea.mxd

Job Title: **COMBIE RESERVOIR SEDIMENT AND MERCURY REMOVAL PROJECT**

Date: June 2009

Drawn By: D. HUNT

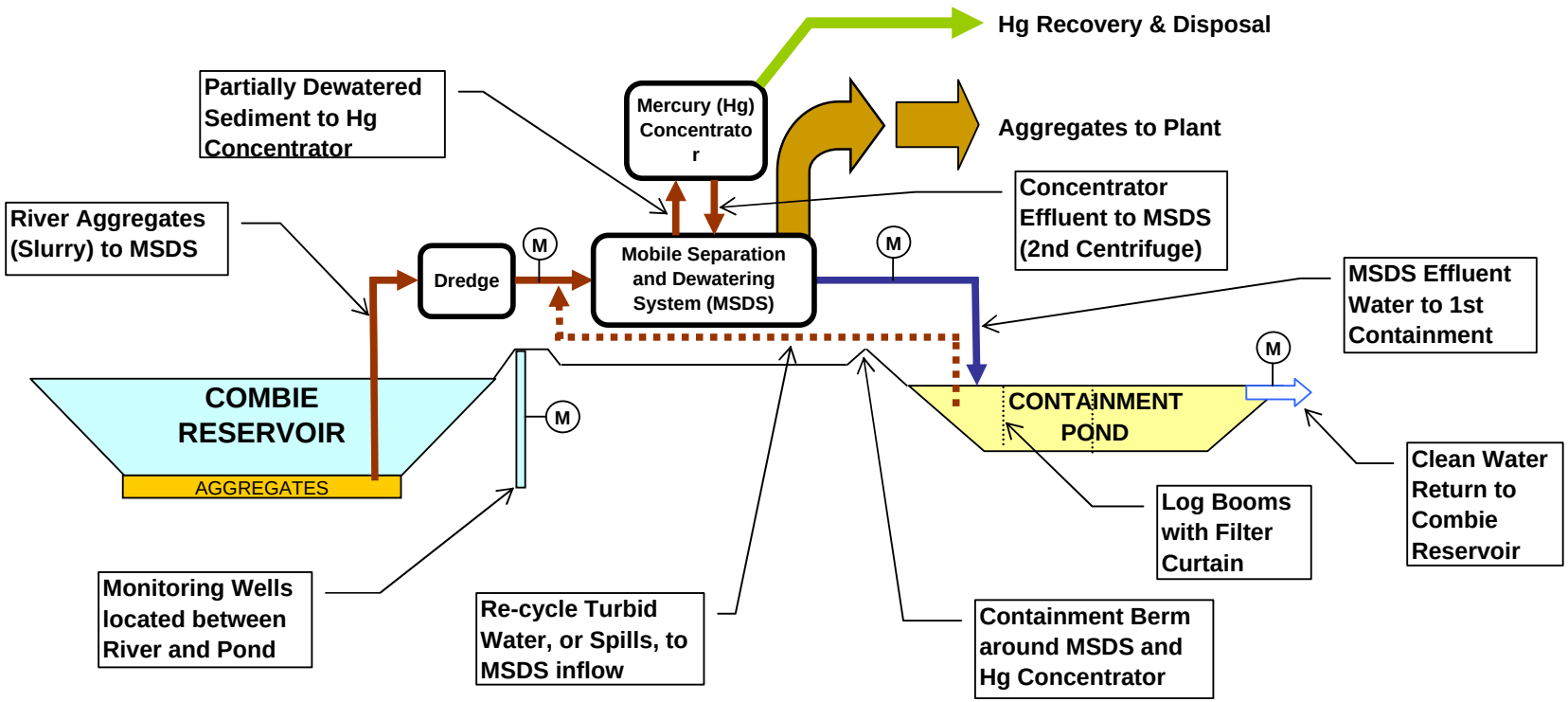
NEVADA IRRIGATION DISTRICT
NEVADA COUNTY & PLACER COUNTY
GRASS VALLEY, CALIFORNIA

Scale: no scale

Sheet: 4 of 6

Figure 4

PROCESS FLOW DIAGRAM



M … WQ Monitoring Point

Job Title: **COMBIE RESERVOIR SEDIMENT AND MERCURY REMOVAL PROJECT**

Date: June 2009

Drawn By: T. Crough

NEVADA IRRIGATION DISTRICT
NEVADA COUNTY -- PLACER COUNTY
GRASS VALLEY, CALIFORNIA

Scale: None

Sheet: 6 of 6

Figure 5

Nevada Irrigation District
July 13, 2009

INITIAL STUDY & CHECKLIST

Project Title: Combie Reservoir Dredge and Mercury Extraction Project

Lead Agency Name and Address: Nevada Irrigation District, 1036 West Main Street, Grass Valley, CA 95945

Contact person and phone number: Tim Crough, Assistant General Manager (530) 273-6185

Project Location: Upper Combie Reservoir southeast of Lake of the Pines community in Nevada County and west of Meadow Vista community in Placer County

Project Sponsor's Name and Address: Nevada Irrigation District, 1036 West Main Street, Grass Valley, CA 95945

Assessor's Parcel Number and acreage:

Nevada County:	11-181-13	89.97 acres
Placer County:	074-250-008	28.92 acres
	074-220-022	48.71 acres

Description of project: (Describe the whole action involved, including but not limited to later phases of the project, and any secondary, support, or off-site features necessary for its implementation. Attach additional sheets if necessary.)

See attached detailed Project Description. The summary project description is as follows: Dredging to maintain water storage capacity has occurred at Combie Reservoir and the Bear River over the past 40 years on an as needed basis. Operations were halted by the Central Valley Regional Water Quality Control Board (CVRWQCB) in 2002 due to elevated mercury levels. As a result, Combie Reservoir has been filling in with sediment with each storm event. The project includes three major features. First, involves the dredging of upper Combie Reservoir to maintain water storage capacity; second, involves the mercury removal and separation process using a Model KC-CD-12 MR [DS] Knelson Concentrator and dewatering of the dredge material using mobile on-shore equipment; and finally, involves the transport of sand and aggregate byproducts to the Chevreaux Aggregates, Inc. processing plant to the northeast of the Project site, or similar plant in Nevada County or Placer County. This project is intended to be an ongoing reservoir maintenance activity. The initial part will be conducted over a three- to five-year period and will remove approximately 150,000 to 200,000 tons of sediments that have been deposited in the upper Combie Reservoir. The purpose of the initial project is to ascertain whether the mercury recovery process can be applied on a long term, as needed, basis. On-going regular maintenance dredging of Combie Reservoir would proceed if the initial project is found to be successful in removing elemental mercury such that the CVRWQCB standards for mercury are met. It is expected that the initial project will continue for approximately three to five years with annual production involving up to 50,000 tons of aggregate material. The long-term operation would occur on an estimated ten year interval, or longer, as needed for as long as sediments continue to fill in the water supply reservoir. On a long term basis there is a public necessity to remove sediments from Combie Reservoir in order to restore and maintain water capacity while improving water quality by addressing legacy mercury contamination within the reservoir.

The primary focus of this Initial Study is for the purpose of obtaining new waste discharge permits from the Central Valley Regional Water Quality Control Board, stream alteration permits from the California Department of Fish and Game and 404 permits or jurisdictional exemption from the U.S. Army Corps of Engineers for dredging operations in waters of the United States. All other land use related project features are exempt from local county land use permits and Surface Mining and Reclamation Act (SMARA) regulations because State Mining and Geology Board staff has determined that the proposed dredging and mercury removal project at Combie Reservoir is exempt from SMARA. This determination was made because the dredging operation is primarily for the purpose of maintaining capacity in an existing water supply reservoir and the extraction of accumulated materials will not extend beyond

the original contours of the reservoir. Should NID be unable to regularly maintain its reservoir capacity, in time, it would fill up with sediments, gravels and sands from upstream sources, thereby reducing water storage capacity, power production opportunities and recreational use including fishing and hunting.

Surrounding land uses and setting: Briefly describe the project's surroundings:
Combie Reservoir bestrides both Nevada and Placer Counties and is located within the Bear River canyon. The immediate uses of the Bear River and Combie Reservoir are for water storage and diversion, hydroelectric power, recreation, riparian uses and aquatic life. Combie Reservoir is a terminus reservoir providing water to the Lake of the Pines Water Treatment Plant. It also provides water to the nearby private lake at the Lake of the Pines gated residential community in Nevada County. Beyond the subject lands include rural home sites on parcels of five acres and larger to the south and west. Much larger parcels occur to the north and east. Most of the larger parcels appear to be unimproved. Beyond these rural parcels the communities of Lake of the Pines (north) and Meadow Vista (south) exist. Elevations in the immediate vicinity of Combie Reservoir are approximately 1,600 feet.

General Plan Designation: Nevada County: Water Area (WA)
Zoning Nevada County: Public-Mineral Extraction (P-ME)

Location	Zoning	General Plan/Community Plan	Existing Conditions & Improvements
Site	Public-Mineral Extraction (P-ME)	Water Area (WA)	Reservoir—water storage and recreation
North	Agriculture with a 30 acre minimum lot size with Mineral Extraction (AG-30-ME) and Open Space (OS)	Rural 30 and Planned Development	Bear River and open space
South	Water Influence-Mineral Reserve (W-MR) (Placer Co)	Water (Placer Co.)	Combie Reservoir
East	Water Influence-Mineral Reserve (W-MR) (Placer Co)	Water (Placer Co.)	Combie Reservoir
West	Agriculture with 10 acre minimum lot size (AG-10) and Open Space (OS)	Rural 10 and Planned Development	Lake Combie Estates (5-acre lots) and open space (Darkhorse)

General Plan Designation: Placer County, Meadow Vista Community Plan: Water (W)
Zoning: Placer County: Water Influence-Mineral Reserve

Location	Zoning	General Plan/Community Plan	Existing Conditions & Improvements
Site	Water Influence-Mineral Reserve (W-MR)	Water (W)	Reservoir—water storage and recreation
North	Water Influence-Mineral Reserve (W-MR)	Water (W)	Combie Reservoir/Bear River
South	Residential with combining Agriculture and Building Site 100,000 sq. ft minimum (RS-AG-B-100)	Rural Residential (RR)	Rural residential (2.3 ac. Min.) (Meadow Vista)
East	RS-AG-B-100	Rural Residential (RR)	Rural residential (2.3 ac. Min.) (Meadow Vista)
West	Public-Mineral Extraction (P-ME)(Nev. Co)	Water Area (WA) (Nev. Co.)	Combie Reservoir (Nev. Co.)

Public agencies whose approval is required (e.g., permits, financing, approval, or participation agreement.)

1. Department of Fish and Game—Streambed Alteration Agreement
2. Water Quality Control Board—Waste Discharge Permit
3. U. S. Army Corps of Engineers—Clean Water Act Section 404 Permit or jurisdictional exemption
4. Placer County--Hazardous Materials Business Plan
5. California Air Resources Board--Portable Equipment Registration Program

ENVIRONMENTAL FACTORS POTENTIALLY AFFECTED

The environmental factors checked below would be potentially affected by this project, involving at least one impact that is a "Potentially Significant Impact" as indicated by the checklist on the following pages:

☐ Aesthetics	☐ Agriculture Resources	☐ Air Quality
☐ Biological Resources	☐ Cultural Resources	☐ Geology / Soils
☐ Hazards & Hazardous Material	☐ Hydrology / Water Quality	☐ Land Use/Planning
☐ Mineral Resources	☐ Noise	☐ Population/Housing
☐ Public Services	☐ Recreation	☐ Transportation/Traffic
☐ Utilities/Service Systems	☐ Mandatory Findings of Significance	

DETERMINATION: (To be completed by the Lead Agency)

On the basis of this initial evaluation:

☐ I find that the proposed project COULD NOT have a significant effect on the environment, and that a NEGATIVE DECLARATION will be prepared.

☒ I find that although the proposed project could have a significant effect on the environment there will not be a significant effect in this case because revisions in the project have been made by or agreed to by the project proponent. A MITIGATED NEGATIVE DECLARATION will be prepared.

☐ I find that the proposed project MAY have a significant effect on the environment, and an ENVIRONMENTAL IMPACT REPORT is required.

☐ I find that the proposed project MAY have a "potentially significant impact" or "potentially significant unless mitigated" impact on the environment, but at least one effect 1) has been adequately analyzed in an earlier document pursuant to applicable legal standards, and 2) has been addressed by mitigation measures based on the earlier analysis as described on attached sheets. An ENVIRONMENTAL IMPACT REPORT is required, but it must analyze only the effects that remain to be addressed.

☐ I find that although the proposed project could have a significant effect on the environment, because all potentially significant effects (a) have been analyzed adequately in an earlier EIR or NEGATIVE DECLARATION pursuant to applicable standards, and (b) have been avoided or mitigated pursuant to that earlier EIR or NEGATIVE DECLARATION, including revisions or mitigation measures that are imposed upon the proposed project, nothing further is required.

Signature: Ron Nelson

Date: 7-13-09

Ron Nelson, General Manager
Print Name

Nevada Irrigation District
For

EVALUATION OF ENVIRONMENTAL IMPACTS:

The Initial Study checklist recommended by the State of California Environmental Quality Act (CEQA) Guidelines is used to determine potential impacts of the proposed project on the physical environment. The checklist provides a list of questions concerning a comprehensive array of environmental issue areas potentially affected by the project (see CEQA Guidelines, Appendix G). Explanations to answers are provided in a discussion for each section of questions as follows:

a) A brief explanation is required for all answers including "No Impact" answers.

b) "Less Than Significant Impact" applies where the project's impacts are insubstantial and do not require any mitigation to reduce impacts.

c) "Less Than Significant with Mitigation Measures" applies where the incorporation of mitigation measures has reduced an effect from "Potentially Significant Impact" to a "Less than Significant Impact." The District, as lead agency, must describe the mitigation measures, and briefly explain how they reduce the effect to a less-than-significant level (mitigation measures from earlier analyses may be cross-referenced).

d) "Potentially Significant Impact" is appropriate if there is substantial evidence that an effect may be significant. If there are one or more "Potentially Significant Impact" entries when the determination is made, an EIR is required.

e) All answers must take account of the entire action involved, including off-site as well as on-site, cumulative as well as project-level, indirect as well as direct, and construction as well as operational impacts [CEQA Guidelines, Section 15063(a)(1)].

f) Earlier analyses may be used where, pursuant to the tiering, Program EIR, or other CEQA process, an effect has been adequately analyzed in an earlier EIR or Negative Declaration [CEQA Guidelines, Section 15063(c)(3)(D)]. A brief discussion should be attached addressing the following:

- ➔ **Earlier analyses used** – Identify earlier analyses and state where they are available for review.
- ➔ **Impacts adequately addressed** – Identify which effects from the above checklist were within the scope of, and adequately analyzed in, an earlier document pursuant to applicable legal standards. Also, state whether such effects were addressed by mitigation measures based on the earlier analysis.
- ➔ **Mitigation measures** – For effects that are checked as "Less Than Significant with Mitigation Measures," describe the mitigation measures which were incorporated or refined from the earlier document and the extent to which they address site-specific conditions for the project.

g) A source list should be attached and other sources used, or individuals contacted, should be cited in the discussion.

I. AESTHETICS – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Have a substantial adverse effect on a scenic vista?			X	
b) Substantially damage scenic resources, including, but not limited to, trees, rock outcroppings, and historic buildings, within a state scenic highway?			X	
c) Substantially degrade the existing visual character or quality of the site and its surroundings?			X	
d) Create a new source of substantial light or glare, which would adversely affect day or nighttime views in the area?			X	

Discussion- Items I a through d: The Bear River corridor/canyon is a natural resource. The Meadow Vista Community Plan in Placer County recognizes that the shore of Lake Combie supports a variety of riparian communities. Riparian zones are also associated with the Bear River corridor. The plan recognizes that these water resources support habitat for fish and wildlife. Combie Reservoir is owned by the Nevada Irrigation District. The Meadow Vista Community Plan a part of the Placer County General Plan and the Nevada County General Plan recognize that Combie Reservoir contains high quality mineral resources in the form of aggregates, sand, silt, and clay. Surrounding land owners are aware of the existence of mineral resources and that mining activities along the hillside quarry on the south side of the Bear River in Placer County and maintenance excavation of the reservoir has and will continue to occur.

In addition to the natural characteristics of the Bear River canyon that provide a scenic quality, mining within Bear River canyon and excavating/dredging of Combie Reservoir to maintain water storage capacity has occurred since 1946. NID has always had a need and has historically taken steps to maintain its water storage capacity in Combie Reservoir. Both Placer and Nevada County have instituted land use policies and designations that maintain relatively large minimum parcel size standards for lands immediately adjoining the upper Combie Reservoir area.

Aside from a limited number of residents who reside on five (5) acre lots and larger, the upper Combie Reservoir is not visible to the public. Due to public access limitations, Combie Reservoir experiences limited recreational activities. The primary recreational use on Combie Reservoir is boating and fishing by residents whose land abuts the lake shore.

The aesthetic impacts are considered less than significant due to the short term and seasonal nature of the operation and the limited number of residents who have frontage on this portion of Combie Reservoir. Furthermore, the project is for the purpose of re-permitting an historical use that was halted due to water quality standards. No mitigation measures are required.

II. AGRICULTURAL RESOURCE – In determining whether impacts to agriculture resources are significant environmental effects, lead agencies may refer to the California Agricultural Land Evaluation and Site Assessment Model (1997) prepared by the California Dept. of Conservation as an optional model to use in assessing impacts on agriculture and farmland. Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Convert Prime Farmland, Unique Farmland, or Farmland of Statewide or Local Importance (Farmland), as shown on the maps prepared pursuant to the Farmland Mapping and Monitoring Program of the California Resources Agency, to non-agricultural use?				X
b) Conflict with existing zoning for agricultural use, or a Williamson Act contract?				X
c) Involve other changes in the existing environment which, due to their location or nature, could result in conversion of Farmland (including livestock grazing) to non-agricultural use?				X

Discussion- All Items:

There are no agricultural values directly associated with Combie Reservoir or the Bear River, but these water bodies do deliver irrigation water to downstream agricultural users. The delivery of agricultural water to downstream sources will not be affected by this project. The project would have no impacts on agricultural resources. No mitigation measures are required

III. AIR QUALITY – Where available, the significance criteria established by the applicable air quality management or air pollution control district may be relied upon to make the following determinations. Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Conflict with or obstruct implementation of the applicable air quality plan?			X	
b) Violate any air quality standard or contribute substantially to an existing or projected air quality violation?			X	
c) Result in a cumulatively considerable net increase of any criteria for which the project region is non-attainment under an applicable federal or state ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors)?			X	
d) Expose sensitive receptors to substantial pollutant concentrations?			X	

e) Create objectionable odors affecting a substantial number of people?			X	

Discussion- Item III-a through e:
The Combie Reservoir area is within the Mountain Counties Air Basin. This area is designated as non-attainment for the state particulate matter (PM-10) standard and ozone. Aside from other mobile equipment sources that are already used at the Chevreaux Aggregates Meadow Vista plant, the only known new air quality pollution source to be regulated is a portable generator. The dredge, dewatering equipment, mercury extraction equipment, and all pumps and controls, will be powered by electric motors with a peak load of 220 Amp at 480 volts. The project will use an appropriately sized trailer mounted, diesel powered generator. The generator will be located on site and all required air quality permits will be obtained. The project would only utilize PG&E power if it became available through the Chevreaux aggregate processing plant. In addition, a small generator will be used for the concentrator and mercury recovery system. This generator will be smaller than 50 horse power and therefore not subject to air quality permits.

While the specific diesel generator has not yet been selected, it is expected to be a Duthie Power Services "whisper quiet" model with a production capacity of approximately 220KVA Generator 480 Volt 300 amp @60 Hz. As a portable generator it would be subject to the California State Air Resources Board (ARB) requirements for portable engines. Portable diesel engines of 50 horsepower or greater require a permit from ARB if it is intended to be used in multiple counties. That permit will ensure that the engine meets the standards of the ARB. As such, it can be operated in either county without further permits. Alternatively, an individual permit could be obtained from either the Placer County Air Pollution Control District or Northern Sierra Air Quality Management District (Nevada County) depending on which jurisdiction the generator is set up.

Mitigation Measures. There are no mitigation measures required as NID will obtain appropriate air quality permits for the portable dredge in accordance with the ARB Portable Equipment Registration Program or as otherwise administered by the respective air quality districts in Nevada and Placer counties.

Discussion- Items III-d and e:
The proposed project will not expose sensitive receptors to substantial pollutant concentrations or create objectionable odors as the diesel generator, if used, will be under permit from the ARB's Portable Equipment Registration Program. To the extent there might be any such impacts; they will be addressed as part of the ARB Portable Equipment Registration Program. No mitigation measures are required.

IV. BIOLOGICAL RESOURCES – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Have a substantial adverse effect, either directly or through habitat modifications, on any species identified as a candidate, sensitive, or special status species in local or regional plans, policies or regulations, or by the California Department of Fish & Game or U.S. Fish & Wildlife Service?		X		
b) Have a substantial adverse effect on any riparian habitat or other sensitive natural community identified in local or regional plans, policies, regulations or by the California Department of Fish and Game or US Fish and Wildlife Service?			X	
c) Have a substantial adverse effect on federally protected wetlands as defined by Section 404 of the Clean Water Act (including, but not limited to, marsh, vernal pool, coastal, etc.) through direct removal, filling, hydrological interruption, or other means?			X	
d) Interfere substantially with the movement of any native resident or migratory fish or wildlife species or with established native resident or migratory wildlife corridors, or impede the use of native wildlife nursery sites?				X

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
e) Conflict with any local policies or ordinances protecting biological resources, such as a tree preservation policy or ordinance?				X
f) Conflict with the provisions of an adopted Habitat Conservation Plan, Natural Community Conservation Plan, or other approved local, regional, or state habitat conservation plan?				X

Discussion- Item IV-a:

Special-status species that may potentially occur in the Project area include hardhead (*Mylopharodon conocephalus*), northwestern pond turtle (*Actinemys marmorata marmorata*), California red-legged frog (*Rana aurora draytonii*), bald eagle (*Haliaeetus leucocephalus*), California black rail (*Laterallus jamaicensis coturniculus*) and Brandegee's clarkia (*Clarkia bioloba* ssp. *brandegeeae*). Potential impacts to these species are summarized below along with recommended avoidance/minimization measures where appropriate. For a more complete discussion of natural history, potential Project impacts, and mitigation measures for special-status species, refer to the Preliminary Biological Evaluation for the CEQA Initial Study for this Project (GANDA 2008).

Hardhead

The presence of hardhead (*Mylopharodon conocephalus*) in the reservoir is unknown, but its potential is reduced by the abundance of introduced predators, particularly centrarchid basses. This native minnow, a California Species of Special Concern (SSC), prefers deep pools in undisturbed riverine environments, but can persist in some reservoirs. Project operations are not anticipated to adversely affect hardhead (if they are indeed present) because hardhead are not likely to occur in the open non-vegetated shallows of the delta fan area where dredging activities will occur. All fish should be easily able to avoid the area of locally active dredging during Project operations. Adult hardhead would reside in deeper water (i.e., hypolimnetic) portions of the reservoir, and any juveniles, if present, would utilize marginal habitats on the edge of the littoral zone in order to avoid introduced predators. Adult hardhead typically move upstream to spawn in riverine habitats during April or May and young-of-the-year fish may remain in the river indefinitely. Because hardhead are unlikely to be affected if present, any impacts would be less than significant. Thus, no mitigation measures are proposed beyond those which may be required as part of permit authorizations, such as may be contained in any Section 1603 Streambed Alteration Agreement issued for this Project.

Northwestern Pond Turtle (NWPT)

NWPT (*Actinemys marmorata marmorata*), a California Species of Special Concern (SSC), are known to occur in the Project area. Indeed, NWPT were observed in the reservoir and pond during reconnaissance-level surveys in April 2008. For most of the year, NWPT prefer sunny south-facing shorelines with adequate basking sites such as emerging logs or boulders; Project operations will not significantly affect these shoreline areas. However, NWPT could be affected by Project operations if overwintering habitats (e.g., reservoir bottom muds, upland areas containing leaf or needle litter) or nesting habitats (i.e., fine upland substrates such as sand, silt, clay) are disturbed during Project operations. It is unlikely that NWPT would use the levee road and fill areas that comprise the upland portion of the Project area for overwintering or oviposition (egg laying), although they may periodically travel across these areas. Direct effects to NWPT could include disturbance of bottom overwintering substrates or mortality from trampling by workers or equipment (e.g., during turtle movements to and from wintering, breeding, and summering habitats). Implementation of Mitigation Measures listed below for this species should reduce any impacts to a less than significant level.

NWPT Mitigation Measures:

MM VI-a1. Because NWPT may overwinter in reservoir bottom muds, timing of dredging operations should occur outside their wintering period (NWPT generally overwinter from November-March).

MM VI-a2. Project personnel should implement precautions (e.g., awareness training, low speed limits, and inspection of vehicles and other equipment prior to operation) to avoid turtle mortality associated with Project activities.

MM VI-a3. A worker education program should be provided in order to reduce the potential for uninformed workers to unintentionally or intentionally harass, injure, or kill NWPT individuals.

MM VI-a4. Relocation of any NWPT individuals found in the work zone would help minimize injury or mortality, although such an action would need to be performed by a permitted biologist.

California Red-legged Frog (CRLF)

CRLF (*Rana aurora draytonii*) is a federally threatened and state SSC amphibian that may possibly occur in the Project area. The Project Area is located within the historical and current potential range of this species; however it is not within designated CRLF critical habitat. The probability of CRLF occurring in the immediate Project area is considered low for several reasons. The nearest known CRLF records are approximately 25 kilometers away, much farther than the known maximum dispersal distance of 3 km. Even so, CRLF could occur at unknown locations in unsurveyed but otherwise suitable habitat closer to the Project area. Secondly, CRLF does not generally occur in large reservoirs, although they can (e.g., adult stages are known from Jamieson Reservoir on the Santa Ynez River). Third, and probably most unfavorable for CRLF occurrence at Combie Reservoir, is the presence of introduced predators such as centrarchid fishes (largemouth and spotted bass) and bullfrogs *(Rana catesbeiana)* which are known to occur in the reservoir and quarry ponds within the Project Area. While the presence of predators like basses and bullfrogs does not completely preclude CRLF, it greatly reduces their likelihood. Finally, the Project area has only very sparse emergent vegetation preferred by CRLF for oviposition and cover from predators; however, aquatic vegetation is not a prerequisite for successful breeding by this species.

A formal CRLF Site Assessment of the Project Area was conducted in 2008 following the procedures outlined in the *USFWS Revised Guidance on Site Assessments and Field Surveys for the California Red-legged Frog* (USFWS 2005). All potential CRLF habitats within a 1.6-km radius surrounding the Project Area were visited, photographed, and assessed in terms of the quality of potential CRLF breeding and estivation habitat. The Site Assessment identified 31 aquatic features providing potential CRLF habitat within this 1.6-km radius. Queries of the California Natural Diversity Database (CNDDB; CDFG 2008) and HerpNet museum specimen records (herpnet.org) identified no known records of CRLF occurring within 1.6 km of the Project Area. However, 22 of the 31 sites identified as potential CRLF habitat in the vicinity of the Project (71%) are located on private property. Based on the results of the CRLF Site Assessment, the USFWS has initially indicated that, without adequate access for protocol-level population surveys within the majority of this 1.6-km radius, the presence of CRLF in the overall Project Area will likely have to be assumed (i.e., CRLF presence cannot be ruled out for privately owned areas that are not able to be surveyed).

If the USFWS indeed directs that CRLF presence must be assumed, or if CRLF are found in or near the Project Area the potential would exist for indirect impacts to habitat and for direct impacts to adults, sub-adults, tadpoles, and eggs in the footprint of the Project. Potential indirect impacts may include the loss of alluvium and the shallow water at the dredging site) and/or the potential loss of riparian or emergent aquatic habitats during dredging or other Project operations. Direct impacts could include injury or mortality to CRLF from being crushed by equipment and worker foot traffic. Work activities, including noise and vibration, may harass CRLF by causing them to move, increasing potential for predation and desiccation. Tadpoles may be entrained by pump intakes, and dredging and filtration work could cause unusually high levels of siltation. Such siltation could smother eggs and reduce overall habitat quality (although existing breeding and nursery habitats in the reservoir and former dredge pond areas are poor to marginal at best; thus CRLF breeding is unlikely in the immediate Project Area). Implementation of the Mitigation Measures listed below for this species should reduce any impacts to a less than significant level.

CRLF Mitigation Measures :

MM VI-a5. Protocol-level CRLF surveys of all accessible sites within the 1.6-km radius of the Project Area should be conducted following USFWS guidelines (USFWS 2005) prior to Project operations. If CRLF are determined to be present as a result of these surveys, or if CRLF presence is assumed, Mitigation Measures VI-a6 through –a11 (below) should be implemented to reduce any impacts to a less than significant level.

MM VI-a6. The boundaries of the Project area and equipment access routes should be minimized and clearly demarcated, and work areas should be located outside of riparian areas and other water bodies.

MM VI-a7. Best management practices should be implemented to confine the area to be disturbed to the minimum necessary.

MM VI-a8. Work activities in or near breeding areas should be avoided during the breeding season (approximately November-June) to reduce potential adverse impacts, particularly to eggs and tadpoles.

MM VI-a9. CRLF individuals found in the work zone should be relocated to minimize injury or mortality; however, such an action would need to be performed by a permitted biologist to minimize any unintended negative consequences of improper handling.

MM VI-a10. A worker education program should be provided; the potential for uninformed workers to unintentionally or intentionally harass, injure, or kill CRLF could be greatly reduced by informing workers of the presence and protected status of this species and the measures that are being implemented to protect it during Project operations.

MM VI-a11. Consultation with USFWS should be sought to identify any additional required authorizations and implement any specified avoidance and minimization measures for CRLF.

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Bald Eagle

Bald eagle (*Haliaeetus leucocephalus*) is a federally delisted and state endangered species that may occur at Combie Reservoir. While foraging and possibly nesting habitat for bald eagle exists at Combie Reservoir, no birds or nests were observed during reconnaissance-level surveys in April 2008, or nesting surveys conducted in 2009. It is possible that the reservoir is used by wintering eagles or eagles nesting close by for foraging; however, the large number of residences populating the shoreline and surrounding area may preclude nesting for eagles that typically choose secluded nesting sites (although this habitat requirement may be less important than previously thought because in recent years eagles have colonized more disturbed areas). Additionally, large trees preferred as nest sites are not within close proximity to the Project area. Project operations would not likely impact foraging eagles because activities would be concentrated in a small portion of the reservoir, sedimentation would be confined behind turbidity curtains, and mercury will be removed from the system. Implementation of the Mitigation Measures listed below for this species should reduce any impacts to a less than significant level.

Bald Eagle Mitigation Measures:

MM IV-a12. Protocol-level bald-eagle nesting surveys should be performed during each year of Project operations following CDFG guidelines (Jackman and Jenkins 2004). If such surveys confirm the absence of this species, the Project will have no impacts on this species and no mitigation is necessary. If such surveys establish the presence of eagles nesting near the Project area, implementation of Mitigation Measures IV-a13 and –a14 (below) would ensure that any potential impacts are less that significant for this species.

MM IV-a13. Dredging and other operational activities that could potentially disturb eagles should occur no closer than 200 meters (660 feet) from any bald eagle nesting site.

MM IV-a14. Work activities near active nests should occur outside the bald eagle breeding season or limited operating period (LOP). The LOP in northern California is typically 1 January to 1 August.

California Black Rail

The California black rail (*Laterallus jamaicensis coturniculus*) is a state threatened and fully protected species. A very small rail about the size of a sparrow, the black rail inhabits densely vegetated saltwater, brackish, and freshwater marshes and wetlands. The closest known black rail occurrences to Combie Reservoir include an undisclosed location near Grass Valley (over 30 km away) and the Spenceville Wildlife Area (approximately 25 km away) near Beale Air Force Base (CNDDB 2008). Black rails in the Sierra Nevada foothills are found primarily in extensive marshes dominated by tules and/or cattails, and require water depths less than 3 cm (1.2 in) for breeding. Because no extensive marsh habitat occurs in or adjacent to Combie Reservoir, it is extremely unlikely that California black rail occurs in the Project area. Therefore, no impacts to this species are anticipated and no mitigation is necessary.

