Colorado Healthy Rivers Fund Grant (*PO# 09-44*)

FINAL REPORT

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"to protect and restore…"

PROJECT DESCRIPTION AND BACKGROUND

In 2008, the Coal Creek Watershed Coalition (CCWC) was awarded funds from the Colorado Healthy Rivers Fund (CHRF) for four tasks:

<u>Task 1. Individual Sewer Distribution System Evaluation</u>:

The townsite of Irwin, which lies approximately 8 miles upstream of the Town of Crested Butte, is located along the headwaters of Coal Creek, adjacent to Lake Irwin. Irwin is an off-the-grid community featuring up to 30 seasonal and permanent residences that fall within the Town's Municipal Watershed District. Due to lack of central water or wastewater systems, the homeowners rely on individual wells and individual sewage disposal systems (ISDS) to dispose of blackwater and graywater generated from their residences.

The historical nutrient data available for Coal Creek is limited to United States Geological Survey (USGS) and United States Forest Service (USFS) sites on Coal Creek at several sites within the watershed. In 2000, a USGS site was placed downstream of the Town of Crested Butte. Data from this site indicates nitrate-nitrite and phosphorus levels were not trending upward in Coal Creek from year-to-year. Typically, the CCWC's water quality sampling results do not detect these nutrients in the samples, or detect them at levels only slightly above the detection limits for the analytical instruments employed in the analysis. Samples collected in 2007 and 2008 detected phosphorous at two sites: one at a location downstream of the town site of Irwin and another just upstream of the Keystone Mine. Due to concerns over potential contamination of Coal Creek due to poorly functioning or poorly maintained ISDS, the CCWC was interested in collecting samples throughout the townsite with the intention of bracketing inflows from ISDS. Historic sampling locations were too far downstream of the Townsite of Irwin to determine the source(s) of nutrients in Coal Creek.

In 2008, the CCWC was awarded funding from the Colorado Healthy Rivers Fund to expand its nutrient sampling in the Coal Creek Watershed. The funding was used as part of a cooperative agreement with the Gunnison County Environmental Health Office to collaborate on monitoring water quality in the townsite of Irwin and throughout the watershed, in order to determine if any issues related to nutrients or microbial activity exist. In August and October of 2009, samples were collected to document nutrient levels throughout the watershed (Figures 1, 2, & 3). Nitrate/Nitrite was not detected in any sample during either of the sampling events. Total phosphorus was detected just above the detection limit of 0.01 mg/L in several October samples (Tables 1 & 2). The CCWC has been monitoring microbes in Coal Creek annually since 2006. None of the samples collected in Coal Creek have ever exceeded the E. coli standard of 126 CFM/100 ml of water.

FUTURE ACTIONS FOR TASK 1

The CCWC plans to continue its collaboration with Gunnison County Environmental Health Department to map individual sewage disposal systems (ISDS) within the watershed. Mapping ISDS in conjunction with the CCWC's annual nutrient monitoring can help the CCWC identify trends indicating conditions within the creek are changing. Continuing to partner and share data with the Gunnison County Environmental Health Department will help ensure any that any declines in water quality will be noticed and addressed proactively.

One possible future action is to expand the seasons when samples are collected to document water quality conditions during extreme low-flow conditions, when the creek's assimilative capacity might be lower due to lower flow and decreased activity by biological processes.

Task 2. Macroinvertebrate Assessments:

The biomonitoring ("bio" = life) data from the macroinvertebrate communities within the Coal Creek watershed are used to complement the physical and water chemistry data the CCWC collects at these same sampling sites. The CCWC was awarded funds from the CHRF to expand the existing biomonitoring sampling sites to refine the CCWC's understanding of water quality impairments within the creek.

Biomonitoring with aquatic insects has established some excellent baseline data on the condition of Coal Creek, Elk Creek, and Splains Gulch. Macroinvertebrate data has led the CCWC to look for sources of contaminants near the Forest Queen Mine, the Irwin town site, and the Town of Crested Butte, and will continue to help shape cleanup efforts in the watershed. From this data, we can also see that the Mt. Emmons Water Treatment Plant protects stream fauna from the historic mining impacts in the area. Macrointerebrate data complements and supplements water quality data to provide a more complete understanding of the Coal Creek Watershed's health and ability to support aquatic life.

The State of Colorado is developing biocriteria for interpreting macroinvertebrate data. The State will use these macroinvertebrate data to decide what streams are impaired and may be added to the list of impaired waters. In the Coal Creek watershed in 2008, the only site that failed to meet the new biocriteria was a site downstream of the Town of Crested Butte, at the Butte Avenue bridge. The CCWC had stopped monitoring this site in 2009 since it tended to score poorly, due to the effects of water diversion of the creek by several upstream ditches. The diversions, coupled with contaminated runoff from the Town, affect the quality of habitat in this area. These diversions can divert all or almost all of the creek's waters upstream of the Butte Avenue bridge during the autumn of most years. The CCWC decided improvements in the macroinvertebrate communities will not occur until Coal Creek has more consistent flow at this site; therefore, it used its resources for monitoring macroinvertebrates elsewhere in the watershed.

According to the new state biocriteria for samples collected in 2009, the sample site below the Forest Queen Mine barely passed the criteria's standards; it is on the borderline for being considered as impaired. This is also the only site where deformed midges were found. The site had a poor score on the CCWC's metric for metal contamination in 2009 as well. With financial assistance from the CHRF grant, the CCWC added sites above and below the Mt. Emmons Iron Fen (fen) to test the theory that the heavy metals in several fen tributaries may be degrading Coal Creek. Based on the multimetric index we have used to evaluate heavy metal contamination, Coal Creek is in fair condition above the fen and has a slightly lower score but is still in fair condition below the fen. At least two more years of data would be necessary to validate these findings, but results from our first year of data collection show that the Coal Creek macroinvertebrates do not show a dramatic decline below the Iron Fen. Considering that the fen has been releasing metals into Coal Creek since at lease the last Ice Age, the macroinvertebrates in the Coal Creek drainage have had a very long time to adapt to this background metal exposure.

Data has also shown an improvement in the water quality of Coal Creek below Kebler Pass Road's fork to Irwin, since beavers built ponds above and below our monitoring site. It is possible the ponds attenuate the effects of the Forest Queen Mine site.

FUTURE ACTIONS FOR TASK 2

Based on the macroinvertebrate data, the CCWC will focus on addressing impairments within the Town of Crested Butte and below the Forest Queen Mine, wherever possible, to improve riparian health.

Task 3. Educational Signage and Tabletop Display:

CHRF funding was used to create and install educational signs throughout the watershed in major parking areas, trailheads, bridge crossings and other higher traffic areas. CCWC staff and volunteers provided in-kind labor to design the signs, obtain the necessary permits through the U.S. Forest Service, and install the signs. To ensure the signage was accurate and appropriate, an ad hoc review committee was formed. It included the Town of Crested Butte Planning Department, local author George Sibley, the Crested Butte History Museum, local historians, and members of the CCWC's steering committee. The ad hoc committee reviewed sign content, structural design, and placement considerations. To date, four of the six signs have been installed (see Figures 4-7) with one sign awaiting installation by Gunnison County Public Works. The final sign will be installed in July, assuming the Irwin homeowners approve the design and placement during their annual meeting scheduled for July 17, 2010.

Some funds requested by the CCWC were to be used for creation of a tabletop display. This subtask was abandoned since tabletop displays were able to designed and constructed through in-kind services instead.

FUTURE ACTIONS

The CCWC will promote the new signage as both an educational and a tourism activity and will look for future sign locations and content to continue the education of locals and visitors within the watershed.

Task 4. AmeriCorps* Office of Surface Mining VISTA Support:

CHRF funds awarded in 2008 were used to provide a year of full-time service by an OSM/VISTA member through the Western Hardrock Watershed Team. In October of 2009, the CCWC hired Amy Weinfurter to build the capacity of the watershed group to create sustainability and to assist with the implementation of tasks funded by the CHRF.

Amy served as the project lead for the educational signage project detailed in Task 2. In her role as project lead she developed cost estimates, formed the ad hoc review committee, drafted and edited the signage, and handled the logistics for the printing of the signage.

In her role as VISTA member Amy also helps produce the organization's quarterly newsletters, coordinates and recruits volunteers and helps draft and submit grants and other funding requests. To date Amy has helped secure over $29,000 in grants and has assisted in the submission of a recently awarded $147,000 grant.

FUTURE ACTIONS

Based on Amy's successes, the CCWC is exploring the possibility of continuing Amy's employment after her term of service with the VISTA program ends in October, 2010. Amy has been an integral part of the CCWC's growth and expansion over the past two years.

APPENDIX A
FIGURES, TABLES AND PHOTOGRAPHS

Figure 1. May 28, 2009 sampling locations and nearby geographic features.

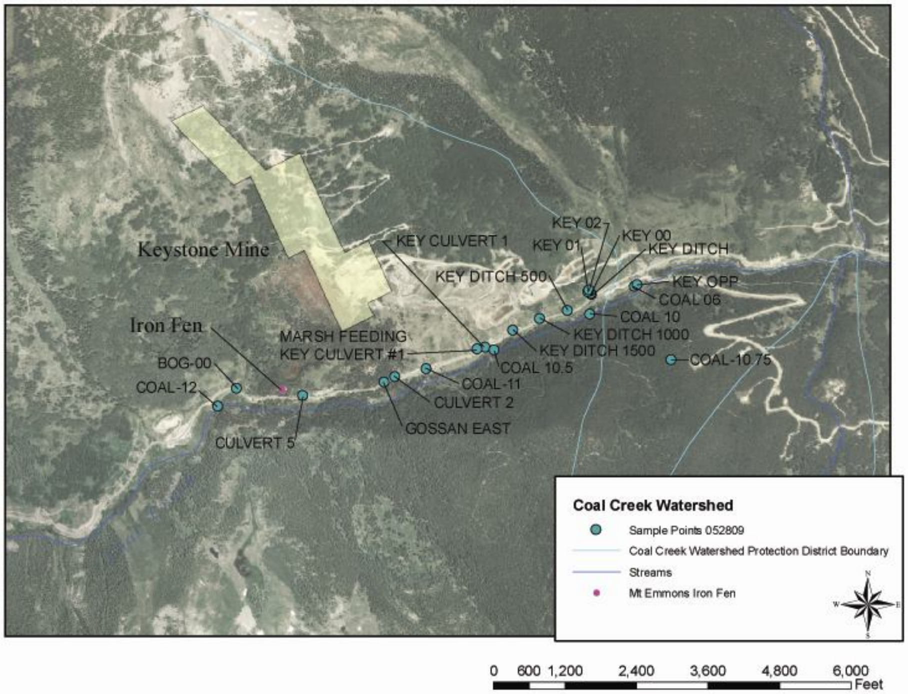


Figure 2. Locations for the August and October nutrient and sampling events.

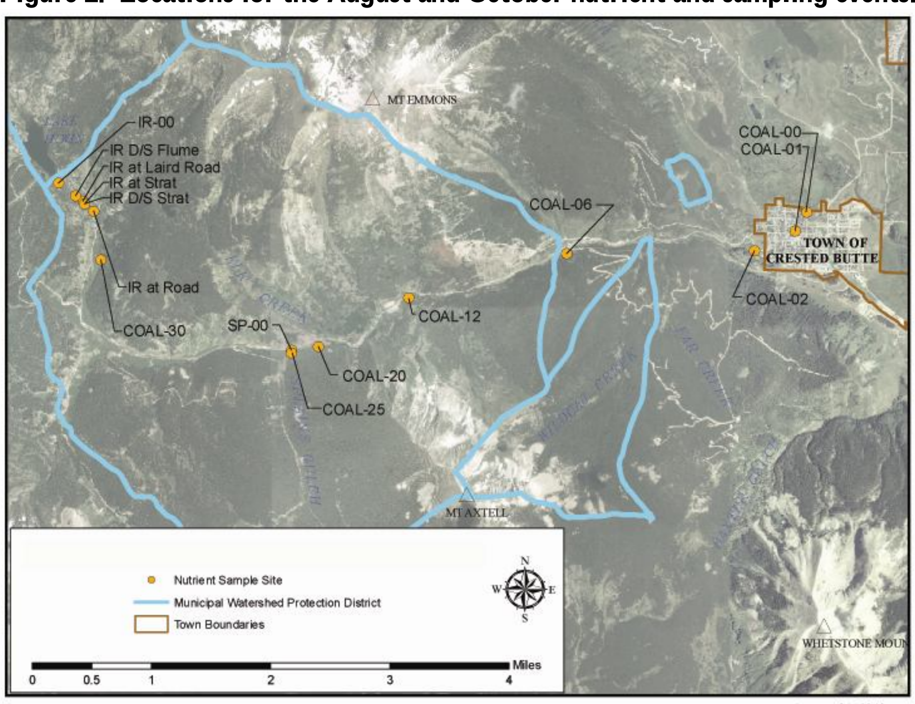


Figure 3. Locations for the August and October nutrient and microbe sampling events within the townsite of Irwin, Colorado.

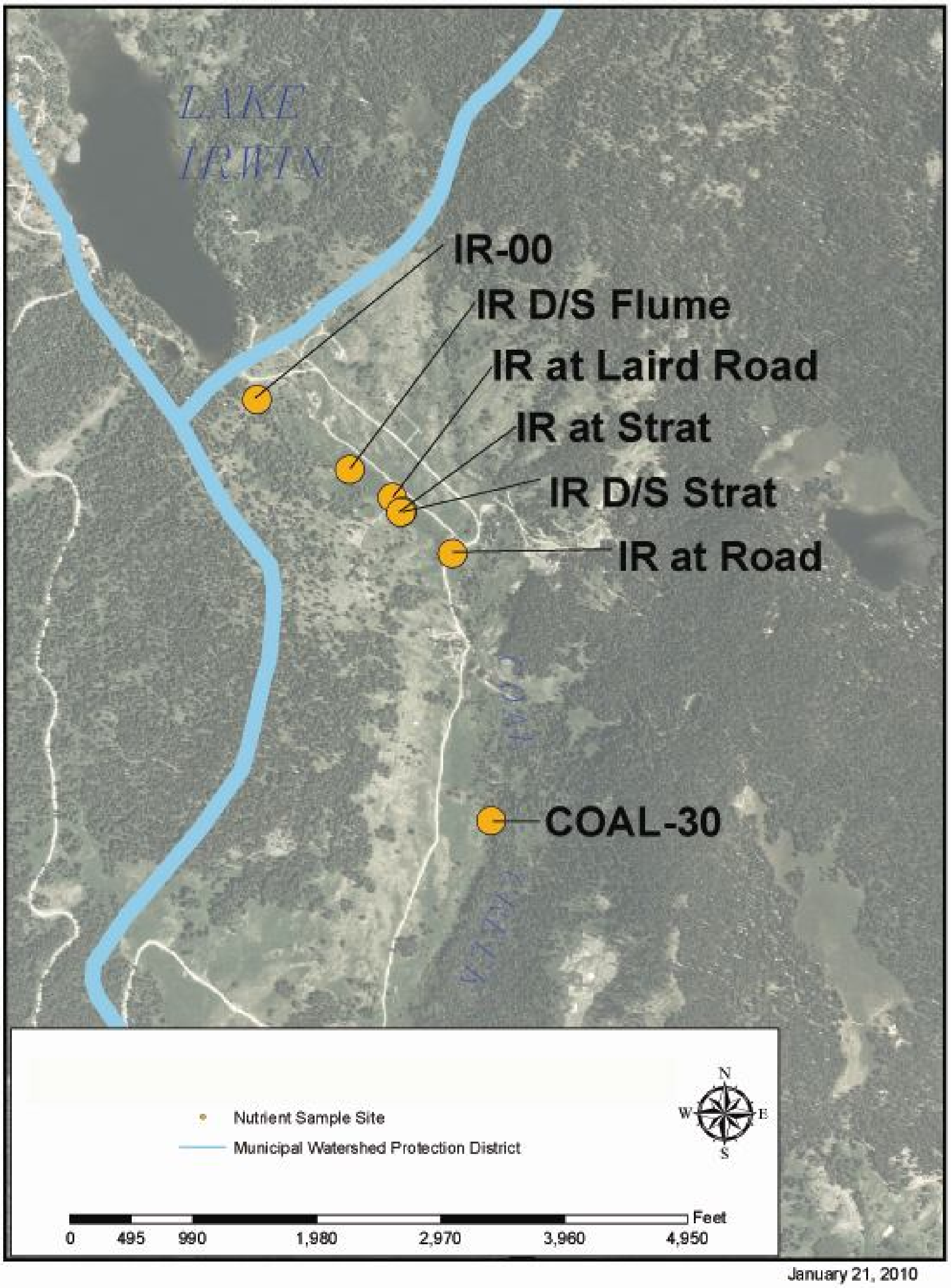


Figure 3. Coal Creek 2006-2009 Biomonitoring
Fore's B- IBI - A Metric for Heavy Metals
Average and standard error

