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Environmental Impact of the Helen, Research, and Chicago Mercury Mines on Water, Sediment, and Biota in the Upper Dry Creek Watershed, Lake County, California

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Abbreviations, definitions, and datum used

Vertical and horizontal coordinate information is referenced to the North American Datum of 1927 (NAD 27 CONUS).

DOC, dissolved organic carbon

DOM, dissolved organic matter

EE/CA, Engineering evaluation/cost analysis for “non-time-critical removal actions,” as defined by the U.S. Environmental Protection Agency’s Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Hg, generic shorthand for mercury; does *not* denote speciation.

Hg_T, total mercury (inorganic plus organic).

Hg_F, total mercury (inorganic plus organic) in a filtered sample (either 0.1 μm or 0.45 μm, as specified in the text).

MMHg, monomethyl mercury, methylmercury, and monomethylmercury (CH₃Hg⁺)

ng/g, nanogram per gram, equivalent to one (1) part per trillion.

ng/L, nanogram per liter, approximately equivalent to one (1) part per trillion.

ppm, parts per million, equivalent to mg/kg or g/g.

SC, specific (electrical) conductivity, reported in units of millisiemens per centimeter (mS/cm).

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Environmental Impact of the Helen, Research, and Chicago Mercury Mines on Water, Sediment, and Biota in the Upper Dry Creek Watershed, Lake County, California

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Introduction

Background and objectives

The Helen, Research, and Chicago mercury (Hg) deposits are among the youngest Hg deposits in the Coast Range Hg mineral belt and are located in the southwestern part of the Clear Lake volcanic field in Lake County, California (fig. 1). The mine workings and tailings are located in the headwaters of Dry Creek. The Helen Hg mine is the largest mine in the watershed having produced about 7,600 flasks of Hg. The Chicago and Research Hg mines produced only a small amount of Hg, less than 30 flasks. Waste rock and tailings have eroded from the mines, and mine drainage from the Helen and Research mines contributes Hg-enriched mine wastes to the headwaters of Dry Creek and contaminate the creek further downstream. The mines are located on federal land managed by the U.S. Bureau of Land Management (USBLM). The USBLM requested that the U.S. Geological Survey (USGS) measure and characterize Hg and geochemical constituents in tailings, sediment, water, and biota at the Helen, Research, and Chicago mines and in Dry Creek (fig. 2). This report is made in response to the USBLM request to conduct a Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA - Removal Site Investigation (RSI). The RSI applies to removal of Hg-contaminated mine waste from the Helen, Research, and Chicago mines as a means of reducing Hg transport to Dry Creek.

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This report summarizes data obtained from field sampling of mine tailings, waste rock, sediment, and water at the Helen, Research, and Chicago mines on April 19, 2001, during a storm event. Further sampling of water, sediment, and biota at the Helen mine area and the upper part of Dry Creek was completed on July 15, 2003, during low-flow conditions. Our results permit a preliminary assessment of the mining sources of Hg and associated chemical constituents that could elevate levels of monomethyl Hg (MMeHg) in the water, sediment, and biota that are impacted by historic mining.

Mining History and Geology

Helen Mine

The main structural control for Hg ores at the Helen, Research, and Chicago Hg mines is a wide fault zone that separates serpentinite from Franciscan sandstone rocks (fig. 3). Silica-carbonate alteration is localized along the fault, and most of the Hg ore bodies occur in the alteration zone. At the Helen Mine, an irregular ledge of silica-carbonate rock occurs on the footwall of the fault and ranges in width from a few meters to 45 m. The ledge ranges in composition from green serpentine cut by fine carbonate veinlets to a dense, black opaline rock with disseminated pyrite. This silica-carbonate ledge hosts the principal ore bodies with veinlets and disseminations of cinnabar primarily occurring in the opalized rock. Prior to the formation of the silica-carbonate ledge, Tertiary or Quaternary basalt dikes intruded the serpentine along the fault zone. These dikes have since been completely altered to an argillic clay assemblage. At the top of the ridge in the northern part of the mined area, remnants of a basalt flow are present. Ore also occurs in the sandstone and in the highly altered basalt dikes on the hanging wall of the fault. Moderate amounts of metacinnabar and tiemannite (HgSe) have also been reported. Native Hg occurs to a lesser extent. Historically, the grade of ore produced by the mine ranged from 8 pounds per ton on the No. 2 shoot, to 20 pounds per ton on the No. 1 shoot, but the overall average of the mine is closer to 8 pounds per ton. Mine workings consist of more than 1,500 m of adits, drifts, and crosscuts on three main levels, as well as intermediate adits, raises, winzes, and stopes (U.S. Bureau of Mines, 1965).

The main haulage adit at the Helen Mine was used to dispose of waste rock from the underground workings. This has resulted in a large waste rock pile (fig. 4) at the base of the adit. The adit releases a constant flow of near neutral mine drainage (table 1) that has deposited a large amount of FeOOH-rich sediment extending from the portal to the end of the broad terrace developed on top of the waste-rock pile (fig. 5). A core sample from the terrace of FeOOH rich sediment downstream from the adit portal penetrated 50 cm of FeOOH sediment (fig. 6). The mine drainage effluent flows through a channel developed in the waste-rock pile (fig. 7) and precipitates FeOOH throughout the length of the channel (fig. 8). The FeOOH precipitate has a high Hg concentration, up to 550 ppm (table 2, sample 22DC9), as compared to the relatively low Hg concentrations in FeOOH precipitate at the Helen mine portal that range from 0.09-14.7 ppm (table 3, samples 21HM1 and 23HM9, and table 2, samples 21HM-1S and 23HM9S).

A lower seep of near neutral mine drainage (table 1) is present at the base of the waste-rock pile and a terrace of FeOOH-enriched sediment has precipitated from the effluent (fig. 9). During the dry season, a large amount of efflorescent salts form along the margin of the seep and the terrace of FeOOH precipitate. The salt consists of magnesium sulfate hydrate epsomite because the mine drainage contains high concentrations of sulfate and magnesium (table 4). During the dry season, efflorescent salts are also present around the margin of the mine drainage

from the main Helen Mine haulage adit. Mine drainage from the haulage adit and the lower seep flows into an unnamed creek, here termed the Helen tributary, and then into Dry Creek. The sediment in the channel of the Helen tributary is coated with FeOOH precipitate (fig. 10).

Most of the calcines and mine equipment at the Helen Mine have been buried in an area to the east of the waste-rock pile. One relatively small calcine pile (fig. 11) is present below the waste rock pile and west of the lower mine-drainage seep.

Research Mine

Research Mine is located between the Helen and Chicago mines along the south bank of Dry Creek (fig. 2). A silica-carbonate rock ledge consisting of serpentine hosts most of the ore. The ledge strikes about 30° west and dips steeply to the northeast. Cinnabar is found inconsistently along the ledge as disseminations along with pyrite in the serpentine rock. The underground workings are inaccessible. The remains of a brick retort with a long brick flue that connected to the chimney are present on the south bank of Dry Creek (fig. 12). Calcines from the retort are present in the bank of Dry Creek along with bricks from the retort (fig. 13). The collapsed adit releases a small flow of near neutral mine drainage (table 1) into Dry Creek (fig. 14). Three large furnaces similar in design to a Scott furnace were built to process ores (fig. 15). The furnaces were not properly vented, and fumes produced during the initial use of the furnaces killed several mine workers. The furnaces were fed from the top with ore, and they had an unusual gas-collection system that apparently failed (fig. 16). As a result, the only calcines present are those at the site of the brick retort.

Chicago Mine

The Chicago Mine is located on a ledge of silica-carbonate rock that strikes northwest and dips approximately 55° southwest. The ledge is localized along a fault zone that separates serpentinite from Franciscan sandstone (fig. 3). The thickness of the silica-carbonate alteration varies from 5.5 to 7.5 m and extends 210 m northwest of the mine. Near the center of the silica-carbonate ledge, cinnabar and native Hg are present as narrow seams along a shear zone. The mine workings along the main stope are restricted to a small carbonate vein in the ledge containing cinnabar. Mine workings consist of about 3.2 km of underground tunnels and a drainage tunnel 90 m below the abandoned workings (U.S. Bureau of Mines, 1965). The remains of a brick retort rests on a pile of medium- to coarse-grained calcines located along the bank of Dry Creek (fig. 17). Adjacent to the calcine pile is a partially collapsed ore crib (fig. 17). Another pile of calcines covered by waste rock is exposed in the bank of Dry Creek just downstream from the ore crib (fig. 18). The underground workings are still accessible and consist of an adit and a winze developed in silica-carbonate altered serpentinite (fig. 19).

Sample Locations and Methods

Sample Locations and Conditions

Samples were collected to assess the concentration of Hg and biogeochemically relevant constituents in tailings and waste-rock piles at the Helen, Research, and Chicago mine areas (fig. 2). Water and sediment samples were collected from mine drainage and FeOOH precipitates at the Helen and Research mines and in the Helen tributary to Dry Creek (fig. 10) that receives Helen Mine drainage (fig. 2). Biota, along with water and sediment were sampled in Dry Creek

above and below the confluence with the Helen tributary in order to assess the impact of Helen Mine drainage and mine wastes on the upper part of Dry Creek (figs. 2, 20, and 21). Water, sediment, and biota were sampled in the lower reach of Dry Creek, 3 to 5 km downstream from the mine areas in order to assess the downstream impact of Hg released from the mine areas (figs. 22 and 23). Sample site locations are shown in figures 2 and 22 and are listed in tables 1, 2, and 5. The April 19, 2001, sampling occurred during a storm event that resulted in higher stream flow and significant surface runoff. Sampling on April 1, 2003, and July 15, 2003, occurred when stream flow was low and there was no precipitation.

Field Sampling Methods

Dry Sediments and Tailings

Samples consisting of 100 to 500 g of mine tailings and waste rock were collected from waste rock and tailings piles at the Helen, Research, and Chicago mines. Sediment samples from mine drainages and creeks were placed in 125-mL jars. Tailings and waste-rock samples were stored and shipped in zip-lock bags at ambient temperature. Wet sediment samples for total Hg (Hg_T) and MMeHg analysis were stored on ice within approximately one hour after collection, kept frozen in the laboratory until shipped overnight on dry ice to analytical laboratories, where they were kept frozen until analysis. The temperature of samples arriving at the analytical facilities ranged from 1 to 4°C, which is within the limits specified in USEPA Method 1631E.

Wet Sediments and Tailings

Wet sediment and tailings samples were collected in Certified TeflonTM-sealed I-CHEMTM glass jars (the same as those used for dry sediments). Polycarbonate jars (100 ml capacity) were used for Hg subsamples. These were frozen with dry ice immediately after collection (freezing time approximately 20-30 minutes) and were kept frozen until analysis.

Water

Mine-drainage and stream-water samples were collected with new 60-mL sterile polypropylene syringes. Bulk water samples were subsampled for analysis of metal(loid)s and anions. Subsamples for metal(loid)s determinations were acidified to pH < 2 with trace metal (*Ultrex*, J.T. Baker)-grade HNO₃ and stored in acid-washed, high-density polyethylene (HDPE) bottles. Subsamples for anion and alkalinity measurements were filtered, stored in HDPE bottles, and chilled to approximately 4°C until analysis, in accordance with USGS protocols for trace metals (<http://pubs.water.usgs.gov/twri9A>). Water samples were filtered with disposable 25-mm-diameter sterile cellulose acetate filters (0.45 μ m openings) in the field for analysis of anions, alkalinity, and inductively coupled plasma-mass spectrometry (ICP-MS) and inductively coupled plasma-atomic emission spectrometry (ICP-AES) analysis. Pore waters were collected and filtered in the field with sterile cellulose acetate filters (0.20 μ m openings).

Water sample parameters, including pH, conductivity, and temperature, were measured in the field with a battery-powered pH meter (Orion Model 290, with low-maintenance sealed gel triode electrode) and a specific conductivity meter (Orion Model 120). The pH triode, which has automatic temperature compensation, was also used for temperature measurements. Measurements were taken by placing the probe directly into the flowing mine drainage or stream water.

Samples for Hg_T and MMeHg analyses were collected in trace metal-free-certified 1-L borosilicate bottles (Nalgene ICHM) with no headspace and Teflon-lined caps. Sampling for Hg analysis followed ultra-clean sampling and handling protocols (Bloom, 1995; Gill and Fitzgerald, 1987) during both the collection of field samples and the analysis to avoid introduction of Hg. Samples were kept on ice until shipped. Samples were shipped overnight on dry ice or blue ice packs, and arrived the next morning at the analytical facilities at temperatures ranging from 1 to 4° C, which is specified by USEPA Method 1631E to minimize biologically induced phase changes and MMeHg degradation.

During every sampling event, a field blank was collected by processing de-ionized water and collecting the same subsamples (except for alkalinity) by the same procedures as those used for the field samples. Laboratory blanks and acid blanks were processed periodically to determine whether our equipment, containers, reagents, and procedures introduced significant contamination.

Invertebrates

The target macroinvertebrates for this study were predatory insects, depending on their abundance and availability at each sample site. Taxa collected were larval dragonflies (order Odonata, family Gomphidae, Aeshnidae, and Cordulegastridae), adults of three families of the order Hemiptera (water striders: family Gerridae; backswimmers, family Notonectidae; and giant water bugs, family Belostomatidae), larval stoneflies (order Plecoptera, family Perlidae), and larval Dobsonflies (order Megaloptera, family Corydalidae; table 6).

Invertebrates were collected using dip nets and by hand and placed in Ziploc[®] plastic bags with native water (fig. 20). Samples were kept in native water in a cooler on wet ice and allowed to depurate for 4-24 hours before they were sorted at the end of each collection day. Individuals were sorted by family and placed in disposable dishes using Teflon-coated forceps or by hand while wearing disposable latex gloves. Organisms were rinsed clean with deionized water and patted dry with a clean paper towel. Then samples were sorted and composited by family with the goal of obtaining a minimum of 1 g wet biomass. Each sample consisted of 1-25 individuals of the same family (0.31–1.92 g total mass). Samples were weighed on an electronic balance, placed into chemically cleaned glass jars with Teflon-lined lids. The lids were sealed with Parafilm[®], and the samples were then stored frozen until they could be shipped to the laboratory for Hg_T analysis. Where mass was sufficient, MMeHg and percent moisture were also analyzed.

Fish

Fish were collected from Lower Dry Creek in April and July 2003. The species collected included riffle sculpin (*Cottus gulosus*) in April, rainbow trout (*Oncorhynchus mykiss*) in July, and California roach (*Hesperoleucus symmetricus*) in both sampling periods (table 7). Fish that were collected using a backpack electroshocker were held in buckets of native water. Each fish was asphyxiated in a cooler and was then weighed and measured for standard and total length, individually wrapped in aluminum foil, placed in polyethylene Ziploc[®] bags, and stored frozen until they could be processed. Within 1-3 days, the fish were thawed for processing. Each fish was examined for gross deformities and dissected to determine sex. The gastrointestinal (GI) tract was removed, and the stomach contents were preserved for later identification. Whole body samples were processed according to procedures described by May and others, (2000). Samples were placed in individual chemically cleaned glass sample jars with Teflon-lined lids; the lids

were sealed with Parafilm[®], and the samples were stored frozen for no more than 30 days before being sent to the laboratory for analysis.

Analytical Methods

Sediments and Tailings

Multi-element analyses for all dry sediments and tailings were performed in the laboratories of ALS Chemex. Bulk samples were ground in a zirconia ring mill and subjected to a near-total four-acid digestion. Major elements were determined by ICP-AES. Minor elements other than Hg were determined by ICP-MS. Mercury was determined by cold vapor atomic absorption spectroscopy (CVAAS) following methods similar to those described by Crock (1996) and O'Leary and others, (1996).

Mercury and MMeHg analyses for all wet sediments were done at Frontier Geosciences. Some dry sediments analyzed by Chemex were also analyzed by Frontier. For Hg_T, the sediment was leached with cold aqua regia, followed by stannous chloride (SnCl₂) reduction, two-stage gold amalgamation, and cold vapor atomic fluorescence spectroscopy (CVAFS) detection. Methylmercury was obtained by acid bromide/methyl chloride extraction followed by aqueous phase ethylation, isothermal gas chromatographic (GC) separation, and CVAFS detection (Horvat and others, 1993). Results were reported on both a wet- and dry-weight basis.

Chemex and Frontier sample preparation steps differ in terms of type of sample analyzed and sample digestion. Chemex preparation utilizes a relatively large split, which is pulverized. The Chemex 4-acid digestion dissolves all but a few resistant minerals such as zircon. It is important to note that our samples were treated as rocks rather than soils, except that crushing was not needed, so no sieving was performed in the laboratory; bulk sample including clasts as large as 1-2 cm diameter was processed. Frontier's preparation avoids handling and uses a strong leach (aqua regia), which removes elemental Hg, adsorbed Hg, Hg in amalgams, and combined Hg including Hg sulfide, but does not affect silicate minerals. Material coarser than sand size, however, is not included in Frontier's leach.

Waters

Alkalinity as CaCO₃ was determined in the laboratory by titration with H₂SO₄ using Gran's technique (Orion Research, Inc., 1978), within 2-4 days after sample collection. Sulfate, chloride, nitrate, and fluoride concentrations were determined by ion chromatography (Fishman and Pyen, 1979).

Cations were analyzed by ICP-AES and ICP-MS. Ion chromatography and alkalinity analyses were performed by USGS laboratories under the direction of Paul Lamothe. The ICP-AES analyses were determined by USGS laboratories under the direction of Paul Briggs. Duplicate water samples, blank samples, and USGS Water Resource Division standard reference waters were analyzed with the data set.

At Frontier Geosciences, samples were handled in a Class-100 clean air station monitored routinely for low levels of total gaseous Hg. An ultra-clean Hg trace metal protocol was followed, including the use of rigorously cleaned and tested TeflonTM equipment and sample bottles and pre-screened and purified reagents. Laboratory atmosphere and water supply were also routinely monitored for low levels of Hg. Primary standards used in the laboratory were NIST-certified or traceable to NIST-certified materials. Monomethylmercury standards were made from pure powder and calibrated against NBS-3133; they were cross-verified by daily

analysis of Certified Reference Material DORM-2 (National Research Council of Canada Institute for National Measurement Standards, 1999). EPA Method 1631 was used. Total mercury was determined by bromine monochloride (BrCl) oxidation followed by SnCl_2 reduction, two-stage gold amalgamation, and detection by CVAFS (Bloom *et al.*, 1988). Methylmercury was liberated from water using an all-TeflonTM distillation system. Distilled samples were analyzed using aqueous phase ethylation with purging onto Carbotrap, isothermal GC separation, and CVAFS detection (Bloom, 1989). To address accuracy and precision, quality-assurance measures were employed with the following minimum frequency: laboratory duplicates, one per ten samples; method blanks, three per analytical batch; filtration blanks, one per ten samples; and spike recovery or standard reference material, one per ten samples.

Biota

Invertebrate samples were analyzed for both Hg_T and MMeHg , while fish samples were analyzed only for Hg_T . Samples collected in April were received frozen within 30 days of collection at Frontier Geosciences, Inc. (Seattle, Wash.) and were assigned unique identification numbers. The samples were placed in frozen storage until sample preparation could take place. Monomethyl Hg in tissue was prepared by a 25% KOH in methanol digestion and analyzed by aqueous phase ethylation, isothermal GC separation, and CVAFS detection (Frontier SOPs FGS-010, FGS-070). Total Hg in tissue was prepared by a 70/30 nitric/sulfuric digestion and analyzed by SnCl_2 reduction, dual gold amalgamation, and CVAFS detection (Frontier SOPs FGS-011, FGS-069). The Method Detection Limit (MDL) for MMeHg was 1.33 ng/g, ww. The MDL for Hg_T was 0.26 ng/g, ww. All results are reported on both a wet- and dry- weight basis.

Samples collected in July were analyzed at the Brooks Rand Laboratory (Seattle, Wash.). Samples were received frozen, were given a unique identification number, and were stored at $<-10^\circ\text{C}$ until preparation. Monomethyl Hg samples were prepared by KOH digestion, and were analyzed by aqueous phase ethylation, purge and trap, GC separation, and CVAFS detection (Brooks Rand LLC SOP). For analysis of Hg_T , samples were digested with nitric/sulfuric acid and heat and further oxidized with BrCl . Samples were analyzed with SnCl_2 reduction, single gold amalgamation, and CVAFS detection using a BRL Model III CVAFS Mercury analyzer. The MDL for MMeHg was 1.5 ng/g, dry weight; the MDL for Hg_T was 0.07 ng/g, dry weight. Results are reported on a wet-weight basis.

