



Preliminary Report on Mercury Geochemistry of Placer Gold Dredge Tailings, Sediments, Bedrock, and Waters in the Clear Creek Restoration Area, Shasta County, California

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Abstract

Clear Creek, one of the major tributaries of the upper Sacramento River, drains the eastern Trinity Mountains. Alluvial plain and terrace gravels of lower Clear Creek, at the northwest edge of the Sacramento Valley, contain placer gold that has been mined since the Gold Rush by various methods including dredging. In addition, from the 1950s to the 1980s aggregate-mining operations removed gravel from the lower Clear Creek flood plain.

Since Clear Creek is an important stream for salmon production, a habitat restoration program is underway to repair damage from mining and improve conditions for spawning. This program includes using dredge tailings to fill in gravel pits in the flood plain, raising the concern that mercury lost to these tailings in the gold recovery process may be released and become available to biota. The purposes of our study are to determine concentrations and speciation of mercury in sediments, tailings, and water in the lower Clear Creek area, and to determine its mobility.

Mercury concentrations in bedrock and unmined gravels both within and above the mined area are low, and are taken to represent background concentrations. Bulk mercury values in flood-plain sediments and dry tailings are elevated to several times these background concentrations. Mercury in sediments and tailings is associated with fine size fractions. Although methylmercury levels are generally low in sediments, shallow ponds in the flood plain may have above-normal methylation potential.

Stream waters in the area show low mercury and methylmercury levels. Ponds with elevated methylmercury in sediments have more methylmercury in their waters as well. One seep in the area is highly saline, and enriched in mercury, lithium, and boron, similar to connate waters that are expelled along thrust faults to the south on the west side of the Sacramento Valley. This occurrence suggests that mercury in waters may at least in part be from sources other than placer mining.

Introduction

The Klamath Mountains of northern California and southwestern Oregon have produced significant amounts of gold, both from placer and lode deposits. The most important placer deposits occur along the major rivers, including Clear Creek and the Trinity, Klamath, and Smith Rivers, and their tributaries (Clark, 1970). The placers of lower Clear Creek, which are the subject of this report, have been mined intermittently by various methods since the 1850s (Clark, 1970; Averill, 1933), with the result that all the alluvial gravel forming the flood plain of Clear Creek and most of the gravel capping adjacent terraces has been disturbed. In addition, in recent decades gravel has been removed from the lower Clear Creek alluvial system for aggregate.

Through most of the placer mining period, mercury was used for recovery of gold by amalgamation, resulting in contamination of the sediment that was processed. Elevated levels of mercury have been recognized as a water quality problem throughout the Sacramento River basin (Domagalski, 1998; Domagalski and others, 2000). Sources of this mercury include mercury mines in the Coast Ranges and mercury losses from gold mining operations, both placer and lode, in the Klamath Mountains and Sierra Nevada.

Habitat restoration for migratory salmon has been underway in the lower Clear Creek basin since 1998. Mercury contents of the sediments impounded behind Saeltzer Dam, in the upper part of the lower Clear Creek basin, were examined as part of a floodway rehabilitation project involving removal of the dam (Yahnke, 2001). Sediments that have been exposed to mercury have been used for flood plain restoration, and may be used in the future. The purpose of this study is to determine how much mercury has been added to the sediments, how it is distributed within them, how it may be released, and whether unusual amounts of methylmercury are associated with sediments under any conditions. In addition we have looked at mercury and methylmercury concentrations in springs, ponds, and Clear Creek itself within and above the restoration area, to determine whether significant amounts of mercury are being leached from sediments into waters, and whether there are conditions permitting high rates of methylation. A study of mercury levels in biota is being carried out concurrently to determine whether amounts of methylmercury greater than background levels are entering the food chain in the area.

Mining History

Following the initial discovery of gold in gravels of the Trinity River in 1848, placer deposits were the main source of gold in the region until the 1880s (Clark, 1970). Gold was discovered in Clear Creek in 1849. Several mining camps were established in the lower Clear Creek drainage basin, including Whiskeytown, Horsetown, Shasta, and Igo. For the first few years, crude methods were used to mine the gravels in the active channel and adjacent flood plain; mercury was not available for gold recovery.

In the mid-1850s hydraulic mining was developed. In this mining method, hydraulic monitors were used to excavate off-stream gravels, especially in paleochannels or on benches. Extensive systems of sluices charged with mercury were used to recover the gold. Hydraulic mining of the terrace deposits in the lower Clear Creek area likely took place mainly before 1884, at which time most hydraulic mining in tributaries of the Sacramento and San Joaquin Rivers was shut down by judicial decree (Sawyer Decision).

From the 1880s until World War I, lode and placer mines produced roughly equal amounts of gold in the Klamath Mountains. Gold production declined in the 1920s, but revived in the 1930s as many dredges were put in operation, returning placer deposits to prominence. The placer deposits of lower Clear Creek supported numerous dredging

operations (Averill, 1933). Large areas in the lower Clear Creek valley and some tributary drainages were dredged during this period, using both drag-line and bucket-line dredges. Most mining operations were forced to close in 1942 in response to War Production Board Order L-208, and few were able to reopen after World War II.

Bedrock in the area hosts some narrow and shallow gold-quartz veins that yielded small but rich pockets. The most productive of these was the Yankee John mine, located about 3 km north of the center of the study area. The French Gulch district, the largest lode gold district in the Klamath Mountains, lies in the Clear Creek drainage basin north of Whiskeytown, above the main placer-mining areas.

Aggregate mining began in the lower Clear Creek basin in the 1950s. Gravel has been obtained both from in-stream and off-stream pits. Mining in-stream and in the adjacent flood plain ceased in the 1980s, but off-stream mining continues.

Geology

The Klamath Mountains in northern California consist of a series of northwest- to north-trending terranes, or belts of deformed and metamorphosed sedimentary and volcanic rocks ranging in age from Ordovician to Jurassic (Irwin, 1972, 1981). These belts represent a stack of east-dipping thrust plates; from east to west the belts comprise progressively younger rocks. The thrust-fault zones that bound the plates contain ultramafic bodies that are mostly serpentinized. Numerous granitic plutons ranging in age from Devonian through Cretaceous intrude the terranes. Groups of plutons of similar age form belts that parallel the trends of their host rocks (Irwin, 1985).

The Clear Creek drainage basin lies entirely within the Eastern Klamath Terrane, the easternmost and oldest of the belts recognized in the Klamath Mountains. The upper part of the basin, in the French Gulch area and northward, is dominated by slates of the Bragdon Formation of Mississippian age. The lower part of the basin is underlain by metavolcanic rocks of Devonian or older age, including the Copley Greenstone and the Balaklala Rhyolite, and granitic rocks including the Mule Mountain stock of Devonian age, and the Shasta Bally batholith of Early Cretaceous age (Strand, 1962; Albers, 1964; Kinkel, Hall, and Albers, 1956; Fraticelli and others, 1987).

The oldest rocks in the Great Valley province are nearly unmetamorphosed Late Jurassic and Cretaceous marine sedimentary rocks of the Great Valley sequence, which crops out along the west side of the Sacramento Valley. Lithologies include mudstone, graywacke, conglomerate, and shale. There are small exposure areas of both Lower and Upper Cretaceous on the north side of Clear Creek (Strand, 1962).

Formations of Tertiary and Quaternary age occupy most of the area of the Great Valley province, including lower Clear Creek. Tertiary rocks in the lower Clear Creek area are

included in the Tehama Formation of Pliocene age (Helley and Harwood, 1986). It consists of sandstone and siltstone with lenses of conglomerate derived from the Coast Ranges and Klamath Mountains to the west and north. The Tehama grades eastward into the Tuscan Formation, which consists of volcanic and volcanoclastic rocks erupted and transported from volcanic vents in the Cascades volcanic province to the east.

The Nomlaki Tuff Member of the Tehama Formation is locally exposed in the bluffs and gulches incised into the terrace on the north side of Clear Creek. Some of the best exposures are in drainage cuts and tunnels related to hydraulic mining. The Nomlaki is a dacitic ash-flow tuff, water-reworked in some areas (Helley and Harwood, 1986). In the vicinity of lower Clear Creek it is typically a white or pale gray massive, non-welded pumice lapilli tuff. Its stratigraphic position is at or near the base of the Tehama Formation, and it has been dated at 3.4 Ma (Evernden and others, 1964).

The Tehama Formation is overlain unconformably by the Red Bluff Formation of Quaternary age, which forms a thin veneer of red, weathered gravels. Helley and Harwood (1986) interpret the Red Bluff as a sedimentary cover on a widespread pediment surface that formed in the Sacramento Valley between 450 Ka and about 1.08 Ma. It occupies the broad flat divide between lower Clear Creek and Dry Creek to the south, and scattered patches remain on the north side of Clear Creek. It probably covered the terrace on the north side of Clear Creek that was extensively mined by hydraulic methods.

The flood plain of Clear Creek, including low terraces adjacent to the active stream channel, is underlain by alluvium of Holocene age. The bulk of this material is probably gravel and sand. As a result of restricted sediment supply in the current hydrologic regime, at many places the stream has eroded down to a hard-pan clay layer.

Sample Sites

Samples were collected to characterize mercury species and associated elements in gold placer tailings, bedrock, sediments, and stream and pond waters in and adjacent to the Clear Creek restoration area. Samples were collected from August 27 to 29, 2001, during late summer base stream-flow conditions. During the time of sampling, the weather was stable and no precipitation occurred. Field sites are shown on Figure 1 and listed and described in Table 1 along with all samples collected at each site. The geographic coordinates in Table 1 were obtained in the field using a hand-held Global Positioning System (GPS) unit.

Field samples are clustered in four parts of the area (Figure 1 and Table 1). The eastern group of samples (21CC1,2,3,4,5,6,7) includes sediments and waters from three ponds in the floodplain. South Pond (Figure 2), the largest of the three, was an aggregate pit. The other two, designated East Pond (Figure 3) and Pond 3 (Figure 4), probably represent

remnants of abandoned channels. South Pond and Pond 3 were filled in summer 2001 as part of the restoration program.

The next group of samples to the west (21CC8,9,10,11) include hydraulic mine tailings, water and tailings from a hydraulic mine drainage tunnel, and the Nomlaki tuff, which forms the substrate beneath the gravels that were mined by hydraulic methods. In addition, sediments and water from Clear Creek were sampled; this site is immediately above the restoration project area, but still within the reach that was mined.

The cluster of samples toward the west end of the area (21CC12,13,14,15,16) comprises mainly tailings. One site yielded gravel from drag-line dredge stacker piles along Spring Creek, an intermittent tributary of Clear Creek (Figure 5). The second site yielded gravel from probable bucket-line dredge stacker piles on a low Clear Creek terrace. The third site is a backhoe trench dug in probable bucket-line dredge tailings on the same low terrace, both coarse stacker tailings and fine sluice tailings, at the site of a former rifle range known as the “Shooting Gallery” (Figure 6). Also in the Spring Creek drainage is an impoundment remaining from dredging known as “Red Pond” (Figure 7), which catches water from saline springs. Adjacent to Red Pond are exposures of Tehama Formation gravels beneath the Nomlaki Tuff that contain prospect and short drift mine tunnels (Figure 8). We sampled Red Pond water and sediment, and unmined gravel from a drift tunnel.

The westernmost samples (21CC18,19) are located at the U.S. Geological Survey stream gauging station known as the “Igo Gauge.” This site provided water and sediment upstream from the mined area.

Field Sampling Methods

Dry sediments and tailings

We separated material coarser than 2 mm (the lower size limit for gravel in the standard Wentworth size classification scheme) from material finer than 2 mm (the upper size limit for sand in the Wentworth scheme), using a steel wire-mesh screen. We did not attempt to separate any finer fractions in the field, because dry sieving done by hand is ineffective in removing fines from coarser particles. Also we did not homogenize and split bulk material to provide all subsamples; we screened approximately 5 kg of material dug from a shallow hole or cut from trench walls at each site. Separate grab samples dug from the same holes or cuts supplied material for the bulk subsamples.

All dry tailings subsamples were placed in pre-cleaned and certified borosilicate glass jars with Teflon™ seals (I-CHEM™ Series 300). The maximum amount of material retained for any subsample was generally 1-2 kg.

Wet sediments and tailings

Wet sediments and tailings were wet-sieved in the field using stainless steel sieves and 1-2 liters of ambient water. The sieves used are dedicated to handling of materials expected to have low levels of mercury and other metals; however, we have not run blanks to determine whether these sieves contribute significant amounts of metals to samples. Although several size fractions were obtained at some sites, those analyzed and reported here are >2 mm, <2 mm, <63 μm , and unsieved bulk.

Certified TeflonTM-sealed I-CHEMTM glass jars (the same as for dry sediments) were used for subsamples analyzed for metals. Polycarbonate jars (100 ml capacity) were used for mercury subsamples. These were frozen with dry ice immediately after collection (freezing time approximately 20-30 minutes), and kept frozen until analysis.

Waters

Spring and stream waters were grab samples collected in 1-liter HDPE bottles; all subsamples for analysis of metals and anions were removed from the same 1-liter bottle.

Water sampling protocols used here, including bottle preparation and sample preservation, generally follow those of Water Resources Division of the U.S. Geological Survey for trace metals (Horowitz and others, 1994). Field filtrations were generally done with disposable 25 mm-diameter sterile cellulose acetate filters (0.45 μm openings) and disposable syringes.

For metals determinations, both filtered and unfiltered subsamples were preserved with Ultrex-grade HNO_3 , acidified to $\text{pH}<2$, and stored in HDPE (high-density polyethylene) bottles pre-rinsed with similar trace-metals grade acid. Subsamples for anion determinations were filtered, stored in HDPE bottles, and chilled to $<4^\circ\text{C}$ until analysis. Subsamples for alkalinity determinations were treated similarly but were not filtered.

