B

Previous Investigations, Helen Mine, Lake County

Prepared in cooperation with the Bureau of Land Management

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

By James J. Rytuba, Roger L. Hothem, Jason T. May, Christopher S. Kim, David Lawler, Daniel Goldstein, and Brianne E. Brussee

Open-File Report 2008-1382

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

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia 2009

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Rytuba, J.J., Hothem, R.L., May, J.T., Kim, C.S., Lawler, D., Goldstein, D., and Brussee, B.E., 2009, Environmental impact of the Helen, Research, and Chicago mercury mines on water, sediment, and biota in upper Dry Creek watershed, Lake County, California: U.S. Geological Survey Open-File Report 2008-1382, 59 p. [http://pubs.usgs.gov/of/2008/1382/].

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Contents

Abbreviations, definitions, and datum used vii
Introduction 1
  Background and objectives 1
Mining History and Geology 2
  Helen Mine 2
  Research Mine 3
  Chicago Mine 3
Sample Locations and Methods 3
  Sample Locations and Conditions 3
  Field Sampling Methods 4
    Dry Sediments and Tailings 4
    Wet Sediments and Tailings 4
    Water 4
    Invertebrates 5
    Fish 5
Analytical Methods 6
  Sediments and Tailings 6
  Waters 6
  Biota 7
  Quality Assurance/Quality Control for Biota 7
Results 8
  Tailings at the Helen, Research, and Chicago Mine Areas 8
  Hg and Associated Elements in Mine Drainage and Dry Creek Waters 8
  Sediment in Dry Creek at and below the Helen and Research Mines 10
  Biota 11
    Invertebrates 11
    Fish 12
Conclusions 13
Acknowledgments 14
References 14

Figures

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. 31
Figure 2. Location map and map of the upper part of Dry Creek showing location of the Helen, Research, and Chicago mercury mines. 32
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. 33
Figure 4. Waste rock removed from underground mine workings at the Helen Mine. 33
Figure 5. Helen Mine adit mine drainage and iron oxyhydroxide precipitate (sample site 21HM1 and 23HM9C; Biota site HMTO). 34

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 (<0.2 m) pore waters (samples HEL0703SED1A and 1B) taken from a core in the FeOOH sediment....34
Figure 7. Mine drainage effluent channel in waste rock developed downstream from the Helen Mine. .35
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....35
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)....36
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). 36
Figure 11. Calcines from Helen Mine located below and west of waste-rock pile....37
Figure 12. Remains of retort at Research Mine, located adjacent to the Dry Creek bank (foreground). ..38
Figure 13. Research Mine calcines (21RE2C) below brick-retort remains adjacent to Dry Creek....39
Figure 14. Research Mine drainage from collapsed adit (sites 21RE1 and 21RE1C) at Dry Creek. 40
Figure 15. Three furnaces at Research Mine, located above the south bank of Dry Creek....40
Figure 16. Central furnace at Research Mine with ore feed (upper right) and gas collectors. 41
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....42
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. 43
Figure 19. Underground stope at Chicago Mine developed along fault in serpentinite altered to silica carbonate rock consisting of calcite, magnesite, and quartz....44
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)....45
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)....45
Figure 22. Map of sample sites in Dry Creek downstream from the Helen, Research, and Chicago mine sites....46
Figure 23. Dry Creek 3 kilometers below Helen Mine at sample sites 23DC1 and 22DC2 (biota site LDCB). 47
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 23HM11and HEL0703W4). 47
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. 48
Figure 26. Log plot of dissolved Hg (filtered 0.45 mm) versus total Hg....49
Figure 27. Log plot of total Hg versus total MMeHg. 49

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). 50
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.....51
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). 52
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). 53
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. 54
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. 55
Figure 34. Geometric mean concentrations of monomethylmercury (MMeHg, 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 (HMTO), 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. 56
Figure 35. Geometric mean concentrations of monomethylmercury (MMeHg, 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. 56
Figure 36. Geometric mean concentrations of monomethylmercury (MMeHg, 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. 57
Figure 37. Monomethylmercury (MMeHg, 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. 57
Figure 38. Geometric mean concentrations of total mercury (Hg_T, 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.....58

Figure 39. Correlation between concentrations of total mercury (Hg_T, g/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. R^2 is 0.97 and $P < 0.001$.....59

Tables

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. 16
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.....17
Table 3. Mercury (Hg) and monomethylmercury (MMeHg) concentrations in waters and sediment at Helen and Research mines, and Dry Creek.....22
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.....23
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. 24
Table 6. Total mercury (Hg_T) and monomethyl mercury (MMeHg; g/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.....25
Table 7. Total mercury (HgT) (g/g, wet weight) in fish collected at Dry Creek in 2003.....28
Table 8. Major and minor element concentration in filtered waters from the Helen and Research mine areas and Dry Creek. 29
Table 9. Major and minor element concentration in unfiltered waters from the Helen and Research mine areas and Dry Creek. 30

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 m or 0.45 m, as specified in the text).

MMHg, monomethyl mercury, methylmercury, and monomethylmercury (CH_3Hg^+)

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).

This page intentionally left blank

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

By James J. Rytuba[1], Roger L. Hothem[2], Jason T. May[3], Christopher S. Kim[4], David Lawler[5], Daniel Goldstein[1], and Brianne E. Brussee[2]

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.

[1]U.S. Geological Survey, Menlo Park, California.
[2]U.S. Geological Survey, Dixon, California.
[3]U.S. Geological Survey, Sacramento, California
[4]Chapman University, Orange, California
[5]U.S. Bureau of Land Management, Sacramento, California

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 21HM1and 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 4ºC, which is within the limits specified in USEPA Method 1631E.

Wet Sediments and Tailings

Wet sediment and tailings samples were collected in Certified Teflon™-sealed I-CHEM™ 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 HNO_3 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 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 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 ICHEM) 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 4º 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 ($SnCl_2$) 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 $CaCO_3$ was determined in the laboratory by titration with H_2SO_4 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 Teflon™ 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-Teflon™ 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°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:

% MMeHg = 100*(MMeHg in ng/g in sediment)/(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 µg/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.

Acknowledgments

The authors thank David Kelly for assistance with field work and data analyses. Funding for the project was provided by the U.S. Bureau of Land Management.

References

Bloom, N.S., 1989, Determination of picogram levels of methylmercury by aqueous phase ethylation, followed by cryogenic gas chromatography with cold vapour atomic fluorescence detection: Canadian Journal of Fisheries and Aquatic Sciences, v. 46, p. 1131-1140.

Bloom, N.S., 1995, Mercury as a case study of ultra-clean sample handling and storage in aquatic trace metal research: Environmental Laboratory, v. 3-4, p. 20-25.

Bloom, N.S., Crecelius, E.A., and Fitzgerald, W.F., 1988, Determination of volatile mercury species at the picogram level by low temperature gas chromatography with cold vapor atomic fluorescence detection: Analytica Chimica Acta, v. 208, p. 151-161.

Crock, J.G., 1996, Mercury-Chapter 29 *in* Sparks, D.L., ed., Methods of soil analysis, part 3, chemical methods: Soil Science Society of America Book Series, Number 5, p. 769-791.

Drott, A., Lambertsson, L., Björn, E., and Skyllberg, U., 2008, Do potential methylation rates reflect accumulated methyl mercury in contaminated sediments?: Environmental Science and Technology, v.42, no.1, p.153-158

Fishman, M.J. and Pyen, G., 1979, Determination of selected anions in water by ion chromatography: United States Geological Survey Water Resources Investigation 79-101, 30 p.

Gill, G.A. and Fitzgerald, W.F., 1987, Picomolar mercury measurements in seawater and other materials using stannous chloride reduction and two-stage gold amalgamation with gas phase detection: Marine Chemistry, v. 20, p. 227-243.

Horvat, M., Bloom, N.S., and Liang, L., 1993, Comparison of distillation with other current isolation methods for the determination of methyl mercury compounds in low level environmental samples; part 1, sediments: Analytica Chimica Acta, v. 281, p. 135-152.

May, J.T., Hothem, R.L., Alpers, C.N., and Law, M.A., 2000, Mercury bioaccumulation in fish in a region affected by historic gold mining: the South Yuba River, Deer Creek, and Bear River Watersheds, California, 1999, United States Geological Survey Open-File Report 00-367, 35 p. [http://ca.water.usgs.gov/archive/reports/ofr00367, last accessed January 28, 2009].

National Research Council of Canada Institute for National Measurement Standards, 1999, DORM-2, DOLT-2, Dogfish muscle and liver certified reference materials for trace metals: INMS Certified Reference Materials Data Sheet 4 p. [http://www.ems.nrc.ca/ems1.htm., last accessed January 28, 2009].

O'Leary, R.M., Hageman, P.L., and Crock, J.G., 1996, Determination of mercury in water, geologic, and plant materials by continuous flow-cold vapor-atomic absorption spectrophotometry, *in* Arbogast B.F., ed., Quality assurance manual for the branch of geochemistry, United States Geological Survey: U.S. Geological Survey Open-File Report 96-525, p. 42-55.

Orion Research, Inc., 1978, Analytical methods guide (9th ed.): Cambridge, Mass., 48 p.

Rytuba, J.J., Hothem, R.L., May, J.T., Kim, C.S., Lawler, D., and Goldstein, D., 2009, Environmental impact of the Contact and Sonoma mercury mines on water, sediment, and biota in Anna Belcher and Little Sulphur Creek watersheds, Sonoma County, California: U.S. Geological Survey Open-File Report 2008-1381, 76 p. [http://pubs.usgs.gov/of/2008/1381/].

U.S. Bureau of Mines, 1965. Mercury potential of the United States: U.S. Department of the Interior, Bureau of Mines, Information Circular 8252, 376 p.

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1-A9. [http://pubs.water.usgs.gov/twri9A, last accessed January 28, 2009].

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 pp
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
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
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

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"
HMTO	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)	Hg_T μg/g (wet weight)	Moisture (percent)
CR-LDCB-040203-001F	LDCB	4/2/2003	riffle sculpin	Cottus gulosus	50	1.63	0.133	75.1
CR-LDCB-040203-002F	LDCB	4/2/2003	riffle sculpin	*Cottus gulosus*	55	2.43	0.106	72.2
CR-LDCB-040203-003F	LDCB	4/2/2003	riffle sculpin	*Cottus gulosus*	64	3.26	0.240	72.2
CR-LDCB-040203-004F	LDCB	4/2/2003	riffle sculpin	*Cottus gulosus*	73	4.97	0.266	73.9
CR-LDCB-040203-005F	LDCB	4/2/2003	California roach	*Hesperoleucus symmetricus*	75	3.84	0.199	77.5
CR-LDCB-040203-006F	LDCB	4/2/2003	California roach	*Hesperoleucus symmetricus*	82	5.18	0.277	76.1
CR-LDCB-040203-007F	LDCB	4/2/2003	California roach	*Hesperoleucus symmetricus*	87	6.07	0.259	78.1
CR-LDCB-040203-008F	LDCB	4/2/2003	California roach	*Hesperoleucus symmetricus*	96	8.70	0.332	74.3
CR-LDCB-071503-001F	LDCB	7/15/2003	California roach	*Hesperoleucus symmetricus*	70	3.36	0.180	78.5
CR-LDCB-071503-002F	LDCB	7/15/2003	California roach	*Hesperoleucus symmetricus*	65	2.44	0.141	82.7
CR-LDCB-071503-003F	LDCB	7/15/2003	California roach	*Hesperoleucus symmetricus*	60	1.81	0.087	81.0
CR-LDCB-071503-004F	LDCB	7/15/2003	California roach	*Hesperoleucus symmetricus*	60	1.82	0.104	82.2
CR-LDCB-071503-005F	LDCB	7/15/2003	rainbow trout	*Oncorhynchus mykiss*	90	7.14	0.127	76.1
CR-LDCB-071503-006F	LDCB	7/15/2003	rainbow trout	*Oncorhynchus mykiss*	76	4.14	0.135	75.5
CR-LDCB-071503-007F	LDCB	7/15/2003	rainbow trout	*Oncorhynchus mykiss*	70	3.45	0.116	78.2
CR-LDCB-071503-008F	LDCB	7/15/2003	rainbow trout	*Oncorhynchus mykiss*	70	3.38	0.147	76.0
CR-LDCB-071503-009F	LDCB	7/15/2003	rainbow trout	*Oncorhynchus mykiss*	66	2.93	0.145	74.2
CR-LDCB-071503-010F	LDCB	7/15/2003	rainbow trout	*Oncorhynchus mykiss*	69	2.97	0.145	80.2
CR-LDCB-071503-011F	LDCB	7/15/2003	rainbow trout	*Oncorhynchus mykiss*	66	2.62	0.101	83.7
CR-LDCB-071503-012F	LDCB	7/15/2003	rainbow trout	*Oncorhynchus mykiss*	57	1.71	0.149	74.9
R-075	BR20	8/25/1995	Brown trout	*Salmo trutta*	230	118	0.063	80.2
R-076	BR20	8/25/1995	Brown trout	*Salmo trutta*	255	177	0.050	75.4
R-077	BR20	8/25/1995	Brown trout	*Salmo trutta*	265	180	0.082	76.3
F-029	BR20	8/25/1995	Brown trout	*Salmo trutta*	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 (<.006), Ga (<0.04), Gd (<0.03), Ge (<0.05),Ho (<0.005), In (<.01), La (<.3), Pb (<0.2), Pr (<0.04), Re (<.02), Sb (<0.3), Se (<.27), Sm (<0.023), Tb (<0.005), Th (<0.6), Tl (<0.1), Tm (<0.005).

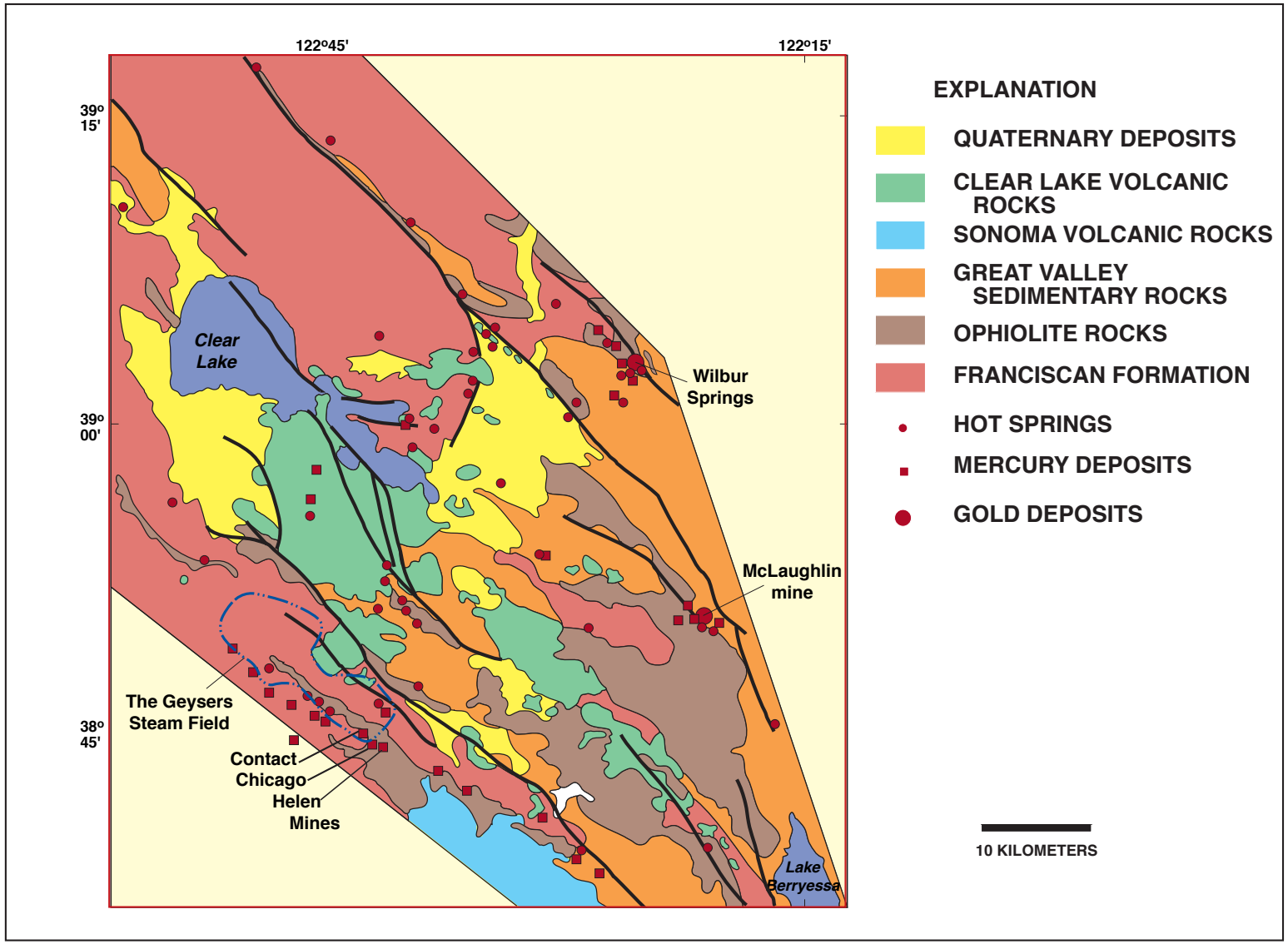


Figure 1. Geologic map of the Clear Lake volcanic field and location of the Helen, Chicago, and Contact mercury mines, Dry Creek watershed, Lake County, California.