Quality Assurance/Quality Control for Biota

All standard environmental laboratory and field Quality Assurance/Quality Control (QA/QC) procedures were followed for this study. Calibration of all instruments utilized four blank and at least five calibration standards. Instrument response was evaluated by running a check standard and a check blank immediately following calibration and thereafter following every 10 samples and at the end of the analytical run. A minimum of three method blanks per batch of 20 samples were run. Matrix spike, matrix spike duplicate recoveries, method duplicates, and Standard Reference Materials were analyzed at least once every ten samples. Analyses of blanks, duplicates, spiked samples, and Standard Reference Materials were performed, and all results were acceptable.

Results

Tailings at the Helen, Research, and Chicago Mine Areas

The concentration of Hg in waste materials at the Helen, Research, and Chicago mine areas varies depending on material type and furnace used. Ores at the Helen Mine were primarily processed in a rotary furnace and calcines (tailings) were deposited to the east of the mine haulage adit. The calcines along with mine equipment were buried during reclamation carried out in the 1990s so no calcines were available for sampling. The only Helen Mine calcines now accessible is a small pile located below the waste-rock pile and west of the lower mine drainage seep (fig. 11). The Hg concentration in the calcines is relatively low, 17.9 ppm (table 2), but Co, Cr, and Ni are present in high concentrations that are typical of ores hosted by serpentinite. The large waste-rock pile was not sampled (fig. 4).

At the Research Mine, the ore was processed in a brick retort, and the calcines were disposed of in a pile adjacent to Dry Creek (figs. 12 and 13). The calcines are poorly sorted and consist of coarse pebble sand with very low Hg concentration (3.4 ppm). At the Research Mine adit, small amounts of calcines are present, and the Hg concentration is low (15.7 ppm; table 2). Both calcine samples have high concentrations of Co, Cr, and Ni because the ores were hosted by serpentinite. Tellurium is also elevated (1.15 ppm) in one of the calcine samples (21RE-1C, table 2).

The Chicago Mine ores were processed in a brick retort and the calcines and waste rock were disposed of at the site of the retort on the bank of Dry Creek (fig.17). The Hg concentration in the calcines ranges from 8.4 to 76.9 ppm. Another pile of calcines is exposed in the bank of Dry Creek downstream from the remains of the ore crib (fig.18). The calcines are fine grained and have very high Hg concentrations, up to 430 ppm (table 2). High concentrations of Co, Cr, and Ni are present in the calcines because the ores were hosted by serpentinite. Altered serpentinite (sample 21CH - 3AR) contains elevated Hg, up to 57.2 ppm, and Te, 2.65 ppm. These concentrations are likely indicative of the Hg and Te concentrations in the waste rock at the Chicago Mine, although no sample of the waste rock was analyzed. A sample of high-grade ore, 17,730 ppm Hg, also has an anomalous Te concentrations and high concentration of Co, Cr, and Ni. All other trace metals (Cu, Pb, and Zn) in the ore and altered rock are relatively low.

Hg and Associated Elements in Mine Drainage and Dry Creek Waters

Mine drainage at the Helen Mine, and to a lesser extent at the Research Mine, is a significant source of Hg to Dry Creek. At the Helen Mine, mine drainage is released from two adits and one seep located at the base of the waste-rock pile (fig. 2). Effluent from these three sources contributes most of the flow to the Helen tributary. The Helen tributary is located at the base of the Helen Mine workings and waste piles. Mine drainage from the main haulage adit at the Helen Mine has relatively low Hg and MMeHg concentrations at the portal (0.6 - 9.56 ng/L; tables 1 and 3, samples 21HM1 and 23HM9) and in the drainage that flows on the terrace of FeOOH precipitate (fig. 5, tables 1 and 3, samples HEL0703W3, 21HM1, and 23HM9). The pH of the mine drainage, 6.44 to 7.63 (table 1), is not highly acidic because carbonate minerals in the altered serpentinite buffer the waters. The water has high sulfate (up to 860 ppm) and Fe (15 ppm) concentrations because of oxidation of the high pyrite content of the ore, and very high concentrations of Mg (up to 267 mg/L) that is derived from the altered serpentinite (tables 4, 8, and 9, samples 21HM1 and 23HM9). As the mine drainage flows through the waste-rock pile it

dissolves Hg. This results in very high concentrations of Hg, up to 550 ppm, in FeOOH precipitated from the mine drainage (figs. 7 and 8, table 2, sample 22DC9), as well as high concentrations of Co, Cr, and Ni. In comparison, the Hg concentration in FeOOH precipitate near the portal of the adit is relatively low, 0.09 to 1.13 ppm (table 3). A core sample from the terrace of FeOOH precipitate downstream from the adit penetrated 50 cm of FeOOH sediment. Hg concentrations in filtered (<0.20 m) pore fluid were very high, 52 and 710 ng/L, as compared to the Hg concentration in surface mine drainage samples (fig. 6, table 3).

The drainage from the seep located below the waste-rock pile has similar chemistry to that of water from the main adit. The mine drainage precipitates FeOOH and forms a layer of Fe-enriched sediment and FeOOH coatings on the waste rock (fig. 9). The Hg concentration in the water from samples at the seep ranges from 1.5 to 17.5 ng/L, and the FeOOH precipitate contains from 0.5 to 16.3 ppm Hg (table 3). The pH of the water ranges from 6.76 to 6.99 (table 1), and concentrations of sulfate (up to 900 ppm), Fe, (up to 9.6 ppm), and Mg (up to 264 ppm) are high (tables 4, 8, and 9, samples 21HM2, 23HM11C, and HEL0703W4). During the dry season, efflorescent Mg sulfate salts form as a result of the high concentration of Mg and sulfate in the mine drainage. The lower seep develops a ring of efflorescent salts with a thickness up to 10 cm (fig. 24) during the dry season. Efflorescent salts also form along the margin of the FeOOH terrace downstream from the main Helen adit during the dry season (fig. 6). The efflorescent salts are highly soluble, dissolve during the first winter rains, and are a significant source of Hg, sulfate, and Mg to Dry Creek.

The concentration of sulfate and Mg in waters from the Helen Mine seep and the main adit are comparably high (fig. 25). The Helen tributary is a mixture of mine-drainage effluent with high concentration of sulfate and Mg and surface water with relatively low concentrations of these constituents (figs. 11 and 25, table 4). Although the volume of flow in the Helen tributary is lower than in Dry Creek, the sulfate concentration in the tributary is sufficiently high to increase the sulfate concentration in Dry Creek downstream from the confluence with the Helen tributary (figs. 25 and 21). At the USGS gaging station, located 1 km downstream from the confluence of the Helen tributary with Dry Creek (fig. 2), sulfate concentration was lower than that measured upstream in Dry Creek during the April 2001 storm event because of dilution by surface runoff (fig. 25). Sulfate concentration at the gaging station sampled during low flow conditions in August 2005 was very high, 324 ppm, and nitrate concentration was extremely high, 5,560 ppm, indicating that a nearby anthropogenic source other than mine drainage contaminates Dry Creek. This source of nitrate contamination is located above the gaging station and below the Helen tributary (table 4, sample 22DC6A). It should be noted that under all flow conditions no nitrate was detected in waters from the mine areas, or in the upper part of the watershed (table 4).

Mine drainage from the north adit at the Helen Mine has significantly different chemistry from the main adit and seep and there is no FeOOH precipitate associated with the drainage. The pH of the water is near neutral (table 1) and the concentration of sulfate (85 ppm), and Fe (<.02 ppm) is much lower (table 4, fig. 25). The Hg concentration of the water is 28.1 ng/L and MMeHg concentration is 0.62 ng/L as compared to no detectable MMeHg in the main adit and seep (table 3).

At the Research Mine, drainage from the collapsed adit has elevated Hg concentration (32.8 ng/L), but no detectable MMeHg. The pH of the water is alkaline (8.3, table 1) because of buffering by serpentinite. Sulfate concentration is elevated (78 ppm), but Fe concentration is below the detection limit of 0.02 ppm, and as a result, no FeOOH precipitate is present. The

mine drainage flows directly into Dry Creek (fig. 14) and contributes to the elevated sulfate concentration of Dry Creek as indicated by the relatively high sulfate concentration in Dry Creek water above the confluence with the Helen tributary (fig. 20; sample 23HM8, table 4, fig. 25, sample noted “A”).

Waters sampled in the lower reach of Dry Creek have low concentrations of Hg (< 3.5 ng/L) and MMeHg (< 0.09 ng/L) (figs. 26 and 27, table 3). During low-flow conditions, most of the Hg in the lower reach of Dry Creek is in the filtered fraction (fig. 26). The concentration of MMeHg is typically less than the detection limit, and in the one sample with detectable MMeHg, the concentration is $< 5\%$ of the total Hg (fig. 27).

Sediment in Dry Creek at and below the Helen and Research Mines

The headwaters of Dry Creek are located above the Chicago Mine, and the creek flows through bank deposits containing calcines and waste rock at the Chicago mine and at the Research Mine further down stream (fig. 28). During high flows, calcines and waste rock are eroded and contribute Hg-enriched sediment to the creek. At the Research Mine, the concentration of Hg in active channel sediment is 3.37 ppm (table 2, sample 21-RE-1S). Further downstream Hg concentration in active channel sediment remains about the same (2.99 ppm) at the sample site located just upstream from the confluence with the Helen tributary (table 2, sample 23HM5S, site shown in fig. 20). Sediment in the Helen tributary has variable Hg concentration, ranging from 0.2 to 90.8 ppm (tables 2 and 3, samples 21HM3, 23HM3S, and 8S), as a result of variable amounts of Hg-enriched FeOOH transported from the Helen mine drainage. Sediment from the Helen tributary increases the Hg concentration in Dry Creek sediment to 3.7 to 5.9 ppm (table 2, sample sites 23HM6 and 7, figs. 21 and 28) downstream from the confluence. At this site, one sample had very high Hg concentration (681 ppm) but this likely reflects the nugget effect because of the small sample size (0.2g) used for the analysis by Frontier Geosciences (table 3). At the USGS gaging station, 1 km downstream from the Helen tributary, Hg concentration in sediment increases and ranges from 2.7 to 90 ppm (table 3, sample 21DR-1S and table 2, sample 22 DC6A). Pre-mining sediment in bank deposits exposed at the gaging station has an elevated Hg concentration (27 ppm) and is a potential source of Hg-enriched sediment to Dry Creek (table 2, sample 22DC6B, fig. 28).

In the reach of Dry Creek 4-5 km downstream from the Helen Mine, elevated but highly variable Hg concentrations are present in sediment in the active stream channel (fig. 29). The concentrations are significantly higher than those in the upper part of Dry Creek, and the increase downstream to a maximum of 230 ppm (table 2, sample 22DC3). Sediment sampled in July 2002 consisted of fine silt to sand deposited from the last storm event of the wet season (fig. 30). Pre-mining sediment exposed in the banks of Dry Creek was sampled at the same sites where sediment from the active channel was collected. The pre-mining sediment consists of coarse gravel with a matrix of fine to coarse sand that was selectively sampled and analyzed (fig. 31). The Hg concentration in the sand matrix of the pre-mining sediment ranged from 0.9 to 66 ppm and was always lower than the concentration in sediment from the active channel at the same site (fig. 29, table 2). The higher Hg concentration in the active channel indicates that Hg-enriched sediment was naturally eroded from the mineralized area prior to mining, but subsequent mining significantly increased the amount of Hg-enriched sediment transported into the watershed.

The concentration of MMeHg in Dry Creek sediments varies considerably, ranging from 0.05 ng/g to 0.59 ng/g (table 3). Low MMeHg concentrations occur in sediment in the upper reach of Dry Creek near the mine areas, and higher concentrations occur in the lower reach of

Dry Creek. The highest MMeHg concentration, 0.73 ng/g, occurs in FeOOH-rich sediment precipitated from mine drainage from the main Helen Mine adit. Lower MMeHg concentration (0.17 ng/g) occurs in the lower Helen Mine seep.

The % MMeHg in sediments (table 3 and fig. 32) can be used as an indicator for net production of MMeHg when the concentration of MMeHg is normalized to total Hg (Drott and others, 2008). The % MMeHg is derived by dividing the measured concentrations of MMeHg in sediment by the total Hg concentration present in the same sample:

$$\% \text{ MMeHg} = 100 * (\text{MMeHg in ng/g in sediment}) / (\text{Hg in ng/g in sediment}).$$

The highest values for % MMeHg are in samples of FeOOH sediment precipitated from the Helen Mine main adit drainage and indicate a high production of MMeHg (fig. 32). The lower values of % MMeHg present in Dry Creek, and other FeOOH-enriched sediment associated with mine drainage at the Helen and Research mines, indicate relatively lower production of MMeHg. Two samples with very high Hg concentrations, (table 3, Dry Creek sediment sample 23HM6 and Helen mine-drainage sediment 23HM10) have exceptionally low values of % MMeHg (< 0.0001) indicating that the Hg is not readily methylated (fig. 32). For comparison, the % MMeHg in the Anna Belcher Creek watershed and Contact mercury mine area, located 5 km to the west, have a comparable range in % MMeHg with the highest MMeHg production in a pond at the Contact Mine (Rytuba and others, 2009). The moderately high levels of % MMeHg in stream sediments in the lower part of Dry Creek indicates that the production of MMeHg is relatively low, even though Hg levels in the sediment are exceptionally high.

The speciation of Hg in Dry Creek sediment was determined by using sequential chemical extraction. Most of the Hg is present as Hg sulfide (F5 fraction) with concentrations ranging from 70-75% of the total Hg present in two sediment samples from the lower reach of Dry Creek- a medium sand and a silt-clay (fig. 33). The F4 fraction, which is interpreted to be elemental Hg, and F3 fraction, which likely represents organic-bound Hg, comprise most of the remainder of the Hg species present. Only a very small fraction, less than 0.3%, consists of Hg salts (F2 fraction) and soluble Hg (F1 fraction). The speciation data indicate that although high concentration of Hg are present in the lower reach of Dry Creek, the Hg is present primarily as Hg sulfide, which is less readily methylated. As a result of the dominance of HgS in the sediment, MMeHg concentrations in Dry Creek sediment are relatively low.

Biota

Invertebrates

We collected 20 samples of aquatic invertebrates from three sites in the Dry Creek watershed on April 2, 2003; another 11 samples were collected on July 16, 2003, from the same sites and one additional site, the Helen Mine adit. All samples were analyzed for Hg_T and MMeHg and, where possible, were compared with samples collected in 1999-2000 at a reference site in the Bear River Watershed (BR20), Nevada County (table 6).

The reference samples from BR20, had Hg_T concentrations ranging from 0.022 to 0.076 g/g (all values are reported on a wet-weight basis) and MMeHg concentrations ranging between 0.014 and 0.068 g/g. The Hg_T and MMeHg concentrations from samples collected from the Dry Creek watershed were more variable, ranging from the lowest concentration of MMeHg in a composite sample of stoneflies (Perlidae) from the Lower Dry Creek site (0.033 g/g Hg_T) to the

highest concentration (0.431 g/g Hg_T) in a Dobsonfly (Corydalidae) from Dry Creek above Helen Mine (DCAH; table 6).

All Hemipterans had higher concentrations of MMeHg than comparable taxa at BR20, with geometric means from 2-9 times higher than the reference samples (fig. 34). The highest levels in Hemipterans were in the Notonectidae (0.16 to 0.32 µg/g MMeHg) from the two sites on Dry Creek, above and below the Helen Mine input. The geometric mean concentration was higher above (0.305 µg/g MMeHg) than (0.221 µg/g MMeHg) below the input. The giant water bugs (Belostomatidae) and water striders (Gerridae) also exhibited levels of MMeHg that were higher than levels from the reference site (BR20; fig 34). The lowest mean MMeHg concentration was in water striders at the Lower Dry Creek site, the furthest distance from the sources of the Hg.

Although larval dragonflies (order Odonata; families Aeshnidae, Cordulegastridae, and Gomphidae) were only collected at the lower Dry Creek site, the site furthest downstream from the mines, the geometric mean MMeHg concentrations in all samples (0.051 to 0.099 µg/g) were higher than the mean concentration of Aeshnidae from the reference site (BR20; 0.019 µg/g; fig. 35).

Individual composites of Dobsonflies (Corydalidae) from the Dry Creek watershed had MMeHg concentrations that ranged from 1.6 to 11 times higher than the geometric-mean MMeHg concentration from the reference site (0.038 µg/g; fig. 36). There appeared to be a seasonal difference in MMeHg concentrations in this taxon, with the April samples being 2-4 times higher than the July samples at the sites above (DCAH) and below (DCBH) the Helen Mine input (table 6).

The differences in concentrations of MMeHg between the reference and the Dry Creek sites were less for the stoneflies (Perlidae) than for the other sampled taxa (table 6). In fact, the MMeHg concentration in a composite sample of stoneflies from DCBH (0.033 µg/g) was lower than the geometric-mean concentration from the reference site (0.052 µg/g; fig. 37).

Fish

Samples of riffle sculpin and California roach collected from Lower Dry Creek at the Bridge (LDCB) in April 2003 and roach and rainbow trout collected at that site in July 2003 were analyzed for Hg_T (table 7, fig. 38). Total Hg concentrations in whole-body fish ranged from 0.087 to 0.332 µg/g (wet weight). Based on a one-way analysis of variance of the log values (ANOVA), the geometric-mean concentration of Hg_T (0.262 µg/g) in California roach caught in April was significantly higher than those collected in July (0.123 µg/g; $F_{1,6} = 16.22$, $P = 0.007$). However, the mean total length of the roach collected in April (85.0 mm) was also greater than that for the July roach (63.75 mm; $F_{1,6} = 17.90$, $P = 0.005$), and a linear regression showed that length and Hg_T were significantly correlated ($R^2 = 0.97$, $P < 0.001$; fig. 39). This indicates that Hg_T was increasing with length and, presumably, age of the fish.

The geometric mean Hg_T concentration for rainbow trout collected from LDCB was 0.132 µg/g, a value below that used for the issuance of human health advisories (0.30 µg/g). However, the average length of these fish (70.5 mm) was less than one-half the normal edible size (200 mm). Trout of larger size were not available for collection. Neither the mean total length nor the geometric mean Hg_T concentration in rainbow trout and California roach collected in July differed. The food habits of these two similar-sized fish were likely similar, leading to the comparable concentrations of Hg_T. However, the whole-body geometric mean of Hg_T in rainbow trout was statistically higher than the geometric mean concentration in fillets of brown trout

(average total length 261.25 mm) from a reference site ($0.07 \mu\text{g/g}$; $F_{1,10} = 29.93$, $P < 0.001$; fig. 38).

Conclusions

Mercury mines in the upper part of the Dry Creek watershed are a significant source of Hg-enriched mine drainage and sediment. FeOOH precipitated from mine drainage from the Helen main adit has exceptionally high Hg concentrations and is transported into the Helen tributary of Dry Creek during storm events. The lower seep at the Helen Mine also contributes FeOOH precipitate, but the concentration of Hg is considerably lower. The Helen Mine drainage contributes a significant amount of sulfate and Mg directly into Dry Creek, and indirectly through the dissolution of efflorescent Mg sulfate salts that accumulate during the dry season. There is only one small pile of calcines at the Helen mine, and erosion of this material has been limited. There is, however, a large amount of waste rock that is a significant potential source of Hg-enriched sediment.

At the Research Mine, both calcines and mine drainage contribute Hg-enriched sediment and waters into Dry Creek. The volume of calcines is relatively small, and the flow from the collapsed adit is low. Elevated concentrations of sulfate are present in the mine drainage that flows directly into Dry Creek. At the Chicago Mine, calcines with very high concentrations of Hg have been eroded, and they contribute Hg-enriched sediment to Dry Creek. The Chicago Mine underground workings are accessible, and there is no mine drainage released from the workings.

The Hg concentration of sediment in the active channel of Dry Creek increases with increasing distance from the mine areas, such that the highest concentrations occur in the lowest part of the creek sampled in this study. Pre-mining sediments exposed in the bank deposits of Dry Creek have elevated Hg concentrations. The relatively high levels of Hg indicate that the Hg deposits were a natural source of Hg to the watershed prior to mining. At all sample sites, the Hg concentration of sediment in the active channel is higher than pre-mining sediment at the same site. This indicates that mining has substantially increased the release of Hg to the watershed from mine wastes and mine drainage. Mine drainage also contributes sulfate and iron, but not nitrate. The very high concentration of nitrate at the USGS gaging station is from an unknown anthropogenic source located below the mine area. The speciation of Hg in Dry Creek sediment is dominated by Hg sulfide. Thus, although Hg concentrations are very high in the lower reach of Dry Creek, the formation of MMeHg is relatively low.