Sampling for mercury analysis followed ultra-clean sampling and handling protocols (Bloom, 1995, Gill and Fitzgerald, 1987) during the collection of field samples and analysis to avoid introduction of mercury. Subsamples for mercury analysis were separate grab samples collected in 1-liter borosilicate bottles (I-CHEMTM Series 300, spot-checked for mercury levels by Frontier Geosciences) with excluding TeflonTM caps (to eliminate head space), and kept chilled to $<4^\circ\text{C}$ until analysis.

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 used for the field samples.

Water 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. Dissolved oxygen concentrations were determined with a CHEMets® colorimetric field test kit (CHEMetrics, Inc.).

Laboratory blanks and acid blanks were processed periodically to determine whether our equipment, containers, reagents, and procedures introduced significant contamination.

Analytical Methods

Sediments and rocks

Multi-element analyses for all dry sediments and rocks 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 inductively coupled plasma-atomic absorption spectroscopy (ICP-AES). Minor elements other than mercury were determined by inductively coupled plasma-mass spectrometry (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 methylmercury analyses for all wet sediments were carried out at Frontier Geosciences. Some dry sediments analyzed by Chemex were also analyzed by Frontier. For total mercury, 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, Bloom, and Liang, 1993). Results were reported on both a wet- and dry-weight basis.

Chemex and Frontier sample preparation steps are shown for comparison in Table 2. 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 mercury, adsorbed mercury, mercury in amalgams, and combined mercury including mercury 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 inductively coupled plasma-atomic emission spectrometry (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS). Ion chromatography and alkalinity analyses were performed by U.S.G.S. laboratories under the direction of Paul Lamothe. The ICP-AES analyses were determined by U.S.G.S. laboratories under the direction of Paul Briggs. Duplicate water samples, blank samples, and U.S.G.S. 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 mercury. An ultra-clean mercury 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 are also routinely monitored for low levels of mercury. Primary standards used in the laboratory were NIST-certified or traceable to NIST-certified materials. Methylmercury (MMHg) standards were made from pure powder and calibrated against NBS-3133, and 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 cold vapor atomic fluorescence spectroscopy (CVAFS) (Bloom, Crecelius, and Fitzgerald, 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 gas chromatographic (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.

Results For Dry Sediments and Tailings

Figure 9 shows results for dry tailings, sediments, and bedrock samples; analytical data are shown in Tables 3 and 4. The bedrock category consists of pebble composites for metamorphic rocks and plutonic rocks (6-10 pebbles each) and Nomlaki Tuff from an exposure in a hydraulic mine drainage cut. The pebbles came from the gravel being used at the time of sampling to fill South Pond, which was from the flood plain in the vicinity

of that pond. Metamorphic rock types dominate the Clear Creek sediments. Granitic rock clasts are common but subordinate to metamorphic types. These materials all show relatively low mercury values (10-30 ng/g). All subsamples of unmined gravel from the Tehama Formation (>2 mm, <2 mm, and bulk) did not have detectable levels of mercury, at a 10 ng/g threshold. These limited data suggest that background mercury values in the area are relatively low, and a background range of <10-30 ng/g is assumed here for comparison purposes.

The remaining categories in Figure 9 represent results for dredge stacker tailings in the Spring Creek area, tailings at the Shooting Gallery, and hydraulic tailings at the hydraulic mine drainage cut. The Clear Creek gravel reported here is from a gravel bar adjacent to the active channel. At all sites where bulk material was analyzed, it is enriched in mercury relative to probable background values, but values for the >2 mm fraction are lower than the bulk values. In several cases the <2 mm fraction is higher than the bulk value, as expected from the relatively lower values for the >2 mm fractions, but the two Spring Creek sites show lower values for the <2 mm fraction than for bulk material. Either sampling or analytical error or both may account for this apparently anomalous relationship between values for bulk versus coarse and fine fractions.

Figure 6 shows in more detail the relationship between mercury concentrations and grain size. The photo shows part of the wall of the backhoe trench sampled at the Shooting Gallery site. Here the coarse tailings at the top of the section are very poorly sorted, and mercury is clearly enriched in the <2 mm fraction, which includes sand, silt, and clay (values for the fractions from this layer are those shown in Figure 9). The layer below contains the finest material in the section (silt-clay), which shows the highest mercury value (160 ng/g), whereas sand interbedded with and underlying the silt-clay shows an intermediate value of 90 ng/g. Bulk values for the >2 mm portion of the coarse upper layer approach background (40 ng/g).

Various criteria have been proposed for evaluating mercury levels in bulk sediments (U.S. Environmental Protection Agency, 1997). The lowest of these is the U.S. EPA Threshold Effects Level (TEL), at 130 ng/g. This is a proposed lower limit for effects on biota, above which there is potential for observable effects such as bioaccumulation and biomagnification. Only the fine sediment fractions at the Shooting Gallery site exceed this level.

Methylmercury values for dry tailings and sediments are all very low, ranging from <0.015 ng/g to 0.387 ng/g, indicating that no extraordinary conditions favorable for methylation of mercury occur in these materials in the area.

Results For Wet Sediments and Tailings

Figure 10 shows results for wet sediments and tailings. Mercury values for bulk material from the South Pond exceed any bulk values obtained for dry tailings. This material was

local tailings being used at the time of sampling to fill the South Pond. Bulk sediments from the other two ponds, which were still undisturbed at the time of sampling, are slightly elevated but close to background levels. Sediment from the mouth of the hydraulic mine drainage tunnel, which probably represents hydraulic tailings, is also clearly enriched in mercury. Bulk sediment from the active channel of Clear Creek west of the restoration project area showed a mercury concentration similar to those in South Pond and the hydraulic drainage tunnel, whereas mercury in Clear Creek sediment at the Igo Gauge is at background levels.

At all sites where silt-clay size material (<63 μm) was separated and analyzed, it shows substantially higher mercury concentrations than bulk material, regardless of the bulk mercury concentration. Mud from Red Pond, which is similarly fine-grained, has a mercury level similar to fine-grained material at other sites. Bulk mercury values are generally below the EPA TEL of 130 ng/g, whereas fine fractions all exceed it.

Figure 11 shows results of methylmercury analyses for the same sites and subsamples as shown in Figure 10. Methylmercury generally shows the same tendency to be enriched in the fine fraction relative to bulk material. With the exception of Red Pond, methylmercury generally accounts for about one percent of total mercury present, which indicates normal rates of conversion of mercury to methylmercury. Conditions in Red Pond, however, apparently strongly favor methylation processes.

We have not attempted to evaluate atmospheric deposition of mercury, which could add to total mercury in sediments and tailings in the area (Fitzgerald and others, 1998). Notable increases in mercury concentrations in soils and sediments from atmospheric deposition, however, are likely to be restricted to within a few centimeters of the surface (see, e.g., Rood and others, 1995). Also we have not yet attempted to evaluate mercury vapor emission and redeposition, which could reduce or redistribute mercury. The observation that finer grain-size materials generally show the highest mercury concentrations, which is anticipated based on the gold recovery processes used, suggests that gold mining is the main source of mercury in the area.

Effect of Sample Treatment on Analytical Results, and Implications

About 60 percent of the sediment and tailings samples, both wet and dry, were analyzed by both Chemex and Frontier laboratories using different methods of preparation and analysis (see section on analytical methods for sediments and rocks, and Table 2).

Results are compared in Figure 12. Identical results fall on the 1:1 line in the figure. The lines on either side of the 1:1 line show a two-standard deviation analytical error envelope. The analytical error is not rigorously determined from replicate analysis, but rather is estimated from laboratory experience. The comparison plot demonstrates that samples with low mercury concentrations (less than 30 ng/g) show similar results by both

methods. At higher mercury concentrations, samples whose median grain size is sand size or smaller also yield similar results by both methods. Results that fall outside the envelope, considered likely to be significantly different, are all for samples with large median grain size, and in all cases the Frontier analyses show the higher mercury values. Because the Frontier analysis method does not include material from the silicate clasts, which are likely low in mercury, this indicates that much of the mercury present is associated with sand or smaller grain sizes and localized in aqua regia-leachable mineral grains or coatings on silicate grains. The mercury in leachable grains and coatings is also incorporated in the Chemex analyses, but the pulverization and digestion includes low-mercury material from clasts. Although mercury losses from the Chemex drying step cannot be ruled out, the similarity between Chemex and Frontier results for other samples, especially those having relatively high mercury concentrations and relatively small grain size, suggest that such losses are not significant.

Results For Waters

Figure 13 shows results for waters, which were sampled at the same sites as wet sediments (Figures 10 and 11; data in Tables 5 and 6). The stacked bars show the total mercury concentrations, as well as proportions of dissolved versus suspended mercury. “Dissolved” mercury is here operationally defined as the concentration of mercury measured in an aliquot passing a 0.45 μm filter. The filtration was done in the laboratory under ultra-clean mercury-free conditions (see section on analytical methods for waters).

Except for water impounded at the outlet of the hydraulic mine drainage tunnel, total mercury values are generally low, and similar to many values for waters obtained elsewhere in the Sacramento River Basin (Domagalski, 1998; Domagalski and others, 2000a,b). In all cases the majority of the mercury present (about 60-90 percent) is associated with suspended particles, which is also typical of waters elsewhere in the Sacramento River basin. Proposed aquatic life criteria for total mercury in water span a wide range. As is the case with the criterion for sediment, this is the level above which there is evidence of potential for observable effects in biota, not necessarily including bioaccumulation and biomagnification. The lowest proposed criterion for chronic effects in fresh-water aquatic life (12 ng/L total recoverable mercury) is shown on Figure 13 for reference. It was first recommended by EPA in 1986, and is the level recommended by BLM’s National Applied Resource Sciences Center (Barkow, 1999). In April 1999 EPA issued a guideline of 770 ng/L (dissolved mercury) for chronic effects in fresh-water aquatic life. The 50 ng/L level shown on Figure 13 is the California Water Quality Standard. This number, proposed in 1997, refers to total recoverable mercury and is a human health standard. Only the drainage tunnel sample exceeds the 12 ng/L level, but low values are generally anticipated during the low-flow late-summer conditions under which we obtained the samples.

With the exception of the Igo Gauge site, where mercury is low in all media, total mercury values in waters show no obvious correlation with mercury levels in bulk or fine sediments at the same sites.

Figure 14 shows amounts of methylmercury versus total mercury for unfiltered waters. Lines of equal proportions of methylmercury are shown for reference (note that the scales for both axes and the intervals between the percentage lines are logarithmic). Methylmercury values for most of the stream and pond waters fall within the range seen elsewhere in the Sacramento River Basin (Domagalski, 1998, 2000b). In these waters between 1 and 10 percent of total mercury is methylmercury, which is within the range of values commonly seen in relatively uncontaminated surface waters with normal methylation potential (see e.g., Kelly and others, 1995). Proportions of methylmercury are high in Red Pond and Pond 3, producing absolute values higher than those reported by Domagalski (1998, 2000b). At the time of sampling these ponds were shallow, warm, and contained decaying organic matter. The high proportion of methylmercury in Pond 3 is particularly significant, as it shows that conditions in shallow ponds on the flood plain may favor methylation of mercury. Further work is needed to explain the extraordinarily low methylmercury level seen in water in the hydraulic drainage tunnel.

Sulfate values are in the normal range seen in West Coast rivers (Hem and others, 1990); however, values in East Pond and the hydraulic drainage tunnel are comparable to the highest values seen in river waters (Figure 15). Prospect tunnels in the gravels of the Tehama Formation exposed above Red Pond in the Spring Creek valley contain fine-grained pyrite that is now being oxidized, because the tunnels provide drainage and have thus lowered the water table. At the time of sampling, a small area of pyrite-bearing conglomerate was also exposed at the north edge of the Clear Creek flood plain near Pond 3. This exposure was too small to determine its relations to other units, but it probably represents Tehama Formation material covered by thin Recent alluvium. These exposures suggest that the Tehama Formation contains pyrite-bearing reduced zones. Where exposed to oxidation, these zones could be sources of sulfate in waters.

Figure 15 shows that in the Clear Creek area sample suite, waters with relatively high sulfate concentrations also have relatively high total mercury values. Methylmercury, however, shows no consistent relationship to sulfate, because methylmercury levels in Red Pond and Pond 3 are relatively high, whereas the methylmercury level in the hydraulic drainage tunnel water is relatively low (Figure 14).

Iron concentrations vary greatly in the waters sampled (Figure 16), but are high only in the Red Pond, as anticipated from the observation that iron oxyhydroxide precipitates on the bottom and on pond vegetation during the summer months (Figure 7). The high iron in Red Pond can be explained in light of other chemical characteristics, as discussed below. Pond 3 showed surprisingly high iron, although no iron mineral precipitates were observed. The source of iron in Pond 3 is not obvious, but oxidizing sulfides in nearby bedrock are a possible source for iron, as well as sulfate. Note that data for filtered

samples are used in Figure 16, because we do not have unfiltered iron data for all samples. In all cases where we have iron analyses for both unfiltered and filtered subsamples, the unfiltered values are several times the filtered values. This indicates that the majority of iron in the waters is present in suspension, probably as iron oxyhydroxide particles or coatings on other particles, a condition that is commonly seen in natural waters.

Chloride concentrations (Figure 17) in pond and stream waters, which fall between about 1.5 and 5 ppm, are in the normal range for surface waters near the Pacific Ocean (Hem and others, 1990). The higher concentrations in East Pond and Pond 3 (about 10-15 ppm) are within the range seen, but since both are shallow small-volume ponds, the values more likely reflect effects of evapoconcentration.

Red Pond has an extremely high chloride concentration (13,000 mg/L), approaching that of seawater (approximately 30,000 mg/L). High-chloride waters that represent connate fluids from the Great Valley sequence at depth appear in springs to the south along the west side of the Sacramento Valley, and contribute to fluids in The Geysers geothermal field (Donnelly-Nolan and others, 1993) and to ore-forming fluids and groundwaters at the McLaughlin gold deposit (Rytuba and others, 1993). A contribution from such high-salinity fluid probably also accounts for the elevated chloride concentration in the hydraulic mine drainage tunnel. Although such fluids may be enriched in mercury, total mercury does not correlate with chloride at these two sites.

