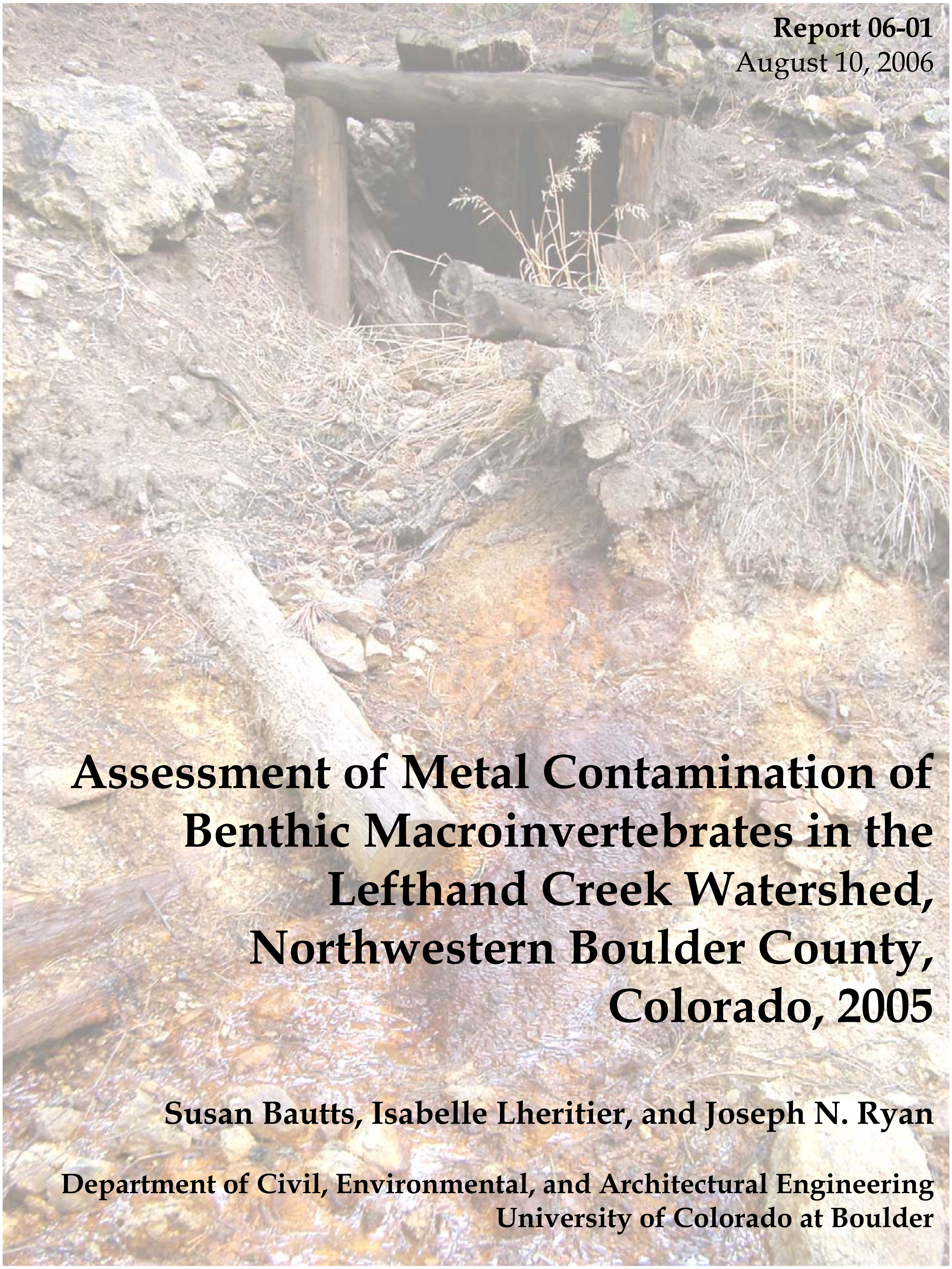

Report 06-01
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EXECUTIVE SUMMARY

This report details the results of Tasks 1 and 2 of the Lefthand Watershed Oversight Group's Regional Geographical Initiative grant "Assessment of Metal Contamination from Numerous Inactive Mines in the Lefthand Creek Watershed, Boulder County, Colorado." Task 1 included collection of benthic macroinvertebrates from in the three major Creeks in the watershed, Lefthand Creek, James Creek, and Little James Creek. Task 2 included the analysis of the metal content of the macroinvertebrate tissues. The macroinvertebrate data, coupled with stream water and sediment data from other University of Colorado and LWOG studies, were used as indicators of intermittent metal contributions to the streams in the Lefthand Creek watershed. The goal was use the benthic macroinvertebrates to find sources of metals that were not found during metal loading tracer dilution tests conducted by Wood et al. (2004).

Samples of benthic macroinvertebrates, water, and sediment were collected during 2005 from 45 locations in Lefthand, James, and Little James Creeks. Metal analysis focused on zinc, copper, and lead. Sediment metal concentrations are reported here to evaluate the role of sediments in affected metal concentrations in the benthic macroinvertebrates.

In Lefthand Creek, zinc concentrations in the benthic macroinvertebrates ranged from 390 to 2,400 µg g^{-1}. The highest zinc concentration occurred just above Lickskillet Road. Copper ranged from 45 to 670 µg g^{-1}, with the highest concentration occurring downstream of the White Raven Mine in California Gulch. Lead ranged from 0.6 to 27 µg g^{-1}, and the highest concentration of lead coincided with that of copper.

In James Creek, zinc concentrations in the benthic macroinvertebrates ranged from 250 to 1370 µg g^{-1}. The highest zinc concentration occurred just upstream of the confluence with Lefthand Creek. Copper ranged from 34 to 86 µg g^{-1} with the highest concentration occurring just downstream of Curie Springs. Lead concentrations ranged from below detection limits to 8.8 µg g^{-1} just above the confluence with Lefthand Creek.

In Little James Creek, macroinvertebrates were absent from seven of the thirteen sites sampled. Zinc concentrations in the benthic macroinvertebrates ranged from 140 to 1,600 µg g^{-1}. The highest concentration of zinc occurred just downstream of the Evening Star Mine. Copper ranged from 14 to 170 µg g^{-1}, with the highest concentration observed just downstream of the Argo Mine. Lead ranged from 11 to 290 µg g^{-1}, with the highest concentration observed in the just downstream of the Argo Mine.

The results of the benthic macroinvertebrate sampling, along with the sediment sampling, resulting in the following re-prioritization of remediation for abandoned mine sites in the Lefthand Creek watershed. The rating for the Slide Mine was elevated from medium to high priority based on increases in concentrations of zinc and lead in benthic macroinvertebrates and sediments downstream of this site. The rating from the Argo Mine was elevated from medium to high based on concentrations of copper and lead in benthic macroinvertebrates collected below this site.

ACKNOWLEDGMENTS

Financial support for this project was provided by Region 8 of the U.S. Environmental Protection Agency through a Regional Geographic Initiative grant and by the University of Colorado Outreach Committee.

Scientific and technical assistance was provided by Kathryn Hernandez at the U.S. Environmental Protection Agency, Diane McKnight and JoAnn Silverstein at the University of Colorado, John Drexler and Fred Luiszer of the Laboratory for Environmental and Geological Studies at the University of Colorado.

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INTRODUCTION

Mining legacy and remediation in the Lefthand Creek watershed

Mining activities around the world have left countless streams, rivers and lakes contaminated with toxic concentrations of heavy metals (Moore and Luoma, 1990; Davies et al., 1994). In Boulder County, Colorado in the mid-1800s, a boom of settlers arrived looking to mine and mill precious metals in Boulder County. The legacy from this era was assessed in 1993 by the Colorado Geological Survey (Sares and Lovekin, 1993) through the identification of 230 mine openings and 186 tailings piles, all presently abandoned, within the Lefthand Creek watershed (Figure 1). It has been determined that these tailings piles and mines continue to provide a source of toxic metals as intermittent streams meander through and erode tailings deposits and transport them into main stream channels threatening human and aquatic life (Lefthand Watershed Task Force, 2002).

Lefthand Creek is a key source of water for the Left Hand Water District and its 14,000 customers in unincorporated Boulder County. It is the concern of local citizens, government agencies, and stakeholder groups that in the event of a catastrophic flood or precipitation event, toxic metals may contaminate the stream water and subsequently, the water supply. Lefthand Creek has always been the principal millstream of Boulder County (Cobb, 1988). It was considered a “dead creek” by fisherman and nearby residents until the 1930s (Cobb, 1988; Lefthand Watershed Task Force, 2002). Around this time, it was reported that the acid mine drainage and toxic components thereof began to attenuate. This allowed the creek to support aquatic life once again. However, to this day, there is still significant contamination in various reaches.

In July, 2001, after much deliberation between local communities and federal and local agencies over concerns of water quality impairment due to abandoned mines, mills and waste rock piles, the Lefthand Watershed Task Force was established by Boulder County. In March, 2002, the Task Force issued a report for the Boulder County Department of Health on the effects of abandoned mines on the upper Lefthand watershed (west of Highway 36). The report indicated that the most significant cause of water quality impairment was due to past mining activities (Lefthand Watershed Task Force, 2002). The Little James Creek, a tributary of James Creek, which is a tributary of Lefthand Creek, was subject to the first documented complaints concerning water quality in the Lefthand Watershed in the mid-1960s. The Boulder County Department of Health Department found water samples near the Burlington Mine (along Little James Creek) to be high in sulfate, total solids, and various heavy metals (Lefthand Watershed Task Force, 2002).

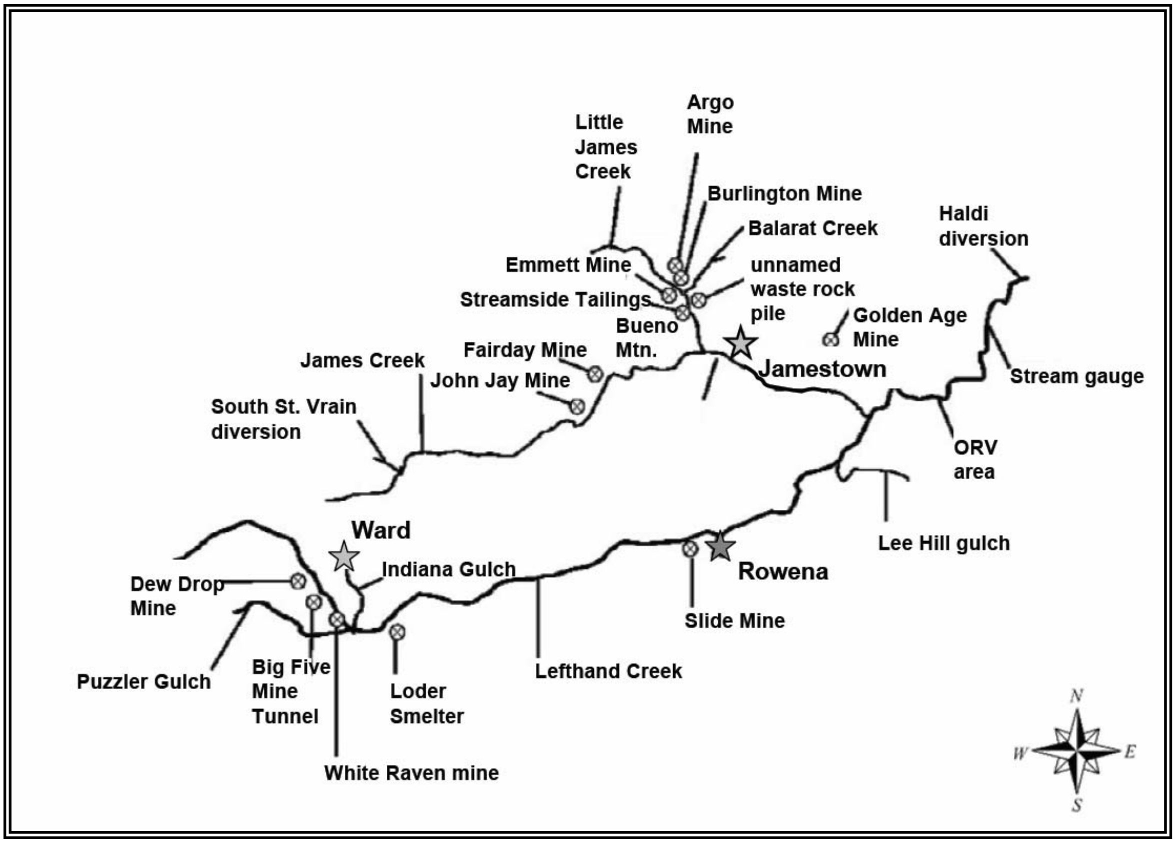

Figure 1. A map of the Lefthand Creek watershed identifying streams, mines (⊗), towns (★), and other geographical features.

Current activities to improve water quality in the watershed are occurring at many sites, including the Captain Jack Mine and Mill, the Burlington Mine, the Slide Mine, the "streamside tailings," the Bueno Mine tailings, the Fairday Mine, and the Golden Age mine.

The Captain Jack Mine and Mill is an EPA Superfund site (includes the Big Five Tunnel drainage, the Blackjack Mine, the Captain Jack mill, and the White Raven Mine) located just south of the town of Ward along a segment of Lefthand Creek referred to locally as "California Gulch." The site was listed on the states National Priority List (NPL) in September, 2003, and the remedial investigation and feasibility study were completed in April, 2006.

The Burlington Mine is located along Little James Creek one mile north of Jamestown. This site was listed as a Voluntary Clean-Up Program (VCUP) site in April, 2002, and remediation of the Burlington Mine was completed in December, 2004. The remediation and VCUP listing was initiated by Honeywell, Inc., the private owner.

The Slide Mine encompasses a 3 hectare area located along Lefthand Creek just upstream of the small town of Rowena (Figure 1). The Slide Mine has recently been considered for VCUP due to occurrences of sediment loading into Lefthand Creek during precipitation events and metals loading.

The Bueno Mine tailings and the "streamside tailings," located just west of Jamestown (Figure 1), are being remediated by the U.S. Forest Service and the EPA's Emergency Response program. Jamestown is surrounded by steep eroding slopes and recently experienced mudslides in the early summer of 2005. Bueno Mountain resides just above Jamestown and the potential exists for the release of toxic metals during a rain storm or rapid snowmelt.

The U.S. Forest Service has completed a reclamation project at the Fairday Mine on James Creek west of Jamestown (Figure 1) and is restoring the Golden Age Mine, which is located northeast of Jamestown, during the summer of 2006.

The Lefthand Watershed Oversight Group (LWOG), a stakeholder group, was formed as a final recommendation of the Lefthand Watershed Task Force. The LWOG, along with the aid of researchers from the University of Colorado, developed a watershed plan (LWOG, 2005) to characterize metal loading in the Lefthand, James, and Little James Creek watersheds and to identify future remediation targets based on an analysis of metals sources in the watershed conducted by University of Colorado researchers (Wood et al., 2004).

The experiments discussed within this report are an extension of this previous outreach by the University of Colorado to assist the LWOG in further characterization and prioritization of toxic metal sources. A list of metals which have exceeded aquatic life standards in the watershed was compiled by the Lefthand Watershed Task Force and includes aluminum, cadmium, copper, iron, lead, manganese and zinc (Lefthand Watershed Task Force, 2002). Based on the frequency of aquatic life standard exceedances and the ability to reinforce metal solubility trends, for this study, we focused on copper, zinc and lead.

Fate and transport of metals

Metal transport from abandoned mine sites and mining waste piles is a secondary process to the natural weathering of pyrite exposed to chemical and biological processes (Evangelou, 1995; Adriano, 2001). The oxidation of reduced sulfur in pyrite results in the release of acidity and sulfate into soil solution. The acidity leaches heavy metals from waste rock and mill tailings.

Geochemical interactions among surface water, colloidal materials, stream bed sediments and mineralogy are the essential components for predicting metal solubility as well as bioavailability (Stumm and Morgan, 1996). During precipitation and snowmelt, low pH runoff from waste rock piles transports zinc, copper and lead away from metal sources and into nearby streams. The metals in the acidic runoff remain in solution due to a lower affinity to bind to surfaces and thus are transported for long distances. Studies have shown that the stream water quality downstream improves with distance in relation to abandoned mines and metal sources (Church et al., 1997; Munk et al., 2002).

In neutral waters, metals precipitate or adsorb to mineral surfaces. Mineral hydroxide surfaces provide adsorption sites for the metals cations. Numerous studies have confirmed the selectivity of metals for adsorption to surfaces follow the general sequence (Axtmann et al., 1990; Kimball et al., 1995; Church et al., 1997; Wang et al., 1997; Davis and Atkins, 2001; Covelo et al., 2004):

$Cr^{3+} > Pb^{2+} > Cu^{2+} > Zn^{2+} > Cd^{2+} > Ca^{2+}$

This sequence has been found to vary with pH, hardness, and other solution chemistry factors. Metals that are immobilized by adsorption or precipitation mechanisms will be retained upon sediments unless all active sites are loaded or there is a change in the chemical environment (pH, redox potential, degradation of organics, fluid composition and temperature changes) which in turn re-mobilizes the metals (Pagnanelli et al., 2003).

Bioavailability of metals

Elevated metal concentrations have been found in benthic macroinvertebrates downstream of abandoned mines in the many streams of the Rocky Mountains and elsewhere. As a consequence of metal pollution in rivers and streams, benthic macroinvertebrates have been known to accumulate metals in concentrations that are indicative of their immediate environment (Hare et al., 1991; Cain et al., 1992; Kiffney and Clements, 1992; Clements and Kiffney, 1994). In addition, it has been found that benthic macroinvertebrate metal concentrations persist great distances downstream from metal sources (Farag et al., 1998).

The metals integrated into the tissues of benthic macroinvertebrates are an accumulation of varying in-stream water quality conditions over time (Clements and Kiffney, 1994). These concentrations can be used indirectly to determine the degree of metal loading by comparing benthic macroinvertebrate metal concentrations at contaminated sites to background sites (Woodward et al., 1994; Woodward et al., 1995; Farag et al., 1999). Background sites include areas of the investigated watershed where previous mining activities did not occur and stream conditions are relatively pristine. The metals that accumulate in the bodies of benthic macroinvertebrates from water and sediments can also be ingested by fish, which studies have shown to be their main source of metal exposure (Farag et al., 1998).

Early studies in the Clark Fork River, Montana showed that with continual downstream copper concentrations in the water decreasing, concentrations in benthic macroinvertebrates (as well as sediments) remained high (Woodward et al., 1994; Lanno et al., 1997; Cain et al., 2000). Furthermore, during a spring sampling event in the upper Arkansas River in Colorado, scientists found that copper and zinc concentrations in benthic macroinvertebrates remained elevated above background levels 45 km downstream of a tributary containing acidic metal-laden flow from abandoned mine sites (Clements and Kiffney, 1994). In a study conducted in 2000, copper and lead concentrations in sediments and in the benthic macroinvertebrate *Hydropsyche californica* were found to be positively correlated in a majority of the samples taken in the Sacramento River (Cain et al., 2000).

The leachability of metals from benthic macroinvertebrates varies considerably between species (Kiffney and Clements, 1992; Clements and Kiffney, 1994; Cain et al., 2004; Prusha and Clements, 2004) and that care should be taken when looking at metal concentrations in pooled communities. The benthic macroinvertebrates *Archtopsyche grandis* (Kiffney and Clements, 1992; Clements and Kiffney, 1994; Maret et al., 2003; Cain et al., 2004; Prusha and Clements, 2004) and *Hydropsyche californica* (Cain et al., 2000) have been used as target species of collection for studies using benthic macroinvertebrate metal accumulation for monitoring metals impacts from abandoned mine sites in Rocky Mountain streams. Using a single species for monitoring metal impacts in streams limits variability in metal accumulation due to varying feeding habits and metal tolerance.

Objectives of this project

One of the suggestions made by the Lefthand Watershed Task Force was to determine the potential effects on water quality in the event of a catastrophic storm event or rapid snowmelt. The impacts on streams in Lefthand Creek are associated with the risk of contaminated sediment moving downstream gradually over time or instantaneously during periods of high discharge or flood. In order to determine the outcome of such an event, it is important to assess the effective methods for measuring the impacts of intermittent storms.

Previous studies conducted by the University of Colorado for LWOG incorporated tracer dilution tests to identify metal loading to streams (Wood et al., 2004). A tracer study uses a highly concentrated salt injected at a point in the stream while synoptic sampling at various locations downstream is conducted. Knowing the initial concentration of the tracer and by how much it is diluted at all sampling locations, the stream flow can be determined. Using these precise measurements for stream flow along with samples analyzed for metal concentrations, metal loading can be calculated. The tracer study was not able to identify metal loading to the stream as a result of intermittent storm events which erode and weather waste rock piles and transport metals to the stream. The tracer tests give only a snapshot in time of the metals transported from an upstream source. If conducted on a day without significant precipitation or snow melt, these studies miss metal inputs that may be present during rainfall and snow melt events.

Anecdotal evidence of metal loading during a precipitation event is represented in Figure 2. Sediment loading, visualized by muddy brown water, from the Slide Mine during numerous precipitation events, have been reported by residents downstream of the Slide Mine in the town of Rowena.

Figure 2. Effect of rainfall on suspended sediment in Lefthand Creek. Photographs of Lefthand Creek in Rowena, about 2 km downstream of the Slide Mine, taken at 5:45, 5:52 and 5:57 pm on April 8, 2004, after a relatively light rainfall that began at 5:10 pm.

The goal of this study was to assess the impacts of these intermittent precipitation events by measuring metal concentrations, specifically copper, zinc and lead in the benthic macroinvertebrates in conjunction with similar metal concentrations in streambed sediments and stream water in the Lefthand, Little James and James Creeks. By completing simple regression analyses on multiple combinations of paired data sets, we identified correlations between metal concentrations in the benthic macroinvertebrates, water, and sediments. Results from both correlative and non-correlative data-sets provided insight into intermittent sources of metals.

Our analyses focused on zinc, copper, and lead because these metals most frequently and consistently exceed aquatic life standards in the watershed (Lefthand Watershed Task Force, 2002; Wood et al., 2004), and because these metals behave quite differently with respect to adsorption to minerals, organic matter, and organisms (Adriano, 2001; Prusha and Clements, 2004).

MATERIALS AND METHODS

Field research area

The Lefthand Creek watershed drains an area of approximately 220 km^2. Located at the northern tip of the Colorado Mineral Belt, the watershed drains mainly Precambrian metamorphic and igneous formations and glacial and alluvial deposits. The watershed terrain is about one-half alpine and sub-alpine forest and one-half agricultural and urban on the high plains east of the front range of the Rocky Mountains. Lefthand Creek, James Creek, and Little James Creek are the primary streams in the upper half of the Lefthand Creek watershed (Figure 1).

Lefthand Creek originates in glacial and snow melt waters at an elevation of approximately 4,200 m in the Indian Peaks Wilderness area near the Continental Divide and approximately 5 km west of Highway 72 (the "Peak to Peak Highway") and the town of Ward, Colorado. It is just east of the town of Ward where Lefthand Creek flows through portions of the Ward mining district, including the Captain Jack Mine and Mill Superfund site. This Superfund site is located on a segment of the stream locally referred to as the California Gulch.

Downstream of California Gulch, Lefthand Creek flows past mine waste rock piles and receives water from multiple tributaries draining mine sites off the steep vertical grades of Lefthand Canyon. The Lefthand Creek empties out onto the high plains at an elevation of approximately 1,400 m which is nearly 40 km downstream of its headwaters. Ultimately, Lefthand Creek flows into the St. Vrain Creek, which eventually feeds the South Platte River.