Brandegee's clarkia

Brandegee's clarkia (*Clarkia biloba* ssp. *brandegeae*) is an annual herb that blooms from May through July. It is typically found in chaparral, cismontane woodlands, and often in road-cut areas between 73 and 915 meters above sea level. Brandegee's clarkia has no federal or state listing status, but is considered by the California Native Plant Society (CNPS) Inventory of Rare and Endangered Plants as a 1B.2 species; generally, CNPS list 1B and list 2 species qualify for protection under CEQA. Botanical surveys targeting Brandegee's clarkia that were conducted in 2008 and 2009 confirm the absence of this species in the immediate Project Area (i.e., the levee road and fill areas that comprise the terrestrial footprint of the Project); however, this species was observed on the west-facing hillslope to the east of Retherford Road (immediately adjacent to the Project Area). Potential colonization of the Project Area by this species is considered unlikely due to the lack of preferred habitat along the levee road and fill areas. Thus, Project operations are not likely to affect Brandegee's clarkia. Implementation of the Mitigation Measures listed below for this species should reduce any potential impacts to a less than significant level.

Brandegee's clarkia Mitigation Measures:

MM IV-a15. Annual protocol-level surveys for Brandegee's clarkia should be conducted during each year of Project operation. If protocol-level surveys confirm the continued absence of this species, the Project will have no impacts and no mitigation is necessary. If such surveys establish the presence of Brandegee's clarkia in the Project area, implementation of the Mitigation Measures MM IV-a16 through –a18 (below) would ensure that any potential impacts would be less that significant for this species.

MM IV-a16. Habitat occupied by Brandegee's clarkia should be protected by establishing an exclusion zone around the perimeter of such habitat where feasible. The exclusion zone should be temporarily fenced or staked and flagged in the field by a trained professional botanist. Project infrastructure and activities (i.e., staging areas, equipment access routes, etc.) will be located outside of this exclusion zone.

MM IV-a17. Activities should be restricted to the dry season, and the flowering period for this species (approximately May-June) should be avoided if possible.

MM IV-a18. All known locations of Brandegee's clarkia in the Project area should be monitored during Project operations to assess the effectiveness of protection measures.

Discussion- Item IV-b:

The Project area contains approximately 1,000 meters of riparian area along the levee road separating the reservoir/pond from the Bear River, as well as approximately 2,500 meters of reservoir/pond shoreline. With the exception of the levee road and a small portion of the reservoir shoreline adjacent to the area to be dredged, these riparian areas will not be disturbed or otherwise affected by Project operations. The slurry pipe line will be placed along the top of the levee road. The Placer County Conservation Plan (PCCP) classifies land coverage using Wildlife Habitat Relations (WHR). Using this scheme, the Project area would be primarily characterized as a lacustrine Aquatic and Wetland Ecosystem. Although the impoundment and creation of reservoirs is generally viewed as alteration of a natural lotic ecosystem and replacement with artificial lacustrine ecosystem, patches of Freshwater Emergent Wetlands (FEWs) may occur in association with this WHR (e.g., around the reservoir and pond margins). FEWs are known to be one of the more productive wildlife habitats providing food, cover, and water for numerous species. Project operations will not adversely affect any FEW communities; indeed, is it assumed that the removal of elemental mercury from the system as part of this Project will have a decidedly positive effect on aquatic habitats and overall water quality.

There will be three to four anchor points for the dredge cable/pulley maneuvering system for the electric dredge. Two points will be on shore with a cable running between them and the others will be submerged. A pulley or winch connected to a cable would provide guidance for the dredge path of travel. The shore-mounted anchor system will be located such that there will be minimal disturbance to riparian vegetation. Cables can be anchored to existing trees or posts with sufficient protective wrapping to avoid damage. Alternatively, temporary anchor points can be placed in upland areas without any impacts to riparian vegetation or habitat. When the dredge is to be re-positioned, it would be able to move without relocating the shore-mounted anchors as it could merely realign its path along the pulley and cable system between the two shore-mounted anchors. If the dredge path necessitates relocation or re-positioning of the anchors, it would be done such that disturbance to the riparian vegetation is avoided or minimized. In addition, the shoreline location where the slurry pipe will cross the riparian area between the reservoir and the upland levee road will be selected such that disturbance to riparian vegetation is minimized by the placement of the pipe. Given the site conditions at the proposed location, the above-ground placement of this pipe over rock or earthen portions of the levee should be possible without harming any vegetation. In general, the robust and prolific nature of the riparian vegetation in the Project Area should allow for minor disturbances to be restored naturally through seasonal re-growth. Therefore, Project impacts to riparian areas are anticipated to be less than significant, and no mitigation is necessary.

Discussion- Item IV-c:

Combie Reservoir is an artificial, man-made surface-water impoundment. The Project area boundary encompasses primarily inundated portions of the reservoir and pond littoral and shorelines zones, plus some upland levee and fill areas. As such the Project area includes both waters of the US and wetlands as defined by Section 404 of the Clean Water Act. Acquisition of a Section 404 permit from the USACOE may be required to conduct dredging operations as part of this Project, thus proposed operations will be subject to agency review and consultation. Other than the dredging area at the bottom of the reservoir near the delta fan, habitat structure in the reservoir and pond will not be affected (i.e., material will only be removed from the delta). No riparian or wetland areas will be disturbed (with the exception of the anchoring system and above-ground slurry pipe crossing mentioned above). Water quality in reservoir and pond areas will be affected (e.g., pond containment areas may

become turbid during operations); however, it is assumed that the removal of elemental mercury will have a decidedly positive net effect on biota, habitat resources, and overall water quality in the Project area. Project impacts to wetland areas are anticipated to be less than significant, and no mitigation is necessary beyond that which may be required as part of permit authorizations.

Discussion- Item IV-d:

Project operations and infrastructure will not impede the movement of any migratory fish or wildlife species. Access to upstream portions of the Bear River and downstream portions of the reservoir will not be affected by Project operations; therefore no impacts are anticipated and no mitigation is necessary.

Discussion- Item IV-e:

Although there are no specific ordinances regarding mosquito abatement in the area, the Placer Mosquito and Vector Control District endorses policies and implements programs to control or eliminate existing mosquito breeding sources, and to prevent new mosquito breeding sources for the protection of public health and comfort. Nevada County does not have a mosquito abatement district; however, Nevada County's Agricultural and Environmental Health Departments have an active mosquito treatment program and the Public Health Department provides mosquito and West Nile virus education programs. This Project may introduce new surface water only in the small containment area surrounding the dewatering and mercury removal equipment. This containment area will be inspected daily during operations; any visible standing water that remains after 72 hours will be pumped into the primary tanks for agitation, making it unsuitable for mosquito breeding (i.e., the mosquito life cycle requires longer-standing stagnant water for larval development). Thus, the Project will not introduce any suitable waters for mosquito breeding.

No other local policies or ordinances protecting biological resources are applicable to this Project (e.g., no trees are to be removed or otherwise harmed as part of the Project). Therefore, no conflicts with such policies are anticipated and no mitigation is necessary.

Discussion- Item IV-f:

Placer County is in the process of developing a joint HCP/NCCP for the western portion of the county that includes the Project area, referred to as the Placer County Conservation Plan (PCCP). Nevada County has no such conservation plan in place. Although the PCCP is not yet adopted, it will define necessary management actions for aquatic and wetland conservation as well as best management practices to be implemented within these areas. No conflicts with any provisions of the forthcoming PCCP are anticipated for this Project, and no mitigation is necessary.

V. CULTURAL RESOURCES – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Cause a substantial adverse change in the significance of a historical resource as defined in §15064.5?				X
b) Cause a substantial adverse change in the significance of an archaeological resource pursuant to §15064.5?		X		
c) Directly or indirectly destroy a unique paleontological resource or site or unique geologic feature?				X
d) Disturb any human remains, including those interred outside of formal cemeteries?		X		

Discussion- Items V-a through c:
The project constitutes dredging operation for the purpose of increasing and restoring reservoir storage capacity. All materials being harvested are transported from natural erosion and abandoned upstream hydraulic mining sources in

the Bear River watershed. It is not expected that any cultural resources will be uncovered due to the operation of the dredge within this portion of the reservoir.

In April 2008 a records search was conducted by Anthropological Studies Center (ASC), Sonoma State University at the North Central Information Center (NCIC) of the California Historical Resources Information System, located at California State University, Sacramento, California (File No. NEV 08 21). The NCIC is the official state repository of archaeological and historical records and reports for a 6 county area that includes both Nevada and Placer counties. The search included examination of all sites and studies on file at the NCIC within a 1/2 mile radius of the study area. Additional research was conducted using the files and literature of the ASC and on line sources.

No archaeological sites or other cultural resources are recorded within the study area and no cultural resource studies have been filed at the NCIC. Two isolated artifacts have been identified within 1/2 mile of the study area (P-29-000830 and P-29000831). These consist of a single basalt flake and a single obsidian flake to the northwest. Five cultural resources studies have been conducted within 1/2 mile of the study area: three were conducted in association with the Dark Horse housing development that extends to Lake Combie in the northwest portion of the project (Jenson and Associates 1996, 1999; Wickstrom 1998); one documents a Timber Harvest Plan survey on a 22 acre parcel that extends to the reservoir in the SE 1/4 of Section 36, T14N/R8E (Ferrier 1995); and the last a survey report for a subdivision to the east (Peak and Associates 1983). Combined, the results of these studies demonstrate prehistoric settlement in the valley to the northwest and limited land use in the hills to the east.

A field survey of the study area was conducted on 23 July 2008. ASC Staff Archaeologists were joined by a member of the local Nisenan-Maidu community. A pedestrian survey was conducted along all of the shoreline in the study area that was natural and not too steep to traverse. The team accessed the study area by boat. All exposed ground surfaces along about a 20 foot strip centered on the high-water line were inspected, including the entire right bank (northwest shoreline) and about half of the left bank (southeast), as depicted in Figure 3 in "A Cultural Resources Study for the lake Combie Mercury Extraction Project." The surveyed area was closely inspected, with particular attention given to cuts created by shoreline erosion in order to examine subsurface conditions.

Five isolated prehistoric artifacts and four segments of a single ditch were identified, all along the right (northwest) bank of the study area (see Figure 4 in the August 13, 2008, ASC study). The isolated artifacts are neither eligible for listing on the California Register of Historical Resources (CRHR) nor are they unique archaeological resources. Pursuant to CEQA Guidelines Section 15064.5(c)(4), no further study of these artifacts or their origin appears necessary at this time. While no further study is warranted, these identified artifacts could be indicative of the presence below water surface potential archaeological resources. Ethnographic and archival data further indicates the inundated southwest corner of the study area is sensitive for cultural resources. The pedestrian survey was not able to fully examine or predict what could be present in the now inundated historical ground surface at the bottom of the reservoir. Potential resources in this culturally sensitive location could be disturbed by dredging operations. For this reason, an adjustment to the southwesterly boundary of the project is recommended as a Mitigation Measure to avoid these potential resources.

The historic-era ditch remains, ASC-Combie-1, may be eligible to the CRHR. However, the resource will not be affected by the project as it is presently conceived. If project plans change to potentially affect this resource, it should be formally evaluated and treated.

Based on the cultural resources study conducted for the project, there may be potentially significant resources inundated within the historical ground surface at the bottom of the reservoir in the southwest corner of the study area that could be affected by the project. The following mitigation measure is recommended:

Mitigation Measure:

> **MM V-1**: Adjust the southwest project boundary to avoid disturbance to a minimum of 200 feet of the shoreline and or by rotating the southwest project boundary at the Placer County shoreline in a north-south direction to avoid the culturally sensitive area in vicinity of the five isolated artifacts identified during the pedestrian survey.

Discussion- Items V-d: The possibility does exit that unidentified buried or inundated cultural deposits are present in the study area. A major component of the proposed mercury remediation project involves dredging sediment buildup within the northeastern area of Combie Reservoir. The now inundated historical ground surface

at the bottom of the lake is sensitive for cultural resources; for obvious reasons, the area could not be investigated through pedestrian survey. Archaeological sensitivity is particularly high for the southwest corner of the study area, in the vicinity of the historic Combie Crossing and identified isolated artifacts (NE 1/4 of the NE 1/4 of Section 2, T13N/R8E). If feasible, dredging operations should be limited to reservoir sediments and avoid disturbing the natural ground surface below.

There is a remote possibility that human remains might be encountered during dredge operations. According to Section 7050.5 of the California Health and Safety Code it is a misdemeanor to knowingly disturb a human burial. If human remains are encountered, work should halt in the vicinity of the remains and, as required by law, the County Coroner should be notified immediately. At the same time, an archaeologist should be contacted to evaluate the situation. If human remains are of Native American origin, the Coroner must notify the Native American Heritage Commission within 24 hours of that determination.

> **M.M. V-2.** Should there be a discovery consisting of human remains, the Placer County or Nevada County Coroner and Native American Heritage Commission shall be contacted. At the same time, an archaeologist should be contacted to evaluate the situation. Work in the area would only proceed after authorization is granted by the respective coroner.

VI. GEOLOGY & SOILS – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Expose people or structures to unstable earth conditions or changes in geologic substructures?				X
i) Rupture of a known earthquake fault, as delineated on the most recent Alquist-Priolo Earthquake Fault Zoning Map issued by the State Geologist for the area or based on other substantial evidence of a known fault? Refer to Division of Mines and Geology Special Publication 42.				X
ii) Strong seismic ground shaking?				X
iii) Seismic-related ground failure, including liquefaction?				X
iv) Landslides?				X
b) Result in substantial soil erosion or the loss of topsoil?				X
c) Be located on a geologic unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on- or off-site landslide, lateral spreading, subsidence, liquefaction or collapse?				X
d) Be located on a geological unit or soil that is unstable, or that would become unstable as a result of the project, and potentially result in on or off-site landslide, lateral spreading, subsidence, liquefaction, or collapse?				X
e) Be located on expansive soils, as defined in Table 18, 1-B of the Uniform Building Code (1994), creating substantial risks to life or property?				X

Discussion- Items VI-a, c and d:

The manmade reservoir contains lake and stream channel deposits chiefly comprised of sand, gravel and silts that continue to wash down the Bear River from natural erosion and hydraulic mining from the 1880s. Vast quantities of tertiary, channel sand and gravels flow unrestricted and continue to accumulate in the streams draining the Bear River. Even with the court ordered cessation of hydraulic mining in 1884, millions of tons of the hydraulic mining debris continue to be transported downstream during storm events into Combie Reservoir.

The river channel and surrounding high ground within which the reservoir lies is composed of Meta volcanic flows. Soils on these flows are from weathering of the parent material. According to the most recent Alquist-Priolo Earthquake Fault Zoning Map, there are no known faults reported in the area.

Combie Reservoir was formed as a water storage feature in 1928 through the impoundment of the Bear River. Due to the long and narrow shape of the reservoir (0.3 miles wide and 2 miles long), the aggregates are roughly sized by water action along the length of the lake. The grain size decreases to the southwest along the lake and becomes predominantly clay and silt directly behind the Van Giesen Dam. The grain size distribution is caused by the decrease in the Bear River transporting energy upon entering the lake. Coarse gravels are deposited first, with progressively finer grains settling out as the transport energy diminishes.

The only materials to be extracted are those that have been transported from upstream sources. There will be no alteration or disturbance to the natural streambed which was cut through formational soils (bedrock). While the dredge boom will have a maximum reach of 30 feet, it is not expected that the sediments will be excavated below the original (1928) contours of the lake. The project would not involve dredging or disturbing natural ground surfaces. The activity associated with dredging the sediments within the reservoir is not expected to impact or create any instability as a result of reservoir maintenance activities.

ITEM VI-b: Since the entire dredging operation is within the reservoir, there will be no soil or earth disturbance associated with the extraction activity. Existing roads will be used to transport the marketable sands, aggregates and silts to the Chevreaux Aggregates processing area approximately one-half mile to the northeast (within Placer County), or other processing plants in Nevada County or Placer County, if necessary. No new roads or surface disturbance will occur with the project. Additional disturbance to create a containment berm will be required around the mobile dewatering system and diesel fuel storage tank, but this disturbance will occur on previously compacted lands. The containment berm will be sized and designed by a licensed civil engineer. All requirements to protect the containment berm will be incorporated to assure it is stable and will withstand erosion due to wind and stormwater. The containment berm will be located above the ordinary high water level of 1,602 MSL and isolated from the Bear River and Combie Reservoir. The containment berm will also be included as part of the Hazardous Materials Business Plan (HMBP) as required by the Placer County Environmental Health Division. The HMBP will ensure that impacts would be less than significant; therefore, no mitigation measures are required.

ITEM VI-e: There will be no buildings constructed.

There are no potential significant impacts to geologic features and therefore no mitigation measures are required.

VII. HAZARDS & HAZARDOUS MATERIALS – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Create a significant hazard to the public or the environment through the routine handling, transport, use, or disposal of hazardous or acutely hazardous materials?			X	
b) Create a significant hazard to the public or the environment through reasonably foreseeable upset and accident conditions involving the release of hazardous materials into the environment?			X	
c) Emit hazardous emissions, substances, or waste within one-quarter mile of an existing or proposed school?			X	

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
d) Be located on a site which is included on a list of hazardous materials sites compiled pursuant to Government Code Section 65962.5 and, as a result, would it create a significant hazard to the public or the environment?				X
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project result in a safety hazard for people residing or working in the project area?				X
f) For a project within the vicinity of a private airstrip, would the project result in a safety hazard for people residing in the project area?				X
g) Impair implementation of or physically interfere with an adopted emergency response plan or emergency evacuation plan?				X
h) Expose people or structures to a significant risk of loss, injury or death involving wildland fires, including where wildlands are adjacent to urbanized areas or where residences are intermixed with wildlands?				X

Discussion- Item VII-a and b: The project will involve the recovery, separation and handling of elemental mercury. All recovered mercury will be isolated into a separate collection vessel within the Model KC-CD12MR [MS] Knelson concentrator. According to laboratory specifications for the Knelson concentrator, the efficiency rate of the elemental mercury recovered is approximately 95 percent. All local and state requirements will be used in handling and transport to avoid accidental spills or other mishaps. All recovered mercury will be transported to a class 1 landfill for disposal. Amalgam will be transported to an independent laboratory for assay and retorting.

The project will store up to 100 gallons of diesel fuel in an above ground storage tank within the work area designated on the site plan. A Hazardous Materials Business Plan will be obtained from Placer County Environmental Health in advance of project start up. The plan will address fuel spill containment, emergency management and all other requirements of the hazardous materials business plan. The dredge, dewatering equipment, pumps, concentrator, and generator will require periodic maintenance onsite. These equipment items will be maintained and serviced annually, or as needed, within the upper area of Combie Reservoir. The methods to be used to protect water quality will be spelled out in the Hazardous Materials Business Plan (HMBP) as required by the Placer County Environmental Health Division. The HMBP will ensure that impacts would be less than significant; therefore, no mitigation measures are required.

Discussion- Item VII-c: The mercury extraction process will take place within Placer County's jurisdiction. Throughout the life of the initial project (three to five years) it is expected that approximately 150 to 200 kilograms (330 to 442 pounds) of elemental mercury will be recovered from the sediments during dredging operation. Elemental mercury collected in the concentrator will be transported from the site on a periodic basis in accordance with the HMBP, as approved by Placer County Environmental Health. Any amount over 100 kg must be removed from the site and deposited at a Class 1 landfill within 90 days. The route of travel will be to the southeast along Combie Road, through Meadow Vista and then to Interstate 80. The Meadow Vista School is located on Placer Hills Drive, south of the Meadow Vista Road intersection. While mercury deposits will be hauled within one-quarter mile of the school, these deposits will be in small, sealed quantities that will not emit emissions, substances, or waste of any kind. The project is considered a waste generator and the appropriate business plan and permit will be required from Placer County Environmental Health before the start of operations. The HMBP will ensure that impacts would be less than significant; therefore no mitigation measures are required.

Discussion- Item VII-d: Combie Reservoir and surrounding areas are not listed on the Government Code Section 65962.5 hazardous sites list compiled by the State Department of Toxic Substance Controls, but it is included on the 2002 CWA Section 303(d) List of Water Quality Limited Segment for mercury contamination. This list is

established by the Central Valley Regional Water Quality Control Board. Under Section 303(d) of the 1972 Clean Water Act, states, territories and authorized tribes are required to develop a list of water quality limited segments. These are water bodies that do not meet water quality standards, even after point sources of pollution have installed the minimum required levels of pollution control technology. The law requires that these jurisdictions establish priority rankings for water on the lists and develop action plans, called Total Maximum Daily Loads (TMDL), to improve water quality. On July 25, 2003 USEPA gave final approval to California's 2002 Section 303(d) List of Water Quality Limited Segments. Combie Reservoir has been included on this list due to the presence of mercury in fish. One of the project objectives is to remove mercury from the sediments in Combie Reservoir. Over time, this mercury remediation project should prove successful in reducing mercury levels in Combie Reservoir to acceptable standards such that de-listing may occur from the CWA Section 303(d) list.

Since the project will remove mercury form the water body, the impacts are considered less than significant and no mitigation measures are required. For a more complete discussion of mercury removal and related water quality impacts see, Section VIII below.

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Discussion- Item VII-e and f: The project site is not located within two miles of a public use airport or within the vicinity of a private airstrip.

Discussion- Item VII-g: There are no known emergency response plans that would be compromised due to the project. The initial mercury extraction project is short term in nature while the on-going maintenance project will be intermittent and on-going, as needed, to remove accumulated sediments. Aside from the current interruption of dredging operations on Combie Reservoir, both phases of the project are part of and constitute an extension of the historic reservoir maintenance activities that have been ongoing since the 1940s. Since the project constitutes a maintenance activity and one that does not impact an existing emergency response plan, the impacts are less than significant and no mitigation measures are required.

Discussion- Item VII-h: Cal Fire adopted its official "Maps of Fire Severity Zones in the State Responsibility Area of California on November 7, 2007. These fire hazard maps were recently updated in accordance with Public Resources Codes 4201 through 4204. The fire severity maps do not establish a fire severity zone within the reservoir and Bear River. Lands immediately adjoining these water bodies are designated "Moderate" in severity along the shore lines and "High" in the surrounding foothills. With the exception of the immediate shore areas, the communities of Lake Combie Estates and the Meadow Vista are designated in the "High" severity zone. Due to the location of the project operations and distance from surrounding residences, there should be no fire danger associated with the dredge or mercury extraction processes. In the event of a wildland fire in the canyon, adequate water is available in Combie Reservoir for fire suppression activities. All flammable fuels and other materials will be stored in a safe manner in accordance with state and local laws, including the HMBP as administered by Placer County Environmental Health. The HMBP will ensure that impacts would be less than significant; therefore no mitigation measures are required.

VIII. HYDROLOGY & WATER QUALITY – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Violate any potable water quality standards?		X		
b) Substantially deplete groundwater supplies or interfere substantially with groundwater recharge such that there would be a net deficit in aquifer volume or a lessening of local groundwater supplies (i.e. the production rate of pre-existing nearby wells would drop to a level which would not support existing land uses or planned uses for which permits have been granted)?				X
c) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, in a manner which would result in substantial erosion or siltation on- or off-site?		X		

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
d) Substantially alter the existing drainage pattern of the site or area, including through the alteration of the course of a stream or river, or substantially increase the rate or amount of surface runoff in a manner which would result in flooding on- or off-site?				X
e) Create or contribute runoff water which would exceed the capacity of existing or planned stormwater drainage systems or provide substantial additional sources of polluted runoff?				X
f) Otherwise substantially degrade surface water quality		X		
g) Place housing within a 100-year flood hazard area as mapped on a federal Flood Hazard Boundary or Flood Insurance Rate Map or other flood hazard delineation map?				X
h) Place within a 100-year flood hazard area improvements which would impede or redirect flood flows?			X	
i) Expose people or structures to a significant risk of loss, injury or death involving flooding, including flooding as a result of the failure of a levee or dam?				X
j) Inundation by seiche, tsunami, or mudflow?				X

Discussion- Item VIII-a: For approximately 40 years, NID contracted to have accumulated sediments dredged from the upper Combie Reservoir area. In 2003, elevated total mercury concentrations were detected in the dredge effluent during routine sampling taken to meet Central Valley Regional Water Quality Control Board (CVRWQCB) permit requirements for the operation. The dredging operation suspended mercury with sand and finer particulates. Laboratory testing confirmed that samples exceeded 50 nanograms per liter (ng/L) of unfiltered water, which is the relevant water quality criterion based on CVRWQCB standards for drinking water. As a result, dredging operations were halted. However, mercury laden sediments coming down from upstream reaches continue to accumulate in Combie Reservoir with storm events. One of the purposes of this project is to introduce a mercury removal component to the dredging operation in order to demonstrate that legacy mercury contamination can be remediated with available technology. If the initial project proves that mercury removal can be effective in reducing mercury levels, it would enable NID to pursue a more active and consistent reservoir maintenance program at Combie Reservoir.

The project will be required to meet the CVRWQCB waste discharge requirements for a new point discharge with a U.S Environmental Protection Agency National Pollution Discharge Elimination System (NPDES) permit. The waste discharge permit will use information from a one year long anti-degradation study and will set standards for all constituents of concern, likely turbidity and mercury. The purpose of the anti-degradation study is to determine existing pre-project water quality conditions so that no degradation to water quality occurs as a result of that project. The waste discharge permit will require periodic monitoring and reporting during operations to verify that the water quality standards are being met on an on-going basis.

Operating conditions are designed to avoid any and all water quality impacts through the use of dewatering equipment, containment berm(s), and a series of containment chambers in the pond (separated by turbidity curtains). Extensive monitoring will be conducted before, during and after project operations to asses any and all water quality concerns. Details will be explicit in the CVRWQCB's waste discharge permit.

While the project is designed to meet drinking water standards with the discharge of effluent from the dredging operation, there could be a potential significant impact that would require operational adjustments. In light of this possibility, the following mitigation measures will be applied in a progressive adaptive management approach:

Mitigation Measures

MM VIII-1 Reduce the quantity and rate of materials processed to a level such that water quality standards are met in the discharge.

MM VIII-2 Reduce mesh size in turbidity curtain within the first containment chamber to trap more fine sediments

MM VIII-3 Add additional turbidity curtains to create additional containment chambers

MM VIII-4 Re-process all turbid effluent water through the dewatering equipment and concentrator for further mercury recovery until waste discharge requirements are met.

With the incorporation of the above mitigation measures, there will be no significant impacts.

Discussion- Item VIII-b: The project will involve dredging of sands, aggregates and silts deposited into the reservoir through annual storm events. Groundwater will not be disturbed through pumping or any other means. Shallow groundwater flow between the pond and the river channel, will be monitored using a series of piezometric wells installed into the levee road to determine if groundwater flows from the pond to the river. The project will not create any potentially significant impacts on groundwater resources; therefore mitigation measures are not required.

Discussion- Item VIII-c and d: The Bear River is currently routed around the easterly side of the old dredge pond. It is separated from the dredge pond by a levy road. No changes are proposed that would alter the course of the Bear River in this area. The dredging operation will occur at the delta where the Bear River enters the upper end of Combie Reservoir where the greatest amounts of sands and gravels have settled. There is currently a rather large sand bar that has formed in the delta area over the past 30 to 40 years and since the cessation of dredging operations in 2002.

The dredged material from the delta would be pumped through a pipeline along the existing levee road to the location of the Mobile Separation and Dewatering Equipment (MSDS) and mercury concentrator (Knelson Concentrator). The material would be processed through several screens, tanks, mercury concentrator, magnetic separator, and centrifuges. The dredge material will be separated by size, partially dewatered, processed by the mercury concentrator (for mercury removal), then fully dewatered. The effluent from the dewatering system (centrate) will be discharged into a series of containment chambers in the pond (filtered through turbidity curtains designed to trap any remaining suspended material), before returning to the reservoir.

The project intends to remove the accumulated aggregates in the delta area to restore reservoir capacity. While the project is intended to restore reservoir capacity, it may cause water quality impacts that could be significant. Operating conditions are designed to avoid any and all water quality impacts through the use of screens, tanks, concentrator, centrifuges, a series of containment chambers separated by turbidity curtains, and extensive monitoring that will be conducted before, during and after project operations to asses any and all water quality concerns. Monitoring details will be explicit in the CVRWQCB's waste discharge permit and NPDES permit. Measures MM VIII-1 through -4 will be applied in a progressive adaptive management approach. These measures will reduce any potential significant impacts to less than significant levels.

Discussion- Item VIII-e: The project will not create any impervious surfaces. All work is within Combie Reservoir, pond area and existing staging area within the shore line area. The dredge equipment is portable and will not require cement foundations; operations will take place in the existing staging area that is already compacted from use. The outcome will increase flood water storage capacity to a minor level. All effluent returned to the reservoir will be treated and allowed to filter through the turbidity curtains in the containment chambers before discharge to the reservoir. The project will not create any potential significant impacts on storm water systems; therefore, mitigation measures are not required

Discussion- Item VIII-f: The dredging operation will create turbid conditions in the immediate area of the dredge cutterhead during operations. The dredge will be tethered on a cable and anchor system with a 20 to 30 foot boom that will reach below the water level to agitate and vacuum the sediment deposits. The dredge will have the ability to anchor in one location and maneuver along a cable to dredge a precise area. After the intended area has been dredged, the dredge will anchor to another portion of the delta where it will resume dredging at discrete depths. A cutter at the end of the boom will loosen the sediments on the bottom of the reservoir. Concurrent with the cutter operation, a suction hose will vacuum the loosened material from the bottom of the reservoir. Normally, this activity will create turbidity in the surrounding water, however, the Eveready dredge is specifically designed to broom or

force the disturbed sediment into the suction inlet with minimal turbidity. The vacuumed material will be transported via a pipe at an approximate rate of 250 gallons per minute to the MSDS. The MSDS is located on land above the 1,602 MSL ordinary high water mark east of the existing dredge pond outside of the reservoir and river channel. Dredging will normally occur between the months of May through October, or the start of the rainy season. Maintenance operations could also be further curtailed if sensitive biological species are found to be present in any given year (see Section IV).

The effluent from the dewatering system and concentrator is similar to the effluent from a water treatment plant, in that it is has been altered to remove a contaminant of concern, in this case mercury. However, it is possible that only one form of mercury is effectively removed, elemental mercury, and another form such as flowered or reactive mercury is not removed or is in fact released by the concentrator. This concern is one of the reasons that monitoring will take place throughout the duration of this project. If reactive or flowered mercury is being released by the concentrator then the best course of action is to cease the operations until such time that the project can be modified to eliminate water discharge that exceeds NPDES permit thresholds.

The project will include water quality monitoring stations around the dredge activity area, at the location of the centrate (dewatering system and concentrator effluent) in the dredge pond, upstream of the reservoir and downstream of the reservoir. In addition, a series of monitoring wells will be installed along the levy road separating the pond (former dredge pond) and the Bear River. If monitoring indicates that the water quality standards are exceeded downstream of the operation, measures shall be taken in accordance with the CVRWQCB waste discharge permit.

The State Regional Water Quality Control Board has established water quality standards for water bodies of all types in California. Those standards are explained in the Water Quality Control Plan for the Sacramento and San Joaquin River Basin, the CA Toxics Rule, Max Contaminant levels Title 22 of CA Code of Regulations, and USEPA ambient water quality recommended criteria. The CVRWQCB will use these standards to set the water quality standards for the dredging and dewatering operation. Said standards will be for purposes of assuring that mercury, turbidity and other water quality features are maintained throughout the operations. While the project is designed to meet water quality standards with the discharge of effluent from the dredging/dewatering operation, there could be a potentially significant impact that would require operational adjustments. If at any time water quality monitoring indicates that water quality thresholds have been exceeded, the following mitigation measures will be applied in a progressive adaptive management approach:

Mitigation Measures

Measures MM VIII-1 thorough 4; and

MM VIII-5 Terminate the project until it can be modified to eliminate water discharge that exceeds NPDES permit thresholds.

With the inclusion of these mitigation measures, potential significant impacts will have been mitigated.