High boron and lithium values are distinguishing geochemical features of the Great Valley connate fluids. As Figure 18 shows, high concentrations of these elements accompany the chloride in the Red Pond water, and confirm that connate water is a major component in the seeps that feed Red Pond. The intermediate boron and lithium values seen in the hydraulic drainage tunnel water, in approximately the same ratio to Red Pond water as chloride, confirm that it contains a small contribution of connate water. The contributions of connate waters at these sites suggests that waters of deep-seated origin may contribute mercury to the surface environment in the Clear Creek area, and that gold mining may not be the only source of mercury.

Conclusions

The following preliminary conclusions are drawn from the results of mercury determinations reported here.

- 1) Background mercury values are low, as determined from bedrock, clasts in gravels, and unmined auriferous gravels.
- 2) Bulk mercury values in sediments and tailings are elevated to as much as several times background concentrations.

- 3) Mercury and methylmercury in sediments and tailings are associated with fine grain-size fractions.
- 4) Mercury and methylmercury values are relatively low in Clear Creek stream waters and ponds on the Clear Creek flood plain.
5. High-salinity connate waters enter the surface environment in the area through springs and seeps. Some mercury in waters in the area may be from this source.

These conclusions are considered preliminary, primarily because the number of sample sites is relatively small, and the data for waters are derived from only one sampling event. Thus for solids, spatial variations cannot be evaluated and the full range of mercury values cannot be determined. For waters, which vary both spatially and temporally, a single sampling event is not enough for reliable characterization.

Characterization of mercury concentrations and speciation in inorganic media of the Clear Creek system will continue in 2002 and 2003, in coordination with studies of mercury in biota. Detailed studies of mercury mobility are underway, focussed on fine-grained size fractions, and colloids that may be released from sediments and tailings.

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TABLE 1. Locations and descriptions of sample sites in and near the Clear Creek Restoration Project area

Field no.	Map no.	Latitude	Longitude	SEDIMENT SAMPLES				WATER SAMPLES						Description
				Bulk sediment	Sediment >2mm	Sediment <2mm	Sediment <63um	Unfiltered unacidified	Filtered unacidified	Filtered acidified	Unfiltered acidified	Alkalinity	Total carbon	
21CC01	1	40° 29.911'	122° 24.942'	21CC01WAS			21CC01WBS F	21CC01W	21CC01WA	21CC01WB		21CC01Wd	21CC01WT C	South Pond, north side, clear
21CC02	2	40° 30.259'	122° 24.419'	21CC02WBS			21CC02WAS F	21CC02W	21CC02WA	21CC02WB		21CC02Wd	21CC02WT C	East Pond
21CC03	3	40° 29.871'	122° 24.925'	21CC03SA 21CC03WSAB			21CC03WSF B	21CC03W	21CC03WA	21CC03WB	21CC03WC	21CC03Wd	21CC03TC	South Pond, south side, turbid
21CC04	4	40° 29.886'	122° 24.997'	21CC04SA										Fill material, west side of South Pond
21CC05	5	40° 29.886'	122° 24.997'	21CC05S										Composite of metamorphic-rock pebbles from fill, west side of South Pond
21CC06	6	40° 29.886'	122° 24.997'	21CC06S										Composite of igneous-rock pebbles from fill, west side of South Pond
21CC07	7	40° 30.026'	122° 24.926'	21CC07S 21CC07ASB			21CC07B	21CC07W	21CC07A	21CC07Wb	21CC07Wc	21CC07d		Pond 3
21CC08	8	40° 29.795'	122° 27.476'		21CC08SC	21CC08SF1 21CC08SF2								Coarse tailings (pebbles, cobbles) at drainage cut
21CC09	9	40° 29.795'	122° 27.476'	21CC09S										Nomlaki Tuff at drainage cut
21CC10	10	40° 29.700'	122° 27.300'	21CC10SB1 21CC10SB2					21CC10A	21CC10c	21CC10b	21CC10d		Water ponded on tailings at outlet of drainage tunnel
21CC11	11	40° 29.719'	122° 27.393'	21CC11SB1 21CC11SB2	21CC11SC	21CC11SF	21CC11SVF	21CC11W	21CC11A	21CC11b			21CC11d	Bed of Clear Creek and gravel bar upstream from (west of) project area
21CC12	12	40° 30.038'	122° 29.257'	21CC12B				21CC12W	21CC12A	21CC12B 1,2			21CC12d	Red Pond
21CC13	13	40° 30.076'	122° 29.236'	21CC13B	21CC13SC	21CC13SF1 21CC13SF2								Drift-mine tunnel in gravels beneath Nomlaki Tuff, near Red Pond
21CC13	13	40° 30.076'	122° 29.236'	21CC13ST										Nomlakai Tuff at drift-mine tunnel, near Red Pond
21CC14	14	40° 29.911'	122° 29.169'	21CC14SB	21CC14SC	21CC14SF1 21CC14SF2								Dredge stacker tailings, Spring Creek
21CC15	15	40° 29.734'	122° 29.150'	21CC15CL1 21CC15CL2										Sluice tailings (clay-silt) exposed in backhoe trench, Shooting Gallery
21CC15	15	40° 29.734'	122° 29.150'	21CC15SC1 21CC15SC2										Sluice tailings (coarse sand) exposed in backhoe trench, Shooting Gallery
21CC15	15	40° 29.734'	122° 29.150'	21CC15SF1 21CC15SF2										Sluice tailings (fine sand) exposed in backhoe trench, Shooting Gallery
21CC16	16	40° 29.734'	122° 29.150'	21CC16B 21CC16SB	21CC16SC	21CC16SF								Stacker tailings (cobbles, pebbles, sand) in backhoe trench, Shooting Gallery
21CC17	17	40° 29.753'	122° 29.150'	21CC17SB	21CC17SC	21CC17SF1 21CC17SF2								Dredge stacker tailings, Spring Creek
21CC18	18	40° 30.862'	122° 31.487'	21CC18SB1 21CC18SB2				21CC18W	21CC18WA	21CC18WB 1, 2	21CC18WC 1, 2	21CC18wd		Bed of Clear Creek at USGS Gauging Station
21CC19	19	40° 30.862'	122° 31.487'	21CC19SB1 21CC19SB2										Beach sand at USGS Gauging Station, Clear Creek

Color code:

Red: analyzed by Frontier Geosciences, Inc.

Green: analyzed by ALS Chemex, Inc.

Black: analyzed by U.S. Geological Survey, Mineral Resource Surveys, Denver

Table 2. Comparison of preparation and analytical procedures used for solid samples by ALS Chemex and Frontier Geosciences laboratories

	ALS Chemex	Frontier Geosciences
Step (in sequence)		
(1) Dry	60°C	—
(2) Remove split	250 g	0.5g
(3) Pulverize	To >85% <75µ	—
(4) Digest/leach	HF-HNO ₃ -HClO ₄ -HCl	Aqua regia (HCl-HNO ₃)
(5) Analysis*	CVAA	CVAFS

*Mercury detection method only. The same chemical procedure for extraction of mercury from solid samples is used by both laboratories.

Table 3. Mercury and methylmercury concentrations in dredge tailings and sediment samples

Field site	Map no.	Subsample number	Sample material	Total Hg, ppb Chemex	Total Hg, ppb Frontier	Methyl Hg, ppb Frontier
21CC01	1	21CC01WAS	Bulk		134	0.588
		21CC01WBSF	<63µm		295	1.18
21CC02	2	21CC02WBS	Bulk		24.9	0.639
		21CC02WASF	<63µm		190	2.07
21CC03	3	21CC03SA	Bulk	90		
		21CC03WSAB	Bulk		109	0.225
		21CC03WSFB	<63µm		269	1.02
21CC04	4	21CC04SA	Bulk	30		
21CC05	5	21CC05S	Bedrock	30		
21CC06	6	21CC06S	Bedrock	<10		
21CC07	7	21CC07S	Bulk	30		
		21CC07ASB	Bulk		22.9	0.574
		21CC07B	<63µm		275	3.00
21CC08	8	21CC08SC	>2mm	20		
		21CC08SF1,2	<2mm	30	60.1	0.387
21CC09	9	21CC09S	Bedrock	<10		
21CC10	10	21CC10SB1,2	Bulk	70	114	0.299
21CC11	11	21CC11SB1,2	Bulk	40	118	0.699
		21CC11SC	>2mm	30		
		21CC11SF	<2mm	60		
		21CC11SVF	<63µm		204	0.775
21CC12	12	21CC12B	Bulk		160	31.1
21CC13	13	21CC13B	Bulk	<10		
		21CC13SC	>2mm	<10		
		21CC13SF1,2	<2mm	<10	2.89	<0.015
		21CC13ST	Bedrock	<10		
21CC14	14	21CC14SB	Bulk	50		
		21CC14SC	>2mm	30		
		21CC14SF1,2	<2mm	40	51.0	0.064
21CC15	15	21CC15CL1,2	Bulk	160	134	0.046
		21CC15SC1,2	Bulk	90	99.5	<0.015
		21CC15SF1,2	Bulk	90	104	<0.015
21CC16	16	21CC16B	Bulk	70		
		21CC16SB	Bulk		202	0.026
		21CC16SC	>2mm	40		
		21CC16SF	<2mm	140		
21CC17	17	21CC17SB	Bulk	60		
		21CC17SC	>2mm	20		
		21CC17SF1,2	<2mm	40	29.7	0.101
21CC18	18	21CC18SB1,2	Bulk	20	22.5	0.188
21CC19	19	21CC19SB1,2	Bulk	20	13.1	0.020

Table 4. Concentrations of major and minor elements in dredge tailings and sediment samples, determined by ICP-MS and ICP-AES

Field site	Map no.	Subsample no.	Sample mtl Units—	Ag ppm	Al %	As ppm	Ba ppm	Be ppm	Bi ppm	Ca %	Cd ppm	Ce ppm	Co ppm	Cr ppm
21CC03	3	21CC03SA	Bulk	0.82	5.57	9	485.5	0.8	0.07	1.55	0.18	26.6	9.4	123
21CC04	4	21CC04SA	Bulk	0.6	5.57	8.8	460.5	0.6	0.07	1.7	0.16	24.5	9	105
21CC05	5	21CC05S	Bedrock	0.46	3.17	6.2	542.7	0.55	0.05	0.17	0.08	15.1	2.6	112
21CC06	6	21CC06S	Bedrock	0.4	6.52	1	650.1	0.9	0.05	0.72	<0.02	16.95	2.2	57
21CC07	7	21CC07S	Bulk	0.3	5.42	4.4	407	0.65	0.05	1.35	0.12	14.75	6.4	126
21CC08	8	21CC08SC	>2mm	0.28	5.27	4	471.5	0.75	0.07	1.35	0.1	13.85	5.6	133
		21CC08SF1	<2mm	0.24	5.59	3.2	479	0.75	0.1	1.2	0.14	17.6	6	156
21CC09	9	21CC09S	Bedrock	0.3	7.3	1.6	867.2	1.35	0.05	1.3	0.12	26.8	4	51
21CC10	10	21CC10SB1	Bulk	0.22	6.29	7.4	444	0.85	0.06	2	0.12	16.65	12.3	168
21CC11	11	21CC11SB1	Bulk	0.22	5.86	7.8	406	0.7	0.07	2.5	0.22	17.4	7.7	160
		21CC11SC	>2mm	0.24	5.83	7.6	403.5	0.55	0.07	2.9	0.18	11.75	10.5	162
		21CC11SF	<2mm	0.22	5.57	9.8	459.5	0.75	0.1	1.65	0.14	31.4	5.1	163
21CC13	13	21CC13B	Bulk	0.2	6.62	6.6	210	0.4	0.22	1.45	0.04	8.5	11.1	171
		21CC13SC	>2mm	0.2	6.99	6.2	174	0.55	0.16	1.65	0.1	8.2	14.1	165
		21CC13SF1	<2mm	0.2	6.42	7.8	541.1	0.75	0.22	1.85	0.14	13.55	15.8	202
		21CC13ST	Bedrock	0.3	6.71	2.4	777.2	1.5	0.32	1.05	0.18	29.8	2.7	59
21CC14	14	21CC14SB	Bulk	0.22	5.29	5.4	544.3	0.75	0.09	1.5	0.16	18.8	9.5	143
		21CC14SC	>2mm	0.26	5.1	5.6	560.3	0.8	0.15	1.45	0.14	18.4	9.1	146
		21CC14SF1	<2mm	0.22	6.22	7	425	0.75	0.14	1.5	0.14	22.2	13.8	237
21CC15	15	21CC15CL1	Bulk	0.26	7.34	7.2	412	0.85	0.14	1.45	0.08	25	11.5	109
		21CC15SC1	Bulk	0.5	5.3	5.2	413.5	0.7	0.07	1.25	0.06	23	6.5	146
		21CC15SF1	Bulk	0.44	6.03	5.2	441.5	0.65	0.07	1.3	0.06	28.3	9.6	162
21CC16	16	21CC16B	Bulk	0.3	5.88	5.8	411	0.7	0.09	1.4	0.08	23.3	10.8	114
		21CC16SC	>2mm	0.36	5.9	4.4	327.5	0.55	0.08	1.6	0.08	18.35	9.8	131
		21CC16SF	<2mm	0.32	6.78	6.6	427.5	0.8	0.12	1.35	0.12	25	13.3	177
21CC17	17	21CC17SB	Bulk	0.26	6	4.4	299	0.65	0.1	2.7	0.1	12.05	11.5	156
		21CC17SC	>2mm	0.28	5.91	4.8	338.5	0.7	0.09	2.1	0.1	13.15	9.6	133
		21CC17SF1	<2mm	0.28	6.47	7.4	385.5	0.75	0.13	1.6	0.14	16.2	14.3	143
21CC18	18	21CC18SB1	Bulk	0.24	6.13	4.2	344	0.85	0.07	2.3	0.14	170.5	7.9	179
21CC19	19	21CC19SB1	Bulk	0.26	6.08	1.6	631.1	0.95	0.07	1.6	0.1	19.55	8.6	152