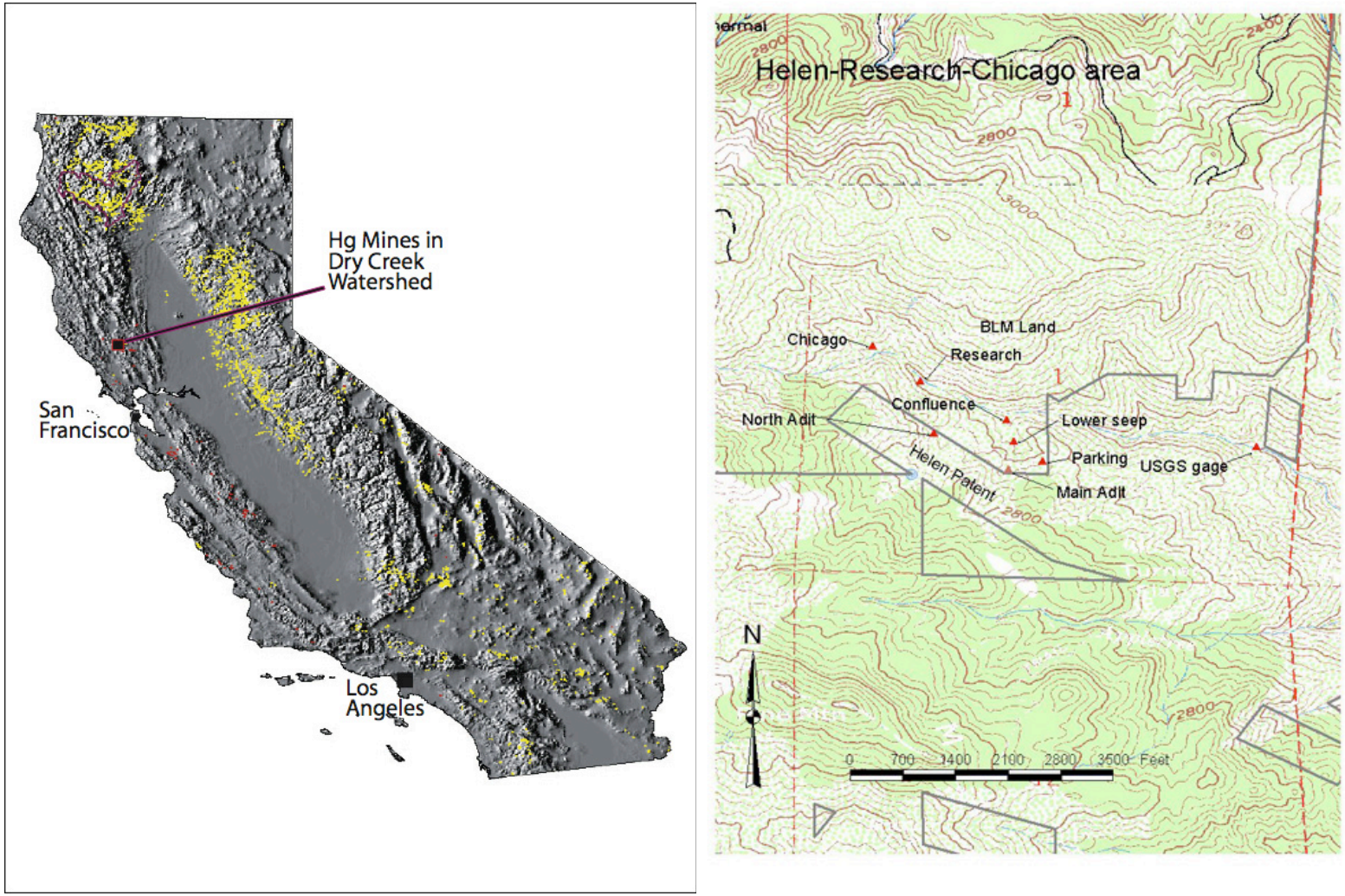


Figure 2. Location map and map of the upper part of Dry Creek showing location of the Helen, Research, and Chicago mercury mines.

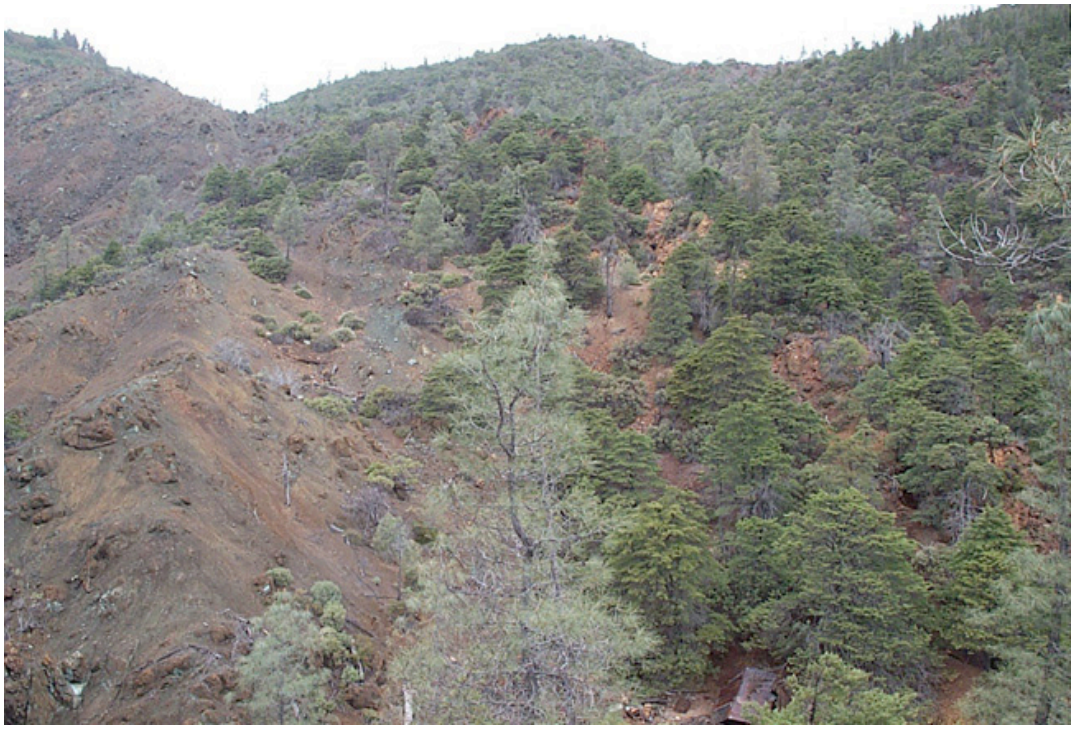


Figure 3. Silica-carbonate alteration developed along the mineralize fault zone in serpentinite (barren slopes) at Chicago mercury mine in the upper part of Dry Creek.

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 HMTO).

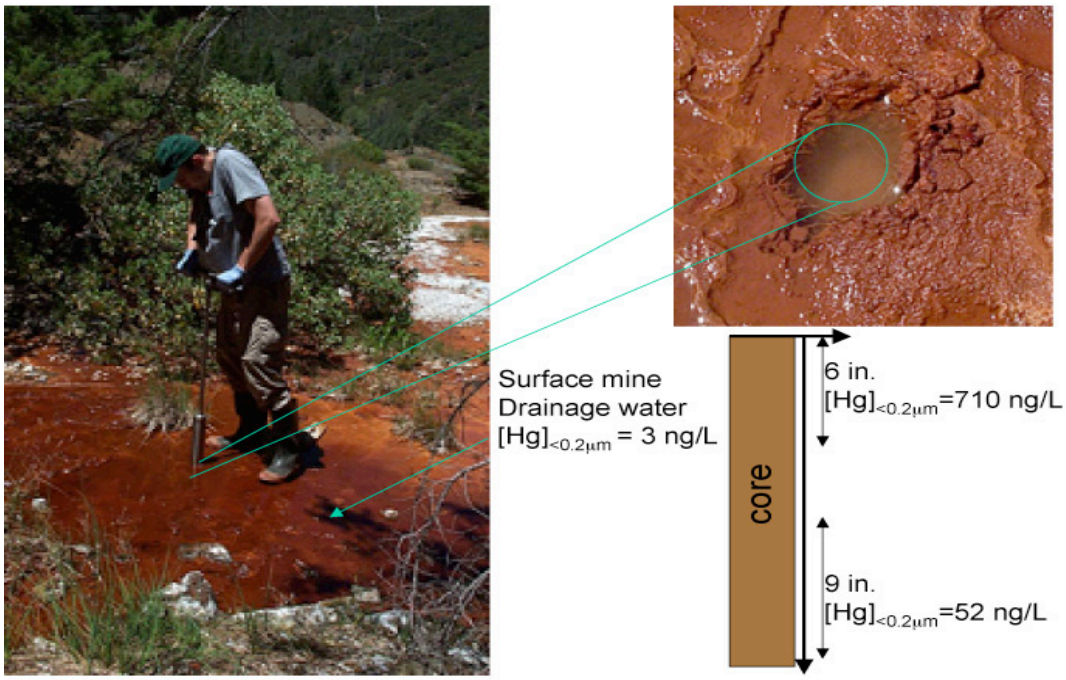


Figure 6. Helen mine drainage and FeOOH precipitate 100 feet from adit. Hg concentration in filtered surface water is 3 ng/L (sample HEL0703W3) and is much higher, 52-710 ng/L in filtered (<0.2μm) pore waters (samples HEL0703SED1A and 1B) taken from a core in the FeOOH sediment.

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.

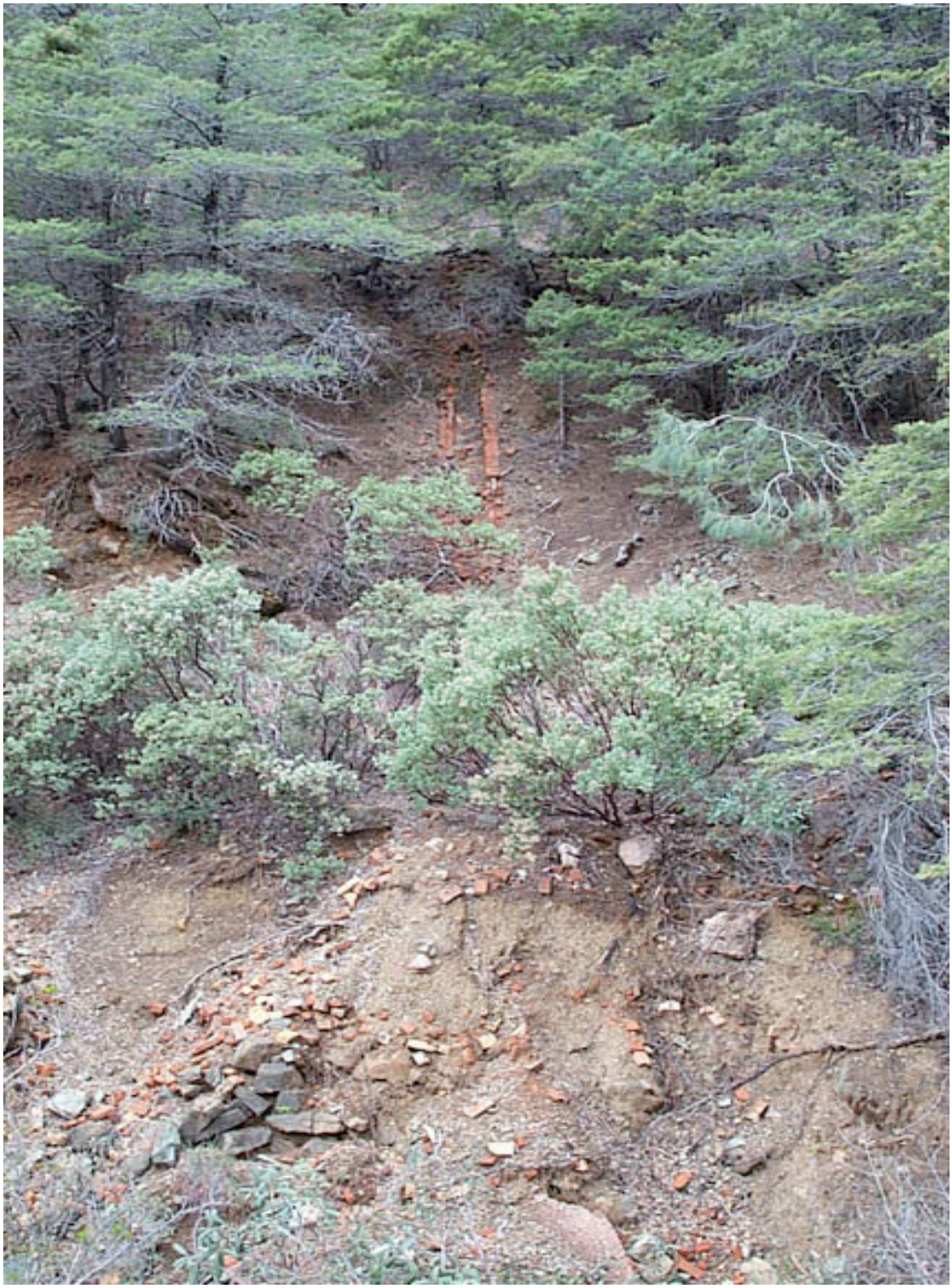


Figure 12. Remains of retort at Research Mine, located adjacent to the Dry Creek bank (foreground).

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.

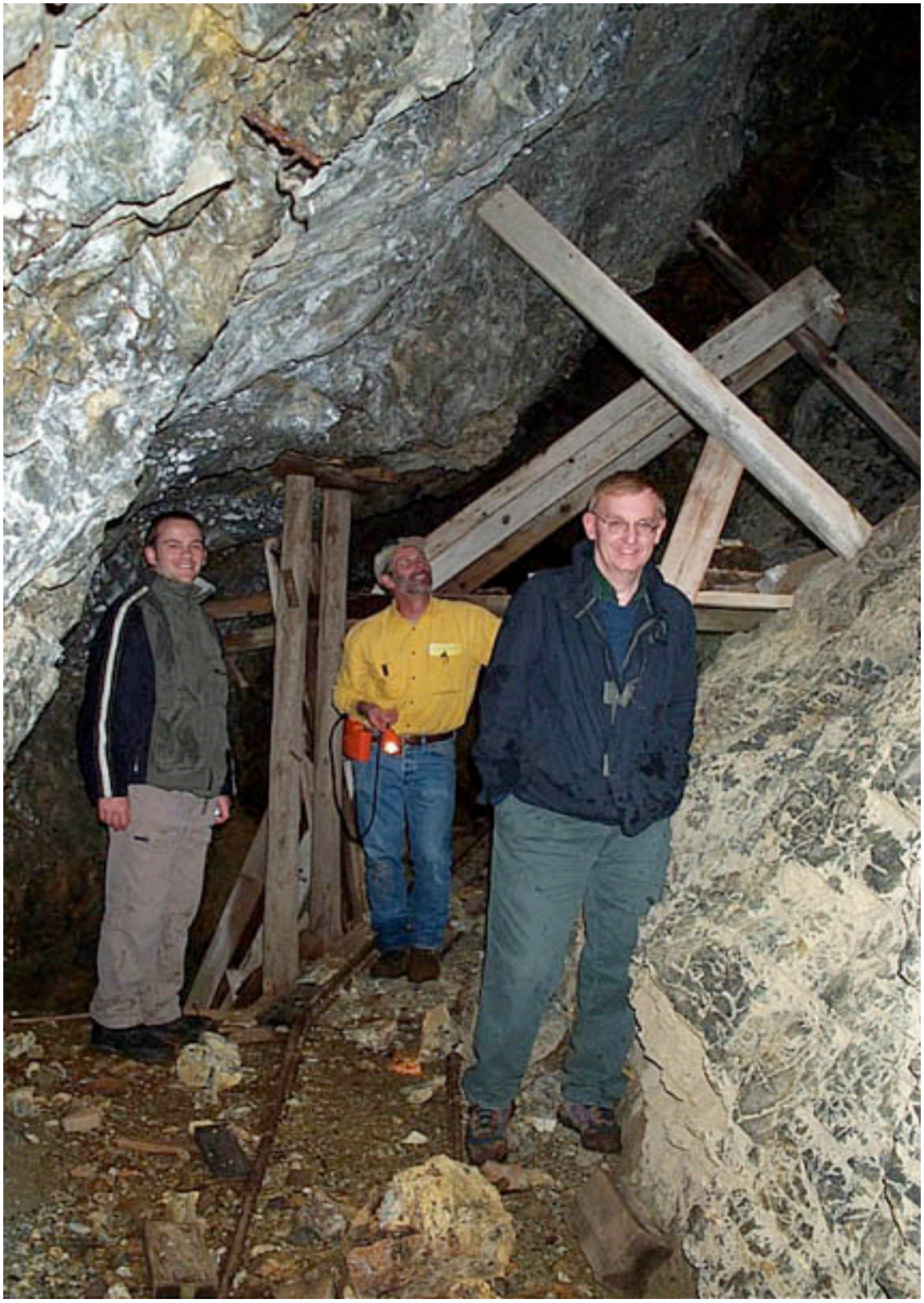


Figure 19. Underground stope at Chicago Mine developed along fault in serpentinite altered to silica carbonate rock consisting of calcite, magnesite, and quartz.

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).