IX. LAND USE & PLANNING – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Physically divide an established community?				X
b) Conflict with any applicable land use plan, policy, or regulation of an agency with jurisdiction over the project (including, but not limited to the general plan, specific plan, local coastal program, or zoning ordinance) adopted for the purpose of avoiding or mitigating an environmental effect?				X
c) Conflict with any applicable habitat conservation plan or natural community conservation?				X

Discussion- Item IX-a-b: As noted in the project description, the dredging and mercury extraction activities will occur initially over a three- to five-year period and if successful will be on-going on an as needed basis. The activities will be conducted within Combie Reservoir. Combie Reservoir is a water supply reservoir that requires regular maintenance. In this capacity, NID is the lead permit holder rather than its contractor. Since reservoir maintenance is the primary purpose of the project, it is not considered a mining activity regulated by the Surface Mining and Reclamation Act (SMARA). This position is supported by a 1995 State Attorney General opinion (78 Ops. Cal. Atty. Gen. 343). All areas above the reservoir are subject to SMARA and local regulations. This opinion is also confirmed by a July 30, 2008 letter from Stephen M. Testa, Executive Officer of the California State Mining and Geology Board that all maintenance activities of a water retention and flood control facility are not subject to SMARA provided that the original contours of the water facility are not altered. This conclusion also recognizes that marketable material will be recovered. Even though the extracted materials will have an economic benefit to Chevreaux, or other commercial businesses and industries, it is not the primary purpose of the maintenance activity. Since the impacts to land use are less than significant, no mitigation measures are required.

All materials harvested will be processed through the MSDS and mercury extraction concentrator; all solid materials will be transported to the Chevreaux Aggregates Inc. Meadow Vista processing plant, located approximately one-half mile to the north of the project area, or to another similar plant in Nevada or Placer County if Chevreaux does not receive it. These materials will be further processed in accordance with demand, stockpiled and sold. Placer County's 1986 approved reclamation plan represents that annual production from Lake Combie/Bear River would be between 50,000 and 250,000 tons per year. This pilot operation will harvest and process a maximum of 50,000 tons of material per year for approximately three- to five-years. Long term annual maintenance dredging will not exceed the annual production volumes reflected in the adopted Reclamation Plan. Materials harvested from the dredge operation will not increase production or transportation of finished product from the Meadow Vista processing plant; therefore, there would not be any conflicts with the production level associated with the Chevreaux operation at Meadow Vista.

Combie Reservoir is located within the Bear River canyon and provides a natural separation of the Lake Combie Estates subdivision and the Meadow Vista community. The project will not serve to physically, further divide these two communities.

Nevada and Placer counties have designated the Bear River and Combie Reservoir as a "water" resource with a mineral extraction designation. As a result, the re-establishment of dredging operations as a water supply maintenance activity is consistent with both general plans and zoning standards, therefore no mitigation measure are required.

Discussion- Item IX-c: Neither Nevada County nor Placer County has established a habitat conservation plan for the Bear River/Combie Reservoir water resource area. Both General/Community Plans set standards for protecting the water resources and related riparian areas through setbacks and other management features to prevent the encroachment of development onto this sensitive resource. Both plans however recognize the mineral resources present within the waterway and encourage the long-term management for sand and gravel extraction. See also discussion under Section IV-f. The maintenance dredging activity will not impact an established habitat management plan or other or other resource management policies, therefore no mitigation measure are required.

X. MINERAL RESOURCES – Would the project result in:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Result in the loss of availability of a known mineral resource that would be of value to the region and the residents of the state?				X
b) Result in the loss of availability of a locally-important mineral resource recovery site delineated on a local general plan, specific plan or other land use plan?				X

Discussion- Item X-a and b: In addition to removing mercury from sediments so that maintenance of Combie Reservoir can be conducted, this project includes the further benefit of utilizing sand, aggregates and silts for productive purposes. According to Section 2711 of SMARA, the state legislature finds that "…the extraction of minerals is essential to the continued economic, well-being of the state and to the needs of society…" As a result, an additional benefit of the reservoir maintenance activity is that this project will remove an environmental toxin, mercury, while utilizing important mineral resources. Both the Nevada County and Placer County General Plans and zoning recognize the presence of important minerals in this shared resource.

Since aggregate resources will be utilized for beneficial uses as an added benefit, the project will not result in land uses or activities that would preclude their removal and utilization. As a result, there will be no potential significant impact associated with the inability to remove a known valuable mineral resource. No mitigation measures are required.

XI. NOISE – Would the project result in:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Exposure of persons to or generation of noise levels in excess of standards established in the local General Plan, Community Plan or noise ordinance, or applicable standards of other agencies?			X	
b) Exposure of persons to or generation of excessive groundborne vibration or groundborne noise levels?				X
c) A substantial permanent increase in ambient noise levels in the project vicinity above levels existing without the project?			X	
d) A substantial temporary or periodic increase in ambient noise levels in the project vicinity above levels existing without the project?			X	
e) For a project located within an airport land use plan or, where such a plan has not been adopted, within two miles of a public airport or public use airport, would the project expose people residing or working in the project area to excessive noise levels?				X
f) For a project within the vicinity of a private airstrip, would the project expose people residing or working in the project area to excessive noise levels?				X

Discussion- Items XI-a, c and d: Maintenance dredging of Combie Reservoir has occurred on an as needed basis over the past 30 to 40 years until it was suspended due to non-compliance with water quality standards due to mercury sampling and reporting in 2003. Historically, dredging and mining within the Bear River corridor has been on-going and intermittent. NID has evaluated the project noise impacts and is committed to incorporating appropriate and reasonable measures to reduce the potential for adverse public reaction to noise generated by the project.

An electric suction dredge and dewatering system will be used to remove sediments from the bottom of the reservoir and separate solid from liquid materials. Sediment is removed and transported to the dewatering equipment by an electrically powered submerged cutter head and pump which is virtually silent. Due to the relative dispersed nature of the sediments to be removed, the floating equipment will move from location to location by a guidance cable controlled from shore. As a result, noise associated with sediment removal operations in any one location will be limited. The dredge will move from place to place in the delta fan area within the north eastern portion of Combie Reservoir. Based on proximity of the shoreline, it is not expected that dredge operations would occur closer than 150 feet to a residence.

Based on 48 hour noise reading conducted by Bollard Acoustical Consultants, Inc. (BAC) in July 2008, existing ambient noise level, Ldn values were found to range from 44 to 47 dB over the monitoring period. Complete

listings and graphical depictions of the ambient noise measurement data are contained in Appendix A of the BAC Combie Dredge Project Environmental Noise Assessment. The conclusion of that report is summarized below.

CRITERIA FOR ACCEPTABLE NOISE EXPOSURE

Since the project area falls within both Nevada and Placer Counties, both noise standards have been reflected, as follows:

Nevada County Criteria

The Nevada County General Plan Noise Element sets forth land use compatibility criteria for various community land uses. The County's performance standards and applicable land use compatibility standards are provided below in Table 1.

Table 1

Noise Exposure Limits

Nevada County Noise Element of the General Plan

Land Use Category	Time Period	Leq, dB	Lmax, dB
Rural	7 a.m. - 7 p.m.	55	75
	7 p.m. - 10 p.m.	50	65
	10 p.m. - 7 a.m.	40	55
Industrial	any time	80	80

Notes:

Where two different zoning districts abut, the standard applicable to the lower, or more restrictive, district plus 5 dBA shall apply.

The above standards shall be measured only on property containing a noise sensitive land use as defined in Policy 9.8 and may be measured anywhere on the property containing said land use.

If the measured ambient level exceeds that permitted, then the allowable noise exposure standard shall be set at 5dB above the ambient.

The above standards shall not apply to those activities associated with the actual construction of a project or to those projects associated with the provision of emergency services or functions.

For purposes of this analysis, it is assumed that the dredging and on-site aggregate trucking operation constitutes an industrial type use. As a result, the 55 Leq dB daytime standard plus 5 dB or 60 dB would ordinarily apply. Furthermore, the dredging and material loading/transporting operations are viewed to be similar to a construction project, in that it is not considered to be a permanent or long term daily noise source. Under this scenario, no noise standards would be applicable.

Placer County Criteria

The Placer County Noise Element establishes an exterior noise level standard of 60 dB L_{dn} for residential land uses affected by industrial uses. The day/night average level, denoted L_{dn}, is the average of all sound occurring over a 24-hour period with a 10 decibel penalty added to noise which occurs during nighttime hours (10 p.m. to 7 a.m.).

The Placer County Noise Ordinance establishes exterior noise level performance standards of 70 dB L_{max} during daytime hours (7 am - 10 pm) and 65 dB L_{max} during nighttime hours (10 pm - 7 am). In addition, the County Noise Ordinance establishes exterior noise level performance standards of 55 dB L_{eq} during daytime hours and 45 dB L_{eq} during nighttime hours. The County's exterior noise level standards are applied at the nearest property line of any affected sensitive receptor.

ANALYSIS OF PROJECT-GENERATED NOISE LEVELS

There are four (4) major noise-producing components of this project. Those components include the floating dredge, the shore mounted mechanical dewatering system, the mercury separator equipment, and the trucks used to haul the aggregates to the Chevreaux facility for subsequent processing. It is also noted that a "whisper quiet" Duthie Power Services, 220KVA 480 Volt 300 amp @60 Hz. diesel generator or equivalent would be used as a power source. The BAC noise study addressed noise from all of these components, as well as discusses their combined contributions to the ambient noise environment at the nearest residences. In addition, the BAC noise study evaluated the off-site traffic noise associated with the worse case truck hauling scenario identified in the K. D. Anderson & Associates June 2009, Traffic Report.

Floating Sediment Removal Equipment Noise Generation

The floating sediment removal equipment (dredge) is relatively simple, consisting primarily of a submerged cutter head and pump. Because both of these processes are electrically powered, the operation of the floating equipment is virtually silent. The dredge will maneuver in small isolated parts of the “Area to be Dredged” (See Figure 3 of the BAC noise study) using a series of cables, pulleys and anchors. The dredge will be tethered on a cable and anchor system with a 20 to 30 foot boom that will reach below the water level to agitate and vacuum the sediment deposits. The dredging of the reservoir will practically not occur closer than approximately 150 feet of the closest residence that fronts on Combie Reservoir (See Figure 2 of the BAC noise study).

Actual noise data has been made available and is incorporated into and analyzed in the noise study. Observations and noise level measurements of an Eveready electric dredge system in operation at a marina in Huntington Beach, CA, on April 22, 2009, were made available for the noise study. Because the cutterhead and pump operate below the surface of the water, and because they are both electrically powered, the floating component of the electric dredge system sounds barely louder than a boat sitting on the water. The noise generation of this aspect of the system was observed to be so low as to be virtually inaudible during the operation in April 2009. The recorded sound level of 52 dB measured at a distance of 10 feet from the floating platform was attributable more to other local noise sources than to the submerged electric pump and cutter head.

The dredge will only be operated Monday through Saturday from 7:00 a.m. through 7 p.m. There will be no dredging activities on Sundays or federal holidays. Furthermore, dredging activities will move from location to location as material is removed from the reservoir bottom, therefore any noise attributed to the operation in any one location will be short term.

Equipment operating beneath the surface of the water, particularly electrically powered equipment generates very low sound levels above the surface. The noise study conservatively assumes that the floating sediment removal component of the Eveready system generates an average noise level of 50 dB Leq at a reference distance of 10 feet. Because this level is below both Placer and Nevada County daytime noise standards, and because this aspect of the project would be limited to daytime hours, noise impacts at the nearest residences are not expected even with the submerged sediment removal equipment located very near the shoreline of those existing residences.

Material Separation and Dewatering System (MSDS)

The electrically powered MSDS is a complete set of portable equipment used to dredge, classify, and dewater aggregate material from the reservoir. This equipment will feed material directly to the concentrator within the shore mounted dewatering system. The dewatered material will produce a liquid effluent, or centrate, resulting in a clean water return to Combie Reservoir and a solid material by-product.

The pumping activity through the pipeline will occur constantly during dredge and mercury removal activities. The dredge pump, cutterhead and dewatering system motors operate remotely through Variable Frequency Drive (VFD) controls. The flow of material will vary based on the pulp density of the slurry material and the capacity of the Concentrator. The flow will be controlled by the on-board operator using the VFD controls.

The noise study also relied upon noise level measurements of the Eveready dewatering equipment in April of 2009. Those measurements indicate that, while the dewatering equipment was in normal operation, an average noise level of 48 dB was measured at a reference distance of 100 feet. Because the Eveready dewatering equipment

would be located well beyond 100 feet from existing residences, average noise levels at those nearest residences are predicted to be less than 48 dB Leq during operation of the dewatering equipment. In addition, because that equipment would only operate during daytime hours, this noise level would be well within compliance of both Placer and Nevada County noise standards.

Mercury Removal Equipment (Concentrator) Noise Generation

The mercury concentrator is located within an enclosed machined unit and mounted on portable trailer unit with a fully enclosed laboratory/office. That data indicates that the concentrator equipment (including the associated small less than 50 h.p.generator) produces sound pressure levels of 75 to 86 dBA Leq at a distance of 3 feet from the concentrator equipment. The nearest residence is located approximately 500 feet from the concentrator equipment, which could run continuously 24 hours per day, 7 days per week. At that distance, the concentrator noise levels would be reduced through spherical spreading of sound (6 dB decrease for each doubling of distance from the source) to approximately 41 dB Leq. This level would satisfy both the target daytime and nighttime noise criteria for this project. As a result, no additional noise mitigation measures would be warranted for this aspect of the project based in the manufacturers' noise emission data. Further attenuation would be achieved, if needed, by housing the concentrator in a mobile enclosure.

Loader / Haul Truck Noise Generation

Haul trucks will be used to transfer the aggregate material to the Chevreaux facility. Based on a maximum of 32 round trips, with each round trip consisting of two pass-bys (1 arriving empty and 1 departing full), a total of 64 trips could be generated in an 8-hour operating day, or about 8 per hour. Based on BAC file data for individual aggregate truck pass-bys, 8 such hourly truck pass-bys would generate a noise level of approximately 57 dB Leq at a distance of 50 feet. Maximum levels of 75 dB at 50 feet are predicted for the truck pass-bys based on extensive testing of aggregate trucks by BAC staff in recent years. Maximum noise levels for back-up warning devices (typically beepers), can also be expected to reach 75 dB Lmax at a reference distance of 50 feet.

The truck pass-by route is approximately 425 feet from the nearest residence. At that distance, truck pass by noise levels would be 46 dB Leq and 61 dB Lmax. These levels are below the target noise level criteria for daytime hours and no nighttime transfer of material to the Chevreaux facility is proposed. As a result, no additional noise mitigation measures appear to be warranted for the haul truck trips occurring between the concentrator and the Chevreaux facility.

Generally haul trucks will be loaded directly from the dewatering equipment via conveyor belts. There will also be times where haul trucks will be filled using loaders. The average level of noise received at the nearest residence from the loader or excavator loading the trucks will depend on the duration of time the loading is taking place during a given hour and any shielding, which may be present between that equipment and the nearest residence. Loader noise generation can reach 75 dB Leq at 100 feet if operating continuously for an hour, which would equate to approximately 60 dB Leq at the nearest residence. As a result, the hourly Leq for loader activity is predicted to be between 65-70 dB Leq at a reference distance of 100 feet. This level would reduce to approximately 50-55 dB Leq at the nearest residence. This level would satisfy the target daytime noise level range of 55-60 dB Leq at the nearest residences, and would therefore, not warrant consideration of additional noise reduction measures.

Maximum noise levels generated by the loading equipment will likely be approximately 80 dB at 100 feet, which would equate to approximately 65 dB Lmax at the nearest residence. This level would be satisfactory relative to both County noise standards and measured existing daytime ambient conditions. As a result, consideration of noise reduction measures for maximum noise levels generated by loaders would not be warranted.

Off-site Transport of Treated Materials on Local Roadways

According to the project traffic engineer (K.D. Anderson), there are an average of approximately 204 existing daily truck trips on Combie Road between Placer Hills Road and the project site. The additional truck trips under the worse case conditions which could be generated through the direct sale of aggregates (not utilizing the on-site Chevreaux aggregate processing plant) resulting from this project would be approximately 72 trips per day. Based on the increase in heavy truck trips alone, the project-related increase in traffic noise would be approximately 1.3 dB Ldn. After consideration of the noise generation of existing passenger cars on this roadway as well, the project-related traffic noise level increase would be even lower at approximately 1 dB. Because these additional truck trips would occur during daytime hours, and because a 3-5 dB change is commonly considered to be the threshold of

significance in areas with lower ambient noise levels, the project-related increase in off-site traffic noise is not predicted to be significant.

ADDITIONAL NOISE CONTROL RECOMMENDATIONS

Noise generated by the various project components are expected to satisfy both Placer County and Nevada County noise standards, as well as CEQA guidelines. Nonetheless, the following recommendations are offered to further reduce the potential for adverse public reaction to noise generated by the project:

1. If the proposed Eveready system is not utilized for this project's sediment-removal activities, an equivalent system which similarly utilizes submerged electric equipment should be utilized for this project.

2. Dredging, loading and on-site transportation operations will be limited to the hours of 7:00 a.m. to 7:00 p.m., Monday through Saturday, with no work on Sundays and Federal holidays.

3. All mechanical equipment (e.g. dredge, loaders and dump trucks) will be equipped with the latest, state-of-the-art mufflers.

4. The mercury concentrating equipment should be located at least 500 feet from any existing residence.

5. To the extent feasible, loading of haul trucks should occur behind intervening topography, such as berms.

6. If possible, the conveyor system associated with the Eveready system should be oriented such that trucks can pass underneath the conveyor belt while moving forward, thereby eliminating the necessity to engage back-up warning devices.

7. If possible, the conventional back-up beeper system on the mobile equipment used to load the treated sand into trucks for transport to the Chevreaux facility should be replaced with a radar-based system or a "growler" system. Any such modifications must, however, comply with applicable safety regulations.

With the inclusion of the above project features there will be no potential significant impacts and no further mitigation measure are required.

Discussion- Item XI-b: The dredging operation will not involve any blasting, pile driving or other activity that will produce shaking or ground vibration. No significant impacts will therefore occur and no mitigation measures are required.

Discussion- Item XI-e and f: There are no airports within two miles of the project.

XII. POPULATION & HOUSING – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Induce substantial population growth in an area, either directly (i.e. by proposing new homes and businesses) or indirectly (i.e. through extension of roads or other infrastructure)?				X
b) Displace substantial numbers of existing housing, necessitating the construction of replacement housing elsewhere?				X
c) Displace substantial numbers of people, necessitating the construction of replacement housing elsewhere?				X

Discussion- Item XII-a through c: The project area within the Bear River canyon, including Combie Reservoir is currently uninhabited. The project will not employ a substantial number of employees that would contribute to population growth. With the exception of a dredge operator and operation of the mercury concentrator, no new

employees are expected to be needed by Chevreaux Aggregates and or NID for this operation. Since there will not be any noticeable population growth and the project will not displace existing residents, the project will not create a potential significant impact and no mitigation measures are required.

XIII. PUBLIC SERVICES – Would the project result in substantial adverse physical impacts associated with the provision of new or physically altered governmental services and/or facilities, the construction of which could cause significant environmental impacts, in order to maintain acceptable service ratios, response times or other performance objectives for any of the public services?

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Fire protection?			X	
b) Sheriff protection?			X	
c) Schools?			X	
d) Parks?				X
e) Other public facilities?				X

Discussion- XIII-a, b, c and e: The proposed initial three year project and on-going operation is a re-introduction of a similar project that was halted in 2003 due to water quality standards. This dredge project has always been relatively small and intermittent. The re-establishment of the operation will not generate any new impacts to fire or sheriff protection and other public facilities over that which currently exists with the current Chevreaux Aggregates operation. The presence of substantial water in Bear River and Combie Reservoir is a benefit to fire suppression activities. Since there will not be any direct burden placed on public services, the project will not create a potential significant impact and no mitigation measures are required.

Discussion- XIII-d: The project will not create the demand for any new parks. As an open space feature, Combie Reservoir will continue to be used in the same manner for recreational purposes. The only reduction in recreational use will be in the immediate vicinity of the dredge operation. The area will be cordoned off with log booms to avoid any direct safety concerns. The area cordoned off will be very limited and temporary. As such, it would not significantly impact historic recreational use on the reservoir. No mitigation measures are required.

No mitigation measures are required.

XIV. RECREATION –

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Would the project increase the use of existing neighborhood and regional parks or other recreational facilities such that substantial physical deterioration of the facility would occur or be accelerated?				X
b) Does the project include recreational facilities or require the construction or expansion of recreational facilities which might have an adverse physical effect on the environment?				X

Discussion- Item XIV-a: The re-establishment of dredging operations will not create new demand on existing recreation facilities in the Meadow Vista area or other areas within Nevada and Placer counties. The project will not create a potential significant impact and no mitigation measures are required.

Discussion- Item XIV-b: The proposed project does not include or require the construction or expansion of any recreational facilities. See also discussion under Impact XIII-d. No mitigation measures are required.

XV. TRANSPORTATION & TRAFFIC – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Cause an increase in traffic which is substantial in relation to the existing traffic load and capacity of the street system (i.e., result in a substantial increase in either the number of vehicle trips, the volume to capacity ratio on roads, or congestion at intersections)?			X	
b) Exceed, either individually or cumulatively, a level of service standard established by the county congestion management agency for designated roads or highways?			X	
c) Result in a change in air traffic patterns, including either an increase in traffic levels or a change in location that results in substantial safety risks?				X
d) Increased impacts to vehicle safety due to roadway design features (i.e. sharp curves or dangerous intersections) or incompatible uses (e.g., farm equipment)?			X	
e) Result in inadequate emergency access?				X
f) Result in inadequate parking capacity?				X
g) Conflicts with adopted policies supporting alternative transportation (i.e. bus turnouts, bicycle racks)?				X

Discussion- Items XV-a: As noted throughout, the initial three year dredging project is a resumption and continuation of a prior operation for the primary purpose of maintaining water supply capacity. After initial dewatering and screening, the projected 50,000 tons of annual gravel, sand and sediment materials are intended to be transferred for processing and sale through the existing Chevreaux Aggregates gravel plant in Meadow Vista (within the Bear River canyon about one mile north of Combie Reservoir). As a result, Chevreaux's aggregate processing plant should not generate new truck trips beyond current market demands. It is not expected that materials harvested as part of the initial dredging project would significantly add to the volumes of material that Chevreaux aggregates will process and/or sell in any given year, as processing and sales are market driven. Having made this assumption, a traffic study has been prepared by KD Anderson & Associates, Inc. from Loomis, CA. The findings of that study are summarized under discussion items XV-b and d below.

Chevreaux Aggregates' approved 1986 Reclamation Plan projected that they could collectively produce and sell up to 750,000 tons per year from their quarry lands within the Bear River Canyon (within Placer County) and the Bear River and Combie Reservoir water supply facilities (within both Placer County and Nevada County) that are leased from NID. The 50,000 tons per year generated from the initial project will not increase these overall volumes of production/sales. On-going periodic reservoir maintenance operations will not exceed these annual amounts either. The material harvested from the dredging project is included within the grandfathered rights held by Chevreaux Aggregates in the Bear River canyon and Combie Reservoir environs. Typical types of new traffic to be generated from the project include the initial move in of equipment, daily employee traffic amounting to a maximum of five daily round trips and weekly transport of mercury captured from the recovery system for disposal at an appropriate Class 1 waste disposal site. More importantly, these new weekly trips will not constitute a significant

increase in traffic to the roads leading to and through Meadow Vista; therefore mitigation measures are not required.

Discussion- Items XV-b and d: As noted above, a traffic study (Traffic Impact Analysis for NID Combie Reservoir Sediment and Mercury Removal Project, June 4, 2009) was prepared for the project. The traffic study is included as a part of this Initial Study. The traffic study was based on actual traffic counts taken in April 2009. Once this data was collected, the study identified the existing levels of service on Combie Road at the Placer Hills Road intersection and two other road segments along Combie Road leading to the Chevreaux Aggregates access road. Due to the current economic downturn, demand for construction aggregates is very low and actual traffic counts attributed to Chevreaux is correspondingly well below normal levels. In order to reflect a more normal material trucking level as a baseline, the traffic study reflected actual volumes shipped from the Chevreaux plant between the years of 2003 and 2008. The volumes of material shipped in 2003 and 2005 were similar and reflected the highest two truck traffic years. For purposes of the traffic study trucking trips from 2003 was picked to reflect the baseline conditions.

Even though the project is not being permitted by Placer County, the traffic study relies upon Placer County's adopted level of service standard as a significance threshold for purposes. Policies contained in the Placer County General Plan indicate that the Level of Service (LOS) minimum standard for intersections shall generally be LOS "C". Land development requirements shall be set to sustain LOS "C" at all intersection locations for as long as possible. The Placer County General Plan also indicates that the LOS standard shall be "D" within ½ mile of state highways. The traffic study and summary below also includes a "worse case" trucking traffic scenario. The "worse case" is defined as one where the dredged material is not processed or handled in any way by the Chevreaux operation. Under this scenario all such materials would be transported as additional traffic from the site in a raw unprocessed manner through a separate hauler for delivery, processing and eventual sale at an unknown off-site location. The following is a summary of traffic levels of service conclusions on area roads (for a more detailed review, please see the traffic study):

Existing Conditions. The current Level of Service on roadway segments and at intersections satisfies the minimum LOS "C" standards established by Placer County. Combie Road itself is in good condition as Placer County installed a pavement overlay in 2004. Pavement markings and shoulder treatment are consistent with the existing 35 mph speed limit. Traffic operations on the roads that provide access to the project site do not result in capacity, congestion and/or safety problems.

Baseline Conditions. The year 2003 truck traffic was identified as the "baseline" conditions. Baseline conditions also satisfy Placer County minimum LOS "C" standards.

Project Trip Generation. Under the expected operation, Chevreaux trucks would haul materials to a stockpile on their site. The 40,000 to 67,000 tons attributable to the project each year could generate 5,000 to 8,375 truck loads annually. Spread uniformly over the entire year (250 haul days), this would equate to 20 to 35 truck loads per day and on peak days 40 percent of these shipments are made during the a.m. peak hour (i.e., 8 to 14 truck loads). It is unlikely that any material would be shipped from the site during the typical weekday p.m. peak hour except under unusual circumstances.

Project Impacts. The impacts of project traffic were evaluated by superimposing "worse case" project traffic onto current and Baseline conditions. Under the "worse case" alternative, the amount of materials shipped from the site could vary, but even "worse case" traffic attributed to NID independently hauling material would not exceed Placer County LOS C standards. Minimum Placer County standards for Level of Service will continue to be satisfied. In addition, the presence of and or the addition of project truck traffic does not result in any appreciable change to the safety of motorists on Combie Road.

Cumulative Impacts. The cumulative impact of the project was evaluated based on assumed development of other approved projects and background traffic growth. Minimum Placer County Level of Service standards will be satisfied with and without the project.

The project could add truck traffic to Combie Road. However, while the truck loadings associated with the proposed project would make use of the "capacity" of Placer County's recent overlay project, truck traffic attributed to the project would not appreciably change the overall condition of the road nor result in the need for Placer County to change its regular maintenance schedule.

Discussion- Items XV-c: The project will not impact air traffic operations or create air traffic safety risks. As noted elsewhere, there are no airports in close proximity to the pilot project area, therefore there will be no significant impacts and no mitigation measures are required.

Discussion- Items XV-d and e: The project will not result in the construction or need for development of new roads or create new emergency access impacts. The primary access into the water resource area is through Combie Road through Meadow Vista. Alternative secondary/emergency access is provided to the north through Rutherford Road on the Nevada County side of the Bear River.

Discussion- Items XV-f: Employee parking is provided at the Chevreaux Aggregates site in Meadow Vista. Additional on-site parking for employees working at the dredge and mercury recovery site would be provided in close proximity to the work site. Said parking is designated on stable lands and will be used only during dry weather periods. There will be no operations during the winter/rainy season.

Discussion- Items XV-g: Traffic to and from the site will be minimal (see item XV-a and b, above). As a result, there will be no conflicts with alternative forms of transportation. There are no public transportation services available to the south side of Combie Reservoir from Meadow Vista.

As there will be no new measurable traffic impacts associated with the initial project and the on-going maintenance dredging operation, there will be no new potential significant impacts. As a result, no mitigation measures are required.

XVI. UTILITIES & SERVICE SYSTEMS – Would the project:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
a) Exceed wastewater treatment requirements of the applicable Regional Water Quality Control Board?			X	
b) Require or result in the construction of new water or wastewater delivery, collection or treatment facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?				X
c) Require or result in the construction of new storm water drainage facilities or expansion of existing facilities, the construction of which could cause significant environmental effects?				X
d). Have sufficient water supplies available to serve the project from existing entitlements and resources, or are new or expanded entitlements needed?				X
e) Result in a determination by the wastewater treatment provider which serves or may serve the project that it has adequate capacity to serve the projects projected demand in addition to the providers existing commitments?				X
f) Be served by a landfill with sufficient permitted capacity to accommodate the project's solid waste disposal needs?			X	
g) Comply with federal, state, and local statutes and regulations related to solid waste?			X	

Discussion- Items XVI-a: The project is seasonal, similar to a long term construction project that is in a remote location and away from urban services. Public water and wastewater treatment services are not available to the site. As a result, an onsite portable toilet will be provided for employees working at the site. The portable toilet will be located in accordance with Placer County standards. One unisex toilet will be provided for the workforce (up to five employees). The portable toilet will be located a minimum of 100 feet from all water sources pursuant to the septic tank standards in Table One of the Placer County On-Site Sewage Manual adopted on December 1, 2004. The portable toilet will be maintained and serviced on a regular basis to prevent health hazards and pollution of

adjoining water sources. It will also be removed following the end of each dredging season. Compliance with the sewage disposal standards will ensure no significant impact; therefore no mitigation measures are required.

Discussion- Item XVI-b, d and e: As noted above, there will be no extension of waste water treatment facilities or potable water lines to serve the project. There will be no on-site permanent water supply provided as the use is a temporary intermittent one. Portable water will be provided via a bottled water source as is typically provided on construction sites. No mitigation measures are required.

Discussion- Items XVI-c: There will be no need to construct or extend storm water facilities to the project site. There will be no change in ground contours and there will be no construction of any permanent impervious surfaces on site. All storm water flows are natural. The project will not involve any disturbance or grading that would interfere with natural storm water flows within the Bear River or Combie Reservoir system. All equipment used in the operation is portable and will be removed each year in advance of the on-set of winter storms or October 30, whichever occurs first. No mitigation measures are required.

Discussion- Item XVI-f and g: All solid waste will be collected in appropriate on-site containers and transported to the county landfill. The only solid waste expected to be generated is associated with refuse (papers, cans, bottles, etc.) generated by on-site employees.

As there will be no new measurable impacts to public services and utilities attributed to the initial project and the on-going maintenance project, there will be no potential significant impacts. As a result, no mitigation measures are required.

MANDATORY FINDINGS OF SIGNIFICANCE:

Environmental Issue	Potentially Significant Impact	Less Than Significant with Mitigation Measures	Less Than Significant Impact	No Impact
1. Does the project have the potential to degrade the quality of the environment, substantially impact biological resources, or eliminate important examples of the major periods of California history or prehistory?		X		
2. Does the project have impacts that are individually limited, but cumulatively considerable? ("Cumulatively considerable" means that the incremental effects of a project are considerable when viewed in connection with the effects of past projects, the effects of other current projects, and the effects of probable future projects.)			X	
3. Does the project have environmental effects, which will cause substantial adverse effects on human beings, either directly or indirectly?		X		

Signature Ron Nelson Date 7-13-09
Ron Nelson, General Manager

OTHER RESPONSIBLE AND TRUSTEE AGENCIES whose approval is required:

☒ California Department of Fish and Game	☐ National Marine Fisheries Service
☐ California Department of Forestry	☐ County of Nevada
☐ California Department of Health Services	☒ County of Placer
☐ California Department of Toxic Substances	☒ U.S. Army Corp of Engineers
☐ California Department of Transportation	☐ U.S. Fish and Wildlife Service
☐ California Integrated Waste Management Board	☒California Air Resources Board
☒ California Regional Water Quality Control Board	☐

SUPPORTING INFORMATION SOURCES: The following public documents were utilized and site-specific studies prepared to evaluate in detail the effects or impacts associated with the project. Unless otherwise noted, this information is available for public review, Monday through Friday, 8am to 5pm, at the Nevada Irrigation District, 1036 W. Main Street, Grass Valley, CA and on NID's website (www.nidwater.com [click on "Planning and Development" and then select "Project Documents" and then scroll down to "Combie Reservoir"].).