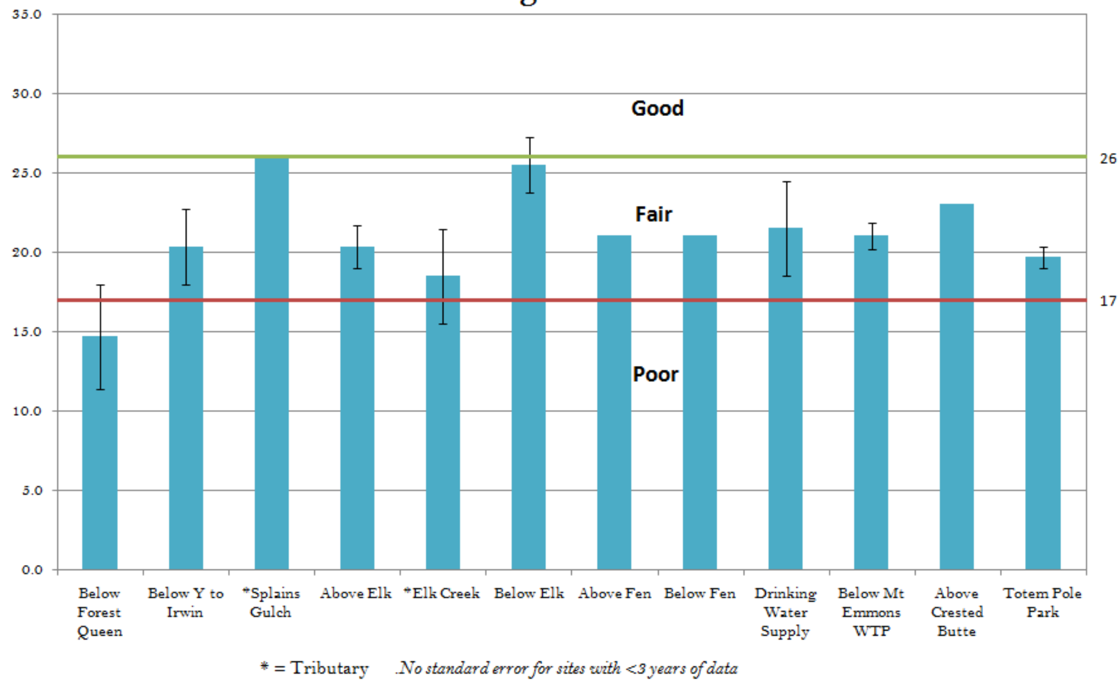


Figure 4 - Educational sign for the Butte Avenue Bridge featuring information on the importance of wetlands.

Figure 5 - Signage near the Creekside Plaza featuring information about armoring and riparian corridors.

Figure 6 - Signage at Totem Pole Park featuring information about non-point source pollutants.

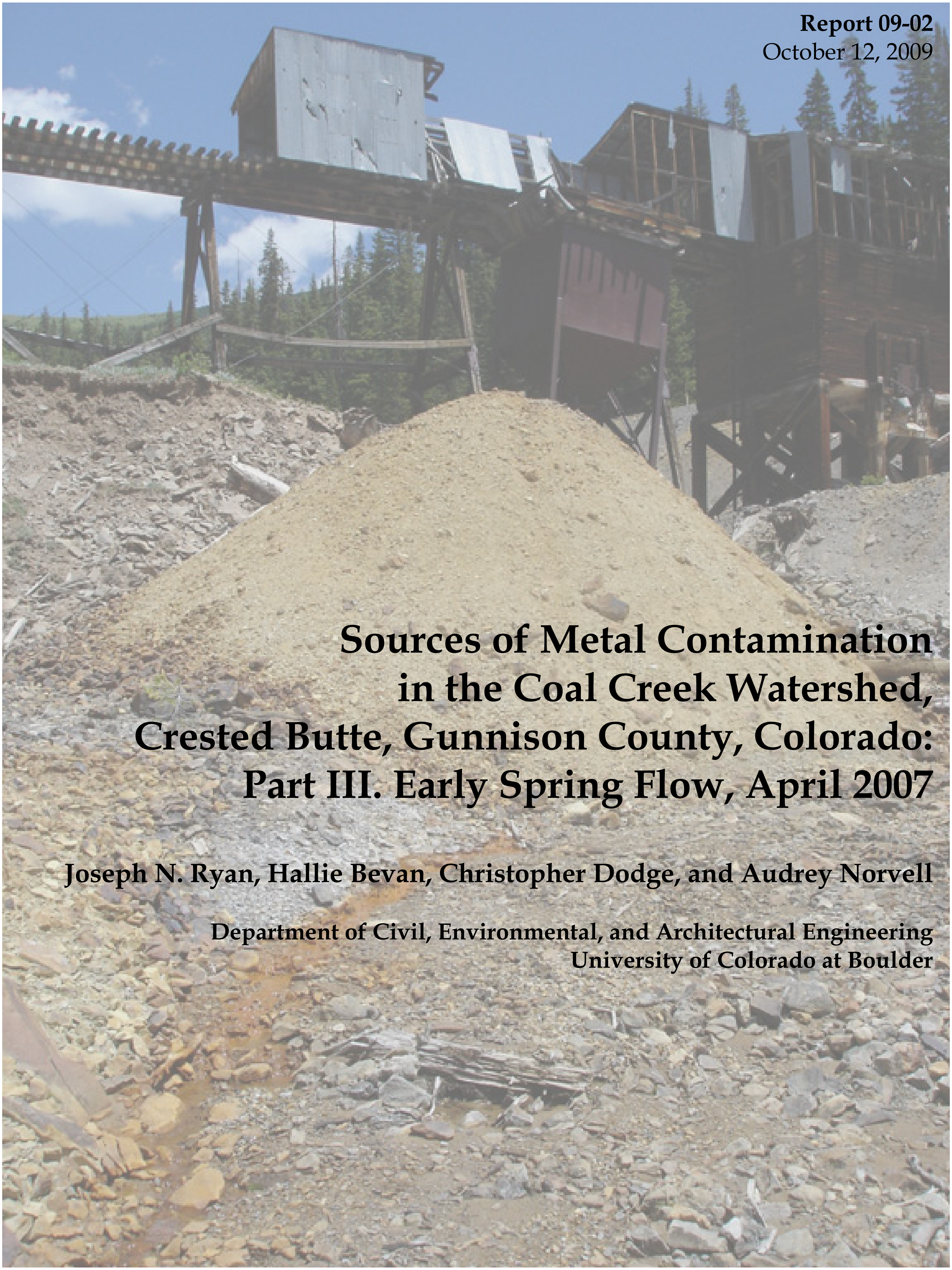
Figure 7 - Signage near Old Town Hall providing information on benthic habitats.

Table 1. Nitrate-nitrite sample results from 2009.

Site Name	Date 8/13/2009	Date 10/5/2009
IR-00	0.05	0.05
IR D/S FLUME	0.05	0.05
IR at Strat	0.05	NS
IR at Laird Road	0.05	0.05
IR D/S STRAT	0.05	0.05
IR D/S STRAT DUP	0.05	NS
IR at Road	0.05	0.05
COAL-30	0.05	0.05
COAL-30 DUP	0.05	0.05
COAL-30 FB	0.05	0.05
COAL-25	0.05	NS
SP-00	0.05	NS
COAL-20	0.05	0.05
COAL-12	0.05	0.05
COAL-06	0.05	0.05
COAL-02	0.05	0.05
COAL-01	0.05	0.05
COAL-00	0.05	0.05

Table 2. Total phosphorus sample results from 2009.

Site Name	Date 8/13/2009	Date 10/5/2009
IR-00	0.020	0.01
IR D/S FLUME	0.020	0.01
IR at Strat	0.020	NS
IR at Laird Road	0.020	0.01
IR D/S STRAT	0.020	0.01
IR at Road	0.020	0.02
COAL-30	0.020	0.01
COAL-25	0.020	NS
SP-00	0.020	NS
COAL-20	0.020	0.02
COAL-12	0.020	0.01
COAL-06	0.020	0.01
COAL-02	0.020	0.01
COAL-01	0.020	0.01
COAL-00	0.020	0.01



Report 09-02
October 12, 2009

Sources of Metal Contamination in the Coal Creek Watershed, Crested Butte, Gunnison County, Colorado: Part III. Early Spring Flow, April 2007

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EXECUTIVE SUMMARY

This report presents the results of a study conducted by University of Colorado researchers for the Coal Creek Watershed Coalition on the source of metals in the Coal Creek watershed during early spring runoff in April 2007. Coal Creek is the main water supply for the Town of Crested Butte in Gunnison County, Colorado. The study was funded by the University of Colorado's Outreach Committee and the Coal Creek Watershed Coalition.

Previous sampling has shown that Coal Creek is contaminated by metals and acidity from the Standard Mine on Elk Creek, a tributary of Coal Creek, and from a natural iron gossan and fen located just west of the Keystone Mine. Drainage from the Keystone Mine, which has been treated at the Mount Emmons treatment facility since 1981, also contributes metals to Coal Creek just downstream of Crested Butte's water supply intake. To further investigate the source of metals from the iron fen and gossan and the Keystone Mine property during a time of snow-melt and runoff in the Coal Creek watershed, a spatially detailed metal loading tracer test was performed by University of Colorado researchers in April 2007. The study was conducted during early spring flow to complement companion studies conducted at low flow in September 2005 and at high flow in June 2006.

The metal loading tracer dilution test was conducted on a 2.9 km reach of Coal Creek from just upstream of the iron fen to just downstream of the Keystone Mine property. The Coal Creek and tributary samples were analyzed for aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc. In this reach, chronic aquatic life toxicity standards were exceeded by aluminum, cadmium, copper, and zinc. Drinking water supply standards were not exceeded. The exceedances occurred over downstream of the iron fen for aluminum, downstream of the iron gossan for cadmium, downstream of the tributary carrying the Mount Emmons treatment plant effluent and drainage from the Keystone Mine property for copper, and over the entire reach for zinc.

For all of the metals exceeding the chronic aquatic life standards, the Mount Emmons treatment plant effluent was a major or minor source. For cadmium, copper, and zinc, a Keystone Mine surface drainage that combined with the treatment plant effluent to form the unnamed tributary at stream distance 5.368 km (stream distance datum was the injection point of the September 2005 metal loading tracer test) was a major or minor source. A tributary draining the iron gossan and possibly the western portion of the Keystone Mine property at 4.168 km was a minor source of aluminum and zinc. Other iron fen and gossan tributaries were trace sources for all of the metals.

Ryan J.N., Bevan H., Dodge C., and Norvell A., 2009. Sources of Metal Contamination in the Coal Creek Watershed, Crested Butte, Gunnison County, Colorado: Part III. Early Spring Flow, April 2007. Report 09-02, Department of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, Colorado, 48 pp.

ACKNOWLEDGMENTS

Funding for this project was provided by the University of Colorado Outreach Committee and the Coal Creek Watershed Coalition.

Scientific and technical assistance and field and laboratory support were provided by the following people:

- Anthony Poponi, Steve Glazer, and Tyler Martineau of the Coal Creek Watershed Coalition for providing information and field assistance,
- Larry Adams and John Hess of the Town of Crested Butte for providing information on the town's water supply system,
- Tim Dittrich and Chase Gerbig of the University of Colorado for field assistance,
- John Drexler and Fred Luiszer of the Laboratory for Environmental and Geological Studies at the University of Colorado

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Overview

The Coal Creek watershed in northern Gunnison County near Crested Butte, Colorado (Figure 1) is contaminated by acid mine drainage (Wentz, 1974; Stantec, 2005; EPA, 2005a). Acid mine drainage results when sulfide minerals such as pyrite (FeS_2) contact water and oxygen and are oxidized. The chemical processes are accelerated by the activities of microbes, and the results are high concentrations of metal ions and acidic compounds that contaminate groundwater and surface runoff. High concentrations of metals can be toxic to aquatic life and can pose health problems for humans if they contaminate drinking water sources.

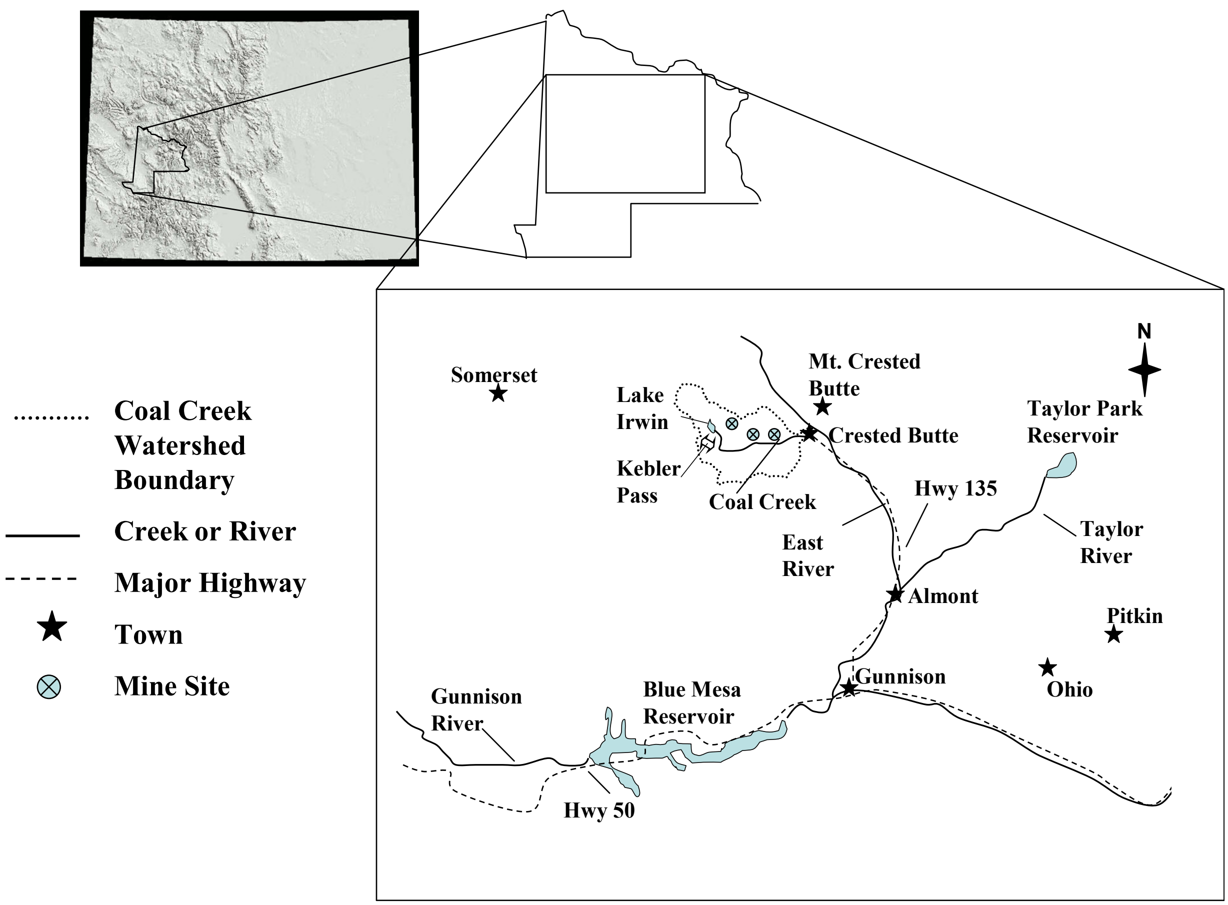

Figure 1. Maps showing the State of Colorado (upper left), Gunnison County (upper right), and the major rivers of the Gunnison-Crested Butte area. The Coal Creek watershed is outlined by the dashed line west of Crested Butte (Shanklin and Ryan, 2006).