Table 4. Concentrations of major and minor elements in dredge tailings and sediment samples, determined by ICP-MS and ICP-AES

Field site	Map no.	Subsample no.	Sample mtl Units—	Cs ppm	Cu ppm	Fe %	Ga ppm	Ge ppm	Hf ppm	In ppm	K %	La ppm	Li ppm	Mg %
21CC03	3	21CC03SA	Bulk	1.25	29.8	2.77	12.15	0.25	0.8	0.04	0.87	13.5	20	0.93
21CC04	4	21CC04SA	Bulk	0.9	35.6	3.11	11.45	0.25	0.8	0.035	0.81	12.5	17.2	1.15
21CC05	5	21CC05S	Bedrock	0.9	19.2	1.68	7	0.1	0.9	0.02	0.68	8.5	19.6	0.53
21CC06	6	21CC06S	Bedrock	0.7	8.8	0.88	17.85	0.15	0.6	0.005	3.71	8	9.8	0.79
21CC07	7	21CC07S	Bulk	0.85	23	2.09	10.5	0.2	0.6	0.03	0.82	8	12.8	0.65
21CC08	8	21CC08SC	>2mm	0.8	22.2	2.43	10.4	0.15	0.8	0.03	0.74	8	14	0.94
		21CC08SF1	<2mm	1.05	22.8	1.91	10.95	0.15	0.5	0.02	1.02	9.5	14.2	0.64
21CC09	9	21CC09S	Bedrock	3.5	13.6	1.49	15.05	0.2	3.6	0.025	1.76	13.5	23.8	0.3
21CC10	10	21CC10SB1	Bulk	1.45	34	3.67	12.85	0.2	1	0.035	0.96	8.5	31	1.15
21CC11	11	21CC11SB1	Bulk	0.8	30.6	3.13	12.4	0.2	0.8	0.04	0.75	9	15.2	1.13
		21CC11SC	>2mm	0.75	31.2	3.69	12.95	0.25	0.9	0.045	0.64	6.5	15.8	1.47
		21CC11SF	<2mm	0.9	30.4	2.1	10.5	0.2	0.5	0.03	1	16.5	13.2	0.66
21CC13	13	21CC13B	Bulk	0.85	85	3.13	12.4	0.15	0.5	0.065	0.68	4	38.2	1.97
		21CC13SC	>2mm	0.8	110.5	3.71	12.55	0.15	0.5	0.065	0.56	4	41.4	2.48
		21CC13SF1	<2mm	1.15	143.1	2.98	11.75	0.15	0.5	0.06	0.73	7	45.4	1.66
		21CC13ST	Bedrock	4	50.2	2.65	14.1	0.15	3.6	0.025	1.97	14	22.4	0.3
21CC14	14	21CC14SB	Bulk	1.3	42.8	3.5	12.75	0.25	1.2	0.045	0.71	13	24.2	1.32
		21CC14SC	>2mm	1.25	50	3.41	12.15	0.2	1.2	0.05	0.65	11.5	24.2	1.28
		21CC14SF1	<2mm	1.2	61.6	4.21	14.4	0.25	1.1	0.065	0.69	12.5	32.2	1.62
21CC15	15	21CC15CL1	Bulk	1.65	57.8	3.54	16.35	0.2	1.4	0.07	0.73	11	51.8	1.16
		21CC15SC1	Bulk	1.05	27.2	2.43	10.2	0.2	0.8	0.035	0.83	11.5	25.2	0.73
		21CC15SF1	Bulk	1.05	28.2	2.4	10.65	0.2	0.9	0.04	1.04	13	23.2	0.61
21CC16	16	21CC16B	Bulk	1.15	39.2	3.22	13.45	0.3	1.2	0.04	0.71	11.5	35.4	1.11
		21CC16SC	>2mm	0.85	30.4	3.59	11.35	0.25	1	0.04	0.63	9.5	28	1.46
		21CC16SF	<2mm	1.4	46.2	3.21	13.9	0.25	1.1	0.045	0.86	11.5	41.6	1.02
21CC17	17	21CC17SB	Bulk	0.9	44	4.2	13.75	0.2	0.9	0.05	0.56	6.5	33.8	1.52
		21CC17SC	>2mm	0.85	37.6	3.59	12.6	0.25	0.9	0.06	0.55	7	28.4	1.45
		21CC17SF1	<2mm	1.45	57	4	14.75	0.25	1.1	0.06	0.74	8.5	60.8	1.45
21CC18	18	21CC18SB1	Bulk	0.65	25.2	2.82	14.45	0.35	0.7	0.045	0.79	67	12.2	0.97
21CC19	19	21CC19SB1	Bulk	1.7	17	2.08	14.5	0.15	0.4	0.025	1.2	11	23.2	0.89

Table 4. Concentrations of major and minor elements in dredge tailings and sediment samples, determined by ICP-MS and ICP-AES

Field site	Map no.	Subsample no.	Sample mtl Units—	Mn ppm	Mo ppm	Na %	Nb ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Re ppm	S %	Sb ppm
21CC03	3	21CC03SA	Bulk	345	1.7	1.5	3.1	24.8	230	7	25.2	<0.002	<0.01	0.75
21CC04	4	21CC04SA	Bulk	395	0.95	1.59	2.3	20.6	230	5.5	17.3	<0.002	<0.01	0.75
21CC05	5	21CC05S	Bedrock	100	2.1	1.04	2.4	19.6	400	4.5	23.2	<0.002	0.03	0.65
21CC06	6	21CC06S	Bedrock	115	1	1.86	2.3	2.6	110	6.5	65.1	<0.002	<0.01	0.1
21CC07	7	21CC07S	Bulk	240	1.9	1.77	1.9	18.6	170	4.5	18.2	<0.002	0.01	0.5
21CC08	8	21CC08SC	>2mm	285	0.85	1.7	2.4	20	280	5	20.2	<0.002	0.01	0.5
		21CC08SF1	<2mm	255	2.2	1.64	2.2	16	180	6	25.8	<0.002	<0.01	0.4
21CC09	9	21CC09S	Bedrock	330	2	2.51	6.2	5.6	80	12.5	46.8	<0.002	<0.01	0.8
21CC10	10	21CC10SB1	Bulk	505	1.8	1.57	2.9	39	250	5.5	23.3	<0.002	0.02	0.65
21CC11	11	21CC11SB1	Bulk	415	1.2	1.5	2.2	22.6	200	5	16.6	<0.002	0.01	0.7
		21CC11SC	>2mm	505	0.95	1.52	2.2	33.4	240	4.5	14.1	<0.002	0.01	0.6
		21CC11SF	<2mm	245	3.5	1.82	1.5	15.8	180	6.5	22.3	<0.002	<0.01	0.6
21CC13	13	21CC13B	Bulk	400	2.85	1.61	1.8	27.2	10	31.5	10.3	0.002	0.37	1.65
		21CC13SC	>2mm	465	2.5	1.53	1.5	35	30	9.5	8.8	0.002	0.49	0.55
		21CC13SF1	<2mm	360	2.2	1.56	1.9	27.8	40	22.5	14.5	0.002	0.96	1
		21CC13ST	Bedrock	325	2.6	2.32	6	7.8	50	16	57.1	<0.002	0.01	0.9
21CC14	14	21CC14SB	Bulk	385	2.05	0.93	3.2	33	200	8	24.2	<0.002	<0.01	0.65
		21CC14SC	>2mm	340	2.05	0.8	3.1	34.4	170	8	23.8	<0.002	<0.01	0.75
		21CC14SF1	<2mm	550	1.3	1.23	2.9	36.2	190	12.5	16.2	<0.002	0.01	0.65
21CC15	15	21CC15CL1	Bulk	410	1.4	1.77	4.9	32.4	130	7	20.4	<0.002	<0.01	0.65
		21CC15SC1	Bulk	265	2.45	1.37	2.2	18.4	140	5	22.1	<0.002	<0.01	0.45
		21CC15SF1	Bulk	370	1.25	1.59	2.6	17.2	100	6.5	23.7	<0.002	<0.01	0.45
21CC16	16	21CC16B	Bulk	435	2.05	1.65	3.4	30.6	230	5.5	21.2	<0.002	<0.01	0.6
		21CC16SC	>2mm	480	2.05	1.67	2.6	28.6	220	4	16.7	<0.002	<0.01	0.55
		21CC16SF	<2mm	550	1.45	1.71	3.4	28	140	6.5	22.4	<0.002	<0.01	0.6
21CC17	17	21CC17SB	Bulk	495	1	1.32	2.2	35	210	6.5	11.4	<0.002	0.01	0.6
		21CC17SC	>2mm	465	0.9	1.59	2.7	28.2	280	5	13.5	<0.002	0.01	0.65
		21CC17SF1	<2mm	470	1.45	1.73	3.1	47.6	260	11	18.9	<0.002	0.01	0.7
21CC18	18	21CC18SB1	Bulk	430	2.95	2.55	2.4	18.6	220	6	14.9	<0.002	0.02	0.4
21CC19	19	21CC19SB1	Bulk	325	1.05	2	3.2	22	160	9	35.6	<0.002	<0.01	0.4

Table 4. Concentrations of major and minor elements in dredge tailings and sediment samples, determined by ICP-MS and ICP-AES

Field site	Map no.	Subsample no.	Sample mtl Units—	Se ppm	Sn ppm	Sr ppm	Ta ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm
21CC03	3	21CC03SA	Bulk	<1	0.6	153.5	0.35	0.05	3.8	0.2	0.18	0.9	113	1.1
21CC04	4	21CC04SA	Bulk	<1	0.4	144.5	0.2	0.05	2.6	0.21	0.16	0.7	122	1
21CC05	5	21CC05S	Bedrock	<1	0.2	29	0.2	0.05	2	0.11	0.16	1.2	81	0.4
21CC06	6	21CC06S	Bedrock	<1	1	243	0.2	0.05	2.4	0.08	0.3	0.5	17	2.7
21CC07	7	21CC07S	Bulk	<1	0.8	163	0.2	<0.05	2.2	0.15	0.12	0.6	74	0.7
21CC08	8	21CC08SC	>2mm	<1	0.4	130	0.2	0.05	2.4	0.17	0.14	0.9	104	0.6
		21CC08SF1	<2mm	<1	0.4	211	0.2	0.05	2.8	0.14	0.14	0.7	66	0.6
21CC09	9	21CC09S	Bedrock	<1	0.8	208	0.6	<0.05	8	0.2	0.36	2.8	40	1.5
21CC10	10	21CC10SB1	Bulk	<1	0.4	209	0.25	0.1	3	0.24	0.18	0.8	141	1.7
21CC11	11	21CC11SB1	Bulk	<1	0.4	128	0.2	0.1	2.4	0.2	0.14	0.7	138	0.6
		21CC11SC	>2mm	<1	0.6	140	0.2	0.05	2	0.22	0.12	0.7	150	0.7
		21CC11SF	<2mm	<1	0.2	235	0.15	0.2	3.2	0.13	0.18	0.6	77	0.5
21CC13	13	21CC13B	Bulk	<1	0.6	155.5	0.15	0.45	0.8	0.21	0.08	0.4	159	4.4
		21CC13SC	>2mm	<1	0.6	160	0.15	0.4	0.8	0.21	0.08	0.4	161	4.3
		21CC13SF1	<2mm	<1	0.6	280	0.15	0.45	1	0.19	0.1	0.5	149	4.8
		21CC13ST	Bedrock	<1	0.8	174.5	0.6	<0.05	9	0.16	0.48	3.5	35	2.5
21CC14	14	21CC14SB	Bulk	<1	0.6	75.6	0.25	0.05	3.2	0.23	0.18	1.2	160	0.8
		21CC14SC	>2mm	<1	0.6	73	0.25	0.05	3.4	0.22	0.18	1.2	166	0.9
		21CC14SF1	<2mm	<1	0.8	109.5	0.3	0.15	2.6	0.27	0.16	1	159	1.3
21CC15	15	21CC15CL1	Bulk	<1	0.8	139	0.45	0.1	3.8	0.39	0.18	1.4	145	1.9
		21CC15SC1	Bulk	<1	0.6	136	0.2	0.05	2.6	0.16	0.14	0.8	107	0.7
		21CC15SF1	Bulk	<1	0.4	151	0.2	0.05	3	0.21	0.14	0.8	98	0.8
21CC16	16	21CC16B	Bulk	<1	0.6	130.5	0.3	0.1	3.2	0.24	0.16	1.1	126	0.9
		21CC16SC	>2mm	<1	0.4	79.7	0.2	0.05	2.4	0.25	0.12	0.9	146	0.9
		21CC16SF	<2mm	<1	0.6	148.5	0.3	0.1	3.2	0.27	0.18	1.1	125	1.3
21CC17	17	21CC17SB	Bulk	<1	0.4	106.5	0.2	0.1	1.8	0.24	0.1	0.7	161	0.8
		21CC17SC	>2mm	<1	0.6	112.5	0.2	0.05	2	0.23	0.1	0.7	153	1.1
		21CC17SF1	<2mm	<1	0.6	129.5	0.25	0.15	2.4	0.28	0.14	1	148	1.1
21CC18	18	21CC18SB1	Bulk	<1	1.6	207	0.25	0.05	8.6	0.19	0.1	1.2	93	0.9
21CC19	19	21CC19SB1	Bulk	<1	0.6	288	0.3	<0.05	4	0.19	0.24	0.8	60	0.7