Biota samples indicate that release of Hg from mine sites has increased the Hg concentration in both invertebrates and fish. Biota composite samples of invertebrates from Dry Creek were all higher, with one exception (stoneflies at site DCBH) than reference samples from a site on the Bear River Watershed. The trend toward higher concentrations of MMeHg in invertebrates from the upper sites on Dry Creek (DCAH and DCBH) as compared to the most downstream site sampled (LDCB) likely reflects the relatively low formation of MMeHg in sediment in the lower reach of Dry Creek. The higher values for MMeHg in both Corydalidae and Perlidae at the site above the Helen tributary compared with the values for samples below the tributary indicates the presence of a significant source of bioavailable Hg from the Research and/or Chicago Mines.

The relatively small fish collected from one site on the lower reach of Dry Creek (LDCB) also were well above background Hg concentrations, especially compared with the fillets of adult brown trout from the reference site. The elevated concentrations were indicative of an upstream

source of bioavailable Hg, but the samples that were collected were too small to be used to evaluate a health hazard for humans. Further sampling of edible-size fish would be required to confirm a health hazard from fish consumption by humans or wildlife.

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Table 1. Sample locations and physical and selected chemical parameters for waters from Helen and Research mine areas and upper part of Dry Creek, Lake County, California.

Field number	Latitude	Longitude	Sampling date	Sample site description	Conductivity micro Siemens	pH	Temperature °C
Helen Mine Area							
21HM1	38.739603	-122.69748	4/19/2001	Helen Mine Main adit	1674	6.44	15.9
21HM2	38.74062	-122.69727	4/19/2001	Helen Mine Lowest Mine drainage seep	1202	6.76	18.2
21HM3	38.74085	-122.69806	4/19/2001	Helen Mine Ck drainage above confluence Dry Ck	606	7.33	10.1
21HM4	38.740924	-122.70018	4/19/2001	North Adit Mine Drainage	439	6.95	12.6
23HM5C	38.74172	-122.6973	4/01/2003	Dry Ck above Helen Mine Tributary confluence	84.1	8.18	9.8
23HM7	38.735533	-122.7002	7/15/2003	Down stream from Helen Mine confluence	633	8.65	18.5
23HM9C	38.739603	-122.69748	7/15/2003	Helen Mine Main adit	1594	7.63	18.2
23HM10C	38.739967	-122.69821	7/15/2003	Helen mine waste rock channel of mine drainage	1569	7.86	20.4
23HM11C	38.740619	-122.69727	7/15/2003	Helen Mine Lowest Mine drainage seep	1787	6.99	20.1
HEL0703SED1A	38.739603	-122.69748	7/15/2003	Pore water from upper 6" of core augered into upper adit mine drainage			
HEL0703SED1B	38.739603	-122.69748	7/15/2003	Pore water from upper 9" of core augered into upper adit mine drainage			
HEL0703W5	38.739600	-122.69748	7/15/2003	Water in standing pool downstream of upper adit drainage terminus			
HEL0703W3	38.739600	-122.69748	7/15/2003	Mine drainage from upper adit			
HEL0703W4	38.740619	-122.69727	7/15/2003	lower seep mine drainage			
HEL0703W3.F	38.739600	-122.69748	7/15/2003	Same as W3 but filtered through a 0.02 micron membrane			
Research Mine							
21RE1	38.742917	-122.70066	4/19/2001	Research Mine drainage	695	8.23	12.8
Dry Creek							
23DC1C	38.73885	-122.63872	7/15/2003	Dry Creek near site of 22DC2 upstream of My Way Road crossing	64.1	7.99	12.1
23DC1B	38.73805	-122.64200	7/15/2003	Dry Creek	449	7.88	20.8
23DC1BB	38.7380	-122.64170	7/15/2003	Dry Creek	449	7.88	20.8
23HM6C	38.74188	-122.69651	7/15/2003	Dry Ck .25 km down from Helen Mine Creek Confluence	85.1	8.30	9.8
23HM8	38.74085	-122.69806	7/15/2003	Helen Mine Ck upstream from confluence with Dry Ck	492	8.23	20.1
21DR1	38.740450	-122.68845	4/19/2001	Gaging station on upper Dry Creek 2 gal/min	487	8.25	10.0
22DC6A	38.740450	-122.68845	8/19/2005	Gaging station on upper Dry Creek 2 gal/min	904	8.04	22.0

Table 2. Mercury and associated major and minor elements in sediment, precipitates, and calcines at Helen, Research and Chicago mine areas and upper part of Dry Creek watershed, Lake County, California.

Field number	Latitude	Longitude	Date	Sample site description	Hg ppm	Ag ppm	Al %	As ppm	Ba ppm	Be ppm
Helen Mine										
21HM-1S	38.73960	-122.697485	4/19/2001	Helen Mine Main adit	1.1	0.05	0.11	2.1	150	0.08
21HM-2S	38.74062	-122.697274	4/19/2001	Helen Mine Lowest Mine drainage seep	1.8	0.02	0.26	0.7	60	<0.05
21HM-2SA	38.74062	-122.697274	4/19/2001	Helen Mine Lowest Mine drainage seep	0.5	0.06	0.03	3.6	260	<0.05
21HM - 3S	38.74085	-122.698067	4/19/2001	Helen Mine Ck drainage above confluence Dry Ck	90	0.16	1.83	1.6	124	0.3
23HM 3S	38.74085	-122.698067	4/01/2003	Helen Mine Ck drainage above confluence Dry Ck	16	0.07	5.31	5.7	400	0.77
23HM 5S	38.74172	-122.697370	4/01/2003	Dry Ck above Helen Mine Tributary confluence	3.0	0.03	1.68	1.9	90	0.21
23HM 6S	38.74188	-122.696510	4/01/2003	Dry Ck .25 km down from Helen Mine Creek Confluence	3.7	0.06	4.89	4.5	410	0.64
23HM 7S	38.73553	-122.700200	7/15/2003	Down stream from Helen Mine confluence	5.9	0.02	1.26	1.4	60	0.18
23HM 8S	38.74085	-122.698067	7/15/2003	Helen Mine Ck upstream from confluence with Dry Ck	6.9	0.10	4.58	4.4	350	0.62
23HM 9S	38.73960	-122.697485	7/15/2003	Helen Mine Main adit	0.1	0.08	0.03	4.6	140	<0.05
23HM 11S	38.74062	-122.697274	7/15/2003	Helen Mine Lowest Mine drainage seep	5.2	0.08	0.62	1.2	100	0.05
22 DC 9	38.74114	-122.699270	7/31/2002	Fe precipitate below waste rock from MD	550	0.06	1.18	2.8	431	0.2
HL0401C1	38.74061	-122.697274	4/19/2001	Calcine below and west of waste rock	18	0.12	0.84	3.6	61	0.3
Research Mine calcines (C) and sediment (S)										
21RE - 1- S	38.74283	-122.700686	4/19/2001	Sediment at collapsed adit drainage	3.4	0.12	0.2	<0.2	8	<0.05
21RE - 1C	38.74283	-122.700686	4/19/2001	Coarse sand to gravel calcine next to creek	3.4	0.12	0.24	1.2	14	<0.05
21RE - 2C	38.74283	-122.700686	4/19/2001	Fine sand calcine at adit	15.7	0.20	0.49	7.8	44	0.05
Chicago Mine calcines (C), ore (OR), altered rock (AR)										
21CH - 1C	38.74409	-122.702427	4/19/2001	Fine sand size calcine adjacent to retort	77	0.08	0.38	1.0	16	<0.05
21CH - 2C	38.74409	-122.702427	4/19/2001	Coarse calcines red-black	8.4	0.12	0.18	2.0	5	0.05
21CH - 4C	38.74409	-122.702427	4/19/2001	Condenser soot below waste rock at ore crib	430	0.14	1.84	3.8	88	0.2
21CH - 3AR	38.74409	-122.702427	4/19/2001	Silica-carbonate alteration and quart veins	57	0.06	0.1	0.6	3	<0.05
21CH - 0R	38.74409	-122.702427	4/19/2001	High grade ore	17700	0.08	0.17	2.0	7	<0.05

Table 2 (continued). Mercury and associated major and minor elements in sediment, precipitates, and calcines at Helen, Research and Chicago mine areas and upper part of Dry Creek watershed, Lake County, California.

Field Number	Latitude	Longitude	Date	Sample site description	Hg ppm	Ag ppm	Al %	As ppm	Ba ppm	Be ppm
Dry Creek active channel										
21DR - 1S	38.74045	-122.68845	4/19/2001	Gaging station on upper Dry Creek 2 gal/min	13	0.30	3.58	3.4	208	0.55
22 DC 1BB	38.73422	-122.64966	7/31/2002	Fine to coarse sand at lower gaging station	71	<0.02	4.34	4.2	357	0.70
22 DC 2	38.74026	-122.63532	7/31/2002	Fine to coarse sand on bank, .25 mi above road cross	43					
22 DC 3	38.74316	-122.63326	7/31/2002	Fine to coarse pebble sand, 15 m upstream road cross	230	0.04	4.46	4.8	374	0.80
22 DC 4A	38.74571	-122.63121	7/31/2002	Coarse pebble to fine sand, 450' below road crossing	150	0.02	4.61	5.6	375	0.80
22 DC 5B	38.74414	-122.63114	7/31/2002	Fine sand to silt from dry pool 100' below road cross creek	25	<0.02	4.90	4.2	325	0.75
22 DC 6A	38.74028	-122.68750	7/31/2002	Pebble sand to fine sand at upper gaging station	90	<0.02	4.23	5.2	386	0.75
22 DC 7	38.73130	-122.65477	7/31/2002	Dry Creek near bridge						
22 DC 11	38.75480	-122.62379	7/31/2002	Fine to coarse pebble sand at highway 175	160	0.02	4.01	5.6	289	0.65
23DC 1S	38.73885	-122.63872	4/01/2003	Dry Creek near site of 22DC2	7.3	0.05	3.66	3.6	220	0.48
23DC 1BS	38.73885	-122.63872	4/01/2003	Silt to fine sand in back eddy pool	5.9	0.04	3.51	3.1	190	0.47
23DC 6S			4/01/2003	High stand bar sand fine to medium grained recent flood	9	0.04	3.26	3.5	210	0.50
DC23-1	38.7438	-122.62125	1/30/2003	Black sand-silt in remnant of high flow pool	4.2	0.06	4.19	5.2	260	0.70
DC23-2	38.7437	-122.63131	1/30/2003	Fine to medium sand in active channel	2.6	0.04	3.04	4.1	170	0.44
Dry Creek pre-mining bank sediment										
22 DC 1BB	38.73422	-122.64966	7/31/2002	Medium to coarse sand at lower gaging station	41	0.02	4.38	4.2	340	0.75
22 DC 4B	38.74571	-122.63121	7/31/2002	Sand matrix of cobble conglomerate, 450' below road	66	0.10	3.69	18.2	276	0.80
22 DC 5	38.74414	-122.63114	7/31/2002	Sand matrix of cobble conglomerate	3.6	0.02	4.47	4.4	338	0.75
22 DC 5A	38.74414	-122.63114	7/31/2002	Medium to coarse sand matrix of conglomerate at road	8.6	0.02	4.82	5.4	264	0.85
22 DC 6B	38.74028	-122.68750	7/31/2002	Sand-silt matrix of conglomerate, upper gaging station	27	0.08	3.34	1.6	150	0.60
23DC 1PMS	38.73885	-122.63872	4/1/2003	Pre-mining conglomerate in bank deposit below paved road	0.9	0.12	6.55	17.4	350	1.09
Dry Creek flood plain										
DC23-3	38.74463	-122.63178	1/30/2003	Red soil from vineyard on Dry Creek flood plain	2.2	0.06	6.79	6.0	300	0.96
DC23-4	38.74229	-122.63281	1/30/2003	Soil from side of vineyard Dry Creek flood plain	0.4	0.03	6.46	5.1	290	1.08
DC23-5	38.74407	-122.63169	1/30/2003	Soil from flood plain adjacent to vineyard	0.3	0.04	6.23	5.2	330	1.00

Table 2 (continued). Mercury and associated major and minor elements in sediment, precipitates, and calcines at Helen, Research and Chicago mine areas and upper part of Dry Creek watershed, Lake County, California.

Field number	Bi ppm	Ca %	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hf ppm	In ppm	K %	La ppm	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	N ppm
21HM-1S	<0.01	0.58	0.04	26	184	80	0.16	1.4	>25	0.61	0.67	<0.1	<0.005	0.02	18.5	0.6	0.48	2110	0.62	0.01	0
21HM-2S	<0.01	0.34	0.02	1	83	1520	0.06	5.1	14	0.72	0.29	<0.1	<0.005	0.02	0.9	1.1	14.80	788	0.26	0.03	0
21HM-2SA	<0.01	1.23	<0.02	1.3	40	102	0.07	1.0	>25	0.33	0.57	<0.1	<0.005	0.01	1.5	0.3	0.67	651	0.22	0.01	0
21HM - 3S	0.03	0.45	0.04	7.7	94	767	1.70	22.2	4.8	3.70	0.25	0.5	0.025	0.28	4.0	9.0	12.50	925	0.35	0.38	1
23HM 3S	0.06	1.40	0.10	28.9	41	692	1.54	31.8	4.3	11.65	0.15	1.7	0.025	1.08	12.5	26.2	6.61	778	0.74	1.18	5
23HM 5S	<0.01	0.46	0.05	6.7	81	2600	0.53	13.5	4.8	3.78	0.14	0.5	<0.005	0.29	3.0	7.4	>15.00	704	0.35	0.30	1
23HM 6S	0.05	1.54	0.08	25.2	29	647	1.20	28.4	3.7	10.70	0.11	1.7	0.021	1.01	11.2	22.3	5.33	632	0.64	1.18	4
23HM 7S	<0.01	0.35	0.04	5.06	87	2360	0.44	12.2	4.8	2.91	0.14	0.4	<0.005	0.22	2.3	5.5	>15.00	705	0.34	0.21	1
23HM 8S	0.06	1.39	0.08	22.2	28	530	1.15	35.6	3.4	10.05	0.1	1.5	0.019	0.97	9.9	20.9	5.20	600	0.58	1.12	4
23HM 9S	<0.01	0.55	0.07	9.9	45	21	0.05	4.1	>25	0.4	0.62	<0.1	<0.005	0.01	7.9	<0.2	0.50	485	0.45	0.01	0
23HM 11S	0.05	0.57	0.04	2.2	95	1900	0.25	13.0	17.5	1.51	0.29	0.1	<0.005	0.10	1.1	2.4	12.7	974	0.35	0.08	0
22 DC 9	0.03	0.86	0.24	11.7	297	2200	2.25	16.4	24.4	3.75	0.85	0.4	0.010	0.17	8	5.8	4.27	3730	0.75	0.2	2
HL0401C1	0.07	0.03	0.06	4.2	85	1520	2.25	21.2	7.8	2.1	0.45	0.1	0.020	0.03	2	5.2	1.76	285	0.25	<0.01	0
21RE - 1- S	0.01	0.24	0.02	0.3	102	784	0.25	16.8	5.2	0.55	0.25	<0.1	0.005	<0.01	<0.5	1.4	>15.00	710	0.20	<0.01	0
21RE - 1C	<0.01	0.26	0.08	0.5	129	949	0.20	10.0	6.0	0.7	0.35	<0.1	0.005	<0.01	<0.5	1.8	>15.00	970	0.20	<0.01	0
21RE - 2C	<0.01	0.56	0.22	1.5	179	1530	1.05	17.4	8.3	1.3	0.6	<0.1	0.015	0.02	0.5	2.6	12.55	1345	0.30	0.01	0
21CH - 1C	<0.01	0.08	0.06	0.6	163	1670	0.35	11.8	7.9	1.0	0.6	<0.1	0.005	<0.01	<0.5	2.0	>15.00	1255	0.20	<0.01	0
21CH - 2C	<0.01	0.10	0.02	0.1	107	745	<0.05	7.2	5.2	0.65	0.35	<0.1	0.010	<0.01	<0.5	1.2	>15.00	780	0.10	<0.01	<0.01
21CH - 4C	0.01	0.23	0.10	7.4	348	4350	2.10	27.6	15.4	4.3	1.05	0.3	0.030	0.12	4	8.2	5.57	2670	0.35	0.27	1
21CH - 3AR	<0.01	0.19	0.02	0.1	72	730	0.35	4.4	3.7	0.5	0.25	<0.1	0.005	<0.01	<0.5	2.8	>15.00	590	0.20	<0.01	<0.01
21CH - 0R	<0.01	0.06	0.12	0.1	94	1805	0.50	8.6	4.9	0.6	0.45	<0.1	<0.005	<0.01	<0.5	2.0	5.01	540	0.40	<0.01	<0.01

Table 2 (continued). Mercury and associated major and minor elements in sediment, precipitates, and calcines at Helen, Research and Chicago mine areas and upper part of Dry Creek watershed, Lake County, California.

Field number	Bi ppm	Ca %	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hf ppm	In ppm	K %	La ppm	Li ppm	Mg %	Mn ppm	Mo ppm	Na %	Nb ppm
21DR - 1S	0.03	0.7	0.10	14	52	702	1.10	25.6	4.49	6.55	0.30	1.0	0.03	0.63	8.0	14.2	10.3	645	0.4	0.84	3.3
22 DC 1BB	0.07	0.9	0.06	24	62	2650	1.75	32.8	4.75	9.95	0.30	1.2	0.03	0.78	13.0	26.2	8.8	805	0.6	1.05	5.9
22 DC 2																					
22 DC 3	0.08	1.0	0.08	25	66	4960	1.90	41.4	5.20	10.4	0.30	1.2	0.03	0.77	13.5	23.4	8.2	925	1.3	1.06	6.0
22 DC 4A	0.08	1.1	0.12	22	78	>10000	1.75	43.6	6.07	11.3	0.30	1.2	0.03	0.73	11.5	20.4	7.6	975	2.0	1.07	5.9
22 DC 5B	0.08	1.4	0.28	23	49	1605	1.60	53.6	5.10	11.7	0.30	1.4	0.04	0.77	12.5	21.6	6.8	805	1.0	1.32	6.6
22 DC 6A	0.08	1.0	0.08	24	68	2120	1.45	35.2	5.03	9.80	0.30	1.2	0.03	0.81	13.0	22.4	9.2	870	1.0	1.04	5.9
22 DC 7																					
22 DC 11	0.06	1.0	0.10	19	66	5990	1.55	34.2	5.23	9.55	0.30	1.1	0.03	0.69	10.0	20.0	8.1	880	1.2	0.95	5.7
23DC 1S	0.05	0.8	0.07	18	52	2250	1.38	23.4	4.58	8.16	0.16	1.2	0.02	0.71	8.0	17.0	9.6	752	0.5	0.70	3.5
23DC 1BS	0.04	0.8	0.06	16	50	1405	1.18	23.0	4.42	8.00	0.16	1.3	0.02	0.65	7.4	17.8	9.7	727	0.4	0.74	3.8
23DC 6S	0.04	0.7	0.06	16	59	1400	1.38	22.4	4.40	7.54	0.15	1.1	0.02	0.65	7.3	16.6	10.1	742	0.5	0.63	3.1
DC23-1	0.08	0.8	0.09	24	57	686	1.89	30.7	4.70	9.70	0.15	1.6	0.03	0.84	10.7	23.5	8.9	874	0.6	0.83	4.6
DC23-2	0.03	0.7	0.06	14	56	1045	1.14	21.5	4.42	7.08	0.13	1.0	0.01	0.56	6.4	17.2	10.4	750	0.5	0.58	2.8
22 DC 1BB	0.09	1.0	0.08	22	69	1680	1.95	37.4	4.95	9.85	0.30	1.2	0.03	0.83	11.5	25.8	9.5	895	0.8	1.03	5.6
22 DC 4B	0.08	0.8	0.12	23	254	7920	2.45	93.1	14.8	10.65	0.60	1.1	0.03	0.52	11.5	17.0	5.5	2760	1.2	0.34	4.7
22 DC 5	0.09	1.0	0.06	21	53	2650	1.80	33.4	4.82	10.50	0.30	1.2	0.03	0.82	11.0	23.6	8.1	915	0.7	1.08	5.5
22 DC 5A	0.09	1.4	0.10	21	44	5670	1.55	45.2	5.84	12.50	0.30	1.6	0.05	0.73	11.0	24.8	4.4	1110	1.0	1.09	6.2
22 DC 6B	0.06	0.4	0.04	18	63	1240	2.30	31.2	3.14	8.50	0.30	0.9	0.02	0.56	8.0	21.6	11.0	2050	0.7	0.25	3.9
23DC 1PMS	0.08	1.1	0.15	44	89	3560	3.53	69.8	9.92	17.45	0.28	3.1	0.05	1.10	15.3	19.8	1.8	1545	1.8	0.96	8.1
DC23-3	0.1	1.7	0.37	38	69	4000	2.62	48.8	7.13	17.0	0.19	2.8	0.05	0.97	15.3	26.4	2.1	1510	0.9	0.88	7.4
DC23-4	0.11	0.7	0.24	40	46	2820	2.85	39.2	5.66	17.0	0.17	3.2	0.05	0.86	17.1	30.2	1.6	1625	0.6	0.52	2.0
DC23-5	0.23	0.6	0.18	42	42	2460	2.82	38.8	5.40	15.9	0.17	3.0	0.05	0.84	18.9	29.1	1.1	1680	0.7	0.49	2.8

Table 2 (continued). Mercury and associated major and minor elements in sediment, precipitates, and calcines at Helen, Research and Chicago mine areas and upper part of Dry Creek watershed, Lake County, California.