The Coal Creek watershed is located west of the Town of Crested Butte in Gunnison County, Colorado (Figure 2). Coal Creek is the main drinking water supply for the approximately 1,500 residents of Crested Butte. The watershed area, which encompasses what was known as the Ruby Mining District, was rich in mineral resources. Hard rock mining began in this area in 1874 when the watershed belonged to the Ute Indian Reservation and continued until 1974 (EPA, 2005a). Vein deposits are contained in north-northeast-trending faults, dikes, and small stocks on the eastern faces of the Ruby Range. These veins are rich in copper, gold, lead, molybdenum, ruby, silver, and zinc (Streufert, 1999). The three largest mines were the Standard Mine, the Keystone Mine, and the Forest Queen Mine, all of which lie on the southern face of Scarp Ridge, and all of which are now inactive (EPA, 2005b). The watershed is now used primarily for residential development, recreation, and water supply.

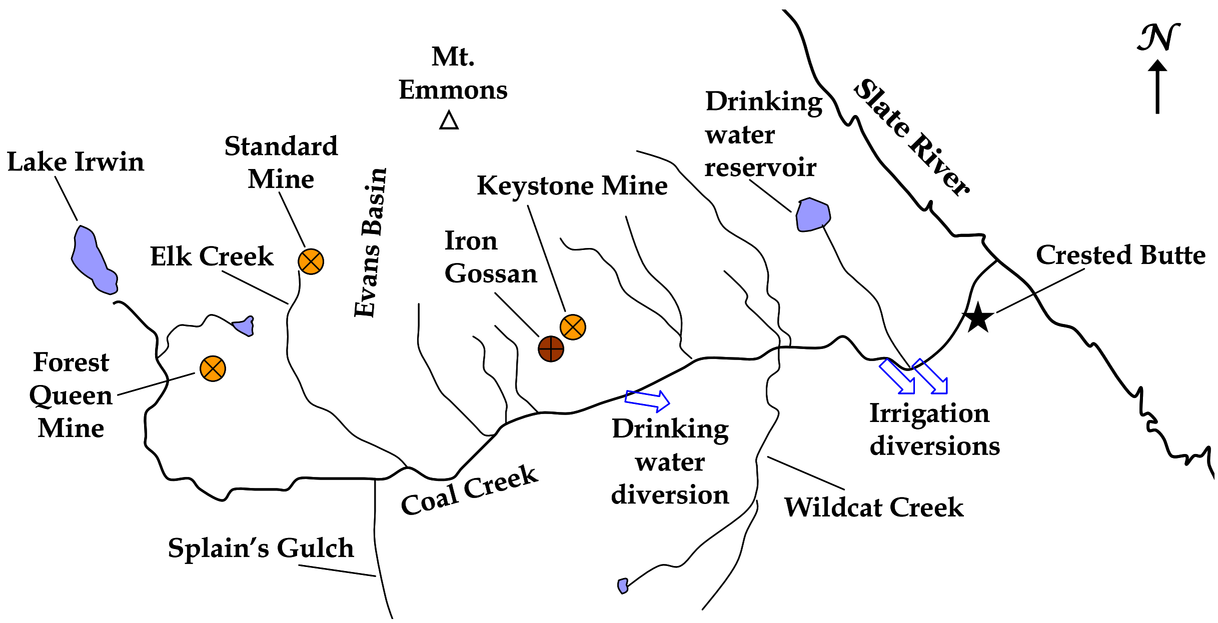

Figure 2. Key landmarks of the Coal Creek watershed, including Lake Irwin, the Forest Queen Mine, Kebler Pass, the Standard Mine, Elk Creek, Mount Emmons, the Keystone Mine, and the Town of Crested Butte (Shanklin and Ryan, 2006).

The Standard Mine, which is located 3.2 km north of Coal Creek along a tributary, Elk Creek, was added to the National Priority List ("Superfund") in September 2005. The Standard Mine was a silver mine that was in operation until 1974. Since then, heavy metals and ground and surface water flow have contaminated Elk Creek and Coal Creek. Site remediation activities by the U.S. Environmental Protection Agency (EPA) were started in the summer of 2006 and continue to the present.

Drainage from the Keystone Mine is treated at the Mount Emmons Treatment Plant and released into Coal Creek just downstream of Crested Butte's drinking water intake (Figure 3). The treatment plant was constructed in 1981 by Amax Gold, Inc., which merged into Cyprus Amax Minerals Company and was later acquired by the Phelps-Dodge Corporation. In February, 2006, Phelps-Dodge transferred ownership of property to the U.S. Energy Corporation. U.S. Energy is currently responsible for operation of the treatment plant. U.S. Energy wants to resume mining operations on

Mount Emmons to exploit a "world-class" molybdenum deposit underneath the mountain (U.S. Energy, 2009).

A naturally occurring iron-rich surface deposit, or gossan, also drains into Coal Creek (Figure 3). Drainage from the gossan is characterized by low pH and high concentrations of aluminum, iron, manganese, zinc, and other metals. The gossan drainage lingers in a wetland, locally referred to as "the iron fen." The iron fen is the home to an endangered plant species, the *Drosera rotundifolia* (USFS, 1981).

The Coal Creek Watershed Coalition (CCWC), a community group based in Crested Butte, is working to restore aquatic life habitat and protect other water uses in Coal Creek (Stantec, 2005). Recreation and tourism are currently the main contributors to the local economy. The CCWC hopes that well-directed remedial action in the Coal Creek watershed will create a sustainable fish population and promote fishing in Coal Creek.

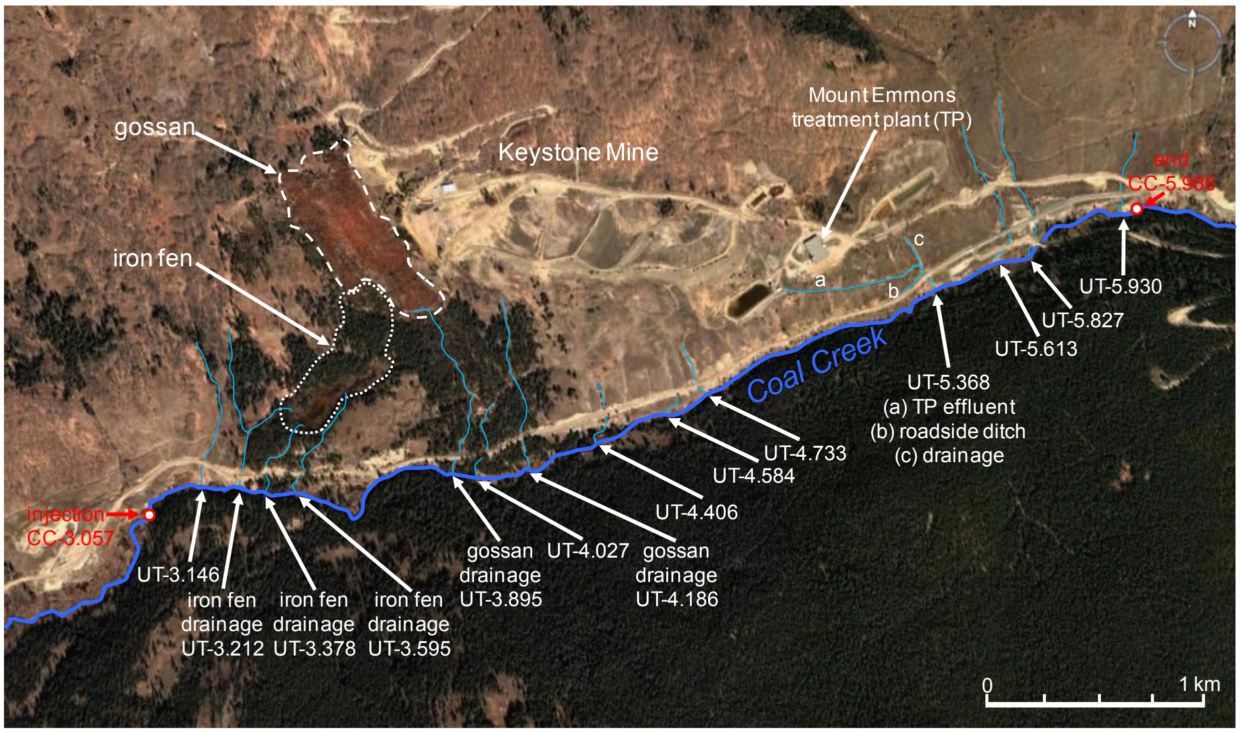

Figure 3. Aerial photograph of Coal Creek near the Keystone Mine at the base of Mount Emmons with tributaries present during the April 2007 metal loading tracer dilution test. The injection was made at a distance of 3.057 km downstream of the injection point for the September 2005 low flow test (Shanklin and Ryan, 2006). Unnamed tributaries ("UT- ") show distances from the September 2005 injection point. The path of the tributaries is approximate. Coal Creek flows from the southwest to the northeast. The aerial photo was retrieved using Google Earth™ (http://earth.google.com).

Characterization of Metal Sources

We are assisting the Coal Creek Watershed Coalition in an effort to identify the major sources of metal contamination in the watershed. To do this, a total of four metal loading tracer dilution experiments have been conducted: one 9.4 km reach at low flow (September 2005; Shanklin and Ryan, 2006), a 4.3 km reach and a 1.9 km reach at high flow (June 2006; Ryan and Bevan, 2009), and a 2.9 km reach in early spring during the start of snow melt and runoff in the lower elevations of the watershed (April, 2007; this report).

The objectives of this study were to (1) locate and quantify sources of metal input to Coal Creek at the time of the snow melt and runoff in the watershed, and (2) compare the results of the low flow and high flow studies with the results of this study to determine the effects of flow rate on the sources of metal input to Coal Creek. The metal loading tracer dilution experiment was focused on a 2.9 reach extending from just upstream of the iron gossan and fen tributaries to just downstream of the Keystone Mine property to determine if surface runoff and seepage from the iron gossan and fen and the Keystone Mine property was carrying metals to Coal Creek.

For a metal loading tracer dilution experiment (Kimball, 1997), water is pumped from the stream and mixed with a high concentration of a tracer that remains dissolved in the water (e.g., a salt like sodium bromide or lithium chloride, or a fluorescent dye like rhodamine). The tracer solution is slowly pumped back into the stream until a steady concentration of the tracer is reached over the reach of the stream being investigated. When the tracer reaches a steady concentration, a synoptic sampling is conducted to provide a "snapshot" of concentration of the tracer and contaminants. If the synoptic sampling is conducted a high spatial resolution, the source of the metal contaminants can be pin-pointed. The tracer concentrations are used to determine the stream flow rate – as tributaries without the tracer enter the stream, the tracer concentration decreases. With flow rates in units of volume per time (e.g., L s^{-1}) and metal concentrations in units of mass of metal per volume (e.g., μg L^{-1}), metal loading rates can be calculated in units of mass of metal passing the sampling point per time (e.g., kg d^{-1}; in the units used for total maximum daily load regulations, lb d^{-1}). These metal loading rates allow identification of the major sources of metal contamination in the watershed.

Coal Creek Watershed

Coal Creek is fed by snow melt and springs in the surrounding Ruby-Anthracite Range of the greater Rocky Mountains. The Coal Creek headwaters are located in the drainage southeast of Lake Irwin at an elevation just over 3,120 m. From the Lake Irwin area, Coal Creek runs eastward, is joined by Splains Gulch, Elk Creek, Wildcat Creek, and other tributaries, and continues through the Town of Crested Butte until reaching its confluence with the Slate River. The Slate River continues south to join the East River, the Gunnison River, and ultimately, the Colorado River. Running parallel to the majority of Coal Creek is County Highway 12, the Kebler Pass Road, a gravel road maintained by Gunnison County.

The watershed drainage area is approximately 22.4 km^2. The watershed elevation is highest in the 4,300 m peaks of the Ruby-Anthracite Range and lowest at 2,900 m in the Town of Crested Butte. The valley creating the Coal Creek Watershed was shaped by glacial erosion during the Pleistocene epoch. The high peaks are characterized by laccoliths, dome-shaped igneous intrusions, and sedimentary and volcanic rock formations. The valley bottom is underlain by sand and gravel deposited by glacial ice and melt water (Streufert, 1999).

Regional vegetation is predominantly boreal forest. Aspen, fir, and spruce forests dominate the lower elevations, while alpine tundra is encountered at elevations above tree line. Microclimates vary with slope angle and aspect. This is demonstrated by the longer snowfall storage on north-facing slopes, which results in higher soil moisture contents and denser forest vegetation. On the contrary, snow on south-facing slopes melts and runs off faster, resulting in drier soils, brush, and grass for vegetation (Soule, 1976).

Coal Creek Stream Flow

Stream flow is not currently recorded for Coal Creek. The annual snowfall on the top of Kebler Pass, which is located just south of Lake Irwin at an elevation of 3,042 m, is about 12.7 m. The average annual watershed precipitation is 29.7 cm.

Between the years of 1941 and 1946, daily flow measures were taken from a location just upstream of the town's water intake, which is located 3.4 km downstream from the Elk Creek Confluence. These records indicate that the average maximum daily flow is 3.31 $m^3\ s^{-1}$ and that the peak flows typically occur during the second week of June (USGS, 2006). The maximum daily flow recorded from 1941 to 1946 was 4.87 $m^3\ s^{-1}$. The minimum recorded flow was 0.030 $m^3\ s^{-1}$ during the winter months. During a sampling event, the EPA measured a flow of 2.4 $m^3\ s^{-1}$ on June 14, 2005 (EPA, 2005b).

There was one surface water diversion along the study reach of Coal Creek. This occurred at the Town of Crested Butte drinking water supply intake. Based on data provided by the Town of Crested Butte, the intake was estimated to divert water from Coal Creek at an average rate of 0.079 $m^3\ s^{-1}$ (Shanklin and Ryan, 2006).

Metal Loading Tracer Dilution Method

The tracer dilution method allows quantification of stream flow rate by monitoring dilution of a tracer as it moves downstream (Kimball, 1997). A specific concentration of tracer is injected at a constant rate to achieve steady-state conditions. This provides a known mass of tracer added to the stream. Tracer concentration is measured upstream and downstream of the injection site. Flow rate is quantified based on the dilution of the tracer by tributaries and groundwater input as it moves downstream from the injection site. The tracer dilution method accounts for flow through the hyporheic zone, or the layer of streambed sediment that rapidly exchanges water with the stream. Flow through the hyporheic zone is normally substantial for high-gradient, shallow mountain streams such as Coal Creek. Traditional current meter flow measurements for mountain streams are typically underestimates because flow through the hyporheic zone is not captured (Bencala et al., 1990).

The tracer dilution method accounts for tributaries and dispersed groundwater inputs as well as seeps or springs discharging over a large area. These non-point sources affect quantification of flow because they contribute to the dilution of the tracer;

however, the portion of flow attributable to point versus non-point sources cannot be distinguished. All downstream reductions in tracer concentration are assumed to be a result of dilution from tributary and groundwater inflow (Kimball et al., 2002). When a surface tributary is present between two sample locations, the calculated inflow rate is assigned solely to the tributary despite the possibility of groundwater inputs. When no visible tributary is present, flow rate increases are assumed to be a result of groundwater inflow. Again, the tracer dilution method is unable to distinguish between tributary and groundwater inflow if both occur between two synoptic sample sites. The method only accounts for the total inflow between two sample sites. The method also cannot specifically identify points where stream flow rates decrease from losses to groundwater. Only losses over an entire reach between two sample sites can be determined.

The tracer-injection method requires the tracer to be inert and transported downstream in a conservative fashion, unaffected by biogeochemical reactions. The injection must continue until all parts of the stream including the hyporheic zone and all surface storage zones become saturated with tracer. Under these saturation conditions, the in-stream tracer concentration is said to be at a steady-state, or plateau, concentration (Bencala et al., 1990). When the tracer concentration reaches a steady state, a synoptic sampling is conducted. A synoptic sampling is a spatially detailed sampling of stream sites and all tributary inflows to provide a "snapshot" of stream and tributary chemistry (Kimball, 1997). The "snapshot" is not actually instantaneous – sampling may actually occur over a period of several hours – but during the sampling, the tracer and metal concentrations are assumed to be at steady state. A sample site spacing of hundreds of meters is recommended for practical analysis of stream chemistry (Bencala et al., 1990). Synoptic sample sites are intended to bracket all tributary inflows. This allows for understanding and quantifying the impacts of many individual sources on the watershed as a whole.