Table 4. Concentrations of major and minor elements in dredge tailings and sediment samples, determined by ICP-MS and ICP-AES

Field site	Map no.	Subsample no.	Sample mtl	Y	Zn	Zr
			Units—	ppm	ppm	ppm
21CC03	3	21CC03SA	Bulk	8.7	58	26.5
21CC04	4	21CC04SA	Bulk	7.6	58	23.5
21CC05	5	21CC05S	Bedrock	6.3	42	34
21CC06	6	21CC06S	Bedrock	5.5	12	11.5
21CC07	7	21CC07S	Bulk	8.1	38	16
21CC08	8	21CC08SC	>2mm	7.8	44	26
		21CC08SF1	<2mm	5.3	40	15
21CC09	9	21CC09S	Bedrock	8.4	44	126
21CC10	10	21CC10SB1	Bulk	8.1	64	30.5
21CC11	11	21CC11SB1	Bulk	7.4	56	25
		21CC11SC	>2mm	9.3	58	29
		21CC11SF	<2mm	5.4	42	15.5
21CC13	13	21CC13B	Bulk	6.4	50	15.5
		21CC13SC	>2mm	7.9	60	14.5
		21CC13SF1	<2mm	9	62	14.5
		21CC13ST	Bedrock	8.5	64	148.5
21CC14	14	21CC14SB	Bulk	10.6	62	44
		21CC14SC	>2mm	9.2	64	47
		21CC14SF1	<2mm	12.4	70	36.5
21CC15	15	21CC15CL1	Bulk	10.8	66	47
		21CC15SC1	Bulk	6.4	42	27.5
		21CC15SF1	Bulk	7	40	29.5
21CC16	16	21CC16B	Bulk	10	54	39.5
		21CC16SC	>2mm	9.5	56	30.5
		21CC16SF	<2mm	9.3	56	36.5
21CC17	17	21CC17SB	Bulk	9.1	62	29
		21CC17SC	>2mm	9.2	52	31.5
		21CC17SF1	<2mm	11.6	70	35
21CC18	18	21CC18SB1	Bulk	13.1	52	15.5
21CC19	19	21CC19SB1	Bulk	5.5	48	8.5

Table 5. Field parameters for water sample sites and concentrations of major anions, mercury, and methylmercury in waters

Field site	Date	pH	Temperature	Conductivity	Alkalinity	Total Hg	Total Hg	Methyl Hg	Methyl Hg
Units—		pH units	°C	µS	ppm, as CaCO ₃	ng/L	ng/L	ng/L	ng/L
Subsample—		(in situ)	(in situ)	(in situ)	Unfiltered	Unfiltered	Filtered	Unfiltered	Filtered
21CC1	8/27/01	8.18	35.3	129.4	64	2.95	0.85	0.087	0.033
21CC2	8/27/01	6.93	31.9	206	73	7.79	0.92	0.454	0.107
21CC3	8/28/01	6.62	24.0	145.5	67	3.54	0.81	0.235	0.039
21CC7	8/28/01	6.65	23.8	220	83	9.98	3.96	4.730	2.280
21CC10	8/28/01	6.92	20.3	1320	97	50.7	2.94	0.061	0.042
21CC11	8/28/01	7.27	21.2	104.3	39	3.75	0.69	0.037	0.038
21CC12	8/29/01	5.57	24.7	36300	*	10.4	2.97	6.72	0.902
21CC18	8/29/01	7.33	18.3	69.2	40	1.55	0.55	0.027	0.018
*Not determined; pH of subsample measured in laboratory was 4.17									

Table 5. Field parameters for water sample sites and concentrations of major anions, mercury, and methylmercury in waters

Field site	Chloride (Cl)	Fluoride (F)	Sulfate (SO4)	Nitrate (NO3)
Units—	ppm	ppm	ppm	ppm
Subsample—	Filtered	Filtered	Filtered	Filtered
21CC1	1.7	0.09	1.8	<0.08
21CC2	13	1.1	13	<0.08
21CC3	5.1	0.2	<1.6	<0.08
21CC7	8.8	0.2	3.5	<0.08
21CC10	260	0.7	24	0.9
21CC11	4.3	0.1	1.9	<0.08
21CC12	13000	<0.08	2.8	<0.08
21CC18	5.1	0.2	<1.6	<0.08
*Not determined				

Table 6. Concentrations of major and minor cations in waters, determined by ICP-MS and ICP-AES

CATION CONCENTRATIONS IN FILTERED WATERS														
Field site	Subsample no.	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs
	Units—	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
	Method—	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-AES	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
21CC1	21CC1WB	<3	7.98	2	8	9.6	<0.05	0.03	11	<0.02	0.01	0.11	<1	< 0.01
21CC2	21CC2WB	<3	1.44	2	13	22	<0.05	0.02	21	<0.02	< 0.01	0.05	<1	< 0.01
21CC3	21CC3WB	<3	1.9	2	7.9	26	<0.05	0.01	12	<0.02	< 0.01	0.12	<1	< 0.01
21CC7	21CC7B	<3	5.48	11.9	18	34	<0.05	0.01	19	<0.02	0.14	0.7	<1	< 0.01
21CC10	21CC10B	<3	1.32	3	86	220	<0.05	0.01	110	<0.02	< 0.01	0.09	<1	< 0.01
21CC11	21CC11B	<3	1.83	<1	10	8.4	<0.05	0.006	6.4	<0.02	< 0.01	<0.02	<1	< 0.01
21CC12	21CC12B1	<3	25.4	24.6	2600	2500	<0.05	0.18	2600	0.05	1.98	11.6	<1	0.28
21CC12	21CC12B2	<3	24.5	26.5	2600	2500	<0.05	0.07	3000	0.04	1.87	11.3	<1	0.26
21CC18	21CC18WB1	<3	1.89	<1	35	8.6	<0.05	< 0.005	7.4	<0.02	< 0.01	0.02	<1	< 0.01
21CC18	21CC18WB2	<3	2.38	<1	20	7.4	<0.05	< 0.005	6	<0.02	< 0.01	0.02	<1	< 0.01
CATION CONCENTRATIONS IN UNFILTERED WATERS														
Field site	Subsample no.	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Ce	Co	Cr	Cs
	Units—	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L
	Method—	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-AES	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
21CC3	21CC3WC	<3	252	3.5	11	31	<0.05	< 0.005	12	<0.02	0.46	0.37	<1	0.02
21CC7	21CC7C	<3	30.5	13	22	36	<0.05	< 0.005	20	<0.02	0.23	0.76	<1	< 0.01
21CC10	21CC10C	<3	3.7	3	85	210	<0.05	< 0.005	100	<0.02	< 0.01	0.1	<1	< 0.01
21CC11	21CC11C	<3	6.74	<1	10	8.1	<0.05	< 0.005	5.9	<0.02	0.01	0.02	<1	< 0.01
21CC18	21CC18WC1	<3	5.91	<1	11	6.9	<0.05	< 0.005	5.2	<0.02	< 0.01	0.03	<1	< 0.01
21CC18	21CC18WC2	<3	6.66	<1	11	6.9	<0.05	< 0.005	5.2	<0.02	0.01	0.03	<1	< 0.01

Table 6. Concentrations of major and minor cations in waters, determined by ICP-MS and ICP-AES

CATION CONCENTRATIONS IN FILTERED WATERS														
Field site	Subsample no.	Cu	Dy	Er	Eu	Fe	Fe	Ga	Gd	Ge	Ho	K	La	Li
	Units—	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L
	Method—	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS
21CC1	21CC1WB	<0.5	< 0.005	< 0.005	< 0.005	0.21	208	< 0.02	< 0.005	< 0.02	< 0.005	0.35	0.01	0.5
21CC2	21CC2WB	0.52	< 0.005	< 0.005	< 0.005	0.048	<50	< 0.02	< 0.005	< 0.02	< 0.005	0.74	< 0.01	0.5
21CC3	21CC3WB	<0.5	< 0.005	< 0.005	< 0.005	0.58	616	< 0.02	< 0.005	< 0.02	< 0.005	0.4	< 0.01	0.7
21CC7	21CC7B	0.5	0.02	0.02	0.01	1	1040	< 0.02	0.03	< 0.02	0.006	1.1	0.06	1
21CC10	21CC10B	<0.5	< 0.005	< 0.005	0.02	<0.02	<50	< 0.02	< 0.005	< 0.02	< 0.005	2	0.01	22.1
21CC11	21CC11B	0.88	< 0.005	< 0.005	< 0.005	<0.02	<50	< 0.02	< 0.005	< 0.02	< 0.005	0.38	< 0.01	2
21CC12	21CC12B1	17.5	0.16	0.13	0.31	5.9	4830	0.2	0.26	< 0.02	0.04	27	2.24	1750
21CC12	21CC12B2	17	0.2	0.11	0.29	5.4	4820	0.2	0.25	< 0.02	0.04	29	2.12	1720
21CC18	21CC18WB1	0.64	< 0.005	< 0.005	< 0.005	<0.02	<50	< 0.02	< 0.005	< 0.02	< 0.005	0.7	< 0.01	1.9
21CC18	21CC18WB2	0.62	< 0.005	< 0.005	< 0.005	<0.02	<50	< 0.02	< 0.005	< 0.02	< 0.005	0.51	< 0.01	1.8
CATION CONCENTRATIONS IN UNFILTERED WATERS														
Field site	Subsample no.	Cu	Dy	Er	Eu	Fe	Fe	Ga	Gd	Ge	Ho	K	La	Li
	Units—	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L
	Method—	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS
21CC3	21CC3WC	1.1	0.066	0.04	0.02	3.1	3850	0.09	0.076	< 0.02	0.02	0.53	0.23	1.8
21CC7	21CC7C	0.8	0.04	0.03	0.02	1.7	1900	< 0.02	0.04	< 0.02	0.009	1.2	0.09	1.9
21CC10	21CC10C	<0.5	< 0.005	< 0.005	0.02	<0.02	<50	< 0.02	0.005	< 0.02	< 0.005	2	0.02	24.6
21CC11	21CC11C	0.65	< 0.005	< 0.005	< 0.005	0.035	<50	< 0.02	< 0.005	< 0.02	< 0.005	0.42	< 0.01	2.7
21CC18	21CC18WC1	0.58	< 0.005	< 0.005	< 0.005	0.035	<50	< 0.02	< 0.005	< 0.02	< 0.005	0.4	< 0.01	2.2
21CC18	21CC18WC2	0.6	< 0.005	< 0.005	< 0.005	0.035	<50	< 0.02	< 0.005	< 0.02	< 0.005	0.39	< 0.01	2

Table 6. Concentrations of major and minor cations in waters, determined by ICP-MS and ICP-AES

CATION CONCENTRATIONS IN FILTERED WATERS														
Field site	Subsample no.	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	P	Pb	Pr	Rb	Sb
	Units—	µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L
	Method—	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
21CC1	21CC1WB	< 0.1	5.6	9.6	0.2	7	0.03	< 0.01	0.5	< 0.01	<0.05	< 0.01	0.73	<0.1
21CC2	21CC2WB	< 0.1	5.4	3.5	0.72	13	0.02	< 0.01	0.6	< 0.01	<0.05	< 0.01	0.3	0.2
21CC3	21CC3WB	< 0.1	6	225	< 0.2	7.1	0.02	< 0.01	0.4	< 0.01	<0.05	< 0.01	0.61	<0.1
21CC7	21CC7B	< 0.1	6.1	619	0.63	8.9	0.02	0.09	1.6	0.03	0.06	0.02	1	<0.1
21CC10	21CC10B	< 0.1	3.6	3.1	0.56	120	0.02	0.02	2.2	0.1	<0.05	< 0.01	1.24	<0.1
21CC11	21CC11B	< 0.1	5.8	2.5	< 0.2	3.4	< 0.02	< 0.01	1.1	< 0.01	<0.05	< 0.01	0.31	<0.1
21CC12	21CC12B1	< 0.1	40	6140	1.62	5500	0.06	0.84	61.7	< 0.01	0.75	0.19	41.9	0.3
21CC12	21CC12B2	< 0.1	35	6130	1.66	5600	0.1	0.77	57.4	< 0.01	0.72	0.2	42	0.26
21CC18	21CC18WB1	< 0.1	6.2	5.3	< 0.2	6.4	< 0.02	< 0.01	1.8	< 0.01	<0.05	< 0.01	0.31	<0.1
21CC18	21CC18WB2	< 0.1	6.1	5	< 0.2	3.8	< 0.02	< 0.01	1.8	< 0.01	<0.05	< 0.01	0.31	<0.1
CATION CONCENTRATIONS IN UNFILTERED WATERS														
Field site	Subsample no.	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	P	Pb	Pr	Rb	Sb
	Units—	µg/L	mg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L
	Method—	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
21CC3	21CC3WC	< 0.1	6	291	< 0.2	7.2	< 0.02	0.31	0.8	0.04	0.2	0.07	0.92	<0.1
21CC7	21CC7C	< 0.1	6.3	699	0.54	9.4	< 0.02	0.12	1.7	0.05	0.09	0.03	0.99	<0.1
21CC10	21CC10C	< 0.1	3.5	3.7	0.53	110	< 0.02	0.02	2.2	0.1	<0.05	< 0.01	1.28	<0.1
21CC11	21CC11C	< 0.1	5.3	4.5	< 0.2	3.3	< 0.02	< 0.01	1.2	< 0.01	<0.05	< 0.01	0.33	<0.1
21CC18	21CC18WC1	< 0.1	6.2	7.1	< 0.2	2.4	< 0.02	0.01	1.8	< 0.01	<0.05	< 0.01	0.32	<0.1
21CC18	21CC18WC2	< 0.1	6.1	7.3	< 0.2	2.3	< 0.02	0.01	1.9	< 0.01	<0.05	< 0.01	0.31	<0.1

Table 6. Concentrations of major and minor cations in waters, determined by ICP-MS and ICP-AES