Annual mean and monthly mean stream flows were recorded in Lefthand Creek by the United States Geological Survey from 1929 to 1980. The survey staff gage was located at 40°07'32" north latitude and 105°18'12" west longitude. The annual mean stream flows in those years ranged from 600 L s^{-1} to 1,180 L s^{-1} (Figure 3). The average monthly stream flow ranged from 90 L s^{-1} to 4,700 L s^{-1} (Figure 4). The peak flows occur in June during the spring snowmelt at higher elevations. During a recent study in the Lefthand Creek, University of Colorado researchers recorded stream flow in Lefthand Creek ranging from 45 L s^{-1} at Peak to Peak Highway to 2,500 L s^{-1} at the Left Hand Water District's Haldi diversion gate (about 30 km downstream of Peak to Peak Highway) during the high flow season (Wood et al., 2004). During this study, James Creek added 550 L s^{-1} to Lefthand Creek and was the major tributary to Lefthand Creek.

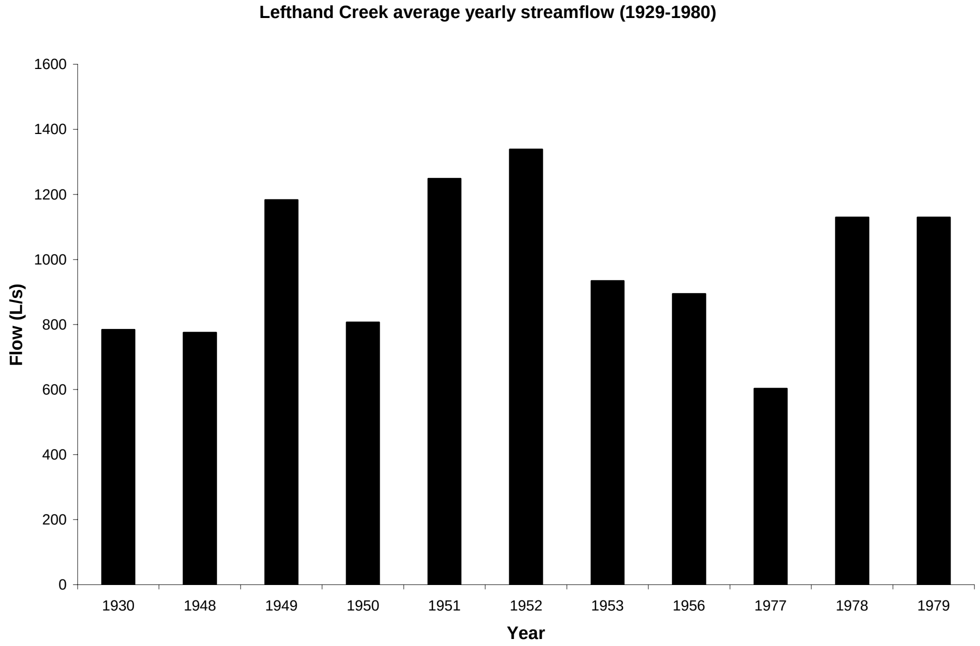

Figure 3. Average annual stream flow in Lefthand Creek for selected years from 1930 to 1979. The years selected were those available from U.S. Geological Survey data.

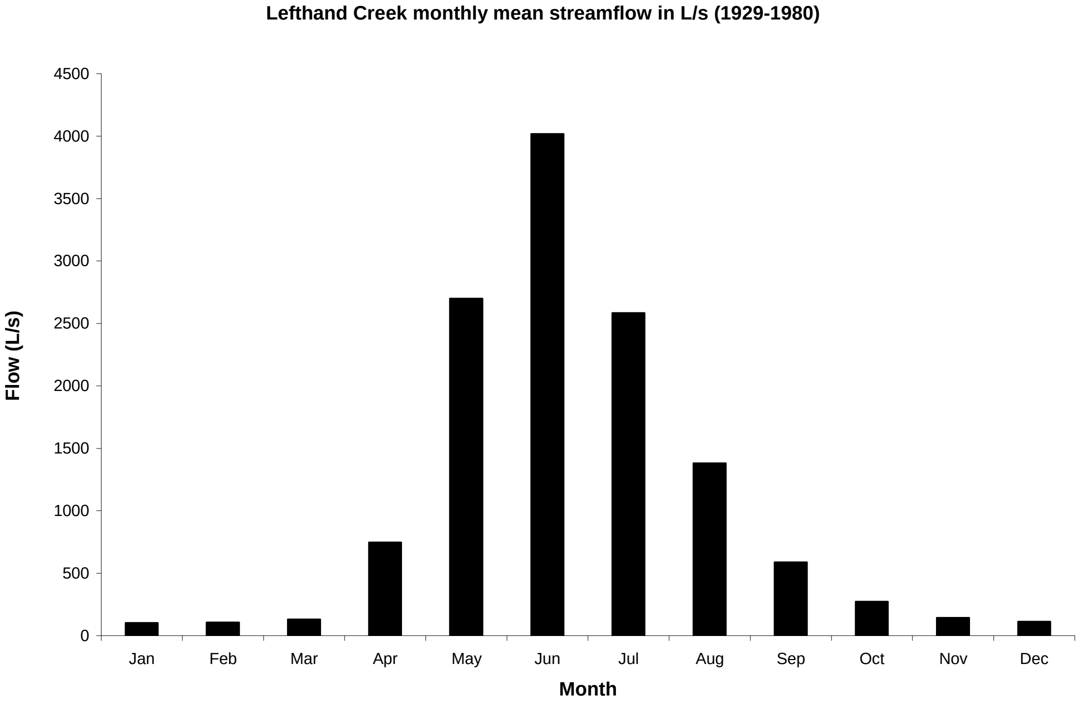

Figure 4. Monthly mean stream flow recorded from 1929-1980 in Lefthand Creek based on available U.S. Geological Survey data.

James Creek flows through Jamestown and is its sole source of drinking water. This sub-watershed is covered entirely by alpine and sub-alpine forest. James Creek drains an area of approximately 48 km^2. Elevations in the James Creek watershed range from approximately 3,000 m at the headwaters in the Indian Peaks Wilderness Area to 2,000 m at the confluence with Lefthand Creek approximately 5 km south of Jamestown. The annual average stream flow in 2004 and 2005 in James Creek was 1070 L s^{-1} and 1300 L s^{-1}, respectively. Average monthly flows between August of 2003 until December of 2005 are illustrated in Figure 5 with the maximum discharge approximately 3,000 L s^{-1} in the month of June. Flows were measured at a staff gauge station in Jamestown located at 40º06′55.8″ north latitude and 105º23′18.9″ west longitude by Colleen Williams of the James Creek Watershed Initiative. The headwaters of the James Creek watershed supply only a small fraction of the flow into James Creek. During parts of the year, a diversion of the South St. Vrain Creek contributes nearly all of the flow of James Creek (CDWR, 2002). Snow melt in the South St. Vrain Creek headwaters feeds high flows in James Creek. James Creek and its tributaries drain steep graded mined areas such as the Jamestown Mining District and the Golden Age Mining District. James Creek is the main source of drinking water for Jamestown. The creek is diverted to a small treatment plant just downstream of Bueno Mountain on Ward Street (County Road 102J).

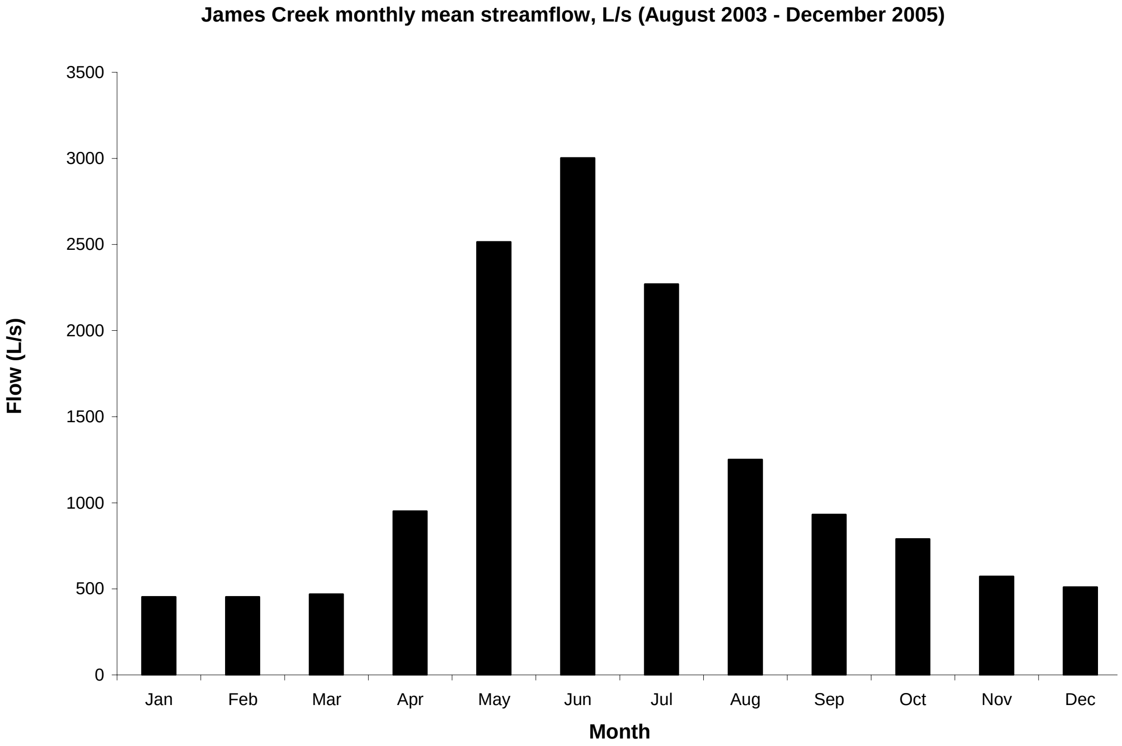

Figure 5. Monthly mean stream flow in James Creek recorded from August 2003 to December 2005. This stream gauge has been monitored by Colleen Williams of the James Creek Watershed Initiative.

Little James Creek is a tributary of James Creek. The confluence occurs just downstream of the Jamestown water treatment plant near the corner of Main Street and

Ward Street in Jamestown. Little James Creek drains a watershed area of approximately 15 km^2. Alpine and sub-alpine forests cover the sub-watershed. Cumulative stream flow data for Little James Creek is unavailable, but University of Colorado researchers measured stream flows ranging from 110 L s^{-1} to 540 L s^{-1} for April 22, 2003, and from 0 to 20 L s^{-1} on June 17, 2003 (Wood et al., 2004). Another tracer experiment on April 15, 2004, not yet reported in a publication, measured stream flows from 52 to 318 L s^{-1} from upstream to the confluence with James Creek. Wood et al. (2004) reported that the creek flow is not continuous along its length in the summer months.

Benthic macroinvertebrate, water, and sediment sampling sites

Field sites along Lefthand, James and Little James Creeks were chosen based upon a University of Colorado report to the LWOG which ranked areas as low, medium and high priority based on pH, toxic metal concentrations and metal loading rates (Wood et al., 2004). Field sites chosen for this study are listed in Table 1, Table 2 and Table 3 and shown in Figure 6. These sites were sampled for benthic macroinvertebrates, stream water, and sediments. The sediment sampling and analysis was conducted for another project. The details of the sediment sampling and analysis are provided by Bautts (2006).

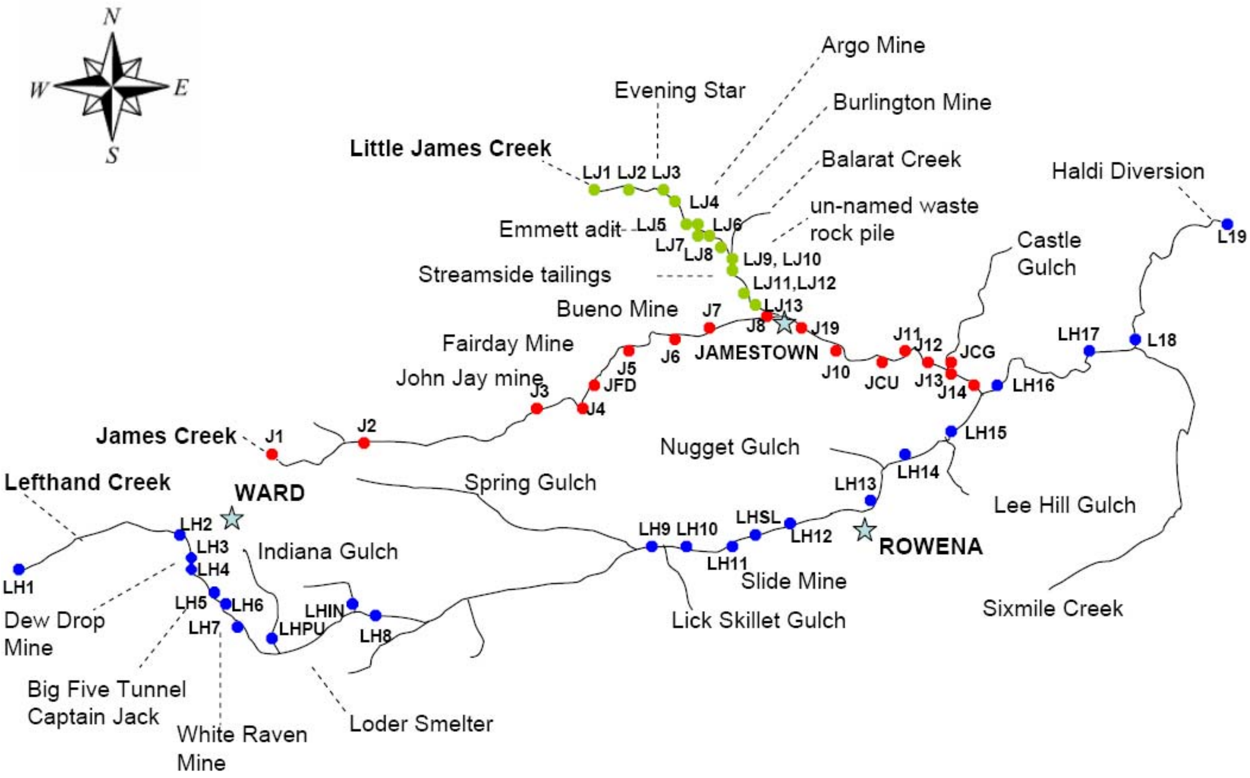

Figure 6. A map of the Lefthand Creek watershed showing benthic macroinvertebrate, water, and sediment sampling sites for Lefthand Creek (blue circles), James Creek (red circles), and Little James Creek (green circles).

Table 1. Lefthand Creek water, sediment, and benthic macroinvertebrate sampling site descriptions and locations by global positioning system.

sample site name	site ID	site description	latitude longitude (°, ‘, “)
LH1	5560A-1	at the Peak-to-Peak Highway	40 04 09.27 N 105 31 00.66 W
LH2	5560A-6	upstream of unnamed tributary that drains mine across Peak-to-Peak	40 03 54.97 N 105 30 47.74 W
LH3	5560A-8	downstream of unnamed tributary that drains mine across Peak-to-Peak	40 03 53.14 N 105 30 42.66 W
LH4	5560A-13	upstream of Big Five Tunnel drainage confluence	40 03 44.21 N 105 30 34.81 W
LH5	5560A-14	downstream of Big Five Tunnel drainage confluence	40 03 42.9 N 105 30 31.54 W
LH6	5560A-17	upstream of White Raven Mine site	40 03 38.45 N 105 30 24.98 W
LH7	5560A-21	downstream of White Raven Mine site	40 03 31.86 N 105 30 21.9 2 W
LH-PU	5560A-PU	Puzzler Gulch	40 03 20.28 N 105 30 06.63 W
LH-IN	5560A-IN	Indiana Gulch	40 03 21.74 N 105 30 04.3 7 W
LH8	5560A-56	downstream of Indiana Gulch confluence at Sawmill Road.	40 03 20.81 N 105 30 02.4 7 W
LH9	5560A-95-1	above Lickskillet Rd and below tailings	40 04 27.77 N 105 24 47.3 3 W
LH10	5560A-96	below Lickskillet Gulch	40 04 27.69 N 105 24 43.82 W
LH11	5560A-101	150 meters upstream of Slide Mine discharge	40 04 28.60 N 105 24 02.9 8 W
LH-SL	5560A-SL1	slide Mine discharge	40 04 28.53 N 105 24 02.8 9 W
LH12	5560A-103	below Slide Mine	40 04 29.70 N 105 23 53.08 W
LH13	5560A-113	below Rowena	40 04 43.50 N 105 23 01.54 W
LH14	5560A-123	below Nugget Gulch, above “Lee Hill Gulch”	40 05 20.04 N 105 21 46.95 W
LH15	5560A-129	below “Lee Hill Gulch”	40 05 35.69 N 105 21 02.18 W
LH16	5560A-136-2	below James Creek confluence at pull-off	40 06 15.61 N 105 20 16.19 W
LH17	5560A-127	downstream of US Forest Service off-highway vehicle access	40 06 31.77 N 105 19 05.67 W
LH18	5560A-171	at Buckingham Park	40 06 40.07 N 105 18 25.34 W
LH19	5560A-184	at Haldi Head gate, Left Hand Water District intake	40 07 53.07 N 105 17 33.11 W

Table 2. James Creek water, sediment, and benthic macroinvertebrate sampling site descriptions and locations by global positioning system.

sample site name	site ID	site description	latitude longitude (°, ', ")
J1	5561A-T1	reference Site above Peak-to-Peak highway	40 05 21.33 N 105 29 46.75 W
J2	5561A-T2	downstream of County Road 100	40 05 31.25 N 105 29 09.56 W
J3	5561A-T3	upstream of Forget-Me-Not Meadow and Fairday drainage	40 05 57.57 N 105 25 59.30 W
J4	5561A-T4	upstream of road crossing, downstream of tailings piles	40 06 04.78 N 105 25 47.83 W
J-FD	5561A-FD	Fairday Mine drainage	40 06 40.77 N 105 25 20.26 W
J5	5561A-JOHN	Downstream of John Jay mine	40 06 19.70 N 105 25 38.60 W
J6	5561A-10	200 m downstream of Fairday drainage	40 06 38.40 N 105 25 14.35 W
J7	5561A-16	upstream of Bueno discharge	40 06 50.24 N 105 24 03.13 W
J8	5561A-28	upstream of DW intake, downstream of Bueno discharge	40 06 54.86 N 105 23 31.55 W
J9	5561A-30-582	downstream of Little James confluence in Jamestown	40 06 55.75 N 105 23 18.86 W
J10	5561A-55	upstream of Curie Springs	40 06 28.45 N 105 22 22.16 W
J-CU	5561A-CU	Curie Springs	40 06 34.53 N 105 21 33.40 W
J11	5561A-52	downstream of Curie Springs	40 06 34.34 N 105 21 29.95 W
J12	5561A-53	upstream of Castle Gulch, downstream of Curie	40 06 34.34 N 105 21 29.95 W
J-CG	5561A-CG	Castle Gulch	40 06 26.36 N 105 21 11.79 W
J13	5561A-61	just downstream of Castle Gulch	40 06 25.78 N 105 21 10.08 W
J14	5561A-62	upstream of confluence with Lefthand Creek	40 06 07.94 N 105 20 33.31 W

Table 3. Little James Creek water, sediment, and benthic macroinvertebrate sampling site descriptions and locations by global position system.

sample site name	site ID	site description	latitude longitude (°, ‘, “)
LJ1	5562A-0	upstream of Argo mine and tailings	40 08 12.91 N 105 24 41.57 W
LJ2	5562A-1	downstream of Evening Star	40 07 52.32 N 105 24 24.41 W
LJ3	5562A-6	upstream of small tailings pile and Argo	40 07 46.70 N 105 24 06.99 W
LJ4	5562A-8	upstream of Argo discharge, upstream of Burlington Mine	40 07 44.75 N 105 24 06.99 W
LJ5	5562A-10	downstream of Argo discharge, upstream of Burlington	40 07 42.02 N 105 24 01.91 W
LJ6	5562A-14	upstream of Balarat, downstream of Emmit discharge	40 07 35.94 N 105 23 57.3 W
LJ7	5562A-16	upstream of Balarat	40 07 33.74 N 105 23 54.61 W
LJ8	5562A-18-1	upstream of Porphyry Mtn. tailings	40 07 27.03 N 105 23 52.35 W
LJ9	5562A-21	downstream of Porphyry Mtn. Tailings	40 07 24.99 N 105 23 50.84 W
LJ10	5562A-28	upstream of “streamside tailings”	40 07 11.52 N 105 23 39.14 W
LJ11	5562A-32	downstream of “streamside tailings”	40 07 04.02 N 105 23 38.08 W
LJ12	5562A-35	below waterfall	GPS not taken
LJ13	5562A-38	upstream of confluence with James Creek	40 06 58.41 N 105 23 28.35 W

Benthic macroinvertebrate sampling and analysis

Sampling for macroinvertebrates occurred from June 15 to August 2, 2005. Specific dates of sampling for each site along Lefthand, James, and Little James Creeks are presented in Appendix A.

Prior to the collection of macroinvertebrates, we selected sites along Lefthand, James, and Little James Creek for monitoring the emergence of *Archtopsyche grandis. Archtopsyche grandis* was chosen based on its known metal tolerance in Rocky Mountain streams (Clements and Kiffney, 1994). Once it was determined the target species was present, collection was planned to progress from lower elevations to higher elevations. This pattern of collection was based on the emergence patterns of *Archtopsyche grandis* (LaFontaine, 1981). Throughout the entire month of May, the streambeds of sites LH1, LH7, LH13, LH19, J14, J9, LJ1, LJ10 and LJ13 (Figure 6Figure) were searched thoroughly for *Archtopsyche grandis*. We were not able to find signs of *Archtopsyche* *grandis* at either low or high elevations during the entire month of May; therefore, we decided that representative samples of macroinvertebrates found at each site would be collected instead of the individual target species.

Macroinvertebrate collection followed the methods defined in the EPA's rapid bioassessment protocol (Barbour et al., 1999). These methods were originally developed for collection of macroinvertebrates for taxonomic identification. At each field site, streambed sediments and rocks were kicked and flipped to allow for release of benthic macroinvertebrates into a rectangular kick net. A 30 m stretch of the streambed was sampled from downstream to upstream in a zig-zag pattern. We periodically emptied the kick nets into plastic buckets and then transferred portions of the buckets onto white plastic trays for macroinvertebrate collection. The macroinvertebrates were collected with plastic forceps and rinsed with deionized water to remove attached sediments and weighed with a battery-powered field balance. A total wet weight of at least 5 g of benthic macroinvertebrates was collected at each sampling location. Duplicate samples were collected at every tenth location. The samples were stored in glass jars and stored on dry ice for transport to the University of Colorado at Boulder. In the laboratory, the samples were stored in a laboratory freezer at 5ºC until further analysis.

The digestion of macroinvertebrates followed the methods outlined in Clements and Kiffney (1994). The samples were dried at 55ºC for 8-10 h. The total dry weight was recorded and the samples were transferred into 50 mL polypropylene centrifuge tubes. Once in the tubes, the digestion solution (15 mL), a 1:1 solution of a trace metal-grade concentrated (15.8 M) HNO_3 and H_2O_2 (30% by volume) and deionized water (10 mL), was added. Samples were placed in a water bath (Sheldon Manufacturing, model 1227) at 60 ºC and shaken at 120 rpm for 2 h. The samples were removed from the bath and allowed to settle by gravity for approximately 12 h. A portion of the supernatant (7.5 mL) was withdrawn using a polyethylene pipette and placed in acid-washed 250 mL polypropylene sample bottles for shipping for analysis of metal concentrations. The analytes that were measured and their methods of analysis are similar to the methods for total and dissolved metals in the water samples (Table 4). A blank without macroinvertebrates was carried through the same digestion procedure.