MATERIALS AND METHODS

Injection and Synoptic Sampling Sites

On April 8, 2007, we conducted a metal loading tracer dilution test over a 2.9 km reach in Coal Creek from upstream of the iron gossan and fen drainages to downstream of the Keystone Mine. The injection site was located at a distance of 3.073 km downstream of the September 2005 injection site, which we used as a point of reference for the later tests. The downstream end of the reach was at a distance of 6.014 km downstream of the September 2005 injection site. The distance of the test reach was 2.941 km. The tributaries at which water samples were collected during the synoptic sampling are shown in Figure 3.

Sample sites in Coal Creek were generally located every 200 m or less. A sample site was established in every tributary and in the creek downstream of every tributary discovered during a walking survey of the creek. Sampling sites downstream of the tributaries were usually located within 50-100 m of the tributary unless another tributary downstream required closer placement. There were 44 sampling sites, 30 in Coal Creek and 14 in tributaries.

The latitude and longitude of each sampling site was measured using a global positioning system (GPS) receiver (Garmin GPS12). Photographs of the tributaries and prominent landmarks were taken. The GPS points were transposed onto a topographic map and relabeled with distances downstream of the upstream site used by the September 2005 study (Shanklin and Ryan, 2006). All sample sites along Coal Creek were designated "CC- " and labeled with the appropriate distance. Sample sites at unnamed tributaries were labeled "UT- ".

Injection Procedure

The tracer used in this study was sodium bromide (NaBr). The previous tracer tests were conducted with lithium chloride (September 2005, low flow; Shanklin and Ryan, 2006) and sodium chloride (June 2006, high flow; Ryan and Bevan, 2009). Lithium was an unreliable tracer because it was attenuated in wetlands near Coal Creek. Chloride was used to determine flow rate in the September 2005 and June 2006 tests. It was a marginally suitable tracer because we could not add it at sufficiently high concentration to exceed background chloride concentrations in some of the tributaries. In this April 2007 early spring runoff test, bromide was an effective tracer – it was transported conservatively and we were able to inject it at concentrations well above background concentrations in the stream and tributaries.

To prepare the tracer solution, 1,135 L (about 300 gallons) of stream water was pumped from Coal Creek into a polyethylene tank using a garden hose and gasoline-powered water pump on the day before the injection. Sodium bromide (234 kg; 520 pounds; Ameribrom, Inc., Fort Lee, NJ) was added to the stream water to create a bromide solution of 2.0 M concentration, stirred using a paddle, and left in the tank overnight to dissolve. On the day of the injection, April 8, 2007, the tracer solution was continuously injected into Coal Creek using a piston-driven metering pump (Fluid Metering, Inc.; QV pump; QCKC pump head with ceramic and polyvinylidene difluoride parts; V200 stroke rate controller) and Tygon® tubing (Fisherbrand, 12.7 mm inside diameter). The injection began at 8:00 and continued for 7.5 h. Injection flow rates were determined by measuring the amount of time needed to fill a 500 mL graduated cylinder with the injectate. The time-weighted average flow rate of the injection was 2.24 L min^{-1} with a range of 2.20 L min^{-1} to 2.30 L min^{-1}. The tank was stirred with a paddle every 15-30 min. The injection setup is shown in Figure 4 and the injection details are recorded in Table 1. A rented snowmobile and sled were used to transport the injection equipment along County Road 12 over the snow-covered portions of the road.

Figure 4. The injection setup at CC-3.085 for the metal loading tracer dilution test on April 8, 2007. From left to right, the tube delivering the injection solution to Coal Creek, the generator that powered the injection pump (in the background), the injection pump in the open container, and the 330 gallon injection tank (dark green, right foreground).

The weather on the day of the injection was recorded as varying from overcast to light rain to snow flurries with an estimated temperature of 1-4°C. No accumulation of snowfall occurred during the injection. The north-facing south bank of Coal Creek was entirely covered by snow, and the south-facing north bank was about 20% covered by snow. At 1-5 °C, it was unlikely that much, if any, melting snow was added to the tributaries, but tributary flow was fed by warmer temperatures of the previous week (average high of 15.6°C with mostly clear skies during the days).

Water Sampling Procedures

At the upstream end of the injection reaches, samples were taken from the injection tubing and from Coal Creek upstream of the injection. Samples were collected on the half-hour from the injection tubing in 60 mL high-density polyethylene Nalgene bottles to monitor the consistency of the injection chloride concentration. "Background" samples were collected nearly hourly from the sites CC-3.503 located just upstream of the injection sites in 250 mL samples high-density polyethylene Nalgene bottles to monitor changes in upstream chloride concentration. Specific conductance was measured at the end of the injection tubing and in the injection tank at various times throughout the injection periods using a Thermo Orion 105A+ meter and Orion 010510 conductivity cell calibrated with Traceable One-Shot™ 1409 µS cm^{-1} conductivity calibration standard.

Table 1. Record of injection for metal loading tracer test in Coal Creek on April 8, 2007.

clock time	experiment time (h)	flow rate (L min^{-1})	conductivity (mS cm^{-1})	activity
8:00	0.00	2.20	189.0	Started injection at CC-3.057
8:30	0.50	2.24	190.3	
9:00	1.00	2.20	181.9	
9:15	1.25			Flow interruption for three minutes caused by tripped circuit breaker on generator; changed injection pump
9:18	1.30	2.22		Flow resumed
9:40	1.67	2.20	179.0	
10:00	2.00	2.30	177.9	
10:30	2.50	2.30	175.9	
11:00	3.00	2.30	185.0 (top) 187.0 (bottom)	Conductivity measurements made at top and bottom of injection tank
11:30	3.50	2.22		Conductivity meter read over maximum; replaced electrode
12:00	4.00	2.20	176.2	
12:30	4.50	2.28	176.4 (before stirring) 177.8 (after stirring)	Conductivity measured in tank before and after stirring
12:45	4.75			Debris removed from pump line; no flow interruption
13:00	5.00	2.20	177.3	
13:15	5.25			Synoptic sampling begins from upstream and downstream ends
13:30	5.50	2.22	178.0	Ended sampling of upstream (background) sampling point
14:00	6.00	2.20	175.3	
14:30	6.50	2.24	174.4	
15:00	7.00	2.20	175.1	
15:30	7.50	2.28	172.9	Synoptic sampling completed; injection ended

At the downstream end of the injection reaches, samples were collected every 15 min from site CC-5.986 in 60 mL high-density polyethylene Nalgene bottles. The conductivity and bromide concentrations of these samples were measured in the field to track the arrival of the tracer and determine the proper time to start the synoptic sampling. A Thermo Orion 250A+ or 290A+ meter and Orion 9435BN bromide electrode with an Orion 900200 double-junction reference electrode were used to measure the bromide concentrations. The electrode was calibrated with sodium bromide standards. The standards were equilibrated to the temperature of the stream water (about 2 °C).

When the bromide concentration reached a plateau at the downstream end of the injection reach, synoptic sampling of the reach was begun. Synoptic sampling lasted two hours. Two teams of two people carried out the sampling from the downstream and upstream ends of the reach. Two water samples were collected from each synoptic sample site in 250 mL high-density polyethylene Nalgene bottles. Accumulation of snow over the creek made sampling challenging. Samples were obtained by wading in the stream from the downstream end and by using a pole from the upstream end (Figures 5 and 6).

Figure 5. University of Colorado undergraduate research assistant Hallie Bevan samples Coal Creek from the downstream end during the April 8, 2007, synoptic sampling using snow shoes and chest waders.

Figure 6. University of Colorado graduate research assistant Tim Dittrich samples Coal Creek from the upstream end during the April 8, 2007 synoptic sampling using snow shoes and a pole to extend the sample bottle into the stream without collapsing the snow accumulated on the north bank.

Sampling of the tributaries was often complicated by dispersal of flow from culverts under County Road 12 and snow cover. As observed during the previous metal loading tracer dilution tests, seepage from north bank slopes flows into road-side ditches and through culverts under the road. Water flowing out of the culverts flows to Coal Creek in clear channels in some cases (Figure 7), but in other cases, flows from the culverts is low and no clear channel to the creek is present (Figure 8). Where no clear tributary channel was present near Coal Creek, the tributary sample was collected from the culvert opening. In some cases, tributaries from culverts spread out as broad sheet flows over saturated soil and peat (Figure 9) or as marshy pools near the creek (Figure 10); these tributaries were also sampled at the culvert opening. The tributary samples collected at the culvert openings may not accurately reflect the concentration of metals reaching Coal Creek because contact with soils and peat may remove some metals; however, it is likely that these soils and peat are saturated with metals and removal of metals is negligible.

All samples were collected after rinsing the sample bottles and lids three times in the waters being sampled. The rinse water was discarded downstream of the sample site, and then the sample bottle was filled. Bottles were labeled with date, time, sample location name, and the name of the sampler. Samples were stored in coolers on ice to preserve them in the field.

Figure 7. Unnamed tributary UT-3.212, the first and main iron fen tributary, followed a clear channel from the culvert under County Road 12 to Coal Creek; the sample was taken at the location of the orange flag within about 2 m of the creek's north bank.

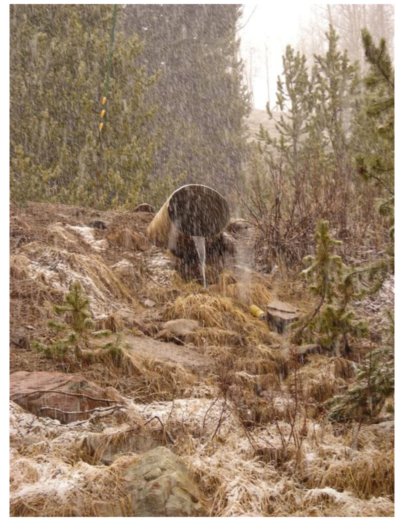

Figure 8. Unnamed tributary UT-3.595, the second iron fen tributary, did not follow a clear channel from the culvert to the Coal Creek; therefore, the sample was taken at the culvert opening.

Field Laboratory Procedures

For each synoptic sample site, portions of one of the two 250 mL samples were tested for pH and specific conductance, filtered, and acidified, and the other 250 mL sample was set aside as a "backup." The pH was measured using a Thermo Orion 250A+ or 290A+ meter and Thermo 91-57BN electrode. The meter and triode were calibrated with pH 4 and 7 buffers with an ambient room temperature of approximately 20 °C. The pH measurements were made after the water reached room temperature. Specific conductance was measured with an Orion 105A+ meter and Orion 010510 Conductivity Cell calibrated with a Traceable One-Shot™ conductivity calibration standard (1409 µS cm^{-1}) at room temperature.

Following pH and specific conductance measurement, the sample was divided into two 60 mL samples. One of the two 60 mL samples was filtered using a syringe (30 mL BD Luer-Lok syringes) and a membrane filter

Figure 9. Unnamed tributary UT-3.895, which drains the iron fen and gossan, flows from a culvert as a thin sheet over saturated soil and peat down to Coal Creek. This tributary was sampled at the culvert under the road. Graduate research assistant Chase Gerbig collected samples while negotiating the terrain on snow shoes.

(Fisherbrand nylon, 0.45 µm pore diameter, 25 mm diameter) for determination of dissolved bromide (total bromine) and major cations and metals by inductively coupled plasma-atomic emission spectroscopy (ICP-AES) and inductively coupled plasma-mass spectrometry (ICP-MS). The second 60 mL sample was not filtered for measurement of total major cations and metals by ICP-AES and ICP-MS. The dissolved and total major cation and metal samples were acidified to pH < 2 by adding 1 mL of concentrated nitric acid (Fisher Chemical, trace metal-grade). The pH and specific conductivity measurements, filtration, and acidification were conducted in a field laboratory within 24 h of collecting the samples.

Figure 10. Marshy pool at the confluence of unnamed tributary UT-4.186, which drains the iron gossan, and Coal Creek. The tributary sample was taken at the culvert under County Road 12.

For every tenth sample, the "backup" sample was processed as described above to provide duplicate samples for ICP-AES and ICP-MS measurements. After every twenty samples, a blank sample (high purity water, Millipore, Milli-Q, >18 Mohm resistivity) was processed for bromide and dissolved and total major cations and metals. All lab personnel wore gloves during the pH, specific conductance, filtration, and acidification processes. The acidified major cation and metal samples were stored at room temperature until analysis.

The 60 mL injection tank and downstream end samples as well as the 250 mL upstream samples were also filtered and acidified for measurement of bromide by ICP-MS. No cation or metals measurements were made for these samples.

Analytical Procedures

Calcium, iron, and magnesium were measured by ICP-AES (Applied Research Laboratories ARL 3410+) in the Laboratory for Environmental and Geological Studies (LEGS) at University of Colorado at Boulder. Three standards and blanks (high-purity water) were run between every ten samples. A 2% nitric acid (trace metal-grade) solution was run through the system for 10 s between each sample. The detection limits for ICP-AES were similar to those presented by Ryan and Bevan (2009) for the June 2006 metal loading tracer dilution tests.

Bromide and aluminum, arsenic, barium, cadmium, chromium, copper, lead, manganese, nickel, and zinc, were measured by ICP-MS (PerkinElmer SCIEX Elan DRC-e) in the Laboratory for Environmental and Geological Studies (LEGS) at University of Colorado at Boulder. Four standards were used to calibrate the ICP-MS. A blank (high-purity water) and a 100 µg L^{-1} standard were run between every ten samples. Each sample was spiked (1:9) with an internal standard consisting of 160 µg L^{-1} of gallium, scandium, and indium and 80 µg L^{-1} bismuth in 2% nitric acid (trace metal-grade). A 2% nitric acid (trace metal-grade) solution was run through the system for 10 s between each sample. The detection limits for ICP-MS were similar to those presented by Ryan and Bevan (2009) for the June 2006 metal loading tracer dilution tests.

Flow Rate Calculations

The tracer dilution method assumes conservation of mass between upstream and downstream sample locations (Kimball, 1997; Kimball et al., 2002). Conservation of mass requires that flow or mass at a downstream sample location is equal to flow or mass at an upstream sample location plus the flow or mass entering the stream at the injection site. Steady-state conditions dependent upon a constant injection tracer concentration and a constant tracer injection rate are assumed. The equations used for determining flow are presented in Table 2.

Table 2. Equations used to calculate flow rates and mass loading rates (Kimball et al., 2002) for the Coal Creek tracer dilution study.

Calculated Variable	Equations		Variable Definition
Mass balance down-stream from injection site	$M_{down} = Q_{down}C_{down}$ $M_{down} = Q_{up}C_{up} + Q_{inj}C_{inj}$ $Q_{down} = Q_{up} + Q_{inj}$	(1) (2) (3)	C_{up}, tracer concentration upstream of injection site C_{down}, tracer concentration down-stream of injection site C_{inj}, injectate tracer concentration M_{down}, mass loading rate downstream of injection site Q_{up}, flow rate upstream of injection site Q_{down}, flow rate downstream of injection site Q_{inj}, injection flow rate
Flow rate at first site downstream of injection site with uniform background concentration	$Q_{down} = Q_{inj}\dfrac{C_{inj} - C_{up}}{C_{down} - C_{up}}$	(4)	
Flow rate at subsequent downstream sites with uniform background concentration and upstream surface inflow contribution	$Q_{down} = Q_{up}\dfrac{C_{up} - C_{in}}{C_{down} - C_{in}}$	(5)	C_{down}, tracer concentration at downstream site C_{up}, tracer concentration at upstream site C_{in}, tracer concentration of inflow Q_{up}, flow rate at upstream site Q_{down}, flow rate at downstream site
Metal loading rates	$M_i = Q_iC_i$	(6)	M_i, metal loading rate of site *i* Q_i, flow rate of site *i* C_i, metal concentration of site *i*
Tributary loading contribution	$tributary\ load\ (\%) = \dfrac{load_i}{\sum_i load} \times 100$	(7)	$load_i$ (kg d^{-1}), loading rate at a specific tributary $\sum load$, cumulative total of all tributary inputs (kg d^{-1})

All inflow between two sites bracketing a visible tributary was assumed to be due to tributary inflow. This may not actually be the case, however, because the tracer dilution method quantifies flow from point sources as well as flow from distributed groundwater input, springs, or seeps discharging over a large area. The fraction of flow input attributable to dispersed sources cannot be quantified using tracer dilution. Tributary flow rates were calculated as the difference between flow at the sample location upstream of the tributary and flow at the sample location downstream of the tributary.