Reference documents available through NID:

1. Lake Combie Specialty Sands and Gravels, California Department of Conservation, Division of Mines and Geology, November 1984 (included on CD as file named "CDC_Combie_Sands_and_Gravel.pdf")
2. Combie Reservoir Water Supply and Maintenance Project: Preliminary Biological Evaluation for CEQA Initial Study, Garcia and Associates, July 2009 (included on CD as file named "Biological_Evaluation.pdf")
3. Cultural Resources Study for the Lake Combie Mercury Extraction Project, Anthropological Studies Center, Sonoma State, August, 2008 (included on CD as file named "Cultural_Res_Study.pdf")
4. Stephen M. Testa, Executive Officer, California State Mining and Geology Board, July 30, 2008 (included on CD as file named "CDC_Letter.pdf")
5. Environmental Noise Assessment, Combie Dredge Project, Bollard Acoustical Consultants, Inc. July 2009 (included on CD as file named "Noise_Assessment.pdf")
6. Traffic Impact Analysis for NID Combie Reservoir Sediment and Mercury Removal Project, KD Anderson & Associates, Inc. June 5, 2009 (included on CD as file named "Traffic_Analysis.pdf")
7. Reclamation Plan, Sand and Gravel Recovery at Lake Combie, January 20, 1986 (hardcopy only)

Documents available through other sources as noted

1. Alquist-Priolo Earthquake Fault Zoning Map (See Department of Conservation website: http://www.conservation.ca.gov/cgs/information/publications/cg_pdfs/Documents/7801_CG.pdf)
2. Meadow Vista Community Plan, Placer County, 1996 (Placer County Planning Department)
3. Meadow Vista Community Plan EIR, 1996 (Placer County Planning Department)
4. Placer County General Plan, 1994 (Placer County Planning Department)
5. Nevada County General Plan, 1995 (Nevada County Planning Department)
6. Water Quality Standards; Establishment of numeric criteria for Priority toxic Pollutants for the State of California Rule. Federal Register. 2000 (http://www.epa.gov/fedrgstr/EPA-WATER/2000/May/Day-18/w11106.pdf)

Notice of Determination

Form C

To: ☒ Office of Planning and Research

For U.S. Mail:
P.O. Box 3044
Sacramento, CA 95812-3044

Street Address:
1400 Tenth Street
Sacramento, CA 95814

From: Public Agency

Agency: Nevada Irrigation District

Address: 1036 West Main Street
Grass Valley, CA 95945

Contact: Tim Crough, Assistant General Manager

Telephone: 530-273-6185

☒ County Clerk

County of: Placer

Address: County Clerk-Recorder
2954 Richardson Drive
Auburn, CA 95603

Lead Agency (if different from above)

Agency: same as above

Address:

Contact:

Telephone:

SUBJECT: **Filing of Notice of Determination in Compliance with Section 21108 or 21152 of the Public Resources Code**

FILED

SEP 25 2009

Jim McCauley
COUNTY CLERK OF PLACER COUNTY
BY _____ Deputy

State Clearinghouse Number (if submitted to State Clearinghouse): 2009072068

Project Title: Combie Reservoir Sediment and Mercury Removal Project

Project Location (include county): Placer and Nevada

Project Description: The proposed project involves the dredging of 150,000 to 200,000 tons of sediments within the upper Combie Reservoir to mainatin water storage capacity. Excavated material will be processed through an on-shore mechancial mobile separation and dewatering system. Mercury will be removed from all excavated and dewatered materail through a concentrator. Separate, clean sand and aggregate material will be processed through an existing aggregate processing plant on lands to the north or simlar plant in Nevada County or Placer County. This project is intended to be an on-going reservoir maintenance activity.

This is to advise that Nevada Irrigation District

☒ ***Lead Agency*** or ☐ ***Responsible Agency*** has approved the above-described project on September 23, 2009

and has made the following determinations regarding the above-described project:

1. The project ☒ ***will*** ☐ ***will not*** have a significant effect on the environment.
2. ☐ An Environmental Impact Report was prepared for this project pursuant to the provisions of CEQA.
   ☒ A Negative Declaration was prepared for this project pursuant to the provisions of CEQA.
3. Mitigation measures ☒ ***were*** ☐ ***were not*** made a condition of the approval of the project.
4. A mitigation reporting or monitoring plan ☒ ***was*** ☐ ***was not*** adopted for this project.
5. A Statement of Overriding Considerations ☐ ***was*** ☒ ***was not*** adopted for this project.
6. Findings ☒ ***were*** ☐ ***were not*** made pursuant to the provisions of CEQA.

This is to certify that the final EIR with comments and responses and record of project approval, or the Negative Declaration, is available to the General Public at: Nevada Irrigation District office at the address above

Signature (Public Agency)	Title	Date
	General Manager	September 23, 2009

Date received for filing at OPR: _____

Authority cited: Sections 21083 and 21087, Public Resources Code. Reference: Sections 21000–21174, Public Resources Code.

POSTED ~~09/25/2009~~
Through
JIM McCAULEY, COUNTY CLERK
By _____ Deputy Clerk

#168

Revised 2004

Notice of Determination

Form C

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Sacramento, CA 95812-3044

Street Address:
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From: Public Agency

Agency: Nevada Irrigation District

Address: 1036 West Main Street
Grass Valley, CA 95945

Contact: Tim Crough, Assistant General Manager

Telephone: 530-273-6185

☒ County Clerk
County of: Nevada
Address: Eric W. Rood Admin. Center
950 Maidu Avenue
Nevada City, CA 95959

Lead Agency (if different from above)

Agency: same as above

Address:

Contact:

Telephone:

2009 SEP 25 PM 2:21 CLERK RECORDER

SUBJECT: **Filing of Notice of Determination in Compliance with Section 21108 or 21152 of the Public Resources Code**

State Clearinghouse Number (if submitted to State Clearinghouse): 2009072068

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	General Manager	September 23, 2009

Date received for filing at OPR: _____

Authority cited: Sections 21083 and 21087, Public Resources Code. Reference: Sections 21000–21174, Public Resources Code.

Revised 2004

ANTIDEGRADATION ANALYSIS

FOR THE

COMBIE RESERVOIR SEDIMENT AND MERCURY REMOVAL PROJECT

NEVADA IRRIGATION DISTRICT

AUGUST 1, 2012

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This report was prepared by

8-28-12

Carrie Monohan, Ph.D. Hydrologist
Science Director
Headwater Sciences
425 Commercial St.
Nevada City, CA 95959

Date

REGISTERED PROFESSIONAL ENGINEER
TIMOTHY CROUGH
No. 38033
EXP. 3-31-2013
CIVIL
STATE OF CALIFORNIA

This report was reviewed and accepted by

8-27-2012

Timothy Crough, P.E.
Assistant General Manager
The Nevada Irrigation District
1036 West Main St.
Grass Valley, CA 95945

Date

Special Thanks to Jason Muir, Dr. Charlie Alpers and Dr. Mark Marvin-DiPasquale for their invaluable assistance and technical comments to this project.

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1 INTRODUCTION

1.1 Discharger Description

The Nevada Irrigation District (NID) owns and operates Combie Reservoir, which was constructed on the Bear River in 1926. Combie Reservoir as well as the ten-mile segment of the Bear River below Combie Reservoir extending to Camp Far West Reservoir, are listed by the State Water Resources Control Board (SWRCB) as impaired for mercury, and SWRCB expects that a Total Maximum Daily Load (TMDL) for mercury associated with Combie and this segment of the Bear River will be developed in 2015.

At full capacity Combie Reservoir has 5,555 acre-feet of operational water storage. For more than 40 years, NID has contracted with aggregate mining companies to remove sediment that migrates toward the reservoir. Dredging operations in Combie Reservoir were halted in 2003 by Chevreaux Aggregates, Inc. (then current aggregate mining operator) due to elevated mercury levels found in dredge effluent. Chevreaux could not continue to dredge the reservoir and keep "Total Mercury" levels (in the reservoir) below the new requirements established by the Central Valley Regional Water Quality Control Board (the Regional Water Board). As a result, NID has been unable to remove sediment from Combie Reservoir, affecting NID's efforts to maintain reservoir storage capacity.

Mercury is commonly found in sediment as a result of the region's gold mining legacy, and maintenance dredging is necessary to maintain storage capacity in reservoirs throughout the region; therefore there is regional need for development of a Best Management Practice for removal of sediment from Sierra reservoirs with historic mercury contamination.

The purpose of the Combie Reservoir Sediment and Mercury Removal Project (the Project) is to:

a. Remove sediment that has accumulated in Combie Reservoir since 2003;
b. Remove free elemental mercury using an innovative recovery process from settled and suspended sediment recovered during the dredging operations; and
c. Develop a Best Management Practice for removal of sediment from Sierra reservoirs with historic mercury contamination.

The Project will dredge sediment from Combie Reservoir using an electric "quiet" dredge while implementing an innovative recovery process to remove elemental mercury from the dredged material, and return clean water to the reservoir. The project will take 3 to 5 years, operating up to nine months per year generally from March to November, each year - weather permitting. The project will remove and treat an estimated 200,000 cubic yards of sediment from the northeastern

arm of Combie Reservoir. The dredged material (slurry) will be pumped to a mobile land-based staging area where it is processed through dewatering and mercury extraction equipment. The dewatering equipment will sort and dewater the dredged material before and after mercury extraction, which is to be performed by centrifuge and subsequent removal of suspended solids using clarification tanks and filters. A process flow diagram is presented as Figure 1.

In order to verify the effectiveness of the mercury extraction equipment and to monitor the Project impacts on Combie Reservoir, the applicant will monitor water quality, reservoir sediment and biota (invertebrates, trout and bass) before, during and after the Project. The water, sediment and biotic data will be analyzed by USGS scientists and published at the end of the Project. The District will also monitor and report water quality according to the standards set forth in the Waste Discharge Permit developed by the Central Valley Regional Water Quality Control Board.

This report summarizes pre-project receiving water quality (Appendix III) and the findings of equipment tests performed to date (Appendix IV). Pre-project water quality data collection included monthly water quality monitoring at locations above, below and at the Project site for one year (2/18/2009-1/20/1010). Equipment tests included four (4) closed system tests that were conducted in September and October of 2009, and analysis of total and dissolved metals concentrations in samples of the system effluent. The goal of the equipment tests was to calculate the efficiency of the mercury extraction equipment.

Based on the equipment tests conducted to date, it is apparent that most of the heavy metals, including mercury can be removed by the extraction equipment, however, a final clarification step is required to remove suspended solids prior to discharge (of effluent) to Combie Reservoir. The analysis presented herein is based on dissolved metals concentrations in system effluent, which are intended to represent metals concentrations in the polished effluent. The analysis presented herein is intended to assist in the development of waste discharge requirements and monitoring requirements for the Project.

1.2 Purpose of Report

The purpose of this report is to document the antidegradation analysis performed to evaluate the Combie Reservoir Sediment and Mercury Removal Project. The information contained in this analysis is intended to provide the Regional Water Board with the information needed to certify that the proposed Project is consistent with state and federal antidegradation policies. In October of 2010, the NID submitted its NPDES permit application for the Project. This report serves as additional documentation to support that application.

This antidegradation analysis follows guidance from the SWRCB regarding the implementation of the antidegradation policy, as set forth in the Administrative Procedures Update (APU) 90-004, “Antidegradation Policy Implementation for NPDES Permitting.” Pursuant to APU 90-004,

this analysis follows the provisions for a 'complete analysis' and evaluates whether changes in water quality resulting from the proposed sediment and mercury removal 'will be consistent with maximum benefit to the people of the State,' 'will not unreasonably affect present and anticipated beneficial use,' and 'will not result in water quality less than that prescribed in the policies.'

The analysis comprises two primary components: (1) a comparison of receiving water quality to the water quality objectives and/or criteria used to protect designated beneficial uses, and (2) a socioeconomic analysis to establish the balance between the proposed spatially localized reduction of water quality and the public interest.

2 REGULATORY ANTIDEGRADATION REQUIREMENTS

Antidegradation policies have been issued at both the federal and state level. These policies are intended to protect existing water quality.

2.1 Federal Antidegradation Policy

The federal policy, originally adopted in 1975, is expressed as a regulation in Title 40 of the Code of Federal Regulations, Section 131.12 (40 CFR 131.12). The federal policy requires that "water quality shall be maintained and protected." More specifically, the federal regulation requires states to develop and adopt a statewide antidegradation policy and identify the methods for implementing such a policy. The state antidegradation policy and implementation methods are required, at a minimum, to ensure that existing water uses and the level of water quality necessary to protect these uses be maintained and protected. Where water quality exceeds the levels necessary to support beneficial uses, measures are to be taken to ensure that water quality is maintained and protected, unless the State finds that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located.

Water bodies can be classified in three tiers of antidegradation protection, pursuant to the provisions of the federal antidegradation policy, although the tiers were not specifically named in the federal policy. The tiers and the corresponding provisions of 40 CFR 131.12 are summarized below.

<u>Tier I</u>: Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.

<u>Tier II</u> (High Quality Waters): Where the quality of water exceeds levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality must be maintained and protected unless the State finds, after full satisfaction of the intergovernmental coordination and public participation provisions of the State's continuing planning process, that

allowing lower water quality is necessary to accommodate important economic or social development in the area in which the waters are located. In allowing such degradation or lower water quality, the State is required to assure water quality adequate to protect existing uses fully. Further, the State is required to assure that the highest statutory and regulatory requirements are achieved for all new and existing point sources and all cost-effective and reasonable best management practices are used for nonpoint source control.

Tier III (Outstanding National Resource Waters): Where high quality waters constitute an outstanding national resource, such as waters of National and State parks and wildlife refuges and water of exceptional recreational or ecological significance, that water quality must be maintained and protected.

Additional guidance pertaining to the federal antidegradation policy can be found in:

- "Guidance on Implementing the Antidegradation Provisions of 40 CFR 131.12" (United States Environmental Protection Agency, Region 9 (USEPA 1987). This document provides general program guidance for states in Region 9 on developing procedures for implementing antidegradation policies. This document is appended to APU 90-004.
- "Tier 2 Antidegradation Reviews and Significance Thresholds" (USEPA, 2005). This memorandum provides technical recommendations to USEPA regions pertaining to the lowering of water quality in high quality waters.

The purpose of Tier 2 protection, according to USEPA (2005), "is to maintain and protect high quality waters and not to allow for any degradation beyond a de minimis level without having made a demonstration that such a lowering is necessary and important." To quantify this de minimis level, USEPA (2005) considers the "available assimilative capacity," which is defined as the difference between the applicable water quality criterion for a specific water quality parameter and the ambient water quality of that parameter, where ambient water quality is better than the water quality criterion. A "significance threshold value" of ten percent (10%) of the available assimilative capacity is set forth for non-bioaccumulative chemicals of concern. Discharges that would reduce the assimilative capacity of a water body by greater than ten percent of its baseline assimilative capacity would typically require a full Tier 2 antidegradation review. Where there are multiple or repeated increases in discharges, a cumulative cap on the reduction of the assimilative capacity of a water body may be considered.

2.2 State Antidegradation Policy

The state policy, "Statement of Policy with Respect to Maintaining High Quality of Waters in California" was issued by the State Water Resources Control Board (SWRCB) in 1968 as Resolution 68-16 and predates the federal policy. As stated in the *Water Quality Control Plan*

(Basin Plan) for the Sacramento River and San Joaquin River Basins (Regional Water Board, 1998, page IV-8.00), the SWRCB has interpreted Resolution No. 68-16 to incorporate the federal antidegradation policy. Resolution No. 68-16 states, in part:

1. Whenever the existing quality of water is better than the quality established in policies as of the date on which such policies become effective, such existing high quality will be maintained until it has been demonstrated to the State that any change will be consistent with maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water, and will not result in water quality less than that prescribed in the policies.

2. Any activity that produces or may produce a waste or increased volume or concentration of waste and which discharges or proposes to discharge to existing high quality waters will be required to meet waste discharge requirements which will result in the best practical treatment or control of the discharge necessary to assure that (a) a pollution or nuisance will not occur and (b) the highest water quality consistent with maximum benefit to the people of the State will be maintained.

3 WATER QUALITY STANDARDS

3.1 Beneficial Uses

Existing beneficial uses set forth in Table II-1 of the Basin Plan (Regional Water Board, 1998) for the Bear River (Hydrologic Unit No. 515.1) include municipal and domestic supply (MUN); irrigation and stock watering (AGR); power production (POW); body contact (swimming and water skiing) and canoeing and rafting (REC-1); other non-body contact water sports (REC-2); warm (WARM) and cold (COLD) freshwater habitat; and wildlife habitat (WILD). Potential beneficial uses include warm and cold migration (MIGR) and spawning (SPWN) habitat.

3.2 Water Quality Objectives/Water Quality Criteria

To protect the designated beneficial uses, the Regional Water Board applies water quality objectives contained in the Basin Plan and other water quality criteria applicable to the receiving water, Combie Reservoir on the Bear River. Pursuant to the *Policy for Implementation of Toxic Standards for Inland Surface Waters, Enclosed Bays and Estuaries of California* (State Implementation Policy; SWRCB, 2005), federal criteria are set forth in the National Toxics Rule (NTR; USEPA 1995) and in the California Toxics Rule (CTR; USEPA 2000), which is promulgated by the USEPA in 40 CFR 131.38. State objectives are listed in the Basin Plan (Regional Water Board, 1998). For constituents not listed in the California Toxics Rule and in the absence of an adopted numeric objective, the Regional Water Board interprets narrative

water quality objectives using water quality criteria developed from other sources. The following objectives and criteria are potentially applicable:

1. Water quality objectives established by the NTR and CTR;
2. Water quality objectives from the Basin Plan (Regional Water Board, 1998), including Maximum Contaminant Levels (MCLs) specified in Title 22 of the California Code of Regulations (22 CCR) and incorporated by reference into the Basin Plan; and
3. USEPA ambient water quality recommended criteria and other criteria commonly used by the Regional Water Board to interpret narrative objectives in the Basin Plan.

Table 1 presents the most conservative water quality objectives that may apply to Combie Reservoir for constituents for which there is an adopted numeric water quality objective. Hardness-based objectives for metals listed in the California Toxics Rule were calculated for each month using the lowest hardness observed in the Bear River upstream of Combie Reservoir.

3.3 303(d) Listings

Section 303(d) of the Clean Water Act requires States to develop lists of water bodies (or segments of water bodies) that do not attain water quality standards after implementation of minimum required levels of treatment by point-source dischargers (i.e. municipalities and industries). Section 303(d) requires States to develop a total maximum daily load (TMDL) for each of the listed pollutant and water body combinations for which there is impairment. Rollins Reservoir, the stretch of the Bear River below Rollins, Combie Reservoir and the ten-mile segment of the Bear River below Combie Reservoir extending to Camp Far West Reservoir, are listed by the SWRCB as impaired for mercury, and SWRCB expects that a TMDL for mercury associated with this segment of the Bear River will be developed in 2015.

3.4 NPDES Permit Requirements

In October of 2010, the NID submitted its NPDES permit application for the Project. Waste discharge requirements are to be developed pursuant to NID's application and the findings of this report.

4 ENVIRONMENTAL SETTING

Combie Reservoir is one of three impoundments on the Bear River. The Bear River flows west from the Sierra Nevada Mountains toward the Feather River and into the California Bay Delta. The Project takes place just northeast of Auburn, approximately 30 miles from Sacramento, California. Combie Reservoir straddles the Nevada-Placer County line east of the Lake of the Pines community in Nevada County and west of the Meadow Vista community in Placer County.

The location of the Project is in the northeastern arm of the Combie Reservoir at the Bear River inflow.

An aerial photograph of Combie Reservoir is presented as Figure 2. Dredging is to take place within the northeastern arm of the reservoir, which is clearly impacted by sediment deposition as depicted on Figure 2. Dredged materials will be pumped as s slurry to the process area, which is described below. The proven dredging technology is not expected to discharge sediment or process water to the reservoir.

The process operations will take place on land, within a 3-acre process area located on the north end of the old dredge pond, above the 1600-foot high water elevation. The locations of the process area and the old dredge pond are depicted on Figure 2. The old dredge pond is an approximately 43-acre excavated area in the northern end of the reservoir that is approximately ¾ mile in length, 400 to 700 feet wide, and 30 feet deep. Project effluent will discharge into the north end of the old dredge pond at the approximate location shown on Figure 2. Surface water from the old dredge pond enters the reservoir at the pond outlet, as depicted on Figure 2.

Surface water sample locations AC (Above Combie), PO (Pond Outlet), and BC (Below Combie) are depicted on Figure 2. Summary statistics and laboratory reports for Combie Reservoir water quality, and for Project effluent water quality, are provided in Appendix II.

4.1 Hydrology

The Bear River watershed covers approximately 292 square miles. The Bear River begins in Nevada County approximately 1 mile southwest of the Spaulding Dam, which is operated by PG&E. It flows southwest 65 miles to its confluence with the Feather River. From the release at Spaulding/Drum afterbay the river flows 15 miles to Rollins Reservoir, which is operated by NID. The Bear River is released from Rollins Reservoir and flows 10 miles to Combie Reservoir, which is also operated by NID. From Combie Reservoir, the river is released and flows another 17 miles to Camp Far West Reservoir, which is operated by the South Sutter Water District. The lower Bear River runs from Camp Far West Reservoir 16 miles to the confluence with the Feather River.

Combie Reservoir was constructed in 1929. Camp Far West Reservoir was constructed in 1963, and Rollins Reservoir was constructed in 1965. NID measures the discharge from Rollins Reservoir and from Combie Reservoir. Flow data for the Bear River are available from the NID gages below Rollins (BRBR), and the NID records for Combie spill (BR338), Combie Powerhouse (BR339) and Combie Fish flows (BR386). Flows were measured daily at Rollins from April 1912 through September 1916, then again from April 1950 through September 1953, then again from September 1964 through November 1966, then again from December 1996 through January 1997, and again from February 1997 through September 2008. Combie spill data and fish flows began in March 1953. The Combie Powerhouse began operations in June

1984. There is also a USGS gage on the Bear River near Wheatland which began operation in 1928 (USGS #11424000).

The hydrology at the two upstream sampling locations (sites AC and PO – see descriptions below) are assumed to be hydrologically represented by the gage below Rollins Reservoir, upstream of Combie Reservoir. The sampling location below Combie Reservoir (site BC) is best represented by the sum of Combie spill (BR338), Combie Powerhouse (BR339) and Combie Fish flows (BR386). The mean daily hydrographs during the sampling period, which began February 2009 and extended until February 2010, at Rollins and at Combie Reservoirs are presented below in Figure 3.

4.2 Water Quality Monitoring Data

Water quality monitoring included one year of monthly water sampling (from February 18, 2009 through January 20, 2010). Water quality samples were taken at three locations: the inlet to Combie Reservoir in the Bear River (AC-Above Combie), at the outlet of Combie Reservoir in the Bear River below the dam (BC-Below Combie) and at the downstream end of the old dredge pond in Combie Reservoir (PO-Pond Outlet). Sample locations are depicted on Figure 2.

Water quality samples were analyzed by BSK Analytical Laboratories, a NELAP certified (certificate number 04227CA) and ELAP certified (certificate number 1180) located in Fresno, California. BSK subcontracted to Brooks Rand Laboratory for the total mercury (Hg) and methyl mercury analysis. Brooks Rand Laboratory specializes in trace metal analysis and is ELAP certified (certificate number 2617). Total Hg was analyzed by EPA Method 1631 with a Method Detection Limit (MDL) of 0.15 ng/L. Methyl Hg was analyzed by EPA Method 1630 with a MDL of 0.020 ng/L. Ultra clean hands methods were used when collecting water samples for mercury analysis (See Section 8.2.3 of the EPA Method 1669 *Sampling Guidance*, trace metals sampling video EPA-821-V-97-001.)

BSK processed unfiltered samples for water quality parameters: general minerals, inorganics, general physical (GMIOGP), dissolved organic carbon (DOC) and volatile organic compounds (VOC) by EPA Methods 200.7, 200.8, 300 and 502. Turbidity, dissolved oxygen, and temperature were also measured in the field using YSI meter (556 Multiparameter Probe) at the time of sampling.

Metals concentrations in receiving water at sample location AC are presented in Table 2. Referencing the hydrograph presented as Figure 3, only three of the monitoring events (July 22, August 25 and September 30, 2009) were performed during periods of low flow. Receiving water data obtained during the three low-flow monitoring events were used as receiving water data. Data obtained during storm events or other high-flow conditions were not considered representative of background water quality data.

Appendix III describes background mercury concentrations in the Bear River. Total mercury exceeded 50ng/L during the February 26 storm event at all three locations. Values ranged from 112-272ng/L.

4.3 Effluent Water Quality Constituents of Concern

Four demonstration tests of the Pegasus mercury removal equipment were conducted in September and October of 2009. The results are summarized briefly here and described in detail in Appendix IV.

The tests of the Pegasus mercury extraction equipment were closed system tests where all of the material that entered the equipment was captured so that mass balances for water, sediment, and mercury could be calculated. The equipment tests were performed using material from two different sources. The first source was the drying beds from the Chevreaux Aggregates Plant (immediately north of the Project area), which was known to be high in mercury. The second source was from the Bear River delta within Combie Reservoir, which contains the material to be dredged as part of the Project.

Effluent water quality data for Test 2, which processed material from the Project area, were used to estimate the potential impact of the Project to the water quality of Combie Reservoir. During Test 2 three effluent samples were obtained and analyzed for the same water quality constituents as the background water samples obtained from the Combie Reservoir, including Title 22 metals by USEPA Methods 200.7 and 200.8, VOCs by USEPA Method 502.2, and general water quality parameters. No VOCs were detected in effluent or receiving waters (Appendix I for Table of Non-Detects). Total metals data indicated that a clarification step was necessary prior to discharge of effluent. Therefore, additional laboratory analysis was performed using effluent that was filtered in the laboratory to simulate the clarification step. Dissolved metals concentrations detected in filtered effluent data are presented in Table 3.

5 ASSESMENT OF WATER QUALITY IMPACTS

To determine whether the Project would adversely affect Combie Reservoir water quality conditions and whether the Project would potentially violate the state and federal antidegradation policies, two questions must be answered:

1. First, would the constituent concentrations in surface water downstream of the Project exceed the applicable water quality objectives?

2. Second, would the Project discharge potentially violate the state and federal antidegradation policies?

To answer these questions, maximum effluent concentration data were compared to receiving water data and water quality objectives, and mixing calculations were performed to estimate the change in chemical concentrations in downstream receiving waters.

5.1 Reasonable Potential Analysis

To determine whether a reasonable potential to degrade water quality exists, maximum effluent concentration (MEC) data were compared to receiving water (B) data and the lowest applicable water quality objective (C) pursuant to the criteria outlined below.

a. If MEC < C and B < C, then there is no reasonable potential.

b. If either MEC > C or B > C, and there are no qualifiers ("J" flags), then there is reasonable potential.

c. If both MEC > C and B > C, and there are qualifiers, then the analysis is inconclusive.

d. If both MEC > C and B > C, and there are no qualifiers, then there is reasonable potential.

Water quality objectives are described in Section 3.2 and are listed in Table 1. Receiving water data are presented in Table 2, and filtered effluent data are listed in Table 3. Laboratory reports are presented in Appendix II.

Pursuant to guidelines set forth in the State Implementation Policy (SWRCB, 2005), the lowest detection limit is used as the MEC value when a constituent was not detected and the reported detection limit is below the C value. The observed maximum ambient background concentration for a constituent, considering only data collected during non-storm conditions, is used as the B value.

The analysis identified arsenic and manganese as constituents for which reasonable potential exists. All background data for arsenic are non-detect, and the arsenic concentration in effluent (2.7 ug/L) exceeds the USEPA NAWQC (0.018 ug/L) for consumption of water and organisms. The arsenic concentration in effluent is lower than the Primary MCL for arsenic (10 ug/L) in drinking water. All background data for manganese are non-detect, and the manganese concentration in effluent (750 ug/L) exceeds the CDPH Secondary MCL for manganese (50 ug/L).

5.2 Critical Flow and Water Quality Measurements

The Project will generally operate from March to November, weather permitting. The worst case analysis considers dry season flow rates, which would allow for the least dilution of Project effluent. Referencing Figure 3 and Table 5, the lowest flow rates during the proposed operating period (March through November) occur from July to November. The analysis considers the flowing low flow rates:

- For assessment of acute aquatic life effects, the receiving water flow rate is equal to the lowest 1-day average flow (1Q10; 500 L/s) that occurs during the proposed operating period once every 10 years (on average).
- For assessment of chronic aquatic life effects, the receiving water flow rate is equal to the lowest 7-day average flow (7Q10; 600 L/s) that occurs on average once every 10 years.
- For assessment of long-term human health and other long term criteria (such as agriculture), the receiving water flow rate is equal to the harmonic mean flow (2,900 L/s) during the proposed operating period.

In the absence of dissolved metals data for receiving water, the analysis conservatively considers total metals concentrations in receiving water for low flow conditions (July, August and September 2009 sampling events). The analysis considers the following concentration data from this low flow period:

- For assessment of aquatic life effects (both acute and chronic), maximum receiving water concentrations are used.
- For assessment of long-term human health effects and other long term criteria (such as agriculture), the average concentration is used.

For "non-detect" values, input concentrations are represented by the MDL value, when "J" data are reported by the laboratory, or by a value equal to one-half of the laboratory reporting limit when "J" data are not reported by the laboratory.

5.3 Mixing Calculations

Chemical concentrations for individual constituents in Combie Reservoir downstream of the Project discharge were estimated by a mass balance calculation using the upstream receiving water and effluent concentrations, as well as the anticipated receiving water and proposed effluent flow rates. Mixing calculations were performed for constituents identified by the Reasonable Potential Analysis. As summarized in Table 4, arsenic and manganese were identified as having a reasonable potential to degrade water quality, based on the existing effluent and receiving water data.

Mixing calculations were performed using receiving water quality data from sample location AC (approximately ¾ mile upstream of the discharge point), filtered effluent water quality data from the equipment tests, receiving water flow rates for the Bear River entering Combie Reservoir, and the planned effluent flow rate of 16 liters per second (L/s), or 250 gallons per minute. The receiving water quality concentrations were calculated using the mass balance approach expressed in the following equation and were compared to the lowest applicable regulatory water quality criteria for impact assessment.

$$C_{R2} = \frac{C_{R1} \times Q_{R1} + C_{eff.} \times Q_{eff.}}{Q_{R1} + Q_{eff.}}$$

Where:
C_{R1} = Constituent concentration in surface water above Combie Reservoir
C_{R2} = Predicted constituent concentration in surface water below the discharge point
Q_{R1} = Flow rate of Bear River into Combie Reservoir
Q_{eff} = Flow rate of effluent discharge from the Project
C_{eff} = Constituent concentration in filtered effluent from the Project equipment tests

Mixing calculations are summarized in Table 6. The predicted downstream concentrations for constituents identified as having reasonable potential to degrade water quality (arsenic and manganese) are lower than their respective water quality standards.

5.4 Assimilative Capacity

The available assimilative capacity is defined as the concentration increment between the existing ambient water quality (C_{R1}) and the water quality standard (WQS). It is a measure of the existing capacity in the receiving water to receive treated effluent without significant deleterious effects and without damage to aquatic life or humans who consume the water or water organisms.

$$\text{Available Assimilative Capacity} = WQS - C_{R1}$$

The change in assimilative capacity is defined as the predicted change in downstream receiving water concentration resulting from the effluent discharge (C_{R2} - C_{R1}) divided by the available assimilative capacity. Expressed as a fraction:

$$\text{Change in Assimilative Capacity} = (C_{R2} - C_{R1}) / (WQS - C_{R1})$$

Expressed as a percentage:

$$\text{Percentage Change in Assimilative Capacity} = 100 * [(C_{R2} - C_{R1}) / (WQS - C_{R1})]$$

Assimilative capacity calculations are summarized in Table 7. The calculations result in a reduction in assimilative capacity for arsenic of 0.1%, and a reduction in assimilative capacity for manganese of 9.1%.