CATION CONCENTRATIONS IN FILTERED WATERS														
Field site	Subsample no.	Sc	Se	Si	Sm	SO4	Sr	Ta	Tb	Th	Ti	TI	Tm	U
	Units—	µg/L	µg/L	mg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
	Method—	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
21CC1	21CC1WB	0.6	< 1	4	< 0.01	< 2	102	< 0.02	< 0.005	0.01	< 0.1	0.08	< 0.005	0.03
21CC2	21CC2WB	1.1	< 1	5.7	< 0.01	11	196	< 0.02	< 0.005	0.01	0.2	<0.05	< 0.005	0.008
21CC3	21CC3WB	1	< 1	5.5	< 0.01	< 2	111	< 0.02	< 0.005	0.01	< 0.1	<0.05	< 0.005	0.005
21CC7	21CC7B	1.6	< 1	8.8	0.02	< 2	213	< 0.02	0.005	0.02	0.4	<0.05	< 0.005	0.02
21CC10	21CC10B	6.9	2.1	37	< 0.01	16	1780	< 0.02	< 0.005	0.008	0.4	<0.05	< 0.005	0.28
21CC11	21CC11B	0.9	< 1	6.1	< 0.01	< 2	35.7	< 0.02	< 0.005	< 0.005	< 0.1	<0.05	< 0.005	0.03
21CC12	21CC12B1	17.7	< 1	11	0.14	5	66800	< 0.02	0.04	0.03	7	<0.05	0.02	0.01
21CC12	21CC12B2	9.6	< 1	10	0.16	4	67400	< 0.02	0.03	0.03	5.8	<0.05	0.02	0.007
21CC18	21CC18WB1	1.7	< 1	6.1	< 0.01	< 2	27.2	< 0.02	< 0.005	< 0.005	0.5	<0.05	< 0.005	0.03
21CC18	21CC18WB2	1.4	< 1	6	< 0.01	< 2	25.3	< 0.02	< 0.005	< 0.005	0.4	<0.05	< 0.005	0.03
CATION CONCENTRATIONS IN UNFILTERED WATERS														
Field site	Subsample no.	Sc	Se	Si	Sm	SO4	Sr	Ta	Tb	Th	Ti	TI	Tm	U
	Units—	µg/L	µg/L	mg/L	µg/L	mg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
	Method—	ICP-MS	ICP-MS	ICP-AES	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
21CC3	21CC3WC	1.5	< 1	5.8	0.06	< 2	118	< 0.02	0.01	0.04	14.3	<0.05	0.005	0.02
21CC7	21CC7C	2.2	< 1	9	0.04	2	226	< 0.02	0.006	0.02	1.9	<0.05	< 0.005	0.02
21CC10	21CC10C	8.8	1.9	36	< 0.01	19	1830	< 0.02	< 0.005	0.006	0.7	<0.05	< 0.005	0.29
21CC11	21CC11C	1.2	< 1	5.7	< 0.01	< 2	36.9	< 0.02	< 0.005	< 0.005	0.3	<0.05	< 0.005	0.03
21CC18	21CC18WC1	1.2	< 1	6	< 0.01	< 2	25	< 0.02	< 0.005	< 0.005	0.2	<0.05	< 0.005	0.03
21CC18	21CC18WC2	1.2	< 1	5.9	< 0.01	< 2	25.2	< 0.02	< 0.005	< 0.005	0.3	<0.05	< 0.005	0.03

Table 6. Concentrations of major and minor cations in waters, determined by ICP-MS and ICP-AES

CATION CONCENTRATIONS IN FILTERED WATERS							
Field site	Subsample no.	V	W	Y	Yb	Zn	Zr
	Units—	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$
	Method—	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
21CC1	21CC1WB	0.9	< 0.02	0.01	< 0.005	7.2	< 0.05
21CC2	21CC2WB	0.4	< 0.02	< 0.01	< 0.005	24.8	< 0.05
21CC3	21CC3WB	0.2	< 0.02	< 0.01	< 0.005	2	< 0.05
21CC7	21CC7B	1.3	< 0.02	0.2	0.02	3.8	< 0.05
21CC10	21CC10B	2.3	< 0.02	0.09	0.005	5.6	< 0.05
21CC11	21CC11B	0.5	< 0.02	0.01	< 0.005	1	< 0.05
21CC12	21CC12B1	<0.1	< 0.02	2.83	0.13	9	< 0.05
21CC12	21CC12B2	<0.1	< 0.02	2.76	0.13	7.5	< 0.05
21CC18	21CC18WB1	0.2	< 0.02	0.01	< 0.005	2	< 0.05
21CC18	21CC18WB2	0.4	< 0.02	0.01	< 0.005	1	< 0.05
CATION CONCENTRATIONS IN UNFILTERED WATERS							
Field site	Subsample no.	V	W	Y	Yb	Zn	Zr
	Units—	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$	$\mu\text{g/L}$
	Method—	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS	ICP-MS
21CC3	21CC3WC	1	< 0.02	0.32	0.03	10.4	< 0.05
21CC7	21CC7C	1.9	< 0.02	0.28	0.02	17.1	< 0.05
21CC10	21CC10C	2.6	< 0.02	0.09	< 0.005	23	< 0.05
21CC11	21CC11C	0.5	< 0.02	0.02	< 0.005	3	< 0.05
21CC18	21CC18WC1	0.4	< 0.02	0.02	< 0.005	0.7	< 0.05
21CC18	21CC18WC2	0.4	< 0.02	0.03	< 0.005	2.5	< 0.05

Figures 1-8 are provided as separate Adobe Acrobat .pdf files. Clicking on a figure number will activate a link to that figure.

Figure 1–Locations of samples in the Clear Creek study area

Figure 2–South Pond, on the flood plain of Clear Creek, showing clouds of fine sediment from local tailings used to fill the pond

Figure 3–East Pond, a marshy pond occupying an abandoned channel (meander scar) on the flood plain of Clear Creek

Figure 4–Pond 3, a shallow pond occupying a meander scar on the flood plain of Clear Creek

Figure 5–Dragline dredge stacker tailings, Spring Creek

Figure 6–Dredge sluice tailings (sand, silt, and clay), overlain by stacker tailings (pebbles and cobbles), exposed in wall of Schmidt Pit, Shooting Gallery area. Bulk mercury concentrations in the various tailings layers are shown

Figure 7–Red Pond, an abandoned dredge pond fed by high-chloride springs

Figure 8–Conglomerate of the Tehama Formation, exposed in prospect tunnels beneath the Nomlaki Tuff, at Red Pond

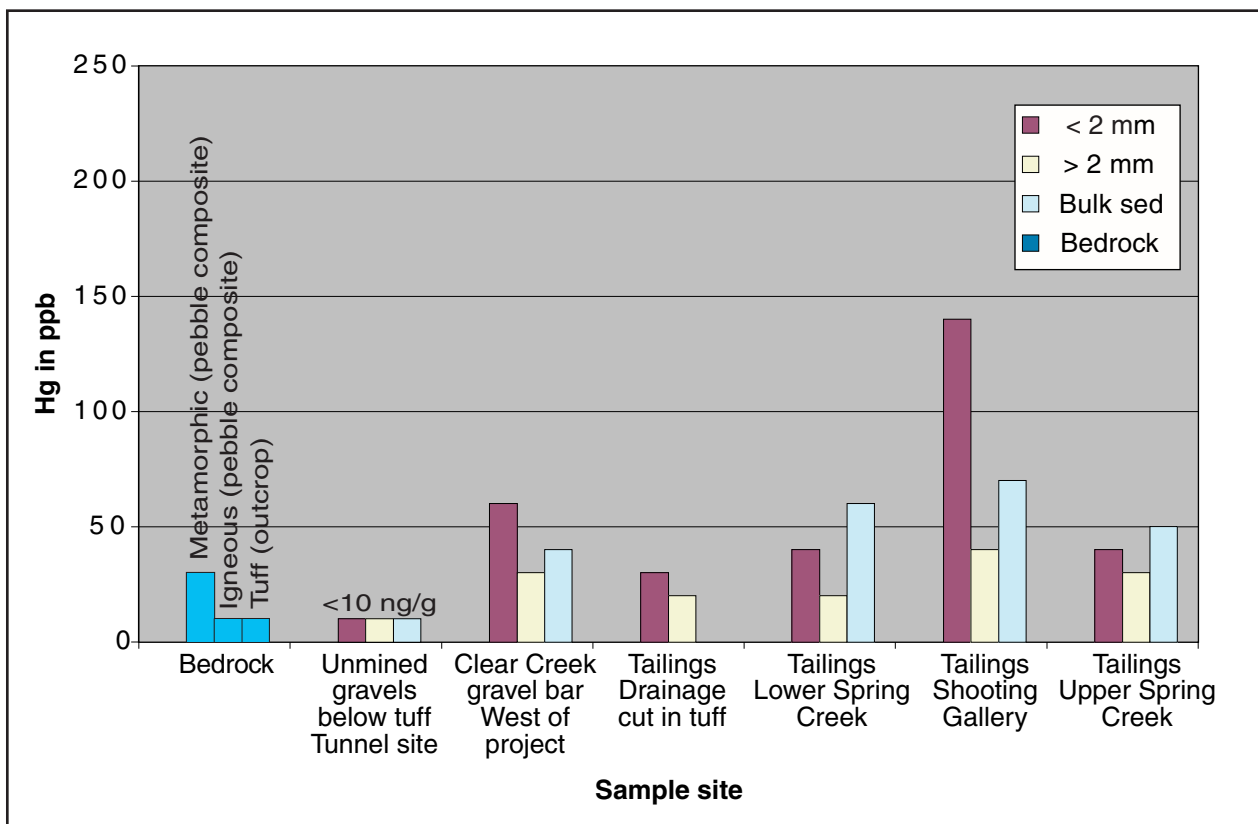


Figure 9. Distribution of mercury in bedrock, unmined conglomerate, and dredge stacker tailings and dredge sluice tailings as a function of grain size.

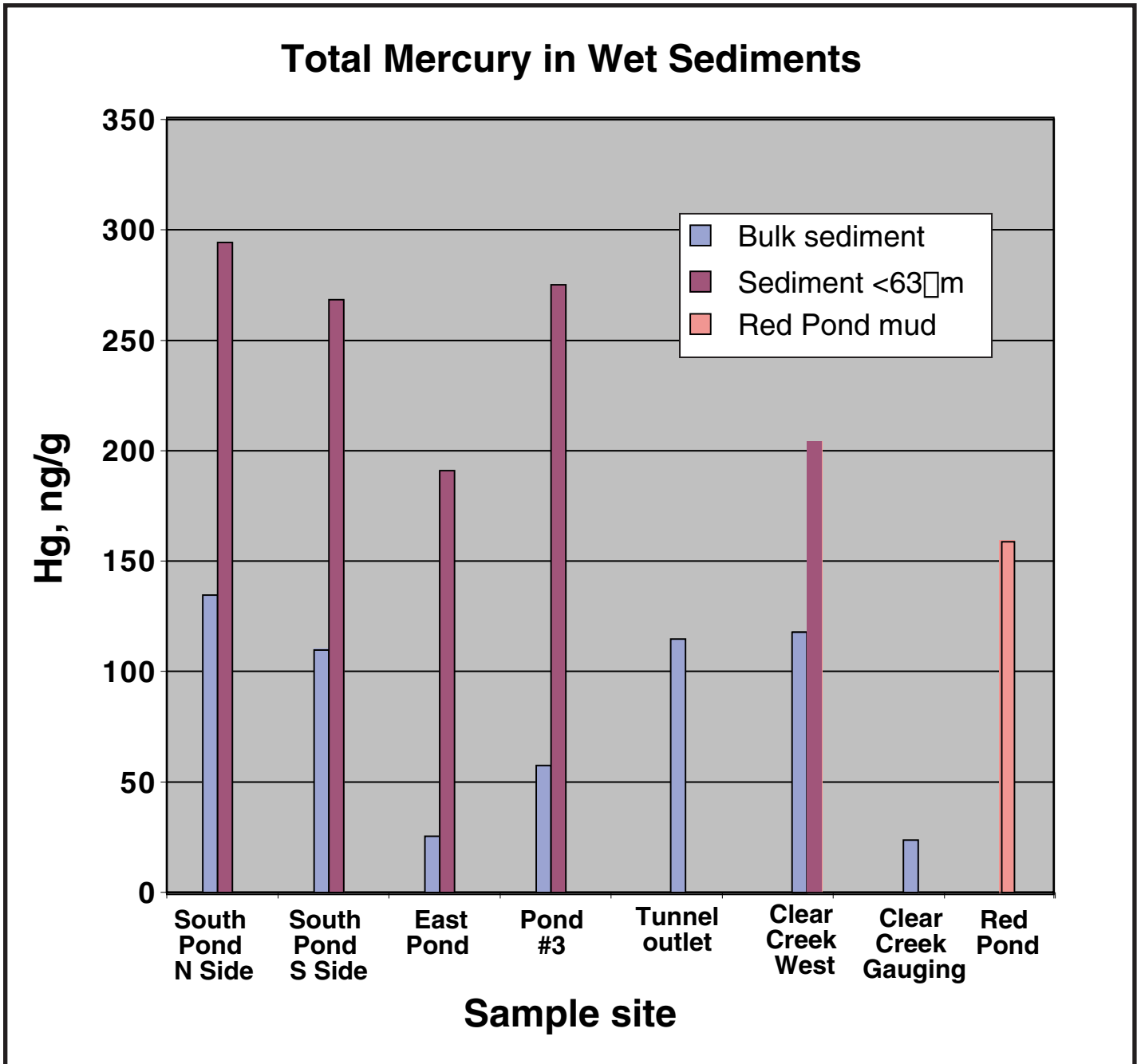


Figure 10. Mercury concentrations in sediments from ponds, hydraulic mine drainage tunnel, and Clear Creek as a function of grain size.