Metal Loading Calculations

Stream flow rate and metal concentration at each synoptic sample site were multiplied to obtain a metal loading rate (kg d^{-1}) for each site (Equation 6). These metal loading rates produce a metal loading profile for the length of the study reach. The load at the downstream end of a stream reach is equal to the load at the upstream end plus load contributions from all sources between the ends of the reach. The load is used to identify metal sources within the watershed. Increases in the metal load between sites indicate a metal source. Metal load decreases indicate a net loss of dissolved metal resulting from precipitation, sorption, or chemical reactions. The downstream load minus the upstream load between two sites is defined as the net load change.

The cumulative load is the sum of the positive load changes for the entire study reach, including both the upper and lower Coal Creek tributaries. The cumulative load is held constant for a negative load change between sites. The cumulative load approximates the minimum possible metal load contributed to the stream (Kimball et al., 2002). The tributary loading contribution (Equation 7) is the percentage of the cumulative metal loading for each metal. The calculation of tributary loading contributions allows the prioritization of major sources of metal contamination.

Hardness and Water Quality Standards

All surface waters in the State of Colorado must meet physical and chemical water quality requirements set by the Colorado Department of Public Health and Environment (CDPHE). Coal Creek is classified as a "Class 1 – Cold Water Aquatic Life" stream because the summer water temperature does not often exceed 20 °C and as a "Domestic Water Supply" because Coal Creek supplies the Town of Crested Butte's drinking water. As such, Coal Creek must meet all requirements put forth by the CDPHE for these stream types. For protection of aquatic life, CDPHE gives chronic and acute toxicity limits for metals. The chronic standard is defined as the concentration limit that protects 95% of the genera from the chronic toxic effects of metals. Acute toxicity is defined as the concentration limit that protects 95% of the genera from the lethal affects of metals. Standard exceedances should not occur more than once every three years on average (CDPHE, 2008).

Many of the CDPHE metal standards are based on hardness measured in units of milligrams of calcium carbonate per liter (mg $CaCO_3$ L^{-1}). Hardness was calculated as the sum of the dissolved calcium and magnesium ion concentrations:

$$Hardness\left(\mathrm{mg\,CaCO_3\,L^{-1}}\right)=50{,}050\times\left(\left[\mathrm{Ca}\right]+\left[\mathrm{Mg}\right]\right) \tag{8}$$

where [Ca] and [Mg] are the dissolved concentrations of the calcium and magnesium ions in units of equivalents per liter (eq L^{-1}).

Using the calcium and magnesium concentrations measured for each synoptic sample site, a hardness profile for the entire length of the stream was calculated. The standard and acute toxicity limits calculated as a function of hardness were compared to the measured dissolved metal concentrations along Coal Creek for cadmium, copper, lead, manganese, and zinc (Table 3). There are two acute toxicity standards given for cadmium, with one specifically pertaining to trout. The chronic toxicity standard for cadmium applies to all aquatic life. Parameters that are not hardness-based included pH and the acute and chronic toxicity standards for aluminum, barium, chromium(VI), and iron. The non-hardness based toxicity standards were also compared to the measured metal concentrations along Coal Creek when possible. The CDPHE does not provide toxicity standard information for barium.

Table 3. Hardness-based equations for calculating acute and chronic aquatic life toxicity standards (CDPHE, 2008).

Metal	Acute Aquatic Life Toxicity Standard (μg L^{-1})
Cadmium	$(1.136672-[\ln(hardness)\times 0.041838])\times e^{0.9151[\ln(hardness)]-3.1485}$
(trout)	$(1.136672-[\ln(hardness)\times 0.041838])\times e^{0.9151[\ln(hardness)]-3.6236}$
Copper	$e^{0.9422[\ln(hardness)]-1.7408}$
Lead	$(1.46203-[\ln(hardness)\times 0.145712])\times e^{1.273[\ln(hardness)]-1.46}$
Manganese	$e^{0.3331[\ln(hardness)]+6.4676}$
Nickel	$e^{(0.846[\ln(hardness)]+2.253)}$
Zinc	$0.978\times e^{0.8525[\ln(hardness)]+1.0617}$
Metal	**Chronic Aquatic Life Toxicity Standard (μg L^{-1})**
Cadmium	$(1.101672-[\ln(hardness)\times 0.041838])\times e^{0.7998[\ln(hardness)]-4.4451}$
Copper	$e^{0.8545[\ln(hardness)]-1.7428}$
Lead	$(1.46203-[\ln(hardness)\times 0.145712])\times e^{1.273[\ln(hardness)]-4.705}$
Manganese	$e^{0.3331[\ln(hardness)]+5.8743}$
Nickel	$e^{(0.846[\ln(hardness)]+0.0554)}$
Zinc	$0.986\times e^{0.8525[\ln(hardness)]+0.9109}$

The Mount Emmons treatment plant adds lime (CaO) to raise the pH of Keystone Mine drainage to between 10 and 10.5 to precipitate and remove cadmium and manganese (other metals are effectively removed at lower pH values). The addition of calcium results in a significant increase in the hardness of Coal Creek downstream of the treatment plant effluent, which enters Coal Creek as part of UT-5.368. The increase in hardness increases the CDPHE hardness-based aquatic life standards. Competition between calcium and other metals for binding sites on colloids is expected to reduce the toxicity of metals to aquatic life.

RESULTS

Metal Loading Tracer Dilution Test

The results of a metal loading tracer dilution tests conducted over a 2.9 km reach of Coal Creek in April 2007 are presented in this section. The test measured metal loading rates during the early spring runoff in the area of iron gossan and fen and the Keystone Mine property. These results can be compared to similar metal loading tracer dilution tests conducted during low flow in September 2005 (Shanklin and Ryan, 2006) and during high flow in June 2006 (Ryan and Bevan, 2009).

All distances presented in the following results were measured in units of kilometers from the injection site used for the September 2005 metal loading tracer test (Shanklin and Ryan, 2006). The September 2005 injection point was used at the point of reference to allow easy comparison of tributary metal loads between the tests at different flow. All distances are presented to the nearest 1 m (0.001 km) to facilitate a clear downstream order; however, the actual distance precision is estimated at 50 m (0.050 km) because the latitude and longitude of the sampling sites was measured with a global position system (GPS) instrument of relatively low precision.

Tracer Dilution, Bromide Concentrations, and Flow Rate in Coal Creek

Bromide concentration in Coal Creek upstream of the injection. The bromide concentration in Coal Creek at sampling site CC-3.025 about 30 m upstream of the injection ranged from below the detection limit (5.0×10^{-7} M) to 6.7×10^{-6} M. The average bromide concentration used for the flow calculations was 2.0×10^{-6} M for which the bromide concentrations measured below the detection limit were calculated with values of the detection limit.

Bromide concentration in injection solution. The average bromide concentration for the upper Coal Creek tracer injection ranged from 1.77 M to 2.40 M (Figure 11). Over the entire injection period, the average bromide concentration was 2.08 M. Because the bromide concentration decreased to a new plateau at 11:00 and because the bromide in Coal Creek during the synoptic sampling was injected after 11:00, the average bromide concentration used for the flow calculations was calculated to be 1.94 M using only the bromide concentrations measured at 11:00 and later.

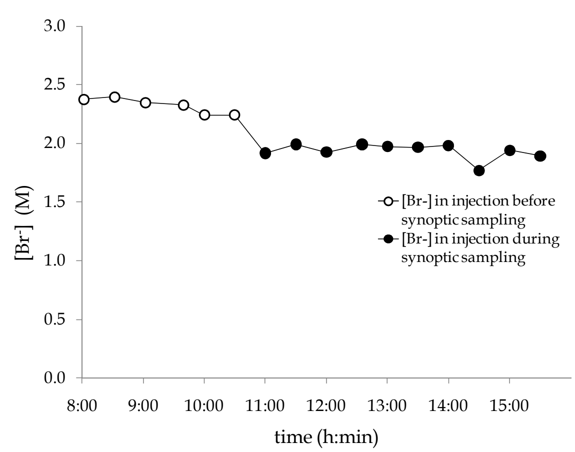

Figure 11. Concentration of bromide in injection solution as a function of time during the metal loading tracer dilution test in Coal Creek in April 2007. The bromide concentrations represented by the filled circles were used to calculate the average bromide concentration for the injection.

Bromide concentration at downstream end of the reach. At the downstream end of the Coal Creek reach at CC-5.986, the bromide concentration ranged from

26 μM to 160 μM (Figure 12). Bromide concentration increased to a plateau of about 120 μM at about 10:30, which indicated that the bromide in the injection solution reached the downstream end of the reach. To be sure that a steady-state bromide concentration was reached, the synoptic sampling was not commenced until 13:15.

Bromide concentration in Coal Creek and the tributaries. The injection of the bromide solution initially increased the concentration of bromide in Coal Creek by a factor of 114, from the average background concentration of 2×10^{-6} M at CC-3.025 to 2.27×10^{-4} M at CC-3.147, the first downstream sampling site following the injection in Coal Creek (Figure 13). Downstream of the injection, the concentration of bromide in Coal Creek was at least about 50 times greater than the concentration of bromide in the tributaries. Problems encountered using chloride as a tracer in Coal Creek (Shanklin and Ryan, 2006; Ryan and Bevan, 2009) were not encountered with bromide.

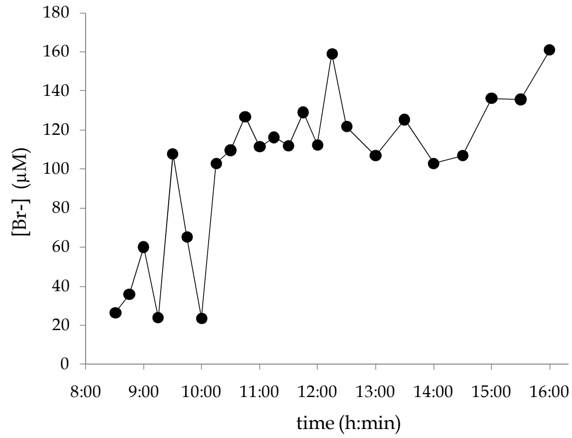

Figure 12. Bromide concentration at the downstream end of the Coal Creek reach (CC-5.986) as a function of time during the metal loading tracer dilution test in April 2007. Synoptic sampling commenced at 13:15.

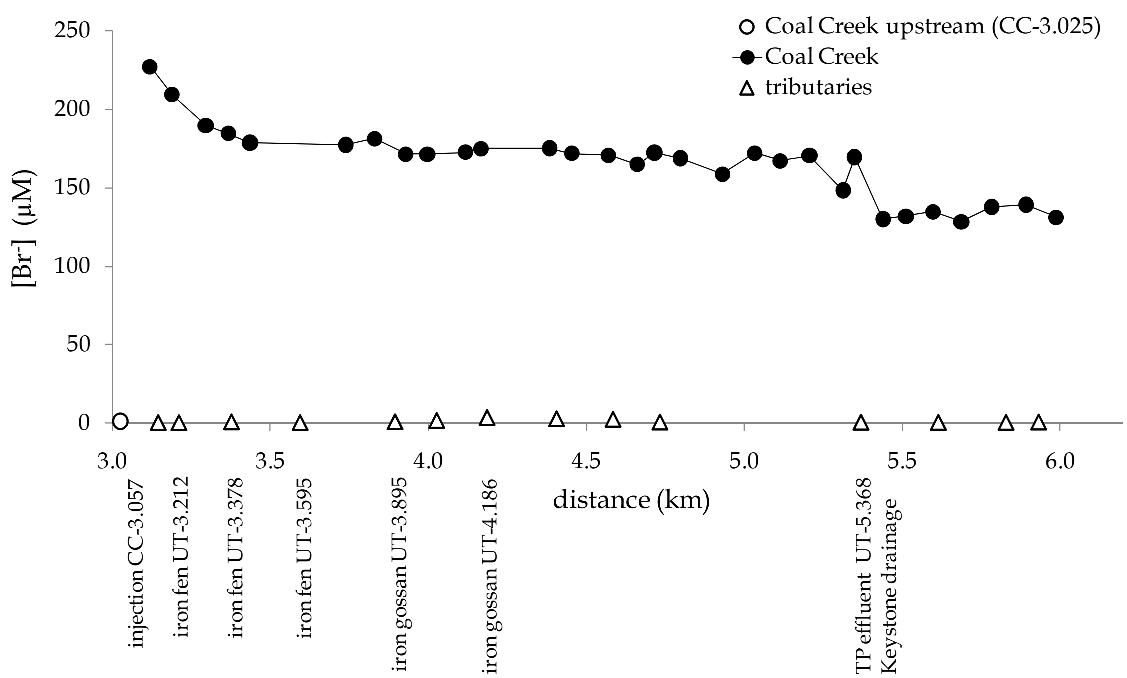

Figure 13. Bromide concentration in Coal Creek and its tributaries as a function of distance downstream during the metal loading tracer dilution test in April 2007.

Flow rate in Coal Creek. Flow rates in Coal Creek were calculated using the bromide concentrations measured during the synoptic sampling (Table 4). One manual adjustment to the flow rate had to be made for the Town of Crested Butte's drinking water intake located at 5.296 km. The drinking water intake flow was estimated at 79 L s^{-1} based on communications with the Town of Crested Butte. This diverted flow was subtracted from the Coal Creek flow rate.

Corresponding with the decrease in bromide concentration with distance, flow rate in Coal Creek increased with distance (Figure 14). Some of the flow decreases may be attributed to uncertainty in the measurement of the bromide concentrations. At the upstream end of the reach, the flow rate was 320 L s^{-1}. At the downstream end (CC-5.986), the flow rate was 560 L s^{-1} (0.56 m^3 s^{-1}, or 20 ft^3 s^{-1}). These flow rates are about one-third of the flow rates measured for this reach at high flow in June 2006. Tributary flows ranged from 0.2 L s^{-1} to 131 L s^{-1}. The maximum tributary flow rate was measured in the Mount Emmons treatment plant effluent. Tributary UT-5.368 received water from three drainages: (1) the effluent from the Mount Emmons treatment plant, (2) a roadside ditch that flows along County Road 12 from the west, and (3) a channel draining Keystone Mine property to the north.

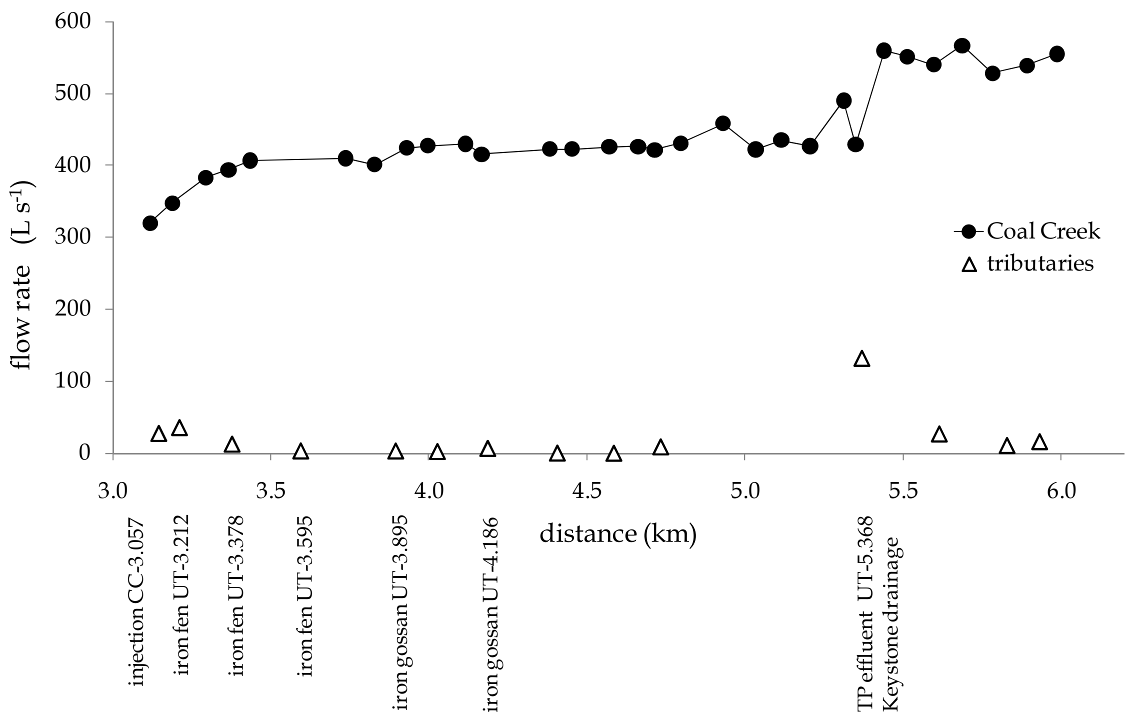

Figure 14. Flow rate in Coal Creek and its tributaries during the metal loading tracer dilution test in April 2007. Flow rates were calculated based on the dilution of the bromide tracer with distance downstream of the injection sites.