Field number	Ni ppm	P ppm	Pb ppm	Rb ppm	Re ppm	S %	Sb ppm	Se ppm	Sn ppm	Sr ppm	Ta ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
21HM-1S	4760	20	0.5	0.7	<0.002	0.08	0.1	<1	<0.2	141	<0.05	0.24	<0.2	0.006	0.02	<0.1	11	0.1	13.5	197	1.6
21HM-2S	1920	10	0.9	0.7	<0.002	0.08	0.2	<1	0.2	115	<0.05	0.07	<0.2	0.011	<0.02	<0.1	23	0.1	0.6	29	1.5
21HM-2SA	1125	10	0.7	0.2	<0.002	0.08	0.1	<1	<0.2	565	<0.05	0.18	<0.2	<0.005	<0.02	<0.1	7	0.1	0.8	8	0.7
21HM - 3S	2030	130	3.5	12.0	<0.002	0.24	0.2	<1	0.6	33	0.15	0.05	1.2	0.090	0.1	0.5	45	<0.1	4.1	52	22.5
23HM 3S	633	430	6.6	38.7	<0.002	0.10	0.5	<1	1.1	63	0.24	<0.05	4.2	0.361	0.23	1.0	122	0.6	11.8	72	49.3
23HM 5S	1770	120	2.5	11.1	<0.002	0.02	0.2	<1	0.4	19	0.08	<0.05	1.1	0.095	0.08	0.3	58	0.3	2.8	56	14.5
23HM 6S	508	430	5.5	35.1	<0.002	0.08	0.5	<1	0.9	63	0.20	<0.05	3.5	0.288	0.19	0.8	107	0.5	10.4	64	41.4
23HM 7S	2060	100	2.2	8.4	<0.002	0.02	0.2	<1	0.3	14	0.06	<0.05	0.8	0.078	0.07	0.2	51	0.2	2.2	53	11.2
23HM 8S	493	390	5.0	33.6	<0.002	0.07	0.4	<1	0.9	54	0.18	<0.05	3.3	0.271	0.17	0.8	100	0.4	9.5	59	42.1
23HM 9S	2710	20	0.8	0.3	<0.002	0.25	0.3	<1	0.7	132	<0.05	0.26	<0.2	<0.005	<0.02	<0.1	9	0.6	5.3	81	1.2
23HM 11S	2090	50	3.0	3.7	<0.002	0.14	0.5	<1	0.3	258	<0.05	0.14	0.3	0.029	0.03	0.1	33	0.2	1.1	44	5.3
22 DC 9	5720	200	5.0	8.3	0.002	0.36	0.3	<1	0.2	138	0.10	0.05	1.2	0.07	0.08	0.3	39	1.3	5.9	258	11.5
HL0401C1	1635	30	4.5	1.7	<0.002	0.31	0.1	<1	0.4	5	<0.05	0.15	1.0	0.04	0.54	0.3	36	0.1	1.8	36	12.5
21RE - 1- S	2420	10	2.0	0.5	<0.002	0.04	0.4	<1	<0.2	2	<0.05	2.65	<0.2	<0.01	<0.02	<0.1	17	<0.1	0.2	36	2.5
21RE - 1C	2680	50	6.5	0.8	<0.002	0.01	2.8	<1	0.2	4	<0.05	1.15	<0.2	0.01	<0.02	<0.1	21	<0.1	0.3	38	2.5
21RE - 2C	3450	100	24.5	1.7	<0.002	0.03	10.4	<1	0.6	5	<0.05	0.50	<0.2	0.03	0.06	<0.1	37	<0.1	0.7	60	4.5
21CH - 1C	3490	50	6.5	0.7	<0.002	0.01	1.3	<1	0.6	3	<0.05	1.45	<0.2	0.01	<0.02	<0.1	33	<0.1	0.3	50	3.5
21CH - 2C	2470	30	1.5	0.1	<0.002	0.01	0.6	1	1.6	1	<0.05	1.25	<0.2	0.01	<0.02	<0.1	16	<0.1	<0.1	34	2.0
21CH - 4C	4920	240	6.0	9.5	<0.002	0.04	2.5	<1	0.6	17	0.10	0.55	1.2	0.08	0.06	0.3	90	<0.1	3.1	116	16.5
21CH - 3AR	1455	<10	0.5	0.2	0.002	0.19	0.1	<1	0.2	4	<0.05	2.65	<0.2	0.01	<0.02	<0.1	12	<0.1	<0.1	26	1.5
21CH - 0R	2300	10	11.5	0.4	<0.002	0.46	5.2	<1	0.4	4	<0.05	0.35	<0.2	0.01	0.34	<0.1	16	<0.1	0.1	38	1.5

Table 2 (continued). Mercury and associated major and minor elements in sediment, precipitates, and calcines at Helen, Research and Chicago mine areas and upper part of Dry Creek watershed, Lake County, California.

Field number	Ni ppm	P ppm	Pb ppm	Rb ppm	Re ppm	S %	Sb ppm	Se ppm	Sn ppm	Sr ppm	Ta ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm	Y ppm	Zn ppm	Zr ppm
21DR - 1S	1215	290	5.5	24.5	<0.002	0.06	0.45	1	0.8	30.8	0.25	0.45	2.8	0.17	0.16	0.8	73	<0.1	7.4	60	40.5
22 DC 1BB	939	310	6.5	32.4	0.004	0.03	0.40	1	0.8	46.2	0.30	<0.05	4.2	0.27	0.20	0.9	106	0.7	9.1	80	37.0
22 DC 2																					
22 DC 3	974	420	9.0	33.1	0.004	0.05	0.40	1	1.4	57.9	0.25	<0.05	3.6	0.29	0.22	0.9	125	0.7	9.7	100	36.0
22 DC 4A	916	400	11.	31.2	0.004	0.05	0.65	1	1.6	58.5	0.25	<0.05	3.4	0.32	0.20	0.8	176	0.8	9.9	152	37.5
22 DC 5B	738	440	13	31.9	0.002	0.05	2.10	1	2.0	71.6	0.30	<0.05	3.8	0.36	0.18	1.0	126	0.7	11.5	120	46.5
22 DC 6A	1040	390	7	32.1	0.002	0.09	0.40	1	0.8	42.0	0.30	<0.05	3.6	0.28	0.20	0.9	103	0.6	9.3	76	37.5
22 DC 7																					
22 DC 11	982	340	11	28.6	0.002	0.03	0.50	1	1.2	51.3	0.25	<0.05	3.0	0.27	0.18	0.8	126	0.7	8.6	104	34.5
23DC 1S	1055	270	5	26.9	<0.002	0.02	0.19	<1	1.0	40.4	0.14	<0.05	2.7	0.24	0.16	0.7	102	0.4	7.7	73	31.8
23DC 1BS	1085	300	4	24.4	<0.002	0.02	0.13	<1	0.7	42.1	0.11	<0.05	2.4	0.245	0.14	0.6	95	0.3	7.6	66	32.7
23DC 6S	1155	240	4.9	25.3	<0.002	0.02	0.10	<1	0.7	37.0	0.10	<0.05	2.5	0.20	0.16	0.6	87	0.3	7.0	63	29.4
DC23-1	1130	370	6.7	34.0	<0.002	0.04	0.26	<1	1.0	46.0	0.14	<0.05	3.6	0.29	0.20	0.9	102	0.4	9.8	68	43.1
DC23-2	1265	250	4.1	22.0	<0.002	0.02	0.14	<1	1.0	34.1	0.09	<0.05	2.1	0.20	0.12	0.5	85	0.4	6.8	61	25.3
22 DC 1BB	1045	360	11	35.4	0.002	0.06	0.35	1	2.2	67.2	0.20	<0.05	3.8	0.26	0.24	0.9	101	0.7	9.3	78	35.0
22 DC 4B	3170	420	8	26.2	0.004	<0.01	1.65	1	0.8	36.0	0.25	0.1	3.0	0.17	0.26	0.7	180	1.8	12.6	134	36.0
22 DC 5	829	320	9.5	34.5	0.002	0.03	0.50	1	0.8	55.0	0.20	<0.05	3.4	0.27	0.20	0.9	112	0.6	9.1	86	37.0
22 DC 5A	485	430	5.5	31.8	0.002	<0.01	0.45	1	1.0	59.4	0.30	<0.05	3.6	0.4	0.34	0.8	168	0.9	13.3	114	45.5
22 DC 6B	1105	240	6.0	27.4	0.002	0.02	0.35	1	0.8	29.2	0.20	<0.05	3.0	0.17	0.20	0.8	74	0.4	6.6	56	30.0
23DC 1PMS	1940	470	7.3	45.3	<0.002	0.01	0.43	<1	1.3	70.7	0.15	0.05	4.9	0.59	0.28	1.4	231	0.9	20.2	116	79.7
DC23-3	708	1640	10.8	54.2	<0.002	0.02	0.64	<1	1.7	77.3	0.30	0.05	4.6	0.63	0.27	1.5	214	0.8	19.4	152	68.3
DC23-4	556	880	10.8	58.5	<0.002	0.02	0.29	<1	1.6	55.7	0.05	<0.05	5.5	0.65	0.27	1.4	180	0.1	15.6	168	87.3
DC23-5	441	1000	12.2	58.6	<0.002	0.02	0.26	1	1.6	58.6	0.08	<0.05	5.2	0.67	0.27	1.3	170	0.2	15.8	212	74.9

Table 3. Mercury (Hg) and monomethylmercury (MMeHg) concentrations in waters and sediment at Helen and Research mines, and Dry Creek.

Sample number	Date	Water Hg total ng/L	Water Hg filtered ng/L	Water total MMeHg ng/L	Sediment Hg ng/g	Sediment MMeHg ng/g	% MMeHg (MMeHg/Hg) in sediment
Helen Mine Area							
21HM1	4/19/2001	9.56	4.78	<0.02	14700.0	N/C	0.000
21HM2	4/19/2001	17.50	1.8	0.026	357.0	N/C	0.000
21HM3	4/19/2001	7.62	1.05	0.051	4910.0	N/C	0.000
21HM4	4/19/2001	28.10	3.9	0.62			
23HM5	4/01/2003	6.06	3.77	<0.025	1440	0.054	0.004
23HM7	7/15/2003	9.15	5.79	<0.025	471	0.05	0.011
23HM9	7/15/2003	0.61	0.37	<0.025	17.4	0.734	4.218
23HM10	7/15/2003	5.94	3.09	<0.025	371169	0.114	0.000
23HM11	7/15/2003	3.44	0.48	<0.025	16320	0.176	0.001
HEL0703SED1A	7/15/2003	741					
HEL0703SED1B	7/15/2003	52					
HEL0703W5	7/15/2003	4.62		0.25			
HEL0703W3	7/15/2003	2.78					
HEL0703FB	7/15/2003	1.89					
HEL0703W4	7/15/2003	1.55					
HEL0703W3.F	7/15/2003	1.76					
Research Mine							
21RE1	4/19/2001	32.8	1.52	<0.020	2520	0.232	0.009
Dry Creek							
23DC1C	4/01/2003	2.64	1.75	<0.025	7500	0.253	0.003
23DC1B	7/15/2003	3.5	2.46	0.096	300	0.195	0.065
23HM6	4/01/2003	24.1	2.75	<0.025	681000	0.106	0.000
23HM8	7/15/2003	17.7	3.2	0.026	204	0.063	0.031
21DR1	4/19/2001	7.24	3.05	<0.020	2710	0.114	0.004
22DC6A	7/31/2002	5.35	3.46	<0.025	293	0.597	0.204

Table 4. Concentration of anions and cations in filtered water from Dry Creek, Anna Belcher Creek, Little Sulphur Creek, and Helen and Contact mine areas.

Sample number	Cl ppm	F ppm	NO3 ppm	SO4 ppm	CaCO3 ppm	Ca mg/L	Fe mg/L	Mg mg/L	K mg/L	Li µg/L	Na mg/L
Contact Mine											
21CT1	2.4	1.3	0.1	20	240	40	<0.02	32	0.85	4.4	8.9
21CT2	2.6	0.1	<0.08	7.2	170	15	<0.02	34	0.39	<1	3.0
21CT3	2.3	0.1	0.1	7.8	300	11	0.024	64	0.30	1.2	1.6
21CT4	2.8	0.2	<0.08	16	440	7.8	<0.02	100	0.23	6.6	1.4
23CT1C	2.5	0.2	<.08	9.9	92	14.4	0.34	14	0.75	<1	3.5
23CT2C	2.4	0.1	<.08	6.3	150	12.3	0.079	29.5	0.39	<1	2.8
Anna Belcher Creek											
23AB1C	2.5	0.2	<.08	9.2	140	21	<0.02	21.5	0.66	<1	4.4
23AB2C	2.5	0.2	<.08	8.5	130	21	<0.02	20.8	0.70	<1	4.3
Little Sulphur Creek											
22LS1C	2.0	0.1	<.08	7.8	120	22.2	<0.02	15.6	0.31	<1	5.6
Helen Mine Area											
21HM1	4.4	0.1	0.1	720	270	32	15	230	0.40	13	3.8
21HM2	4.7	0.2	<0.08	430	240	40	6.4	140	0.69	11	13.0
21HM3	3.8	0.1	0.08	150	180	29	<0.02	60	0.49	3.4	5.9
21HM4	2.2	0.1	<0.08	85	160	18	<0.02	46	0.36	2.3	2.9
23HM5C	3.7	0.1	<0.08	18	200	9.5	<0.02	46.3	0.18	<1	32.0
23HM7D	6.4	<.08	<0.08	13	290	10.1	<0.02	64.9	0.14	1.1	29.0
23HM9C	6.9	<.08	<0.08	860	310	37.6	10.4	267	0.38	14	4.1
23HM10C	6.3	<.08	<0.08	760	360	27.4	.09	251	0.19	9.1	3.9
23HM11C	7.6	<0.8	<0.08	900	320	63.8	9.6	264	1.40	22	32.0
Research Mine											
21RE1	10.0	0.2	<0.08	78	340	4	<0.02	97	<0.1	<1	0.68
Dry Creek											
21DR1	4.3	<0.08	<0.08	44	230	12	<0.02	57	0.17	1.1	2.6
22DC6A	13.1	0.3	5560	324	0	15.4	<20	103	0.24	<1	4.5
23DC1C	3.3	0.2	<0.08	7.7	150	10.2	<0.02	32.6	0.36	<1	3.0
23DC1BC	5.3	<.08	<0.08	12	250	15.6	<0.02	54.1	0.41	1.3	4.1
23HM8D	6.3	0.2	<0.08	130	280	20.4	0.048	89.2	0.24	2.2	18.0
23HM6C	3.4	0.1	0.08	32	180	13.4	0.17	43.6	0.24	<1	40

Table 5. Collection sites for biological samples, and water/sediment samples in the Dry Creek watershed, 2003 and at a reference site (BR20) in 1999-2002.

Site code	Water/sediment site code	Site	Watershed	County	Sampling dates	Latitude	Longitude
DCAH	23HM3; 23HM8	Dry Cr. Above Helen Mine	Putah Creek	Lake	4/2/03; 7/16/03	38° 44' 30.5"	122° 41' 52.7"
DCBH	23HM6	Dry Cr. Below Helen Mine	Putah Creek	Lake	4/2/03; 7/16/03	38° 44' 30.6"	122° 41' 47.8"
LDCB	22 DC 7	Lower Dry Creek	Putah Creek	Lake	4/2/03; 7/16/03	38° 44' 23.2"	122° 41' 51.0"
HMT0	23HM9	Helen Mine Tunnel Outlet	Putah Creek	Lake	7/16/03	38° 44' 17.3"	122° 38' 27.3"
BR20	NA	Bear Creek at HWY 20	Bear River	Nevada/Placer	1999-2002	39° 18' 23.0"	120° 40' 41.0"

Table 6. Total mercury (Hg_T) and monomethyl mercury (MMeHg; µg/g, wet weight) in individual composites of invertebrates collected at Dry Creek in 2003, and at a reference site, Bear River at Highway 20 (BR20), during 1999-2002.

Unique Sample Code	Site code	Order	Family	Common name	Collection date	N	Sample mass (g)	Average mass (g)	MMeHg (µg/g, wet weight)	Hg _T , (µg/g, wet weight)	Moisture (percent)
CR-DCAH-040203-004	DCAH	Hemiptera	Gerridae	Water Striders	4/2/2003	4	0.31	0.078	0.147	0.213	NA ¹
CR-DCAH-040203-002	DCAH	Megaloptera	Corydalidae	Dobsonflies	4/2/2003	1	1.22	1.220	0.431	0.598	78.8
CR-DCAH-040203-003	DCAH	Megaloptera	Corydalidae	Dobsonflies	4/2/2003	7	1.08	0.154	0.216	0.385	79.2
CR-DCAH-040203-001	DCAH	Plecoptera	Perlidae	Stoneflies	4/2/2003	5	1.01	0.202	0.078	0.115	71.2
CR-DCBH-040203-002	DCAH	Plecoptera	Perlidae	Stoneflies	4/2/2003	10	1.43	0.143	0.092	0.121	74.1
CR-DCBH-040203-001	DCBH	Hemiptera	Gerridae	Water Striders	4/2/2003	23	1.49	0.065	0.135	0.213	55.6
CR-DCBH-040203-003	DCBH	Megaloptera	Corydalidae	Dobsonflies	4/2/2003	3	1.08	0.360	0.140	0.292	80.0
CR-LDCB-040203-002	LDCB	Megaloptera	Corydalidae	Dobsonflies	4/2/2003	1	0.59	0.590	0.080	0.120	NA
CR-LDCB-040203-003	LDCB	Megaloptera	Corydalidae	Dobsonflies	4/2/2003	6	0.72	0.120	0.107	0.232	NA
CR-LDCB-040203-004	LDCB	Odonata	Aeshnidae	Dragonflies	4/2/2003	6	1.19	0.198	0.074	0.084	83.4
CR-LDCB-040203-001	LDCB	Plecoptera	Perlidae	Stoneflies	4/2/2003	9	1.32	0.147	0.071	0.100	73.1
CR-DCAH-071503-002	DCAH	Hemiptera	Notonectidae	Backswimmers	7/16/03	12	1.26	0.105	0.317	0.280	69.4
CR-DCAH-071503-003	DCAH	Hemiptera	Notonectidae	Backswimmers	7/16/03	12	1.28	0.107	0.293	0.226	61.5
CR-DCAH-071503-004	DCAH	Hemiptera	Gerridae	Water Striders	7/16/03	25	1.53	0.061	0.166	0.167	63.5
CR-DCAH-071503-005	DCAH	Hemiptera	Gerridae	Water Striders	7/16/03	25	1.58	0.063	0.117	0.122	65.0
CR-DCAH-071503-001	DCAH	Megaloptera	Corydalidae	Dobsonflies	7/16/03	3	0.77	0.257	0.078	0.354	80.0
CR-DCBH-071503-004	DCBH	Hemiptera	Notonectidae	Backswimmers	7/16/03	12	1.41	0.118	0.299	0.288	60.8
CR-DCBH-071503-005	DCBH	Hemiptera	Notonectidae	Backswimmers	7/16/03	12	1.39	0.116	0.163	0.319	71.2
CR-DCBH-071503-006	DCBH	Hemiptera	Gerridae	Water Striders	7/16/03	25	1.64	0.066	0.120	0.190	60.2
CR-DCBH-071503-007	DCBH	Hemiptera	Gerridae	Water Striders	7/16/03	25	1.72	0.069	0.255	0.155	59.0
CR-DCBH-071503-002	DCBH	Megaloptera	Corydalidae	Dobsonflies	7/16/03	6	1.92	0.320	0.073	0.185	82.2
CR-DCBH-071503-003	DCBH	Megaloptera	Corydalidae	Dobsonflies	7/16/03	6	1.56	0.260	0.061	0.200	82.2
CR-DCBH-071503-001	DCBH	Plecoptera	Perlidae	Stoneflies	7/16/03	19	1.50	0.079	0.033	0.061	80.9

Table 6. Total mercury (Hg_T) and monomethyl mercury (MMeHg; µg/g, wet weight) in individual composites of invertebrates collected at Dry Creek in 2003, and at a reference site, Bear River at Highway 20 (BR20), during 1999-2002.