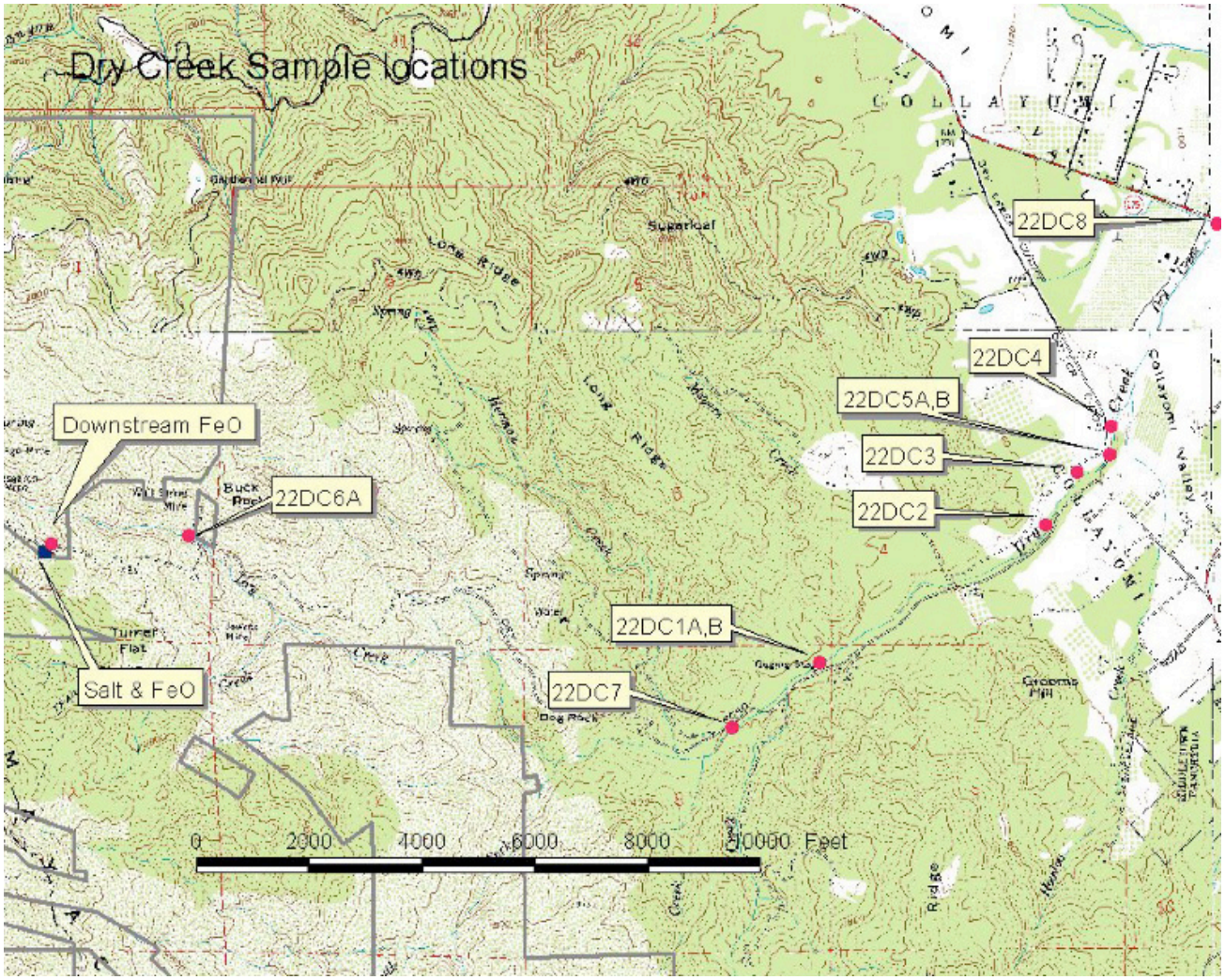


Figure 22. Map of sample sites in Dry Creek downstream from the Helen, Research, and Chicago mine sites.

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 23HM11and HEL0703W4).

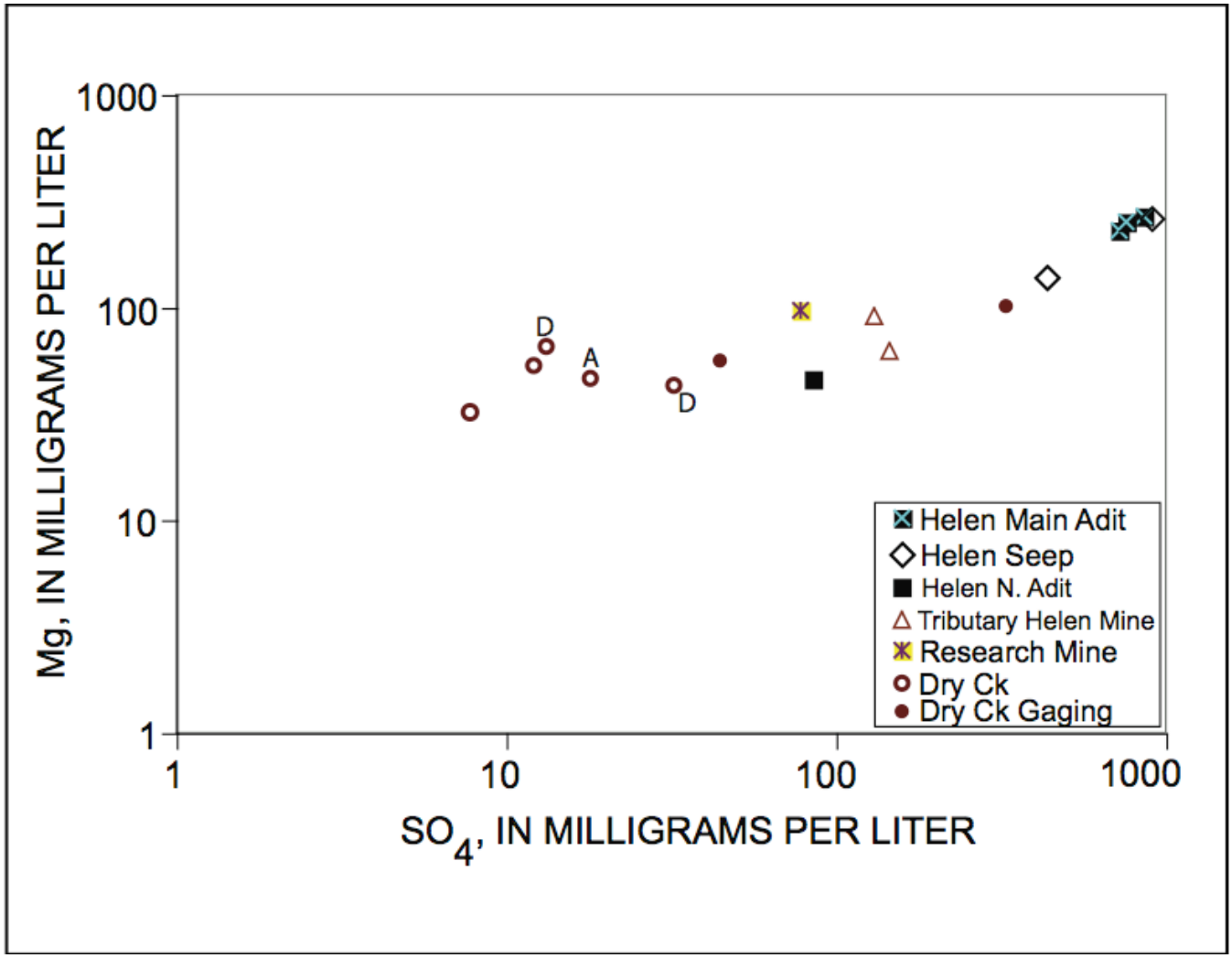


Figure 25. Log plot of Mg verses SO4 in mine drainage from the Helen and Research mines and in waters in Dry Creek and the Helen Mine tributary to Dry Creek. The Helen Mine tributary is dominantly mine drainage effluent that is diluted by surface water. Dry Creek water downstream, noted by "D," from 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.

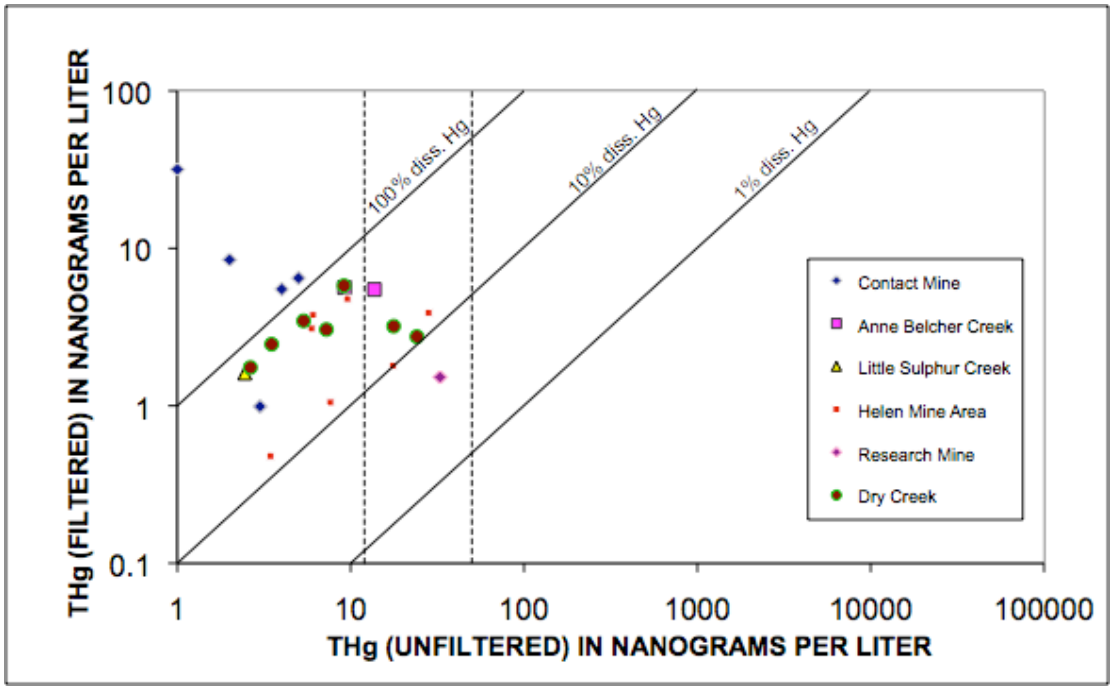


Figure 26. Log plot of dissolved Hg (filtered 0.45 mm) versus total Hg.

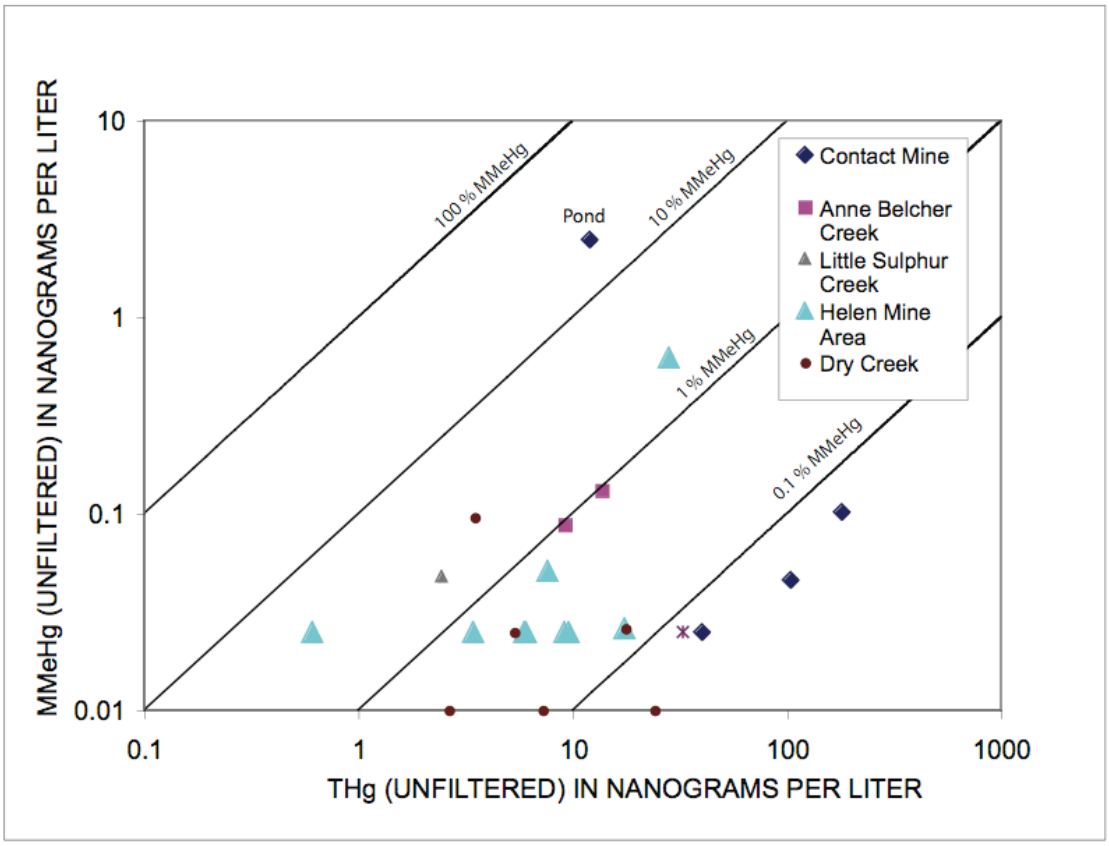


Figure 27. Log plot of total Hg versus total MMeHg.

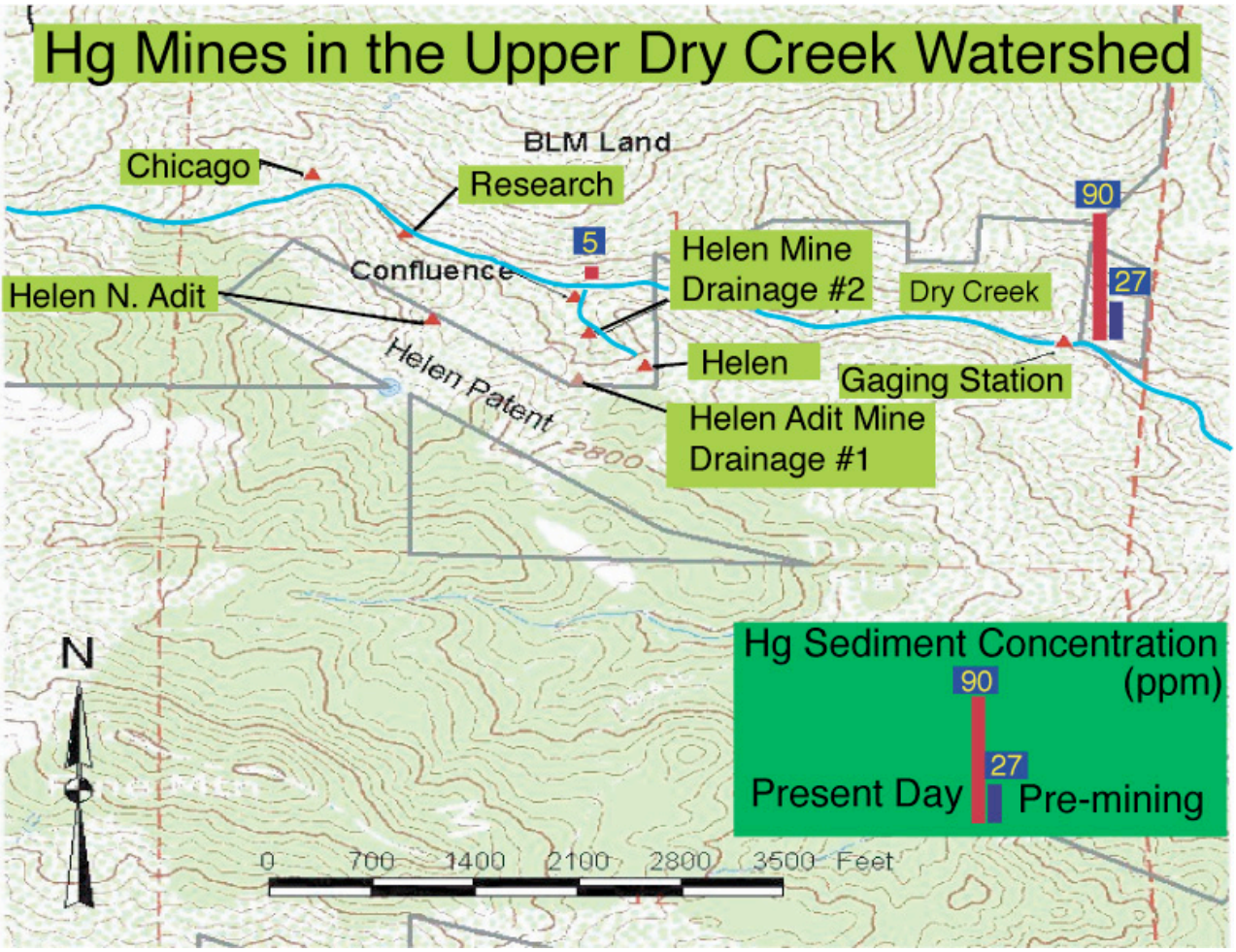


Figure 28. Hg concentration in pre-mining sediment exposed in the banks of Dry Creek and sediment in active channel downstream from the Helen, Research, and Chicago Mines (sample sites 22DC6A and B, table 4).

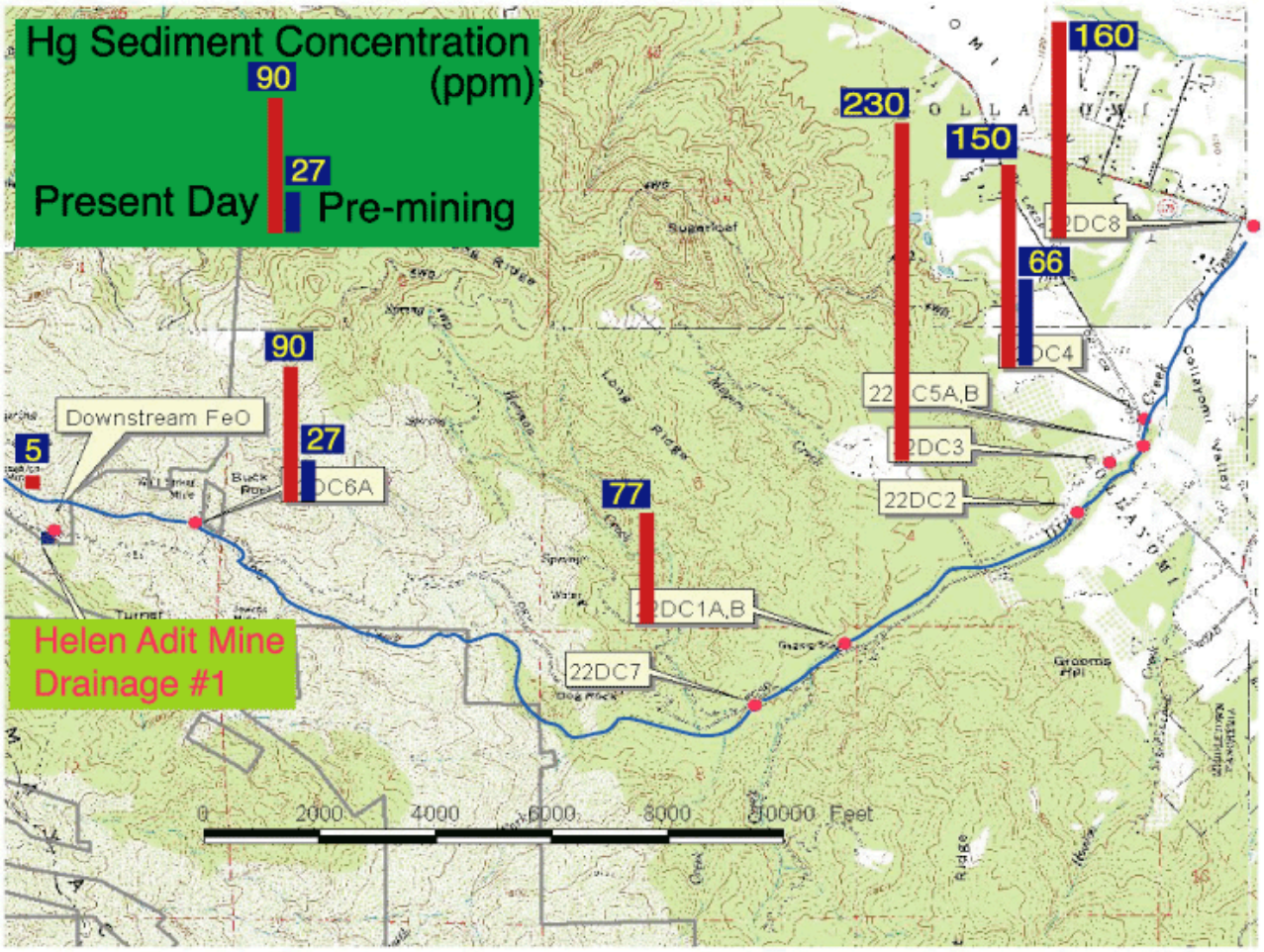


Figure 29. Hg concentration in pre-mining sediment exposed in banks of lower part of Dry Creek and sediment in active channel 4-5 km downstream from the Helen, Research, and Chicago mines.