Table 4. Coal Creek flow rates at sample sites and tributaries during the metal loading tracer dilution test in April 2007. Site names are "CC- " for samples from Coal Creek and "UT- " for samples from unnamed tributaries.

site name	site description / details	Coal Creek flow rate (L s^{-1})	tributary flow rate (L s^{-1})
CC-0.000	September 2005 study upstream sample site		
CC-3.057	April 2007 injection site		
CC-3.119		320	
UT-3.146	tributary draining area west of iron fen		28
CC-3.189		347	
UT-3.212	first iron fen tributary		36
CC-3.296		383	
CC-3.367		394	
UT-3.378	second iron fen tributary		13
CC-3.435		407	
UT-3.595	third iron fen tributary		3.4
CC-3.738		410	
CC-3.829		401	
CC-3.875		424	
UT-3.895	first iron gossan tributary		3.4
CC-3.997		427	
UT-4.027	tributary draining area south of iron gossan		2.6
CC-4.117		430	
CC-4.167		415	
UT-4.186	second iron gossan tributary		6.9
CC-4.383		422	
UT-4.406	Keystone Mine drainage		0.5
CC-4.453		423	
CC-4.570		426	
UT-4.584	seepage from north bank of creek		0.2
CC-4.662		441	
CC-4.715		422	
UT-4.733	Keystone Mine drainage		8.9
CC-4.797		431	
CC-4.930		458	
CC-5.033		422	
CC-5.114		435	
CC-5.206		427	
CC-5.312		490	
CC-5.349		429	
UT-5.368	Tributary made up by (a) Mount Emmons treatment plant effluent, (b) a roadside ditch, (c) a tributary draining the Keystone Mine property		131
CC-5.439		560	
CC-5.511		551	
CC-5.597		540	
UT-5.613	Keystone Mine drainage		27
CC-5.687		567	
CC-5.782		528	
UT-5.827	Keystone Mine drainage		11
CC-5.891		539	
UT-5.930	Keystone Mine drainage		16
CC-5.986		555	

pH and Hardness in Coal Creek

pH in Coal Creek. The pH in Coal Creek steadily increased from 5.9 to 6.5 over the distance downstream during the April 2007 metal loading tracer dilution test (Figure 15). Just upstream of the Town of Crested Butte's drinking water intake at CC-5.114, the pH was measured as 6.4, which falls within the domestic drinking water supply pH range of 5.0 to 9.0 set by the Colorado Department of Public Health and Environment. The pH range established for cold water aquatic life is 6.5 to 9.0 (CDPHE, 2008). Only the downstream end of the reach sampled during this metal loading tracer dilution test meets this standard, and most of the tributaries are in violation of this standard.

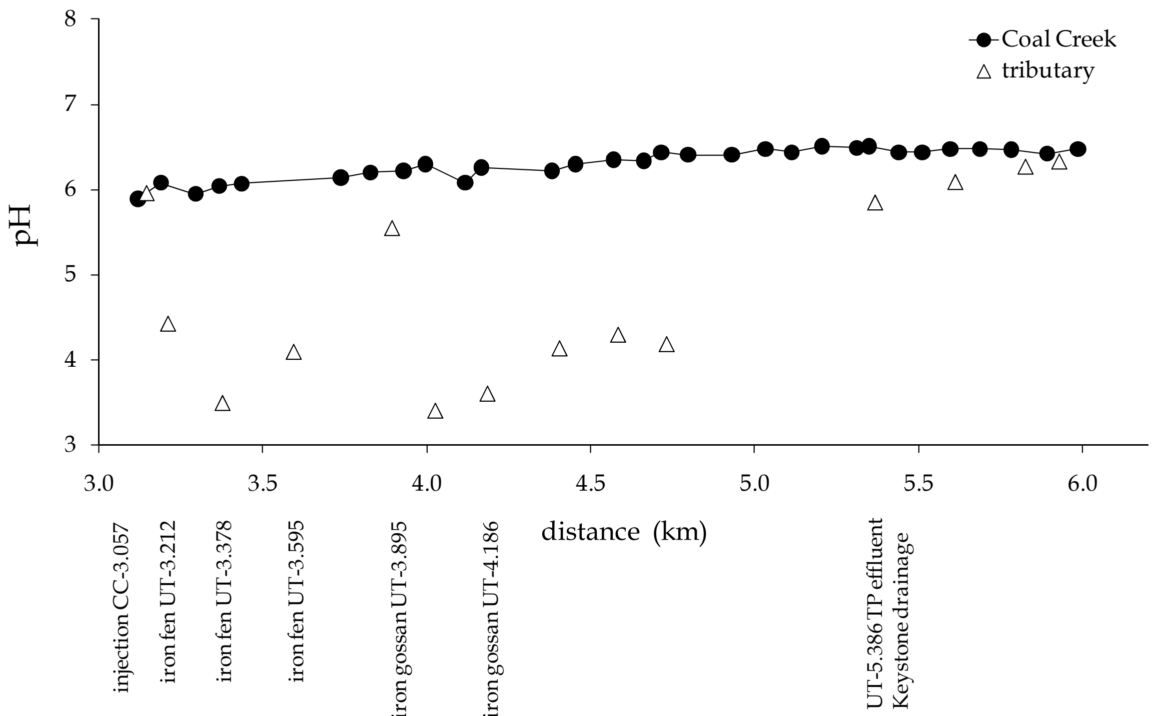

Figure 15. Coal Creek and tributary pH during the metal loading tracer dilution test in April 2007.

Calcium, magnesium, and hardness in Coal Creek. The concentration of calcium averaged about 10 mg L^{-1} from the upstream end of the reach to the Mount Emmons treatment plant effluent. The addition of the treatment plant effluent (98 mg L^{-1} total calcium) increased the concentration of calcium in Coal Creek by about a factor of three. Further tributary inputs of lower calcium concentration resulted in a decrease in calcium concentration downstream of the treatment plant effluent. The dissolved and total calcium concentrations were nearly equal.

The concentration of magnesium increased gradually with stream distance from about 1.2 mg L^{-1} to 2.1 mg L^{-1} owing to magnesium inputs from the tributaries draining the iron gossan and western side of the Keystone Mine.

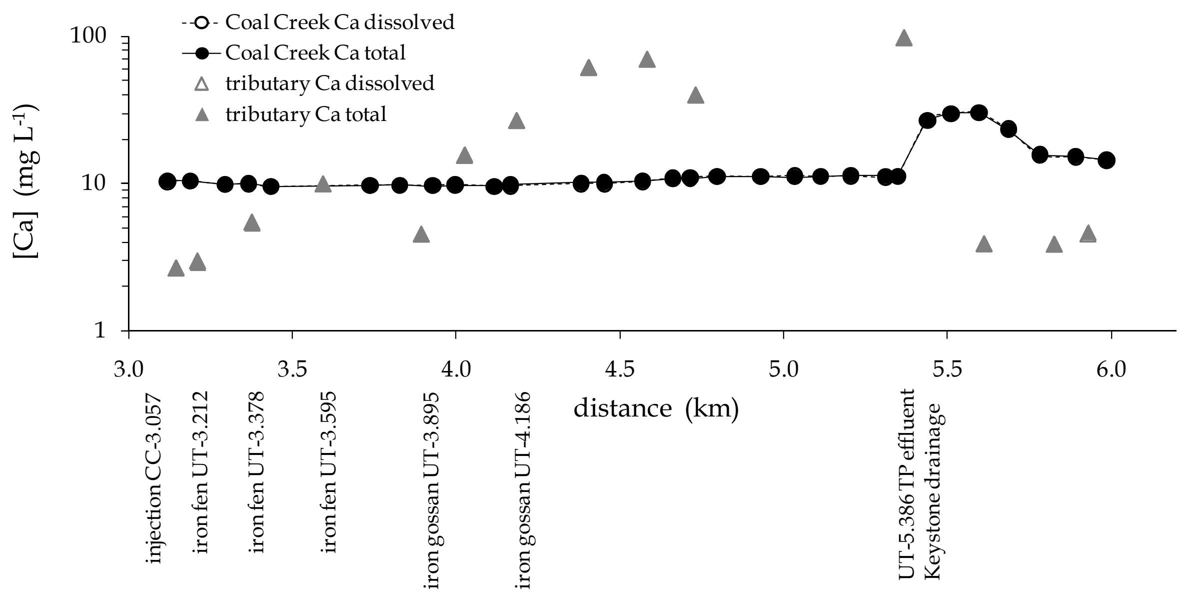

Figure 16. Stream and tributary calcium concentrations as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 μm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines.

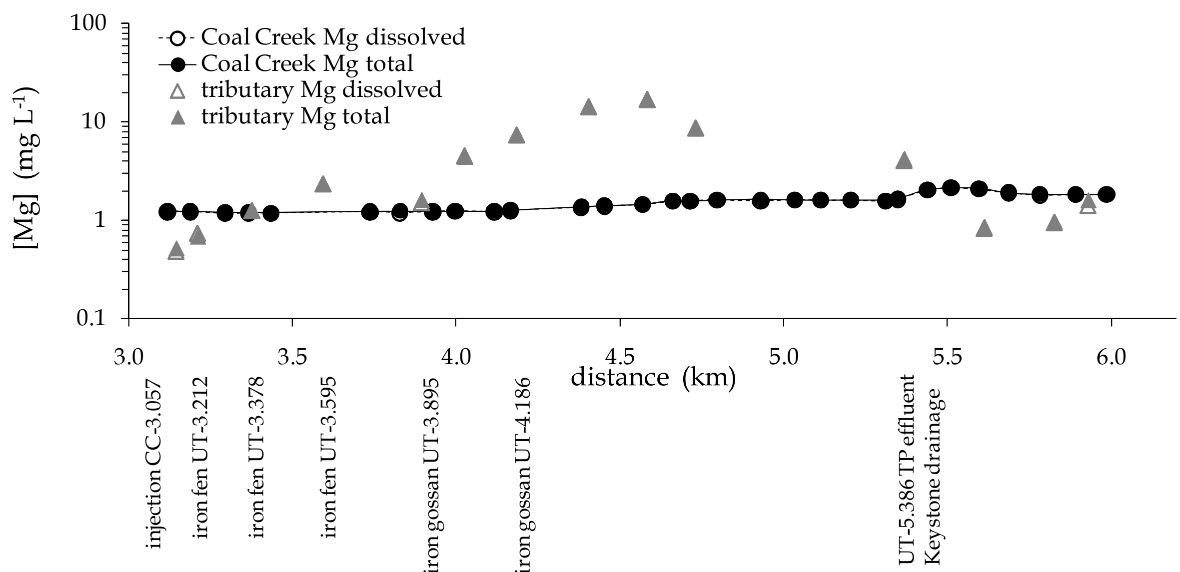

Figure 17. Stream and tributary magnesium concentrations as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 μm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines.

Hardness was calculated as the sum of the dissolved calcium and magnesium concentrations (Equation 8). The concentration of calcium exceeded the concentration of magnesium by about 10-15 times over the reach of the metal loading tracer dilution test; therefore, hardness varied with stream distance similarly to calcium (Figure 18). Because the Mount Emmons treatment plant effluent increases the calcium concentration in Coal Creek, the effluent increases the hardness in Coal Creek. The increase in hardness resulted in increases in the hardness-based standards for metal toxicity to aquatic organisms downstream of the effluent at UT-5.368.

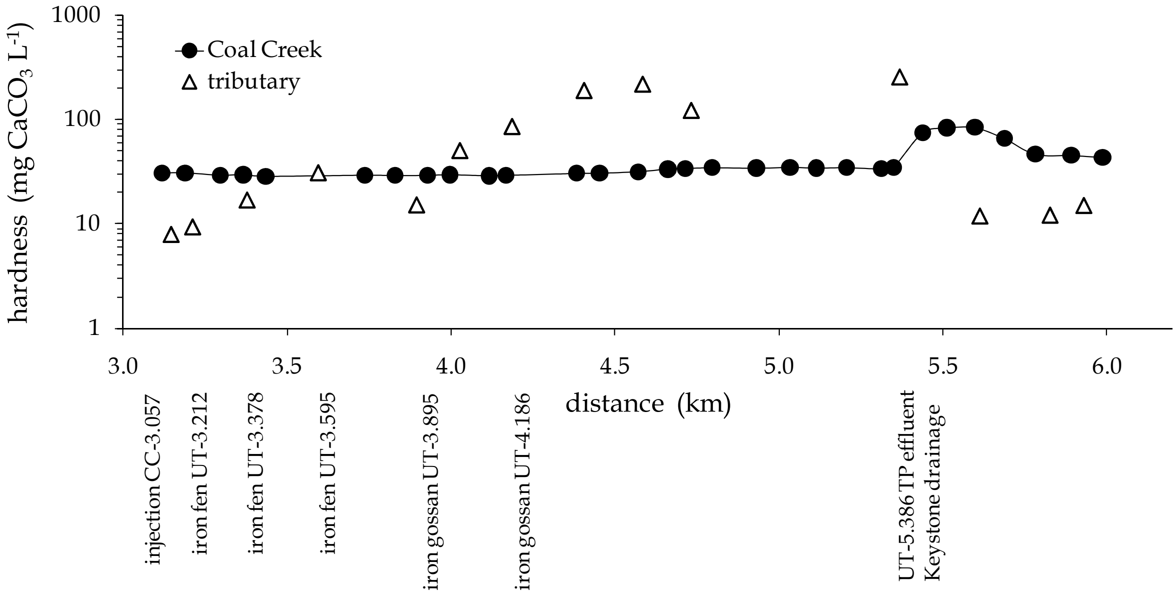

Figure 18. Stream and tributary hardness as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. The stream concentrations are connected by lines.

Metals in Coal Creek

For the April 2007 metal loading tracer dilution test, we measured the total and dissolved concentrations of aluminum, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc. Dissolved metal concentrations were operationally defined by 0.45 μm membrane filtration. The metal concentrations are compared to chronic toxicity standards for aquatic life (CDPHE, 2008), some of which were calculated using the measured hardness (Figure 18). The metal loading rates were calculated as the product of the metal concentrations and flow rates (Equation 7) for each stream and tributary sampling site.

Aluminum. The concentration of aluminum in Coal Creek ranged from 27 to 230 μg L^{-1} for dissolved aluminum and from 310 to 1,060 μg L^{-1} for total aluminum (Figure 19). The tributary concentrations were typically higher than the stream concentrations, which resulted in a steady increase in aluminum concentration in Coal Creek along the test reach. The total aluminum concentrations were always greater than the dissolved aluminum concentrations in the stream and some of the tributaries;

therefore, most of the aluminum was in the colloidal form (retained on 0.45 μm filters). In some tributaries, particularly those with lower pH, total and dissolved aluminum concentrations were similar.

For most of the Coal Creek reach tested, dissolved aluminum concentrations were higher than the chronic toxicity standard for aquatic life (87 $\mu g\ L^{-1}$ for waters of pH below 7.0; CDPHE, 2008). The addition of the Mount Emmons treatment plant effluent as part of UT-5.368 resulted in a significant decrease in the dissolved aluminum concentration even as it increased the total aluminum concentration. There is no drinking water supply standard for Colorado (CDPHE, 2008).