Background data were not available for chromium VI or molybdenum; however, these constituents were not detected at significant levels in effluent and are not considered constituents of concern. Cyanide and thallium were also not detected in effluent nor in receiving water; however, the reporting limits exceeded the lowest water quality criteria.

6 INCREMENTAL CHANGES IN COMBIE RESERVOIR WATER QUALITY

Incremental changes in Combie Reservoir water quality that are predicted to occur as a result of the Project are described below.

6.1 Constituent Concentrations

As shown in Table 7, the Project is not expected to result in significant reduction in water quality in Combie Reservoir. Reduction of assimilative capacity less than 10 percent of the available assimilative capacity is not considered significant. For arsenic and manganese, the constituents identified as having a reasonable potential to degrade water quality based on the Reasonable Potential Analysis described in Section 5.1, the anticipated reductions in assimilative capacity are 0.1 percent and 9.1 percent, respectively.

6.2 Mass Loading

Although bioaccumulation is considered in the development of human health and aquatic life criteria, the nature of downstream water bodies may facilitate extended residence time or deposition of sediment. Therefore, mass loading is also considered to assess the potential for degradation of downstream water quality from bioaccumulative constituents in Project effluent. The available mass loading assimilative capacity is defined as the maximum mass loading downstream of the Project that the water body could carry without exceeding the corresponding water quality criteria and objectives, minus the upstream load. There are no previously permitted loads associated with the Project.

$$\text{Available Mass Loading} = (WQS \times Q_{R2}) - (Q_{R1} \times C_{R1})$$

Where:
C_{R1} = Constituent concentration in surface water above Combie Reservoir
Q_{R1} = Flow rate of Bear River into Combie Reservoir without Project
Q_{R2} = Predicted flow rate of Bear River and Project discharge into Combie Reservoir ($Q_{R1} + Q_{eff}$)
Q_{eff} = Flow rate of effluent discharge from the Project

The change in assimilative capacity, calculated on a mass loading basis, is defined as the new load divided by the available mass loading.

$$\text{Change in Assimilative Capacity} = (C_{eff} \times Q_{eff}) / [(WQS \times Q_{R2}) - (Q_{R1} \times C_{R1})]$$

Where:
C_{eff} = Constituent concentration in filtered effluent from the Project equipment tests

As summarized on Table 8, the reduction in mass loading assimilative capacity associated with Project discharge of potentially bioaccumulative constituents (mercury, selenium and TDS) is estimated to be less than one percent. Because mass loading is a long-term impact, the harmonic mean flow of the Bear River was used in the assessment, and average constituent concentrations were used when available. Although organic forms of mercury and selenium have the greatest potential to bioaccumulate, inorganic monitoring data are used because they are more readily available.

6.3 Effects of Receiving Water Quality Changes

Mercury

The most stringent applicable water quality criterion for mercury is the CTR human health criterion (0.050 µg/L) for consumption of water and organisms). This criterion is based primarily on the consumption of fish; the applicable criterion for consumption of drinking water is the CDPH Primary MCL (2 µg/L). Dissolved mercury in Project effluent, and total mercury concentrations detected in Combie Reservoir during low flow conditions, do not exceed the MCL value. However, mass loading of mercury is a concern because mercury is known to bioaccumulate in fish tissue. Rollins Reservoir to Camp Far West, which includes Combie Reservoir and the segments of the Bear River between these impoundments, are listed by the SWRCB as impaired for mercury, and SWRCB expects that a TMDL for mercury associated with this segment of the Bear River will be developed in 2015.

The mass loading calculations described in Section 6.2 indicate that the discharge of Project effluent would not have a significant effect on mass loading assimilative capacity in Combie Reservoir. Furthermore, the Project is expected to result in long-term reduction of mercury loading because mercury is to be extracted from the dredged sediment. The proposed sediment and mercury removal from Combie Reservoir should decrease, over the long term, the potential for mercury transport downstream from Combie Reservoir.

Water quality criteria for mercury have changed in recent years as more has been learned about how mercury bioaccumulates in the aquatic and terrestrial food chain. The current water quality standard for mercury is 50 ng/L. Mercury concentrations detected in water quality samples from Combie Reservoir and the project effluent are well below this criterion, averaging concentrations of 9-14 ng/L. However, mercury concentrations are known to increase above 50 ng/L in river water during storm events (See Appendix III). Mercury is thought to be transported bound to silt and clay suspended in the water column during storm events when the water is turbid. Combie Reservoir is 303(d) listed as impaired for mercury due to elevated levels in fish.

Mercury was used extensively during the gold rush. It is estimated that as much as 26 million pounds were transported to the Sierra Nevada for use in hydraulic and hard rock gold mining operations. With an estimated mercury loss rate of 10-30% during past gold mining operations,

there remains a large amount of mercury in Sierra Nevada streams and rivers. The Project is expected to remove approximately 50 lbs of mercury per year for a total removal of 150 lbs of mercury from dredged sediment in Combie Reservoir over three years.

Turbidity

Turbidity varies significantly with discharge throughout the year at Combie Reservoir. During the February 26, 2009 storm event turbidity was detected at 60 NTU at the Above Combie site. Turbidity ranged from 3 NTU to 0.6 NTU during the months of May through September. The effluent from the equipment tests had an average turbidity level of 600 NTU. This highly turbid water was the result of mixing water with the dredged material in order to pass it through the mercury extraction equipment. Treatment of the effluent will be required to remove suspended solids prior to discharge into Combie Reservoir.

7 SOCIOECONOMIC CONSIDERATIONS

The project entails the use of an innovative recovery process to remove elemental mercury from settled or suspended sediments recovered following dredging operations. The technology associated with this project has not been used in the Sierra Nevada Region. The Project includes dredging and transport of sediment from the dredged area by a slurry pipeline to the process equipment, which is designed to remove mercury and sediment. Turbid water exiting the process equipment is to be clarified to remove suspended sediment, and discharge of effluent must comply with waste discharge requirements that are to be developed in cooperation with the Water Board. The existing dredge pond, which was utilized by gravel mining companies in the past, is not a lined pond nor is it hydraulically disconnected from the reservoir. However, it is a large pond measuring approximately 43-acres, ¾ mile in length, and 30 feet deep. Its retention time is estimated to be 30 days. Monitoring will be performed at the point of discharge at the upstream end of the old dredge pond, as well as at the downstream end of the pond near the pond outlet, in insure the project meets or exceeds effluent water quality standards.

Many waterways in the Sierra Nevada foothills are affected by legacy mercury pollution. Together with other Sierra Nevada Reservoirs, Combie Reservoir has been placed on CWA Section 303(d) due to elevated mercury levels. A fish advisory accompanies the 2002 designation by the Central Valley Regional Water Quality Control Board.

This project will demonstrate an effective and efficient method to remove mercury from sediments that have built up in Sierra Nevada water storage facilities. If implemented throughout the Sierra Nevada, a project, such as this, could result in tremendous economic benefits that would be felt in the Bay Delta Region and throughout the state of California.

Simply stated, if elemental mercury can be removed closer to the source of the legacy mercury contamination, it would reduce environmental impacts and overall health impacts before mercury has been transported and transformed into greater environmental, health and economic impacts

downstream. The research opportunities associated with this project are also critical to improving our understanding of the fate and transport of legacy mercury throughout the Sierra Nevada watersheds and the NID has partnered with USGS scientists to maximize this opportunity so that before, during and after environmental monitoring of sediment, water and biota will enable the project benefits to be quantified.

7.1 Alternatives

Alternatives to the project are evaluated below. Each alternative is evaluated for feasibility in implementation and effectiveness while maintaining water quality. These alternatives were not selected because they were determined to be infeasible for technological or environmental reasons.

No Project

Under the No Project alternative, sediment and mercury would continue to collect in Combie Reservoir and the reservoir storage capacity would continue to diminish, adversely affecting the water storage capacity and water supply for downstream uses. As the reservoir storage capacity continues to decrease, additional mercury-laden sediments will continue to fill the reservoir, and the discharge of mercury from the reservoir during winter storm flow would continue and may even increase. This alternative is considered infeasible because it would not meet the Project objectives, would result in insufficient reservoir storage capacity, and could result in future exceedance of regulatory water quality discharge limits as the reservoir storage capacity is diminished and continues to be a contaminated water body.

Dry Operations

Under the Dry Operations alternative, no dredging would be performed. Instead, mechanical excavation would be performed during a period of low water level in Combie Reservoir. The water level in Combie Reservoir would need to be reduced significantly to allow dry operations, this would take about 20 days (at an average of 200 cfs release rate); this reduced water level would need to be maintained for at least 45 days to allow for initial drying of the in-place sediment to allow earthmoving equipment to travel on the material (30 days), and at least another week for excavation and transport of the sediment from the reservoir bed. During this time the reservoir would be devoid of all beneficial uses and it would take an unknown amount of time to refill the reservoir based on seasonal rainfall.

Lowering the water level below 13ft causes numerous water quality problems for The Lake of the Pines Water Treatment Plant (WTP). The Lake of the Pines WTP supplies treated water to 2000 homes, a commercial center, a high school, a middle school, and a grade school. There are no alternative sources of water supply for this community.

Lowering the water level in Combie is limited because the elevation of the lowest outlet point, the Combie North Penstock, only allows for a 30 ft elevation drop in water table height. In addition, recreational use agreements prohibit lowering the reservoir prior to Labor Day (September 3).

Dry Operations also have multiple unwanted impacts on the surrounding residence such as dust and equipment noise.

This alternative is considered infeasible for environmental and technological reasons. The reasons are as follows; 1) lowering the water would cause water quality problems for Lake of the Pines WTP and Combie is the only water supply for Lake of the Pines WTP, 2) the water release structures in Combie do not allow for lowering the reservoir level below 30ft, and 3) there is insufficient time during the fair weather period (after Labor Day and prior to the onset of seasonal rain storms) to allow for dewatering, excavation and transportation of material (estimated 80 days).

Land Application

Under the Land Application alternative, effluent from the Project would be applied to land using methods such as spray irrigation or ponding to eliminate the discharge of Project effluent to surface water. This alternative is considered infeasible due to the amount of real estate needed for storage and/or ponding. As much as 120,000 gal/day of effluent will be generated by the Project (assuming an 8 hour day at 250gal/min production). For spraying (irrigation) the effluent on land, about 25 acres of gently sloping fertile land will be needed to adequately dispose of the effluent (assuming a evapotranspiration rate of 1-inch per week), For ponding the effluent, about 4 acres of level area would be needed to percolate and prevent erosion and/or turbid surface runoff (This calculation assumes a percolation rate of 4 inches/hour, and a factor of safety of two). The District does not own land beyond the shoreline of the Bear River that would be suitable and close enough to the dredge area for spray irrigation or ponding. This alternative is considered infeasible because of insufficient space.

7.2 Benefits of the Project

Maintenance dredging is required to maintain the storage capacity of Combie Reservoir, which is an integral part of the region's water supply system. Because mercury is commonly found in sediment as a result of the region's gold mining legacy, and because maintenance dredging is necessary to maintain storage capacity in reservoirs throughout the region, there is need for development of a Best Management Practice for removal of sediment from Sierra Nevada reservoirs with historic mercury contamination. Benefits of the Project include:

1. ***Water Supply Reliability.*** By developing an action strategy to remove mercury in conjunction with accumulated sediments, NID will be able to maintain the needed water storage capacity and water levels in Combie Reservoir.

2. ***Removing Mercury Contamination***. This project intends to develop Best Management Practices (BMPs) for restoring water storage capacity and removing legacy mercury contamination from Combie and other Sierra Nevada reservoirs, thus reducing the potential for mercury discharge from the reservoir and mercury methylation in the reservoir.

3. ***Mercury Fate and Transport Research.*** While the main intent of the Project is to remove sediments and mercury from Combie Reservoir, there are numerous research opportunities within this intent that may serve to fill critical scientific data gaps in our understanding of mercury in and below reservoir environments.

4. ***Recreation and Public Access.*** This project will work to remove sediment barriers that limit private boat dock access at the northeastern end of Combie Reservoir. It will also improve water quality and aquatic habitat. Removal of the sediment will help to keep water temperatures low by maintaining a deeper pool depth at upper reaches in the reservoir.

5. ***Water Quality Protection and Improvement.*** This project will remove mercury from sediment deposits in Combie Reservoir. Systematic removal of mercury from the reservoir may allow for the future removal of Combie Reservoir from the California 303 (d) list under the Clean Water Act.

8 ANTIDEGRADATION ANALYSIS FINDINGS

The primary finding of this analysis is that the loading of constituents in the proposed Project discharge produce minor effects that are not considered significant. The assessment considers dissolved constituents in effluent, acknowledging that a final clarification step is required to remove suspended solids prior to discharge of effluent to Combie Reservoir.

The results of this analysis are intended to assist in the development of effluent limitations for the Project, thus establishing requirements for the discharge of clarified effluent. Effluent limitations may be partially based on the reduction of assimilative capacity for arsenic and manganese. Effluent limitations for other constituents may be based on water quality objectives, considering that discharge of effluent at concentrations equal to the water quality objectives is not expected to result in significant reduction in assimilative capacity.

Routine monitoring for water quality parameters including turbidity, total dissolved solids, arsenic, manganese and mercury is considered appropriate to verify that the clarified effluent does not degrade water quality.

1. The proposed action will or will not lower receiving water quality

Sections 5 and 6 present the rational for determining whether degradation of water quality is predicted to occur. Based on the anticipated constituent concentrations at the discharge location, the Project is not expected to lower water quality at significance threshold for any of the constituents evaluated. In fact the primary source of impairment to water quality in Combie Reservoir, which is 303(d) listed for mercury, will decrease as the project removes elemental mercury from sediments that have accumulated in reservoir.

2. A description of the alternative control measures that are being considered

The Project alternatives listed below have been considered and described in Section 7.

- No project,
- Dry operations, and
- Land application.

In summary, based on the analysis presented herein, the anticipated water quality changes in Combie Reservoir, that are associated with the Project, a) will be consistent with state and federal antidegradation policies, b) will be to the socioeconomic benefit of the people of the region, c) will be to the maximum benefit of the State, and d) will not result in water quality less than those prescribed in the polices, or those required to prevent a nuisance, or those required to protect beneficial uses.

9 REFERENCES

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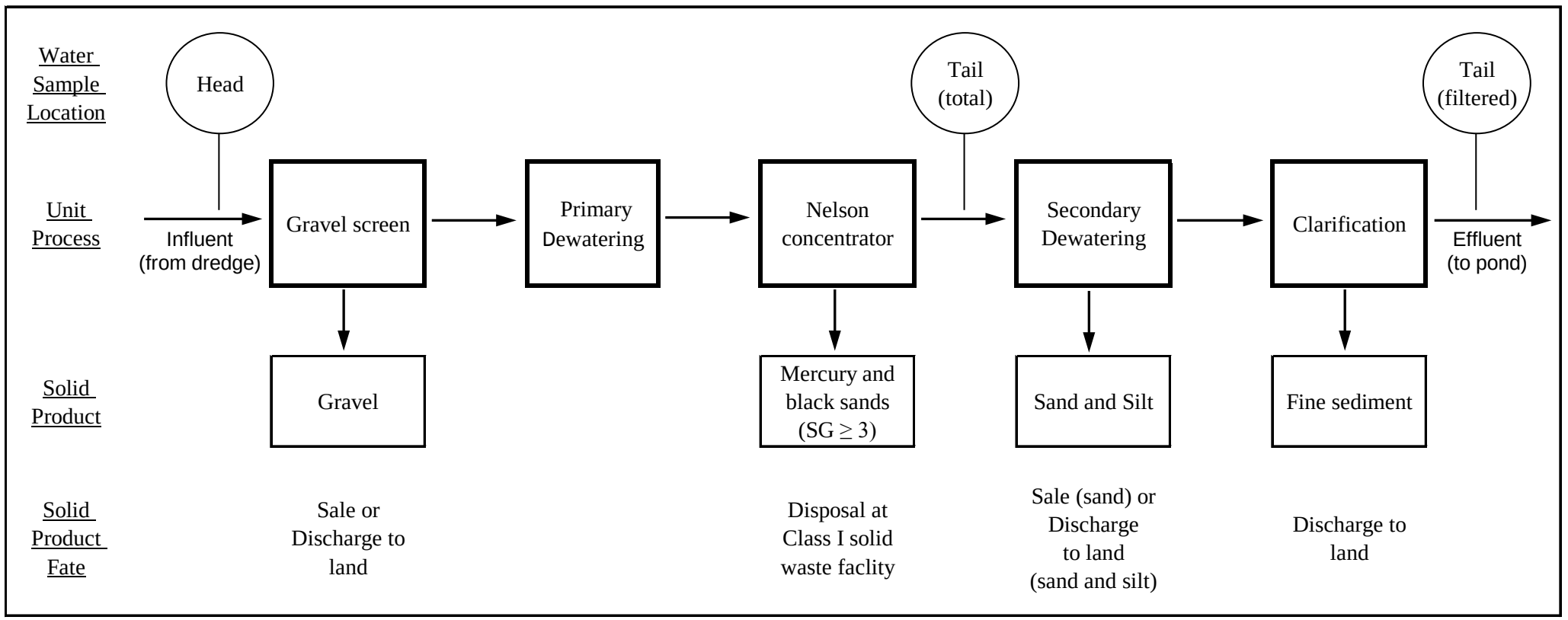


Figure 1. Process Flow Diagram for Combie Reservoir Sediment and Mercury Removal Project.

BASE MAP FROM GOOGLE EARTH; IMAGE DATE OCTOBER 31, 2011

NID

AERIAL PHOTOGRAPH

COMBIE RESERVOIR

NEVADA AND PLACER COUNTIES, CALIFORNIA

FIGURE 2

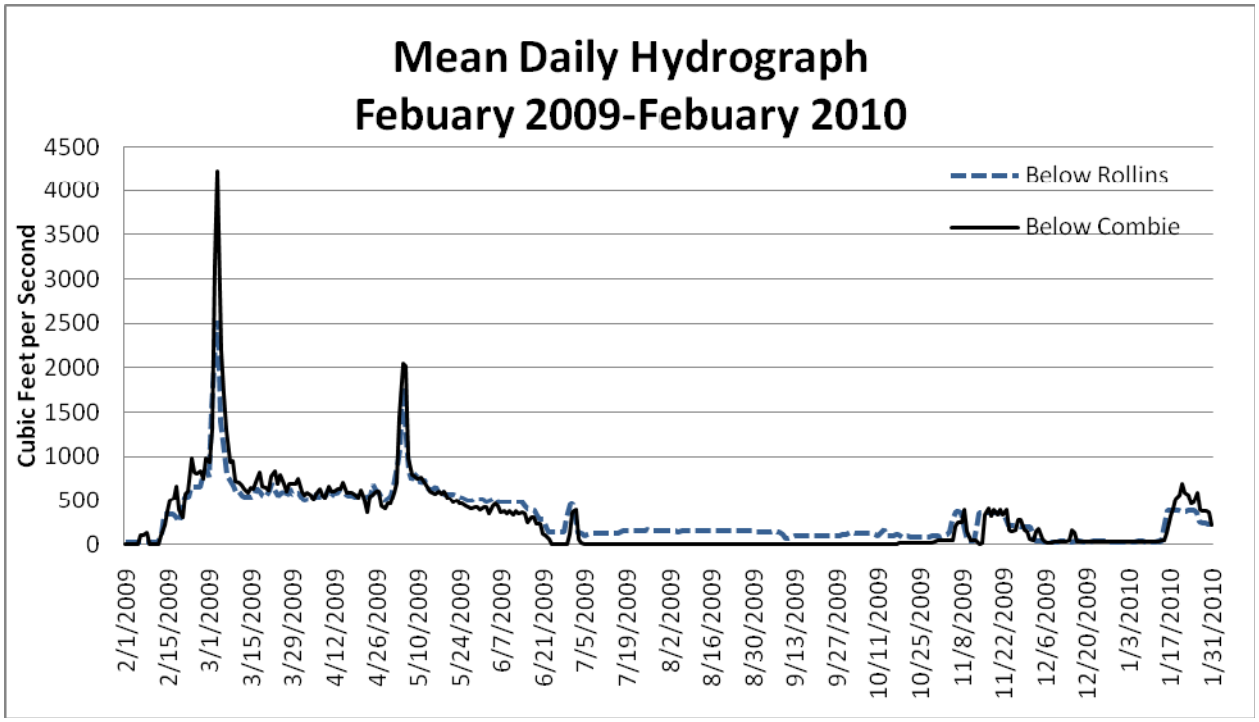


Figure 3. The mean daily hydrograph of Rollins and Combie Resevoirs from Febuary 2009 through Febuary 2010.

Table 1. Water Quality Objectives and Criteria for Combie Reservoir

Constituent	Objective	Units	Reference
Aluminum	87	µg/L	USEPA NAWQC, CCC
Antimony	6	µg/L	CPDH MCL
Arsenic	0.018	µg/L	USEPA NAWQC, Water and Organisms
Barium	1,000	µg/L	CTR, Water and Organisms
Beryllium	4	µg/L	CDPH MCL
Cadmium	2.13	µg/L	CTR CCC
Chromium III	180	µg/L	CTR CCC
Chromium, total	50	µg/L	CDPH MCL
Chromium VI	11	µg/L	CTR CCC
Chloride	106,000	µg/L	Narrative Chemical Constituents Objective (Ag)
Copper	9	µg/L	CTR CCC
Cyanide	5.2	µg/L	CTR CCC
Iron	300	µg/L	CDPH Secondary MCL
Lead	2.45	µg/L	CTR CCC
Manganese	50	µg/L	CDPH Secondary MCL
Mercury, total	2	µg/L	CDPH MCL
Molybdenum	10	µg/L	Narrative Chemical Constituents Objective (Ag)
Nickel	52	µg/L	CTR CCC
Selenium	5	µg/L	CTR CCC
Silver	100	µg/L	CDPH Secondary MCL
Thallium	0.24	µg/L	USEPA NAWQC, Water and Organisms
Zinc	120	µg/L	CTR CCC
Sulfate	250,000	µg/L	CDPH Secondary MCL
Total Dissolved Solids	450,000	µg/L	Narrative Chemical Constituents Objective (Ag)
Fluoride	1,000	µg/L	Narrative Chemical Constituents Objective (Ag)

Notes:

Ag = Agricultural

CCC = Criterion Continuous Concentration: highest concentration of a pollutant to which aquatic life can be exposed for an extended period of time (4 days) without deleterious effects

CTR = California Toxics Rule

CPDH = California Department of Public Health

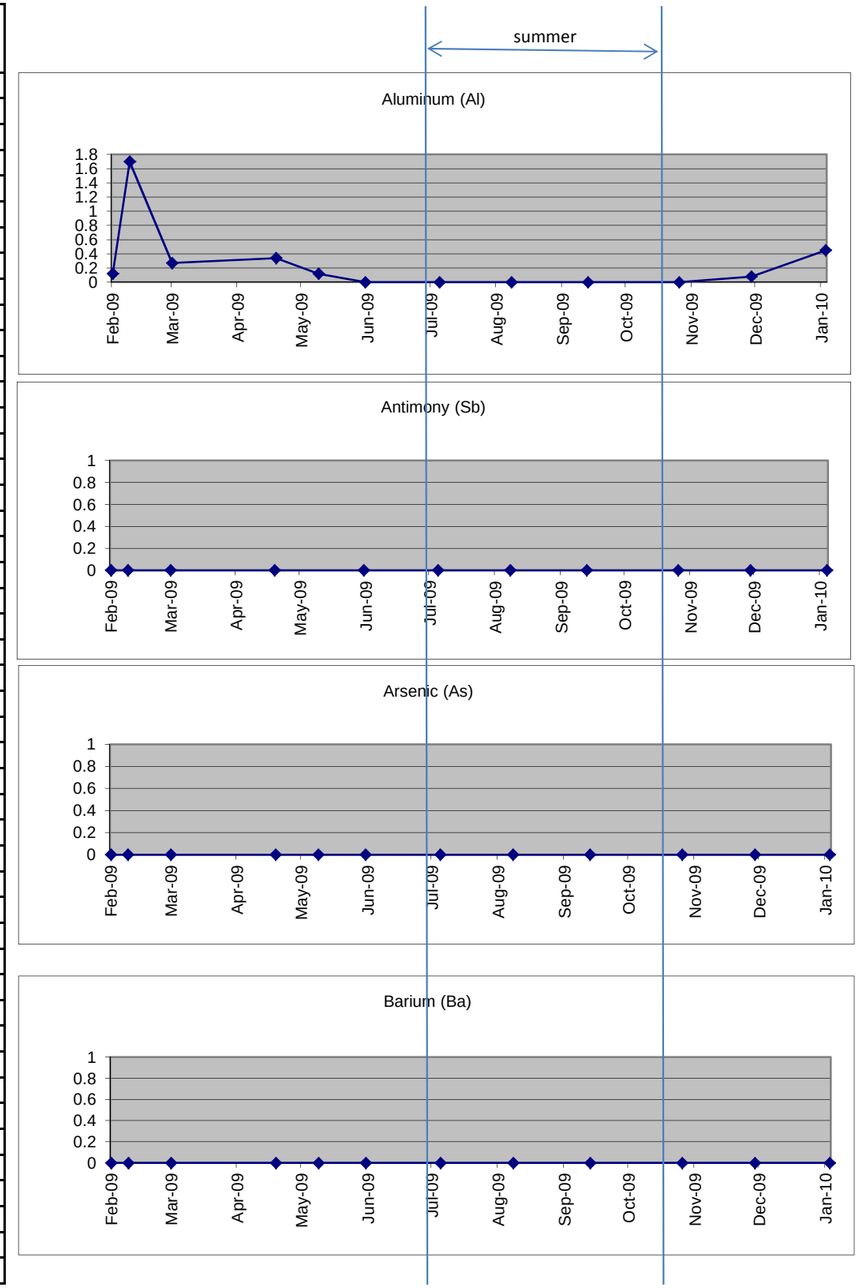
MCL = Maximum Contaminant Level

USEPA = United States Environmental Protection Agency

NAWQC = National Ambient Water Quality Criteria

Table 2. Total Metals in Receiving Water, Sample Location AC

Analyte	Method	Date Sampled	Result	Units	Flag	B	MDL	PQL
Aluminum (Al)	EPA 200.7	02/18/09	**0.12**	mg/L		0.12	0.015	0.05
Aluminum (Al)	EPA 200.7	02/26/09	**1.7**	mg/L		1.7	0.015	0.05
Aluminum (Al)	EPA 200.7	03/18/09	**0.27**	mg/L		0.27	0.015	0.05
Aluminum (Al)	EPA 200.7	05/06/09	**0.34**	mg/L		0.34	0.015	0.05
Aluminum (Al)	EPA 200.7	05/26/09	**0.12**	mg/L		0.12	0.015	0.05
Aluminum (Al)	EPA 200.7	06/17/09	ND	mg/L		0.05	0.015	0.05
Aluminum (Al)	EPA 200.7	07/22/09	ND	mg/L		0.05	0.015	0.05
Aluminum (Al)	EPA 200.7	08/25/09	ND	mg/L		0.05	0.015	0.05
Aluminum (Al)	EPA 200.7	09/30/09	ND	mg/L		0.05	0.015	0.05
Aluminum (Al)	EPA 200.7	11/12/09	ND	mg/L		0.05	0.015	0.05
Aluminum (Al)	EPA 200.7	12/16/09	**0.08**	mg/L		0.08	0.015	0.05
Aluminum (Al)	EPA 200.7	01/20/10	**0.45**	mg/L		0.45	0.015	0.05
Antimony (Sb)	EPA 200.8	02/18/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	02/26/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	03/18/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	05/06/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	06/17/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	07/22/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	08/25/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	09/30/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	11/12/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	12/16/09	ND	µg/L		0.8	0.8	2
Antimony (Sb)	EPA 200.8	01/21/10	ND	µg/L		0.8	0.8	2
Arsenic (As)	EPA 200.8	02/18/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	02/26/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	03/18/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	05/06/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	05/26/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	06/17/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	07/22/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	08/25/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	09/30/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	11/12/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	12/16/09	ND	µg/L		2	0.2	2
Arsenic (As)	EPA 200.8	01/20/10	ND	µg/L		2	0.2	2
Barium (Ba)	EPA 200.7	02/18/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	02/26/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	03/18/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	05/06/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	05/26/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	06/17/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	07/22/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	08/25/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	09/30/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	11/12/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	12/16/09	ND	mg/L		0.05	0.0004	0.05
Barium (Ba)	EPA 200.7	01/20/10	ND	mg/L		0.05	0.0004	0.05



Annual average
277.5 ug/L
Annual maximum
1700 ug/L

Summer average
50 ug/L
Summer maximum
50 ug/L

Annual average
0.8 ug/L
Annual maximum
0.8 ug/L

Summer average
0.8 ug/L
Summer maximum
0.8 ug/L

Annual average
2 ug/L
Annual maximum
2 ug/L

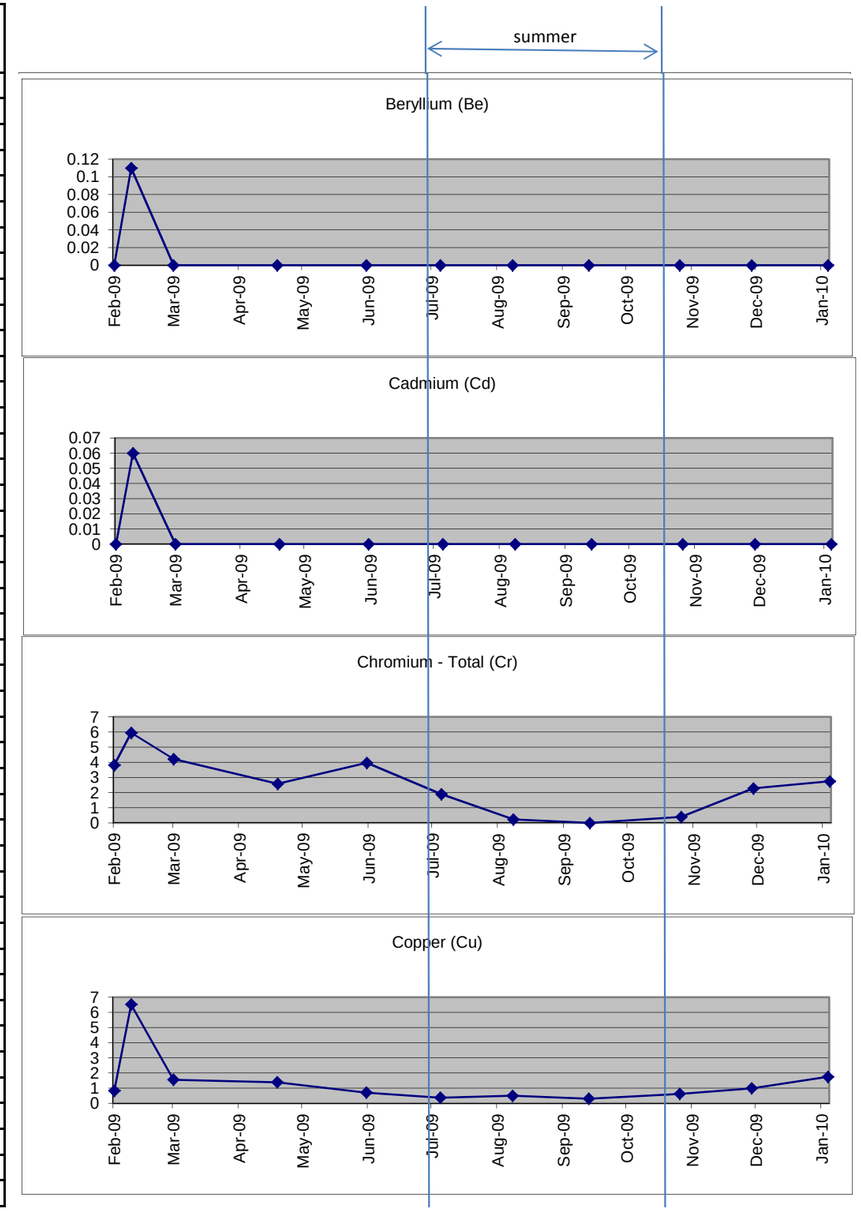
Summer average
2 ug/L
Summer maximum
2 ug/L