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).

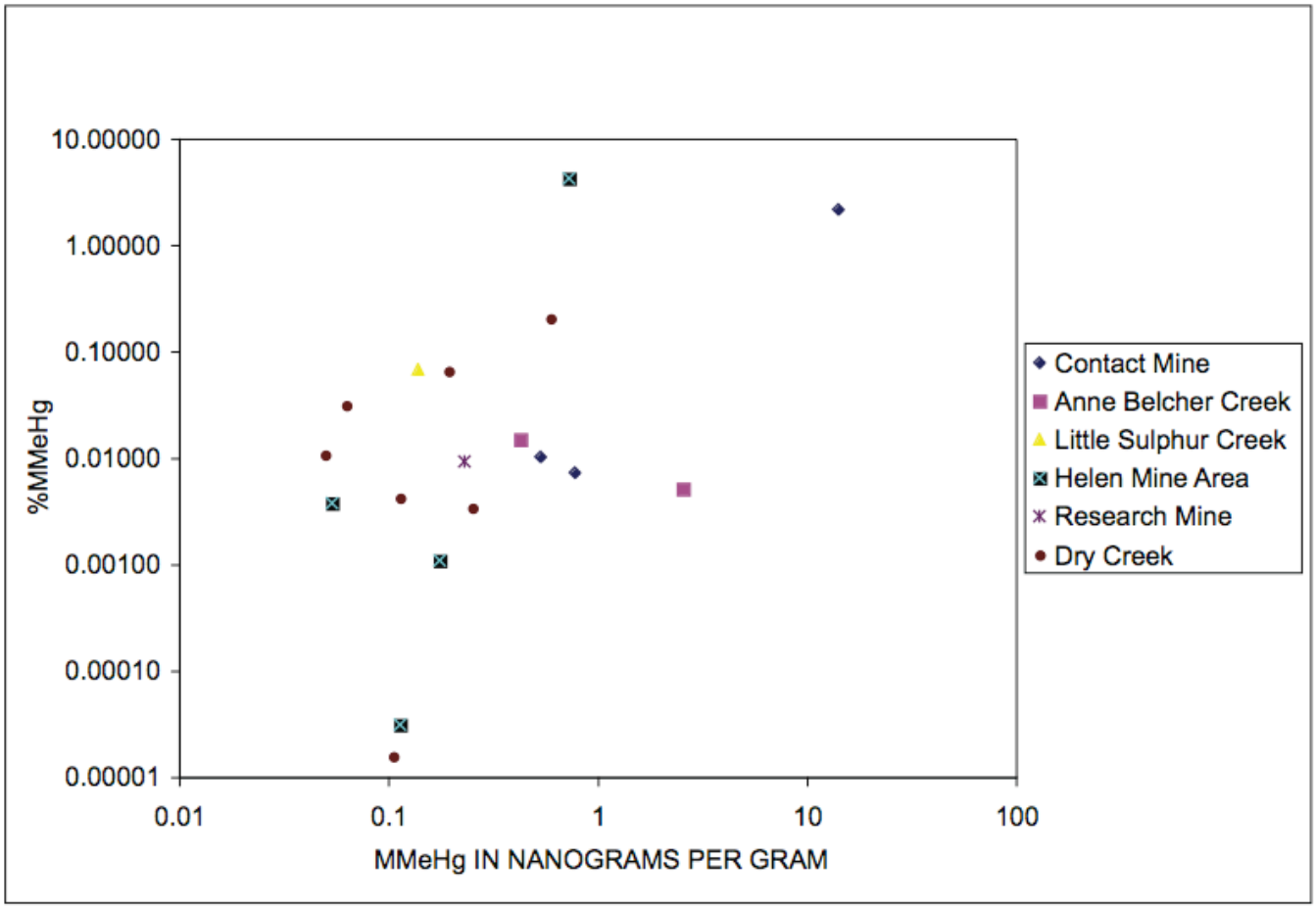


Figure 32. Log plot of % MMeHg versus MMeHg in sediment in Dry Creek and in the Anna Belcher and Little Sulphur Creek watersheds located 5 km to the west. In the Dry Creek watershed, the highest % MMeHg occurs in FeOOH-enriched sediment precipitated from drainage from the Helen Mine main adit.

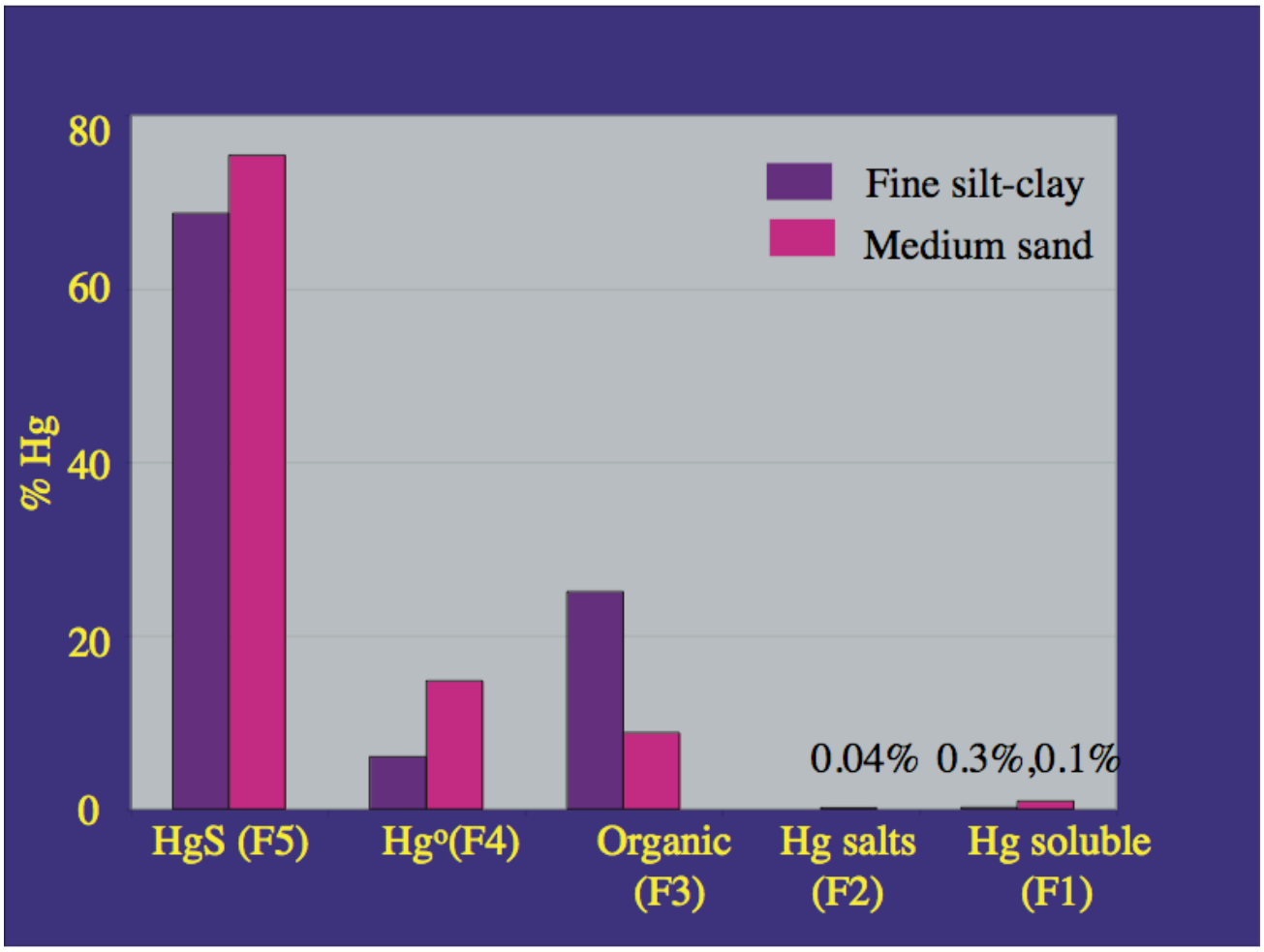


Figure 33. Speciation of Hg in Dry Creek sediment samples, collected 4 km downstream from the Helen Mine consisting of a clay-silt and a medium sand sample. Hg speciation determined by sequential chemical extraction indicates that most of the Hg is present as HgS (F5 fraction) with smaller amounts present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

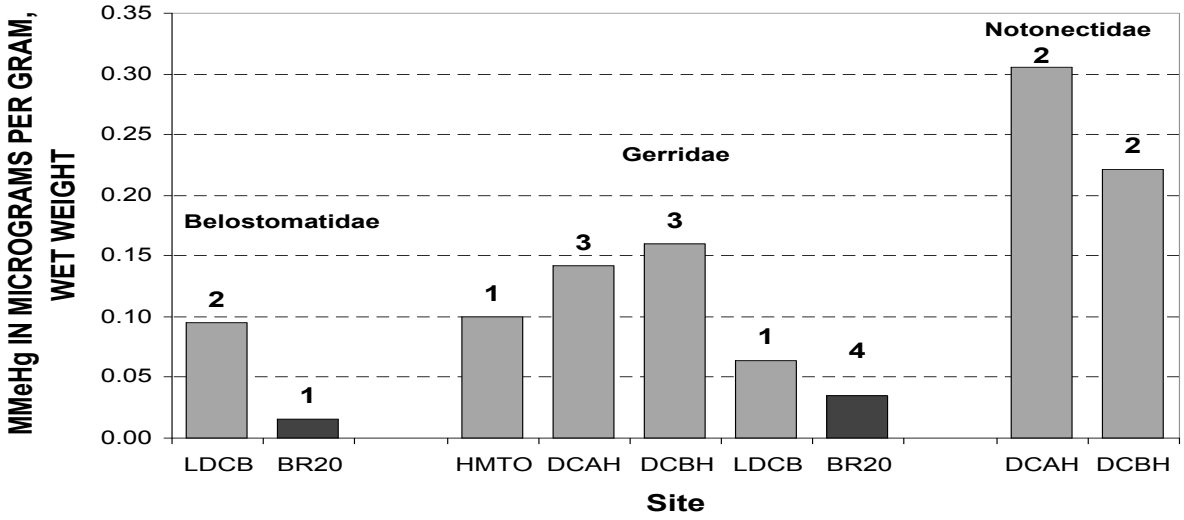


Figure 34. Geometric mean concentrations of monomethylmercury (MMeHg, μg/g, wet weight) in individual composite samples of invertebrates (order Hemiptera; families Belostomatidae, Gerridae, and Notonectidae) from the Dry Creek (LDCB, DCAH, DCBH) watershed in 2003, Helen Tributary (HMTO), and geometric 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.

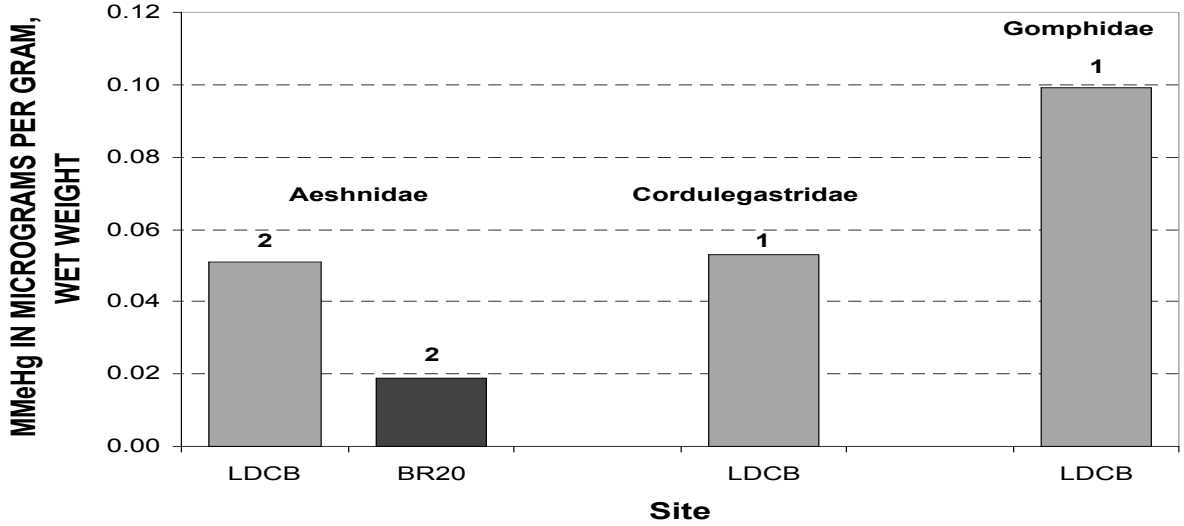


Figure 35. Geometric mean concentrations of monomethylmercury (MMeHg, μg/g, wet wt) in samples of dragonfly larvae (order Odonata; families Aeshnidae, Cordulegastridae, and Gomphidae) collected from the Dry Creek watershed in 2003 and the geometric mean of MMeHg in Aeshnidae, collected from a reference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

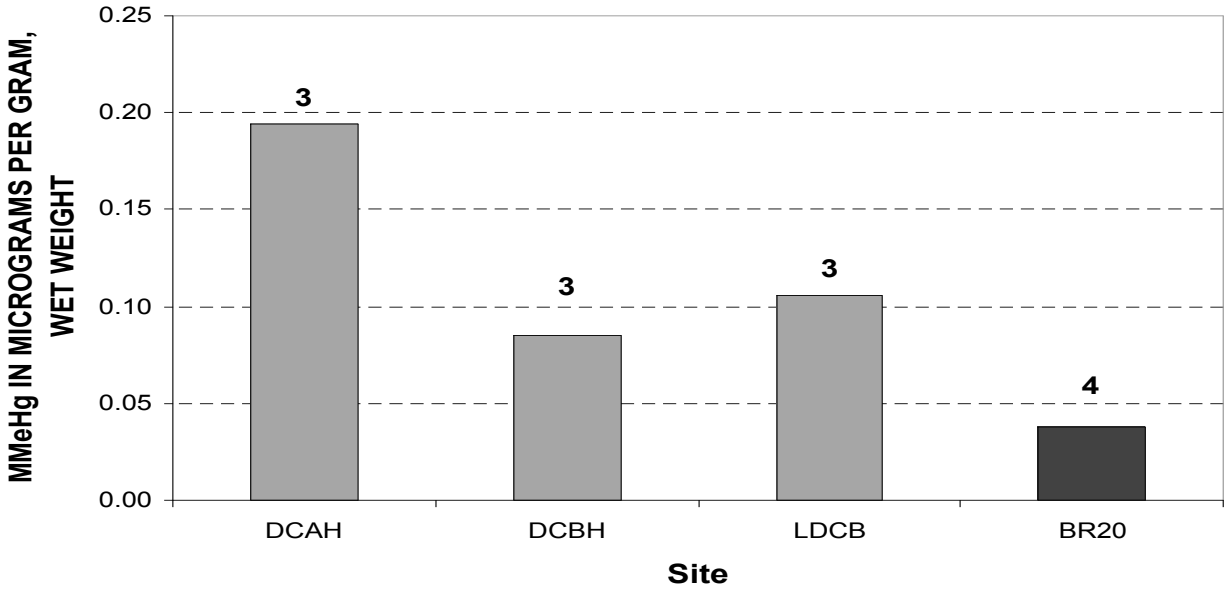


Figure 36. Geometric mean concentrations of monomethylmercury (MMeHg, μg/g, wet wt) in composite samples of Dobsonflies (order Megaloptera, family Corydalidae) from Dry Creek in 2003 and from a reference site, the Bear River at the Highway 20 Bridge (BR20) during 1999-2002. Number of samples noted above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