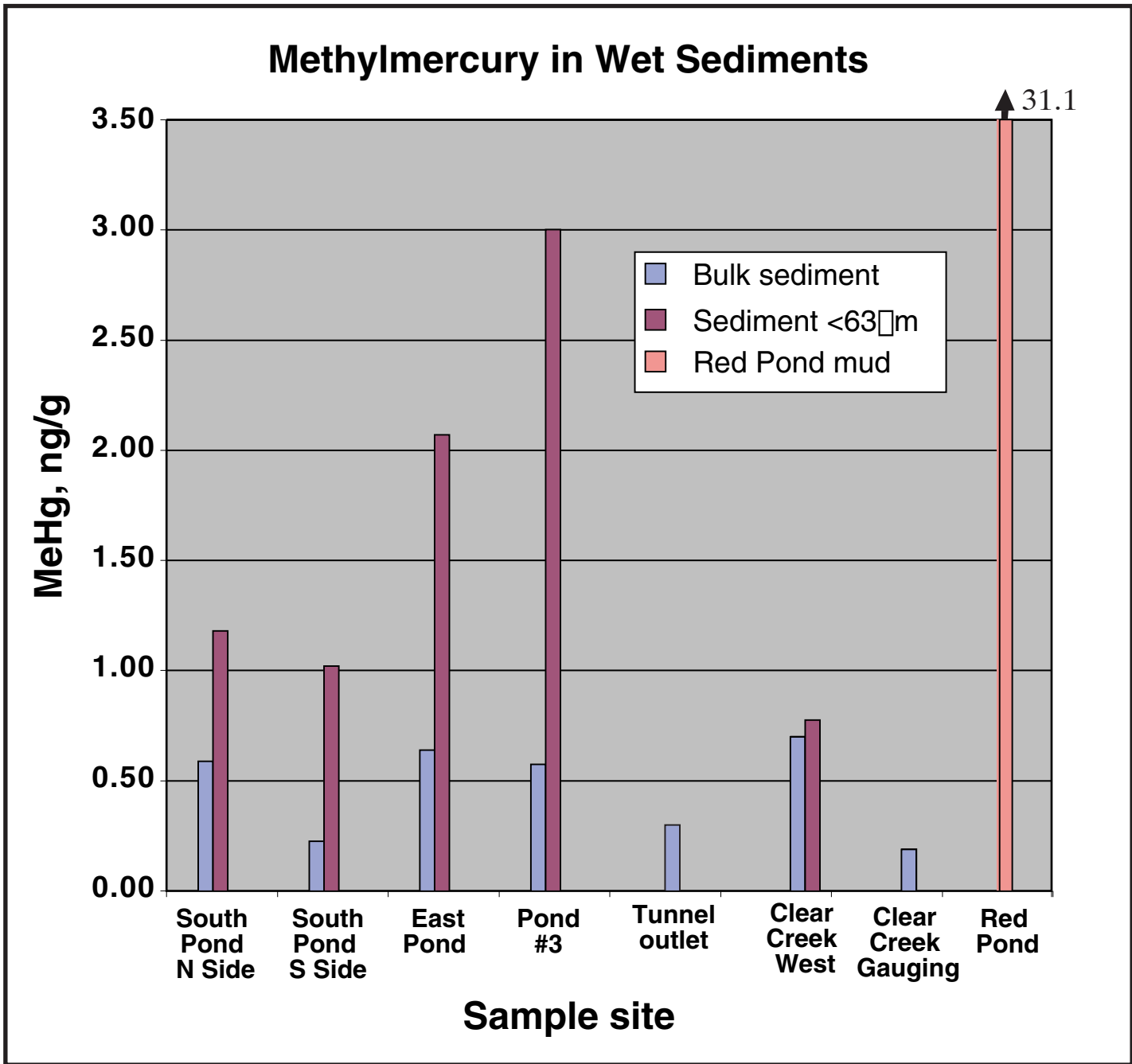


Figure 11. Methylmercury concentrations in sediments from ponds, hydraulic mine drainage tunnel, and Clear Creek as a function of grain size.

Hg, Frontier- vs. Chemex results

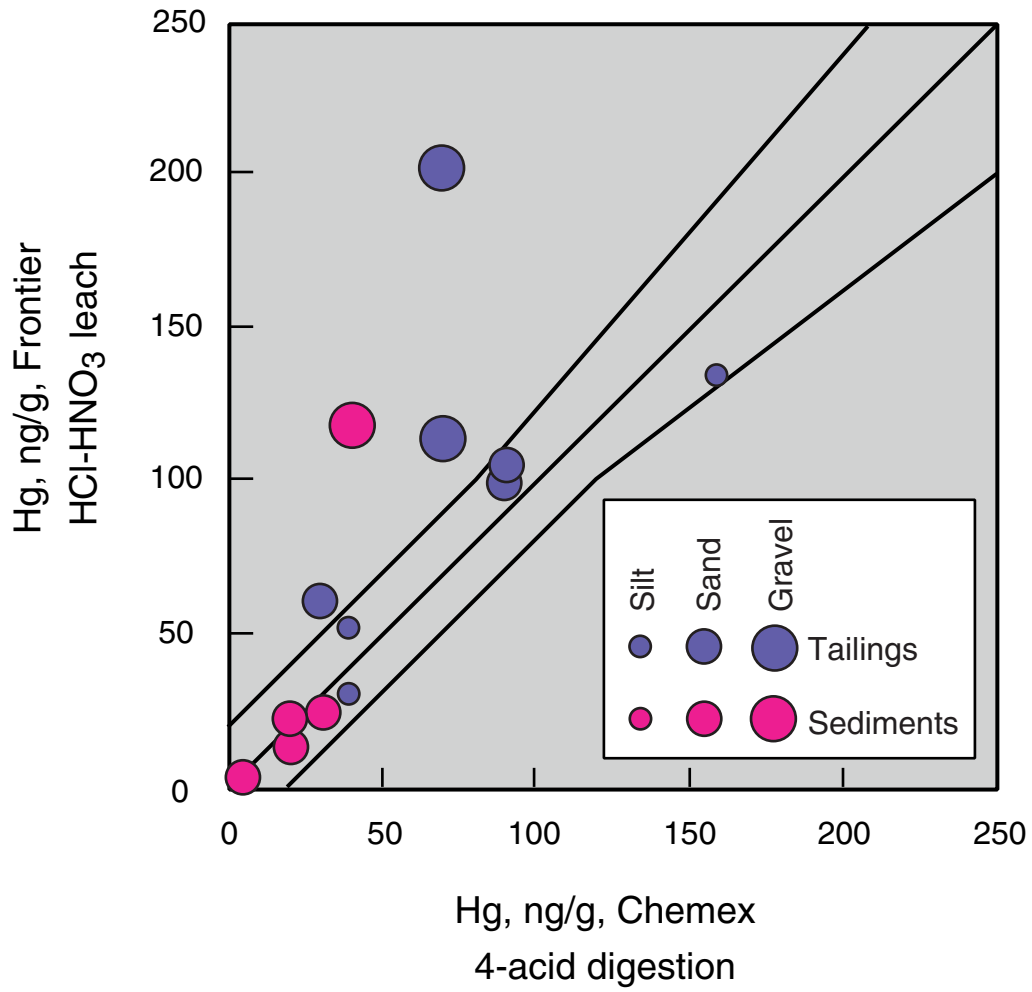


Figure 12. Concentrations of total mercury in sediments and tailings, comparison of results obtained by two different methods.

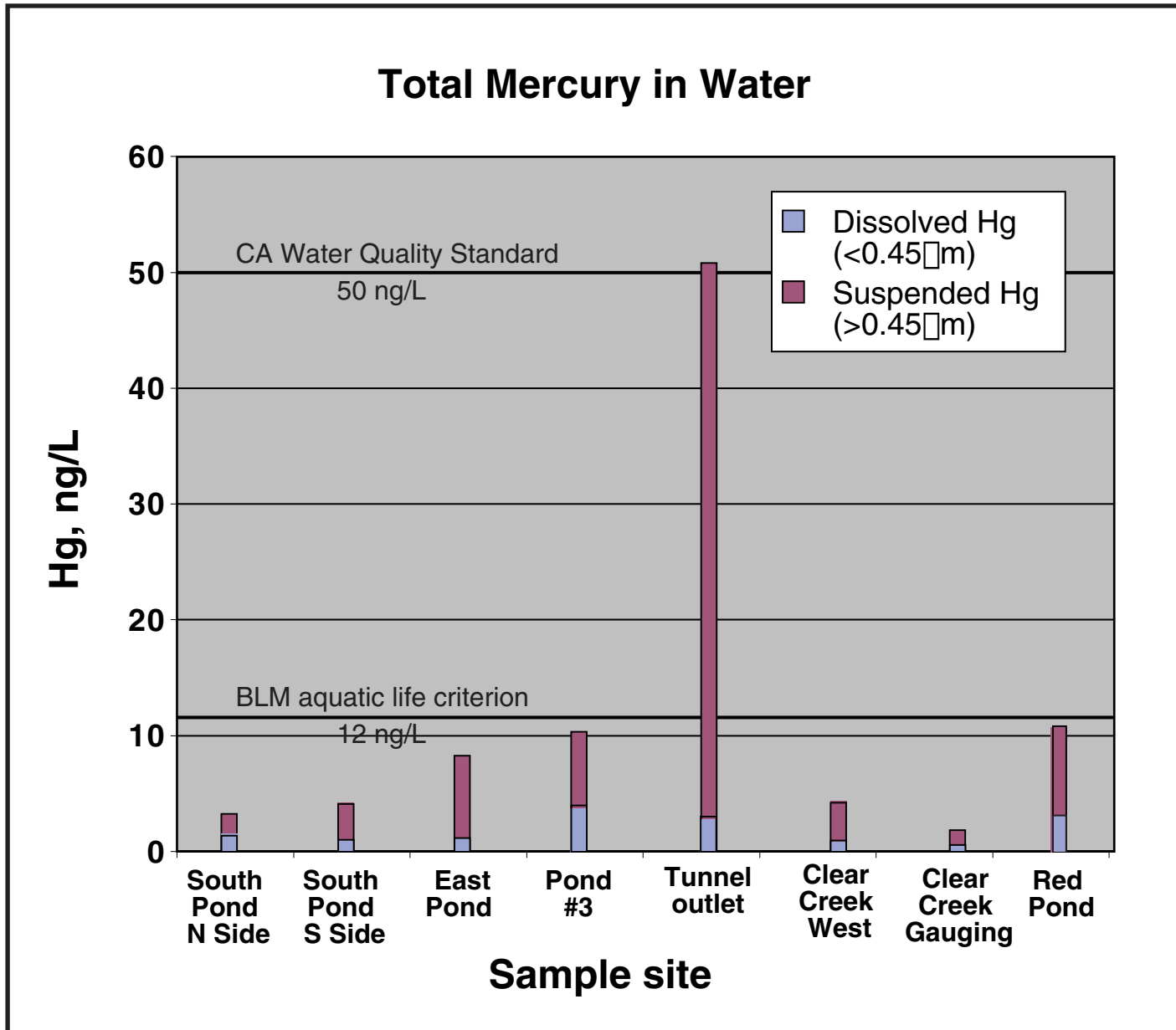


Figure 13. Mercury concentrations in waters from ponds, Clear Creek, and hydraulic mine drainage tunnel. Bars show amounts of dissolved mercury (passing 0.45µm filter) and suspended mercury (difference between total and dissolved mercury).

Methyl Hg- vs. total Hg

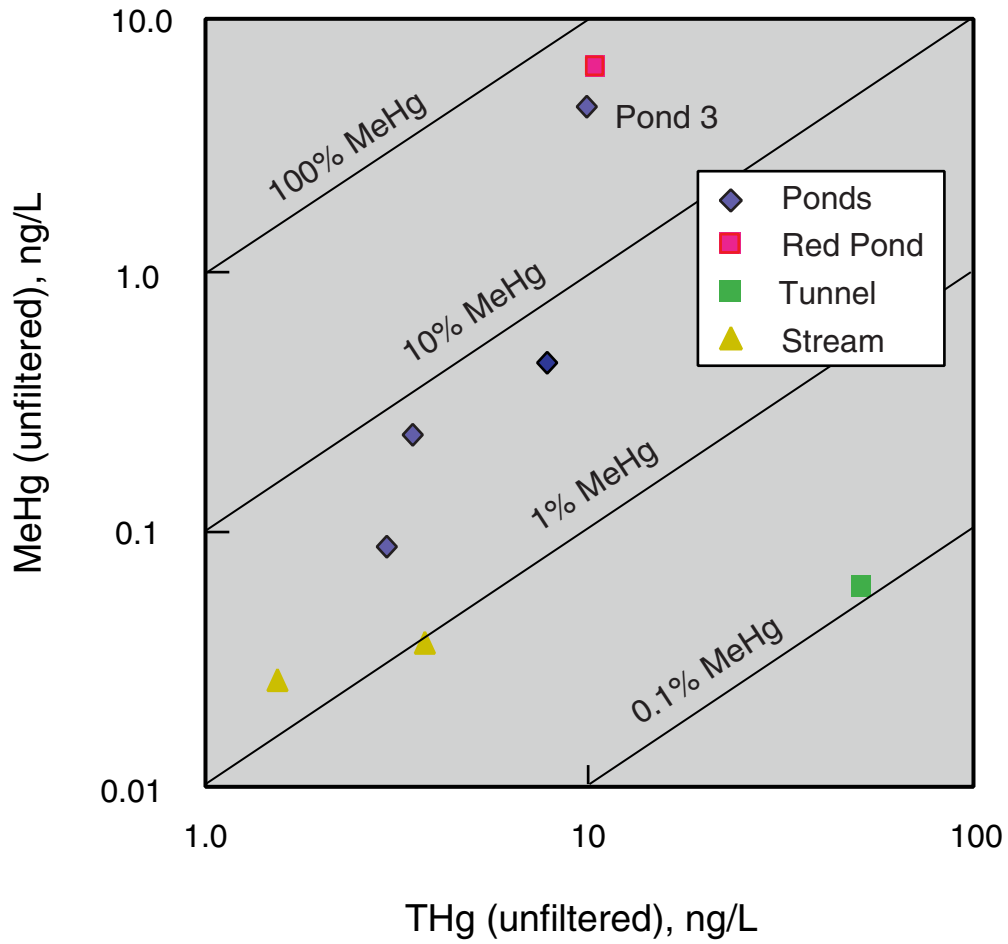


Figure 14. Methylmercury versus total mercury concentrations in waters from ponds, Clear Creek, and hydraulic mine drainage tunnel.