The loading rates for total and dissolved aluminum gradually increased over the Coal Creek reach down to the Mount Emmons treatment plant effluent. The Mount Emmons treatment plant effluent was the largest aluminum load over the study reach (59% of the total loading rate from the tributaries). Slightly less than half of the aluminum from the effluent was dissolved and the effluent addition resulted in an increase in the total aluminum loading rate, but a decrease in the dissolved aluminum loading rate. The iron gossan tributary UT-4.186 contributed 12% of the aluminum to Coal Creek, all in the dissolved form because of the low pH of this tributary, and the other iron fen and gossan tributaries combined to contribute nearly 17% of the total aluminum, nearly all in the dissolved form. The tributaries draining the Keystone Mine property to the west and east of the treatment plant did not contribute significant amounts of aluminum.

Arsenic. The concentration of arsenic in Coal Creek ranged from the detection limit to 2.2 $\mu g\ L^{-1}$ for dissolved arsenic and from 1.6 to 2.9 $\mu g\ L^{-1}$ for total arsenic (Figure 20). The tributary concentrations were typically lower than the stream concentrations, which resulted in a steady decrease in arsenic concentration over the test reach. The total arsenic concentrations were slightly greater than the dissolved concentrations in the stream and some of the tributaries; therefore, some of the arsenic was in colloidal form (retained on 0.45 μm filters). In some tributaries, particularly those with lower pH, total and dissolved arsenic concentrations were similar.

For all of the Coal Creek reach tested, dissolved arsenic concentrations were much lower than the chronic toxicity standard for aquatic life (150 $\mu g\ L^{-1}$; CDPHE, 2008). Arsenic did not exceed the 30-day drinking water supply standard of 10 $\mu g\ L^{-1}$ based on Safe Drinking Water Act maximum contaminant levels, but the CDPHE human health-based standard of 0.02 $\mu g\ L^{-1}$ was exceeded throughout the reach.

The only significant arsenic loading came from the Mount Emmons treatment plant effluent, but this loading rate is based on total arsenic concentration of only 1.2 $\mu g\ L^{-1}$, just above the detection limit. None of the tributaries significantly changed the arsenic loading rate in Coal Creek.

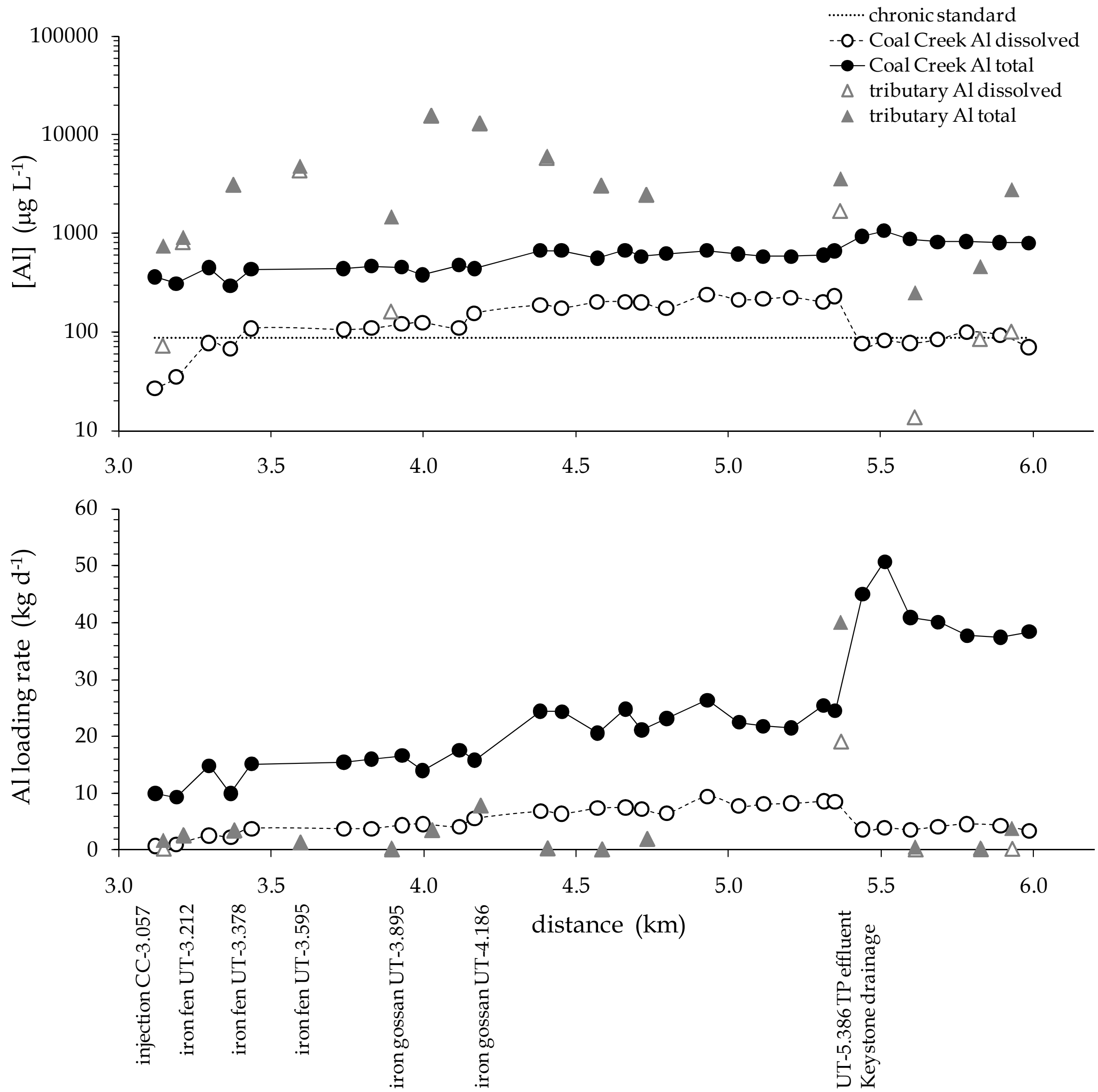

Figure 19. Stream and tributary aluminum concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 µm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

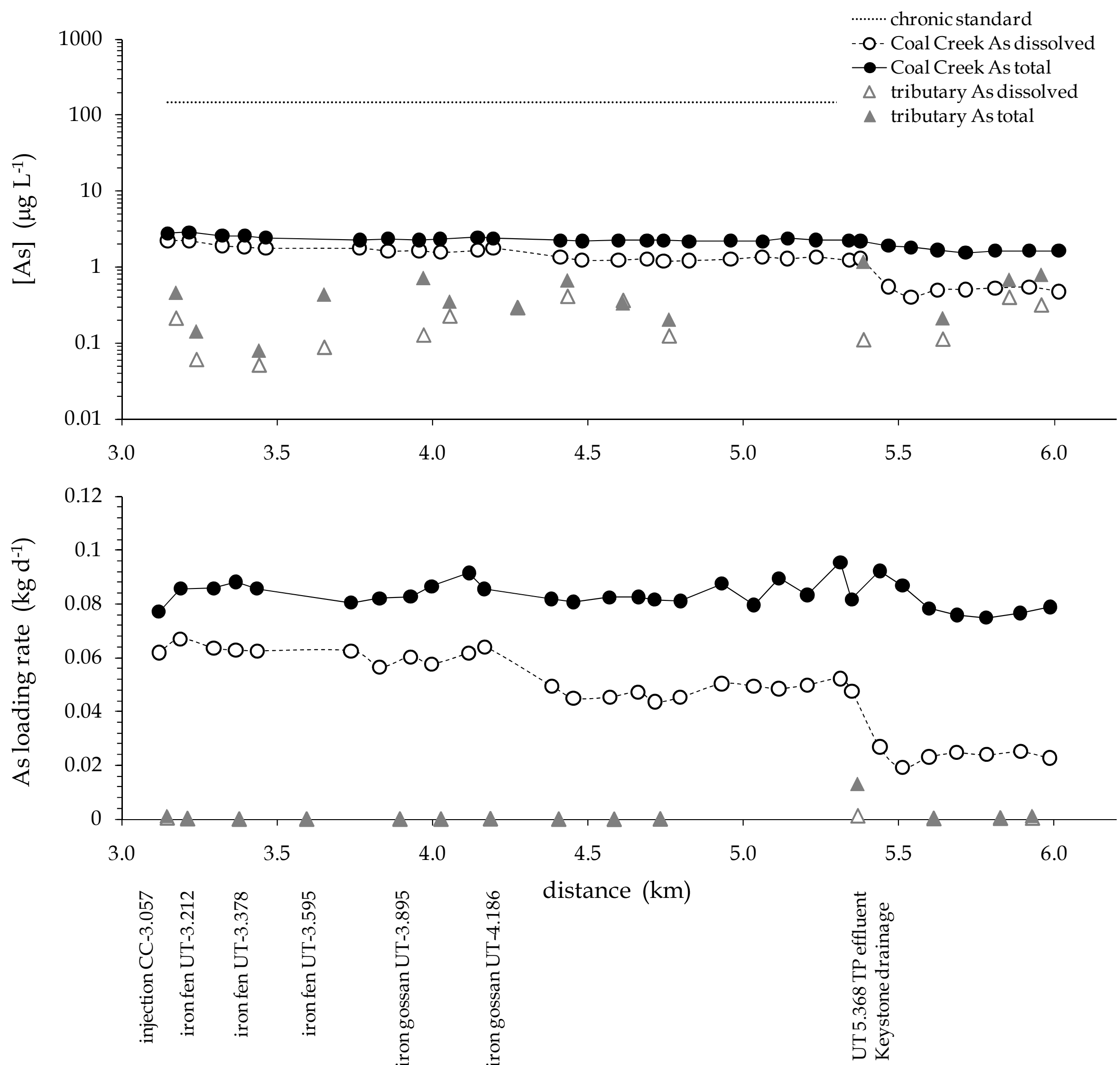

Figure 20. Stream and tributary arsenic concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 μm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

Barium. The concentration of barium in Coal Creek ranged from 15 to 17 μg L^{-1} for dissolved barium and from 16 to 19 μg L^{-1} for total barium (Figure 21). Some of the tributary concentrations were higher than and some were lower than the narrow range of barium concentrations in the stream. The total barium concentrations were slightly greater than the dissolved concentrations in the stream and some of the tributaries; therefore, a small fraction of the barium was in colloidal form (retained on 0.45 μm filters). In some tributaries, particularly those with lower pH, total and dissolved barium concentrations were similar. There is no toxicity standard for aquatic life for barium in Colorado (CDPHE, 2008). Barium did not except the drinking water supply standards of 1,000 μg L^{-1} (1-day) or 490 μg L^{-1} (30-day) in the study reach.

The only significant barium loading came from the Mount Emmons treatment plant effluent (65% of the total load). The effluent caused a small increase in the Coal Creek barium concentration. None of the other tributaries significantly changed the barium loading rate in Coal Creek.

Cadmium. Over the 2.9 km of Coal Creek examined in this metal loading tracer dilution test, cadmium concentration increased from about 0.3 to 4.1 μg L^{-1} (Figure 22). Most of the tributaries over the upper 2 km of the reach contained higher concentrations of cadmium than Coal Creek. Downstream of the Mount Emmons treatment plant effluent, the cadmium concentrations in the tributaries draining the eastern Keystone Mine property were lower than those in Coal Creek. In the stream and in the tributaries, the total and dissolved cadmium concentrations were the same – the colloidal fraction of cadmium was essentially zero.

From the tributary draining the iron gossan at 4.186 km, the dissolved cadmium concentration in Coal Creek exceeded the chronic aquatic life standard. Even below the Mount Emmons treatment plant effluent, where the increase in calcium results in an increase in hardness and an increase in the toxicity standard, the cadmium concentration exceeded the standard because the effluent also adds cadmium to Coal Creek. The 1-day drinking water supply standard of 5.0 μg L^{-1} cadmium (CDPHE, 2008) was not exceeded in Coal Creek.

The two main contributions to the cadmium loading rate in Coal Creek are UT-4.186, one of the tributaries gaining the iron gossan (24%), and the Mount Emmons treatment plant effluent (54%). The flow rate of the iron gossan tributary is low and the cadmium concentration is high (about 95 times greater than the Coal Creek concentration). For the treatment plant effluent, the cadmium concentration is only 4 times greater than the Coal Creek concentration, but the flow rate is 19 times greater than the flow rate of the iron gossan tributary.

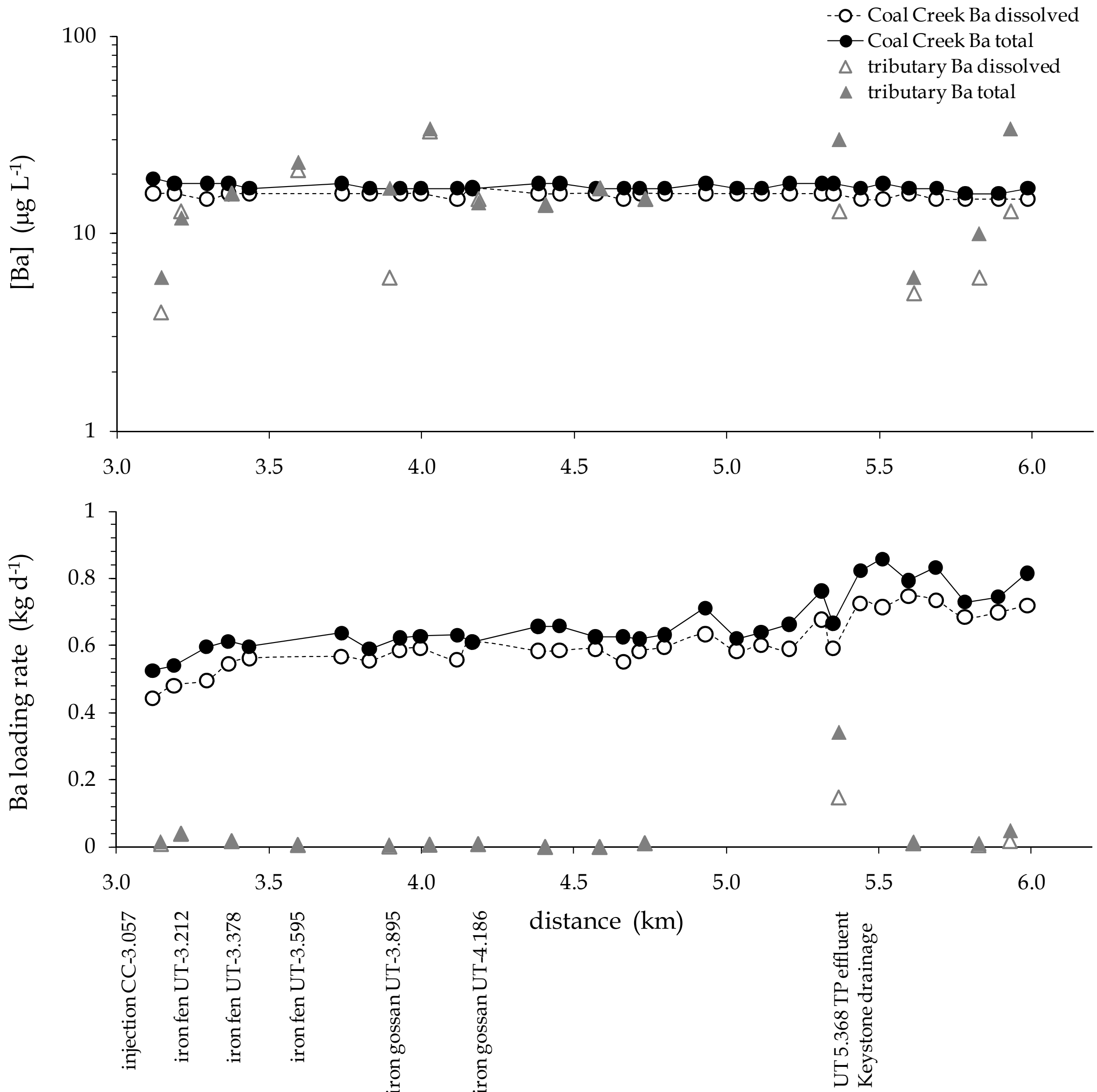

Figure 21. Stream and tributary barium concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 μm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. There is no acute or chronic standard for toxicity to aquatic life for Colorado (CDPHE, 2008).