Annual average
50 ug/L
Annual maximum
50 ug/L

Summer average
50 ug/L
Summer maximum
50 ug/L

Table 2. Total Metals in Receiving Water, Sample Location AC

Analyte	Method	Date Sampled	Result	Units	Flag	B	MDL	PQL
Beryllium (Be)	EPA 200.8	02/18/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	02/26/09	**0.11**	µg/L	T	0.11	0.08	1.0
Beryllium (Be)	EPA 200.8	03/18/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	05/06/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	06/17/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	07/22/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	08/25/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	09/30/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	11/12/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	12/16/09	ND	µg/L		0.08	0.08	1.0
Beryllium (Be)	EPA 200.8	01/21/10	ND	µg/L		0.08	0.08	1.0
Cadmium (Cd)	EPA 200.8	02/18/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	02/26/09	**0.06**	µg/L	T	0.06	0.04	1.0
Cadmium (Cd)	EPA 200.8	03/18/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	05/06/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	06/17/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	07/22/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	08/25/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	09/30/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	11/12/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	12/16/09	ND	µg/L		0.04	0.04	1.0
Cadmium (Cd)	EPA 200.8	01/21/10	ND	µg/L		0.04	0.04	1.0
Chromium - Total (Cr)	EPA 200.8	02/18/09	**3.81**	µg/L	T	3.81	0.1	10
Chromium - Total (Cr)	EPA 200.8	02/26/09	**5.95**	µg/L	T	5.95	0.1	10
Chromium - Total (Cr)	EPA 200.8	03/18/09	**4.21**	µg/L	T	4.21	0.1	10
Chromium - Total (Cr)	EPA 200.8	05/06/09	**2.57**	µg/L	T	2.57	0.1	10
Chromium - Total (Cr)	EPA 200.8	06/17/09	**3.96**	µg/L	T	3.96	0.1	10
Chromium - Total (Cr)	EPA 200.8	07/22/09	**1.9**	µg/L	T	1.9	0.1	10
Chromium - Total (Cr)	EPA 200.8	08/25/09	**0.22**	µg/L	T	0.22	0.1	10
Chromium - Total (Cr)	EPA 200.8	09/30/09	ND	µg/L		0.1	0.1	10
Chromium - Total (Cr)	EPA 200.8	11/12/09	**0.39**	µg/L	T	0.39	0.1	10
Chromium - Total (Cr)	EPA 200.8	12/16/09	**2.28**	µg/L	T	2.28	0.1	10
Chromium - Total (Cr)	EPA 200.8	01/21/10	**2.75**	µg/L	T	2.75	0.1	10
Copper (Cu)	EPA 200.8	02/18/09	**0.83**	µg/L	T	0.83	0.05	50
Copper (Cu)	EPA 200.8	02/26/09	**6.52**	µg/L	T	6.52	0.05	50
Copper (Cu)	EPA 200.8	03/18/09	**1.56**	µg/L	T	1.56	0.05	50
Copper (Cu)	EPA 200.8	05/06/09	**1.39**	µg/L	T	1.39	0.05	50
Copper (Cu)	EPA 200.8	06/17/09	**0.71**	µg/L	T	0.71	0.05	50
Copper (Cu)	EPA 200.8	07/22/09	**0.38**	µg/L	T	0.38	0.05	50
Copper (Cu)	EPA 200.8	08/25/09	**0.5**	µg/L	T	0.5	0.05	50
Copper (Cu)	EPA 200.8	09/30/09	**0.31**	µg/L	T	0.31	0.05	50
Copper (Cu)	EPA 200.8	11/12/09	**0.63**	µg/L	T	0.63	0.05	50
Copper (Cu)	EPA 200.8	12/16/09	**0.99**	µg/L	T	0.99	0.05	50
Copper (Cu)	EPA 200.8	01/21/10	**1.75**	µg/L	T	1.75	0.05	50



Annual average
0.082727 ug/L
Annual maximum
0.11 ug/L

Summer average
0.08 ug/L
Summer maximum
0.08 ug/L

Annual average
0.041818 ug/L
Annual maximum
0.06 ug/L

Summer average
0.04 ug/L
Summer maximum
0.04 ug/L

Annual average
2.558182 ug/L
Annual maximum
5.95 ug/L

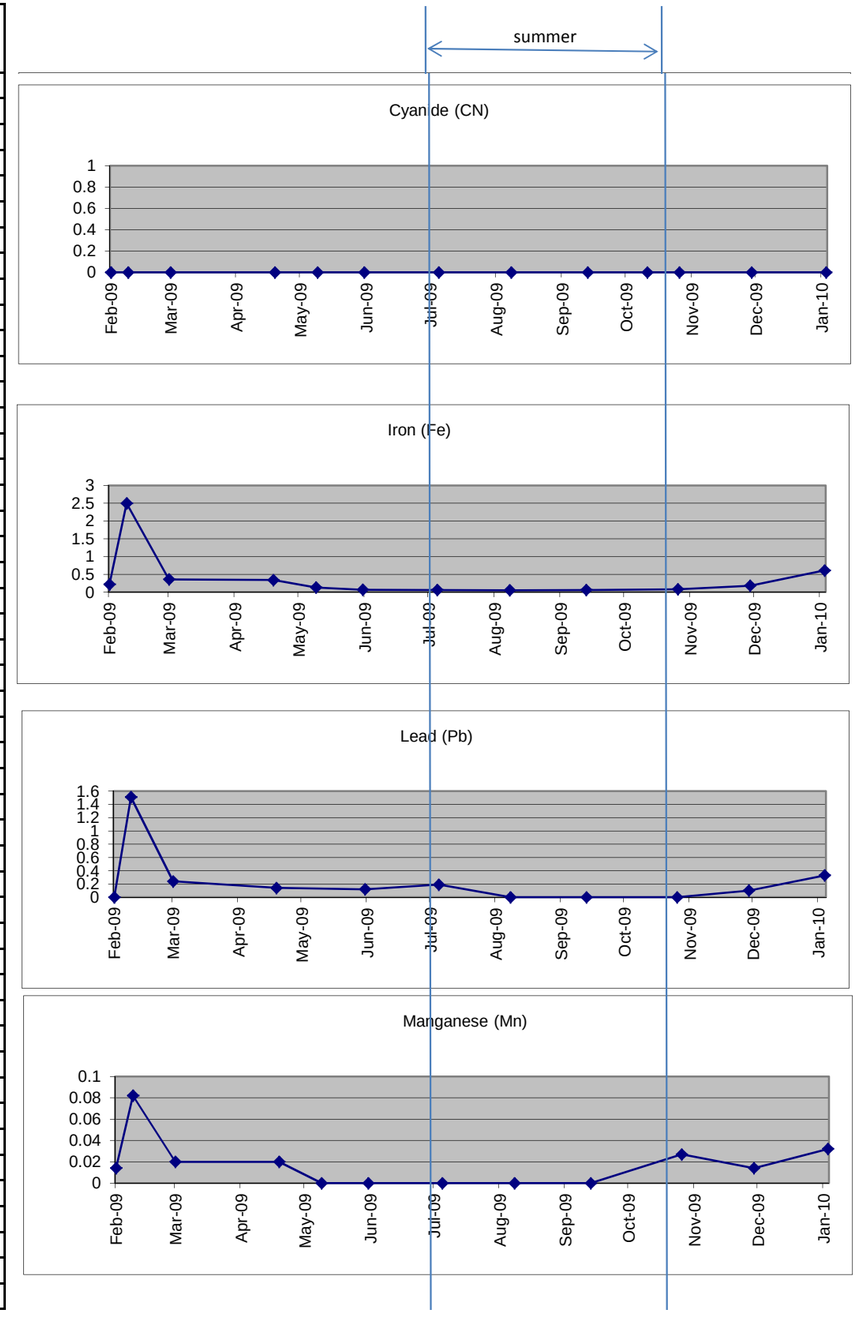
Summer average
0.74 ug/L
Summer maximum
1.9 ug/L

Annual average
1.415455 ug/L
Annual maximum
6.52 ug/L

Summer average
0.396667 ug/L
Summer maximum
0.5 ug/L

Table 2. Total Metals in Receiving Water, Sample Location AC

Analyte	Method	Date Sampled	Result	Units	Flag	B	MDL	PQL
Cyanide (CN)	SM 4500-CN-F	02/18/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	02/26/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	03/18/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	05/06/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	05/26/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	06/17/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	07/22/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	08/25/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	09/30/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	10/28/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	11/12/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	12/16/09	ND	µg/L		20	4	20
Cyanide (CN)	SM 4500-CN-F	01/20/10	ND	µg/L		20	4	20
Iron (Fe)	EPA 200.7	02/18/09	**0.22**	mg/L		0.22	0.004	0.05
Iron (Fe)	EPA 200.7	02/26/09	**2.5**	mg/L		2.5	0.004	0.05
Iron (Fe)	EPA 200.7	03/18/09	**0.36**	mg/L		0.36	0.004	0.05
Iron (Fe)	EPA 200.7	05/06/09	**0.34**	mg/L		0.34	0.004	0.05
Iron (Fe)	EPA 200.7	05/26/09	**0.13**	mg/L		0.13	0.004	0.05
Iron (Fe)	EPA 200.7	06/17/09	**0.065**	mg/L		0.065	0.004	0.05
Iron (Fe)	EPA 200.7	07/22/09	**0.062**	mg/L		0.062	0.004	0.05
Iron (Fe)	EPA 200.7	08/25/09	**0.052**	mg/L		0.052	0.004	0.05
Iron (Fe)	EPA 200.7	09/30/09	**0.059**	mg/L		0.059	0.004	0.05
Iron (Fe)	EPA 200.7	11/12/09	**0.08**	mg/L		0.08	0.004	0.05
Iron (Fe)	EPA 200.7	12/16/09	**0.18**	mg/L		0.18	0.004	0.05
Iron (Fe)	EPA 200.7	01/20/10	**0.61**	mg/L		0.61	0.004	0.05
Lead (Pb)	EPA 200.8	02/18/09	ND	µg/L		0.08	0.08	5.0
Lead (Pb)	EPA 200.8	02/26/09	**1.51**	µg/L	T	1.51	0.08	5.0
Lead (Pb)	EPA 200.8	03/18/09	**0.24**	µg/L	T	0.24	0.08	5.0
Lead (Pb)	EPA 200.8	05/06/09	**0.14**	µg/L	T	0.14	0.08	5.0
Lead (Pb)	EPA 200.8	06/17/09	**0.12**	µg/L	T	0.12	0.08	5.0
Lead (Pb)	EPA 200.8	07/22/09	**0.19**	µg/L	T	0.19	0.08	5.0
Lead (Pb)	EPA 200.8	08/25/09	ND	µg/L		0.08	0.08	5.0
Lead (Pb)	EPA 200.8	09/30/09	ND	µg/L		0.08	0.08	5.0
Lead (Pb)	EPA 200.8	11/12/09	ND	µg/L		0.08	0.08	5.0
Lead (Pb)	EPA 200.8	12/16/09	**0.1**	µg/L	T	0.1	0.08	5.0
Lead (Pb)	EPA 200.8	01/21/10	**0.33**	µg/L	T	0.33	0.08	5.0
Manganese (Mn)	EPA 200.7	02/18/09	**0.014**	mg/L		0.014	0.001	0.01
Manganese (Mn)	EPA 200.7	02/26/09	**0.082**	mg/L		0.082	0.001	0.01
Manganese (Mn)	EPA 200.7	03/18/09	**0.02**	mg/L		0.02	0.001	0.01
Manganese (Mn)	EPA 200.7	05/06/09	**0.02**	mg/L		0.02	0.001	0.01
Manganese (Mn)	EPA 200.7	05/26/09	ND	mg/L		0.01	0.001	0.01
Manganese (Mn)	EPA 200.7	06/17/09	ND	mg/L		0.01	0.001	0.01
Manganese (Mn)	EPA 200.7	07/22/09	ND	mg/L		0.01	0.001	0.01
Manganese (Mn)	EPA 200.7	08/25/09	ND	mg/L		0.01	0.001	0.01
Manganese (Mn)	EPA 200.7	09/30/09	ND	mg/L		0.01	0.001	0.01
Manganese (Mn)	EPA 200.7	11/12/09	**0.027**	mg/L		0.027	0.001	0.01
Manganese (Mn)	EPA 200.7	12/16/09	**0.014**	mg/L		0.014	0.001	0.01
Manganese (Mn)	EPA 200.7	01/20/10	**0.032**	mg/L		0.032	0.001	0.01



Cyanide (CN)
Annual average 20 ug/L
Annual maximum 20 ug/L
Summer average 20 ug/L
Summer maximum 20 ug/L

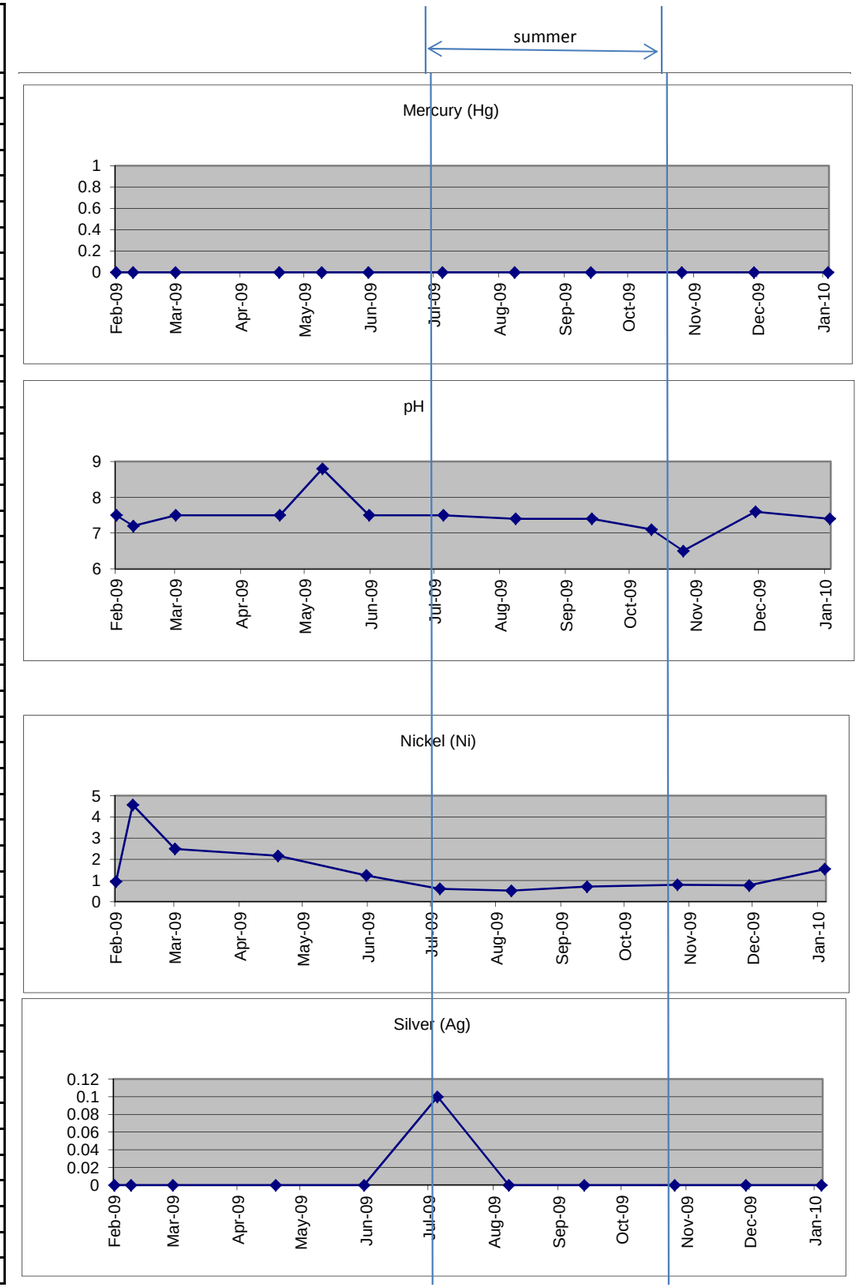
Iron (Fe)
Annual average 388.1667 ug/L
Annual maximum 2500 ug/L
Summer average 57.66667 ug/L
Summer maximum 62 ug/L

Lead (Pb)
Annual average 0.268182 ug/L
Annual maximum 1.51 ug/L
Summer average 0.116667 ug/L
Summer maximum 0.19 ug/L

Manganese (Mn)
Annual average 21.58333 ug/L
Annual maximum 82 ug/L
Summer average 10 ug/L
Summer maximum 10 ug/L

Table 2. Total Metals in Receiving Water, Sample Location AC

Analyte	Method	Date Sampled	Result	Units	Flag	B	MDL	PQL
Mercury (Hg)	EPA 200.8	02/18/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	02/26/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	03/18/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	05/06/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	05/26/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	06/17/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	07/22/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	08/25/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	09/30/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	11/12/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	12/16/09	ND	µg/L		0.4	0.05	0.4
Mercury (Hg)	EPA 200.8	01/20/10	ND	µg/L		0.4	0.05	0.4
pH	SM 4500-H+ B	02/18/09	7.5	Std. Unit		-	-	-
pH	SM 4500-H+ B	02/26/09	7.2	Std. Unit		-	-	-
pH	SM 4500-H+ B	03/18/09	7.5	Std. Unit		-	-	-
pH	SM 4500-H+ B	05/06/09	7.5	Std. Unit		-	-	-
pH	SM 4500-H+ B	05/26/09	8.8	Std. Unit		-	-	-
pH	SM 4500-H+ B	06/17/09	7.5	Std. Unit		-	-	-
pH	SM 4500-H+ B	07/22/09	7.5	Std. Unit		-	-	-
pH	SM 4500-H+ B	08/25/09	7.4	Std. Unit		-	-	-
pH	SM 4500-H+ B	09/30/09	7.4	Std. Unit		-	-	-
pH	SM 4500-H+ B	10/28/09	7.1	Std. Unit		-	-	-
pH	SM 4500-H+ B	11/12/09	6.5	Std. Unit		-	-	-
pH	SM 4500-H+ B	12/16/09	7.6	Std. Unit		-	-	-
pH	SM 4500-H+ B	01/20/10	7.4	Std. Unit		-	-	-
Nickel (Ni)	EPA 200.8	02/18/09	**0.95**	µg/L	T	0.95	0.05	10
Nickel (Ni)	EPA 200.8	02/26/09	**4.57**	µg/L	T	4.57	0.05	10
Nickel (Ni)	EPA 200.8	03/18/09	**2.49**	µg/L	T	2.49	0.05	10
Nickel (Ni)	EPA 200.8	05/06/09	**2.16**	µg/L	T	2.16	0.05	10
Nickel (Ni)	EPA 200.8	06/17/09	**1.24**	µg/L	T	1.24	0.05	10
Nickel (Ni)	EPA 200.8	07/22/09	**0.61**	µg/L	T	0.61	0.05	10
Nickel (Ni)	EPA 200.8	08/25/09	**0.52**	µg/L	T	0.52	0.05	10
Nickel (Ni)	EPA 200.8	09/30/09	**0.71**	µg/L	T	0.71	0.05	10
Nickel (Ni)	EPA 200.8	11/12/09	**0.8**	µg/L	T	0.8	0.05	10
Nickel (Ni)	EPA 200.8	12/16/09	**0.77**	µg/L	T	0.77	0.05	10
Nickel (Ni)	EPA 200.8	01/21/10	**1.54**	µg/L	T	1.54	0.05	10
Silver (Ag)	EPA 200.8	02/18/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	02/26/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	03/18/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	05/06/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	06/17/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	07/22/09	**0.1**	µg/L	T	0.1	0.05	10
Silver (Ag)	EPA 200.8	08/25/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	09/30/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	11/12/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	12/16/09	ND	µg/L		0.05	0.05	10
Silver (Ag)	EPA 200.8	01/21/10	ND	µg/L		0.05	0.05	10



Annual average
0.4 ug/L
Annual maximum
0.4 ug/L

Summer average
0.4 ug/L
Summer maximum
0.4 ug/L

Annual Minimum
6.5

Summer Minimum
7.4

Annual average
1.487273 ug/L
Annual maximum
4.57 ug/L

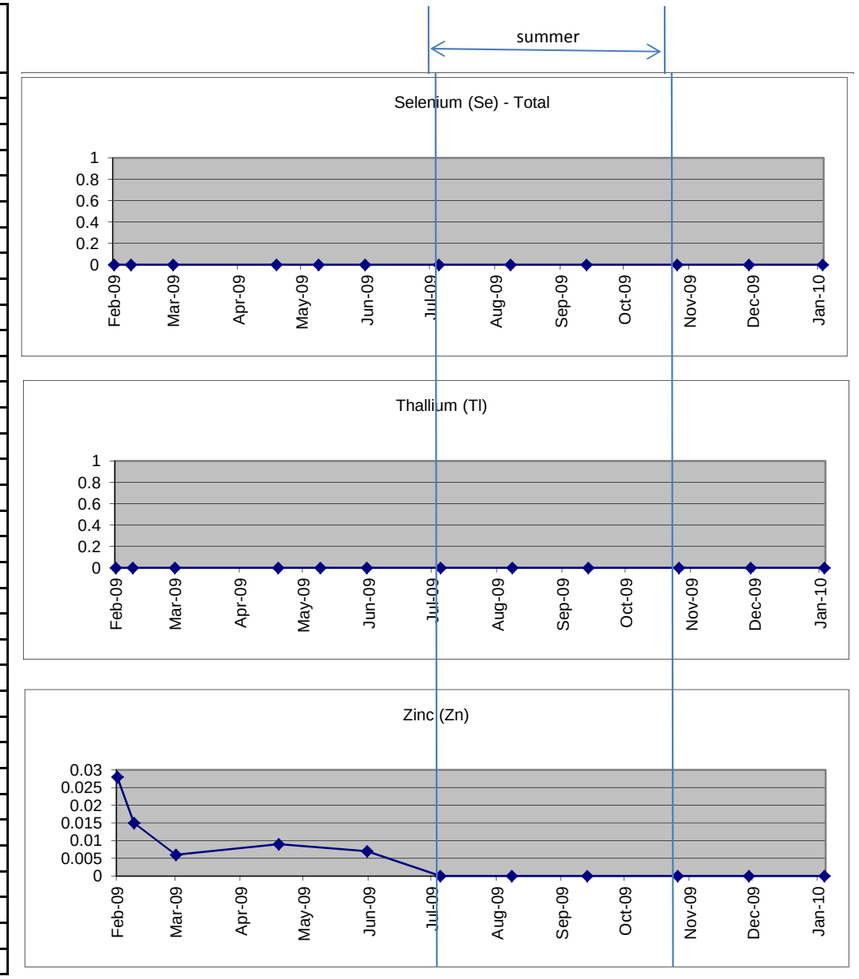
Summer average
0.613333 ug/L
Summer maximum
0.71 ug/L

Annual average
0.054545 ug/L
Annual maximum
0.1 ug/L

Summer average
0.066667 ug/L
Summer maximum
0.1 ug/L

Table 2. Total Metals in Receiving Water, Sample Location AC

Analyte	Method	Date Sampled	Result	Units	Flag	B	MDL	PQL
Selenium (Se) - Total	EPA 200.8	02/18/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	02/26/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	03/18/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	05/06/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	05/26/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	06/17/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	07/22/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	08/25/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	09/30/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	11/12/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	12/16/09	ND	µg/L		2	0.7	2
Selenium (Se) - Total	EPA 200.8	01/20/10	ND	µg/L		2	0.7	2
Thallium (Tl)	EPA 200.8	02/18/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	02/26/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	03/18/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	05/06/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	05/26/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	06/17/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	07/22/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	08/25/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	09/30/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	11/12/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	12/16/09	ND	µg/L		1	0.1	1
Thallium (Tl)	EPA 200.8	01/20/10	ND	µg/L		1	0.1	1
Zinc (Zn)	EPA 200.7	02/18/09	**0.028**	mg/L	T	0.028	0.005	0.050
Zinc (Zn)	EPA 200.7	02/26/09	**0.015**	mg/L	T	0.015	0.005	0.050
Zinc (Zn)	EPA 200.7	03/18/09	**0.006**	mg/L	T	0.006	0.005	0.050
Zinc (Zn)	EPA 200.7	05/06/09	**0.009**	mg/L	T	0.009	0.005	0.050
Zinc (Zn)	EPA 200.7	06/17/09	**0.007**	mg/L	T	0.007	0.005	0.050
Zinc (Zn)	EPA 200.7	07/22/09	ND	mg/L		0.005	0.005	0.050
Zinc (Zn)	EPA 200.7	08/25/09	ND	mg/L		0.005	0.005	0.050
Zinc (Zn)	EPA 200.7	09/30/09	ND	mg/L		0.005	0.005	0.050
Zinc (Zn)	EPA 200.7	11/12/09	ND	mg/L		0.005	0.005	0.050
Zinc (Zn)	EPA 200.7	12/16/09	ND	mg/L		0.005	0.005	0.050
Zinc (Zn)	EPA 200.7	01/21/10	ND	mg/L		0.005	0.005	0.050



Annual average
2 ug/L
Annual maximum
2 ug/L

Summer average
2 ug/L
Summer maximum
2 ug/L

Annual average
1 ug/L
Annual maximum
1 ug/L

Summer average
1 ug/L
Summer maximum
1 ug/L

Annual average
0.008636 ug/L
Annual maximum
0.028 ug/L

Summer average
0.005 ug/L
Summer maximum
0.005 ug/L

T = Trace result, value estimated (>MDL, <PQL). MDL = Method detection limit. PQL = Practical quantitiation limt. ug/L = micrograms per liter. mg/L = milligrams per liter.

Table 3. Dissolved Metals in Effluent

Constituent	Laboratory Method	Result	MDL	RL	Units	Qualifier
Aluminum	USEPA 200.7	42	23	50	µg/L	J
Antimony	USEPA 200.8	0.59	0.13	0.50	µg/L	
Arsenic	USEPA 200.8	2.7	0.85	1.0	µg/L	
Barium	USEPA 200.8	62	2.3	5	µg/L	
Beryllium	USEPA 200.8	<0.18	0.18	0.5	µg/L	ND
Cadmium	USEPA 200.8	0.21	0.10	0.25	µg/L	J
Chromium, total	USEPA 200.8	1.4	0.28	0.50	µg/L	
Chromium VI	USEPA 218.6	0.082	0.019	0.20	µg/L	J
Copper	USEPA 200.8	0.92	0.18	0.50	µg/L	
Cyanide	USEPA 200.8	<20	4	20	µg/L	ND
Iron	USEPA 200.7	24	23	50	µg/L	J
Lead	USEPA 200.8	<0.20	0.20	0.50	µg/L	ND
Manganese	USEPA 200.7	750	4.5	10	µg/L	
Mercury, total	USEPA 200.8	<0.18	0.18	0.40	µg/L	ND
Molybdenum	USEPA 200.8	<4.5	4.5	10	µg/L	ND
Nickel	USEPA 200.8	26	0.30	1.0	µg/L	
Selenium	USEPA 200.8	<0.91	0.91	2.0	µg/L	ND
Silver	USEPA 200.8	<0.13	0.13	0.25	µg/L	ND
Thallium	USEPA 200.8	<0.45	0.45	1.0	µg/L	ND
Zinc	USEPA 200.8	28	5.0	10	µg/L	

Notes:
USEPA = United States Environmental Protection Agency
MDL = Method detection limit
J = Result is greater than MDL but less than RL value, and is estimated
na = not available
RL = Laboratory Reporting Limit
µg/L = micrograms per liter

Table 4. Summary of Reasonable Potential Analysis

Inorganic Constituents - Metals

Constituent Name	CAS Number	CTR Number	MEC (ug/L)	B (ug/L)	C (ug/L)	CTR/NAWQC Criteria: Freshwater Aquatic Life: CMC (Acute)	CTR/NAWQC Criteria: Freshwater Aquatic Life: CCC (Chronic)	CTR/NAWQC Criteria: Human Consumption: Water & Organisms	CTR/NAWQC Criteria: Human Consumption: Organisms Only	Ag Use	MCL	Basin Plan	Reasonable Potential?
Aluminum	7429905		J 42	< 50	87	750	87	N/A	N/A	5000	200	N/A	No
Antimony	7440360	1	0.59	< 0.8	6	9000	1600	14	4300	N/A	6	N/A	No
Arsenic	7440382	2	2.7	< 2	0.018	340	150	0.018	0.14	100	10	N/A	Yes
Barium	7440393		62	< 50	1000	N/A	N/A	1000	N/A	N/A	1000	N/A	No
Beryllium	7440417	3	< 0.18	< 0.08	4	150	5.3	N/A	N/A	100	4	N/A	No
Cadmium	7440439	4	J 0.21	< 0.04	2.13	4.3	2.13	N/A	N/A	10	5	N/A	No
Chromium (III)			1.4	J 1.9	180	550	180	N/A	N/A	N/A	N/A	N/A	No
Chromium (total)	7440473	5a	1.4	J 1.9	50	N/A	N/A	N/A	N/A	N/A	50	N/A	No
Chromium (VI)	18540299	5b	J 0.082	No Data	11	16	11	N/A	N/A	100	N/A	N/A	Inconclusive
Copper	7440508	6	0.92	J 0.5	9	13	9	1300	N/A	200	1000	N/A	No
Cyanide	57125	14	< 20	< 20	5.2	22	5.2	700	220000	N/A	150	N/A	Inconclusive
Iron	7439896		J 24	62	300	N/A	1000	N/A	N/A	5000	300	N/A	No
Lead	7439921	7	< 0.2	J 0.19	2.45	64.35	2.45	N/A	N/A	5000	15	N/A	No
Manganese	7439965		750	< 10	50	N/A	N/A	100	N/A	200	50	N/A	Yes
Mercury, Total	7439976	8	< 0.18	< 0.4	2	N/A	N/A	N/A	N/A	N/A	2	N/A	No
Molybdenum	7439987		< 4.5	No Data	10	N/A	N/A	N/A	N/A	10	N/A	N/A	Inconclusive
Nickel	7440020	9	26	J 0.71	52	470	52	610	4600	200	100	N/A	No
Selenium	7782492	10	< 0.91	< 2	5	20	5	170	4200	20	50	N/A	No
Silver	7440224	11	< 0.13	J 0.1	100	N/A	N/A	N/A	N/A	N/A	100	N/A	No
Thallium	7440280	12	< 0.45	< 1	1.7	1400	40	1.7	6.3	N/A	2	N/A	No
Zinc	7440666	13	28	< 5	120	120	120	7400	26000	2000	5000	N/A	No

Table 5. Bear River Flow Data, February 2009 through January 2010

Date	**Q_{AC}** [1] (L/s) (aka Q_{R1})
02/18/2009	8892
02/26/2009	18606
03/18/2009	16907
05/06/2009	33701
05/26/2009	14670
06/17/2009	11186
07/22/2009	4418
08/25/2009	4418
09/30/2009	3200
11/12/2009	984
12/16/2009	935
01/20/2010	11050

Notes:

Q_{AC} = Flow rate of Bear River into Combie Reservoir, L/s, also referred to as Q_{R1}.