Unique sample code	Site code	Order	Family	Common name	Collection date	N	Sample mass (g)	Average mass (g)	MMeHg, (µg/g, wet weight)	Hg _T , (µg/g, wet weight)	Moisture (percent)
CR-HMTO-071503-001	HMTO	Hemiptera	Gerridae	Water Striders	7/16/03	25	1.66	0.07	0.100	0.106	60.1
CR-LDCB-071503-002	LDCB	Hemiptera	Belostomatidae	Giant Water Bugs	7/16/03	1	0.86	0.80	0.123	0.130	79.8
CR-LDCB-071503-003	LDCB	Hemiptera	Belostomatidae	Giant Water Bugs	7/16/03	1	0.92	0.92	0.074	0.112	76.3
CR-LDCB-071503-007	LDCB	Hemiptera	Gerridae	Water Striders	7/16/03	25	1.09	0.04	0.064	0.099	64.1
CR-LDCB-071503-001	LDCB	Megaloptera	Corydalidae	Dobsonflies	7/16/03	2	1.10	0.55	0.139	0.184	71.3
CR-LDCB-071503-004	LDCB	Odonata	Cordulegastridae	Dragonflies	7/16/03	2	0.83	0.42	0.053	0.070	81.2
CR-LDCB-071503-005	LDCB	Odonata	Aeshnidae	Dragonflies	7/16/03	4	0.90	0.23	0.035	0.047	85.1
CR-LDCB-071503-006	LDCB	Odonata	Gomphidae	Dragonflies	7/16/03	9	1.14	0.13	0.099	0.125	66.1
BY-BH20-091501-005	BR20	Hemiptera	Belostomatidae	Giant water bugs	2001	1	4.47	4.47	0.016	0.022	72.6
BY-BH20-100199-001	BR20	Hemiptera	Gerridae	Water strider	1999	21	1.07	0.05	0.027	NA	57.2
BY-BH20-091200-001	BR20	Hemiptera	Gerridae	Water strider	2000	26	1.30	0.05	0.027	0.028	76.1
BY-BH20-091501-003	BR20	Hemiptera	Gerridae	Water strider	2001	25	1.25	0.05	0.050	0.071	64.7
BY-BR20-082302-001	BR20	Hemiptera	Gerridae	Water strider	2002	25	1.37	0.05	0.041	0.045	63.0
BY-BH20-091200-004	BR20	Megaloptera	Corydalidae	Dobsonflies	2000	1	1.52	1.52	0.038	0.035	74.9
BY-BH20-091501-002	BR20	Megaloptera	Corydalidae	Dobsonflies	2001	4	0.61	0.15	0.040	0.041	79.6
BY-BH20-091501-001	BR20	Megaloptera	Corydalidae	Dobsonflies	2001	4	3.48	0.87	0.029	0.040	75.7
BY-BR20-082302-002	BR20	Megaloptera	Corydalidae	Dobsonflies	2002	2	3.03	1.52	0.048	0.050	71.2
BY-BH20-091501-009	BR20	Odonata	Aeshnidae	Dragonfly	2001	7	3.89	0.56	0.014	0.022	81.9
BY-BR20-082302-005	BR20	Odonata	Aeshnidae	Dragonfly	2002	8	3.63	0.45	0.026	0.024	79.9
BY-BH20-100199-002	BR20	Plecoptera	Perlidae	Stoneflies	1999	14	1.94	0.14	0.039	0.037	69.2
BY-BH20-091200-002	BR20	Plecoptera	Perlidae	Stoneflies	2000	5	1.20	0.24	0.068	NA	68.9
BY-BH20-091501-006	BR20	Plecoptera	Perlidae	Stoneflies	2001	12	2.51	0.21	0.060	0.076	69.3
BY-BH20-091501-007	BR20	Plecoptera	Perlidae	Stoneflies	2001	12	1.72	0.14	0.058	0.056	72.2
BY-BR20-082302-004	BR20	Plecoptera	Perlidae	Stoneflies	2002	12	1.53	0.13	0.044	0.052	68.8

Table 7. Total mercury (HgT) (µg/g, wet weight) in fish collected at Dry Creek in 2003

Sample code	Site acronym	Collection date	Common name	Species	Total length (mm)	Sample mass (g)	HgT µg/g (wet weight)	Moisture (percent)
CR-LDCB-040203-001F	LDCB	4/2/2003	riffle sculpin	<i>Cottus gulosus</i>	50	1.63	0.133	75.1
CR-LDCB-040203-002F	LDCB	4/2/2003	riffle sculpin	<i>Cottus gulosus</i>	55	2.43	0.106	72.2
CR-LDCB-040203-003F	LDCB	4/2/2003	riffle sculpin	<i>Cottus gulosus</i>	64	3.26	0.240	72.2
CR-LDCB-040203-004F	LDCB	4/2/2003	riffle sculpin	<i>Cottus gulosus</i>	73	4.97	0.266	73.9
CR-LDCB-040203-005F	LDCB	4/2/2003	California roach	<i>Hesperoleucus symmetricus</i>	75	3.84	0.199	77.5
CR-LDCB-040203-006F	LDCB	4/2/2003	California roach	<i>Hesperoleucus symmetricus</i>	82	5.18	0.277	76.1
CR-LDCB-040203-007F	LDCB	4/2/2003	California roach	<i>Hesperoleucus symmetricus</i>	87	6.07	0.259	78.1
CR-LDCB-040203-008F	LDCB	4/2/2003	California roach	<i>Hesperoleucus symmetricus</i>	96	8.70	0.332	74.3
CR-LDCB-071503-001F	LDCB	7/15/2003	California roach	<i>Hesperoleucus symmetricus</i>	70	3.36	0.180	78.5
CR-LDCB-071503-002F	LDCB	7/15/2003	California roach	<i>Hesperoleucus symmetricus</i>	65	2.44	0.141	82.7
CR-LDCB-071503-003F	LDCB	7/15/2003	California roach	<i>Hesperoleucus symmetricus</i>	60	1.81	0.087	81.0
CR-LDCB-071503-004F	LDCB	7/15/2003	California roach	<i>Hesperoleucus symmetricus</i>	60	1.82	0.104	82.2
CR-LDCB-071503-005F	LDCB	7/15/2003	rainbow trout	<i>Oncorhynchus mykiss</i>	90	7.14	0.127	76.1
CR-LDCB-071503-006F	LDCB	7/15/2003	rainbow trout	<i>Oncorhynchus mykiss</i>	76	4.14	0.135	75.5
CR-LDCB-071503-007F	LDCB	7/15/2003	rainbow trout	<i>Oncorhynchus mykiss</i>	70	3.45	0.116	78.2
CR-LDCB-071503-008F	LDCB	7/15/2003	rainbow trout	<i>Oncorhynchus mykiss</i>	70	3.38	0.147	76.0
CR-LDCB-071503-009F	LDCB	7/15/2003	rainbow trout	<i>Oncorhynchus mykiss</i>	66	2.93	0.145	74.2
CR-LDCB-071503-010F	LDCB	7/15/2003	rainbow trout	<i>Oncorhynchus mykiss</i>	69	2.97	0.145	80.2
CR-LDCB-071503-011F	LDCB	7/15/2003	rainbow trout	<i>Oncorhynchus mykiss</i>	66	2.62	0.101	83.7
CR-LDCB-071503-012F	LDCB	7/15/2003	rainbow trout	<i>Oncorhynchus mykiss</i>	57	1.71	0.149	74.9
R-075	BR20	8/25/1995	Brown trout	<i>Salmo trutta</i>	230	118	0.063	80.2
R-076	BR20	8/25/1995	Brown trout	<i>Salmo trutta</i>	255	177	0.050	75.4
R-077	BR20	8/25/1995	Brown trout	<i>Salmo trutta</i>	265	180	0.082	76.3
F-029	BR20	8/25/1995	Brown trout	<i>Salmo trutta</i>	295	275	0.095	77.8

Table 8. Major and minor element concentration in filtered waters from the Helen and Research mine areas and Dry Creek.

Sample	Al mg/L	B µg/L	Ba µg/L	Ca mg/L	Ce µg/L	Co µg/L	Cr µg/L	Cs µg/L	Cu µg/L	Eu µg/L	Fe mg/L	Ga µg/L	Gd µg/L	Ge µg/L	K mg/L	La µg/L	Li µg/L
Dry Creek																	
23DC1B	<0.5	75	52	10.0	< 0.01	<0.02	4.9	< 0.01	<0.5	< 0.005	8.1	< 0.02	< 0.005	< 0.02	220	< 0.01	0.45
23DC1BB	<0.01	113	85	15.6	< 0.01	<0.02	3.2	< 0.01	<0.5	< 0.005	<0.02	< 0.02	< 0.005	< 0.02	0.41	< 0.01	0.7
23HM6B	0.50	30	46	12.2	< 0.01	<0.02	7.7	< 0.01	<0.5	< 0.005	14	< 0.02	< 0.005	< 0.02	150	< 0.01	0.64
23HM8B	0.03	58	68	20.4	< 0.01	<0.02	12	< 0.01	0.52	< 0.005	0.048	< 0.02	< 0.005	< 0.02	0.24	< 0.01	1.4
Helen Mine Area																	
23HM5B	<0.5	30	36	9.2	< 0.01	<0.02	8.8	< 0.01	<0.5	< 0.005	7.5	< 0.02	< 0.005	< 0.02	95	< 0.01	0.63
23HM7B	<0.01	38	47	10.1	< 0.01	<0.02	12	< 0.01	<0.5	< 0.005	<0.02	< 0.02	< 0.005	< 0.02	0.14	< 0.01	0.6
23HM9B	<0.01	353	18	37.6	0.086	53	1.1	0.54	1.4	< 0.005	10.4	0.038	< 0.005	0.1	0.38	0.086	12.0
23HM10B	<0.01	257	29	27.4	< 0.01	<0.02	2.3	0.014	1.4	< 0.005	0.087	< 0.02	< 0.005	0.04	0.19	< 0.01	7.6
23HM11B	<0.01	480	22	63.8	< 0.01	11	1.0	1.9	1.3	< 0.005	9.6	< 0.02	< 0.005	0.1	1.4	0.014	19.0
Sample	Mg mg/L	Mn µg/L	Mo µg/L	Na mg/L	Nd µg/L	Ni µg/L	Pb µg/L	Rb µg/L	Se µg/L	SiO2 mg/L	Sr µg/L	U µg/L	V µg/L	W µg/L	Y µg/L	Yb µg/L	Zn µg/L
Dry Creek																	
23DC1B	31.7	0.65	0.09	2.9	0.013	3.3	<0.05	0.22	< 0.2	14	110	0.005	0.4	< 0.03	0.014	< 0.01	0.72
23DC1BB	54.1	<10	0.19	4.1	< 0.01	4.6	<0.05	0.33	< 0.2	21	160	0.006	0.93	< 0.02	0.023	< 0.01	1.8
23HM6B	39.0	0.11	0.16	2.5	< 0.01	8.4	<0.05	0.14	< 0.2	10	130	0.011	0.2	0.06	< 0.01	< 0.01	1.0
23HM8B	89.2	<10	0.17	4.7	< 0.01	14	<0.05	0.2	< 0.2	16	200	0.02	0.21	< 0.02	0.021	< 0.01	1.4
Helen Mine Area																	
23HM5B	44.5	0.03	0.13	2.3	< 0.01	7.9	<0.05	0.1	< 0.2	12	80	< 0.005	0.3	0.13	< 0.01	< 0.01	1.8
23HM7B	64.9	<10	0.06	2.0	< 0.01	8.3	<0.05	0.13	< 0.2	18	90	< 0.005	0.14	< 0.02	< 0.01	< 0.01	1.8
23HM9B	267	1420	0.29	4.1	0.028	1700	<0.05	0.51	0.25	20	290	< 0.005	0.35	0.02	0.06	< 0.01	6.3
23HM10B	251	<10	0.08	3.9	< 0.01	120	<0.05	0.22	0.31	19	200	0.007	0.35	< 0.02	0.011	< 0.01	8.5
23HM11B	264	414	0.09	32	< 0.01	220	<0.05	2.2	0.35	21	1400	< 0.005	0.29	< 0.02	0.079	< 0.01	2.4

Element not detected (detection limit in parentheses): Ag(<0.01), Au (< 0.01), As (<2), Be (<0.05), Bi (< 0.03), Cd (<0.02), Dy (<0.005), Er (<0.005), Eu (< 0.005), Ga (<0.02), Ho (<0.005), In (< 0.01), Lu (<0.1), P (<3), Pr (<0.01), Re (< 0.02), (Sb (<0.1), Sm (<0.01), Tb (<0.005), Th (<0.04), Tl (<0.1), Tm (<0.005).

Table 9. Major and minor element concentration in unfiltered waters from the Helen and Research mine areas and Dry Creek.

Sample	Ag μg/L	Al mg/L	B μg/L	Ba μg/L	Ca mg/L	Ce μg/L	Co μg/L	Cr μg/L	Cs μg/L	Cu μg/L	Fe mg/L	Ge μg/L	K mg/L	Li μg/L	Mg mg/L
Dry Creek															
21DR1a	<0.01	<0.01	40	42	12	< 0.01	<0.02	12	< 0.01	<0.5	<0.02	< 0.02	0.17	0.3	57
23DC1A	<0.01	<0.01	79	53	10	< 0.01	0.024	5.2	< 0.01	<0.5	<0.02	< 0.02	0.36	0.46	32
23DC1BA	<0.01	1.4	113	84	15	< 0.01	<0.02	3.8	< 0.01	<0.5	6.2	< 0.02	430	1.7	54
23HM6A	<0.01	0.05	33	52	13	0.11	0.48	9.3	< 0.01	1.9	0.2	< 0.02	0.24	0.85	43
23HM8A	<0.01	30	58	66	19	0.015	0.04	13	< 0.01	0.54	60	< 0.02	220	2.5	84
Mine Areas															
21RE1a	<0.01	<0.01	270	1	4	< 0.01	<0.02	13	0.07	<0.5	<0.02	< 0.02	<0.1	< 0.3	97
21HM1a	0.55	<0.01	340	17	32	0.4	78	6	0.56	1	15	0.09	0.4	9.2	230
21HM2a	<0.01	<0.01	310	23	40	< 0.01	5.9	4	0.83	0.9	6.4	0.07	0.69	8.7	140
21HM3a	<0.01	<0.01	98	91	29	< 0.01	0.53	7	0.1	0.6	<0.02	< 0.02	0.49	2.1	60
21HM4a	<0.01	0.01	70	46	18	0.08	0.8	3	0.2	0.5	<0.02	0.03	0.36	1.1	46
23HM5A	<0.01	<0.01	32	36	9.5	< 0.01	<0.02	8.1	< 0.01	<0.5	<0.02	< 0.02	0.18	0.72	46
23HM7A	<0.01	1.90	38	46	10	< 0.01	<0.02	13.0	< 0.01	<0.5	9	< 0.02	140	1.3	67
23HM9A	<0.01	0.91	353	18	35	0.1	53	1.4	0.52	1.3	9900	0.11	320	14	250
23HM10A	<0.01	0.30	257	28	25	< 0.01	0.16	2.4	0.013	1.3	120	0.039	160	9.6	220
23HM11A	<0.01	<0.2	480	21	54	0.018	10	1.2	1.9	1.3	8300	0.089	1200	21	220
Sample	Mn μg/L	Mo μg/L	Na mg/L	Ni μg/L	P μg/L	Rb μg/L	Sb μg/L	SiO2 mg/L	Sr μg/L	U μg/L	V μg/L	W μg/L	Y μg/L	Yb μg/L	Zn μg/L
Dry Creek															
21DR1a	0.05	0.20	2.6	5.6	1	0.1	0.03	14	120	0.009	0.5	0.06	0.02	< 0.01	0.8
23DC1A	<10	0.22	3.0	3.5	< 3	0.21	<0.1	14	110	0.006	0.6	0.06	0.02	< 0.01	0.9
23DC1BA	1	0.22	3.8	4.4	< 2	0.31	0.037	23	160	0.007	1.1	0.04	0.02	< 0.01	3.2
23HM6A	<10	0.35	2.8	15.0	< 3	0.23	<0.1	11	150	0.027	0.4	0.14	0.06	< 0.01	6.3
23HM8A	1.5	0.18	4.1	15.0	< 2	0.21	0.021	17	190	0.020	0.3	0.02	0.02	< 0.01	2.1
Mine Areas															
21RE1a	<0.02	0.10	0.7	0.9	< 1	0.08	<0.02	8.2	6.6	< 0.005	1.0	0.06	< 0.01	< 0.01	1.0
21HM1a	1100	0.68	3.8	2400	2	0.4	0.07	21	240	0.010	2.0	0.10	0.30	0.01	20
21HM2a	190	0.20	13	130	< 1	1.1	0.03	17	710	< 0.005	1.0	0.09	0.10	< 0.01	2.0
21HM3a	19	0.50	5.9	33	< 1	0.4	0.07	11	340	0.040	0.6	0.07	< 0.01	< 0.01	1.0
21HM4a	18	0.20	2.9	76	< 1	0.82	0.02	15	140	0.040	0.5	0.06	0.07	< 0.01	1.0
23HM5A	<10	0.46	2.4	8.2	< 3	0.13	<0.1	12	82	< 0.005	<0.2	0.24	< 0.01	< 0.01	3.5
23HM7A	0.23	0.09	2.0	8.7	< 2	0.12	<0.02	20	86	< 0.005	0.2	0.03	< 0.01	< 0.01	6.7
23HM9A	1400	0.32	3.5	1700	< 2	0.48	<0.02	21	280	< 0.005	0.4	0.07	0.07	< 0.01	5.5
23HM10A	3.7	0.09	3.1	120	< 2	0.21	<0.02	19	190	0.007	0.3	0.03	0.02	< 0.01	28
23HM11A	400	0.11	25	210	< 2	2.1	<0.02	20	1300	< 0.005	0.4	0.03	0.07	< 0.01	2.0

Elements not detected (detection limits in parentheses): As (<2), Be (<0.05), Bi (<0.12), Cd (<0.02), Dy (<0.02), Er (<0.005), Eu (<0.006), Ga (<0.04), Gd (<0.03), Ge (<0.05), Ho (<0.005), In (<0.1), La (<0.3), Pb (<0.2), Pr (<0.04), Re (<0.02), Sb (<0.3), Se (<0.27), Sm (<0.023), Tb (<0.005), Th (<0.6), Tl (<0.1), Tm (<0.005).