Dissolved organic carbon (DOC) was measured because of its direct correlation with metal bioaccumulation in the caddis fly *Arctopsyche grandis* in metal-polluted streams (Prusha and Clements, 2004). Water samples to be analyzed for dissolved organic carbon were taken at each site and stored in 1 L amber-colored glass bottles. The samples were stored on ice and transported to the University of Colorado where they were vacuum-filtered in a 500 mL filter apparatus (Nalgene) with a 0.45 µm nylon membrane. The filtrate was acidified using phosphoric acid (85%, Fisher) to a pH less than 4 and stored in a laboratory refrigerator until analysis. DOC was measured using a total organic carbon (TOC) analyzer (Ionic-Sievers, model 800) by the persulfate-ultraviolet oxidation method (Clesceri et al., 1999).

Stream water sampling and analysis

Stream water samples were collected from June 15 to August 2 at all sites listed in Table 1, Table 2, and Table 3 and shown in Figure 6. Site-specific sampling dates can be found in Appendix A. Duplicate samples were taken at every tenth site sampled as indicated in the EPA's sampling and analysis plan for the Lefthand Creek watershed (Hernandez et al., 2004). Two water samples were collected at each site to be later analyzed for total and dissolved metals. De-ionized water was brought to the field and filled into a 1 L polypropylene bottle to serve as the field blank.

All field samples were collected in 1 L polypropylene bottles and placed in a cooler on ice. In the laboratory, the samples were stored in a refrigerator at 5°C. Samples to be analyzed for total metals were immediately acidified to a pH of less than 2 using a concentrated trace metal-grade nitric acid. Samples to be analyzed for dissolved metals were filtered with a 0.45 µm nylon membrane (Osmonics, Inc., Magna) prior to acidification. All samples were filtered using vacuum extraction and a 500 mL polypropylene filter apparatus (Nalgene). The difference between total and dissolved values was used as the concentration of colloidal metals for a sample. All samples were stored at 5°C until EPA metal analysis.

Water samples were sent to a laboratory certified under the EPA's Contract Laboratory Program (CLP), where a full suite of analytes (Table 4) were measured using EPA method 200.7 (inductively coupled plasma-atomic emission spectrometry, ICP-AES). If cadmium, copper or lead concentrations were measured below detection limits (BDL) using ICP-AES, then the laboratory re-analyzed samples using EPA method 200.8 (inductively coupled plasma-mass spectrometry, ICP-MS). At the time of sample receipt, the contracted lab checked the pH and modifications were only made if pH measured below 2.

Table 4. EPA inorganic target analyte list and contract required quantitation limits (CRQLs) for methods 200.7 (ICP-AES for water samples), and 200.8 (ICP-MS) for water samples.

Analyte	**ICP-AES CRQL for water ($\mu g\ L^{-1}$)**	**ICP-MS CRQL for water ($\mu g\ L^{-1}$)**
Aluminum	200	--
Antimony	60	2
Arsenic	10	1
Barium	200	10
Beryllium	5	1
Cadmium	5	1
Calcium	5000	--
Chromium	10	2
Cobalt	50	1
Copper	25	2
Iron	100	--
Lead	10	1
Magnesium	5000	--
Manganese	15	1
Mercury	0.2	--
Nickel	40	1
Potassium	5000	--
Selenium	35	5
Silver	10	1
Sodium	5000	--
Thallium	25	1
Vanadium	50	1
Zinc	60	2

The contract requirement quantitation limits (CRQLs) reported in Table 4 are the minimum standards that EPA contracted laboratories need to demonstrate the ability to meet prior to analyzing field samples. These values are reported in the laboratory data if an individual sample is below the instrumentation's method detection limits (MDLs). The laboratories are required to document methods used to generate analytical results and determine MDLs.

Water quality parameters

The field water quality parameters measured include pH, specific conductance, and temperature. Specific conductance is a measure of the dissolved ions in the water. A field pH meter (Orion 250A) and combination electrode (Orion 91-07, low maintenance triode) was used to measure pH, temperature and specific conductance. The meters were recalibrated every three hours or every third site, depending upon which came first. The meter electrodes were rinsed with de-ionized water before and after each measurement.

Water hardness and aquatic life standards

Stream water hardness, reported in units of mg $CaCO_3$ L^{-1}, was determined by adding dissolved calcium and magnesium concentrations in the following equation:

$$Hardness = 50.05([Ca^{2+}] + [Mg^{2+}]) \tag{1}$$

where $[Ca^{2+}]$ and $[Mg^{2+}]$ are the dissolved concentrations of calcium and magnesium ions in units of milliequivalents per liter (meq L^{-1}) (CDPHE, 2005). Hardness was calculated for all sites. Hardness is used as an indication of differences between the complexation capacity of natural waters and the corresponding variation of metal toxicity. Traditionally, it has been accepted that increasing hardness decreases the toxicity of some metals (Erickson et al., 1996). In terms of metal toxicity, this is interpreted as increasing competition of calcium and magnesium for metal binding sites on the gills of invertebrates or cell membranes (Paquin et al., 2002). Using mean hardness values, appropriate Colorado of Public Health and the Environment (CDPHE) chronic (thirty day exposure) and acute (one-day exposure) aquatic life table value standards (TVS) for zinc, copper, and lead can be determined. The CDPHE requires use of the mean hardness during low flow season where there is insufficient paired hardness and flow data. Mean hardness values from the spring sampling event were used to calculate appropriate TVS values. Standard deviations and relative standard deviations were recorded for mean hardness values calculated for each creek. Using the equations in Table 5, appropriate chronic and acute values for zinc, copper, and lead were calculated.

Table 5. Colorado Department of Public Health and the Environment hardness-based equations for chronic and acute value standards for copper, zinc, and lead.

Metal	**Acute Value (μg L^{-1})**
Zn	$0.978e^{\{0.8525[\ln(hardness)]+1.0617\}}$
Cu	$e^{\{0.9422[\ln(hardness)]-1.7408\}}$
Pb	$\{1.46203-[\ln(hardness)0.145712]\}e^{\{1.273[\ln(hardness)]-1.46\}}$

Metal	**Chronic Value (μg L^{-1})**
Zn	$0.986e^{\{0.8525[\ln(hardness)]+0.9109\}}$
Cu	$e^{\{0.8545[\ln(hardness)]-1.7428\}}$
Pb	$\{1.46203-[\ln(hardness)0.145712]\}e^{\{1.273[\ln(hardness)]-4.705\}}$

RESULTS

Water quality measurements: pH, temperature, and specific conductance

Lefthand Creek pH values measured during the spring sampling period ranged from 6.5 to 7.3 (Figure 7Figure) with the minimum and maximum values occurring at sites LH7 and LH15, respectively (for sample site locations, see Figure 6Figure). Lefthand Creek pH values all fell within the acceptable range according to CDPHE's Water Quality Control Division (WQCD) standards for a Class I cold-water stream. The highest specific conductance of 115 µS cm^{-1} was measured at LH15, and the lowest, 25.2 µS cm^{-1}, was measured at LH4 (Figure 7Figure). The average temperature in Lefthand Creek was 12.0±1.2°C with the uncertainty representing one standard deviation of the mean temperature.

The pH in James Creek ranged from 6.1 to 6.9. Out of fourteen field sites along James Creek, ten exhibited pH values below the acceptable range according to CDPHE standards (Figure 8). Specific conductance increased steadily from 20.5 µS at site J1 above the Peak to Peak Highway to 33.6 µS cm^{-1} at site J14, just above the confluence with Little James Creek. The average stream water temperature was 13.9 ± 2.1°C.

Little James Creek exhibited the lowest pH values, the highest specific conductance values, and the highest temperature values of the three creeks (Figure 9). The pH values ranged from 5.4 - 6.7. The maximum specific conductance was 1620 µS cm^{-1} downstream of the Burlington Mine. This value is approximately eight times greater than the specific conductance of the Little James Creek water sampled at the most upstream site (209 µS cm^{-1}). The average stream water temperature was 16.7 ± 2.8°C.

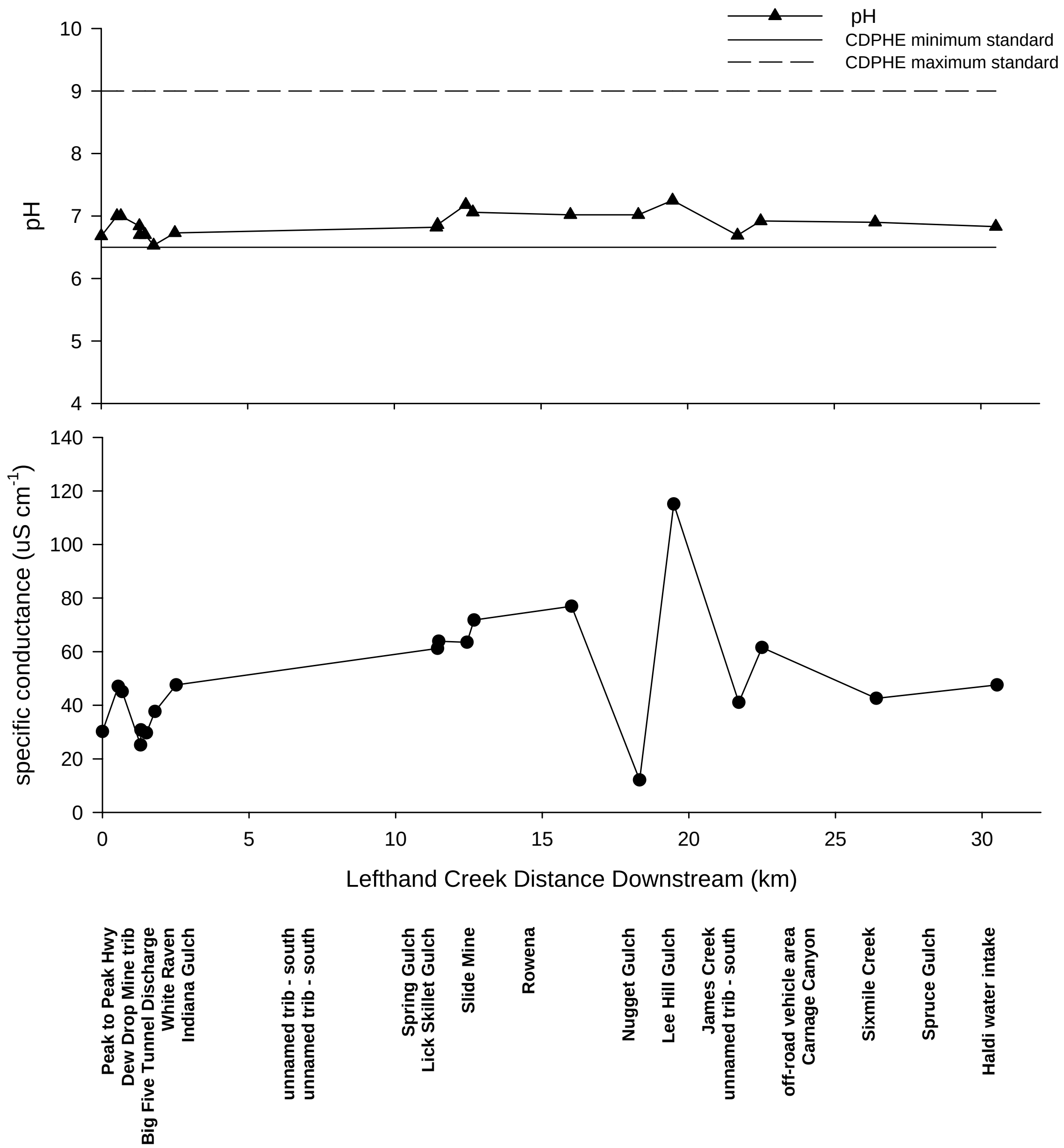

Figure 7. Lefthand Creek pH and specific conductance measured in the field during macroinvertebrate and water sampling (June 15 to August 2, 2005).

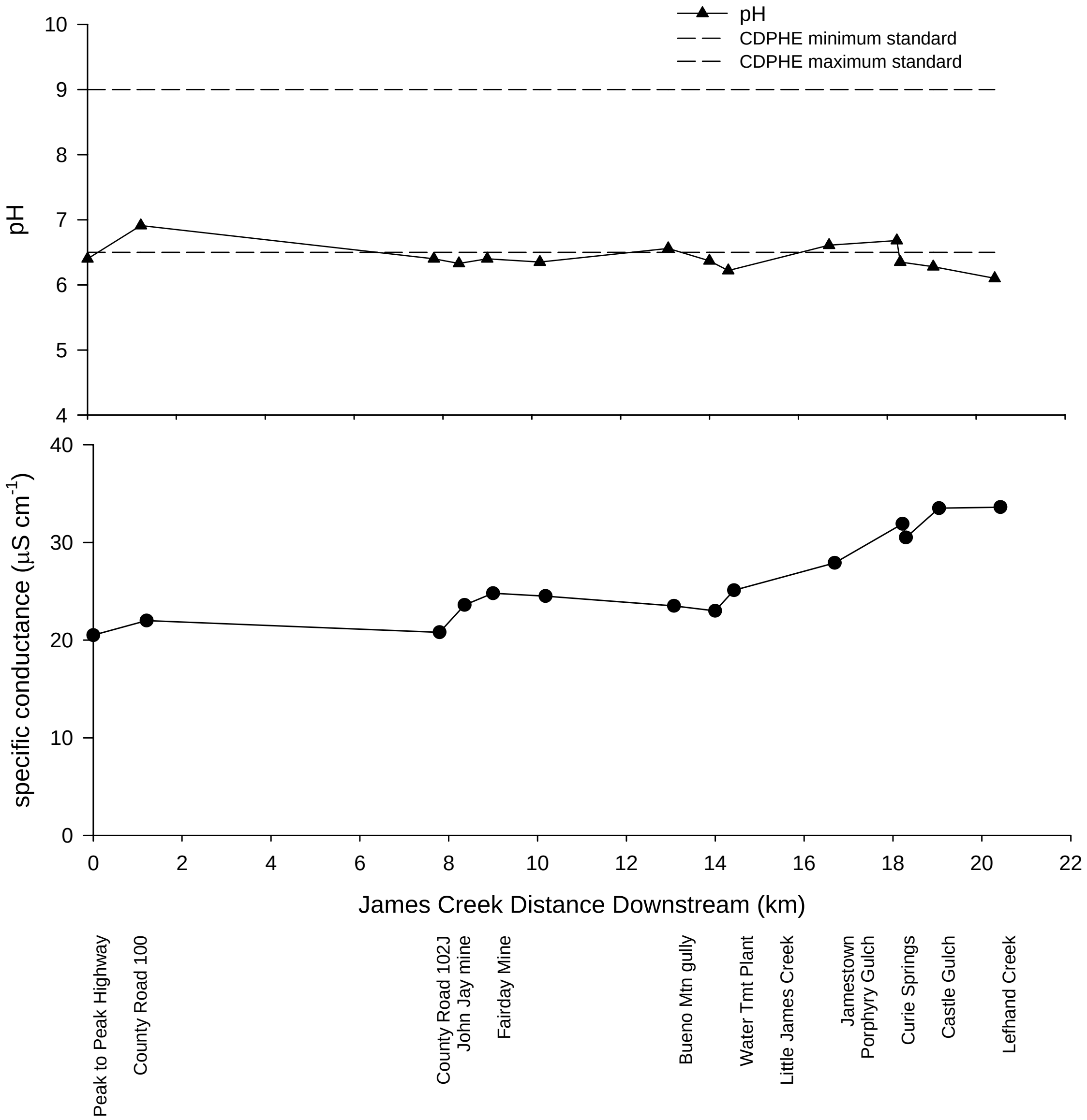

Figure 8. James Creek pH and specific conductance measured in the field during macroinvertebrate and water sampling (June 30 to August 1, 2005).

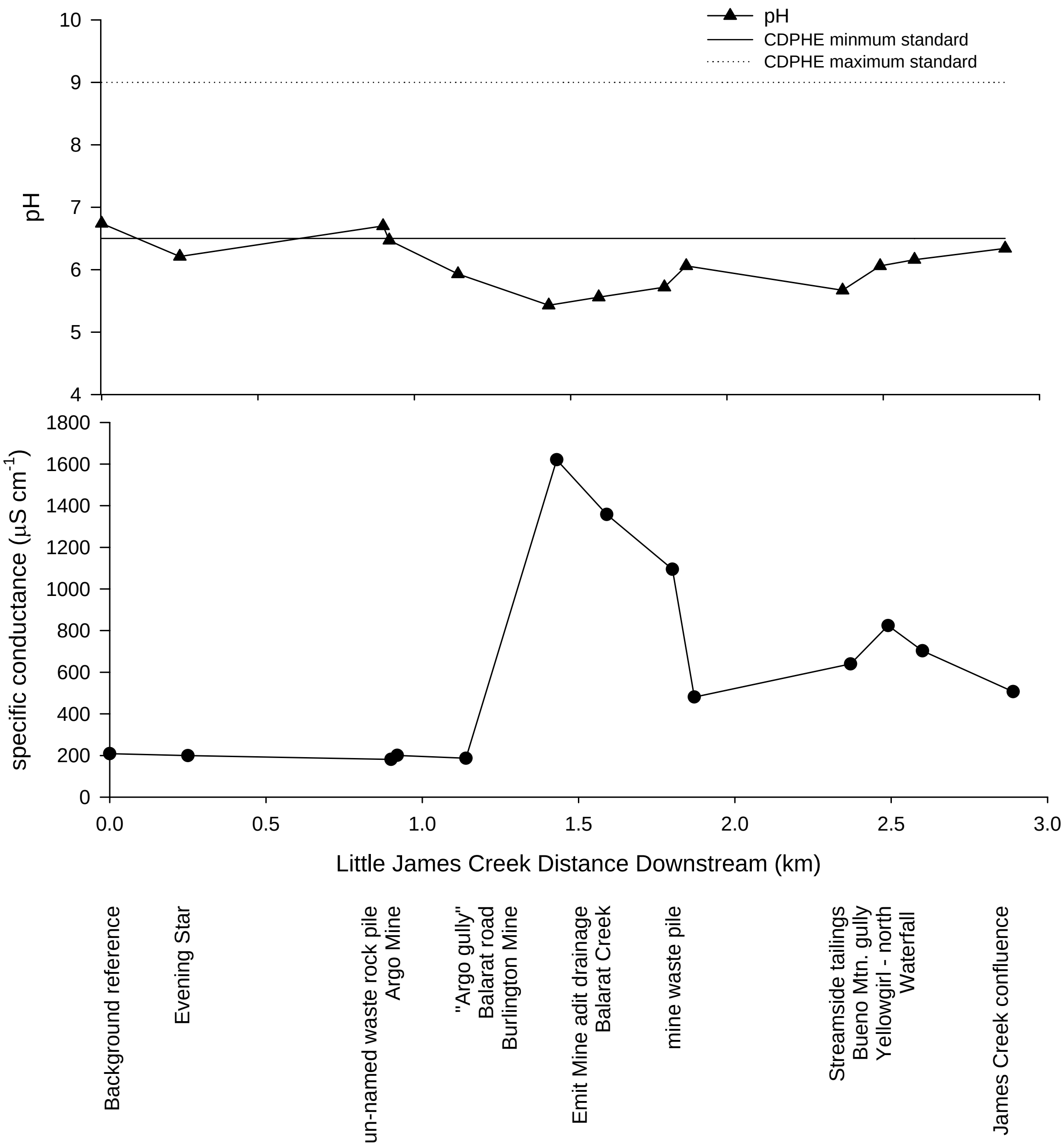

Figure 9. Little James Creek pH and specific conductance measured in the field during macroinvertebrate and water sampling (June 22 to July 18, 2005).

Dissolved Organic Carbon

Upstream of the confluence with James Creek, the DOC concentration measured in Lefthand Creek was approximately 2.8 mg L^{-1} (Figure 10). Deviations from this value occurring just downstream of the confluence with the Big Five tunnel drainage, where the DOC concentration increased to 3.3 mg L^{-1}. Downstream of the confluence with James Creek, the DOC drops to about 2.0 mg L^{-1}.

The DOC concentration in James Creek ranges from 1.7 to 2.8 mg L^{-1} (Figure 11). The high end of the DOC concentration range occurs just downstream of the John Jay Mine and the Bueno Mountain gully.

The DOC concentrations measured along Little James Creek ranged from 1.7 to 4.4 mg L^{-1} (Figure 12). The higher DOC concentrations in Little James Creek can be attributed to low flow and the prevalence of wetlands along parts of the creek. DOC decreases in areas of the stream where pH is low and are most likely due to the type of organic acids composing the DOC.

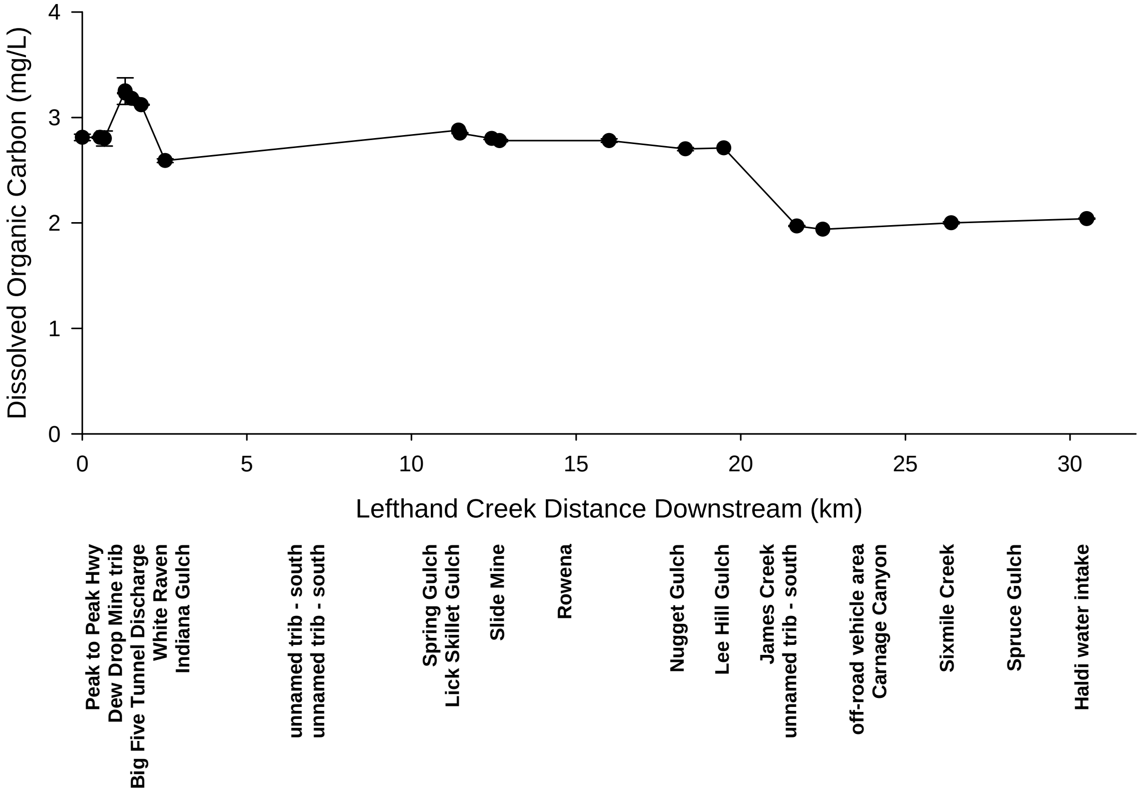

Figure 10. Lefthand Creek dissolved organic carbon with standard deviations determined from five replicate analyses of selected samples.