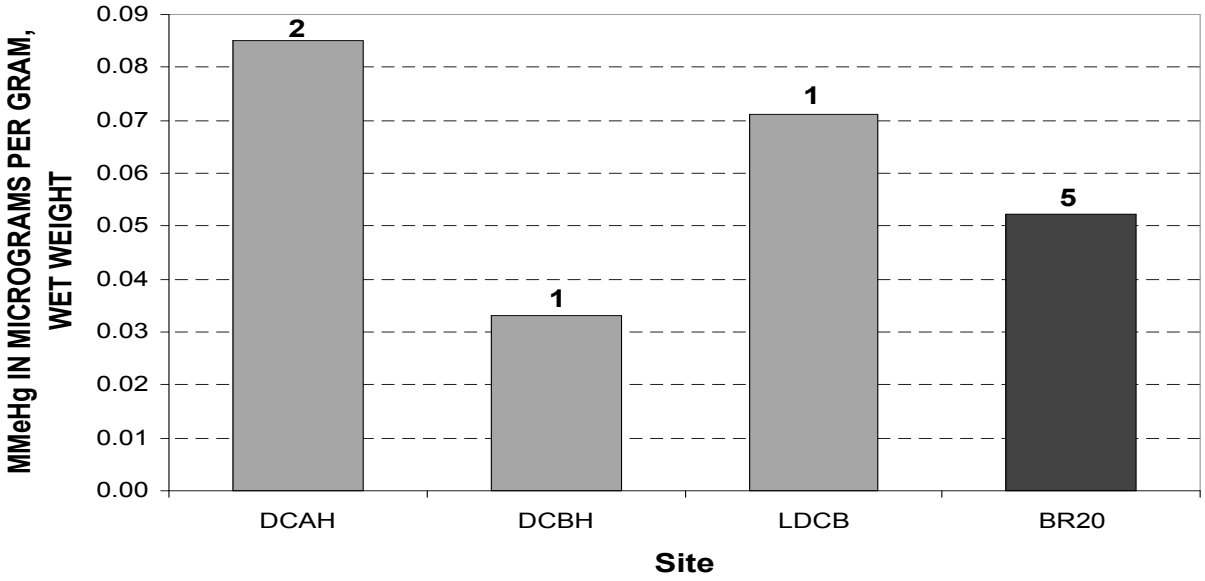


Figure 37. Monomethylmercury (MMeHg, μg/g, wet wt) in individual composite samples of larval stoneflies (order Plecoptera, family Perlidae) from Dry Creek in 2003 and geometric mean concentrations of MMeHg in larval stoneflies from a reference site, the Bear River at the Highway 20 Bridge (BR20) during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

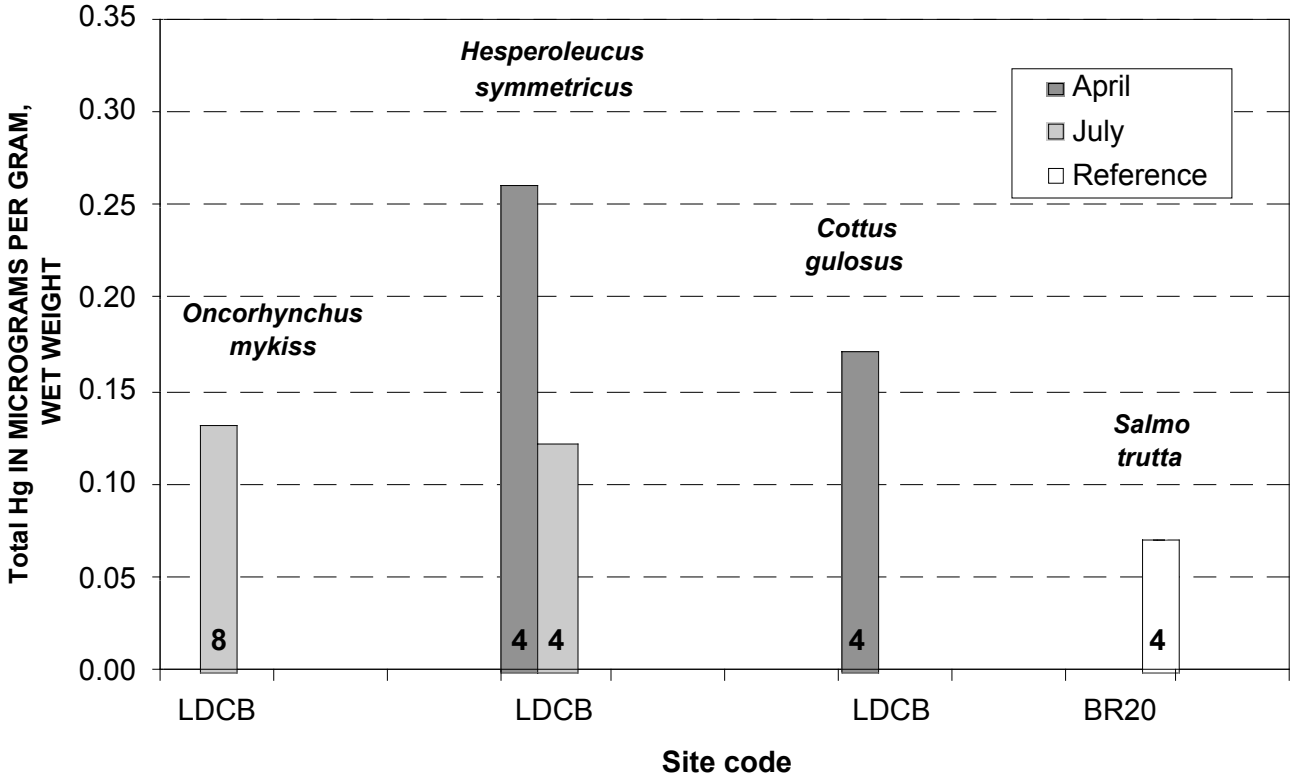


Figure 38. Geometric mean concentrations of total mercury (Hg_T, μg/g, wet wt) in individual fish whole bodies collected from Dry Creek in April and July of 2003 and in fillets of brown trout (*Salmo trutta*) from a reference site, the Bear River at the Highway 20 Bridge (BR20), in 1999. Number of samples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

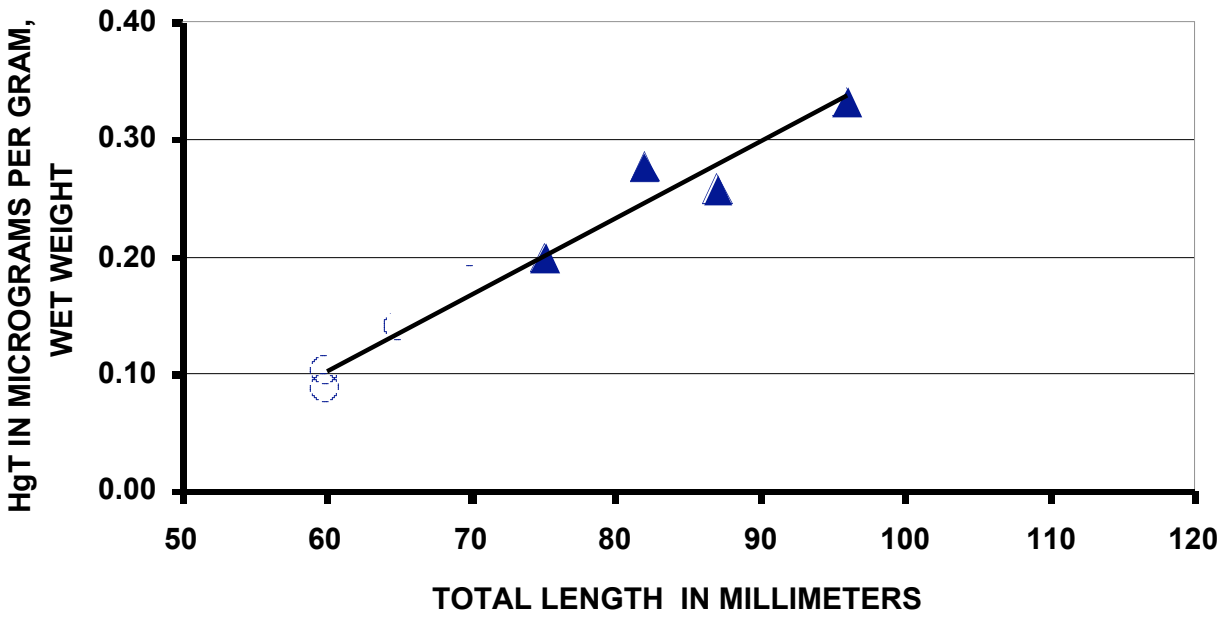
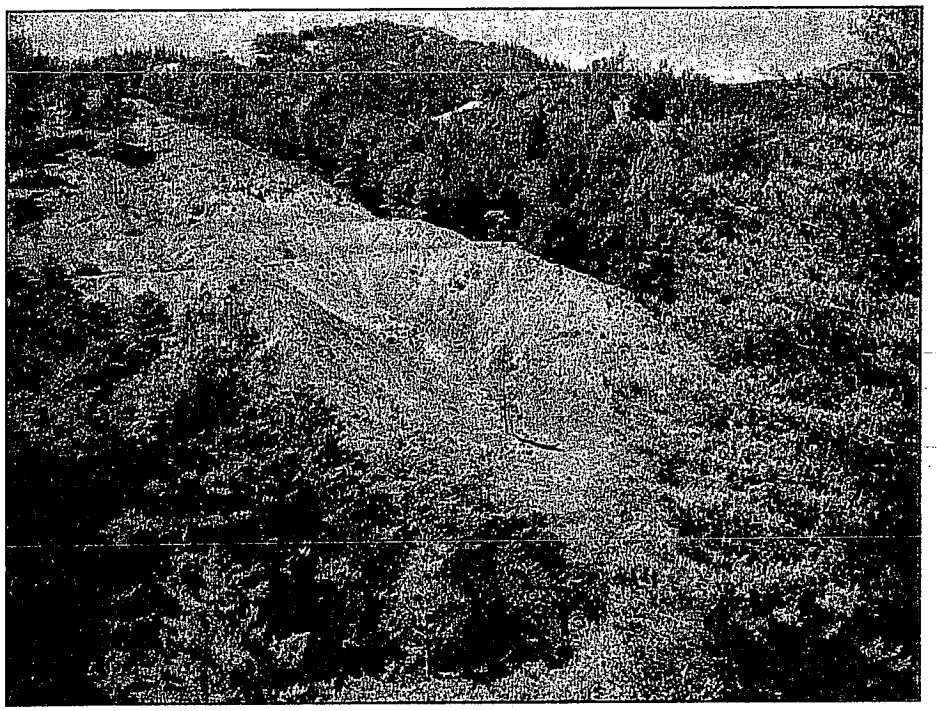
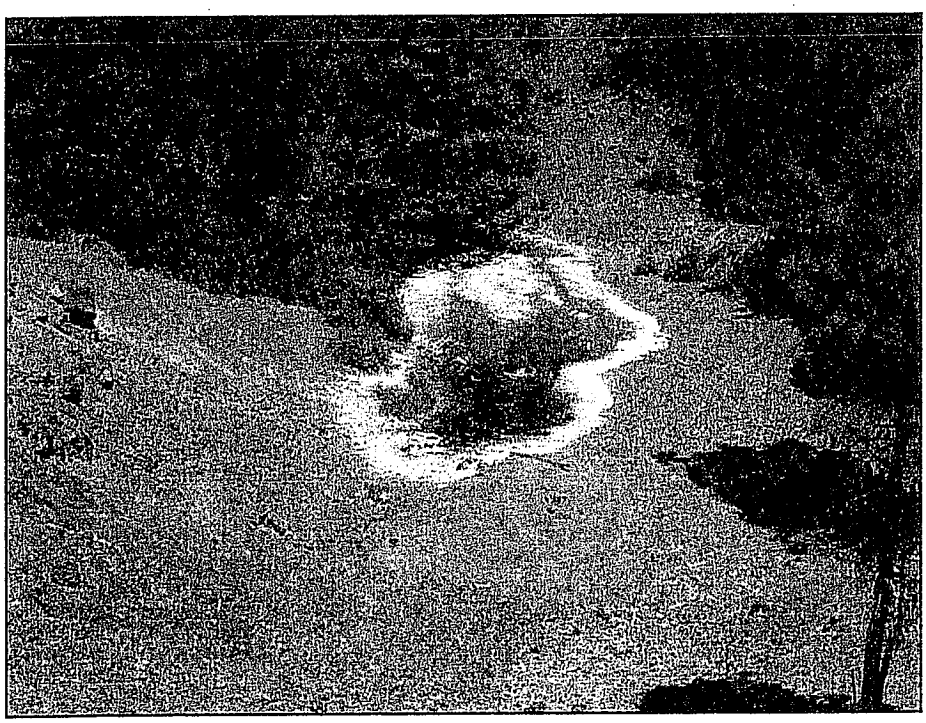


Figure 39. Correlation between concentrations of total mercury (Hg_T, μg/g, wet wt) in individual whole bodies and total length (mm) of California roach collected from Dry Creek (LDCB) in April (1) and July (15) of 2003. R^2 is 0.97 and $P < 0.001$.

REMOVAL SITE INVESTIGATION
HELEN MINE
LAKE COUNTY, CALIFORNIA



View to southwest of waste rock at the Main Adit (out of view to left), Helen Mine



View to north of overburden seep below Main Adit, Helen Mine

Submitted to:

Mr. David Lawler
Coordinator
Abandoned Mine Lands Program
California State Office
U.S. Department of the Interior
Bureau of Land Management
2800 Cottage Way
Room W-1834
Sacramento, CA 95825
(916) 687-4365

Prepared by:

Burleson Consulting, Inc.
950 Glenn Drive, Suite 135
Folsom, CA 95630
916.984.4651
916.984.8261 fax

May 20, 2009

Table of Contents

Section **Page**

1.0 INTRODUCTION 1

2.0 SITE DESCRIPTION 1

- 2.1 Location and Topography 1
- 2.2 Site History and Features 2
- 2.3 Climate 3
- 2.4 Geology and Soils 3
- 2.5 Hydrology and Hydrogeology 3
- 2.6 Vegetation and Wildlife 4

3.0 SUMMARY OF ENVIRONMENTAL INVESTIGATIONS 4

- 3.1 Mine Waste Mercury Content 4
- 3.2 Mine Drainage Mercury Content 5
- 3.3 Surface Water Mercury Content 5
- 3.4 Sediment Mercury Content 6
- 3.5 Biota Sampling 8
- 3.6 Preliminary Conceptual Site Model 9

4.0 RISK SCREENING 10

- 4.1 Human Health Risk Screening 10
- 4.2 Ecological Risk Screening 11
- 4.3 Water Quality 12

5.0 BASIS FOR REMOVAL ACTION 12

6.0 REFERENCES 14

List of Figures

Figure 1 Site Location Map

Figure 2 Site Features

Figure 3 Conceptual Site Model

List of Tables

Table 1	Mine Waste and Precipitated Analytical Results
Table 2	Mine Drainage and Surface Water Mercury Concentrations
Table 3	Mercury in Sediment, Helen Mine Vicinity
Table 4	Mercury in Dry Creek Sediment

List of Appendices

Appendix A	Bureau of Land Management Cultural Resources Survey
Appendix B	Bureau of Land Management Biological Resources Survey

List of Acronyms and Abbreviations

BLM	Bureau of Land Management
Burleson	Burleson Consulting, Inc.
CFS	cubic feet per second
CFR	Code of Federal Regulations
CHHSL	California Human Health Screening Levels
CSM	conceptual site model
DOI	U.S. Department of the Interior
EPA	U.S. Environmental Protection Agency
°F	Fahrenheit
MSL	mean seal level
µg/kg	micrograms per kilogram
mg/kg	milligrams per kilogram
mm	millimeter
ng/L	nanograms per liter
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NRHP	National Register of Historic Places
RMC	Risk Management Criteria
RSI	Removal site investigation
RSL	Regional Screening Levels
USGS	U.S. Geological Survey

1.0 INTRODUCTION

U.S. Department of the Interior (DOI) Bureau of Land Management (BLM) issued Order No. BAD080131 under Burleson Consulting Inc. (Burleson) General Services Administration Environmental Services Contract No. GS10F0277R on September 16, 2008. The BLM order requests that Burleson prepare a removal site investigation (RSI) report for the Helen Mercury Mine to evaluate the need for a removal action at the site. This RSI report is based on information provided to Burleson by the BLM.

The Helen Mercury Mine is located in Lake County, California, approximately four and one-half miles west of Middletown, California (see Figure 1).

This RSI report consists of the following:

1.0 Introduction

2.0 Site Description

3.0 Summary of Environmental Investigations

4.0 Risk Screening

5.0 Basis for Removal Action

6.0 References

2.0 SITE DESCRIPTION

2.1 Location and Topography

Helen Mine is located approximately 4.5 miles west of Middletown in Lake County, California (see Figure 1). The Northern California Power Agency 2 geothermal power plant is located approximately 0.8 mile northwest of Helen Mine.

Helen Mine is reached as follows:

1. Follow Dry Creek Cutoff Road northwest from the intersection with Highway 29, approximately 0.6 mile to Dry Creek Road.
2. Turn left (to the southwest) at the intersection with Dry Creek Road, and proceed approximately 4.7 miles along Dry Creek Road to the site.

Access to the site is controlled by a locked gate after driving 3.1 miles along Dry Creek Road.

The elevation at Helen Mine varies from about 2,500 feet to 2,800 feet above mean sea level (msl) on steep northeast facing slopes within the headwaters of Dry Creek. A prominent north to northwest oriented ridge covered in graded waste rock is located east of BLM administered property (see Figure 2). This ridge is separated from the BLM portion of the mine by an unnamed tributary to Dry Creek. Rock and soil disturbed by mining are distributed on about 2 acres within the unnamed tributary and on steep slopes above it.

2.2 Site History and Features

According to the U.S. Bureau of Mines (1965) the Helen Mine was discovered in 1871 and several hundred flasks[1] of mercury were produced from 1873 to 1876. The mine then operated intermittently from 1900 to 1956 producing about 7,000 flasks of mercury.

Mine workings reportedly included more than 5,000 feet of adits (horizontal mine entrance), drifts (horizontal tunnels), and cross-cuts (connecting tunnels) on three main levels, several intermediate adits and associated raises (vertical tunnel going up), winzes (vertical tunnel going down), and stopes (voids from which ore was removed) (U.S. Bureau of Mines 1965). The reported strike length of the workings was 1,600 feet over a vertical range of 300 feet.

A diesel generator-powered reduction plant was used to recover mercury during later operations (U.S. Bureau of Mines 1965). The plant included a jaw crusher, a 25-ton-capacity oil fired rotary furnace, a cyclone dust collector, vertical pipe condensers, a settling tank, and stack. Soot was reportedly hand hoed and then processed in a D-retort to recover mercury. Calcines were reportedly trammed to the waste dump. According to the U.S. Geological Survey (USGS), a reclamation project during the 1990s resulted in burial of the calcines and plant components in the disturbed area to the east of the main adit (USGS 2008).