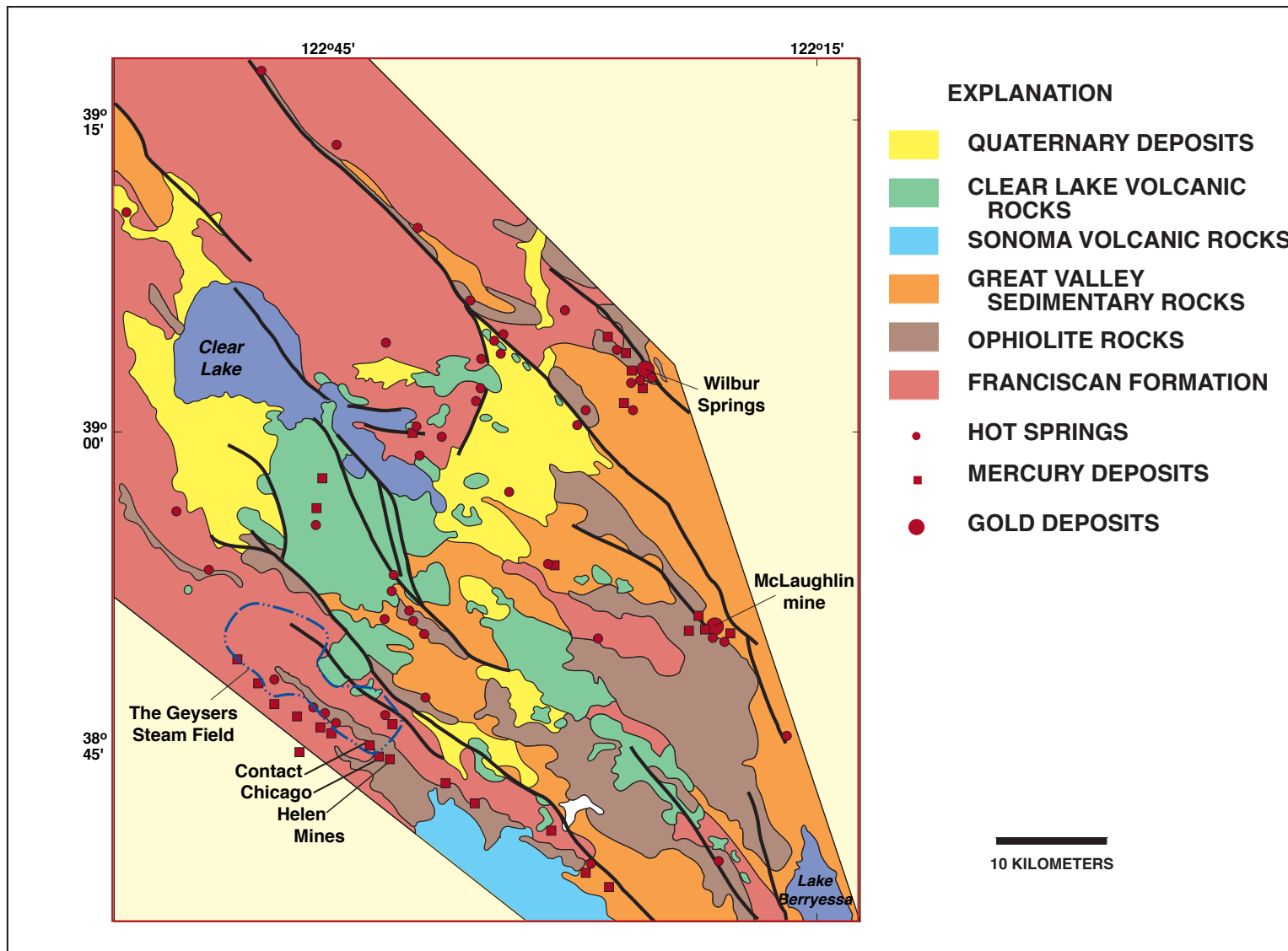


Figure 1. Geologic map of the Clear Lake volcanic field and location of the Helen, Chicago, and Contact mercury mines, Dry Creek watershed, Lake County, California.

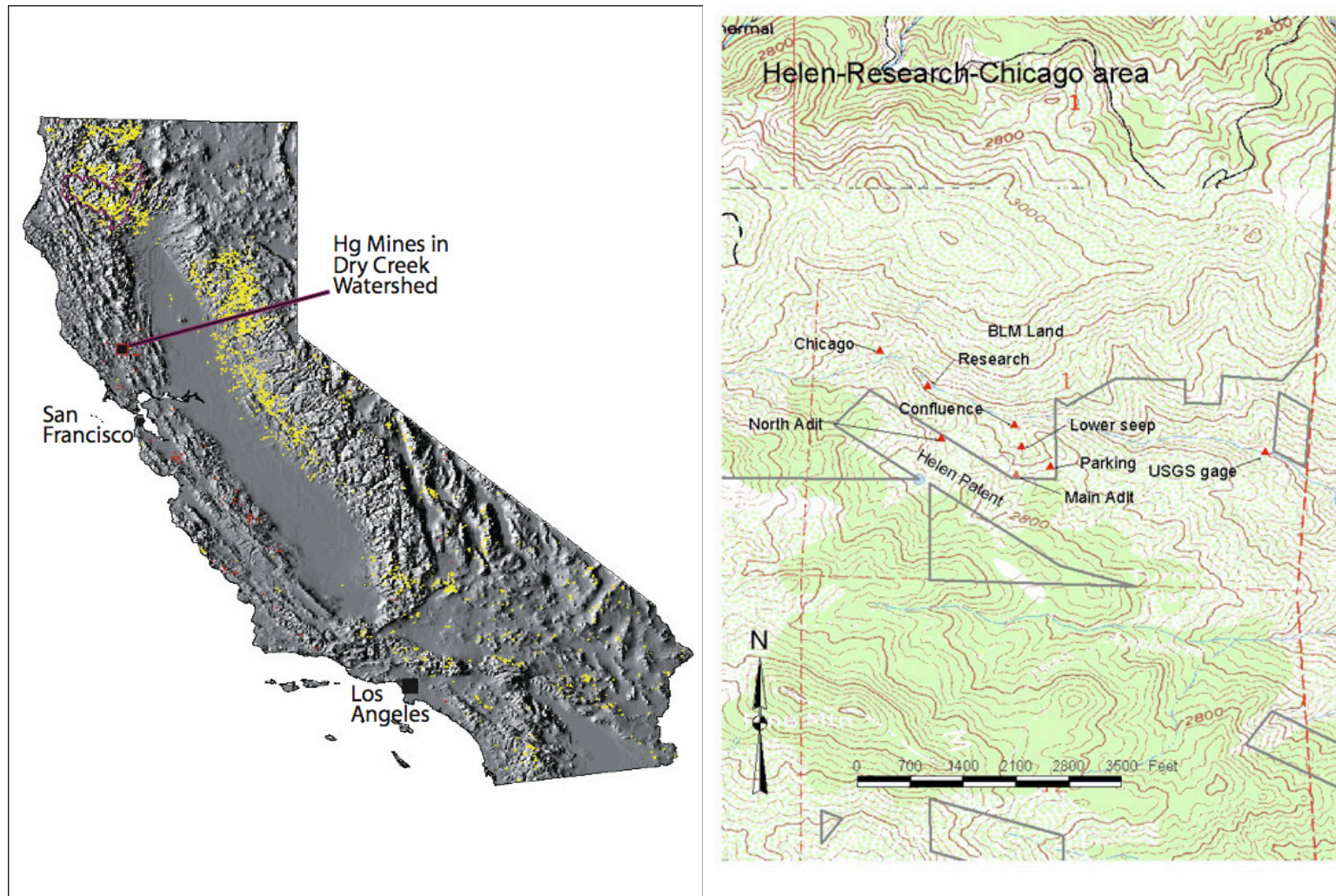


Figure 2. Location map and map of the upper part of Dry Creek showing location of the Helen, Research, and Chicago mercury mines.



Figure 3. Silica-carbonate alteration developed along the mineralize fault zone in serpentinite (barren slopes) at Chicago mercury mine in the upper part of Dry Creek.



Figure 4. Waste rock removed from underground mine workings at the Helen Mine.



Figure 5. Helen Mine adit mine drainage and iron oxyhydroxide precipitate (sample site 21HM1 and 23HM9C; Biota site HMT0).

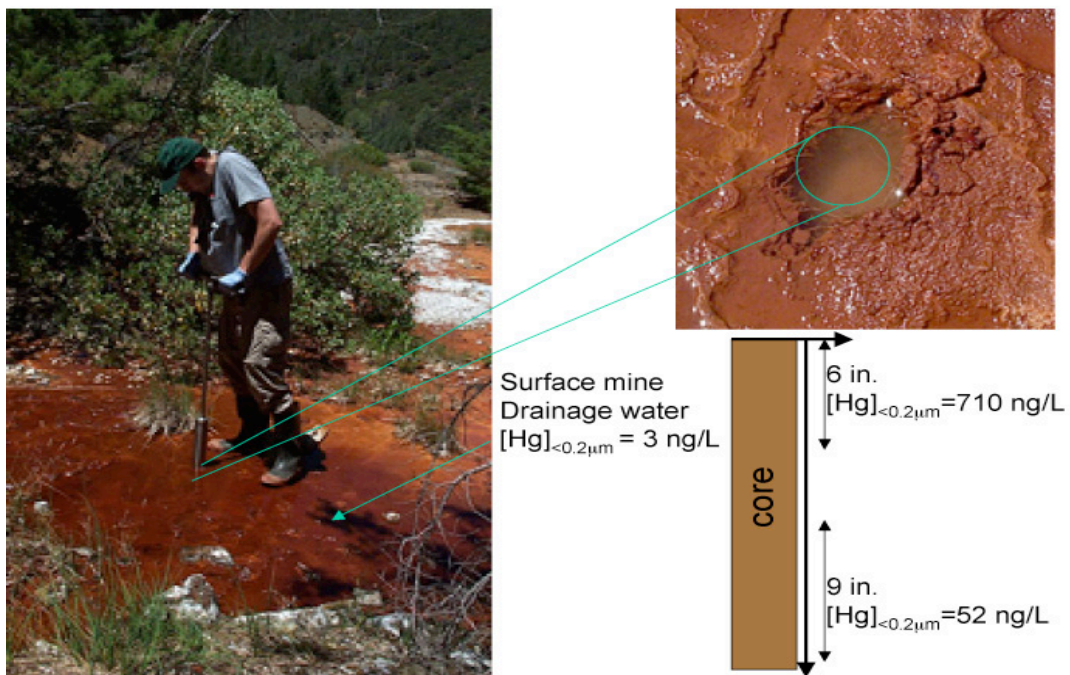


Figure 6. Helen mine drainage and FeOOH precipitate 100 feet from adit. Hg concentration in filtered surface water is 3 ng/L (sample HEL0703W3) and is much higher, 52-710 ng/L in filtered (<0.2μm) pore waters (samples HEL0703SED1A and 1B) taken from a core in the FeOOH sediment.



Figure 7. Mine drainage effluent channel in waste rock developed downstream from the Helen Mine.



Figure 8. Iron oxyhydroxide precipitate containing 550 ppm mercury precipitated from mine drainage effluent from the Helen Mine after waters have reacted with waste rock.



Figure 9. Lower mine drainage seep at Helen Mine at the base of the waste-rock pile sampled in April during the wet season (sample site 21HM2).



Figure 10. Helen tributary coated with FeOOH resulting from mine drainage from the Helen Mine area. The site is located just above the confluence with Dry Creek (sample sites 21HM3 and 23HM8).



Figure 11. Calcines from Helen Mine located below and west of waste-rock pile.



Figure 12. Remains of retort at Research Mine, located adjacent to the Dry Creek bank (foreground).



Figure 13. Research Mine calcines (21RE2C) below brick-retort remains adjacent to Dry Creek.



Figure 14. Research Mine drainage from collapsed adit (sites 21RE1 and 21RE1C) at Dry Creek.



Figure 15. Three furnaces at Research Mine, located above the south bank of Dry Creek.



Figure 16. Central furnace at Research Mine with ore feed (upper right) and gas collectors.



Figure 17. Chicago Mine remains of brick retort and pile of waste rock and calcines (sample sites for 21-CH-1C and 2C). The remains of the ore crib are located on the north bank of Dry Creek, which is shown in the lower right of the photo.



Figure 18. Calcines and condenser soot (sample sites 21-CH-4C, 450 ppm Hg,) below waste rock near ore crib (lower right in fig. 15) in north bank of Dry Creek at Chicago Mine area.

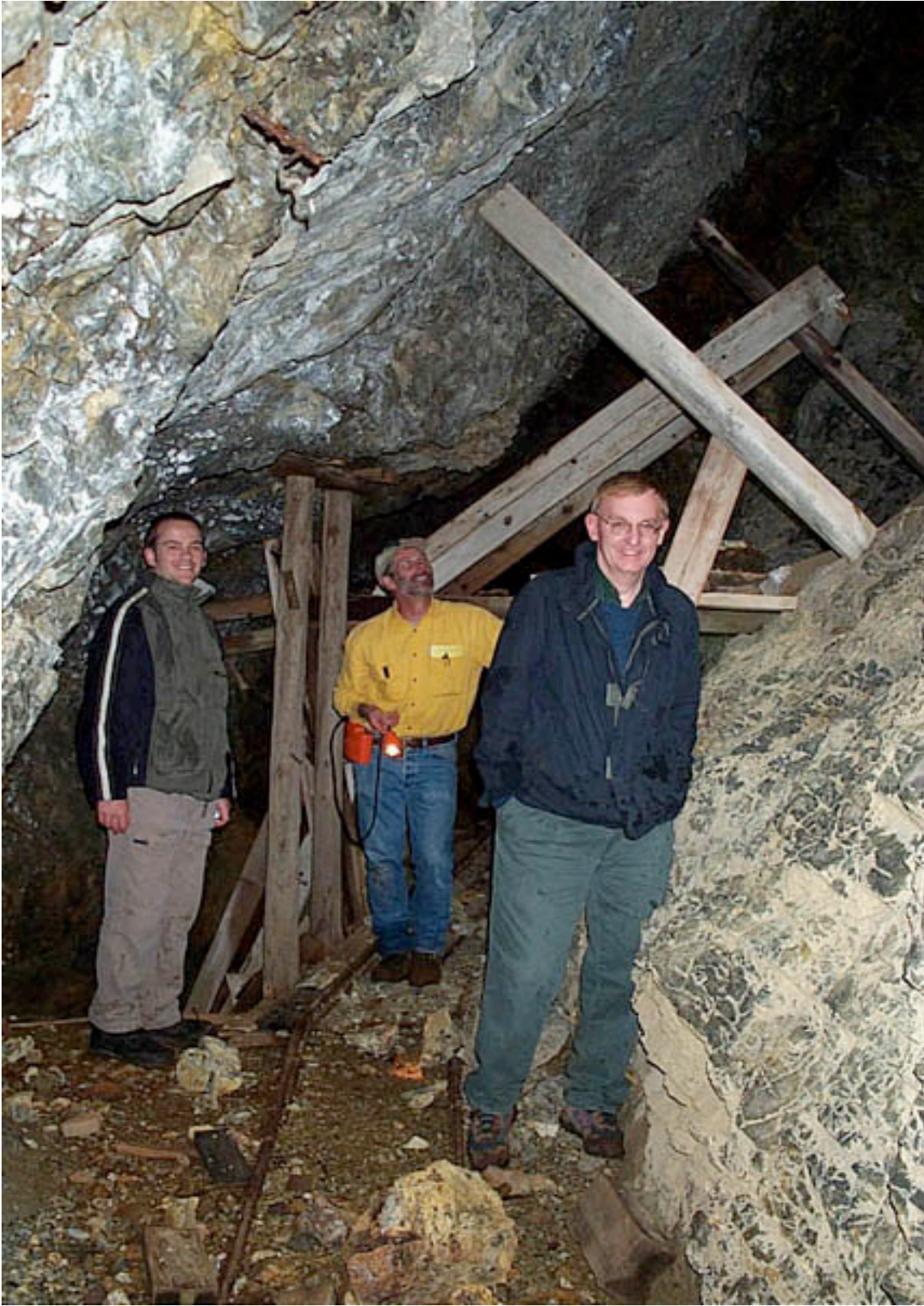


Figure 19. Underground stope at Chicago Mine developed along fault in serpentinite altered to silica carbonate rock consisting of calcite, magnesite, and quartz.



Figure 20. Dry Creek above confluence with unnamed creek from Helen Mine area during low-flow conditions on July 15, 2003 (sample site 23HM8; biota site DCAH).



Figure 21. Dry Creek below confluence with unnamed creek from Helen Mine area during low-flow conditions on July 15, 2003 (sample site 23HM6; biota site DCBH).

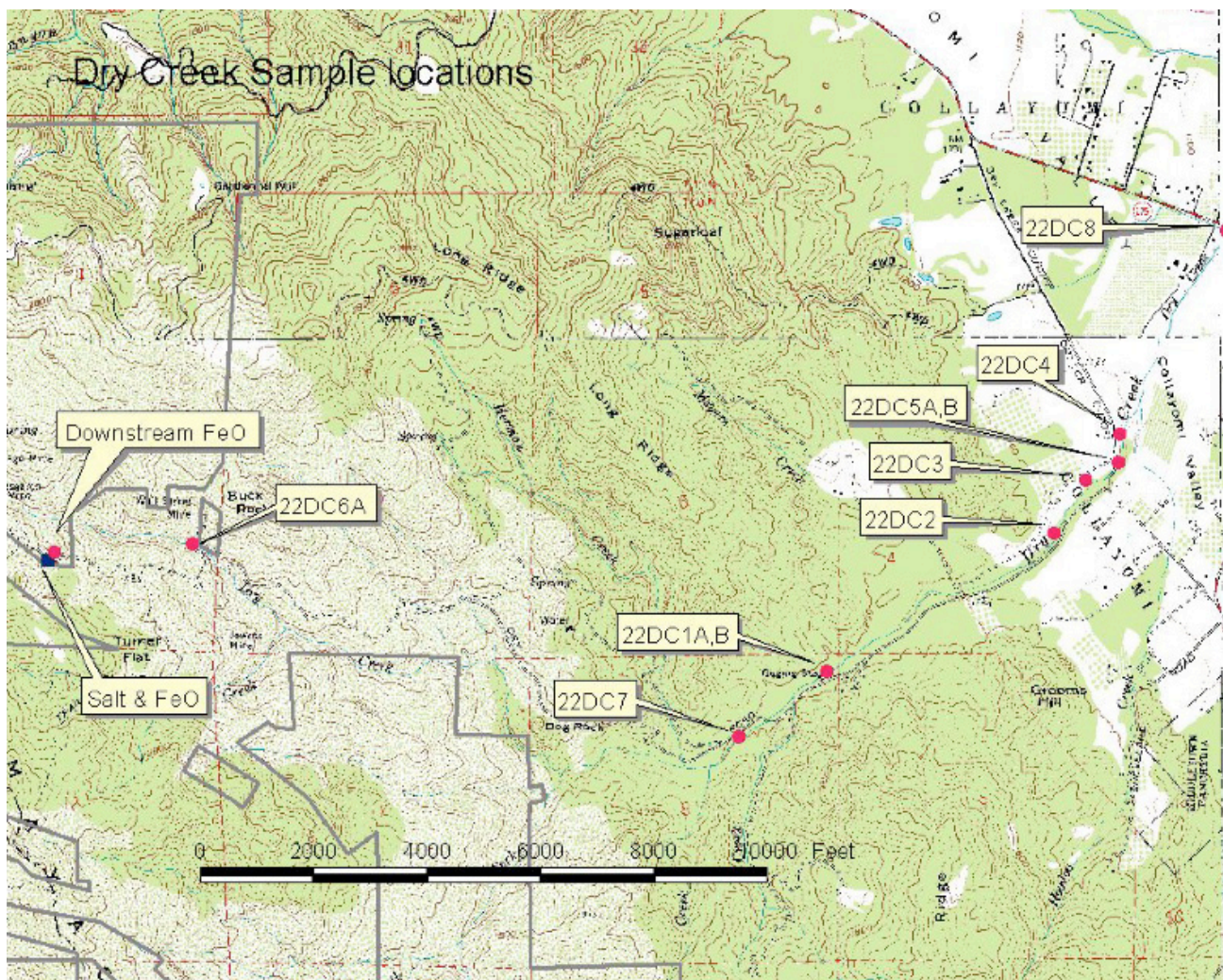


Figure 22. Map of sample sites in Dry Creek downstream from the Helen, Research, and Chicago mine sites.



Figure 23. Dry Creek 3 kilometers below Helen Mine at sample sites 23DC1 and 22DC2 (biota site LDCB).



Figure 24. Lower mine drainage seep at Helen Mine (as in fig. 8). The white, efflorescent salt along the margin was sampled in July during dry season (sample sites 23HM11 and HEL0703W4).