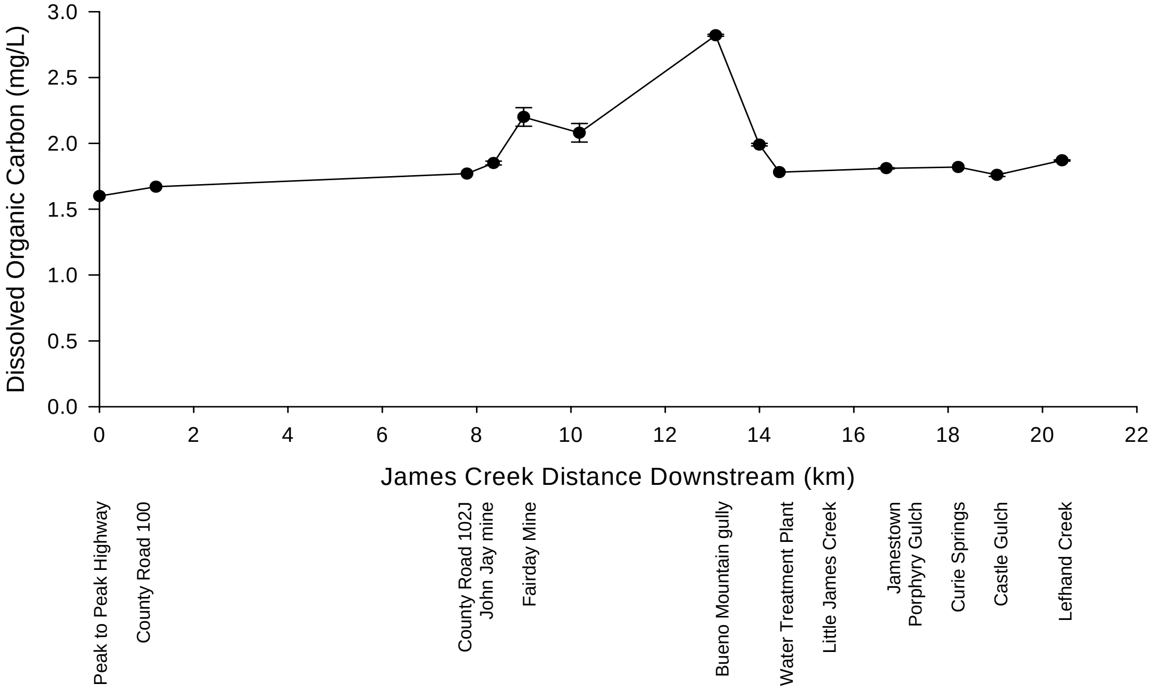

Figure 11. James Creek dissolved organic carbon with standard deviations determined from five replicate analyses of selected samples.

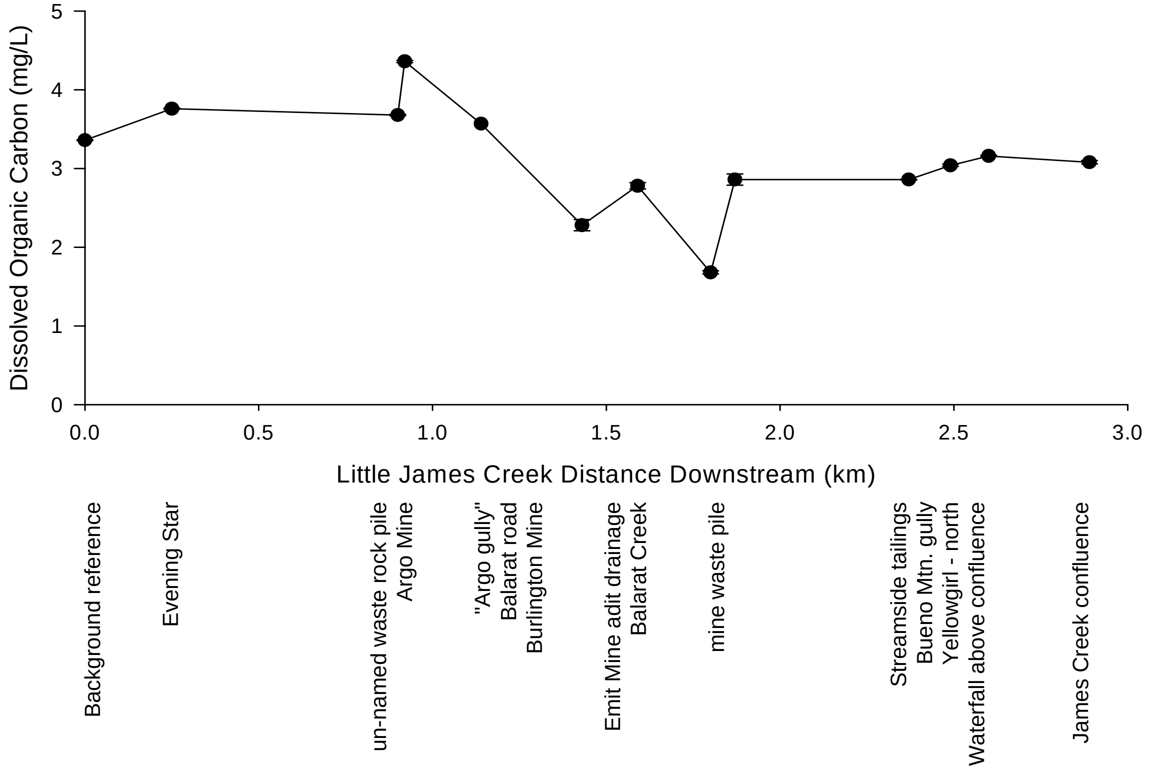

Figure 12. Little James Creek dissolved organic carbon with standard deviations determined from five replicate analyses of selected samples.

Hardness and aquatic life standards

In Lefthand Creek, hardness increased downstream of the Big Five Tunnel and in the area of the Slide Mine (Figure 13). Hardness was diluted by about a factor of three by the addition of the James Creek water. In James Creek, hardness increased with distance (Figure 14Figure). The James Creek water was the softest of three creeks. In Little James Creek, the hardness peaks just downstream of the flows from the Burlington and Emmit Mines (Figure 15Figure). The hardness downstream of Balarat Creek can be attributed to fluorite (CaF_2), which was extracted from this area during previous mining activities.

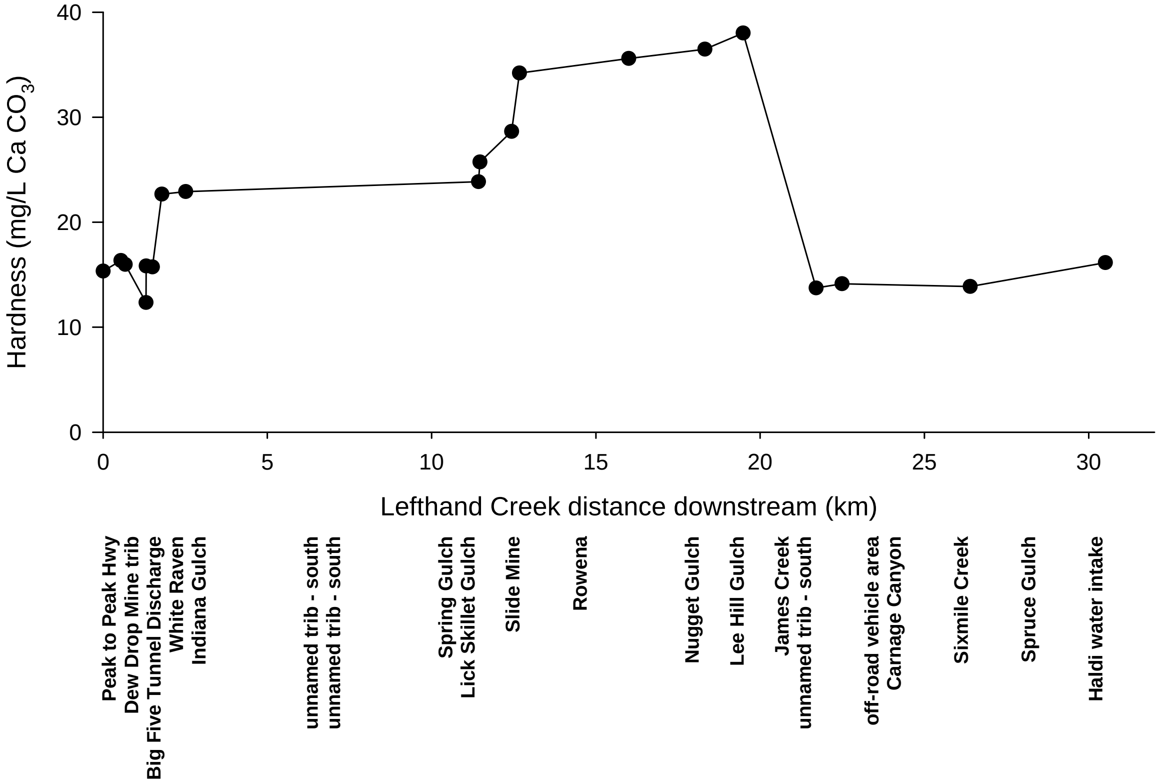

Figure 13. Hardness calculated from magnesium and calcium concentrations in Lefthand Creek.

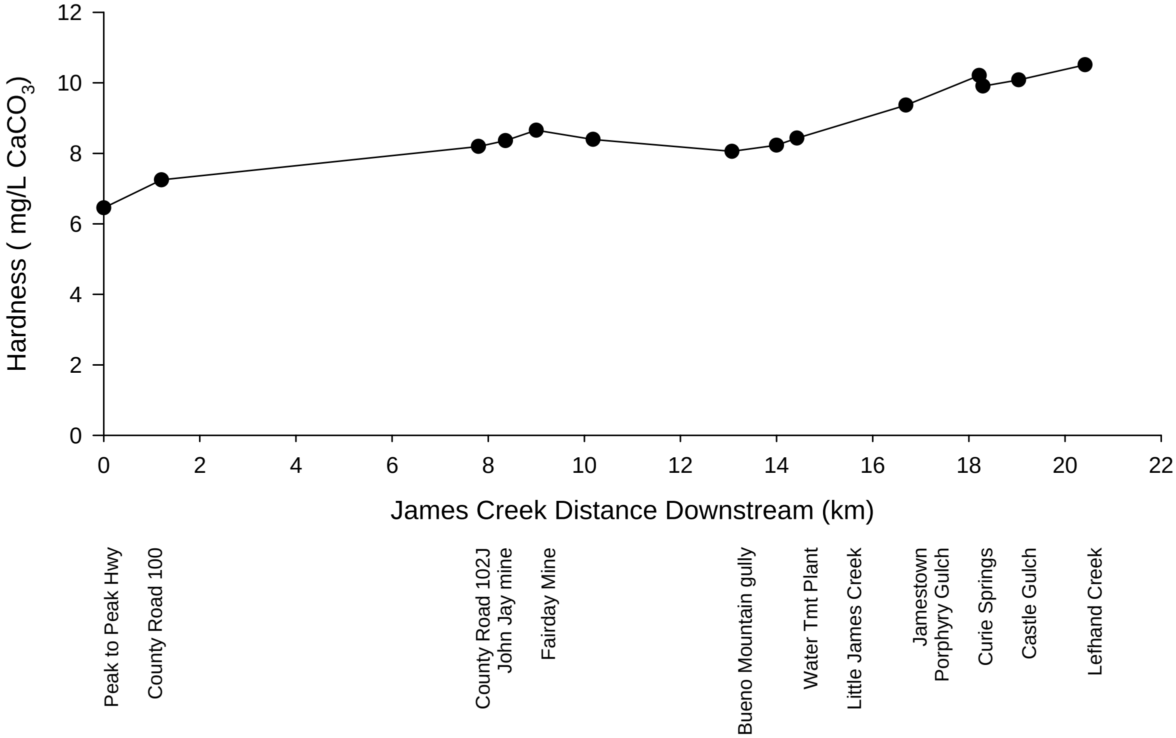

Figure 14. Hardness calculated from magnesium and calcium concentrations in James Creek.

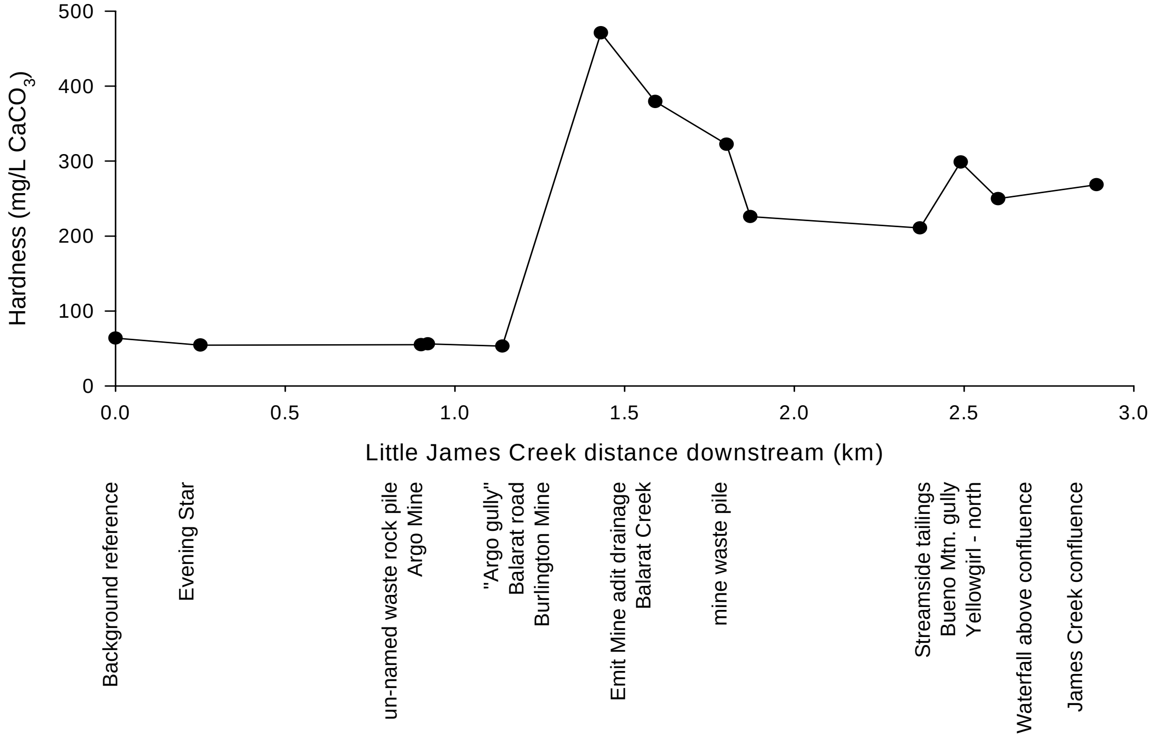

Figure 15. Hardness calculated from magnesium and calcium concentrations in Little James Creek.

Initially, the average chronic and acute table value standards (TVS) were calculated for each individual creek using the average hardness throughout the creek. Since hardness varied so much throughout each stream (especially Lefthand Creek), we decided to calculate the chronic TVS for zinc, copper, and lead at every site in the watershed. These standards were calculated using the hardness-based equations provided in Table 5 and reported in the figures showing the metal concentrations in the water samples.

Stream water: Iron

The concentrations of iron in samples from Lefthand, James, and Little James Creeks are represented in Figures 16-18. The CDPHE chronic aquatic life standard for iron, which does not depend on hardness, is 1000 $\mu g\ L^{-1}$. This standard is exceeded in the Little James Creek only. The reaches of the stream where this standard is exceeded includes the length of stream just downstream of Argo Mine and above Porphyry tailings and the length of stream just downstream of Bueno Mountain gully and just upstream of the confluence with James Creek. In both James and Lefthand Creek, a majority of the iron is in the colloidal form. The average colloidal percentage of iron in Lefthand Creek was 63±10%, James Creek was 70±8%, and Little James Creek was 36±20%. The high standard deviation in Little James Creek was due to the greater pH range in the creek water.

Background total and dissolved iron concentrations in Lefthand Creek are higher than most in-stream water samples. The drop in iron concentrations after the Big Five Tunnel drainage is uncharacteristic of this area. Previous studies have documented concentrations above the chronic aquatic life standard (1000 $\mu g\ L^{-1}$) in this area. Spikes in iron concentrations in Lefthand Creek are seen downstream of Sixmile Creek, also the highest total concentration measured at 277 $\mu g\ L^{-1}$. The highest total iron concentrations in Little James Creek are seen just downstream of Balarat Creek at 8,130 $\mu g\ L^{-1}$. The highest concentration of total iron in James Creek measured was 285 $\mu g\ L^{-1}$ and occurred downstream of Curie Springs.

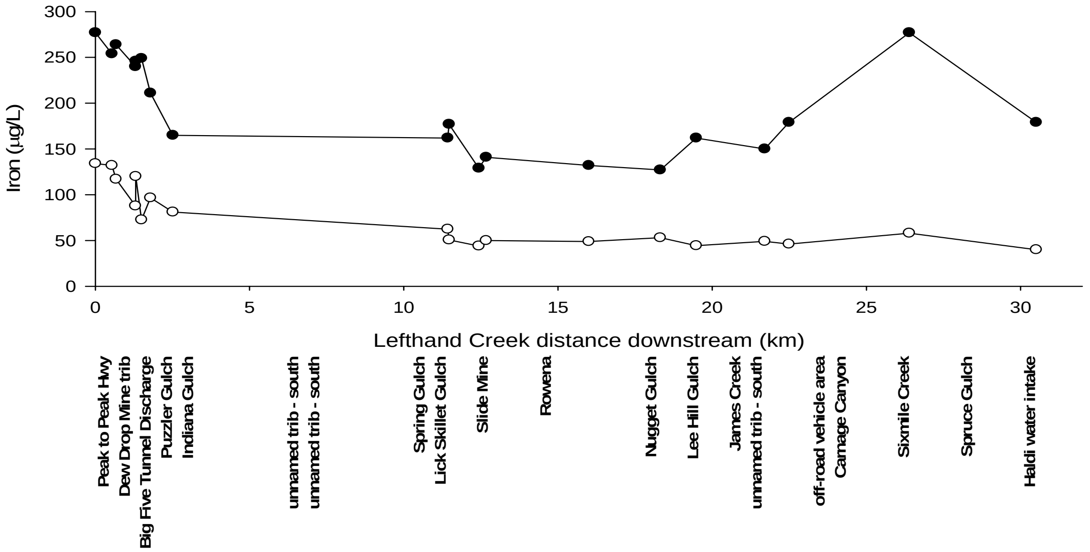

Figure 16. Total (•) and dissolved (o) iron along the length of Lefthand Creek. The chronic aquatic life standard for iron is 1000 µg L^{-1}, which was not exceeded.

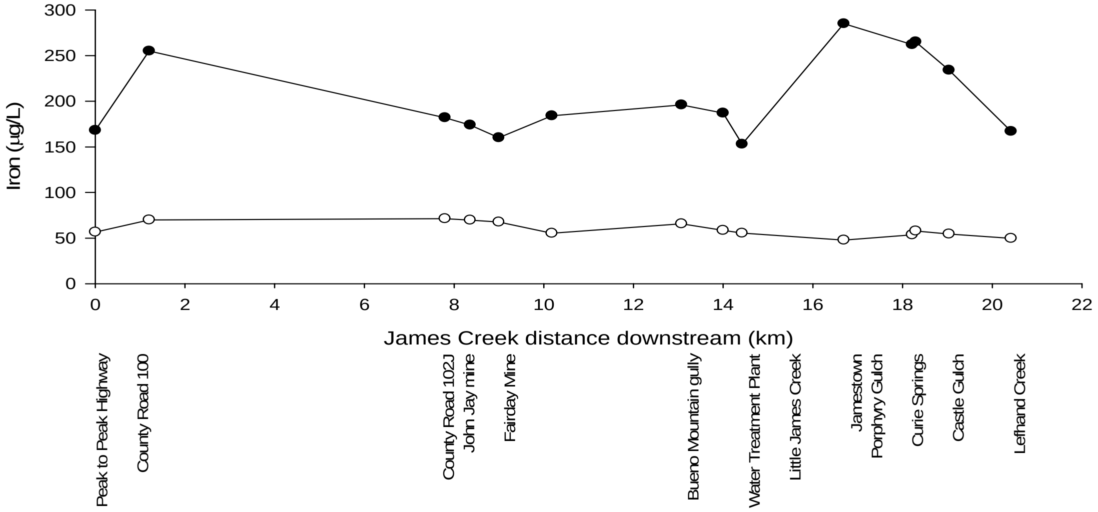

Figure 17. Total (•) and dissolved (o) iron along the length of James Creek. The chronic aquatic life standard for iron is 1000 µg L^{-1}, which was not exceeded.

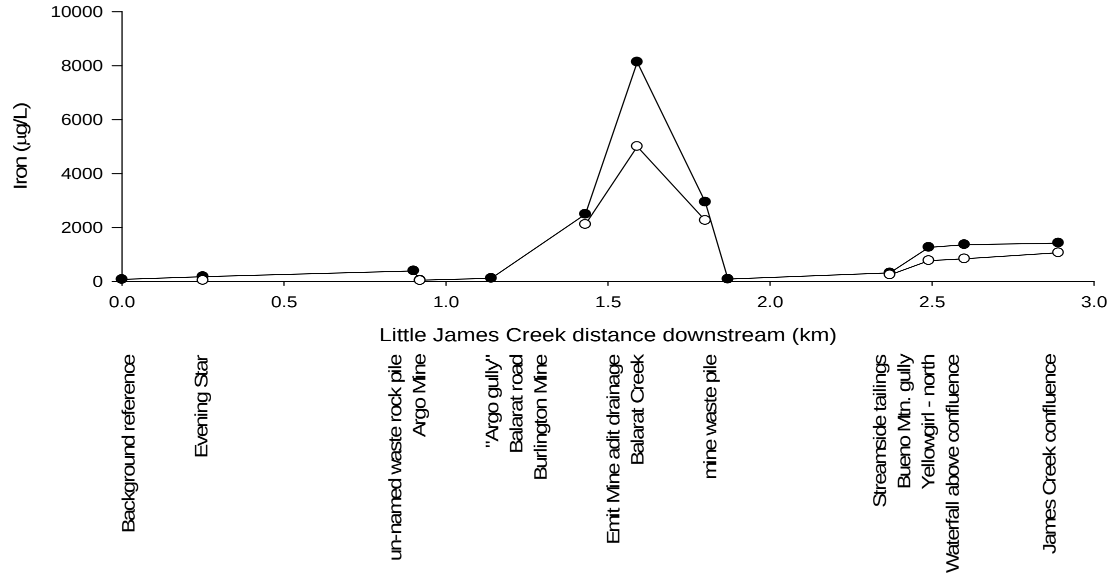

Figure 18. Total (•) and dissolved (o) iron along the length of Little James Creek. The chronic aquatic life standard for iron is 1000 µg L^{-1}, which was not exceeded.

Stream water: Zinc, copper, and lead

The single field blank concentrations for zinc, copper, and lead were mostly below detection limits (Table 6). Total copper and dissolved lead concentrations in the field blanks were reported as values above, but very close to the detection limits. Because total lead was below detection limits, and dissolved lead was not, we can assume that dissolved lead is close to detection limits. For all of the cases where the dissolved concentrations are higher than the total, the dissolved will be used in place of the total. In these cases, it was suggested by EPA laboratory managers that this would indicate concentrations measured near detection limits. The detection limits were not reported by the EPA laboratory on the concentration data reports. Concentrations below detection limits were indicated with a flag. Multiple efforts to obtain the exact limits were not successful because the detection limits changed with each run of approximately 50 samples.

Table 6. Field blank metal concentrations measured at site LJ7 on Little James Creek. BDL is below detection limits.

Metal	Total (µg L^{-1})	Dissolved (µg L^{-1})
Copper	5	BDL
Zinc	BDL	BDL
Lead	BDL	2.8

Lefthand Creek water: zinc, copper, and lead concentrations. Total lead in Lefthand Creek ranged from 0.25-4.6 µg L^{-1}, with the maximum concentration occurring just downstream of Slide Mine (Figure 19). The dissolved fraction of samples was high for all three metals in Lefthand Creek. Dissolved copper averaged approximately 79% of the total copper, and zinc averaged 80%. The fraction of dissolved lead was not estimated because so many of the lead concentrations were measured below detection limits.

Concentrations of dissolved copper and zinc exceeded chronic TVSs in Lefthand Creek. For zinc, the exceedance occurred at sites just downstream the Big Five tunnel drainage and White Raven Mine site. Lead concentrations exceeded the chronic TVS at all sites including the background site. Copper exceeded the chronic TVS downstream of the Big Five tunnel drainage, White Raven Mine site and downstream of the Slide Mine.