Remaining visible features at Helen Mine are two adits (referred to as the north adit and the main adit), and disturbed areas covered with mine wastes (waste rock, calcines, and overburden). Figure 2 shows the approximate location of the boundary between patented claims that are private property and BLM-administered lands. The north adit is located on private property and is a source of mine drainage that crosses BLM-administered lands. The prominent north to northwest-oriented ridge covered in graded waste rock is also located on private property. The main adit is located on BLM-administered lands as are most of the mine wastes. The main adit is also a source of mine drainage. The disturbed area extends from slopes to the southwest of the main adit toward the north and east across the unnamed tributary to Dry Creek and to the property boundary east of the adit. This area includes overburden, waste rock and calcines deposited during active mining. A seep (overburden seep) is present in the unnamed tributary below the main adit.

A cultural resources inventory report was completed by BLM on October 2, 2008 (BLM 2008a). The site was surveyed on September 5, 2008. Structural debris (bricks, timbers and graded areas), an intact adit, and mine wastes were noted during the survey. The cultural resources inventory report found that the site had no integrity due to collapse of structures and removal of much material for salvage. There were no sites determined eligible for inclusion to the National Register of Historic Places (NRHP), or that need data for this determination, therefore no sites are required to be avoided during future contamination cleanup projects. A determination of no-adverse effects on cultural resources was recommended for the proposed Helen Mine cleanup project. The cultural resources inventory report is included on compact disc as an appendix to this report.

[1] A flask contained 76 pounds of mercury

2.3 Climate

Annual precipitation records are available from Middletown, California, about 4.5 miles east of the site. The average annual rainfall from 1893 to 2008 observed at Middletown was 44.37 inches, with an average of 1.3 inches as snow (Western Region Climate Center 2008). Most of the precipitation (approximately 40 inches) occurred during the October through April rainy season. Temperature data were not available for Middletown. The nearest station with reported temperature data is located southeast of Clear Lake, north of the site. The lowest monthly average temperature of 30.6 degrees Fahrenheit (°F) occurs in January, and the highest monthly average temperature of 93.1 °F occurs in July at the Clear Lake station (Western Region Climate Center 2008).

2.4 Geology and Soils

Helen Mine is located at the faulted contact between serpentinite and Franciscan sandstone (U.S. Bureau of Mines 1965). The fault zone strikes northwest and dips to the southwest. Altered basalt dikes occur within the fault zone and serpentinite. Serpentinite altered to a silica-carbonate rock occurs discontinuously along the fault. The main ore bodies occurred within the silica-carbonate rock, with some ore in the sandstone and in basalt dikes (U.S. Bureau of Mines 1965). The silica carbonate-hosted ore consisted of cinnabar with less abundant native mercury, metacinnabar, and tiemannite. Sandstone and basalt dikes also contained disseminated cinnabar.

Soils at Helen Mine are described as the Okiota-Henneke-Dubakella Association and are derived from weathering of underlying serpentinite bedrock. The typical depth to bedrock ranges from 14 to 30 inches below ground surface. These soils are described as consisting of gravelly clay loam at the surface with increasing gravel as depth increases and bedrock is approached.

2.5 Hydrology and Hydrogeology

Helen Mine is located at the headwaters of Dry Creek in Lake County, California. Dry Creek is an intermittent stream at Helen Mine and is a perennial stream approximately 0.1 mile downstream from the site. Dry Creek is not known to be used as a source for drinking water, but is used for irrigation and provides habitat for fish, insects, and amphibians.

A USGS stream gauge located approximately 0.6 mile downstream from Helen Mine recorded flows from October 1977 through June 1978. The monthly mean discharge rate in cubic feet per second (cfs) at this gauge ranged from 0.095 cfs in October 1977 to 14.9 cfs in January of 1978 (USGS National Water Information System, 2008).

Site specific groundwater elevation measurements, and aquifer hydraulic parameter estimates are not available for the Helen Mine site. However, shallow groundwater elevations generally mimic the topography with a lower slope or gradient. Shallow groundwater at the Helen Mine is expected to flow from areas of higher elevation to areas of lower elevation. Based on this reasoning, shallow groundwater is inferred to flow northeast from the ridge above the Helen Mine to Dry Creek. Dry Creek is likely a groundwater discharge boundary in the vicinity of Helen Mine. The drainage flowing from the North and Main Adits likely represents groundwater intercepted by the underground mine workings.

2.6 Vegetation and Wildlife

BLM prepared a biological/botanical resource report (BLM 2008b) for the Helen Mine area. The report identified five special status species in the vicinity of Helen Mine based on review of the California Natural Diversity Database.

The five species include four plants:

1. Cobb Mountain Lupine (*Lupinus sericatus*)
2. Freed's Jewelflower (*Streptanthus brachiatus* ssp. *hoffmanii*)
3. Calistoga Ceanothus (*Ceanothus divergens*)
4. Snow Mountain Buckwheat (*Eriogonum nervulosum*)

And one mammal:

1. Townsend's Big-eared Bat (*Corynorhinus townsendii*)

The biological/botanical resource report (BLM 2008b) noted that Freed's Jewelflower was reported as present at the Helen Mine site. The report recommended that:

1. Helen Mine be surveyed during the May-June flowering period for Freed's Jewelflower to map the population.
2. Freed's Jewelflower should be avoided during remediation activities.
3. Projects proceed with mitigations to protect the Freed's Jewelflower.

A copy of the BLM biological/botanical resource report is included on compact disc as an appendix to this report.

3.0 SUMMARY OF ENVIRONMENTAL INVESTIGATIONS

Environmental sampling at Helen Mine was performed by the USGS during 2001, 2002, 2003 and 2005. USGS personnel collected mine drainage, mine waste, sediment, surface water and biota samples for mercury, methyl mercury, and metals analyses. Results of USGS field sampling and laboratory analysis are documented in USGS Administrative Report 08-1297 (USGS 2008). Mercury analytical results are summarized below.

3.1 Mine Waste Mercury Content

Mine wastes present at the Helen Mine site include overburden, waste rock, tailings, and chemical precipitates from mine drainage. Waste rock and overburden were not sampled, and most of the tailings (calcines) were buried and inaccessible for sampling (USGS 2008). Mine waste analytical results are summarized in Table 1.

One tailings sample was collected from a small pile located west of the lower mine drainage seep. The tailings sample contained 17.9 milligrams per kilogram (mg/kg) total mercury.

Chemical precipitates include iron oxy-hydroxides and epsomite (hydrated magnesium sulfate). Iron oxy-hydroxides were sampled at the main adit and in the lower seep. Total mercury

concentrations of the main adit iron oxy-hydroxides ranged from 0.09 mg/kg to 14.7 mg/kg and the methyl mercury concentration was 0.00073 mg/kg. Total mercury concentrations in lower seep iron oxy-hydroxides ranged from 0.36 mg/kg to 550 mg/kg, and the methyl mercury concentration was 0.00018 mg/kg.

3.2 Mine Drainage Mercury Content

Mine drainage was sampled at the Main Adit, Lower Seep, and Helen Mine tributary to Dry Creek (USGS 2008). Total and dissolved (<0.45 μm) mercury and total methyl mercury were analyzed in mine drainage. Mine drainage analytical results are summarized in Table 2.

Total mercury concentrations in Main Adit drainage ranged from 0.61 nanograms per liter (ng/L) to 9.56 ng/L, and dissolved mercury concentrations ranged from 0.37 ng/L to 4.78 ng/L. About 50 percent of the mercury in Main Adit drainage was dissolved. Methyl mercury was not detected (< 0.025 ng/L) in drainage from the Main Adit.

Two samples of pore water from a core in the iron oxy-hydroxide sediment at the Main Adit contained dissolved (<0.2 μm) mercury at concentrations of 52 ng/L and 741 ng/L; and were not analyzed for methyl mercury.

Mine drainage from a pool in the channel between the Main Adit and lower seep contained 4.62 ng/L total mercury. Methyl mercury was detected at a concentration of 0.25 ng/L in this sample. Mine drainage from the waste rock channel between the Main Adit and Lower Seep contained 5.94 ng/L total mercury, 3.09 ng/L dissolved mercury, and <0.025 ng/L methyl mercury. About 50 percent of the mercury in this sample was dissolved.

Drainage from the Lower Seep contained 1.55 ng/L to 17.5 ng/L total mercury and 0.48 ng/L to 1.8 ng/L dissolved mercury. About 10 to 14 percent of the mercury in Lower Seep drainage was dissolved. Methyl mercury was detected at a concentration of 0.026 ng/L in Lower Seep drainage.

Drainage from the Helen Mine tributary contained 7.62 ng/L to 17.7 ng/L total mercury, and 1.05 ng/L to 3.2 ng/L dissolved mercury. About 14 to 18 percent of the mercury in the Helen Mine tributary was dissolved. Methyl mercury was detected at concentrations from 0.026 ng/L to 0.62 ng/L in drainage from the Helen Mine tributary.

The analytical data summarized above indicate that mercury in mine drainage appears to increase from the adit (up to 9.56 ng/L) to lower seep and Helen Mine tributary (about 17.5 ng/L). USGS attributed this to reactions between the mine drainage and waste rock along the flow path. Pore water within iron oxy-hydroxide sediment contained the highest mercury concentrations (up to 741 ng/L), but these elevated concentrations were not observed in other mine drainage at the site.

3.3 Surface Water Mercury Content

Surface water was sampled upstream and downstream from the confluence with the Helen Mine tributary in April 2003 and downstream from the confluence in 2001, 2002, and July 2003 USGS (2008). Total and dissolved (<0.45 μm) mercury and total methyl mercury were analyzed in surface water samples. Surface water analytical results are summarized in Table 2.

In the April 2003 sample, the total mercury concentration detected in Dry Creek above the confluence with the Helen Mine tributary was 6.06 ng/L, and the detected dissolved mercury concentration was 3.77 ng/L. About 60 percent of the mercury in Dry Creek above the confluence with the Helen Mine tributary was dissolved. Methyl mercury was not detected (< 0.025 ng/L) in Dry Creek above the Helen Mine tributary.

Total mercury concentrations detected in Dry Creek downstream from the Helen Mine tributary in 2001, 2002, and July 2003 were 7.24 ng/L, 5.35 ng/L, and 9.15 ng/L respectively.

In the April 2003 sample, the total mercury concentration detected in Dry Creek about 800 feet downstream from the confluence with the Helen Mine tributary was 24.1 ng/L, and the detected dissolved mercury concentration was 2.75 ng/L. About 10 percent of the mercury in Dry Creek downstream from the confluence with the Helen Mine tributary was dissolved. Methyl mercury was not detected (< 0.025 ng/L) in Dry Creek downstream from the Helen Mine tributary.

The total mercury concentration in the April 2003 downstream sample (24.1 ng/L) was nearly four times the total mercury concentration in the upstream sample (6.06 ng/L).

3.4 Sediment Mercury Content

Mercury concentrations in sediment in the vicinity of the Helen Mine are affected by natural ambient sources and abandoned mercury mines. The Research and Chicago Mines are located in the Dry Creek watershed upstream from the Helen Mine; and the Wall Street and Jewess Mines are located in the Dry Creek watershed downstream from the Helen Mine. The geologic processes that created the mercury ore deposits at the mines also enriched the surrounding rock in mercury. This natural rock also provides a source for mercury to the watershed. USGS (2008) collected samples of active channel sediment believed to be affected by mercury mining activities, and bank sediment samples believed to pre-date mining impacts. Analytical results of chemical precipitates associated with mine drainage are described under mine waste sampling in Section 3.1 above.

USGS (2008) collected sediment samples near the Helen Mine and for several miles downstream. Sediment samples in the vicinity of Helen Mine were collected from Dry Creek upstream of the Helen Mine tributary, in the Helen Mine tributary, and downstream of the Helen Mine tributary.

Sediment in the Vicinity of Helen Mine. Active channel sediment samples for total mercury analysis were collected from Dry Creek above the Helen Mine tributary confluence (one split sample, 1.44 mg/kg to 2.99 mg/kg), from the Helen Mine tributary (three samples [two split], 0.204 mg/kg to 90.8 mg/kg), from Dry Creek about 800 feet downstream from the Helen Mine tributary confluence (two split samples, 0.471 mg/kg to 681 mg/kg), and about 0.6 mile downstream of the Helen Mine at the inactive USGS gauging station (three samples [two splits] 0.29 mg/kg to 90.01 mg/kg). These data are summarized in Table 3.

Total mercury concentrations reported for split samples analyzed by two different laboratories were significantly different, including the Helen Mine tributary (90.8 mg/kg and 4.91 mg/kg), Dry Creek about 800 feet downstream from the Helen Mine tributary confluence (3.7 mg/kg and 681 mg/kg), and the inactive USGS gauging station (90.01 mg/kg and 0.29 mg/kg). USGS (2008) speculated that this observation reflects nugget effects due to the inter-laboratory differences in collection of subsamples for processing in the analysis. This discrepancy between

split samples could also reflect quality control issues in the different laboratories. The wide variation reported for mercury concentrations in split samples contributes uncertainty to the evaluation of the data.

Active channel samples for methyl mercury analysis were also collected from Dry Creek above the Helen Mine tributary confluence (0.054 µg/kg), from the Helen Mine tributary (0.063 µg/kg), from Dry Creek about 800 feet downstream of the Helen Mine tributary confluence (two samples, 0.05 µg/kg to 0.105 µg/kg), and about 0.6 mile downstream of the Helen Mine at the inactive USGS gauging station (three samples [two splits] 0.11 µg/kg to 0.597 µg/kg).

These sediment data appear to show an increase in the total mercury concentration in Dry Creek sediment from upstream of Helen Mine to downstream of Helen Mine. To evaluate the influence of Helen Mine on mercury in Dry Creek sediment, average total mercury concentrations were estimated for four locations (upstream of Helen Mine, Helen Mine Tributary, 800 feet downstream and at the inactive USGS gauge). The extreme concentrations (both high and low values from splits analyzed by Frontier Geosciences) were removed from the data prior to estimating average concentrations. These values were removed because Frontier analyzed a 0.2 gram subsample instead of the entire sample leading to potential nugget effects (USGS 2008). Samples analyzed by Chemex are less prone to nugget effects because a larger sample size was analyzed.

The average total mercury concentration in Dry Creek sediment above the confluence with the Helen Mine tributary was 2.2 mg/kg. The average total mercury concentration in Helen Mine tributary sediment was 23.8 mg/kg. The average total mercury concentration in Dry Creek sediment about 800 feet downstream from the Helen Mine tributary was 4.8 mg/kg. The average total mercury concentration at the inactive USGS gauge was 28.8 mg/kg. These average total mercury concentrations appear to show that release of sediment from Helen Mine approximately doubled the total mercury concentration in Dry Creek sediment. Total mercury concentrations in sediment at the inactive USGS gauge are also likely influenced by the Wall Street mine. Sediment total mercury data from the Wall Street Mine are not available.

Sediment Downstream from the Inactive Gauging Station. USGS collected sediment samples from areas believed to be impacted by mining and from areas believed to not be impacted by historical mercury mining. These data are summarized in Table 4. Sediment samples located downstream from the inactive gauging station and collected from the active channel were believed to be impacted by mercury mining, and samples collected from bank deposits were believed to predate mining activity (USGS 2008).

The total mercury concentrations detected in stream bank deposits believed to reflect pre-mining mercury concentrations ranged from 0.3 mg/kg to 66 mg/kg. The methyl mercury concentration was analyzed in one stream bank deposit sample and reported at a concentration of 0.195 µg/kg.

Total mercury detected in active channel sediments believed to reflect post mining mercury concentrations ranged from 5.92 mg/kg to 230 mg/kg. Mercury mining in the Dry Creek watershed may have resulted in a four-fold increase of mercury in sediment based on these data.

3.5 Biota Sampling

USGS performed biota sampling by collecting fish in lower Dry Creek, and collecting insects from the vicinity of Helen Mine and lower Dry Creek. Fish were analyzed for total mercury (wet weight), and insects were analyzed for total and methyl mercury (wet weight).

Fish. The mercury contents of fish in lower Dry Creek are difficult to interpret with respect to Helen Mine because of the presence of other mercury mines in the watershed. Riffle sculpin, California roach, and rainbow trout were collected from lower Dry Creek. USGS (2008) noted that the mercury concentration (wet weight) of whole fish increased with fish length, and that mercury contents of small rainbow trout (average length 70.5 millimeters [mm]) were below the 0.30 mg/kg California Office of Environmental Health Hazard Assessment screening level for total mercury in fish tissue.

Insects. Water Striders, Dobsonflies, Stoneflies, Backswimmers, Giant Water Bugs, and Dragonflies were collected for mercury analysis. Samples were collected from Dry Creek upstream and downstream of the Helen Mine tributary. One sample of water strider was collected at the Helen Mine adit. Giant water bugs, and dragonflies were not collected in the vicinity of the Helen Mine. Insects collected from lower Dry Creek are not discussed here due to the presence of mercury mines downstream from Helen Mine in the watershed that likely affect these samples.

Water Striders collected upstream of the Helen Mine tributary contained 0.122 mg/kg to 0.213 mg/kg total mercury and 0.117 mg/kg to 0.166 mg/kg methyl mercury. Water striders at the Helen Mine adit contained 0.106 mg/kg total mercury and 0.100 mg/kg methyl mercury. Water Striders collected about 800 feet downstream of the Helen Mine tributary contained 0.155 mg/kg to 0.213 mg/kg total mercury and 0.120 mg/kg to 0.255 mg/kg methyl mercury.

Dobsonflies collected upstream from Helen Mine tributary contained 0.354 mg/kg to 0.598 mg/kg total mercury and 0.078 mg/kg to 0.431 mg/kg methyl mercury. Dobsonflies collected about 800 feet downstream of the Helen Mine tributary contained 0.185 mg/kg to 0.292 mg/kg total mercury and 0.061 mg/kg to 0.140 mg/kg methyl mercury.

Backswimmers collected upstream of the Helen Mine tributary contained 0.226 mg/kg to 0.280 mg/kg total mercury and 0.293 mg/kg to 0.317 mg/kg methyl mercury. Backswimmers collected about 800 feet downstream of the Helen Mine tributary contained 0.288 mg/kg to 0.319 mg/kg total mercury and 0.163 mg/kg to 0.299 mg/kg methyl mercury.