1 Based on mean daily hydrograph data below Rollins Reservoir, see Figure 3.

Table 6. Summary of Mixing Calcualtions

Constituent	C_{R1} (µg/L)	C_{R1} Source	Q_{R1} (L/s)	Q_{R1} Source	Qeff (L/s)	C_{eff} (µg/L)	C_{eff} Source	C_{R2} (µg/L)	WQS (µg/L)	WQS Source
Aluminum	25	½ RL	600	7Q10	16	42	MEC	25.4	87	USEPA NAWQC, CCC
Antimony	0.8	MDL	2,900	HM	16	0.59	MEC	0.80	6	CPDH MCL
Arsenic	1	½ RL	2,900	HM	16	2.7	MEC	1.0	10	USEPA Primary MCL
Barium	25	½ RL	2,900	HM	16	62	MEC	25.2	1,000	CPDH MCL
Beryllium	0.08	MDL	2,900	HM	16	0.18	MDL	0.08	4	CDPH MCL
Cadmium	0.04	MDL	600	7Q10	16	0.21	MEC	0.04	2.13	CTR CCC
Chromium, total	0.74	AVG	2,900	HM	16	1.4	MEC	0.74	50	CDPH MCL
Chromium VI	no data	na	600	7Q10	16	0.082	MEC	na	11	CTR CCC
Copper	0.5	MAX	600	7Q10	16	0.92	MEC	0.51	9	CTR CCC
Cyanide	10	½ RL	600	7Q10	16	10	½ RL	10.0	5.2	CTR CCC
Iron	57.7	AVG	2,900	HM	16	24	MEC	57.5	300	CDPH Secondary MCL
Lead	0.19	MAX	600	7Q10	16	0.2	MDL	0.19	2.45	CTR CCC
Manganese	5	½ RL	2,900	HM	16	750	MEC	9.09	50	CDPH Secondary MCL
Mercury, total	0.2	½ RL	2,900	HM	16	0.18	MDL	0.20	2	CDPH MCL
Molybdenum	no data	na	2,900	HM	16	4.5	MDL	na	10	Narrative Chemical Constituents Objective (Ag)
Nickel	0.71	MAX	600	7Q10	16	26	MEC	1.37	52	CTR CCC
Selenium	1	½ RL	600	7Q10	16	0.91	MDL	1.0	5	CTR CCC
Silver	0.067	AVG	2,900	HM	16	0.13	MDL	0.067	100	CDPH Secondary MCL
Thallium	0.5	½ RL	2,900	HM	16	0.45	MDL	0.50	0.24	USEPA NAWQC, Water and Organisms
Zinc	0.005	MDL	600	7Q10	16	28	MEC	0.732	120	CTR CCC

Notes:

7Q10 = Lowest 1-day average flow that occurs during the proposed operating period (March through November) once every 10 years (on average).

Ag = Agricultural

AVG = Average receiving water concentration for July, August and September 2009; used for assessment of long-term human health effects and other long term criteria (such as agriculture).

B = Maximum receiving water concentration, low flow conditions (July, August and September 2009 sampling events)

C_{R1} = Constituent concentration in receiving water, ug/L. For non-detects, C_{R1} = MDL when "J" data are available, and C_{R1} = 0.5*(RL) when "J" data are not available.

C_{eff} = Constituent concentration in Project effluent, ug/L

C_{R2} = Predicted constituent concentration in surface water below the discharge point, ug/L

CCC = Criterion Continuous Concentration: highest concentration of a pollutant to which aquatic life can be exposed for an extended period of time (4 days) without deleterious effects

CTR = California Toxics Rule

CPDH = California Department of Public Health

HM = Harmonic mean flow during the operating period (March through November).

MAX = Maximum receving water concentration for July, August and September 2009; used for assessment of aquatic life effects (both acute and chronic).

MCL = Maximum Contaminant Level

MDL = Method Detection Limt

MEC = Maximum observed effluent concentration, ug/L

na = Not applicable

NAWQC = National Ambient Water Quality Criteria

Q_{AC} = Flow rate of Bear River above Combie Reservoir, L/s, based on flow data obtained below Rollins Reservoir.

Q_{eff} = Flow rate of effluent discharge from the Project to receiving water, L/s

Q_{R1} = Flow rate of Bear River into Combie Reservoir, L/s, also referred to as Q_{AC}.

RL = Laboratory reporting limit

USEPA = United States Environmental Protection Agency

WQS = Water quality standard, ug/L

$$C_{R2} = \frac{C_{R1} \times Q_{R1} + C_{eff.} \times Q_{eff.}}{Q_{R1} + Q_{eff.}}$$

Table 7. Summary of Assimilative Capacity Calcualtions

Constituent	Concentration in Receiving Water		Water Quality Standard		Assimilative Capacity	
	C_{R1} (µg/L)	C_{R2} (µg/L)	WQS (µg/L)	WQS Source	Avialable (µg/L)	Percentage Change
Aluminum	25	25.4	87	USEPA NAWQC, CCC	62	0.7%
Antimony	0.8	0.80	6	CPDH MCL	5.2	-0.02%
Arsenic	1	1.0	10	USEPA Primary MCL	9.0	0.1%
Barium	25	25.2	1,000	CPDH MCL	975	0.02%
Beryllium	0.08	0.08	4	CDPH MCL	3.92	0.01%
Cadmium	0.04	0.04	2.13	CTR CCC	2.09	0.2%
Chromium, total	0.74	0.74	50	CDPH MCL	49.26	0.01%
Chromium VI	no data	na	11	CTR CCC	na	na
Copper	0.5	0.51	9	CTR CCC	8.5	0.1%
Cyanide	10	10.0	5.2	CTR CCC	-4.8	0.00%
Iron	57.7	57.5	300	CDPH Secondary MCL	242	-0.08%
Lead	0.19	0.19	2.45	CTR CCC	2.26	0.01%
Manganese	5	9.09	50	CDPH Secondary MCL	45	9.1%
Mercury, total	0.2	0.20	2	CDPH MCL	1.8	-0.01%
Molybdenum	no data	na	10	Narrative Chemical Constituents Objective (Ag)	na	na
Nickel	0.71	1.37	52	CTR CCC	51.3	1.3%
Selenium	1	1.0	5	CTR CCC	4.0	-0.06%
Silver	0.067	0.067	100	CDPH Secondary MCL	99.9	0.00%
Thallium	0.5	0.50	0.24	USEPA NAWQC, Water and Organisms	-0.26	0.1%
Zinc	0.005	0.732	120	CTR CCC	120	0.6%

Notes:

Ag = Agricultural

Available Assimilative Capacity = WQS – C_{R1}

C_{R1} = Constituent concentration in receiving water, ug/L. See Table 6.

C_{R2} = Predicted constituent concentration in surface water below the discharge point, ug/L. See Table 6.

CCC = Criterion Continuous Concentration

CTR = California Toxics Rule

CPDH = California Department of Public Health

MCL = Maximum Contaminant Level

na = Not applicable

NAWQC = National Ambient Water Quality Criteria

Percentage Change in Assimilative Capacity = (C_{R2} - C_{R1}) / (WQS – C_{R1}). Positive value indicates reduction in assimilative capacity.

USEPA = United States Environmental Protection Agency

WQS = Water quality standard, ug/L

Table 8. Summary of Mass Loading Assimilative Capacity Calcualtions

Constituent	Concentrations		Flow Rates			Water Quality Standard		Mass Loading Assimilative Capacity		
	C_{R1} (µg/L)	C_{eff} (µg/L)	Q_{R1} (L/s)	Qeff (L/s)	Q_{R2} (L/s)	WQS (µg/L)	WQS Source	Avialable (µg/s)	Avialable (kg/day)	Percentage Change
Mercury, total	0.2	0.18	2,900	16	2,916	2	CDPH MCL	5252	0.45	0.05%
Selenium	1	0.9	2,900	16	2,916	5	CTR CCC	11680	1.01	0.12%
Total Dissolved Solids	25,000	160,000	2,900	16	2,916	500,000	CDPH Secondary MCL	1.39E+09	119,707	0.18%

Notes:

Available Mass Loading Assimilative Capacity = (WQS x QR2) – (QR1 x CR1)

C_{R1} = Constituent concentration in receiving water, ug/L. See Table 6.

C_{eff} = Constituent concentration in Project effluent, ug/L

CCC = Criterion Continuous Concentration

CTR = California Toxics Rule

CPDH = California Department of Public Health

MCL = Maximum Contaminant Level

Percentage Change in Mass Loading Assimilative Capacity = (Ceff x Qeff) / [(WQS x QR2) – (QR1 x CR1)]

Q_{AC} = Flow rate of Bear River above Combie Reservoir, L/s, based on flow data obtained below Rollins Reservoir

Q_{eff} = Flow rate of effluent discharge from the Project to receiving water, L/s

Q_{R1} = Flow rate of Bear River into Combie Reservoir, L/s

QR2 = Predicted flow rate of Bear River and Project discharge into Combie Reservoir (QR1 + Qeff)

USEPA = United States Environmental Protection Agency

WQS = Water quality standard, ug/L

APPENDIX I
TABLE OF NON-DETECTS

Non-Detect Effluent overflow Water Quality Summary

Data from Test 2, three samples taken during the test

Name of Constituent	Units	Begin Date	End Date	Number of Samples	Number of Samples Detected	Percent Detected	Min	Ave	Max	Reporting Limit
1,1,1,2-Tetrachloroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,1,1-Trichloroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,1,2,2-Tetrachloroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,1,2-Trichloro-1,2,2-Trifluoroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	10
1,1,2-Trichloroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,1-Dichloroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,1-Dichloroethene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,1-Dichloropropene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,2,3-Trichlorobenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,2,3-Trichloropropane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,2,4-Trichlorobenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,2,4-Trimethylbenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,2-Dibromo-3-chloropropane (DBCP)	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	5
1,2-Dibromoethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	5
1,2-Dichlorobenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,2-Dichloroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,2-Dichloropropane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,3,5-Trimethylbenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,3-Dichlorobenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,3-Dichloropropane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
1,4-Dichlorobenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
2,2-Dichloropropane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
2-Butanone	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	10
2-Chlorotoluene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
2-Hexanone	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	10
4-Chlorotoluene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
4-Methyl-2-pentanone	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	10
Acetone	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	10
Antimony (Sb)	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	2
Bromobenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Bromochloromethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Bromodichloromethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Bromoform	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Bromomethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Carbon Disulfide	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	5
Carbonate (as CaCO3)	mg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	1
Carbontetrachloride	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Chlorobenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Chloroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Chloroform	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Chloromethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
cis-1,2-Dichloroethene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
cis-1,3-Dichloropropene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Dibromochloromethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Dibromomethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Dichlorodifluoromethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Ethyl t-Butyl Ether	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	3
Ethylbenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Hexachlorobutadiene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Hexachloroethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	50
Hydroxide (as CaCO3)	mg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	1
Iodomethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	5
Isopropylbenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
m,p-Xylenes	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
MBAS, Calculated as LAS, mol wt 340	mg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.05
Methylene Chloride	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Methyl-t-Butyl Ether	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	3
Naphthalene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	1
n-Butylbenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Nitrate (NO3)	mg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	1
Nitrite (NO2-N)	mg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.05
n-Propylbenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
o-Xylene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
p-Isopropyltoluene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
sec-Butylbenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Selenium (Se) - Total	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	2
Silver (Ag)	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	10
Styrene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
t-Amyl Methyl Ether	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	3
tert-Butylbenzene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Tetrachloroethene (PCE)	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Toluene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Total 1,3-Dichloropropene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Total Trihalomethanes	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0
Total Xylene Isomers	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
trans-1,2-Dichloroethene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
trans-1,3-Dichloropropene	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Trichloroethene (TCE)	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5
Trichlorofluoromethane	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	5
Vinyl Chloride	µg/L	10/1/2009	10/6/2009	3	0	0%	0	0	0	0.5

APPENDIX II
LABORATORY REPORTS

BSK Associates
Engineers & Laboratories

A2E1884

06/05/2012

Carrie Monohan
Nevada Irrigation District
1036 W. Main Street
Grass Valley, CA 95945-5424

Dear Carrie Monohan,

Thank you for selecting BSK Associates for your analytical testing needs. We have prepared this report in response to your request for analytical services. Enclosed are the results of analyses for samples received by the laboratory on 05/23/2012 10:30.

If additional clarification of any information is required, please contact your Client Services Representative, John Montierth at (800) 877-8310 or (559) 497-2888.

BSK ASSOCIATES

Roy Diaz

Roy Diaz For John Montierth
Client Services Representative

A2E1884 FINAL 06052012 1609

06/05/2012

Case Narrative

Work Order Information

Client Name:	Nevada Irrigation District	**Submitted by:**	Carrie Monohan
Client Code:	Nevad6185	**Shipped by:**	UPS
Work Order:	A2E1884	**COC Number:**	
Project:	Combie Reservoir - Dissolved	**TAT:**	10
		PO #:	

Sample Receipt Conditions

Cooler: **Default Cooler** **Temp. ºC:** 21

Containers Intact
COC/Labels Agree
Received with no thermal preservation.
Packing Material - Bubble Wrap
Packing Material - Foam
Sample(s) split after receipt at the laboratory.
Sample(s) preserved after receipt at lab.
Initial receipt at BSK-FAL

Report Manager	Report Format
Carrie Monohan	Final.rpt
Connie Petty	Final.rpt

A2E1884 FINAL 06052012 1609

BSK Associates Engineers & Laboratories

Certificate of Analysis

Carrie Monohan
Nevada Irrigation District
1036 W. Main Street
Grass Valley, CA 95945-5424

Report Issue Date: 06/05/2012 16:09
Received Date: 05/23/2012
Received Time: 10:30

Lab Sample ID: A2E1884-01
Sample Date: 05/22/2012 00:00
Sample Type: Grab
Sampled by: Carrie Monohan
Matrix: Water

Sample Description: Combie Test Discharge

General Chemistry

Analyte	Method	Result	MDL	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
***Hexavalent Chromium**	EPA 218.6	**0.082**	0.019	0.20	ug/L	1	A205456	05/24/12	05/24/12	BL02, J
Total Dissolved Solids	SM 2540C	**160**		5.0	mg/L	1	A205453	05/24/12	05/30/12	
***Total Suspended Solids**	SM 2540D	**1800**		5.0	mg/L	1	A205549	05/29/12	06/01/12	
Turbidity	SM 2130 B	**1400**		20	NTU	200	A205402	05/23/12 16:57	05/23/12 16:57	

Metals

Analyte	Method	Result	MDL	RL	Units	RL Mult	Batch	Prepared	Analyzed	Qual
Aluminum	EPA 200.7	**0.042**	0.023	0.050	mg/L	1	A205659	05/31/12	06/05/12	J
***Antimony (2)**	EPA 200.8	**0.59**	0.13	0.50	ug/L	1	A205661	05/31/12	06/04/12	
***Arsenic (2)**	EPA 200.8	**2.7**	0.85	1.0	ug/L	1	A205661	05/31/12	06/04/12	
Barium	EPA 200.8	**62**	2.3	5.0	ug/L	1	A205659	05/31/12	06/04/12	
*Beryllium	EPA 200.8	ND	0.18	0.50	ug/L	1	A205660	05/31/12	06/04/12	
***Cadmium**	EPA 200.8	**0.21**	0.10	0.25	ug/L	1	A205660	05/31/12	06/04/12	J
***Chromium (2)**	EPA 200.8	**1.4**	0.28	0.50	ug/L	1	A205661	05/31/12	06/04/12	
***Copper**	EPA 200.8	**0.92**	0.18	0.50	ug/L	1	A205660	05/31/12	06/04/12	
Iron	EPA 200.7	**0.024**	0.023	0.050	mg/L	1	A205659	05/31/12	06/05/12	J
*Lead	EPA 200.8	ND	0.20	0.50	ug/L	1	A205660	05/31/12	06/04/12	
Manganese	EPA 200.7	**0.75**	0.0045	0.010	mg/L	1	A205659	05/31/12	06/05/12	
Mercury	EPA 200.8	ND	0.18	0.40	ug/L	1	A205659	05/31/12	06/04/12	
*Molybdenum	EPA 200.8	ND	4.5	10	ug/L	1	A205659	05/31/12	06/04/12	
***Nickel**	EPA 200.8	**26**	0.30	1.0	ug/L	1	A205660	05/31/12	06/04/12	
Selenium	EPA 200.8	ND	0.91	2.0	ug/L	1	A205659	05/31/12	06/04/12	
*Silver (2)	EPA 200.8	ND	0.13	0.25	ug/L	1	A205661	05/31/12	06/04/12	
Thallium	EPA 200.8	ND	0.45	1.0	ug/L	1	A205659	05/31/12	06/04/12	
***Zinc**	EPA 200.8	**28**	5.0	10	ug/L	1	A205660	05/31/12	06/04/12	

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BSK Associates Engineers & Laboratories

General Chemistry Quality Control Report

Analyte	Result	MDL	RL	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Date Analyzed	Qual
Batch: A205402					Analyst: DFS		Prepared: 05/23/2012					
Blank (A205402-BLK1) SM 2130 B - Quality Control												
Turbidity	ND		0.10	NTU							05/23/12	
Duplicate (A205402-DUP1) SM 2130 B - Quality Control							**Source: A2E1781-01**					
Turbidity	0.53		0.10	NTU		0.58			9	20	05/23/12	
Duplicate (A205402-DUP2) SM 2130 B - Quality Control							**Source: A2E1901-06**					
Turbidity	ND		0.10	NTU		ND				20	05/23/12	
Batch: A205453					Analyst: DEH		Prepared: 05/24/2012					
Blank (A205453-BLK1) SM 2540C - Quality Control												
Total Dissolved Solids	ND		5.0	mg/L							05/30/12	
Blank (A205453-BLK2) SM 2540C - Quality Control												
Total Dissolved Solids	ND		5.0	mg/L							05/30/12	
Duplicate (A205453-DUP1) SM 2540C - Quality Control							**Source: A2E1877-01**					
Total Dissolved Solids	1000		5.0	mg/L		1000			0	20	05/30/12	
Duplicate (A205453-DUP2) SM 2540C - Quality Control							**Source: A2E1924-01**					
Total Dissolved Solids	470		5.0	mg/L		460			1	20	05/30/12	
Batch: A205456					Analyst: RCN		Prepared: 05/24/2012					
Blank (A205456-BLK1) EPA 218.6 - Quality Control												
Hexavalent Chromium	0.045	0.019	0.20	ug/L							05/24/12	J
Blank Spike (A205456-BS1) EPA 218.6 - Quality Control												
Hexavalent Chromium	2.1	0.019	0.20	ug/L	2.0		104	90-110			05/24/12	
Blank Spike Dup (A205456-BSD1) EPA 218.6 - Quality Control												
Hexavalent Chromium	2.1	0.019	0.20	ug/L	2.0		103	90-110	1	10	05/24/12	
Matrix Spike (A205456-MS1) EPA 218.6 - Quality Control							**Source: A2E1884-01**					
Hexavalent Chromium	2.2	0.019	0.20	ug/L	2.0	0.082	104	90-110			05/24/12	
Matrix Spike Dup (A205456-MSD1) EPA 218.6 - Quality Control							**Source: A2E1884-01**					
Hexavalent Chromium	2.1	0.019	0.20	ug/L	2.0	0.082	101	90-110	3	10	05/24/12	
Batch: A205549					Analyst: DEH		Prepared: 05/29/2012					
Blank (A205549-BLK1) SM 2540D - Quality Control												
Total Suspended Solids	ND		5.0	mg/L							06/01/12	
Duplicate (A205549-DUP1) SM 2540D - Quality Control							**Source: A2E2107-01**					
Total Suspended Solids	77		5.0	mg/L		79			3	20	06/01/12	

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CABY Headwaters Resilience Project Application Program - Attachment 3018
Attachment 7 - CABY Mercury Initiative References - 1 of 3
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BSK Associates Engineers & Laboratories

Metals Quality Control Report

Analyte	Result	MDL	RL	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Date Analyzed	Qual
Batch: A205659					Analyst: NRE		Prepared: 05/31/2012					
Blank (A205659-BLK2) EPA 200.7 - Quality Control												
Aluminum	ND	0.023	0.050	mg/L							06/05/12	
Iron	ND	0.023	0.050	mg/L							06/05/12	
Manganese	ND	0.0045	0.010	mg/L							06/05/12	
Blank Spike (A205659-BS2) EPA 200.7 - Quality Control												
Aluminum	0.20	0.023	0.050	mg/L	0.20		102	85-115			06/05/12	
Iron	2.0	0.023	0.050	mg/L	2.0		101	85-115			06/05/12	
Manganese	0.20	0.0045	0.010	mg/L	0.20		101	85-115			06/05/12	
Blank Spike Dup (A205659-BSD2) EPA 200.7 - Quality Control												
Aluminum	0.21	0.023	0.050	mg/L	0.20		103	85-115	1	20	06/05/12	
Iron	2.0	0.023	0.050	mg/L	2.0		102	85-115	1	20	06/05/12	
Manganese	0.20	0.0045	0.010	mg/L	0.20		102	85-115	1	20	06/05/12	
Blank (A205659-BLK1) EPA 200.8 - Quality Control												
Barium	ND	2.3	5.0	ug/L							06/04/12	
Mercury	ND	0.18	0.40	ug/L							06/04/12	
Molybdenum	ND	4.5	10	ug/L							06/04/12	
Selenium	ND	0.91	2.0	ug/L							06/04/12	
Thallium	ND	0.45	1.0	ug/L							06/04/12	
Blank Spike (A205659-BS1) EPA 200.8 - Quality Control												
Barium	190	2.3	5.0	ug/L	200		96	85-115			06/04/12	
Mercury	4.7	0.18	0.40	ug/L	5.0		94	85-115			06/04/12	
Molybdenum	200	4.5	10	ug/L	200		102	85-115			06/04/12	
Selenium	190	0.91	2.0	ug/L	200		95	85-115			06/04/12	
Thallium	210	0.45	1.0	ug/L	200		104	85-115			06/04/12	
Blank Spike Dup (A205659-BSD1) EPA 200.8 - Quality Control												
Barium	190	2.3	5.0	ug/L	200		96	85-115	1	20	06/04/12	
Mercury	4.9	0.18	0.40	ug/L	5.0		98	85-115	3	20	06/04/12	
Molybdenum	190	4.5	10	ug/L	200		96	85-115	5	20	06/04/12	
Selenium	180	0.91	2.0	ug/L	200		90	85-115	5	20	06/04/12	
Thallium	210	0.45	1.0	ug/L	200		105	85-115	1	20	06/04/12	
Batch: A205660					Analyst: PSK		Prepared: 05/31/2012					
Blank (A205660-BLK1) EPA 200.8 - Quality Control												
Beryllium	ND	0.18	0.50	ug/L							06/04/12	
Cadmium	ND	0.10	0.25	ug/L							06/04/12	
Copper	ND	0.18	0.50	ug/L							06/04/12	
Lead	ND	0.20	0.50	ug/L							06/04/12	
Nickel	ND	0.30	1.0	ug/L							06/04/12	
Zinc	ND	5.0	10	ug/L							06/04/12	
Blank Spike (A205660-BS1) EPA 200.8 - Quality Control												
Beryllium	230	0.18	0.50	ug/L	200		114	85-115			06/04/12	
Cadmium	190	0.10	0.25	ug/L	200		94	85-115			06/04/12	

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BSK Associates Engineers & Laboratories

Metals Quality Control Report

Analyte	Result	MDL	RL	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Date Analyzed	Qual
Batch: A205660					Analyst: PSK		Prepared: 05/31/2012					
Blank Spike (A205660-BS1) EPA 200.8 - Quality Control												
Copper	200	0.18	0.50	ug/L	200		99	85-115			06/04/12	
Lead	190	0.20	0.50	ug/L	200		93	85-115			06/04/12	
Nickel	200	0.30	1.0	ug/L	200		102	85-115			06/04/12	
Zinc	180	5.0	10	ug/L	200		92	85-115			06/04/12	
Blank Spike Dup (A205660-BSD1) EPA 200.8 - Quality Control												
Beryllium	230	0.18	0.50	ug/L	200		113	85-115	1	20	06/04/12	
Cadmium	190	0.10	0.25	ug/L	200		93	85-115	1	20	06/04/12	
Copper	200	0.18	0.50	ug/L	200		98	85-115	1	20	06/04/12	
Lead	180	0.20	0.50	ug/L	200		92	85-115	1	20	06/04/12	
Nickel	210	0.30	1.0	ug/L	200		103	85-115	1	20	06/04/12	
Zinc	190	5.0	10	ug/L	200		93	85-115	1	20	06/04/12	
Matrix Spike (A205660-MS1) EPA 200.8 - Quality Control							**Source: A2E1846-01**					
Beryllium	230	0.18	0.50	ug/L	200	ND	113	70-130			06/04/12	
Cadmium	180	0.10	0.25	ug/L	200	0.29	90	70-130			06/04/12	
Copper	250	0.18	0.50	ug/L	200	68	91	70-130			06/04/12	
Lead	180	0.20	0.50	ug/L	200	2.2	88	70-130			06/04/12	
Nickel	200	0.30	1.0	ug/L	200	2.9	100	70-130			06/04/12	
Zinc	290	5.0	10	ug/L	200	130	81	70-130			06/04/12	
Matrix Spike Dup (A205660-MSD1) EPA 200.8 - Quality Control							**Source: A2E1846-01**					
Beryllium	240	0.18	0.50	ug/L	200	ND	118	70-130	4	20	06/04/12	
Cadmium	180	0.10	0.25	ug/L	200	0.29	91	70-130	1	20	06/04/12	
Copper	250	0.18	0.50	ug/L	200	68	93	70-130	1	20	06/04/12	
Lead	180	0.20	0.50	ug/L	200	2.2	87	70-130	2	20	06/04/12	
Nickel	210	0.30	1.0	ug/L	200	2.9	101	70-130	1	20	06/04/12	
Zinc	300	5.0	10	ug/L	200	130	84	70-130	2	20	06/04/12	
Batch: A205661					Analyst: PSK		Prepared: 05/31/2012					
Blank (A205661-BLK1) EPA 200.8 - Quality Control												
Antimony (2)	ND	0.13	0.50	ug/L							06/04/12	
Arsenic (2)	ND	0.85	1.0	ug/L							06/04/12	
Chromium (2)	0.28	0.28	0.50	ug/L							06/04/12	J
Silver (2)	ND	0.13	0.25	ug/L							06/04/12	
Blank Spike (A205661-BS1) EPA 200.8 - Quality Control												
Antimony (2)	200	0.13	0.50	ug/L	200		99	85-115			06/04/12	
Arsenic (2)	190	0.85	1.0	ug/L	200		97	85-115			06/04/12	
Chromium (2)	210	0.28	0.50	ug/L	200		103	85-115			06/04/12	
Silver (2)	95	0.13	0.25	ug/L	100		95	75-125			06/04/12	
Blank Spike Dup (A205661-BSD1) EPA 200.8 - Quality Control												
Antimony (2)	200	0.13	0.50	ug/L	200		101	85-115	2	20	06/04/12	
Arsenic (2)	200	0.85	1.0	ug/L	200		100	85-115	3	20	06/04/12	
Chromium (2)	210	0.28	0.50	ug/L	200		107	85-115	4	20	06/04/12	
Silver (2)	95	0.13	0.25	ug/L	100		95	75-125	0	20	06/04/12	

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BSK Associates Engineers & Laboratories

Metals Quality Control Report

Analyte	Result	MDL	RL	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Date Analyzed	Qual
Batch: A205661					Analyst: PSK		Prepared: 05/31/2012					
Matrix Spike (A205661-MS1)	**EPA 200.8 - Quality Control**						**Source: A2E1846-01**					
Antimony (2)	200	0.13	0.50	ug/L	200	1.6	98	70-130			06/04/12	
Arsenic (2)	200	0.85	1.0	ug/L	200	3.0	99	70-130			06/04/12	
Chromium (2)	250	0.28	0.50	ug/L	200	22	112	70-130			06/04/12	
Silver (2)	37	0.13	0.25	ug/L	100	0.15	37	70-130			06/04/12	MS02 ***Low***
Matrix Spike Dup (A205661-MSD1)	**EPA 200.8 - Quality Control**						**Source: A2E1846-01**					
Antimony (2)	200	0.13	0.50	ug/L	200	1.6	98	70-130	1	20	06/04/12	
Arsenic (2)	200	0.85	1.0	ug/L	200	3.0	99	70-130	0	20	06/04/12	
Chromium (2)	250	0.28	0.50	ug/L	200	22	114	70-130	1	20	06/04/12	
Silver (2)	38	0.13	0.25	ug/L	100	0.15	37	70-130	2	20	06/04/12	MS02 ***Low***

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BSK Associates Engineers & Laboratories

Certificate of Analysis

06/05/2012

Notes:

- The Chain of Custody document and Sample Integrity Sheet are part of the analytical report.
- Any remaining sample(s) for testing will be disposed of one month from the final report date unless other arrangements are made in advance.
- Sample(s) received, prepared, and analyzed within the method specified criteria unless otherwise noted within this report.
- The results relate only to the samples analyzed in accordance with test(s) requested by the client on the Chain of Custody document. Any analytical quality control exceptions to method criteria that are to be considered when evaluating these results have been flagged and are defined in the data qualifiers section.
- All results are expressed on wet weight basis unless otherwise specified.
- All positive results for EPA Methods 504.1, 502.2, and 524.2 require the analysis of a Field Reagent Blank (FRB) to confirm that the results are not a contamination error from field sampling steps. If Field Reagent Blanks were not submitted with the samples, this method requirement has not been performed.
- Results contained in this analytical report must be reproduced in its entirety.
- Samples collected by BSK Analytical Laboratories were collected in accordance with the BSK Sampling and Collection Standard Operating Procedures.
- BSK Analytical Laboratories certifies that the test results contained in this report meet all requirements of the NELAC Standards for applicable certified drinking water chemistry analyses unless qualified or noted in the Case Narrative.
- Analytical data contained in this report may be used for regulatory purposes to meet the requirements of the Federal or State drinking water, wastewater, and hazardous waste programs.
- J-value is equivalent to DNQ (Detected, not quantified) which is a trace value. A trace value is an analyte detected between the MDL and the laboratory reporting limit. This result is of an unknown data quality and is only qualitative (estimated). Baseline noise, calibration curve extrapolation below the lowest calibrator, method blank detections, and integration artifacts can all produce apparent DNQ values, which contribute to the un-reliability of these values.
- (1) - Residual chlorine and pH analysis have a 15 minute holding time for both drinking and waste water samples as defined by the EPA and 40 CFR 136. Waste water and ground water (monitoring well) samples must be field filtered to meet the 15 minute holding time for dissolved metals.
- * - This is not a NELAP accredited analyte.
- Summations of analytes (i.e. Total Trihalomethanes) may appear to add individual amounts incorrectly, due to rounding of analyte values occurring before or after the total value is calculated, as well as rounding of the total value.
- (2) The digestion used to produce this result deviated from EPA 200.2 by excluding hydrochloric acid in order to produce acceptable recoveries for affected metals.
- (2C) Result reported from secondary analytical column.
- RL Multiplier is the factor used to adjust the reporting limit (RL) due to variations in sample preparation procedures and dilutions required for matrix interferences.

Certifications:

State of California - CDPH - ELAP	1180
State of California - CDPH - NELAP	04227CA
State of Nevada - NDEP	CA000792009A
State of Hawaii - DOH	04227CA

Definitions and Flags for Data Qualifiers

mg/L:	Milligrams/Liter (ppm)	M:	Method Detection Limit	MDA95:	Min. Detected Activity
mg/Kg:	Milligrams/Kilogram (ppm)	RL:	Reporting Limit	MPN:	Most Probable Number
µg/L:	Micrograms/Liter (ppb)		:DL x Dilution	CFU:	Colony Forming Unit
µg/Kg:	Micrograms/Kilogram (ppb)	ND:	None Detected at RL	Absent:	Less than 1 CFU/100mLs
%:	Percent Recovered (surrogates)	pCi/L:	Picocuries per Liter	Present:	1 or more CFU/100mLs
		NR:	Non-Reportable	RL Mult:	RL Multiplier

MS02 Matrix spike recovery was low; the associated blank spike recovery was acceptable.

J DNQ (Detected, not quantified) or trace value. Analyte was detected between MDL and laboratory reporting limit (estimated value).

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BL02 Target analyte detected in method blank at or above the method detection limit (MDL).