James Creek water: zinc, copper, and lead concentrations. The maximum total concentrations for copper, zinc, and lead were lowest in James Creek (Figure 20). Zinc was present mostly in the dissolved form (76%). Chronic standards were never exceeded for Zn. The maximum concentration of copper in James Creek occurred just downstream of the Bueno Mountain gully and exceeded chronic table value standards here as well.

Lead concentrations were also fairly low compared to other creeks in the watershed; however, the chronic standard was exceeded at all times because the stream water is so soft. Total lead concentrations ranged from 0.36-0.73 µg L^{-1} and colloidal concentrations were highest among all metals (75%). The average percentage of dissolved Cu was 67%.

Little James Creek water: zinc, copper, and lead concentrations. The highest concentrations of zinc, copper, and lead occurred along Little James Creek (Figure 21). Concentrations of total zinc ranged from 95 to 1,440 µg L^{-1} with the peak total zinc concentration occurring just downstream of Balarat Creek, which delivers the acid mine drainage from the Burlington Mine to Little James Creek. Both lead and zinc concentrations show similar trends to each other along James Creek with background levels at site locations upstream of Argo Mine increasing concentrations downstream. Both lead and zinc reach peak concentrations after the Burlington Mine and Emmit Mine adit and decline before entering Jamestown. Copper concentrations at the background reference point are below the detection limit. Approximately 0.25 km downstream from the reference site and downstream of the Evening Star Mine, total copper climbs to 48 µg L^{-1}. At this site, total zinc claims the highest concentration at 117 µg L^{-1}, while lead is still below detection limits.

Zinc and copper exceeded both chronic and acute standards periodically along Little James Creek. As with both James and Lefthand Creek, Little James Creek always exceeds the chronic standard for lead. High concentrations of metals are indicative of a low flow stream such as Little James Creek.

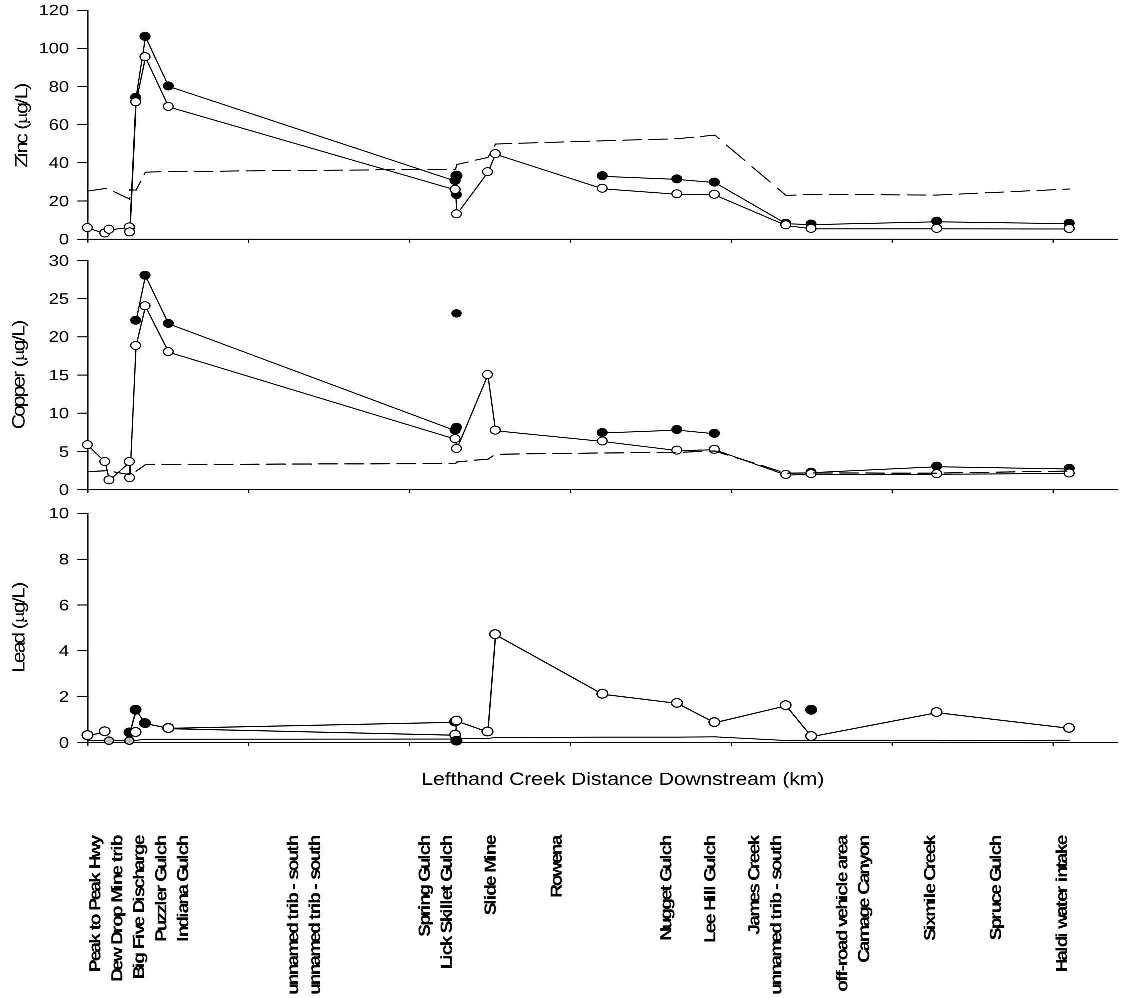

Figure 19. Total (•) and dissolved (∘) concentrations and chronic aquatic life standards for zinc, copper, and lead in Lefthand Creek. Chronic standards are a function of hardness and are represented by dashed lines.

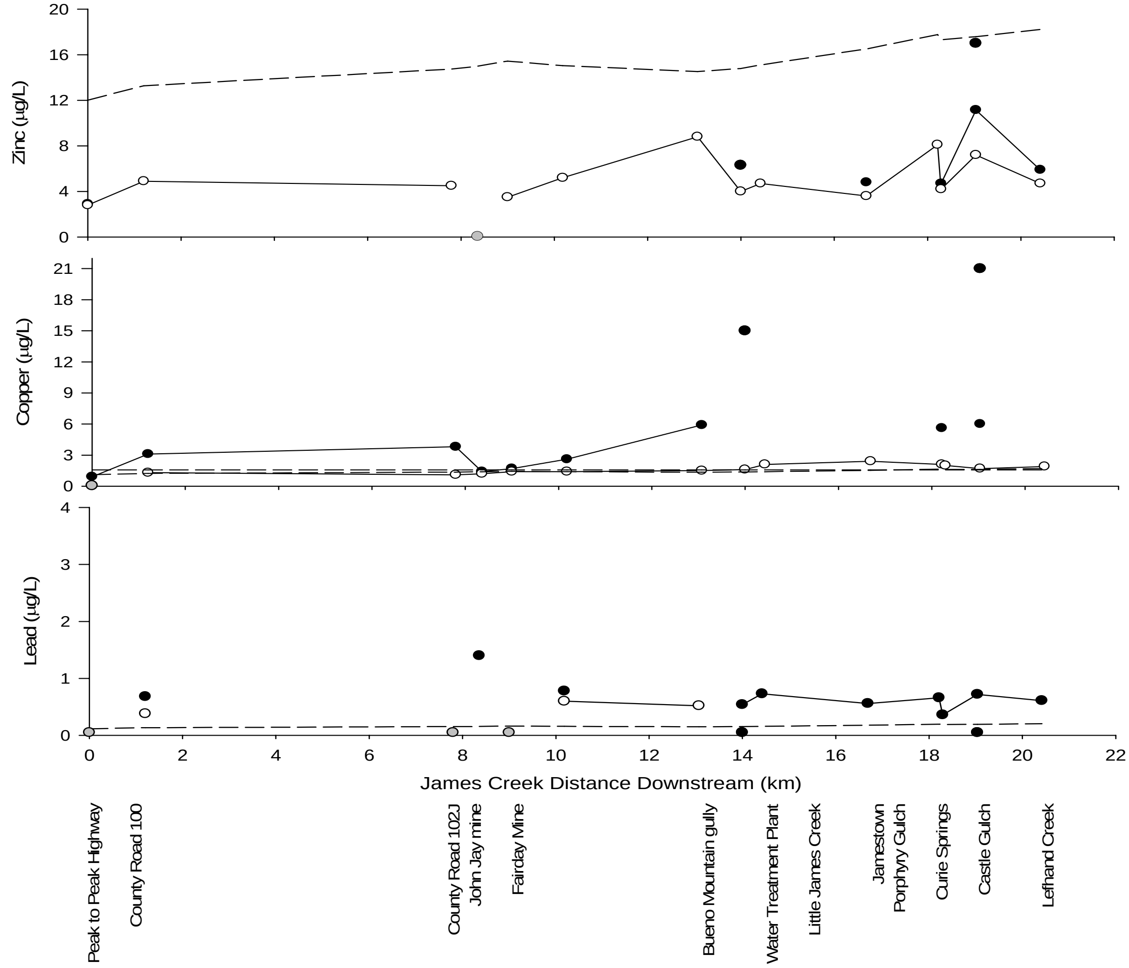

Figure 20. Total (•) and dissolved (∘) concentrations and chronic aquatic life standards for zinc, copper, and lead in James Creek. Chronic standards are a function of hardness and are represented by dashed lines. Grey closed circles are below detection limits and chronic standards are represented by dashed lines.

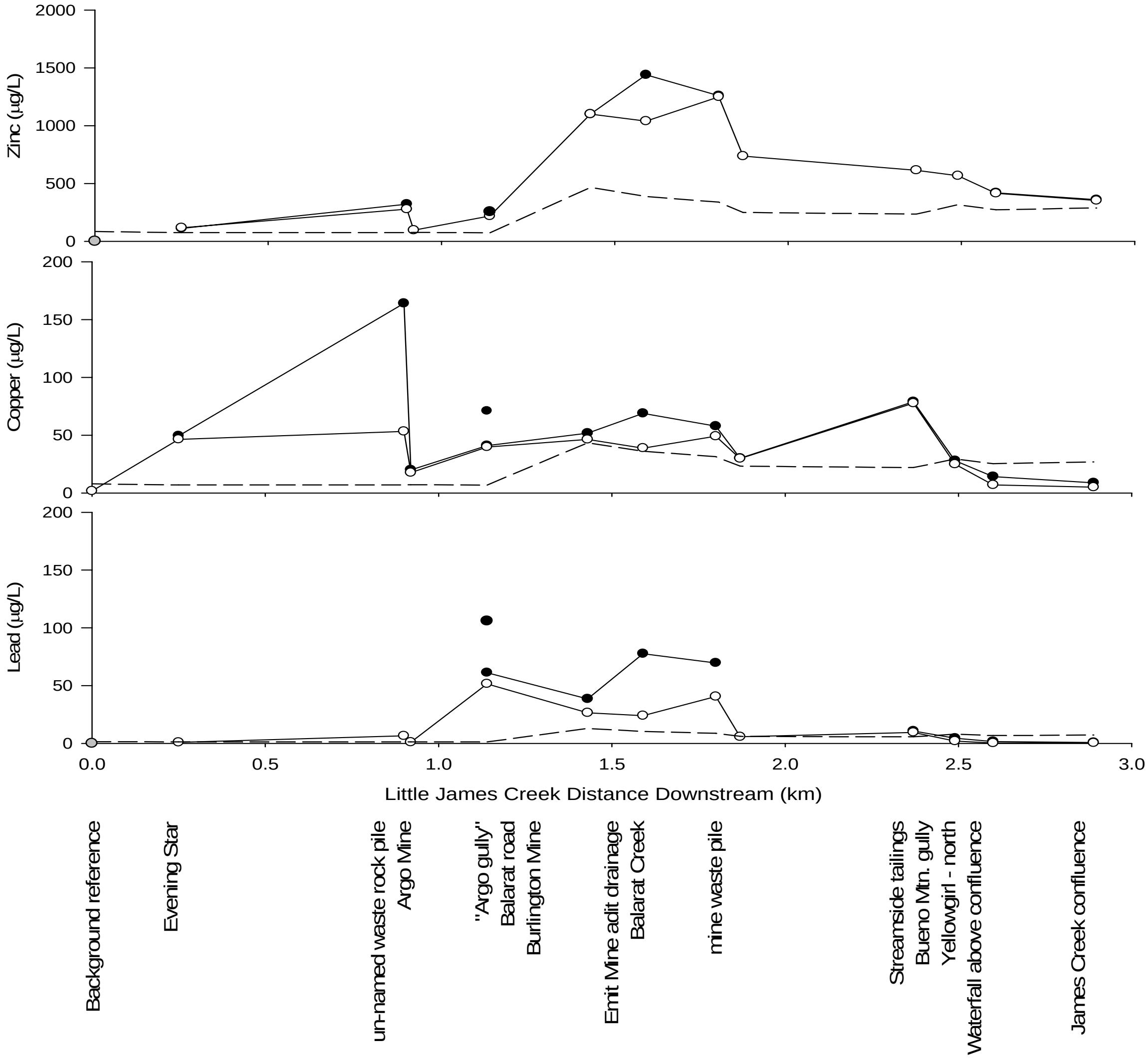

Figure 21. Total (•) and dissolved (o) concentrations and chronic aquatic life standards for zinc, copper, and lead in Little James Creek. Chronic standards are represented by dashed lines.

Benthic macroinvertebrates: Zinc, copper, and lead

Local taxonomic evaluations were not completed in order to avoid complexity of species diversity within each individual site sample, as well as to save time in the field. Metal concentrations are discussed in terms of the entire sample comprised of many individual species representative of each field site. However, in the case of Little James Creek, a majority of the sites were inhabited by a single species, the caddis fly, *Dicosmoecus atripes*. In this case, metal concentrations will be discussed in terms of the individual species where appropriate. Little James Creek was also unique in its lack of benthic macroinvertebrates at seven out of thirteen sites. Benthic macroinvertebrate metal concentrations are presented as the mass of metal per mass of dry body weight ($\mu g_{metal}\ g_{bm}^{-1}$, where *bm* is benthic macroinvertebrate). The benthic macroinvertebrate samples consisted of multiple individuals and entire bodies.

Laboratory blanks did not indicate confounding effects of the reagents used to digest the benthic macroinvertebrates. This was deduced by concentrations for copper, zinc, and lead measuring below detection limits. Duplicate sample locations are identical to those taken for stream water in each creek and are represented on the associated figures.

Background concentrations are reported for comparison for each creek in Table 7Table . Background concentrations for lead are lowest for all streams. However, in Little James Creek, lead is substantially higher than in Lefthand and James Creeks. Lead measured at the James Creek background site was below detection limits.

Table 7. Benthic macroinvertebrate background concentrations measured at sites upstream of known previous mining activities. BDL is below detection limits.

Creek	**Site Name**	**Cu (µg g^{-1})**	**Pb (µg g^{-1})**	**Zn (µg g^{-1})**
Lefthand	LH1	44.9	0.63	387
James	J1	33.6	BDL	251
Little James	LJ1	27.5	21.7	267

Lefthand Creek benthic macroinvertebrates: zinc, copper, and lead. The concentrations of metals in the benthic macroinvertebrates in Lefthand Creek (Figure 22) increased in the order of

Zn > Cu > Pb

Duplicate samples taken at site LH10, downstream of Spring Gulch, indicated excellent reproducibility of results for the benthic macroinvertebrate analysis.

Zinc concentrations in benthic macroinvertebrates steadily increased from 390 µg g^{-1} at the reference site, north of Peak to Peak Highway, to 1300 µg g^{-1} downstream of the Big Five tunnel drainage (LH5). The zinc concentration in benthic macroinvertebrates upstream of the White Raven Mine at site (LH6, 0.2 km downstream of LH5) decreased to 1100 µg g^{-1}. The zinc concentration in benthic macroinvertebrates increased again to 2000 µg g^{-1} from site LH6 to downstream of the White Raven Mine (LH7). The zinc concentration in benthic macroinvertebrates in California Gulch (sites LH3 – LH8) was highest at Sawmill Road (site LH8, 2200 µg g^{-1}). The highest zinc concentrations in benthic macroinvertebrates were found between sites LH9 (above Lickskillet Road, 2400 µg g^{-1}) and LH14 (downstream of Nugget Gulch, 3100 µg g^{-1}). Zinc concentrations in benthic macroinvertebrates steadily decrease from site LH15 (downstream of Lee Hill Gulch, 2000 µg g^{-1}) to LH19 (above Haldi water intake, 830 µg g^{-1}). The zinc concentration in benthic macroinvertebrates at the furthest downstream site along Lefthand Creek (above the Haldi water intake) was comparable to zinc concentration in benthic macroinvertebrates downstream of the Dew Drop Mine.

The copper and lead concentrations in benthic macroinvertebrates at the reference site were 45 µg g^{-1} and 0.6 µg g^{-1}, respectively. Copper and lead concentrations in benthic macroinvertebrates follow similar trends in California Gulch (Figure 22). The increases and decreases in copper and zinc concentrations in benthic macroinvertebrates from sites LH1 (above Peak to Peak highway) to LH7 (downstream of the White Raven Mine) in California Gulch are similar to those discussed for zinc. However, in contrast to zinc, copper and lead concentrations in benthic macroinvertebrates decrease from the site downstream of the White Raven Mine (copper, 670 µg g^{-1}; lead, 27 µg g^{-1}) to the site at Sawmill Road (copper, 290 µg g^{-1}; lead, 5.9 µg g^{-1}).

The copper concentrations in benthic macroinvertebrates steadily decline from the site just above Lickskillet Road (220 µg g^{-1}) to the site above the Left Hand Water District's Haldi water intake (59 µg g^{-1}). Just before the Haldi water intake, the copper concentration in benthic macroinvertebrates is observed to be close to the reference site concentration, with a difference of about 10 µg g^{-1} higher at the intake.

Lead concentrations in benthic macroinvertebrates generally increase from the site just above Lickskillet Road (7 µg g^{-1}) to the site 5 km downstream, downstream of the town of Rowena (16 µg g^{-1}). Downstream of Rowena the lead concentration in benthic macroinvertebrates generally decreases from 16 to 5 µg g^{-1}. The single deviation from this general decrease in lead concentrations in benthic macroinvertebrates is indicated by a small peak which occurs downstream of Lee Hill Gulch.

James Creek benthic macroinvertebrates: zinc, copper, and lead. Duplicate samples taken at sites J8 (downstream of the Jamestown water treatment plant) and J13 (above the confluence with Lefthand Creek) indicate excellent reproducibility of results for the benthic macroinvertebrate laboratory analysis (Figure 23). These duplicates are difficult to see because of the overlaying of points. A unifying trend is observed between metal concentrations in benthic macroinvertebrates in James Creek along the 10 km reach downstream of the Bueno Mountain gully to the confluence with Lefthand Creek.

Zinc concentrations ranged from 250 to 1,370 µg g^{-1} displaying a steady increase from the background reference location at Peak-to-Peak Highway to the confluence with Lefthand Creek.

Copper concentrations were among the lowest in the watershed ranging from 34 µg g^{-1} (site J1, reference site at Peak to Peak highway) to 86 µg g^{-1}(J12, downstream of Curie Springs). The second highest copper concentrations in macroinvertebrates in James Creek occurs downstream of County Road 102J (site J3, 84 µg g^{-1}). Fluctuations in copper concentrations in benthic macroinvertebrates were not observed for the stream reach between and including sites J4 – J11.

Lead concentrations in benthic macroinvertebrates were significantly lower in James Creek as compared to all other sites and creeks sampled in the watershed. Lead concentrations in macroinvertebrates measured below detection limits at six out of fourteen locations along James Creek. Lead concentrations in benthic macroinvertebrates show a steady increase from the site downstream of the Bueno Mountain gully (1.6 µg g^{-1}) to the site just above the confluence with Lefthand Creek (8.8 µg g^{-1}). The tributaries and discharges to James Creek along this reach include the Bueno Mountain gully, Little James Creek, Porphyry Gulch, Curie Springs, and Castle Gulch.

Little James Creek benthic macroinvertebrates: zinc, copper, and lead. The duplicate samples taken at site LJ5 (downstream of the Argo Mine gully) indicated moderate reproducibility of results for copper (160 and 140 µg g^{-1}) and zinc (210 and 160 µg g^{-1}) concentrations in benthic macroinvertebrates for Little James Creek (Figure 24). The same duplicate samples indicated that the reproducibility of results for the lead concentration in benthic macroinvertebrates was poor for Little James Creek (290 and 180 µg g^{-1}).

The observed zinc concentration in benthic macroinvertebrates at the reference site was 140 µg g^{-1} in Little James Creek was the lowest background zinc concentration among the three investigated creeks. The highest zinc concentration in benthic macroinvertebrates along Little James Creek occurred just downstream of the Evening Star Mine (1600 µg g^{-1}). This was the only site where zinc concentrations were found to be well above the background concentration.

The observed background copper concentration in benthic macroinvertebrates at the reference site was 14 µg g^{-1} and similar to the background zinc concentration in Little James Creek, was the lowest background copper concentration among the three investigated creeks. The copper concentration in benthic macroinvertebrates increases from 14 µg g^{-1} at the reference site to 120 µg g^{-1} 0.25 km downstream, downstream of the Evening Star Mine. The concentration of copper in benthic macroinvertebrates are highest between the downstream of the Argo Mine tailings pile (170 µg g^{-1}) and downstream of the Argo Mine (160 µg g^{-1}). There were no macroinvertebrates present from downstream of Balarat Creek to just upstream of the Porphyry Mountain tailings pile.

The observed lead concentration in benthic macroinvertebrates at the reference site was 11 µg g^{-1}. Lead concentrations in benthic macroinvertebrates remained near the background concentration for the first 0.92 km downstream of the reference site. The first significant increase in lead concentrations in macroinvertebrates occurred just downstream of the Argo Mine gully (duplicate samples, 290 µg g^{-1} and 180 µg g^{-1}). The second highest lead concentration in benthic macroinvertebrates in Little James Creek occurred just upstream of the Porphyry Mountain tailings pile (210 mg kg^{-1}). Besides this record, trends are difficult to infer from the data with no benthic macroinvertebrates at half of the sites. However, these sites may indicate water quality impairment which directly effects aquatic life.

Between the Porphyry Mountain tailings pile and the confluence with James Creek, only site LJ9 (0.5 km downstream of Porphyry Mountain tailings and just upstream of the "streamside tailings") contained benthic macroinvertebrate life. In relation to the closest upstream site sampled (LJ5, downstream of Argo Mine), the concentration of zinc in benthic macroinvertebrates decreased (160 to 140 µg g^{-1}), copper in benthic macroinvertebrates decreased (140 to 60 µg g^{-1}), and lead in benthic macroinvertebrates increased slightly (180 to 210 µg g^{-1}).