Stoneflies collected upstream of the Helen Mine tributary contained 0.121 mg/kg to 0.115 mg/kg total mercury and 0.078 mg/kg to 0.092 mg/kg methyl mercury. Stoneflies collected about 800 feet downstream of the Helen Mine tributary contained 0.061 mg/kg total mercury and 0.033 mg/kg methyl mercury.

Mercury concentrations in insects do not appear to show a significant difference based on location relative to the Helen Mine. Mercury concentrations appear to decrease in Dobsonflies and Stoneflies downstream of Helen Mine. Water strider mercury concentrations were similar in samples collected upstream and downstream of Helen Mine. Total mercury concentrations in backswimmers downstream of Helen Mine were higher than upstream concentrations; however, methyl mercury appeared to decrease in backswimmers downstream from Helen Mine.

3.6 Preliminary Conceptual Site Model

The purpose of a conceptual site model (CSM) is to identify complete exposure pathways for both human and ecological receptors in the vicinity of Helen Mine. An exposure pathway describes the course a chemical takes from a source to an exposed individual. A complete exposure pathway must exist for a contaminant to pose a potential health risk, and must consist of the following four elements:

1. Contaminant source
2. Release mechanism
3. Secondary source
4. Migration pathway
5. Exposure route

If an exposure pathway is incomplete, then it can be concluded that there is no current exposure. Consequently, adverse effects to either human health or ecological receptors would not be expected under the conditions of the CSM. Conversely, a completed exposure pathway indicates that adverse effects to human or ecological receptors are possible under the conditions of the CSM. The need for a removal action is evaluated for completed pathways in accordance with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) criteria. The NCP criteria are intended to evaluate the urgency of the situation as compared to the risks potentially associated with the presence of completed pathways. NCP criteria at Helen Mine are discussed in Section 5.0 of this RSI report.

A preliminary CSM indicating sources, release mechanisms, migration pathways, and exposure routes to receptors at the Helen Mine is presented in Figure 3. The CSM is described below for each environmental medium of concern.

Contaminant Source. Based on findings of previous environmental investigations, the primary source of mercury at Helen Mine is mine waste. Waste rock and calcines containing mercury are present on and below the ground surface at the site. Waste rock samples for chemical analysis have not been collected at the Helen Mine. One sample of calcines was collected and contained 17.9 mg/kg mercury.

Release Mechanisms. Mechanisms that could release mercury at Helen Mine include surface water runoff, infiltration, and erosion. Runoff releases mercury by eroding mine wastes and then transporting the eroded mine waste to soil or waterways. Infiltration causes release of mercury when infiltrating water interacts with mine waste to dissolve mercury and transport it to groundwater, or surface water. Wind erosion can release mercury by suspending mercury containing dust in the air, and water erosion can transport mine waste to sediment and surface water.

Secondary Source. Secondary sources at Helen Mine include surface water in the Helen Mine tributary, sediment, groundwater after interaction with the mine waste, soil containing mercury from mine wastes, and dust containing mercury.

Migration Pathway. Migration pathways at the site likely include direct exposure of humans and biota to mercury in water, direct contact of humans and biota with sediment and/or soil

containing mercury, and inhalation of mercury on dust. The groundwater pathway for humans is not complete because no wells exist at the site, and most of the groundwater likely discharges to surface water at Dry Creek.

Exposure Routes. Humans (trespassers, workers or surveyors) or wildlife could be exposed to mercury released from the Helen Mine by direct contact with mine wastes, sediment, and/or surface water affected by the mine; by eating plants or animals that have accumulated mercury from the mine; by drinking water affected by the mine; by ingesting mercury containing sediment or soil from the mine; and/or by breathing dust containing mercury from the mine.

Review of site data and consideration of site features results in fate and transport scenarios primarily involving dissolution of mercury from mine wastes and mechanical erosion of solids at the Helen Mine.

Mercury present in mine wastes is mobilized by chemical reactions with mine drainage and infiltrating surface water as water from these two sources flows through the mine waste (USGS 2008). This dissolved mercury is then available to be adsorbed onto sediment particles or remain in solution. In both forms (dissolved or adsorbed), mercury is transported into Dry Creek. The limited data available from the site (USGS 2008) show that mercury concentrations in Dry Creek surface water increase from upstream to downstream as water flows past Helen Mine.

Mine wastes are also mechanically eroded by wind and water. Eroded mine waste containing mercury (mostly as cinnabar) is transported to Dry Creek where it resides in the active channel sediment. Fine particles of mine waste that contain mercury may also become airborne as dust. USGS (2008) data appear to show that mercury concentrations in Dry Creek sediment increase at Helen Mine, however the data are not conclusive.

Dissolution of mercury from mine waste and erosion of mine waste both transport mercury to Dry Creek. A portion of this mercury is available to be methylated and accumulate in the food chain. Mercury is likely accumulating in Dry Creek biota, though available data do not demonstrate a significant effect in the food chain from the Helen Mine (USGS 2008).

4.0 RISK SCREENING

The completed pathways shown in the CSM identify the media and routes of exposure evaluated in human health and ecological risk screening presented in this section and that should be addressed by potential future response actions if necessary. Potential risks to human health and ecological receptors are evaluated by comparison to soil screening criteria. Sediment mercury concentrations are compared to risk based screening criteria for soils because generally applicable sediment screening criteria are not available. Burleson believes that the exposure of humans and fauna to mercury in sediment at the Helen Mine is similar to exposure of fauna and humans to soil for the purposes of risk screening. Threats to water quality are also described.

4.1 Human Health Risk Screening

Potential risks to human health were evaluated by comparing mercury concentrations in sediment and mine waste at the Helen Mine to screening criteria. Screening criteria used for this comparison include Risk Management Criteria (RMC) for Metals at BLM Mining Sites (BLM 2004), U.S. Environmental Protection Agency (EPA) Regional Screening Levels (RSL) for

Contaminants at Superfund Sites (EPA 2008), and California Human Health Screening Levels (CHHSL). The EPA RSLs and CHHSLs are calculated based on an industrial use scenario (for humans working at a site), which is routinely thought to reflect exposures greater than recreational exposures. The industrial exposure calculation assumes exposure of five 8-hour days per week for 50 weeks per year for 25 years. This is likely a greater exposure time than would be selected for recreational exposures. Therefore, use of the industrial RSL and CHHSL likely overstates the potential risk for recreational visitors.

Table 3 compares total mercury concentrations at Helen Mine to these human health risk-based screening criteria. The total mercury concentration in the Helen Mine calcines (17.9 mg/kg) was below human health screening criteria indicating a low risk for potential human receptors working or recreating at Helen Mine.

Total mercury concentrations in sediment from the Helen Mine tributary exceeded screening criteria for a BLM worker and the EPA RSL (from one to 10 times the RMC and the RSL indicating a moderate risk). Slight exceedance of screening levels is not thought to pose a significant risk (BLM 2004). Humans who work in contact with sediment in the Helen Mine tributary would be exposed to a moderate risk from exposure to mercury through ingestion, dermal contact, and inhalation of dust.

The total mercury concentrations in Dry Creek sediment about 800 feet downstream from Helen Mine are below human health screening criteria indicating a low risk for potential human receptors working or recreating there.

Total mercury concentrations in Dry Creek sediment at the inactive gauging station exceed screening criteria for a BLM worker and the EPA RSL (from one to 10 times the RMC and the RSL, indicating a moderate risk). Mercury concentrations at this location likely include contributions from the Wall Street Mine located downstream from Helen Mine. Slight exceedance of screening levels is not thought to pose a significant risk (BLM 2004). Humans who work in contact with sediment in Dry Creek at the inactive gauge would be exposed to a moderate risk from exposure to mercury through ingestion, dermal contact, and inhalation of dust.

4.2 Ecological Risk Screening

Potential risks to ecological receptors were evaluated by comparing mercury concentrations reported in sediment at Helen Mine to the median RMC for ecological receptors (BLM 2004); and by comparing the results of fauna sampling for mercury near Helen Mine to mercury in fauna downstream from the Helen Mine.

Table 3 presents a comparison of mercury concentrations in sediment at Helen Mine to the ecological screening criteria. Total mercury concentrations in sediment from the Helen Mine tributary slightly exceed 10 times the median wildlife screening concentration. Slight exceedance of screening criteria is not thought to pose a significant risk. However, the reported mercury concentrations in Helen Mine tributary sediment are above 10 times the median wildlife RMC. This degree of exceedance of the screening criteria is considered to potentially pose a high risk to ecological receptors (BLM 2004). Thus, fauna at the Helen Mine may be at high risk when exposed to Helen Mine tributary sediment by direct contact, incidental ingestion, and/or inhalation of dust.

Another way to evaluate potential ecological risk is to compare mercury concentrations detected in fauna upstream and downstream from the Helen Mine. Insects were sampled in Dry Creek upstream and downstream from Helen Mine. Insect mercury data do not appear to show a significant impact from the Helen Mine. Mercury appears to decrease in Dobsonflies and Stoneflies downstream from Helen Mine versus upstream. Water strider mercury levels appear to be the same in samples collected upstream and downstream from Helen Mine. Total mercury in backswimmers is elevated downstream from Helen Mine versus upstream; however, methyl mercury appears to decrease downstream. Thus, risks to ecological receptors from mercury at the Helen Mine, as represented by mercury in insects, appears to be negligible.

4.3 Water Quality

Water quality impacts at Helen Mine were evaluated by comparing detected concentrations to water quality criteria. The EPA ambient water quality criteria for total mercury based on human consumption of water and organisms is 51 ng/L. Water quality criteria are not currently available for methyl mercury.

Pore water in iron oxyhydroxide precipitates contained up to 741 ng/L dissolved total mercury. However, the mercury contained in pore water is incorporated into the downstream waters sampled within the Helen Mine tributary before the water discharges from the site. Sampling of surface water (mine drainage and runoff) at the Helen Mine detected unfiltered total mercury in water at concentrations up to 17.5 ng/L.

Limited water sampling data available from Dry Creek show an increase in mercury concentrations from upstream to downstream from Helen Mine. Total mercury concentrations increase as much as four times in Dry Creek based on comparison of surface water samples collected upstream (6.06 ng/L) and downstream (24.1 ng/L) from the confluence with the Helen Mine tributary.

Total mercury concentrations in on-site surface water at Helen Mine and in Dry Creek downstream from Helen Mine were below the 51 ng/L water quality criteria for mercury. Thus, water quality impacts from Helen Mine appear to be negligible.

5.0 BASIS FOR REMOVAL ACTION

The NCP identifies the following factors at 40 Code of Federal Regulations (CFR) Section 300.415(b)(2) to consider when determining the appropriateness of a removal action:

i. Actual or potential exposure to nearby human populations, animals, or the food chain from hazardous substances or pollutants or contaminants;

ii. Actual or potential contamination of drinking water supplies or sensitive ecosystems;

iii. Hazardous substances or pollutants or contaminants in drums, barrels, tanks, or other bulk storage containers, that may pose a threat of release;

iv. High levels of hazardous substances or pollutants or contaminants in soils largely at or near the surface that may migrate;

v. Weather conditions that may cause hazardous substances or pollutants or contaminants to migrate or be released;

vi. Threat of fire or explosion;

vii. The availability of other appropriated federal or state response mechanisms to respond to the release;

viii. Other situation or factors that may pose threats to public health or welfare of the United States or the environment.

These factors are evaluated for the Helen Mine below.

Factor (i) Actual or potential exposure to nearby human populations, animals, or the food chain from hazardous substances or pollutants or contaminants. Mercury levels in insects collected near the mine do not show a significant impact from the Helen Mine. Thus, the food chain does not appear to be affected by Helen Mine. While humans could potentially be exposed to mercury in sediment at the Helen Mine, the associated risks are anticipated to be moderate at the worst and are comparable to those risks from exposure to pre-mining sediment in the watershed. Mercury in soil sampled at the site to date is within screening levels for protection of human health, and presents a moderate risk to potential ecological receptors.

Factor (ii) Actual or potential contamination of drinking water supplies or sensitive ecosystems. Dry Creek is a tributary to Putah Creek which contributes to Lake Berryessa, a drinking water reservoir. Mercury concentrations in Dry Creek increased in downstream versus upstream samples with respect to the Helen Mine tributary. However, the maximum concentrations of mercury in surface water at Helen Mine and in Dry Creek below Helen Mine are below the water quality criteria, and other potential sources of contamination are present such as the Wall Street Mine located downstream from Helen Mine. The mass of mercury and volume of water contributed by Helen Mine to the watershed are insignificant with respect to the size of the watershed, and significant impacts to water quality are not anticipated based on available information. Sensitive ecosystems are not known to be present near Helen Mine.

Factor (iii) Hazardous substances or pollutants or contaminants in drums, barrels, tanks, or other bulk storage containers, that may pose a threat of release. There are no drums, barrels, tanks or other bulk storage containers at Helen Mine.

Factor (iv) High levels of hazardous substances or pollutants or contaminants in soils largely at or near the surface that may migrate. High levels of hazardous substances or pollutants or contaminants have not been reliably detected in soils at Helen Mine.

Factor (v) Weather conditions that may cause hazardous substances or pollutants or contaminants to migrate or be released. Rainfall can cause runoff that could erode and transport mercury containing mine waste from Helen Mine to Dry Creek. However, available data from Helen Mine do not identify mercury concentrations above levels measured by USGS (2008) in pre-mining sediment.

Factor (vi) Threat of fire or explosion. There is no known threat of fire or explosion at Helen Mine.

Factor (vii) The availability of other appropriated federal or state response mechanisms to respond to the release. There are no other federal or state response mechanisms known that would respond to a release from Helen Mine.

Factor (viii) Other situation or factors that may pose threats to public health or welfare of the United States or the environment. There are no other situations or factors that may pose threats to public health or welfare of the United States or the environment known at Helen Mine.

Based upon consideration of these NCP factors, and consideration of the risk screening in Section 4 above, a removal action does not appear to be necessary at Helen Mine. However, data from only one sample of calcines, and six samples of iron oxy-hydroxide were collected from Helen Mine. It is possible that the evaluation of Factors (i), (iv), and (v) would change if data from sampling of waste rock present at the site were available. Burleson recommends that BLM conduct sampling and analysis to determine the mercury content of waste rock at the site. These data would document whether mine waste containing elevated mercury was present at Helen Mine, and verify the evaluation of removal action factors for the site. Burleson also recommends sampling and analysis of sediment in Dry Creek upstream and downstream of the tributary from the Wall Street Mine to evaluate impacts of this feature on the watershed.

6.0 REFERENCES

U.S. Bureau of Mines. 1965. Information Circular 8252: Mercury Potential of the United States. Page 108.

U.S. Department of the Interior Bureau of Land Management. 2004. Risk Management Criteria for Metals.at BLM Mining Sites. Technical Note 390 revised. October

U.S. Department of the Interior Bureau of Land Management. 2008. Cultural Resource Inventory Report: *An Archaeological Inventory and Recordation of the Helen Mercury Mine*. October.

U.S. Department of the Interior Bureau of Land Management. 2008. Biological/Botanical Resource Inventory Report: *Helen Mine RSI*. October.

U. S. Environmental Protection Agency. 2008. Regional Screening Levels (RSL) for Chemical Contaminants at Superfund Sites. RSL Table Update. September.

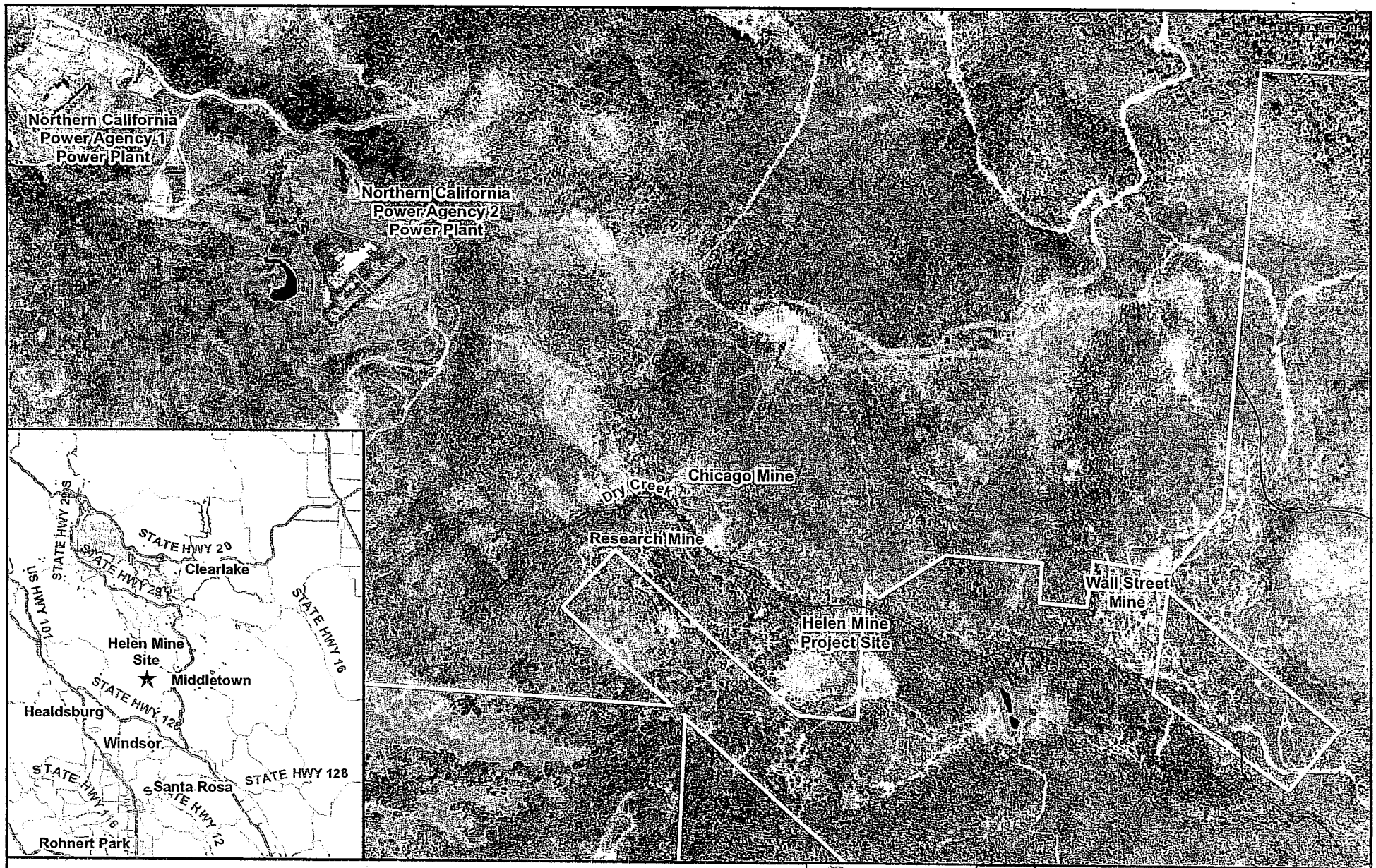
U.S. Geological Survey. 2008. Administrative Report 08-1297: Environmental Impact of the Helen, Research, and Chicago Mercury Mines on Water, Sediment, and Biota in the Upper Dry Creek Watershed, Lake County, California.