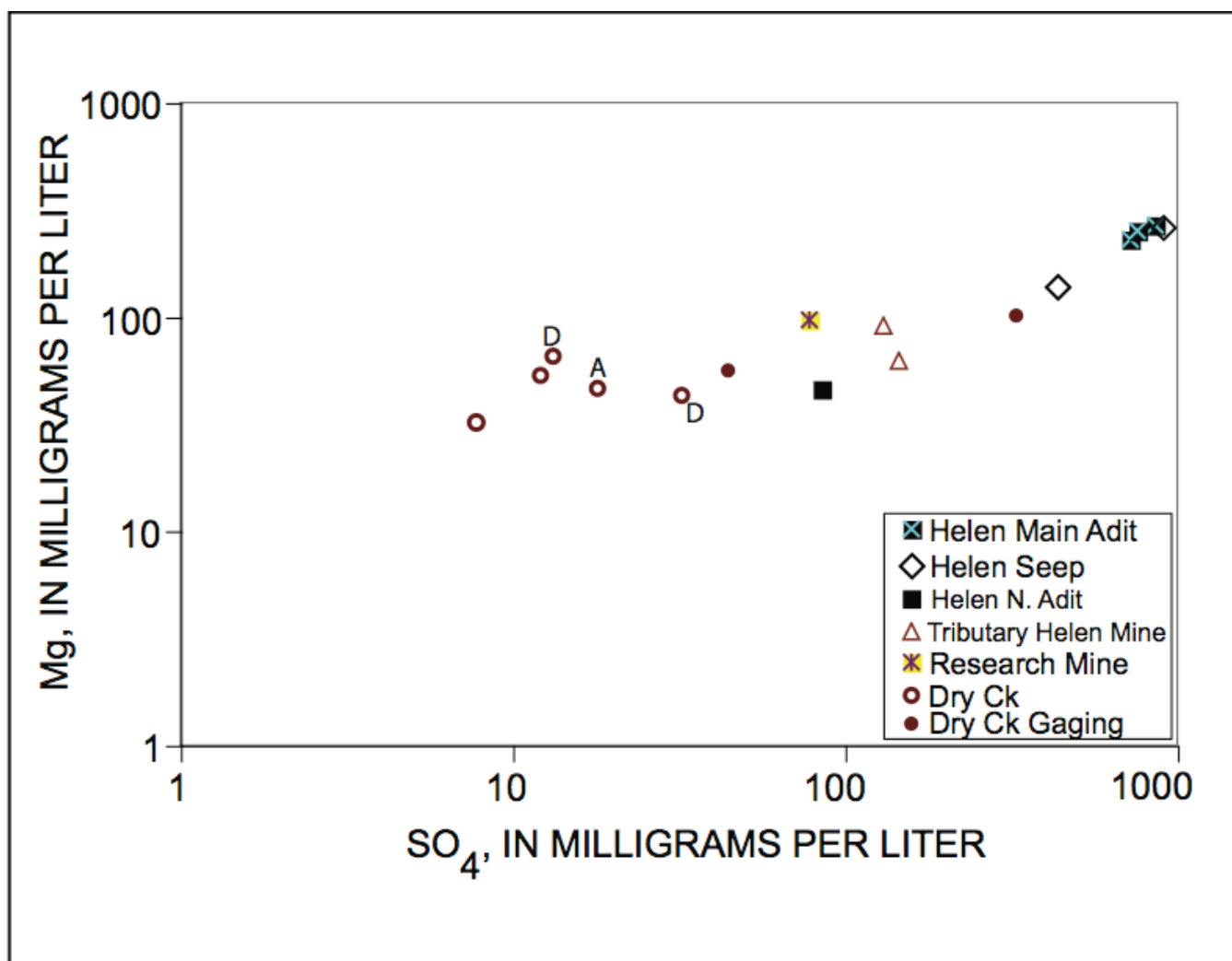


Figure 25. Log plot of Mg verses SO₄ in mine drainage from the Helen and Research mines and in waters in Dry Creek and the Helen Mine tributary to Dry Creek. The Helen Mine tributary is dominantly mine drainage effluent that is diluted by surface water. Dry Creek water downstream, noted by "D," from the confluence with the Helen Mine tributary has higher sulfate than water above the confluence, noted by "A." The sample point noted by "D" has a higher sulfate concentration than does point A, which was sampled during a higher flow regime.

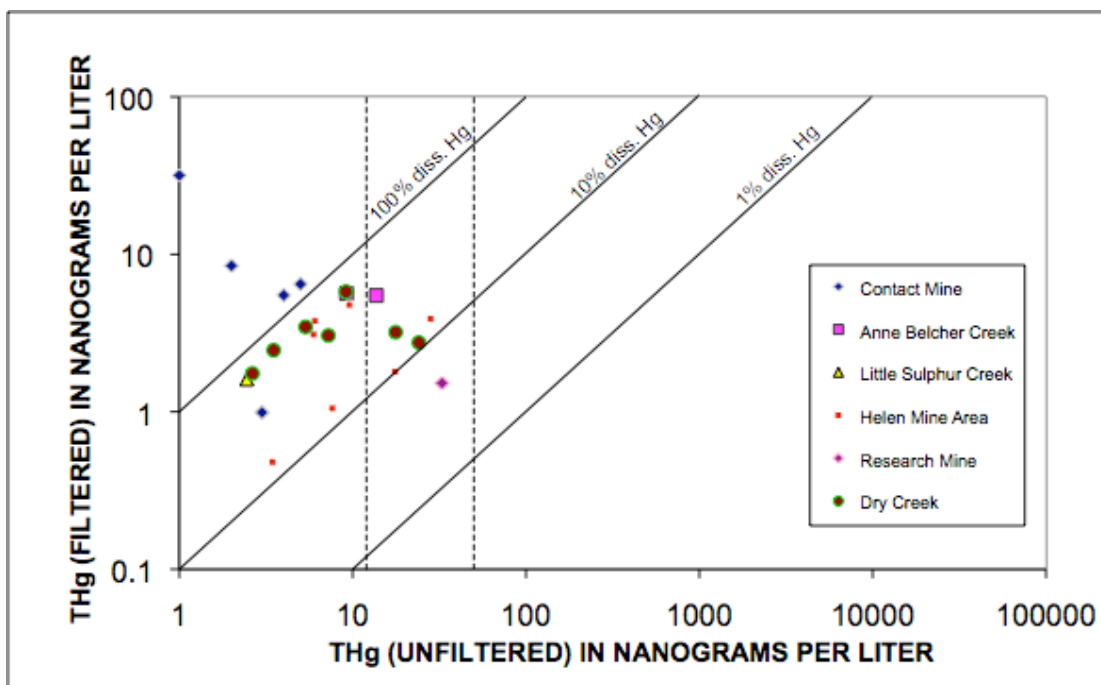


Figure 26. Log plot of dissolved Hg (filtered 0.45 mm) versus total Hg.

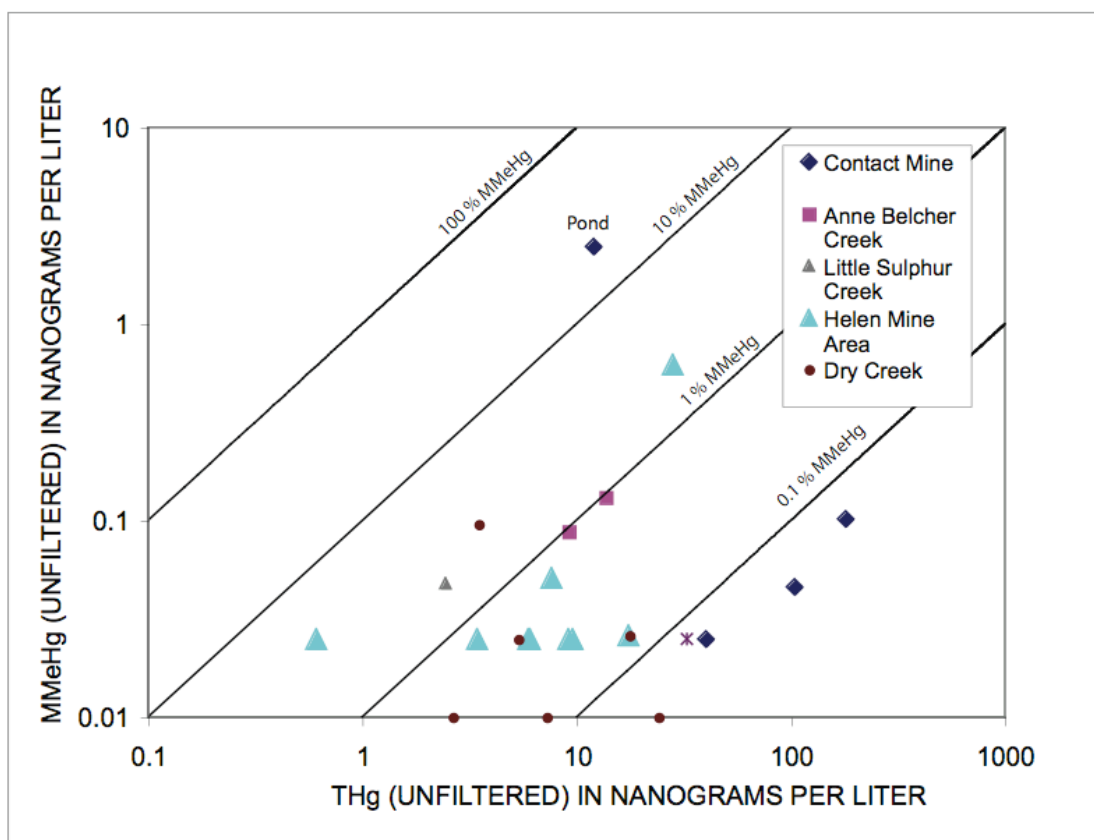


Figure 27. Log plot of total Hg versus total MMeHg.

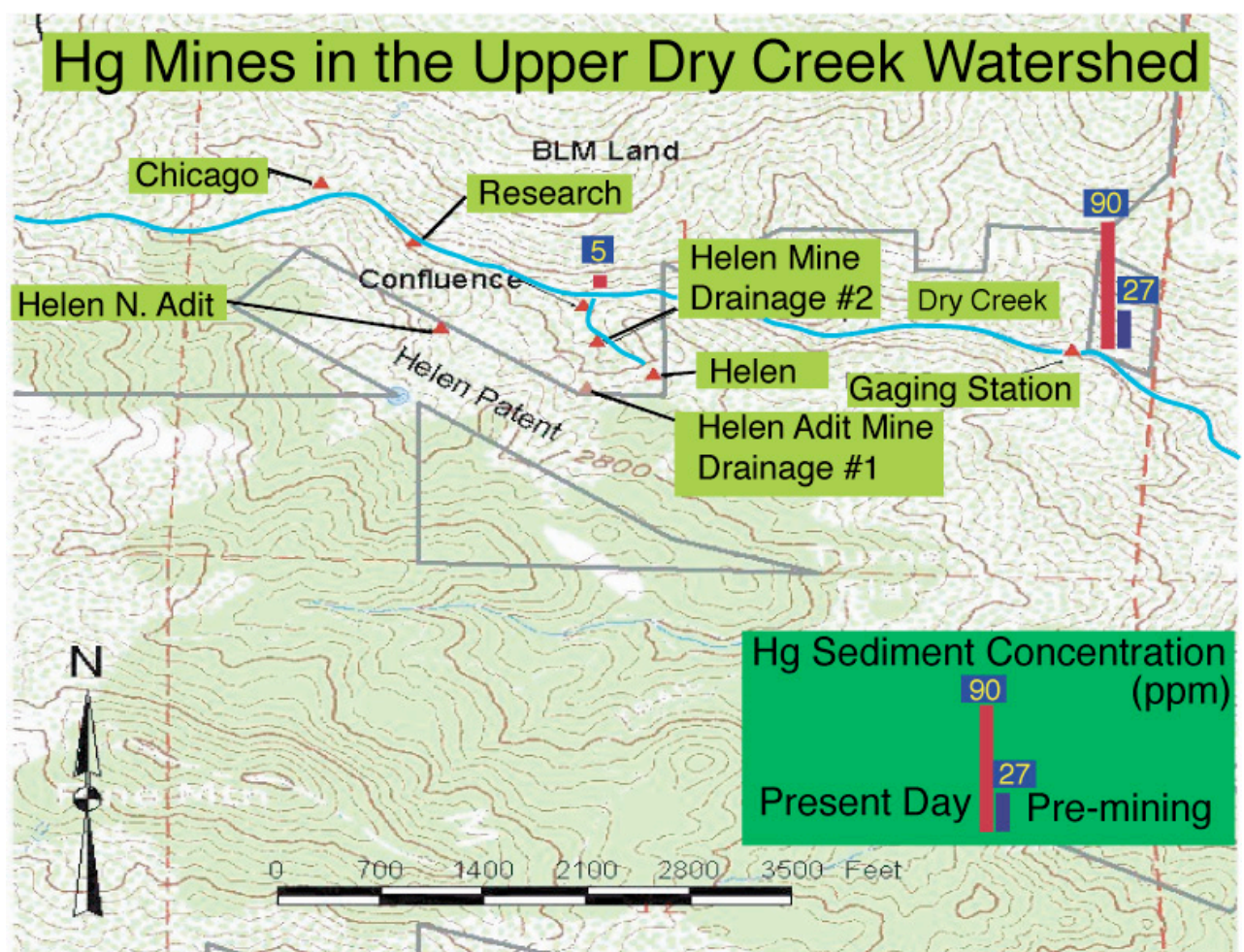


Figure 28. Hg concentration in pre-mining sediment exposed in the banks of Dry Creek and sediment in active channel downstream from the Helen, Research, and Chicago Mines (sample sites 22DC6A and B, table 4).

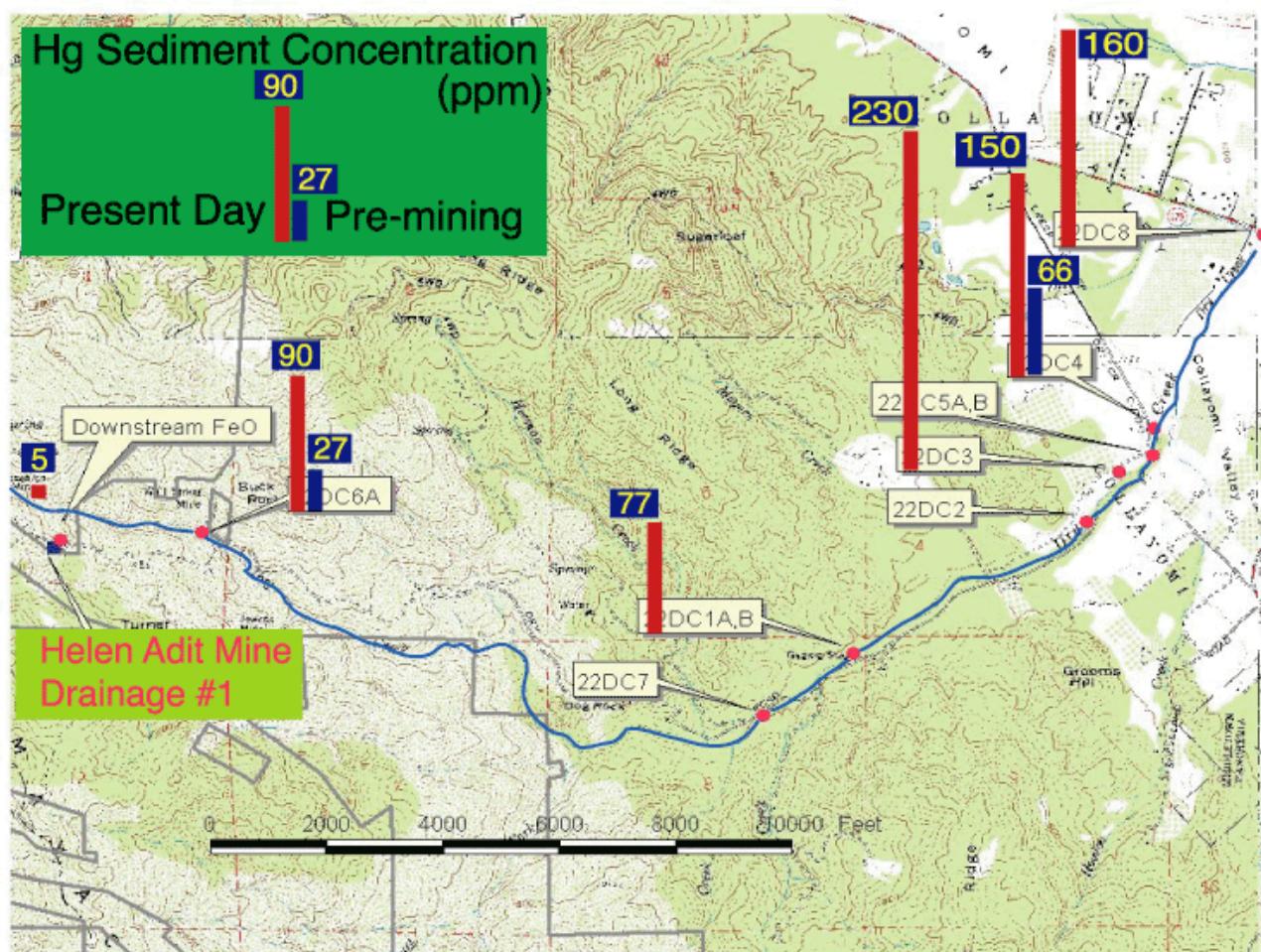


Figure 29. Hg concentration in pre-mining sediment exposed in banks of lower part of Dry Creek and sediment in active channel 4-5 km downstream from the Helen, Research, and Chicago mines.



Figure 30. Dry Creek downstream from Dry Creek road crossing with fine-grained sediment deposited from spring storm event. Insert image is of silt to medium sand deposited between boulder-armored stream channel having Hg concentration of 150 ppm (sample site 22DC 4A).



Figure 31. Pre-mining sediment exposed in the bank of Dry Creek having an elevated Hg concentration of 66 ppm (sample site 22DC4B near Dry Creek road crossing). Sediment in active channel having a much higher Hg concentration of 150 ppm (sample site 22DC4A).

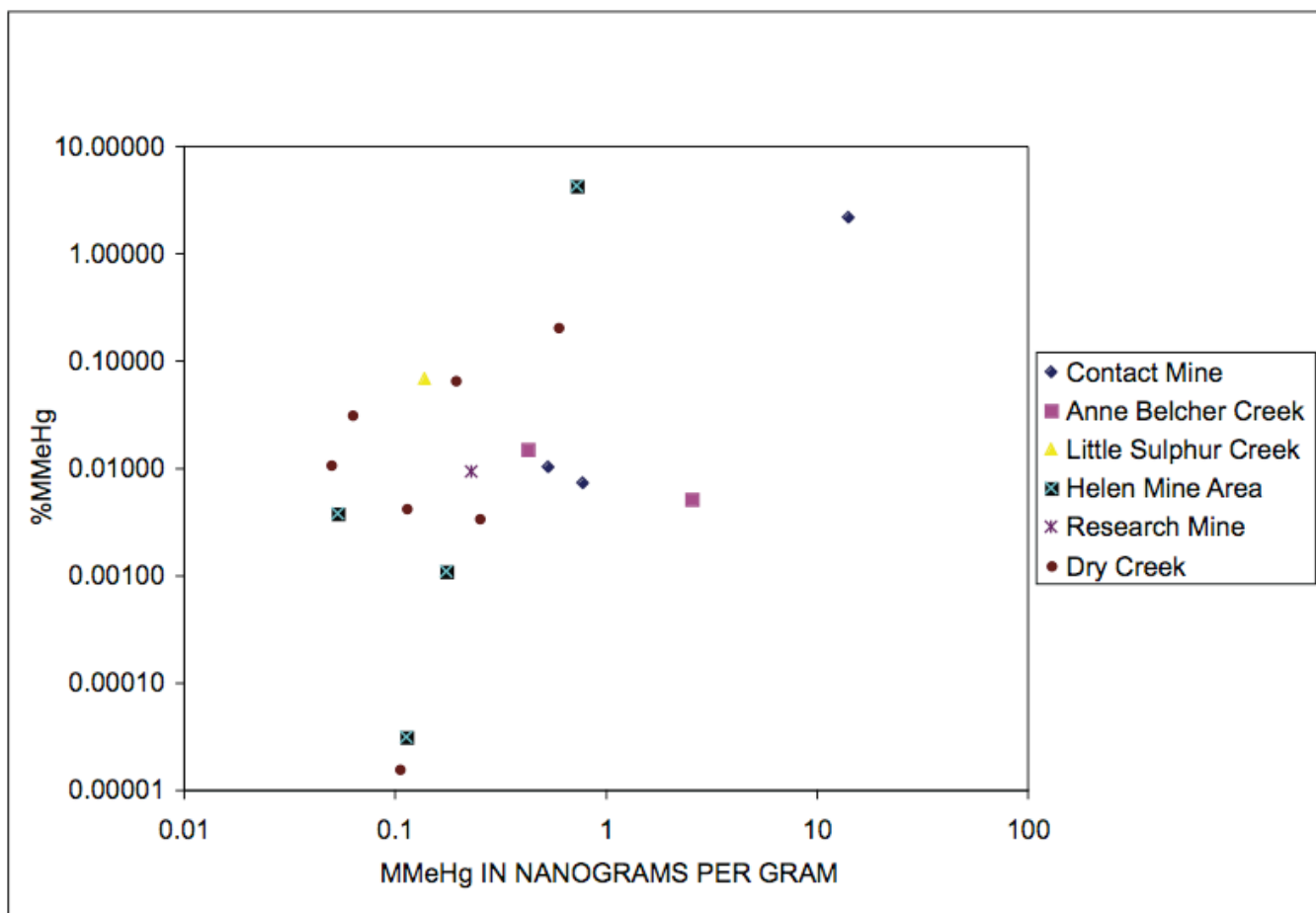


Figure 32. Log plot of % MMeHg versus MMeHg in sediment in Dry Creek and in the Anna Belcher and Little Sulphur Creek watersheds located 5 km to the west. In the Dry Creek watershed, the highest % MMeHg occurs in FeOOH-enriched sediment precipitated from drainage from the Helen Mine main adit.