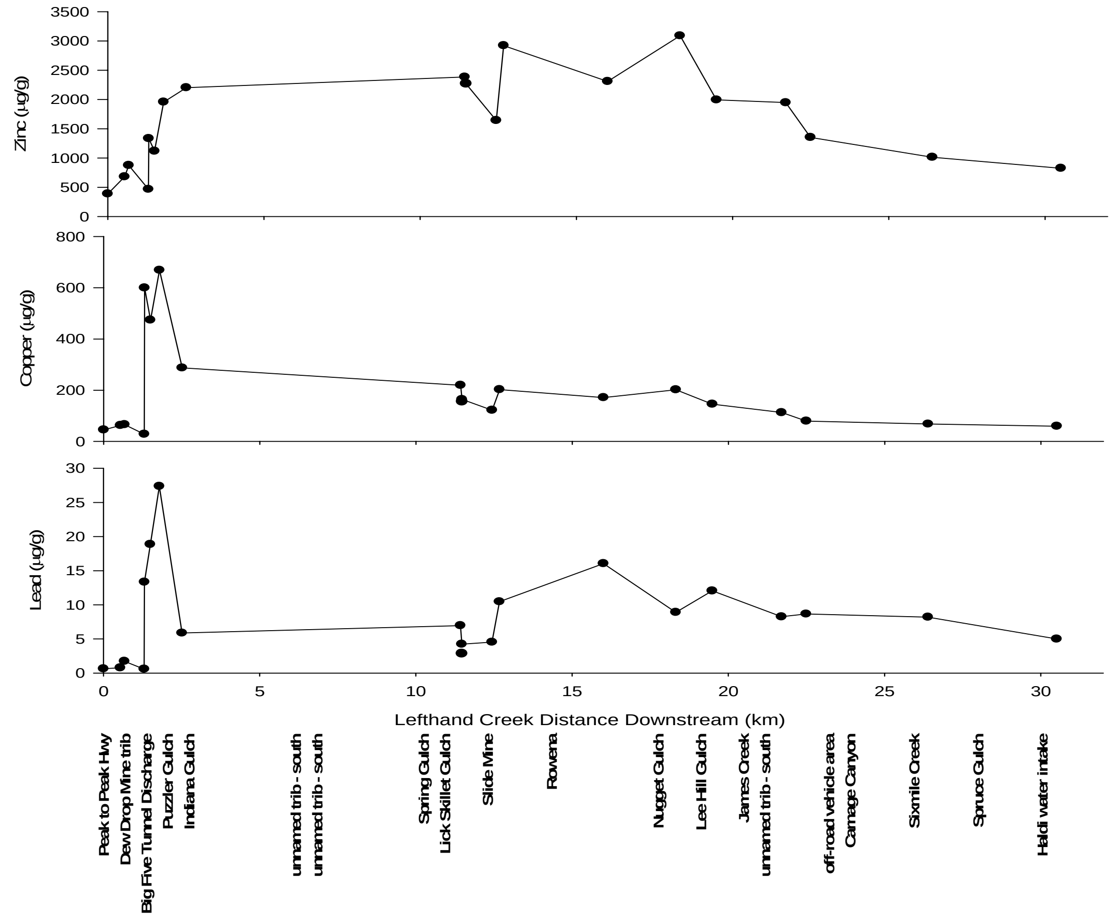

Figure 22. Zinc, copper, and lead concentrations measured in benthic macroinvertebrates in Lefthand Creek.

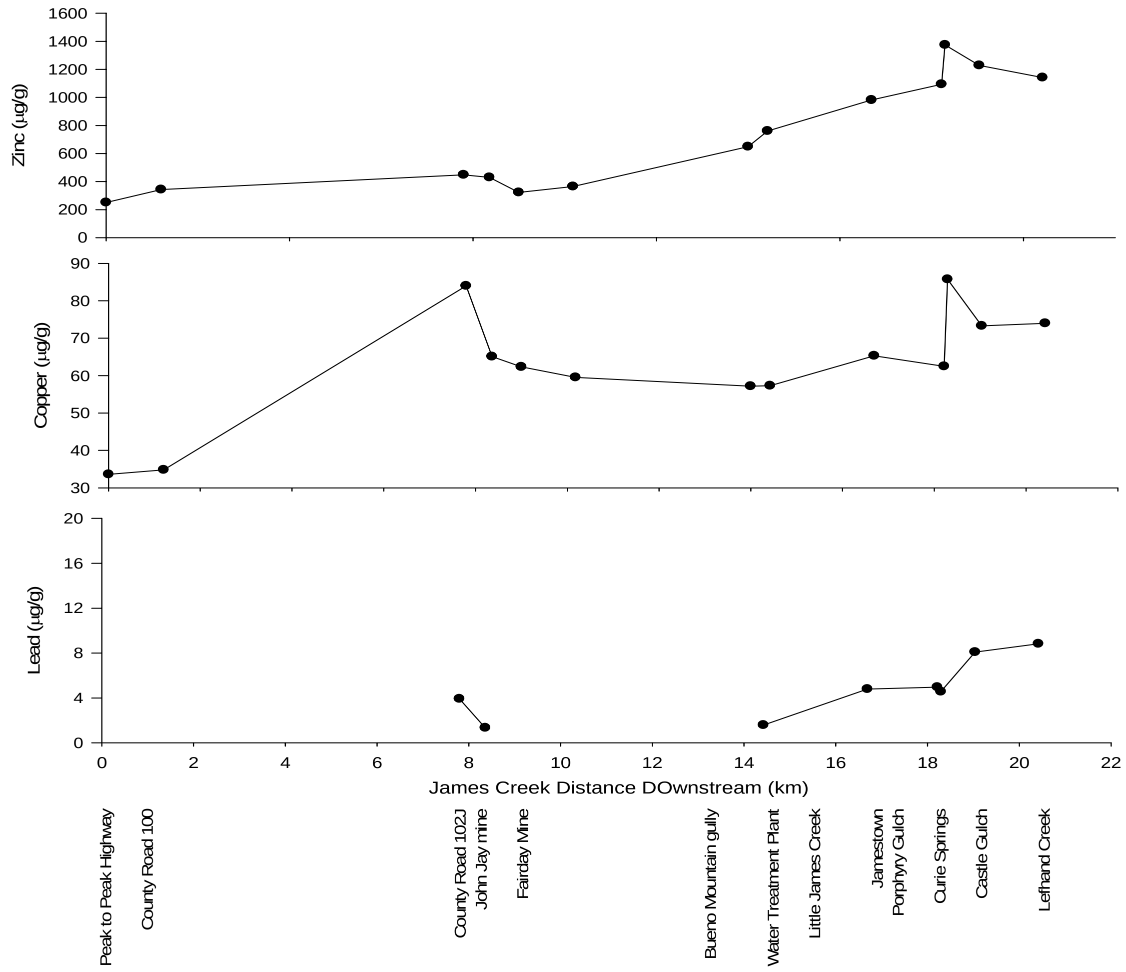

Figure 23. Zinc, copper, and lead concentrations measured in benthic macroinvertebrates in James Creek. Missing data points indicates levels measured below detection limits.

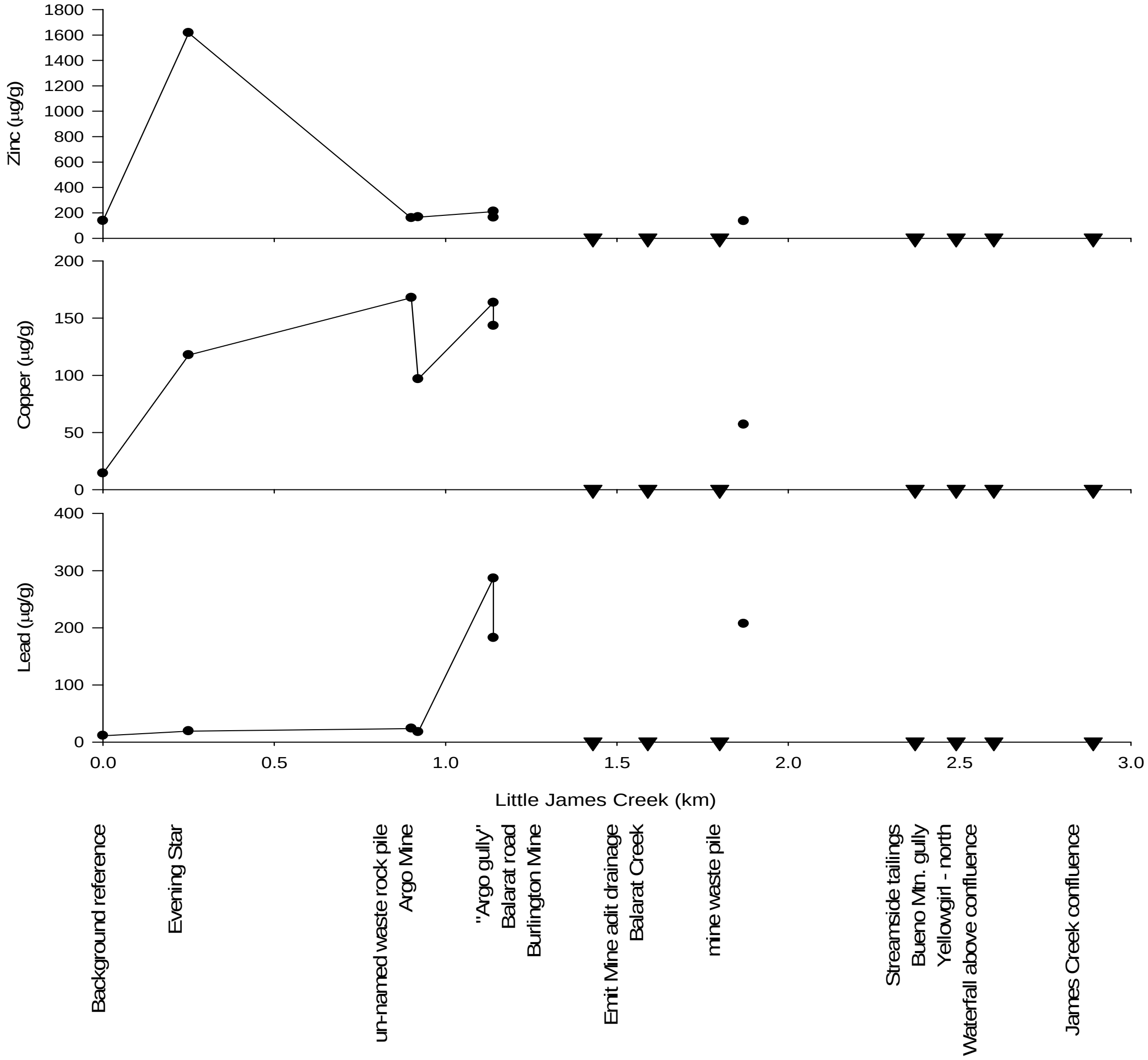

Figure 24. Zinc, copper, and lead concentrations measured in benthic macroinvertebrates in Little James Creek. Missing data points indicates levels measured below detection limits. Upside-down triangles represent sites with no macroinvertebrates present at the time of sampling.

Streambed sediments: Zinc, copper, and lead

Details of the measurement of metal concentrations in the streambed sediments are available in Bautts (2006). We present the results of the streambed sediment analysis here for comparison with the benthic macroinvertebrate analysis.

Background concentrations for the three investigated streams are reported in Table 8. Little James and James Creeks have similar background sediment concentrations, indicating similar geology, while Lefthand Creek background concentrations are much less for all investigated metals. Widely accepted standards for metals in stream sediments do not exist at this time.

Table 8. Streambed sediment background metal concentrations at sites upstream of known previous mining activities.

Creek	**Cu (mg kg^{-1})**	**Pb (mg kg^{-1})**	**Zn (mg kg^{-1})**
Lefthand Creek	12.3	26.3	35
James Creek	41.8	59.6	72.7
Little James Creek	48.3	64.8	77.4

Lefthand Creek streambed sediments: zinc, copper, and lead. Similarities in metal concentration changes along Lefthand Creek are observed between zinc, copper, and lead (Figure 25). The concentrations of copper, zinc, and lead in the sediments downstream of California Gulch (11-32 km) are represented separately in Figure 26 in order to observe the distribution of the investigated heavy metals on a smaller scale. In Lefthand Creek, zinc concentrations ranged from 35 mg kg^{-1} at the reference site (site LJ1upstream of Peak to Peak highway) to 4,900 mg kg^{-1} downstream of the White Raven Mine site (site LJ7). Copper concentrations in the sediments ranged from 12 mg kg^{-1} at the reference site (site LJ1) to 4,900 mg kg^{-1} downstream of the White Raven Mine site (site LJ7). Lead concentrations in the sediments of Lefthand Creek ranged from 26 mg kg^{-1} at the reference site (site LJ1) to 2,600 mg kg^{-1} downstream of the White Raven Mine site (site LJ7). The concentrations of zinc, copper, and lead in the sediments downstream of the White Raven Mine site were the highest among all sites tested in the watershed. Approximately 0.7 km downstream of the White Raven Mine at Sawmill Road (site LJ8), all metal concentrations are observed to be lower in the sediments. In Lefthand Creek at Sawmill Road, the zinc concentration in the sediment is 5 times lower (950 mg kg^{-1}) than at White Raven, 0.7 km upstream (LJ7), while the copper concentration in the sediment is 7 times lower (670 mg kg^{-1}), and the lead concentration in the sediment is 10 times lower (260 mg kg^{-1}). In California gulch, the fractions of the investigated metals in the sediments are dominated by zinc, less by copper, and the least by lead.

James Creek streambed sediments: zinc, copper, and lead. The concentrations of zinc in the sediments along James Creek ranged from 42.3 mg kg^{-1} just downstream of Castle Gulch to 286 mg kg^{-1} just upstream of the confluence with Lefthand Creek (Figure 27). Copper concentrations in the sediments along James Creek ranged from 21.1 mg kg^{-1} downstream of the treatment plant to 345.4 mg kg^{-1} just upstream of the confluence with Lefthand Creek. Lead concentrations in the sediments along Lefthand Creek ranged from 51.6 mg kg^{-1} just below Castle Gulch to 319 mg kg^{-1} just upstream of the confluence with Lefthand Creek. The background reference concentrations of metals in sediments sampled just upstream of Peak to Peak highway were higher than concentrations measured downstream of known abandoned mine and mill sites and waste rock piles. This site did show the lowest metal concentrations in the stream water and benthic macroinvertebrates and was expected to show the lowest metal concentrations in sediments. These metal concentrations in the sediments are most likely a result of the local mineralogy and geology in the watershed.

Little James Creek streambed sediments: zinc, copper, and lead. The concentrations of zinc in the sediments of Little James Creek ranged from 40 mg kg^{-1} downstream of the Argo mine to 1400 mg kg^{-1} just upstream of the Argo Mine (Figure 28). The concentrations of copper in the sediments ranged from 14 mg kg^{-1} below the Argo Mine to 250 mg kg^{-1} just upstream of the "streamside tailings." The concentrations of lead in the sediments of Little James Creek ranged from 60 mg kg^{-1} at the background reference location (2.3 k m north of Jamestown) to 690 mg kg^{-1} just downstream of the "streamside tailings" and the Bueno Mountain gully.

The concentrations of copper and zinc in the streambed sediments in Little James Creek show distinctly similar increases and decreases along the entire stream length. The minimum concentrations of copper and zinc occurred just downstream of the Argo Mine. Near the confluence with James Creek, concentrations of copper (50 mg kg^{-1}) and zinc (80 mg kg^{-1}) return to concentrations measured at the background reference site, while lead remains above background level concentrations (373 mg kg^{-1}).

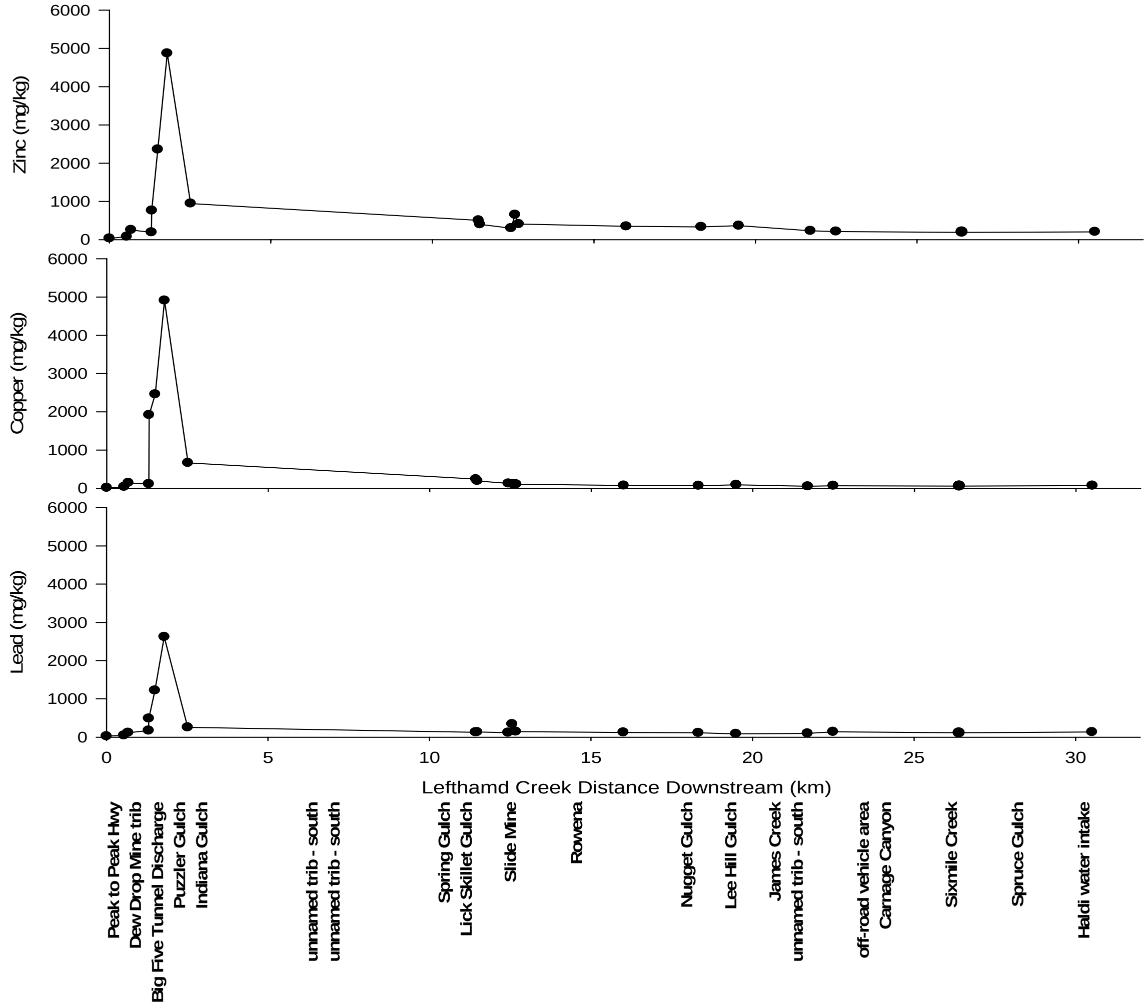

Figure 25. Zinc, copper, and lead concentrations in the streambed sediments (grain size <63 µm) of Lefthand Creek. Metals released by a partial acid digestion. Samples were collected from October 1 to October 17, 2005.

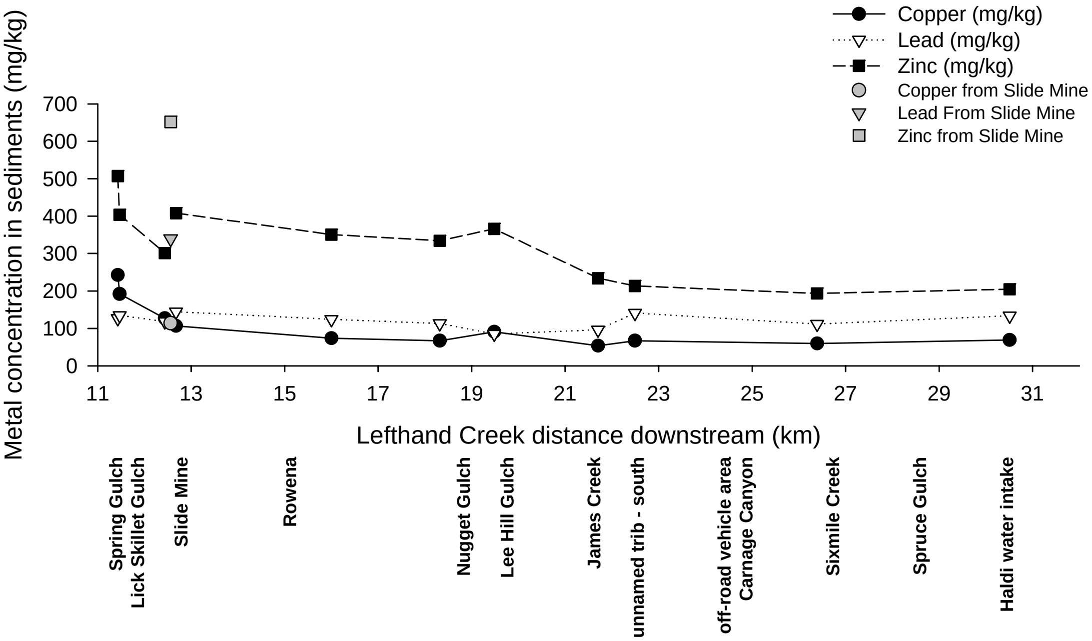

Figure 26. Zinc, copper, and lead concentrations in the streambed sediments (grain size <63 µm) of Lefthand Creek from 11-30 km downstream of the Peak to Peak Highway. Metals were released by a partial acid digestion. Samples were collected from October 1 to October 17, 2005.

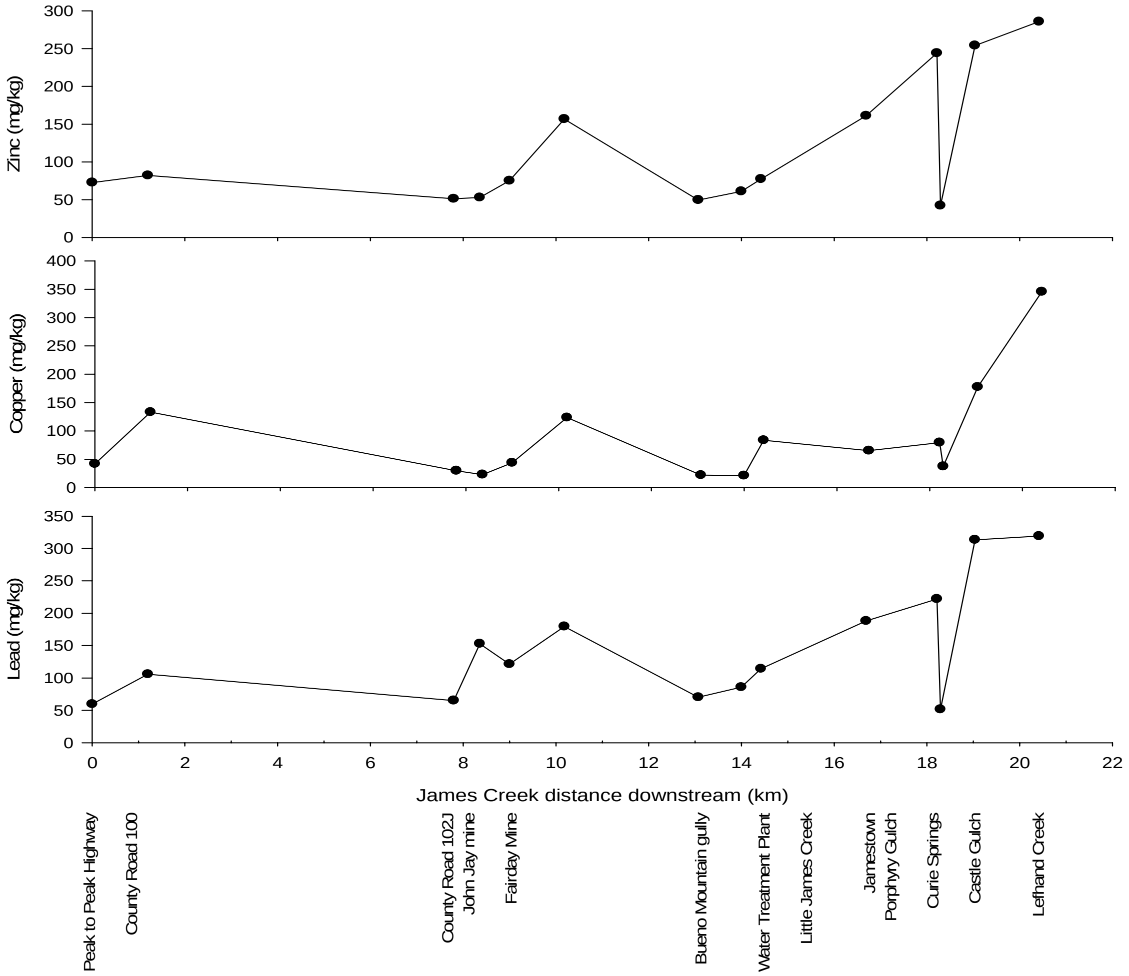

Figure 27. Zinc, copper, and lead concentrations in the streambed sediments (grain size <63 µm) of James Creek. Metals released by a partial acid digestion. Samples were collected from October 1 to October 17, 2005.