1414 Stanislaus Street Fresno, CA 93706 (559) 497-2888 FAX (559) 485-6935 www.bsklabs.com

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Environmental Engineering | Geotechnical Engineering | Materials Testing

A2E1884

Nevada Irrigation District

Nevad6185

05232012

Turnaround: Standard

Due Date: 6/7/2012

Printed: 5/23/2012 6:33:07PM

BSK ANALYTICAL LABORATORIES

1414 Stanislaus Street, Fresno, CA 93706-1623
(559) 497-2888 • FAX (559) 497-2893 • www.bsklabs.com

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Nevad6185

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TEMP: 21°

* Required Fields

Client/Company Name *:	Report Attention *:	Phone * #: / FAX * #:
NID	John Monteith	530 277-2040
		E-mail: carrie.monohan@sierrafund.org

Address *: 425 Commercial St. Nevada City CA 95959
City * / State * / Zip *

Project Information: Combie Reservoir
PO #
Quote #

How would you like your completed results sent? (E-Mail) Fax EDD Mail Only

Sampler Name Printed / Signature: Carrie Monohan
QC Request: STD Level II
Result Request ** Surcharge: STD 5 Day** 2 Day** 1 Day**

Carbon Copies: CDHS Fresno Co EPA Merced Co Tulare Co Other:

Regulatory Compliance: Electronic Data Transfer: Y N System No. *

ANALYSIS REQUESTED: Gross alpha, Gross beta, DOC, low level ethylene dibromide (EDB) of method, per EPA 504.1 Dale

Matrix Types: RSW = Raw Surface Water, CFW = Clorinated Finished Water, CWW = Chorinated Waste Water, BW = Bottled Water, RGW = Raw Ground Water, FW = Finished Water, WW = Waste Water, SW = Storm Water, DW = Drinking Water, SO = Solid

Sample #	# Bottles	Sampled Date	Sampled Time	Sample Description / Location *	Matrix *	Comments / Station Code	Gross alpha	Gross beta	DOC	low level ethylene dibromide (EDB) of method, per EPA 504.1 Dale
~~1~~	~~BC~~	~~7-22-09~~	~~10:00 am~~	~~Below Combie~~						
~~2~~	~~AC~~	~~7-22-09~~	~~11:00 am~~	~~Above Combie~~						
~~3~~	~~PO~~	~~7-22-09~~	~~12:00 pm~~	~~Pond outlet~~						
1	1	5/22/12		Combie Test Discharge						X

Relinquished by: (Signature and Printed Name)	Company	Date	Time	Received by (Signature and Print Name)	Company
Carrie Monohan	NID	1:00	5-22-12		
Relinquished by: (Signature and Printed Name)	Company	Date	Time	Received by (Signature and Print Name)	Company
Received for Lab by: (Signature and Printed Name)	BSK	5/23/12	1030	Payment Received at Delivery: Date: Amount: Check/Cash/Card PIA # Init.	

Shipping Method: CAC UPS GSO WALK-IN SJVC FED EX OTHER

Cooling Method: WET BLUE NONE

Packing Material: B/W Foam

Notice: Payment for services rendered as noted herein are due in full within 30 days from when invoiced. If not so paid, account balances are deemed delinquent. Delinquent balances are subject to monthly service/re-billing charges and interest calculated at 1 1/2 % per month, 18% per annum. BSK & Associates shall be entitled to recover on delinquent accounts, costs of collections, including attorneys' fees incurred prior to or in litigation whether concluded by judgement, settlement, compromise or otherwise. The person signing for the client/Company expressley acknowledges that they are either the Client or authorized agent to the Client, and the Client agrees to be responsible for payment for analytical services on this Chain of Custody. Any modification of the analysis requested, either type or quantities, will be noted and agreed upon this Chain of Custody. The turn around time for any samples received after 3:00 pm will begin the next business day.

SR-FL-0012-09 (Analytical)

Sample Integrity Pg. 1 of 2

A2E1884
Nevad6185

05/23/2012
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Date Received 5/23/12

Section 1- Receiving Information

Sample Transport: ONTRAC (UPS) PMS Walk-In BSK-Courier GSO Fed Exp. Other: _____

Samples arrived at lab on same day sampled: Yes ____ No X Has Chilling Process Begun: Yes____ No X

Coolers/Ice Chests Description/Temperature(s): (If more than 5 received, list information in comment section)

1) 21° 2) _____ 3) _____ 4) _____ 5) _____

Was Temperature In Range: Y (N) N/A Received On Ice: Wet Blue Received Ambient (Y) N

Describe type of packing materials: (Bubble Wrap) (Foam) Packing Peanuts Paper Other: _____

Initial Receipt: BSK-Visalia BSK-Bakersfield BSK-SAC (BSK-FAL)

Were ice chest custody seals present? Y (N) Intact: Y N

Section 2- COC Info.	Completed Yes	Completed No	Info From Container		Completed Yes	Completed No	Info From Container
Was COC Received	X			Analysis Requested	X		
Date Sampled	X			Hold times less than 72hr	X		
Time Sampled	X			Client Name	X		
Sample ID	X			Address	X		
Special Storage/Handling Ins.		X		Telephone #	X		

Section 3- Bottles / Analysis	Yes	No	N/A	Comment
Did all bottles arrive unbroken and intact?	X			
Were bottle custody seals present?		X		
Were bottle custody seals intact?		X		
Did all bottle labels agree with COC?	X			
Were correct containers used for the tests requested?		X		X
Were correct preservations used for the tests requested?		X		X
Was a sufficient amount of sample sent for tests indicated?		X		X
Were bubbles present in VOA Vials? (**Volatile Methods Only**)			X	
Were Ascorbic Acid Bottles received with the VOAs?			X	

Section 4- Comments / Discrepancies

Sample(s) (Split) (Preserve) (Yes) No Container: 250P ½ bottle only Preservation: Cr+6 Dt/Time/Init 5/23/12 1410

Container: _____ Preservation: _____ Dt/Time/Init _____

Was Client Service Rep. notified of discrepancies: (Yes) No N/A CSR: John Notified By/Time:

Explanations / Comments

Limited Volume, only about 500mL

Report Comment Entered:

Labeled by: @ 1446 Labels checked by: IA @ 1535 RUSH Paged by: _____ @ _____

(4/11)

A2E1884
Nevad6185

05/23/2012
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Sample Integrity Pg 2 of 2

BSK Bottles (Yes) No

250ml (A) 500ml (B) 1Liter (C) Amber Glass (AG)

Container(s) Received	1
Bacti $Na_2S_2O_3$	
None (p) White Cap	1C
None (p) Blue Cap w/NH4 + Buffer	
HNO_3 (p) Red Cap	
H_2SO_4 (p) Yellow Cap	
NaOH (p) Green Cap	
EDA (p) Brown Cap/Label	
Other:	
Dissolved Oxygen 300ml (g)	
250ml (AG) None	
250ml (AG) H_2SO_4 COD Yellow Label	
250ml (AG) $Na_2S_2O_3$ 515,547 Blue Label	
250ml (AG) $Na_2S_2O_3$+ MCAA 531.1 Orange Label	
250ml (AG) NH_4Cl 552 Purple Label	
250ml (AG) EDA DBPs Brown Label	
250ml (AG) Other:	
500ml (AG) None	
500ml (AG) H_2SO_4 Yellow Label	
1 Liter (AG) None	
1 Liter (AG) H_2SO_4 O&G / TPH-Diesel Yellow Label	
1 Liter (AG) $Na_2S_2O_3$ 548 / 525 / 521 Blue Label	
1 Liter (P) $Na_2S_2O_3$+ H_2SO_4 549	
1 Liter (AG) NaOH+ZnAc Sulfide	
40ml VOA Vial Clear – HCL	
40ml VOA Vial Clear – Buffer pH 4	
40ml VOA Vial Clear – None	
40ml VOA Vial Amber – $Na_2S_2O_3$	
40ml VOA Vial Clear - $Na_2S_2O_3$ 504, 505	
40ml VOA Vial Clear – H_3PO_4	
Other:	
½ Gallon (p)	
Asbestos 1Liter Plastic/Foil	
Radon 200ml Clear (g)	
Low Level Hg/Metals Double Baggie	
Bioassay Jug	
Ampule	
PT Sample Bottle	
250 Clear Glass Jar	
500 Clear Glass Jar	
1 Liter Clear Glass Jar	
Plastic Bag	
Soil Tube Brass / Steel / Plastic	
Tedlar Bags	

5/23/12

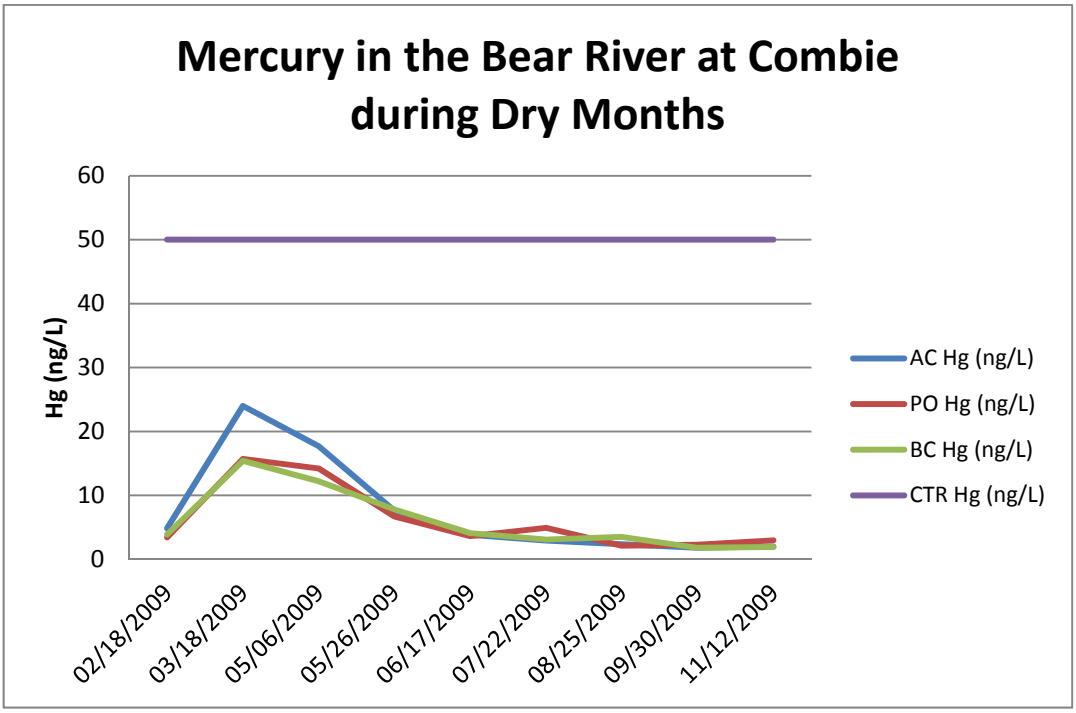
(4/11)

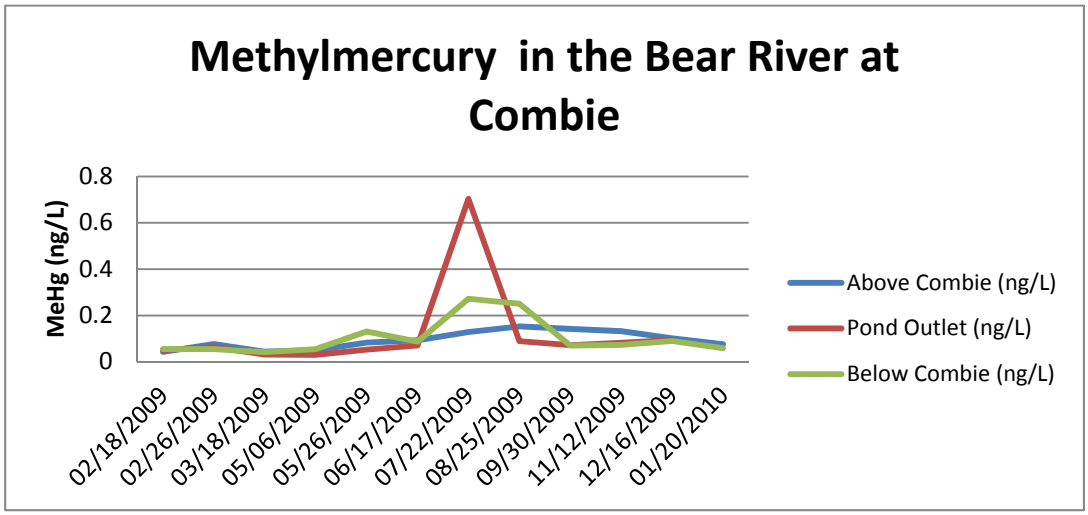
SR-FL-0002-06

Appendix III

Background Mercury and Methylmercury Concentrations in the Bear River

The graphs below display the total and methyl mercury concentrations at the three monitoring sites around Combie Reservoir, Above Combie (AC), Below Combie (BC) and at the Pond Outlet (PO) where the project is proposed to take place.





The methylmercury peak is in a warm shallow area. The sample was taken of the water collum in the area to be dredged at the river delta.

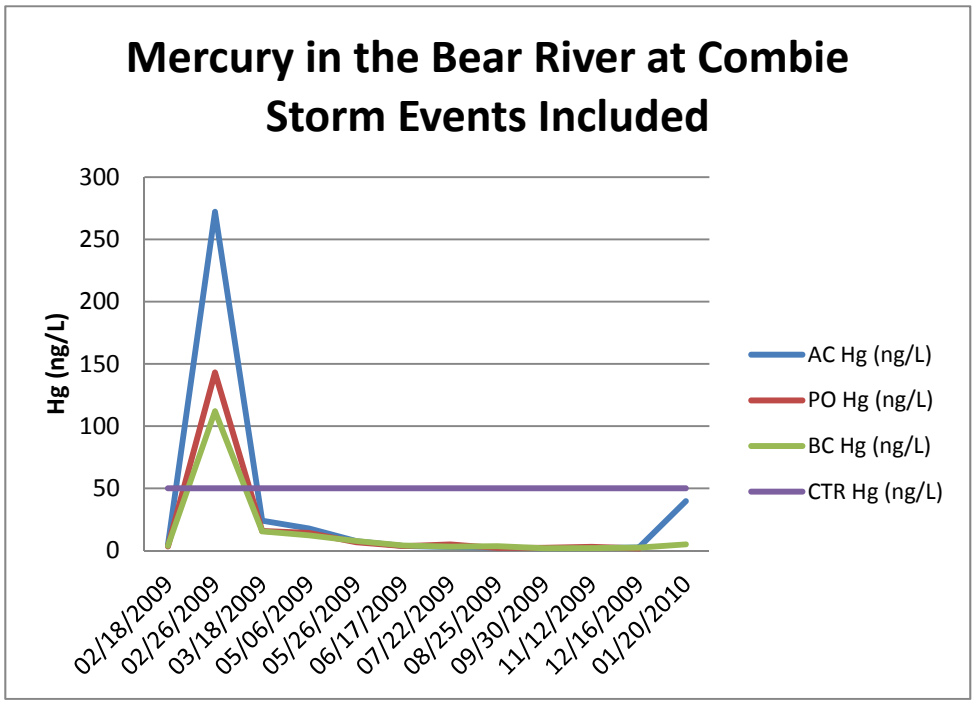


Table of Febuary 26th storm and mercury and methyl mercury consentrations:

Febuary 26th, 2009 Storm Event					
Sample Date	Sample Time	Analyte	Result	Units	Location
02/26/2009	11:15	Hg	272	ng/L	Above Combie
02/26/2009	12:07	Hg	143	ng/L	Pond Outlet
02/26/2009	10:25	Hg	112	ng/L	Below Combie
02/26/2009	11:15	MeHg	0.077	ng/L	Above Combie
02/26/2009	12:07	MeHg	0.064	ng/L	Pond Outlet
02/26/2009	10:25	MeHg	0.055	ng/L	Below Combie

The above data represent the exsisting conditions at Combie Resevoir pre project. This information may help determine the months/conditions of operation.

APPENDIX IV
PEGASUS MERCURY EXTRACTION TESTS RESULTS

Introduction

The efficiency of the Pegasus Mercury Extraction Equipment was measured by conducting four closed system tests. The goal of the closed system tests was to be able to account for all of the material that entered the equipment at the end of the test so a mass balance could be calculated for the processed material including; water, sediment, total mercury, methyl mercury and reactive mercury. These mass balance calculations were used to determine the percent efficiency of mercury removal by looking at the change in mercury content in the material that entered the machine, head material, and compare it to the mercury content in the effluent or tail material.

The equipment tests were run with material from two different sources. The first source was the drying beds from an old aggregate plant, which were suspected to be high in mercury. The second source was from the Bear River delta within Combie Reservoir, which contains the material to be dredged as part of the Nevada Irrigation District Sediment and Mercury Removal Project (the project).

Material collection

Two scuba divers collected material from the river delta area at the north end of Combie Reservoir. The material was scooped into 5 gallon buckets. The material was collected from three different areas in the river delta. The material for the first set of nine buckets was collected from the upstream end on the delta deposit on the east side of the thalweg. The material for the second set of nine buckets was collected approximately 100 feet downstream also on the east side of the thalweg. The material for the third set of nine buckets was collected approximately 200 feet downstream also on the east side of the thalweg. The divers tried to collect sandy material without a lot of organic material such as woody debris.

A backhoe was used to collect material from drying beds on the day of the equipment tests. The back hoe collected material below the first foot of surface soil. Buckets of material were scooped up by the backhoe and added to 5 gallon buckets.

Setup

The equipment demonstration site was set up with the mercury extraction equipment which was mounted on a 30 ft long triple axel trailer, two water trucks, a small holding tank with a pump and a generator to run the pump, and a scale (O'haus beam balance, 2002) set up on the back of the equipment trailer. One water truck was full of clean potable water and the other was empty. Both trucks were weighed at the start of the test. And the water from the fist water truck was sampled at the start of the test to verify that there was not any contamination.

A 2 inch garden hose extended from the base of the first water truck to the equipment.
A 6 inch hose extended from the holding tank and pump outlet back into the top of the empty water truck.

The four independent tests were run over a period of 4 days, a single test on each day, equipment was thoroughly washed with potable water between each test.

Sampling the head material

All of the head material that was processed during a test was mixed and weighed before it went into the mercury extraction equipment.

- The buckets of material that the divers collected (9 buckets/test) were split into two equal parts using a set of clean buckets and a shovel.
- Water was added to the buckets creating 18 buckets with approximately 50 percent solids.
- This mixture of dredged material and water was mixed with a hand-held grout mixer.
- Composite samples were taken of this head material using acid washed glass jars.
- Each sample jar was filled half way with the material from bucket 1A and then filled the rest of the way with the material from bucket 1B.
- The composite sample of the head material was taken immediately after the grout mixer was removed.
- This process was repeated for all 18 buckets creating a total of 9 head samples for each test. These samples were labeled (1-9) and immediately placed on ice.

Once the head material had been sampled and each bucket of head material was weighed by a scale mounted on the back of the equipment trailer, the material was ready to be processed.

Processing the material

The equipment was started up using power from a trailer mounted generator.

Water that ran from the first water truck passed though the equipment and was pumped into the second water truck for approximately 1 minute prior to adding any head material.

Head material from the buckets was added to the Pegasus Mercury Extraction Equipment by hand. As each bucket was added its number was shouted out so that those capturing the effluent could be sure to collect a trail sample at the right time.

The head material was added into a screen shaker, where the material was washed though a screen of 80 mesh size (175 microns) using water from the first water truck. The material that washed through the screen flowed into a specialized centrifuge or concentrator where it was spun at 60-80 Gs (9.8 meters per second squared). The heavy metals of specific gravity of 3 g/cm^3 or greater, such as mercury (Hg), gold (Au), and gold-mercury amalgam (AuHg) were spun to the outer edges of the concentrator and into an outer water jacket, this concentrated material was collected by the Pegasus Mercury Extraction Equipment. The material that was less than 3 g/cm^3 specific gravity was not spun to the outer edges of the concentrator but instead was flushed out of the cone as effluent which was pumped back into the second water truck.

Sampling the tail material

The effluent, which looked like turbid water, was sampled at regular intervals throughout the tests. The tail samples were collected directly (mid stream) as they flowed from the Pegasus Mercury Extraction Equipment into the small holding tank (where it would be pumped into the second water truck) to minimize size fractionation that likely occurred upon settling in the tank.

Three tail samples were taken in acid washed glass jars during each test. The three tail samples were analyzed for general mineral, inorganic, organic, and general physical parameters at BSK Analytical Laboratories, and total reactive and methyl mercury were analyzed at USGS laboratories in Menlo Park. (The water quality samples that were taken of the effluent water were analyzed for the same water quality constituents at the same lab as the background water quality samples taken from Combie Reservoir and the Bear River so that data comparison for the Antidegradation Study could be completed.) All effluent samples were immediately placed on ice and shipped overnight to two different labs: USGS in Menlo Park and BSK Laboratories in Fresno.

Weighing the material at the end of the test

The effluent was captured and weighted after each test to confirm that little to no material was lost during the test so that mass balance calculations could be conducted.

The effluent water and sediment was pumped into the second water truck and the truck was weighed after the test. Any remaining material that was in the holding tank that was not pumped into the second water truck because it settled out, was scooped into empty tarred 5 gallon buckets and weighed by hand at the trailer mounted scale (O'haus beam balance, 2002). Any material that had been collected as overflow from other areas of the machinery was sampled and added to the holding tank so that it could get pumped into the second water truck and weighed as effluent.

The liquid elemental mercury that was collected by the extraction equipment was weighed in a portable laboratory on the front end of the trailer (Electronic ACCulab 2008 balance ALC-210.4, #23250797 ACC. (±0.00001gm)).

Lab methods

The heads and tails samples were analyzed by USGS laboratory in Menlo Park for total mercury, methyl mercury, and reactive mercury(II), plus water content and grain size (% < 0.063 mm). The bulk density of each sample was recorded so that the percent water content of the head material could be used in the mass balance equations to get a dry weight of the material processed. USGS analyzed the proportion of silt-clay sized material (< 0.063 mm) in each sample (head and tail) in duplicate.

For each test there were nine head samples that were composited into batches of three, so that samples 1-3 were mixed together, as were samples 4-6 and samples 7-9. The heads and tails samples were dewatered in the USGS lab (Menlo Park) by centrifuge so that all samples could be treated in a similar manner (as sediment samples without overlying water).

The USGS used methods equivalent to EPA methods 1631 and 1630 for total mercury and methylmercury, respectively. The reactive mercury(II) analysis is based on a 15-minute digestion with

$SnCl_2$, a strong reducing agent followed by a second analysis without the addition of $SnCl_2$ and analysis by atomic fluorescence spectrometry.

Results

Four demonstration tests with the Pegasus Mercury Extraction Equipment were conducted at Combie Reservoir in September and October of 2009. Each independent test was approximately 20 minutes in length.

On September 28, 2009 the test was conducted using material from the drying beds as the source material. On October 1, 5, and 6th the tests were conducted using the river delta deposit as the source material.

Test 1: The September 28th test processed material that was scooped out of the drying beds by a backhoe and then in 5-gallon buckets with a grout mixer.

Test 2: The October 1st test processed material that was dredged from the river delta on 9/10/09 at the river confluence. This material sat in five-gallon buckets for two weeks prior to the test.

Test 3: The October 5th test processed nine 5-gallon buckets of material that were collected on October 4th using buckets and shovels at a point that was 100 ft from the river confluence. This material sat in five-gallon buckets for 24 hours prior to the test.

Test 4: The October 6th test processed nine 5-gallon buckets of material that were collected using buckets and shovels at a point that was 200 ft from the river confluence. This material sat in five-gallon buckets for 48 hours prior to the test.

Analysis of the Operational Efficiency of the Mercury Removal Equipment

To determine how efficiently the mercury extraction equipment operated, a series of mass balance calculations were conducted. This was accomplished by conducting closed system field tests of the equipment where all of the material that entered the equipment (water and sediment) was sampled and weighed, and all of the material that exited the equipment was captured, weighed and sampled.

Sediment and water Mass Balance

A sediment and water mass balance was conducted to achieve a standard of quality control between tests. This analysis was done to ensure that no material was lost or unaccounted for during the test.

The dry weight of the head material was calculated using the weight of the material that entered the equipment and the percent water content of the head samples.

Table 1: Sediment and water results

Description		Test 1	Test 2	Test 3	Test 4
Truck 1 weight full	kg	13290	13227	13127	12020
Truck 1 weight empty	kg	5697	10877	9725	8527
Water Used	kg	3511	2350	3402	3493
Material Processed wet	kg	234	399	738	716
Material Processed dry*	kg	108	288	280	268
Total weight of water and solids going IN	kg	3745	2749	4140	4208
Truck 2 weight empty	kg	5996	5915	6006	6196
Truck 2 weight full	kg	9235	8065	9235	9616
Water Captured	kg	3239	2150	3230	3420
Small amounts of water that could have gone in Truck 2	kg	0	195	**	**
Total weight of solid material left in various places	kg	189	270	359	247
Small amounts of solids that could have gone in trough	kg	0	8	45	33
Weight of USGS samples sent off		***	***	***	***
Total weight of water and solids going OUT	kg	3428	2623	3633	3700
IN -OUT= Error	kg	317	126	506	509
Mercury captured in accumulator	g	0.315	0.315		0.173

* Dry weight of material was calculated later by USGS using average bulk density of head material
* *water was just added to truck 2 and weighed in the truck rather than separately
** *Weight of tail samples is not accounted for, would be included in the out weight

Total mercury mass balance

The concentrations of total mercury, methyl mercury and reactive mercury needed to be extrapolated into a mass which would enable a percent recovery calculation. A total mercury mass balance was conducted for each test, to ensure that all the mercury that entered the equipment could be accounted for and a percent recovery calculation could be made.

The total mercury mass balance calculation was complicated by the surprising result that the average concentration of mercury in the samples taken of the head material was less than or equal to the average concentration of mercury in the samples of the tail material for each of the four tests.

In addition, each test was successful at removing elemental liquid mercury from the material that was processed, a range of 187-329 mg of mercury was recovered after each test.

Table 2. The amount of liquid mercury that was recovered at the end of each test.

Test #	Date of Test	Length of Test (min)	Amount of water used during test (lbs)	Amount of material Processed DRY (kg)	Mercury Extracted (g) by Pegasus
1	9/28/2009	20	7740	108	0.3297
2	10/1/2009	20	5180	288	0.3154
3	10/5/2009	23	7500	280	Missing
4	10/6/2009	31	7700	268	0.1873

The fact that the average concentration of mercury in the head material was equal to or greater than the average concentration of mercury in the tail samples indicated that the head samples were not representative of the head material despite the team's best efforts to homogenize batches of the head material with a grout mixer prior to the test and taking composite samples.

In fact, the proportion of fines (% < 0.063 mm) in the tail samples was consistently higher than that in the head samples, indicating a sampling bias toward finer material in the tails. Additionally, the mass of free elemental mercury recovered at the end of each test greatly exceeded the mass of mercury indicated by the head samples. It was therefore concluded that the samples taken of the head material were not an accurate representation of the head material, due to the "nugget effect".

In order to determine how efficient the mercury extraction equipment was operating, rather than conduct a mass balance for the entire processed material in bulk, we fine tuned the analyzed to conduct a mass balance for the two different size fractions of the processed material, the material that was < 0.063 mm and the material that was > 0.063 mm.

The mercury content of the fine fraction in both heads and tails was calculated for each test by applying the assumption that sand-sized material had an average mercury concentration of 0.01 µg/g, based on analyses of reservoir sediment in a similar setting, downstream of numerous hydraulic gold mines at Englebright Lake (Alpers et al., 2006) and Daguerre Point Dam (Hunerlach et al., 2004) in the Yuba River watershed.

The calculations of the mass balance of mercury for the fine fraction (< 0.063 mm) indicated that there was no apparent reduction in the Hg content during the tests, i.e. the concentrations of Hg in the fines of the head materials are approximately equal to the concentrations of Hg in the fines of the tails materials.

Table 3: Percent fines in head and tails.

Average	Test	% FINES Average	% FINES Standard Deviation
Heads	1	86.31	3.59
Tails	1	100.01	1.74
Heads	2	4.03	0.98
Tails	2	5.05	2.52
Heads	3	6.87	0.84
Tails	3	14.92	7.61
Heads	4	16.79	12.69
Tails	4	25.43	8.99

The mass balance calculations for mercury in the size fraction > 0.063 mm was calculated by estimating the mercury content in the head material as the sum of the free mercury that was removed plus the mercury that was measured in the head samples. The mass of mercury not recovered in the effluent was calculated using concentrations in the tails samples, modified by their water content.

Assuming that all of the free elemental mercury and coarse gold-mercury amalgam was removed during the test, and that the head samples were a representation of the mercury associated with the fine particles (silt-clay) (< 0.063 mm) rather than the material as a whole, the percent mercury removed was calculated. This calculation is likely a minimum, in that it does not account for the mercury in the portion of the concentrate samples that remains to be analyzed.

Test 1 was conducted with the drying bed material/Chevreaux waste product, which was mostly silt and clay (86% fines). Test 2 was conducted with the project material (mostly sand, 4% fines) that was collected from the river delta in the area to be dredged. The table below indicates the calculated percent removal of mercury for each test, as well as the estimated head mercury content.

Table 4. The percent mercury removed by Pegasus Mercury Extraction Equipment for each test.

Test #	Date of Test	Length of Test (min)	Amount of water used during test (lbs)	Amount of material Processed DRY (kg)	Mercury Extracted (g) by Pegasus	Hg Extracted [ug/g] DRY WT	Heads THg (ug/g dry) [USGS] AVG	Heads THg (ug/g dry) [USGS] StdDev	**% Mercury Removal by Pegasus {AVG}**
1	9/28/2009	20	7740	108	0.3297	3.06	0.20	0.04	**93.740**
2	10/1/2009	20	5180	288	0.3154	1.10	0.08	0.01	**93.496**
3	10/5/2009	23	7500	280	missing	missing	0.09	0.01	**missing**
4	10/6/2009	31	7700	268	0.1873	0.70	0.24	0.09	**74.432**

In conclusion the mercury extraction equipment removed approximately 93% of the free elemental mercury in the material that was size fraction > 0.063 mm, sand size.

Reactive and methylmercury mass balance

A reactive and methylmercury mass balance was conducted to ensure that reactive and/or methylmercury was not being created by the equipment and to be able to account of the different mercury components in the mass balance equations for total mercury. Below is a table containing the average and standard deviation of the mercury component in the heads and tails for each test.

Table 5: Table of total, methyl and reactive mercury

Average	Test	Total Hg (ng/g) dry AVG	Total Hg (ng/g) dry DEV	MeHg (ng/g) dry AVG	MeHg (ng/g) dry DEV	%MeHg	Corrected Hg(II)R (ng/g dry wt)	%Hg(II)R
Heads	1	204.60	42.62	0.40	0.08	0.20%	8.92	4.36%
Tails	1	231.67	18.90	0.51	0.10	0.22%	13.22	5.71%
Heads	2	76.23	13.44	0.27	0.09	0.35%	0.14	0.19%
Tails	2	111.46	42.86	0.34	0.16	0.30%	0.27	0.24%
Heads	3	94.30	9.48	0.41	0.05	0.44%	0.97	1.03%
Tails	3	189.38	67.31	0.64	0.07	0.34%	0.50	0.26%
Heads	4	240.39	92.72	0.70	0.22	0.29%	0.44	0.18%
Tails	4	309.08	115.93	0.73	0.13	0.24%	0.40	0.13%

Discussion

Miners have long since understood that taking a sample of a supposedly homogenous mixture does not give you an accurate representation of whether or not there is mercury or gold in the mixture. Scientist have long since relied on homogenization, duplicate sampling, and split sample techniques to characterize material. These equipment tests, where miners and scientists worked closely together for the duration of the experiments and report writing has bridged that age old gap in a new way. Scientists working with mercury contamination issues in the natural environment need to be especially aware of the “nugget effect” and how it affects sampling accuracy and data interpretation.

Our understanding of mercury, how it behaves and how to remove it has been broadened as a result of these tests. Primarily, the fact that mercury on the fine/silts and clays is not readily removed by physical separation using a concentrator means that additional treatment of the processed material to remove any suspended solids is important to ensuring that mercury does not re-enter the environment in the turbid effluent. In addition, it appears that the Pegasus Mercury Extraction Equipment removes over 90% of the free elemental mercury bound to sediment that is greater than 0.063 microns, specifically sand.

Mercury removal techniques that can operate on a large scale and can accompany a dredge operation remain a viable, yet developing way, to remove legacy mercury from dredged sediment. Adaptive management and pre and post sampling will remain an integral component of

the design and fabrication of the next generation of mercury removal equipment. Transparency and collaboration remain the two most valuable assets of the project team and are critical to its continued success at Combie Reservoir.

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