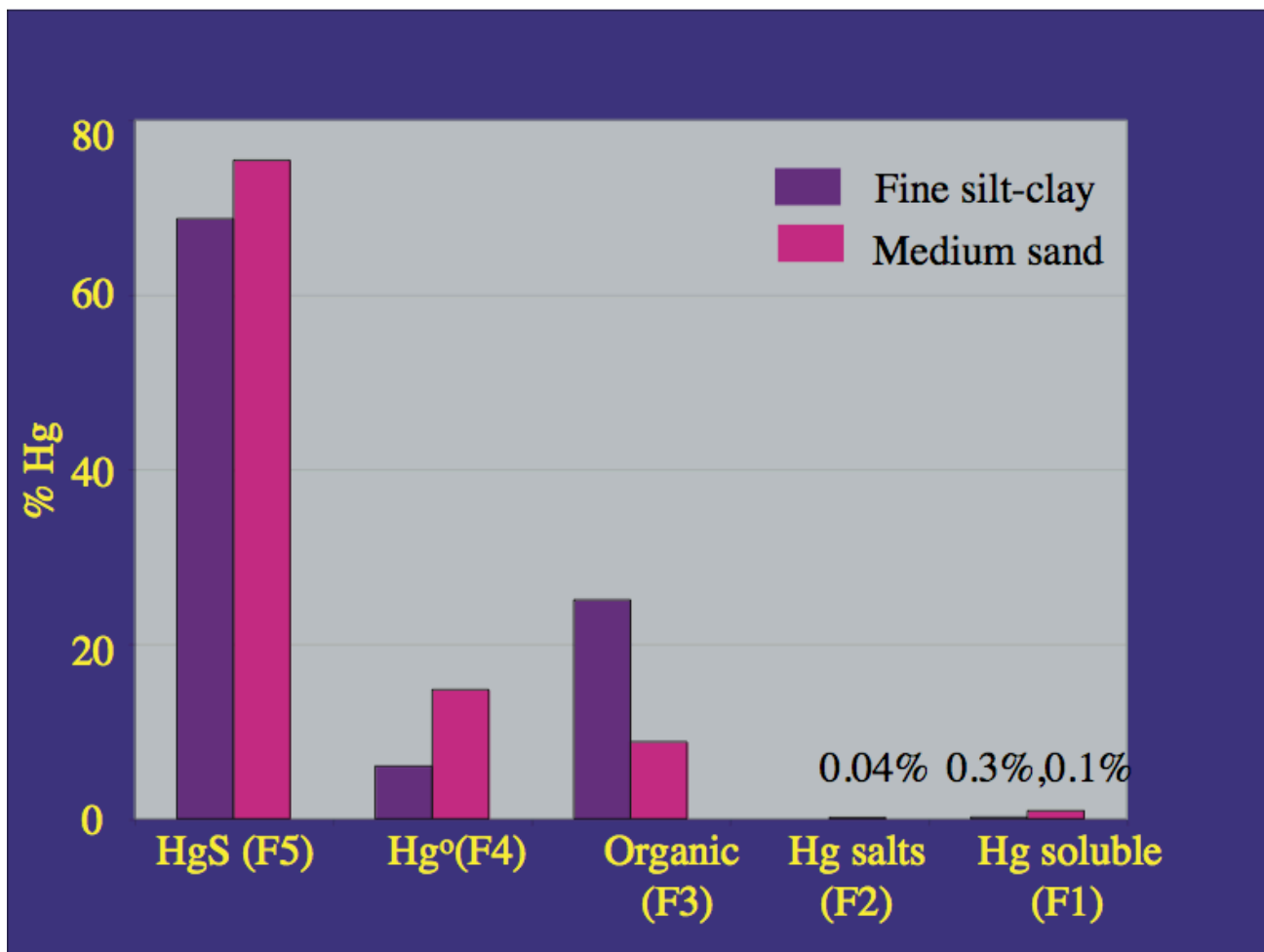


Figure 33. Speciation of Hg in Dry Creek sediment samples, collected 4 km downstream from the Helen Mine consisting of a clay-silt and a medium sand sample. Hg speciation determined by sequential chemical extraction indicates that most of the Hg is present as HgS (F5 fraction) with smaller amounts present as elemental Hg (F4 fraction) and Hg associated with organic matter.

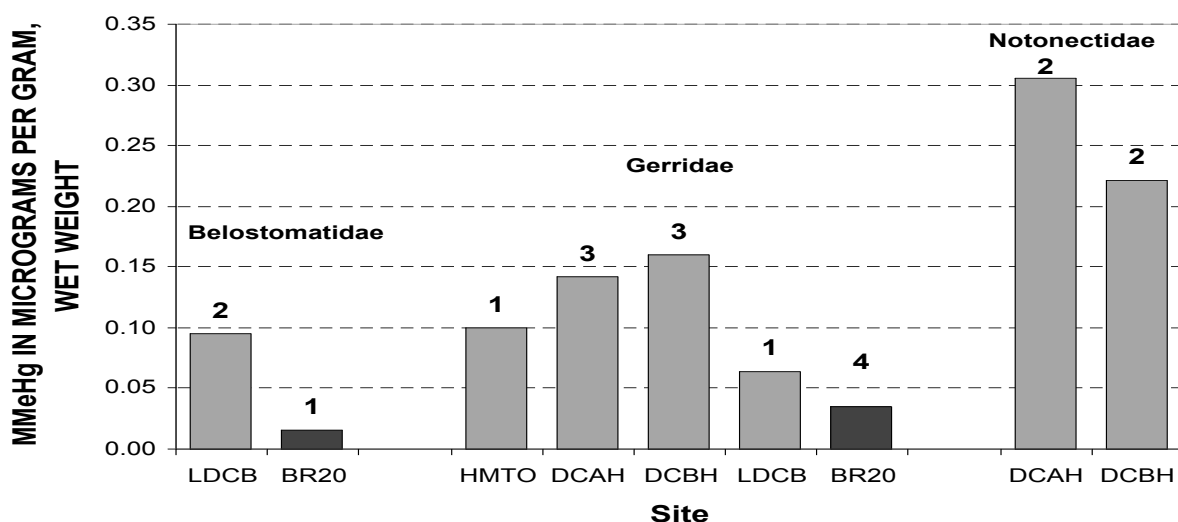


Figure 34. Geometric mean concentrations of monomethylmercury (MMeHg, $\mu\text{g/g}$, wet weight) in individual composite samples of invertebrates (order Hemiptera; families Belostomatidae, Gerridae, and Notonectidae) from the Dry Creek (LDCB, DCAH, DCBH) watershed in 2003, Helen Tributary (HMT0), and geometric mean concentrations of MMeHg in hemipterans, collected from a reference site, the Bear River at the Highway 20 Bridge (BR20), during 1999-2002. Number of samples noted above bar.

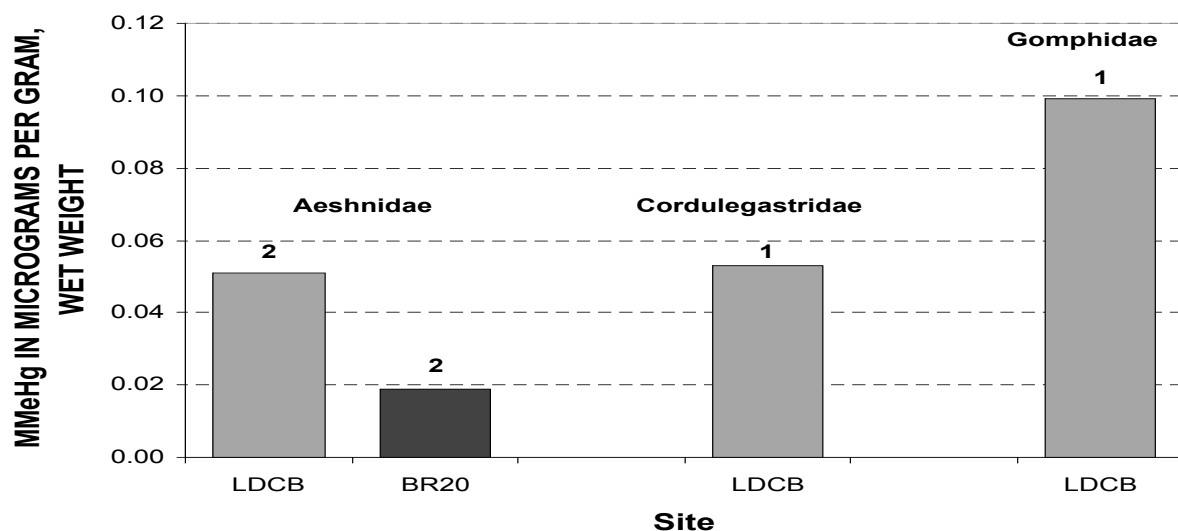


Figure 35. Geometric mean concentrations of monomethylmercury (MMeHg, $\mu\text{g/g}$, wet wt) in samples of dragonfly larvae (order Odonata; families Aeshnidae, Cordulegastridae, and Gomphidae) collected from the Dry Creek watershed in 2003 and the geometric mean of MMeHg in Aeshnidae, collected from a reference site, the Bear River at the Highway 20 Bridge (BR20) during 1999-2002. Number of samples noted above bar.

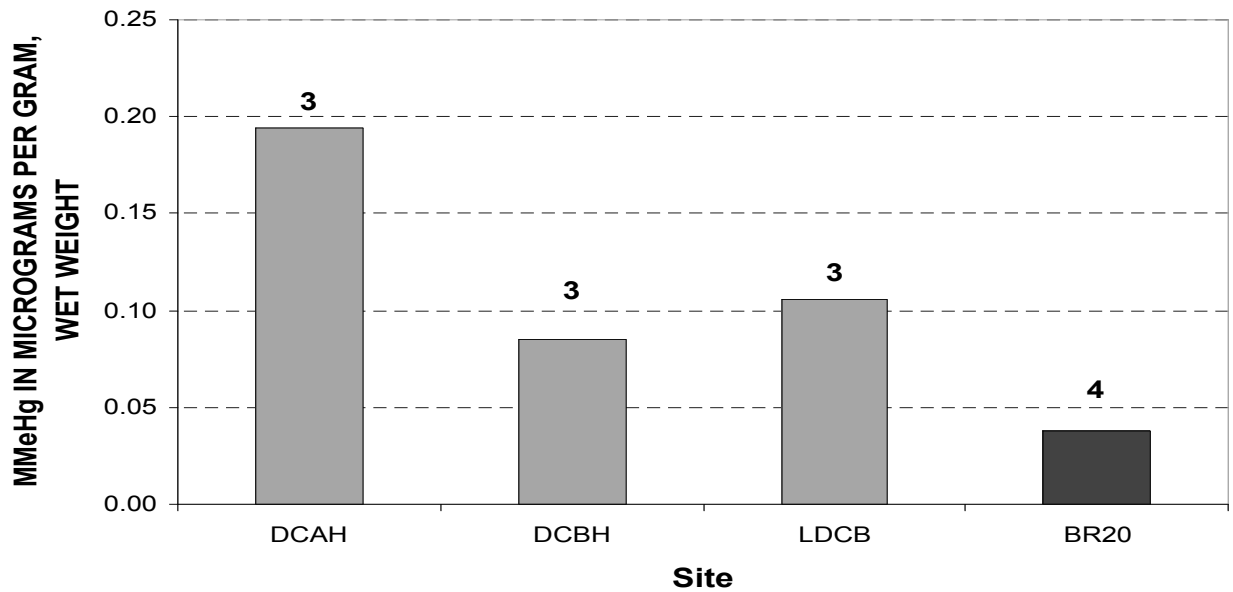


Figure 36. Geometric mean concentrations of monomethylmercury (MMeHg, $\mu\text{g/g}$, wet wt) in composite samples of Dobsonflies (order Megaloptera, family Corydalidae) from Dry Creek in 2003 and from a reference site, the Bear River at the Highway 20 Bridge (BR20) during 1999-2002. Number of samples noted above bar.

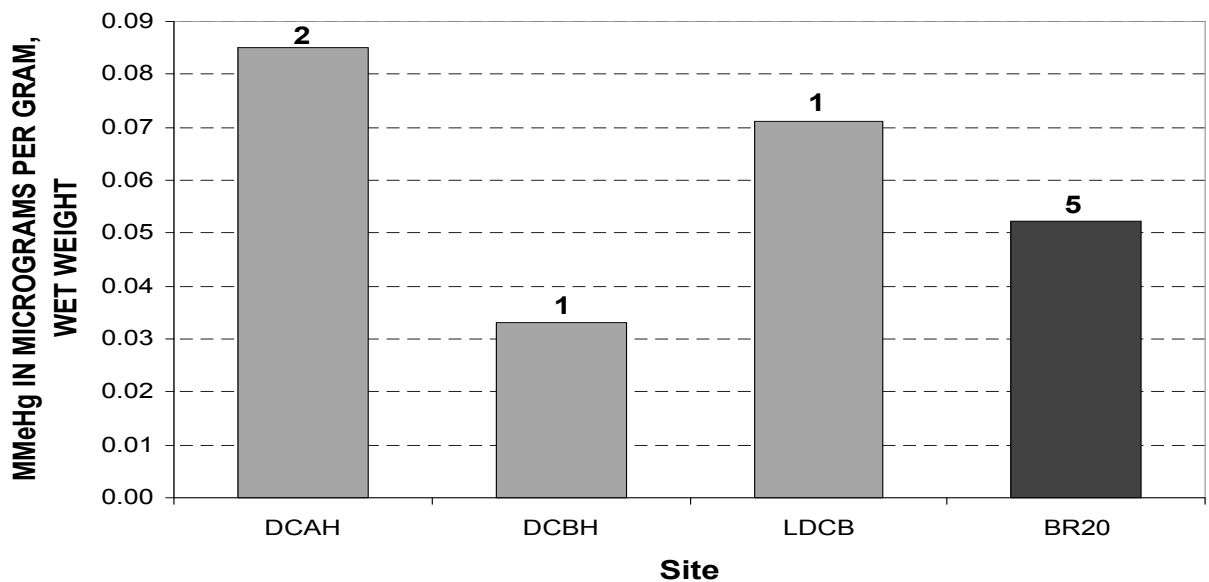


Figure 37. Monomethylmercury (MMeHg, $\mu\text{g/g}$, wet wt) in individual composite samples of larval stoneflies (order Plecoptera, family Perlidae) from Dry Creek in 2003 and geometric mean concentrations of MMeHg in larval stoneflies from a reference site, the Bear River at the Highway 20 Bridge (BR20) during 1999-2002. Number of sample noted above bar.

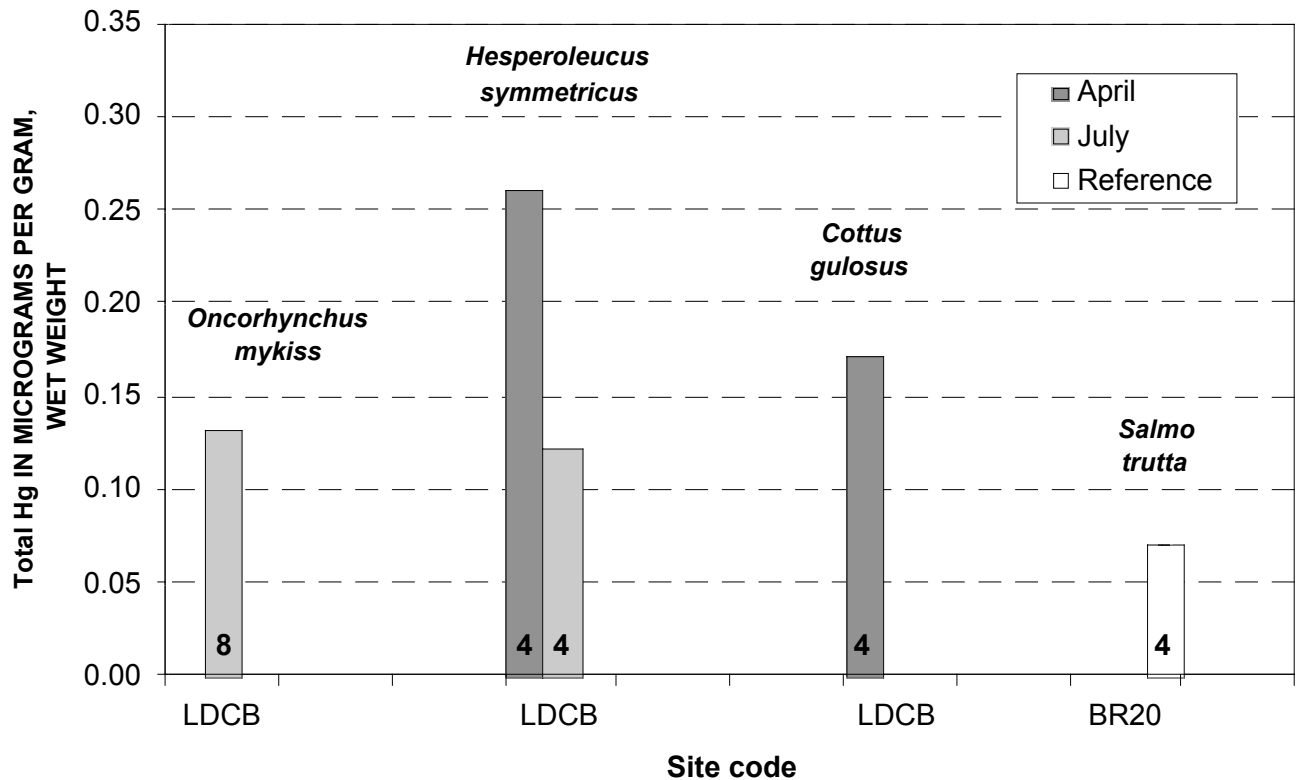


Figure 38. Geometric mean concentrations of total mercury (Hg_T , $\mu g/g$, wet wt) in individual fish whole bodies collected from Dry Creek in April and July of 2003 and in fillets of brown trout (*Salmo trutta*) from a reference site, the Bear River at the Highway 20 Bridge (BR20), in 1999. Number of samples noted within bar.

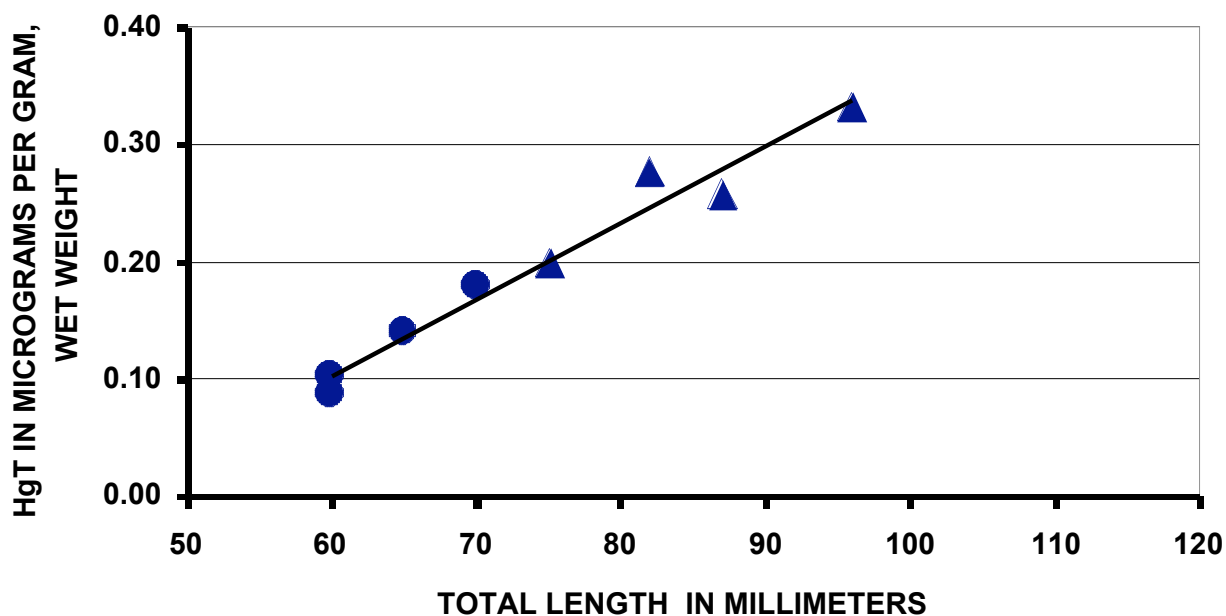


Figure 39. Correlation between concentrations of total mercury (Hg_T, μg/g, wet wt) in individual whole bodies and total length (mm) of California roach collected from Dry Creek (LDCB) in April (1) and July (15) of 2003. R² is 0.97 and P < 0.001.