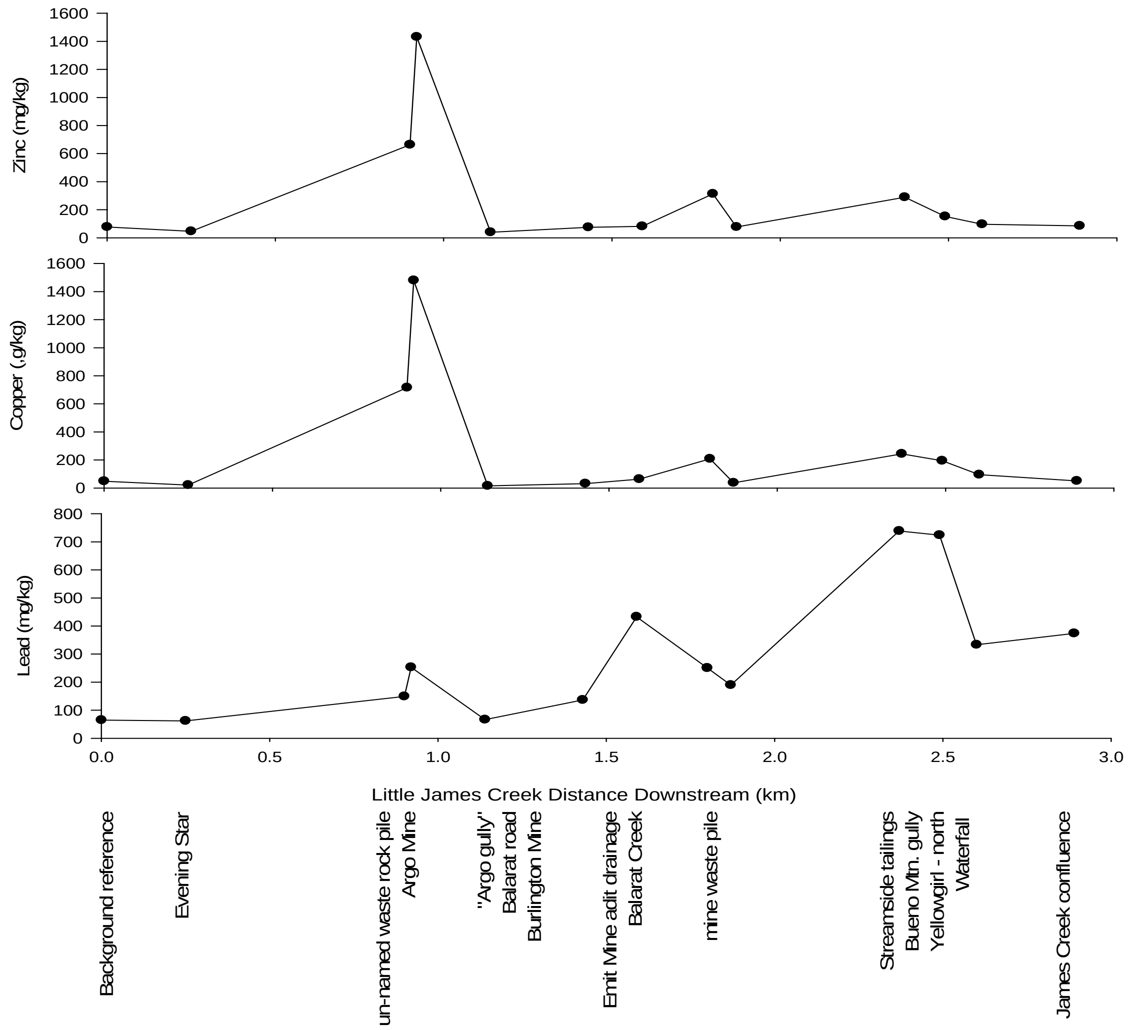

Figure 28. Zinc, copper, and lead concentrations in the streambed sediments (grain size <63 µm) of Little James Creek. Metals released by a partial acid digestion. Samples were collected on September 24, 2005.

DISCUSSION

In order to assess the impacts of intermittent sources of toxic metals to streams in the Lefthand Creek watershed, metal concentrations were measured in the stream water, benthic macroinvertebrates, and stream sediments. Our analyses focused on zinc, copper, and lead because these metals most frequently and consistently exceed aquatic life standards in the watershed (Lefthand Watershed Task Force, 2002; Wood et al., 2004), and because these metals behave quite differently with respect to adsorption to minerals, organic matter, and organisms (Dzombak and Morel, 1990; Erickson et al., 1996; Farag et al., 1998; Galan et al., 2003). Exposure time to toxic metals and the fate and transport of metals in streams were key factors in creating hypotheses.

We hypothesized that benthic macroinvertebrates and sediments, which have proved to be good monitors of metal loading over time (Hare et al., 1991; Woodward et al., 1994), would provide evidence of metal inputs in to the streams by intermittent tributaries and snow melt.

Because both benthic macroinvertebrates and sediments are expected to be good monitors of metal loading from intermittent sources, we expected that the metal concentrations in the benthic macroinvertebrates and the sediments would be correlated, but that the metal concentrations in the benthic macroinvertebrates and sediments would not be correlated with the metal concentrations in the stream water. We examined the data for these correlations in order to test this hypothesis. We expected that zinc, copper, and lead would follow the patterns of speciation observed in other streams and soils (Kimball et al., 1995; Farag et al., 1998; Fey et al., 1999; Schemel et al., 2000; Adriano, 2001; Munk et al., 2002). In the stream water samples, we expected that zinc would be mostly dissolved, lead would be mostly bound to colloids, and copper would be found in both fractions. Because of this behavior, we expected to find more lead and less zinc accumulation in the sediments and benthic macroinvertebrates as a fraction of the total amount of metals in the streams. We expected that the amount of dissolved organic matter in the streams would play a role in the metal distributions between water, sediments, and benthic macroinvertebrates as well – more organic matter would increase the amount of metals in the dissolved fraction. We tested these hypotheses by assessing dissolved and colloidal metal concentrations and correlations between dissolved metal and organic matter concentrations.

The final section of the Discussion contains our analysis of the implications of these finding for prioritization of abandoned mine cleanup in the Lefthand Creek watershed.

Metal concentrations in benthic macroinvertebrates, water, and sediments

Regression analyses for were completed between stream water metal concentrations and benthic macroinvertebrates and stream water metal concentrations and sediments in order to find correlations among media (Figures 29-31). Few strong correlations were found using this analysis and all but one existed in Lefthand Creek. A single positive correlation in Little James Creek was found between lead in benthic macroinvertebrates and stream water samples ($R^2 = 0.74$). In addition to this correlation, the absence of macroinvertebrates in seven of the thirteen sampling sites in Little James Creek, and nearby benthic macroinvertebrate lead concentrations highest in the watershed, it appears that lead impairs the stream water quality. Concentrations of zinc and copper were ruled out as targets of impairment due to similar concentrations found in the watershed which contained an abundance of macroinvertebrates (i.e., downstream of the White Raven Mine and the Big Five Tunnel drainage). Besides this single comparison, water concentrations did not show strong correlations with macroinvertebrate or sediment concentrations within the watershed.

Regression analyses were completed to assess correlations between stream water metal concentrations and benthic macroinvertebrates and stream water metal concentrations and sediments (Figures 32-34). Along the entire length of Lefthand Creek, strong correlations were observed between macroinvertebrates and sediments for copper ($R^2 = 0.80$) and lead ($R^2 = 0.64$). These were a result of the strong correlations found within California Gulch, and not representative of the entire stream. For the California Gulch segment of Lefthand Creek, correlations between macroinvertebrates and sediments improve to $R^2 = 0.82$ for copper and $R^2 = 0.90$ for lead. Copper and lead have a higher affinity to bind to surfaces and form complexes than does zinc in the pH range found in Lefthand Creek which end up in the sediments.

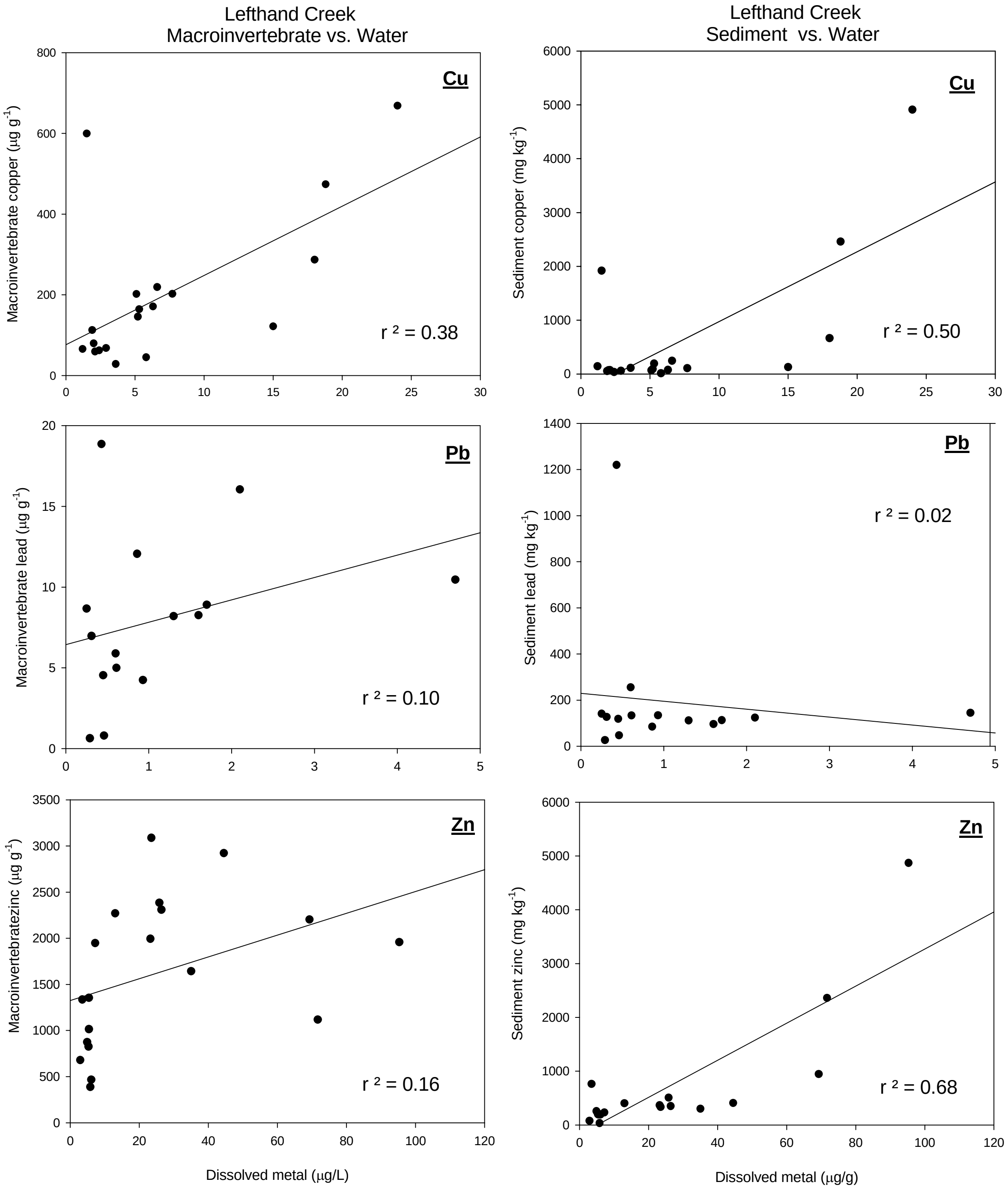

Figure 29. Comparisons of metals in benthic macroinvertebrates and dissolved metals in water (left column) and metals in sediments and dissolved metals in water (right column) for zinc, copper, and lead in Lefthand Creek.

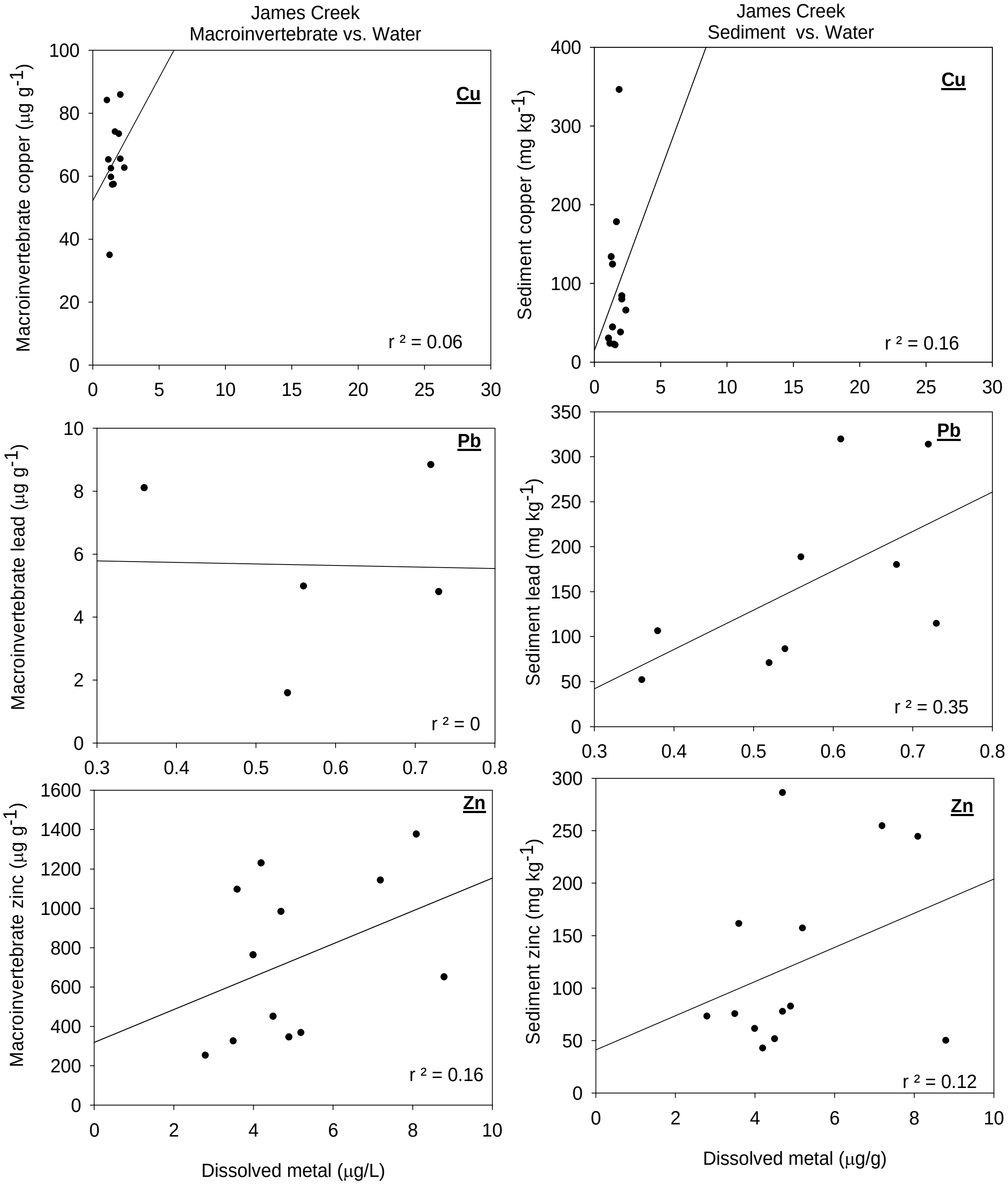

Figure 30. Comparisons of metal concentrations in benthic macroinvertebrates and dissolved metals in water (left column) and metal concentrations in sediments and stream water (right column) for copper, zinc, and lead in James Creek.

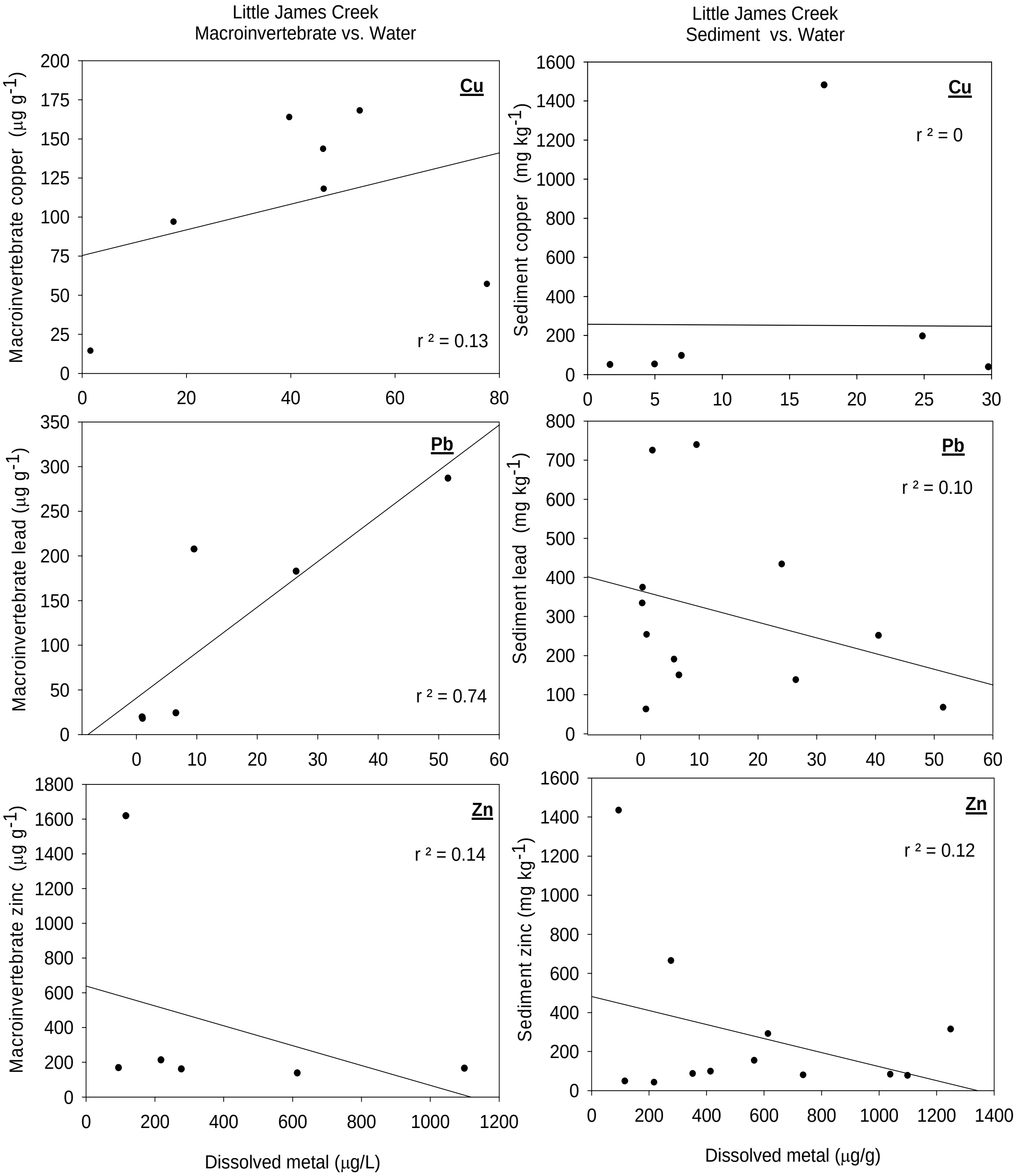

Figure 31. Comparisons of metal concentrations in macroinvertebrates and stream water (left column) and metal concentrations in sediments and stream water (right column) for copper, zinc, and, lead in Little James Creek.

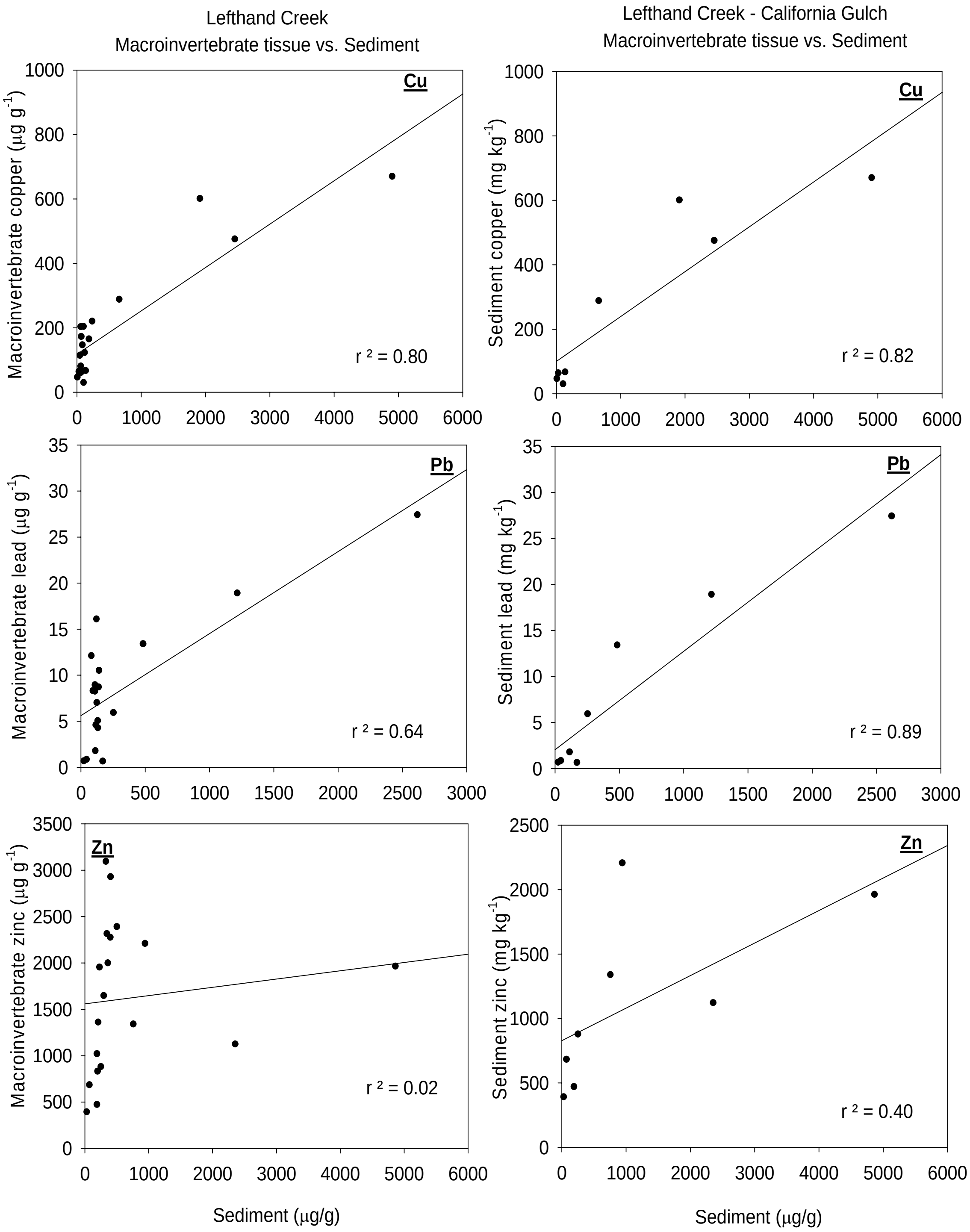

Figure 32. Comparisons of metals in benthic macroinvertebrates and metals in sediments for all of Lefthand Creek (left column) and for only the California Gulch reach of Lefthand Creek (right column).