U.S. Geological Survey National Water Information System: Web Interface. 2008. http://waterdata.usgs.gov/nwis/nwismap, Accessed December 19.

Western Region Climate Center. 2008. http://www.wrcc.dri.edu/ Accessed December 17.

Figures

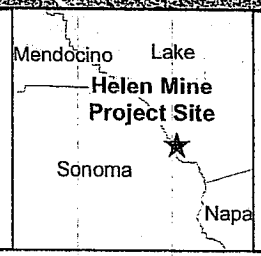
3 Pages



Legend

Bureau of Land Managment Administered Land

Creeks



N

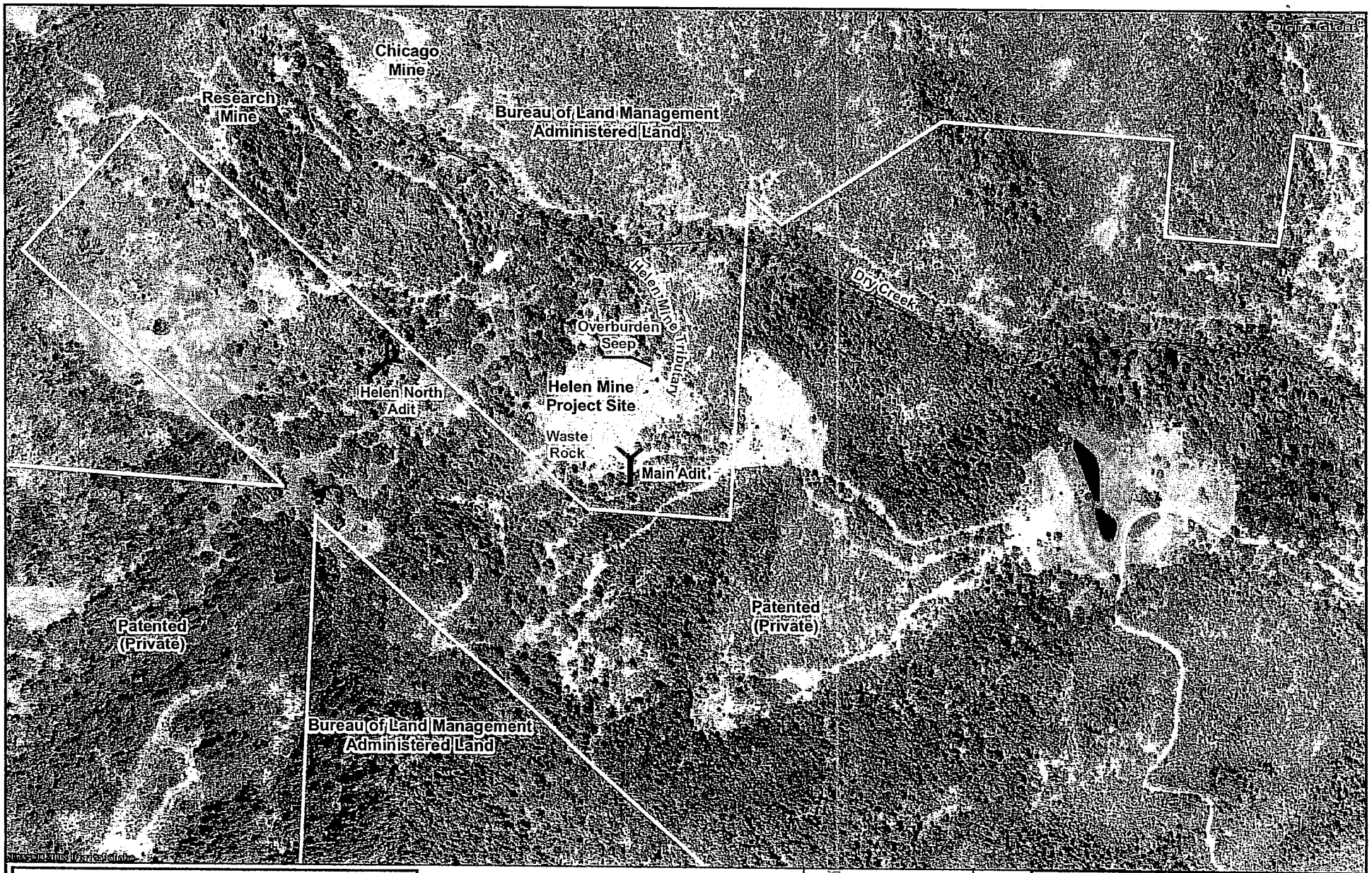
Figure 1

Site Location
Bureau of Land Management
Helen Mine

Burleson Consulting, Inc.

0 750 1,500 2,250
Feet

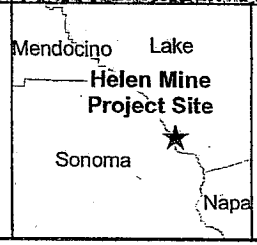
Data Source: BLM administered land designation provided by the Bureau of Land Management GIS Deptartment
Aerial image provided by Digital Globe 4-1-2007



Legend

- Bureau of Land Managment Administered Land
- Creeks
- Helen Mine Tributary

Data Source: BLM administered land designation provided by the Bureau of Land Management GIS Deptartment
Aerial image provided by Digital Globe 4-1-2007



N

Figure 2

Site Features
Bureau of Land Management
Helen Mine

Burleson Consulting, Inc.

0 300 600 900
Feet

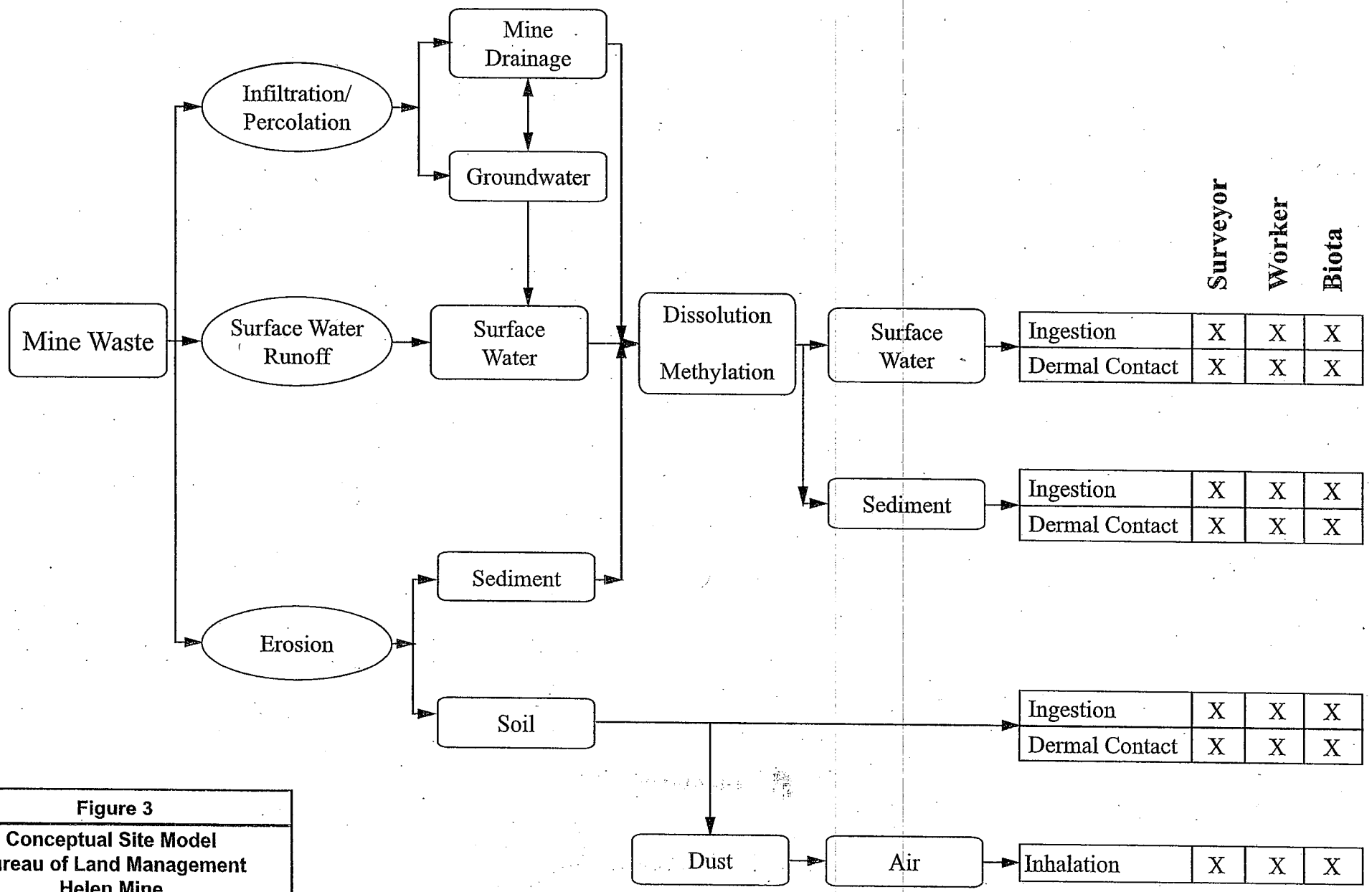


Figure 3

Conceptual Site Model
Bureau of Land Management
Helen Mine

Burleson Consulting, Inc.

Tables

4 Pages

Table 1
Mine Waste and Precipitate Analytical Results
Helen Mine, Lake County, California

Sample Number	Date	Sample Site Description	Material	Total Hg (mg/kg)	Methyl Hg (mg/kg)
21HM-1S	4/19/2001	Helen Mine Main Adit	Iron Oxy-Hydroxide Precipitate	1.13	NA
21HM-1	4/19/2001	Helen Mine Main Adit	Iron Oxy-Hydroxide Precipitate	14.70	NA
23HM 9S	7/15/2003	Helen Mine Main Adit	Iron Oxy-Hydroxide Precipitate	0.09	NA
23HM 9	7/15/2003	Helen Mine Main Adit	Iron Oxy-Hydroxide Precipitate	0.017	0.000734
21HM-2S	4/19/2001	Helen Mine Lowest Mine Drainage Seep	Iron Oxy-Hydroxide Precipitate	1.79	NA
21HM-2SA	4/19/2001	Helen Mine Lowest Mine Drainage Seep	Iron Oxy-Hydroxide Precipitate	0.54	NA
21HM-2	4/19/2001	Helen Mine Lowest Mine Drainage Seep	Iron Oxy-Hydroxide Precipitate	0.357	NA
23HM 11S	7/15/2003	Helen Mine Lowest Mine Drainage Seep	Iron Oxy-Hydroxide Precipitate	5.19	NA
23HM 11	7/15/2003	Helen Mine Lowest Mine Drainage Seep	Iron Oxy-Hydroxide Precipitate	16.32	0.000176
22 DC 9	7/31/2002	Iron Precipitate Below Waste Rock from Mine Drainage	Iron Oxy-Hydroxide Precipitate	550.00	NA
HL0401C1	4/19/2001	Calcine Below and West of Waste Rock	Tailings	17.91	NA

Note: Source is USGS (2008)
NA = Not Analyzed
mg/kg = milligrams/kilogram

Table 2
Mine Drainage and Surface Water Mercury Concentrations
Helen Mine, Lake County, California

Sample Number	Location	Date	Total Hg (ng/L)	Dissolved Hg (ng/L)	Total Methyl Hg (ng/L)
21HM1	Helen Mine Main Adit	4/19/2001	9.56	4.78	<0.02
23HM9	Helen Mine Main Adit	7/15/2003	0.61	0.37	<0.025
HEL0703SED1A	Pore Water from Upper 6" of Core Augered into Upper (Main) Adit Mine Drainage	7/15/2003	741	NA	NA
HEL0703SED1B	Pore Water from Upper 6" of Core Augered into Upper (Main) Adit Mine Drainage	7/15/2003	52	NA	NA
HEL0703W3	Mine Drainage from Upper (Main) Adit	7/15/2003	2.78	NA	NA
HEL0703W3.F	Same as W3 but Filtered through a 0.02 Micron Membrane	7/15/2003	1.76	NA	NA
HEL0703W5	Water in Standing Pool Downstream of Upper (Main) Adit Drainage Terminus	7/15/2003	4.62	NA	0.25
21HM2	Helen Mine Lowest Mine Drainage Seep	4/19/2001	17.5	1.8	0.026
23HM10	Helen Mine Waste Rock Channel of Mine Drainage	7/15/2003	5.94	3.09	<0.025
23HM11	Helen Mine Lowest Mine Drainage Seep	7/15/2003	3.44	0.48	<0.025
HEL0703W4	Lower Seep Mine Drainage	7/15/2003	1.55	NA	NA
HEL0703FB	Field Blank	7/15/2003	1.89	NA	NA
21HM3	Helen Mine Creek Drainage above Confluence with Dry Creek	4/19/2001	7.62	1.05	0.051
23HM8	Helen Mine Creek Upstream from Confluence with Dry Creek	7/15/2003	17.7	3.2	0.026
23HM5	Dry Creek above Helen Mine Tributary Confluence	4/1/2003	6.06	3.77	<0.025
23HM6	Dry Creek 0.25 Kilometer Down from Helen Mine Creek Confluence	4/1/2003	24.1	2.75	<0.025
23HM7	Down Stream from Helen Mine Confluence	7/15/2003	9.15	5.79	<0.025
21DR1	Gaging Station on Upper Dry Creek	4/19/2001	7.24	3.05	<0.020
22DC6A	Upper Gaging Station	7/31/2002	5.35	3.46	<0.025

Notes: Source is USGS (2008)
NA = Not analyzed
< = not detected at level of detection
mg/L = milligrams/Liter
ng/L = nanograms/Liter

Table 3
Mercury in Sediment, Helen Mine Vicinity
Helen Mine, Lake County, California

Sample Number	Location	Date	Total Mercury (mg/kg)	Methyl Mercury (ng/g)
23HM 5S	Dry Creek above Helen Mine Tributary Confluence	4/1/2003	2.99	NA
23HM5		4/1/2003	1.44	0.054
21HM - 3S	Helen Mine Ck Tributary above confluence with Dry Creek	4/19/2001	**90.80**	N/C
21HM3		4/19/2001	4.91	N/C
23HM 3S		4/1/2003	**16.45**	N/C
23HM 8S		7/15/2003	6.92	N/C
23HM8		7/15/2003	0.204	0.063
HL0401C1	Helen Mine Calcines	4/19/2001	**17.91**	N/C
23HM 6S	Dry Creek 800 feet Downstream from Helen Mine Tributary Confluence	4/1/2003	3.70	N/C
23HM6		4/1/2003	**681.00**	0.106
23HM 7S		7/15/2003	5.93	N/C
23HM7		7/15/2003	0.471	0.05
21DR - 1S	Inactive USGS Gaging Station on Upper Dry Creek	4/19/2001	**13.50**	N/C
21DR - 1		4/19/2001	2.71	0.11
22DC 6A		7/31/2002	**90.01**	N/C
22DC 6A		7/31/2002	0.293	0.597
23DC 6S		4/1/2003	**9.02**	N/C
US EPA Regional Screening Level-Industrial			28.00	100,000
California Human Health Screening Level-Industrial			180.00	NP
US BLM Risk Management Criteria-Surveyor			480.00	NP
US BLM Risk Management Criteria-Worker			60.00	NP
US BLM Risk Management Criteria-Median Wildlife Criteria			8.00	NP

Notes: Source of Data is USGS (2008)
N/C = Sample not collected for this analysis
N/A = Sample not analyzed for this analyte
NP = Not Provided
mg/kg = milligrams/kilogram
ng/kg = nanograms/kilogram

Table 4
Mercury in Dry Creek Sediment
Helen Mine, Lake County, California

Type	Number	Date	Location	Total Mercury (mg/kg)	Methyl Mercury (ng/g)
Pre-Mining Sediment	22 DC 6B	7/31/2002	Inactive USGS Gaging Station on Upper Dry Creek	27.10	N/C
	22 DC 1BB	7/31/2002	Lower Gaging Station	41.50	N/C
	22 DC 1B	7/15/2003		0.30	0.195
	23DC 1PMS	4/1/2003	Below Paved Road	0.93	N/C
	22 DC 5	7/31/2002	At Road	3.61	N/C
	22 DC 5A	7/31/2002		8.57	N/C
	22 DC 4B	7/31/2002	450 Feet Below Road	66.20	N/C
Active Channel Sediment	22 DC 1BB	7/31/2002	Lower Gaging Station	71.00	N/C
	22 DC 2	7/31/2002	0.25 Miles Above Road Crossing	43.00	N/C
	23DC 1S	4/1/2003	Dry Creek near Site of 22DC2	7.36	N/C
	23DC 1BS	4/1/2003	Back Eddy Pool near 22DC2	5.92	N/C
	22 DC 3	7/31/2002	50 Feet Upstream Road Cross	230.00	N/C
	22 DC 5B	7/31/2002	Dry Pool 100' Below Road Cross Creek	25.50	N/C
	22 DC 4A	7/31/2002	450' Below Road Crossing	150.00	N/C
	22 DC 11	7/31/2002	Highway 175	160.00	N/C

Notes: Source of data is USGS (2008)
N/C = Sample not collected for this analysis
N/A = Sample not analyzed for this analyte
mg/kg = milligrams/kilogram
ng/kg = nanograms/kilogram