Sulfate- vs. total Hg

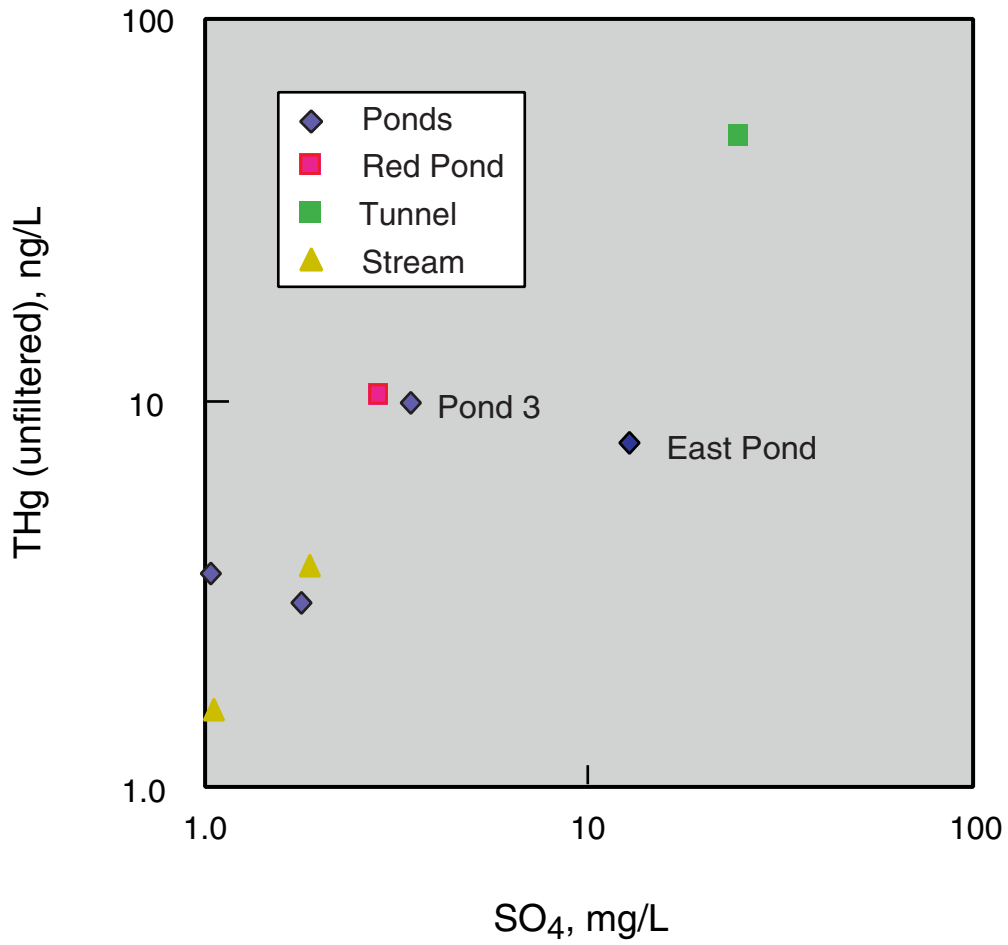


Figure 15. Sulfate versus total mercury concentrations in waters from ponds, Clear Creek, and hydraulic mine drainage tunnel.

Total iron- vs. Hg

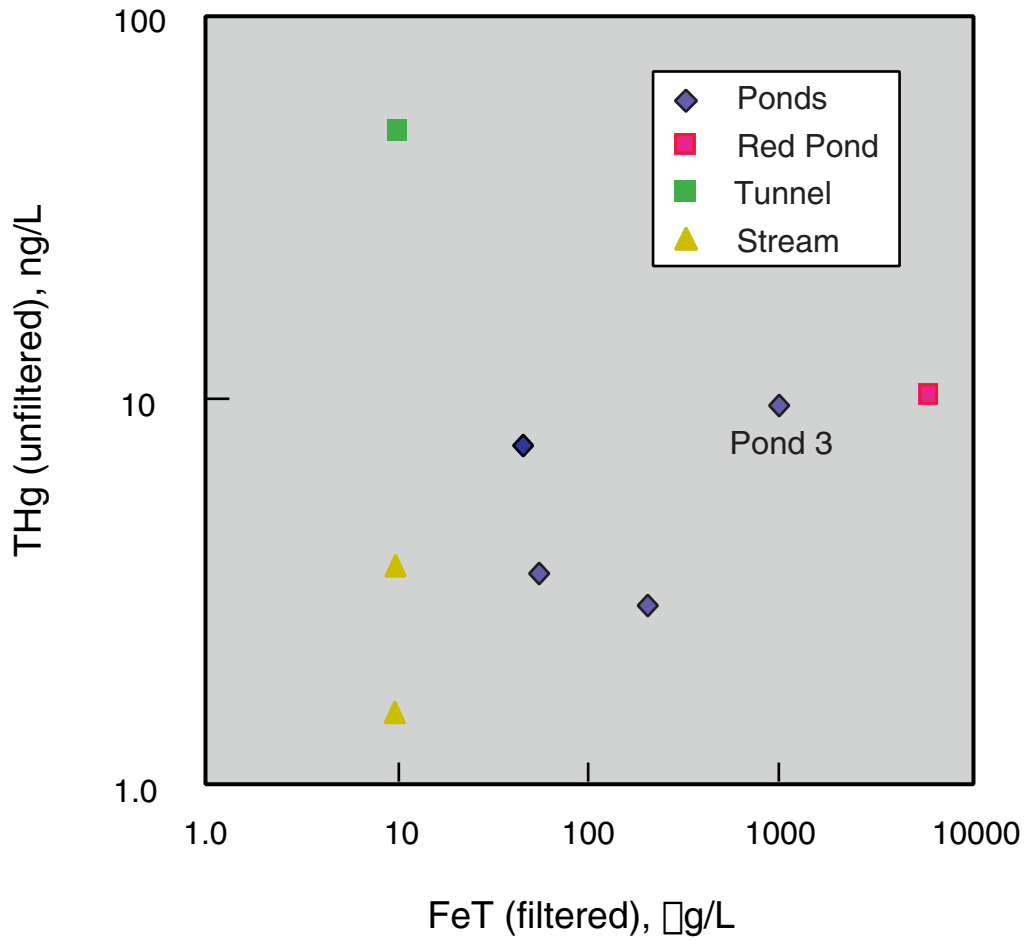


Figure 16. Total dissolved (filtered, 0.45 μm) iron versus total mercury concentrations in waters from ponds, Clear Creek, and hydraulic mine drainage tunnel.

Chloride vs. total Hg

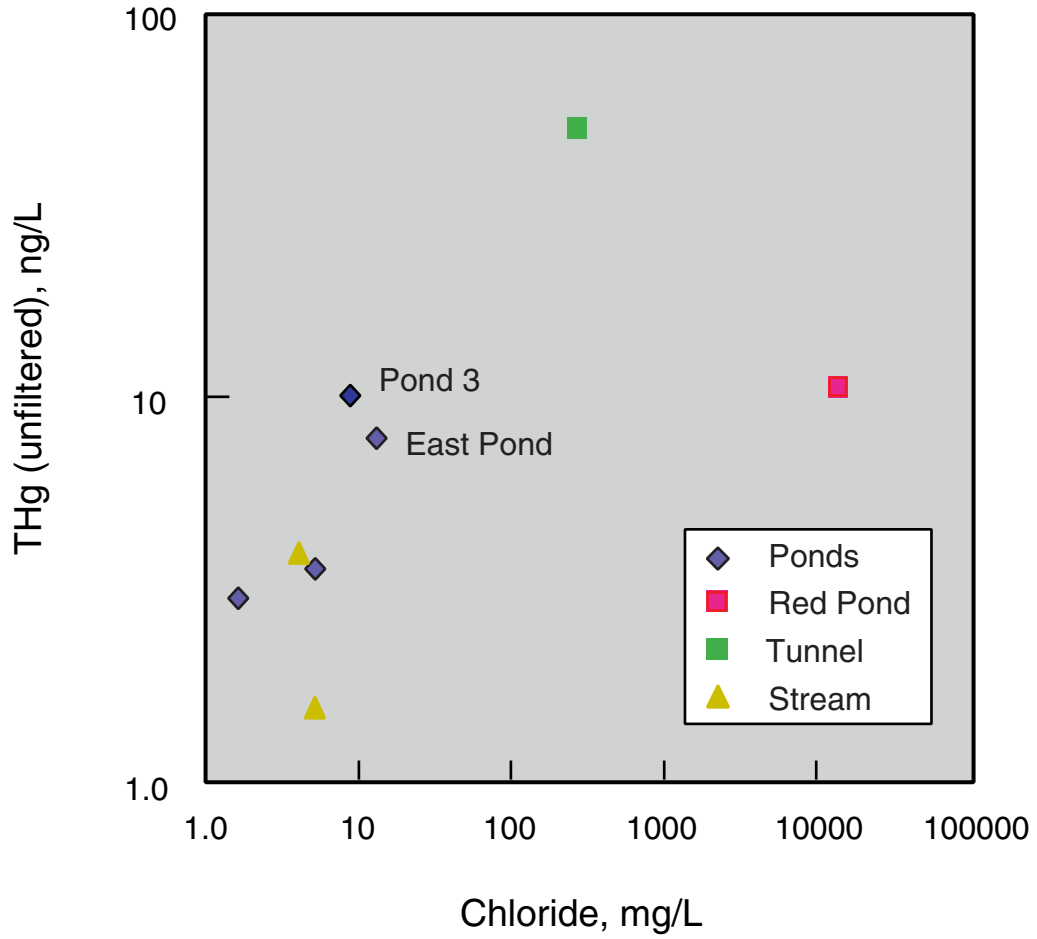


Figure 17. Chloride versus total mercury concentrations in waters from ponds, Clear Creek, and hydraulic mine drainage tunnel.

Chloride vs. boron and lithium

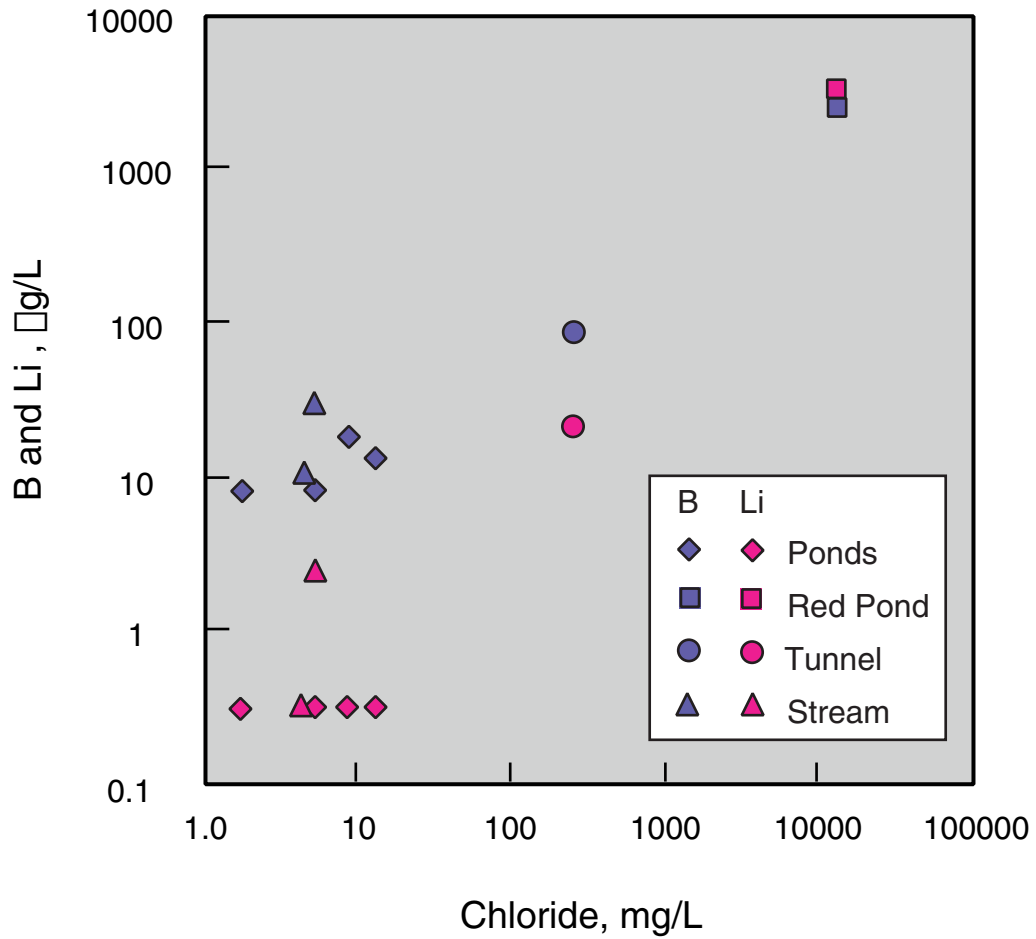


Figure 18. Chloride versus lithium and boron concentrations in waters from ponds, Clear Creek, and hydraulic mine drainage tunnel.