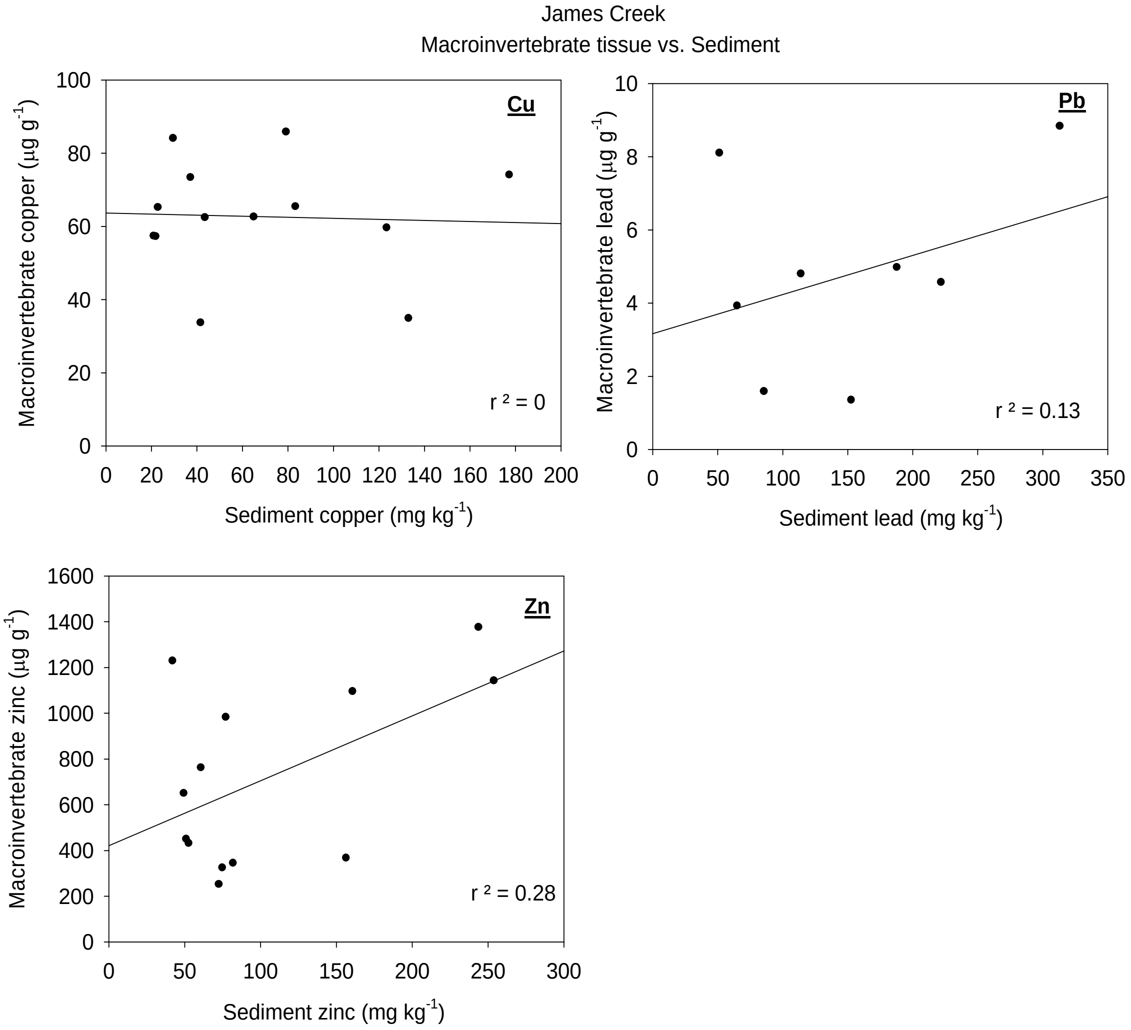

Figure 33. Comparisons of metals in benthic macroinvertebrates and metals in sediments for zinc, copper, and, lead in all of James Creek.

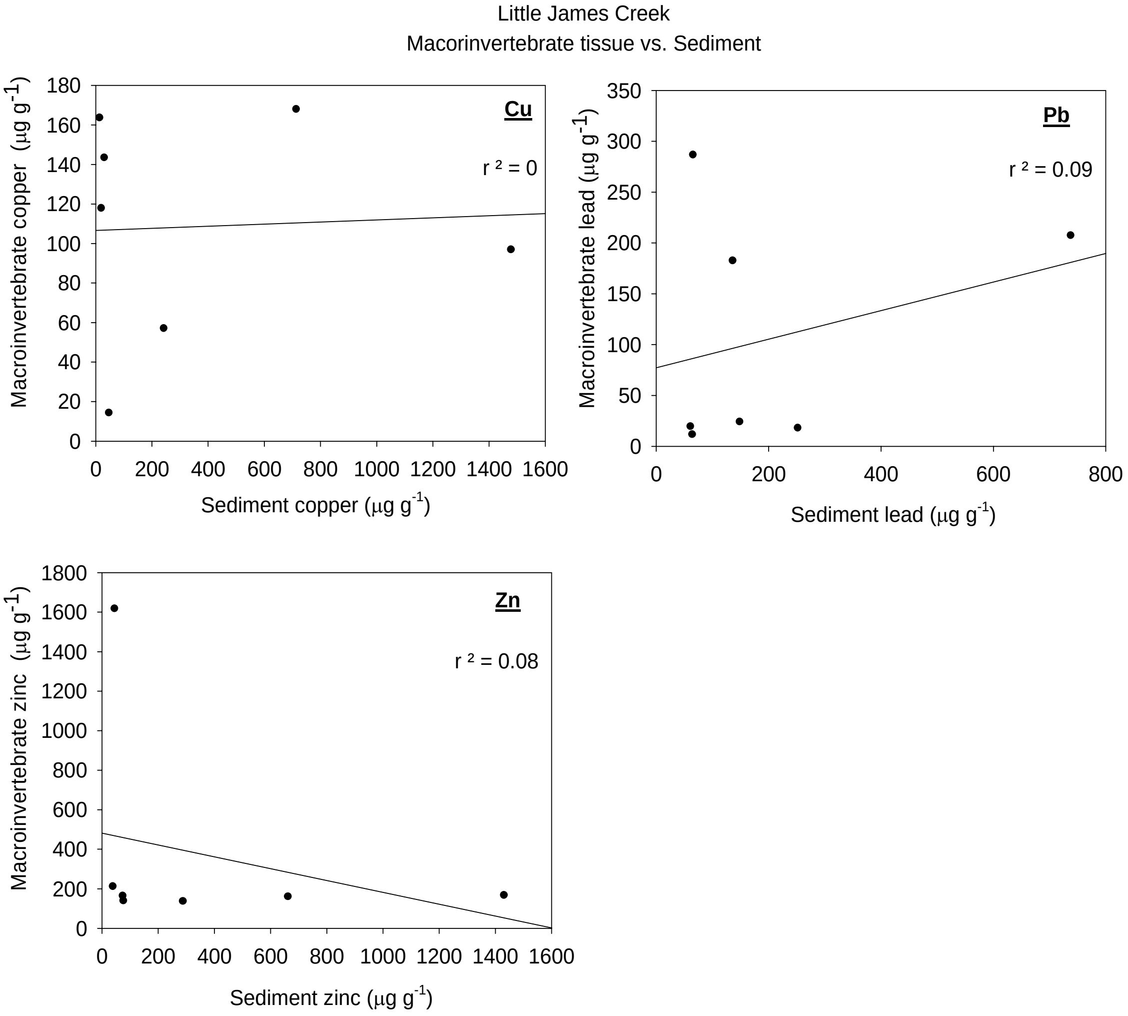

Figure 34. Comparisons of metals in benthic macroinvertebrates and metals in sediments for zinc, copper, and lead in all of Little James Creek.

Benthic macroinvertebrates as biomonitors

Benthic macroinvertebrates have been used extensively to assess water quality impairment in Rocky Mountain streams (Hare et al., 1991; Cain et al., 1992; Hare, 1992; Clements and Kiffney, 1994; Maret et al., 2003; Meyer et al., 2006). Even with the large variability among benthic macroinvertebrates in their uptake and accumulation of metals, we are still able to observe elevated metal concentrations in benthic macroinvertebrates in areas downstream of abandoned mine and mill sites. Bioaccumulation of metals in benthic macroinvertebrates aided in the discovery of sources of metals which were not revealed by water sampling. In many instances, stream water metal concentrations indicated decreases or no change in metal loading, but metal concentrations in benthic macroinvertebrates (along with metal concentrations in sediments) showed clear increases.

For example, in James Creek downstream of Bueno Mountain, zinc and lead concentrations were low in water and sediments and continued to decline in concentration downstream; however, metal concentrations in benthic macroinvertebrates remained high and increased with stream distance until the confluence with Little James Creek.

Copper and zinc concentrations in the stream water decreased from above (LH4) to downstream of (LH5) the Big Five tunnel drainage while lead remained below detection limits at both sites (Table 9). These samples were both taken on July 8, 2005, when there was not observable flow from the tunnel. However, zinc concentrations in macroinvertebrates increased by a factor of 1.4, copper concentrations in macroinvertebrates increased by a factor of 16, and lead concentrations in macroinvertebrates increased by a factor of 30. We observed similar increases in sediments. Zinc concentrations in sediments increased by a factor of 12, the concentration of copper in sediments increased by a factor of 21, and the concentration of lead in sediments increased by a factor of 6. This finding supports the hypothesis that stream water concentrations would not be indicative of metal sources while intermittent streams are not flowing.

Better correlations were observed between zinc and copper concentrations in stream water and benthic macroinvertebrates than with lead concentrations in stream water and benthic macroinvertebrates. This correlation was more common for copper and zinc than it was for lead because of the affinity for lead to adsorb to colloidal materials compared to copper and zinc, which could make lead less bioavailable to aquatic organisms. Zinc adsorbs the least to colloidal surfaces and is thus found in the highest concentrations in the dissolved phase. Dissolved metals are assimilated into the bodies of benthic macroinvertebrates, which explains why zinc occurs in the highest concentrations in benthic macroinvertebrates downstream of abandoned mine and mill sites relative to copper and lead. High concentrations of zinc in all media, including waste rock piles is due to its abundance in minerals throughout the watershed.

In the future, benthic macroinvertebrate collections should include the collection of two species from separate feeding guilds in order to decrease variability among samples. This is possible if further investigations into the abundance of metal tolerant species can be conducted to find a target species. Future methods of collection could possibly include harvesting a single species from background sites and placing them in encasements throughout the study area. The amount of time the target species should remain in the encasements shall rely on the lifespan and time of molting of the species chosen. Researchers indicate that care must be taken when using pooled communities to assess metal inputs to streams (Clements and Kiffney, 1994). The feeding guild of the benthic macroinvertebrates determines their sensitivity to metals in the stream water column and the sediments. The benthic macroinvertebrates used at each site varied in community diversity. Whole communities were digested to get a representative sample at each site. The nature of this type of collection leads to various questions pertaining to the accumulation of metals by individuals. Some individual fly larvae filter feed through the sediments and detritus on rocks while others spin webs and capture food moving downstream in the form of organic matter and, sometimes, other larvae. We can also pose questions as to the extent of metal resistance among individuals. The tolerance of these individuals depends on their success in passing metals through the body.

As an additional note to future investigators, we advise that samples for sediments and benthic macroinvertebrates should be taken along the 8 km length of stream from Sawmill Road to Lickskillet Road. Results from such a study will enable future researchers to determine the extent of metal loading from California Gulch.

Table 9. Increases in concentrations of zinc, copper, and lead in stream water, benthic macroinvertebrates, and sediments from upstream of to downstream of the Big Five Tunnel drainage. These sites were sampled on July 8, 2005, when the drainage was not flowing into Lefthand Creek. Negative values indicate decreases in concentrations.

	stream water (µg L^{-1})			**macroinvertebrate (µg g^{-1})**			**streambed sediments (mg kg^{-1})**		
metal	**up**	**down**	**increase (%)**	**up**	**down**	**increase (%)**	**up**	**down**	**increase (%)**
zinc	6.1	3.5	-43%	467	1118	139%	194	2361	1120%
copper	3.6	1.5	-58%	28.4	474	1570%	112	2460	2100%
lead	0.05	0.05	0%	0.6	18.9	3050%	172	1220	609%

Dissolved organic carbon and metal speciation

Metals are known to bind to organic matter and their total concentrations in many waters have been correlated with the concentration of dissolved organic carbon (DOC) (McKnight et al., 1992; Church et al., 1997; Prusha and Clements, 2004). Metals that bind to DOC are less bioavailable and because of this we expected to see a decrease in metal accumulation in macroinvertebrates as DOC increased. High DOC levels can inhibit metals from bioaccumulating in benthic macroinvertebrates (Prusha and Clements, 2004). This process is most effective for metals with a high affinity to bind to organic matter.

Figure 35 shows the concentration of DOC compared to the metal concentrations in benthic macroinvertebrates for all of the sampling sites. A negative correlation between macroinvertebrate metal concentrations and DOC was expected for all metals and in the order Pb > Cu > Zn due to their affinity to adsorb to organic matter. However, we did not see such correlation among the pooled data. Negative correlations were found between benthic macroinvertebrates and DOC for all investigated metals in James Creek and for zinc and lead in Little James Creek; however, these correlations were not significant ($R^2 < 0.15$). DOC becomes less effective at controlling metal bioaccumulation in benthic macroinvertebrates at higher metal concentrations. When available sites on organic matter become saturated with metals, leaving no available sites, free metals have a greater chance to bioaccumulate in the bodies of benthic macroinvertebrates.

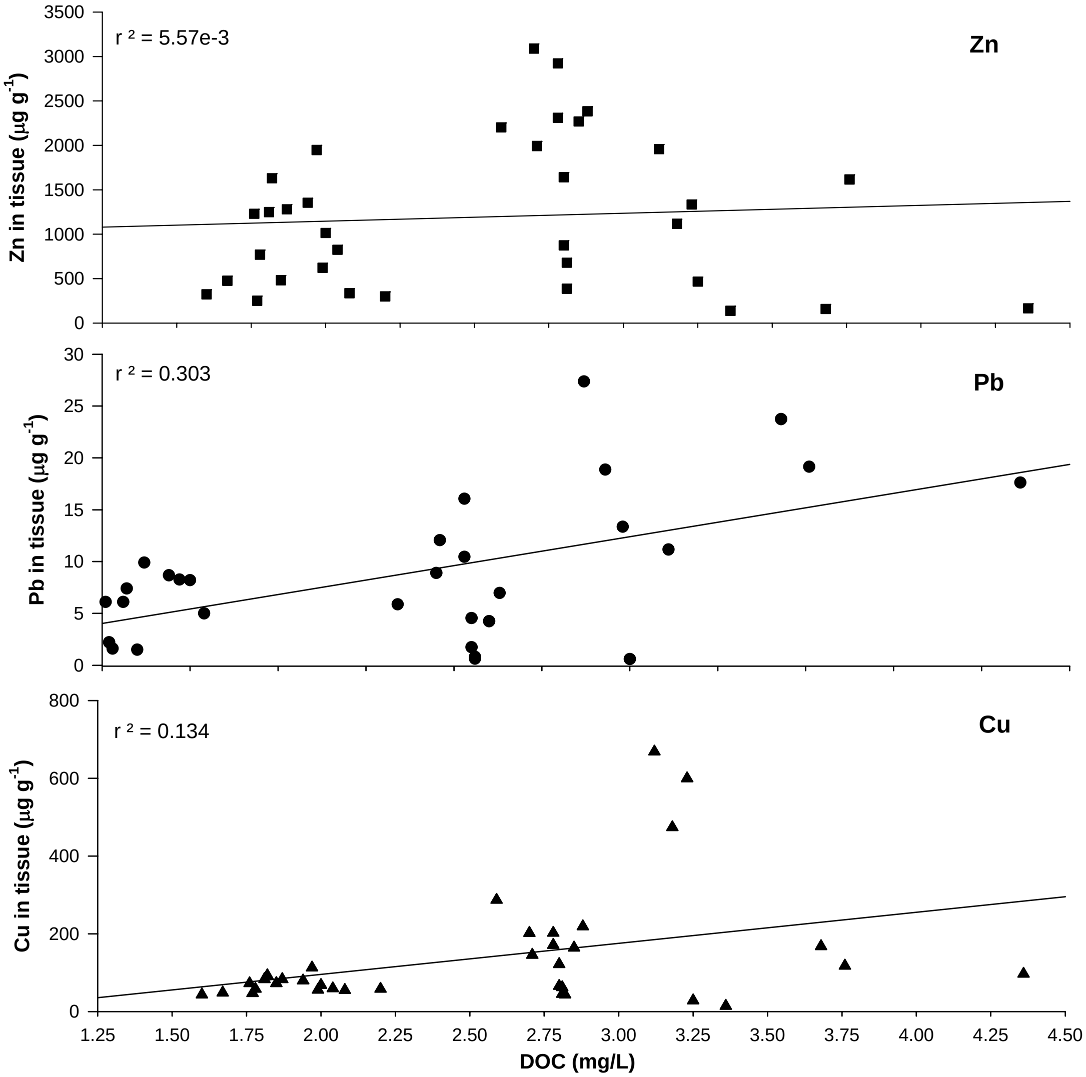

Figure 35. Concentration of metals in benthic macroinvertebrates as a function of concentration of dissolved organic carbon (DOC) for all sampling sites.

Recommendations for remediation

We expected sediment and macroinvertebrate metal concentrations to lead us to new sources of metal inputs to the streams that flow only intermittently. We did not find any new sources of metal loading within the watershed, but we were able to confirm previous recommendations and reprioritize a few sites.

Along Lefthand Creek, Wood et al. (2004) rated the Dew Drop mine as medium priority because of copper and zinc concentrations and pH. This ranking is supported by the increases in metals in benthic macroinvertebrates and sediments downstream of the site. The Big Five tunnel received a high priority ranking from Wood et al. (2004) based on pH, zinc, copper and lead. This study supports the ranking with the high concentrations of copper, lead and zinc downstream of the Big Five tunnel in benthic macroinvertebrates, sediments, and stream water. The Slide Mine was given a medium priority ranking by Wood et al. (2004) due to pH, zinc, and copper. Based upon increases in concentrations of zinc and lead downstream of this site in benthic macroinvertebrates (also the highest concentrations in the creek among benthic macroinvertebrates), we would change the prioritization of this site to high. Current efforts are underway to remediate the Slide Mine as a voluntary cleanup program (VCUP) site.

Along James Creek, the Bueno Mountain Mine was given a high priority ranking based upon Al, Mn, Zn, Cu and Pb by Wood et al. (2004). Concentrations in benthic macroinvertebrates and sediments support this ranking with escalating increases of Copper, Zn and Pb for 8 km downstream of known metal inputs. It is possible that these sources may also emanate from upstream sources, such as the Fairday Mine or John Jay Mine.

The Bueno Mountain gully along Little James Creek also received a high priority ranking based upon the same metals and pH. This area, including the “streamside tailings,” was ranked as high priority by Wood et al. (2004). These are supported by the lack of aquatic life, low pH, and high concentrations of copper, zinc and, lead in the sediments. The most problematic metal to aquatic life in this area is attributed to lead. The Evening Star Mine, which was referred to as the “un-named” mine between 0.37 – 0.64 km by Wood et al. (2004), was assigned a medium priority ranking due to Al, Cu, and Pb loading. Streambed sediment and benthic macroinvertebrate metal concentrations did not confirm lead loadings within the vicinity of the Evening Star Mine inflows, but we did detect elevated copper and zinc concentrations in benthic macroinvertebrates in this area. We advise maintaining the medium priority ranking of Wood et al. (2004), but we recommend further investigations into the transport of metals from this site. The Argo Mine gully was given a medium priority ranking by Wood et al. (2004) due to Al and Cu, but this was found to be inappropriate from the findings within this study. Concentrations of copper and zinc in sediments just downstream of the gully were highest among all samples taken in the creek and benthic macroinvertebrates exhibited the highest lead and copper concentrations. We would recommend raising the priority of the Argo Mine gully from medium to high.

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APPENDIX

Table A.1. Lefthand Creek water, benthic macroinvertebrate, and sediment field sampling dates.

sample name	GPS site name	water & macroinvertebrate sampling date	sediment sampling date
LH1	5560A-1	7/6/2005	10/3/2005
LH2	5560A-6	7/22/2005	10/3/2005
LH3	5560A-8	7/22/2005	10/3/2005
LH4	5560A-13	7/8/2005	10/3/2005
LH5	5560A-14	7/8/2005	10/3/2005
LH6	5560A-17	7/8/2005	10/17/2005
LH7	5560A-21	7/8/2005	10/17/2005
LH-PU	5560A-PU	7/8/2005*	10/17/2005
LH-IN	5560A-IN	7/6/2005*	10/10/2005
LH8	5560A-56	7/6/2005	10/10/2005
LH9	5560A-95-1	6/20/2005	10/1/2005
LH10	5560A-96	7/6/2005	10/1/2005
LH11	5560A-101	7/2/2005	10/1/2005
LH-SL	5560A-SL1	7/2/2005*	10/1/2005
LH12	5560A-103	7/2/2005	10/1/2005
LH13	5560A-113	6/20/2005	10/1/2005
LH14	5560A-123	6/29/2005	10/1/2005
LH15	5560A-129	6/18/2005	10/1/2005
LH16	5560A-136-2	6/29/2005	10/1/2005
LH17	5560A-127	6/15/2005	10/1/2005
LH18	5560A-171	6/29/2005	10/1/2005
LH19	5560A-184	6/29/2005	10/27/2005

* Creek/tributary was dry upon sampling.

Table A.2. James Creek water, benthic macroinvertebrate, and sediment sampling dates.

sample name	GPS site name	water & macroinvertebrate sampling date	sediment sampling date
J1	5561A-T1	7/25/2005	10/3/2005
J2	5561A-T2	7/23/2005	10/4/2005
J3	5561A-T3	8/1/2005	10/8/2005
J4	5561A-T4	8/1/2005	10/8/2005
J-FD	5561A-FD	8/1/2005	10/8/2005
J5	5561A-JOHN	8/1/2005	10/8/2005
J6	5561A-10	8/1/2005	10/8/2005
J7	5561A-16	7/23/2005	10/8/2005
J8	5561A-28	7/13/2005	10/17/2005
J9	5561A-30-582	7/13/2005	10/4/2005
J10	5561A-55	7/1/2005	10/4/2005
J-CU	5561A-CU	7/2/2005	10/4/2005
J11	5561A-52	7/1/2005	10/4/2005
J12	5561A-53	7/1/2005	10/4/2005
J-CG	5561A-CG	7/1/05*	10/4/2005
J13	5561A-61	7/1/2005	10/4/2005
J14	5561A-62	6/30/2005	10/1/2005

* Creek/tributary was dry upon sampling.

Table A.3. Little James Creek water, benthic macroinvertebrate, and sediment sampling dates.

sample name	GPS site name	water-macroinvertebrate sampling date	sediment sampling date
LJ1	5562A-0	7/18/2005	9/24/2005*
LJ2	5562A-1	7/18/2005	9/24/2005*
LJ3	5562A-6	7/18/2005	9/24/2005
LJ4	5562A-8	7/18/2005	9/24/2005
LJ5	5562A-10	7/18/2005	9/24/2005
LJ6	5562A-14	7/18/2005	9/24/2005
LJ7	5562A-16	7/18/2005	9/24/2005*
LJ8	5562A-18-1	7/13/2005	9/24/2005*
LJ9	5562A-21	6/30/2005	9/24/2005
LJ10	5562A-28	7/13/2005	9/24/2005*
LJ11	5562A-32	7/13/2005	9/24/2005*
LJ12	5562A-35	7/13/2005	9/24/2005
LJ13	5562A-38	6/22/2005	9/24/2005

*Creek/tributary was dry upon sampling.