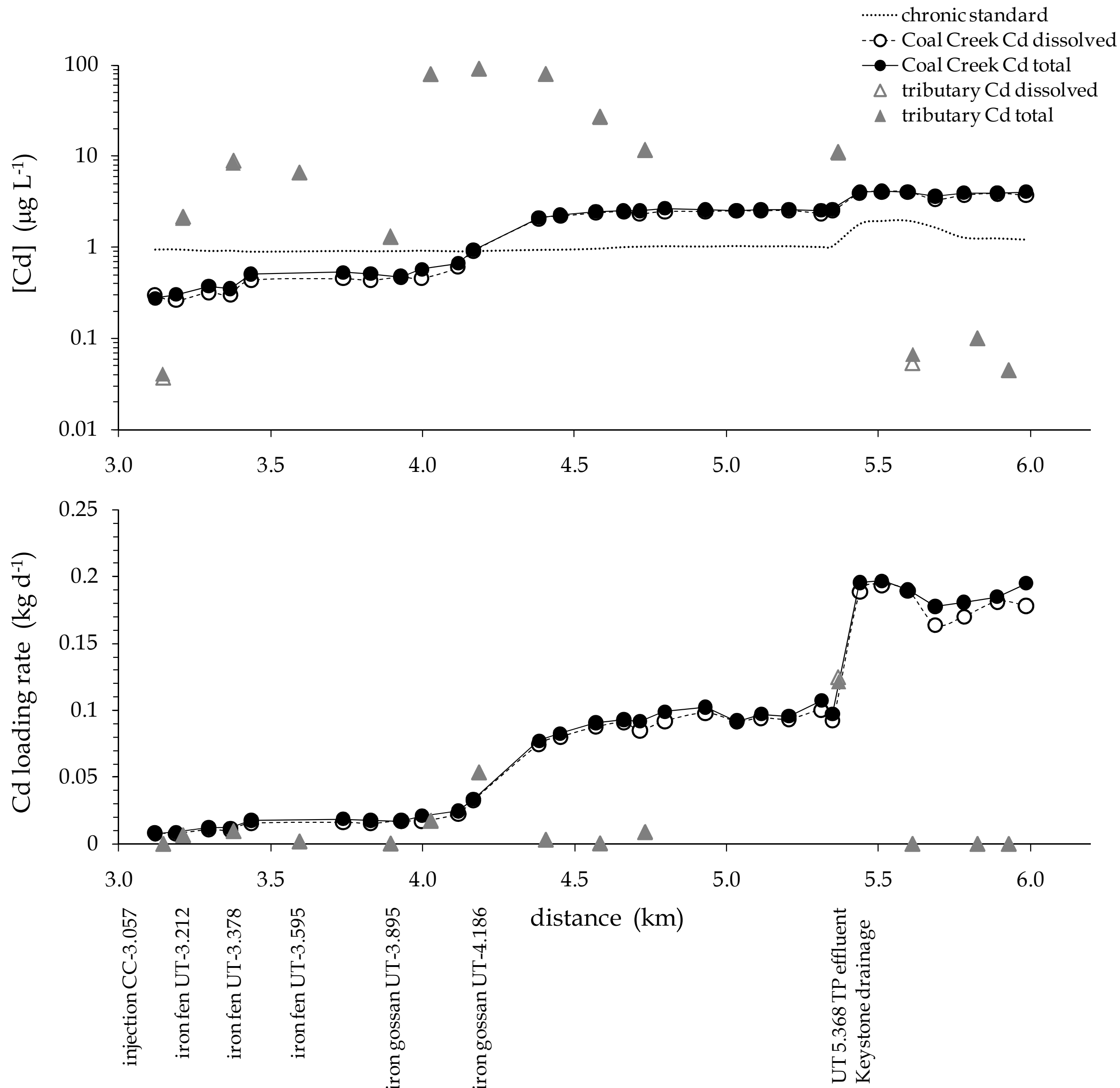

Figure 22. Stream and tributary cadmium concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 µm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The hardness-based chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

Chromium. The chromium concentration in Coal Creek was highest at the upstream end of the reach examined in this metal loading tracer dilution test – 1.5 μg L^{-1} dissolved and 3.4 μg L^{-1} total – and declined rapidly by about a factor of ten to chromium concentrations near the detection limit (Figure 23). The tributary chromium concentrations are similar to those in the stream. In the stream and in the tributaries, the total chromium concentrations typically exceed the dissolved chromium concentrations, which indicated that some of the chromium was in the colloidal fraction.

Aquatic life standards exist for chromium(III) and chromium(VI) (CDPHE, 2008). In a stream open to the atmosphere, we can assume that most of the chromium is present in the oxidized hexavalent chromium form, which is the more toxic oxidation state of chromium. The chronic aquatic life toxicity standard is 11 μg L^{-1}, and this standard was not exceeded in Coal Creek. The 1-day drinking water supply standards of 50 μg L^{-1} for chromium(III) or chromium(VI) (CDPHE, 2008) were not exceeded in Coal Creek.

The main contributor of chromium to Coal Creek is the Mount Emmons treatment plant effluent, but this contribution is small and it did not increase the concentration of chromium in Coal Creek.

Copper. Over the 2.9 km of Coal Creek examined in this metal loading tracer dilution test, the concentration of copper increased from about 0.9 to 20 μg L^{-1} (Figure 24). Most of the tributaries over the upper 2 km of the reach contained higher concentrations of copper than Coal Creek. Downstream of the Mount Emmons treatment plant effluent, the copper concentrations in the tributaries draining the eastern Keystone Mine property were lower than those in Coal Creek. In the stream and in the tributaries, the total copper concentration typically exceeded the dissolved concentration by 20-100%, which resulted in a maximum of about half of the copper in the colloidal fraction.

The dissolved copper concentration in Coal Creek exceeded the chronic aquatic life standard below the Mount Emmons treatment plant effluent even though the effluent adds hardness and results in a higher copper standard. Copper did not except the 30-day drinking water supply standard of 1,000 μg L^{-1} in the study reach.

The main copper contributor is the Mount Emmons treatment plant effluent (91%). The iron gossan tributary at 4.186 km roughly doubles the copper loading rate in Coal Creek by adding 4.3% of the total copper load.

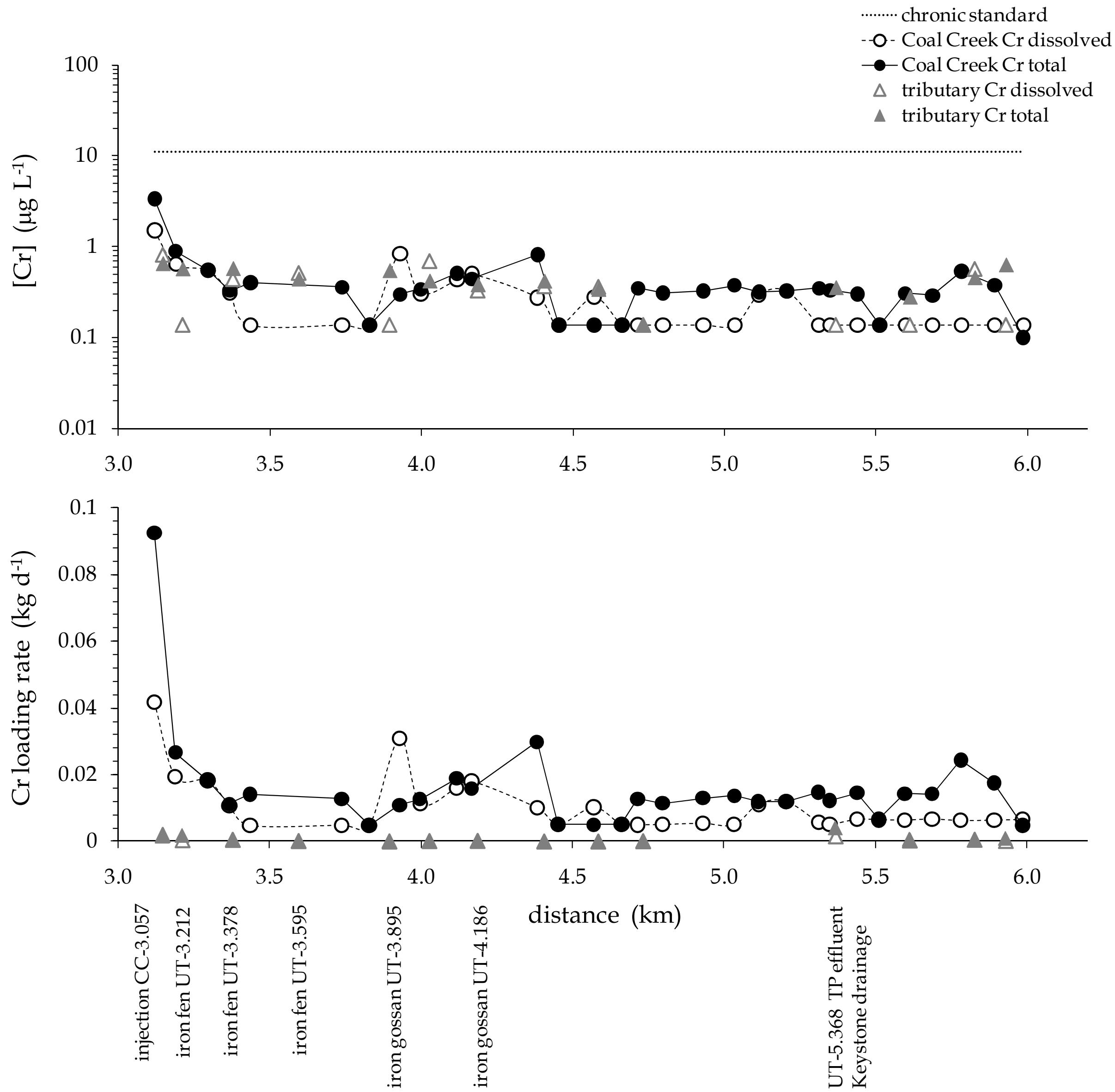

Figure 23. Stream and tributary chromium concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 μm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

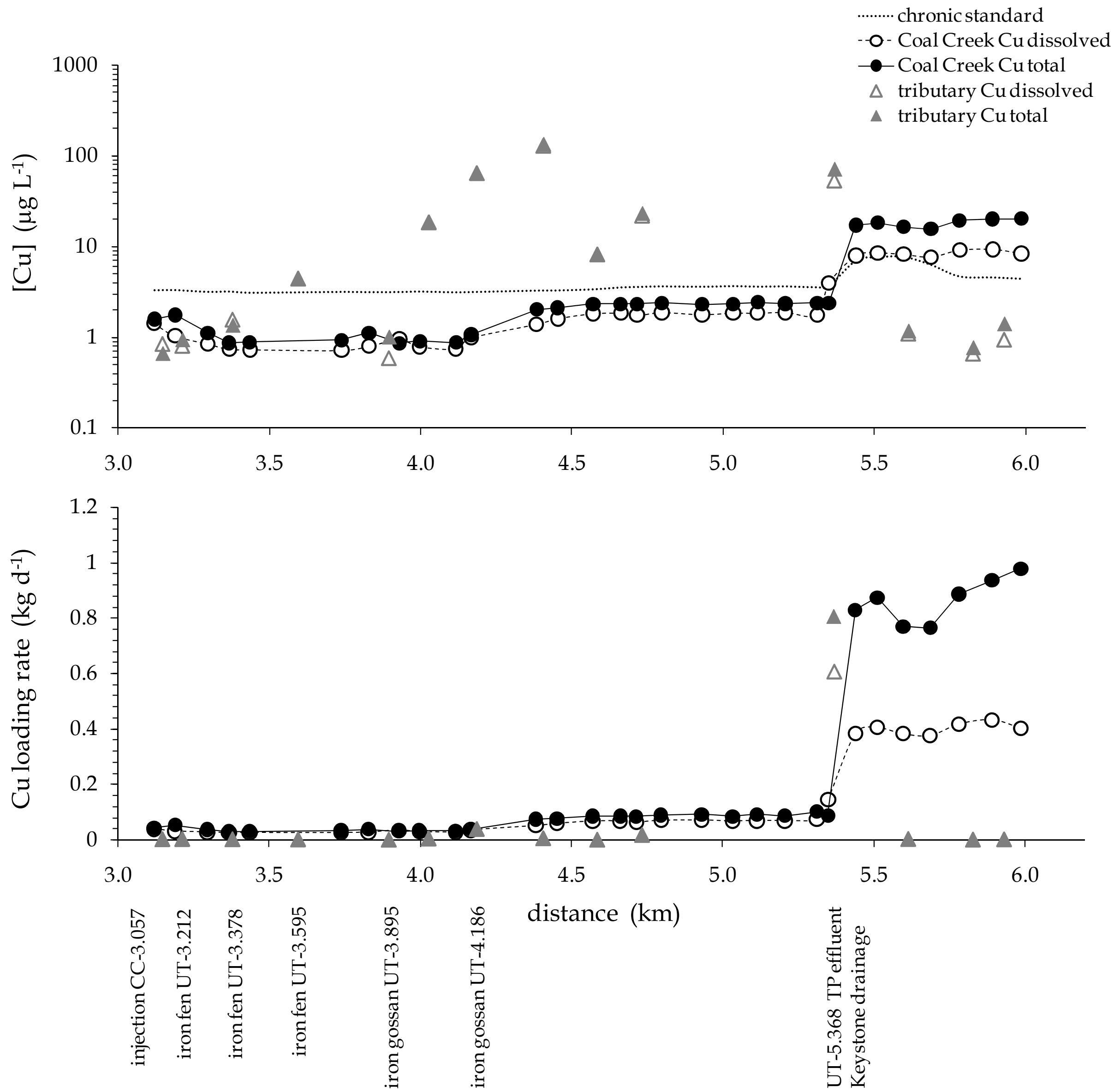

Figure 24. Stream and tributary copper concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 µm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The hardness-based chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

Iron. The total concentration of iron in Coal Creek ranged from 220 to 320 μg L^{-1}. The dissolved iron concentration ranged from 5 to 130 μg L^{-1} (Figure 24). Total iron concentration increased by about 50% and dissolved iron decreased by about a factor of 10 downstream of the Mount Emmons treatment plant effluent. Some tributaries contained concentrations of total iron in excess of the stream concentrations, and other tributaries had lower concentrations of total iron. In the stream and in most of the tributaries, the total iron concentration exceeded the dissolved iron concentration by a factor of 2-4, which indicated that most of the iron was in the colloidal fraction. Most of the other metals in colloidal form are expected to be associated with iron in the colloidal form. Only in the iron gossan tributaries was most of the iron dissolved.

The chronic aquatic life toxicity standard for iron is 1,000 μg L^{-1} total recoverable iron (CDPHE, 2008). The "total recoverable" iron concentration is determined by a heated digestion of the water sample. Our total iron is determined by acidification of the water sample to a pH of less than 2 for about two weeks before analysis. If we had subjected our samples to the "total recoverable" procedure, our iron concentrations might have been slightly higher, but it would be unlikely that the "total recoverable" procedure would have resulted in exceedance of the standard. The 30-day drinking water supply standard for dissolved iron, 300 μg L^{-1} (CDPHE, 2008), was not exceeded in Coal Creek.

The main contributor of iron to Coal Creek is the Mount Emmons treatment plant effluent (73%). One of the tributaries draining the east side of the Keystone Mine property, UT-5.930, contributed 8.1% of the total iron loading rate.

Lead. Over the 2.9 km of Coal Creek examined in this metal loading tracer dilution test, the total concentration of lead increased from about 0.5 to 2.5 μg L^{-1} and the dissolved concentration decreased from about 0.2 to 0.1 μg L^{-1} (Figure 26). Some tributary lead concentrations were higher than those in Coal Creek, and other tributary lead concentrations were lower than those in Coal Creek. Immediately downstream of the Mount Emmons treatment plant effluent, the total lead concentration increased by a factor of four and the dissolved lead concentration decreased by a factor of about two. In the stream and in most of the tributaries (expect those of low pH), the total lead concentration exceeded the dissolved concentration by a factor of 4-12, which indicates that most of the lead was in the colloidal fraction.

The dissolved lead concentrations in Coal Creek never exceeded the hardness-based chronic aquatic life toxicity standard. Lead did not except the 1-day drinking water supply standard of 50 μg L^{-1} in the study reach.

Downstream of the Mount Emmons treatment plant effluent, the total lead concentration did exceed the standard, but 90-95% of that lead is colloidal, and colloidal metals are not considered toxic to aquatic life. The main copper contributor is the Mount Emmons treatment plant effluent (84%).

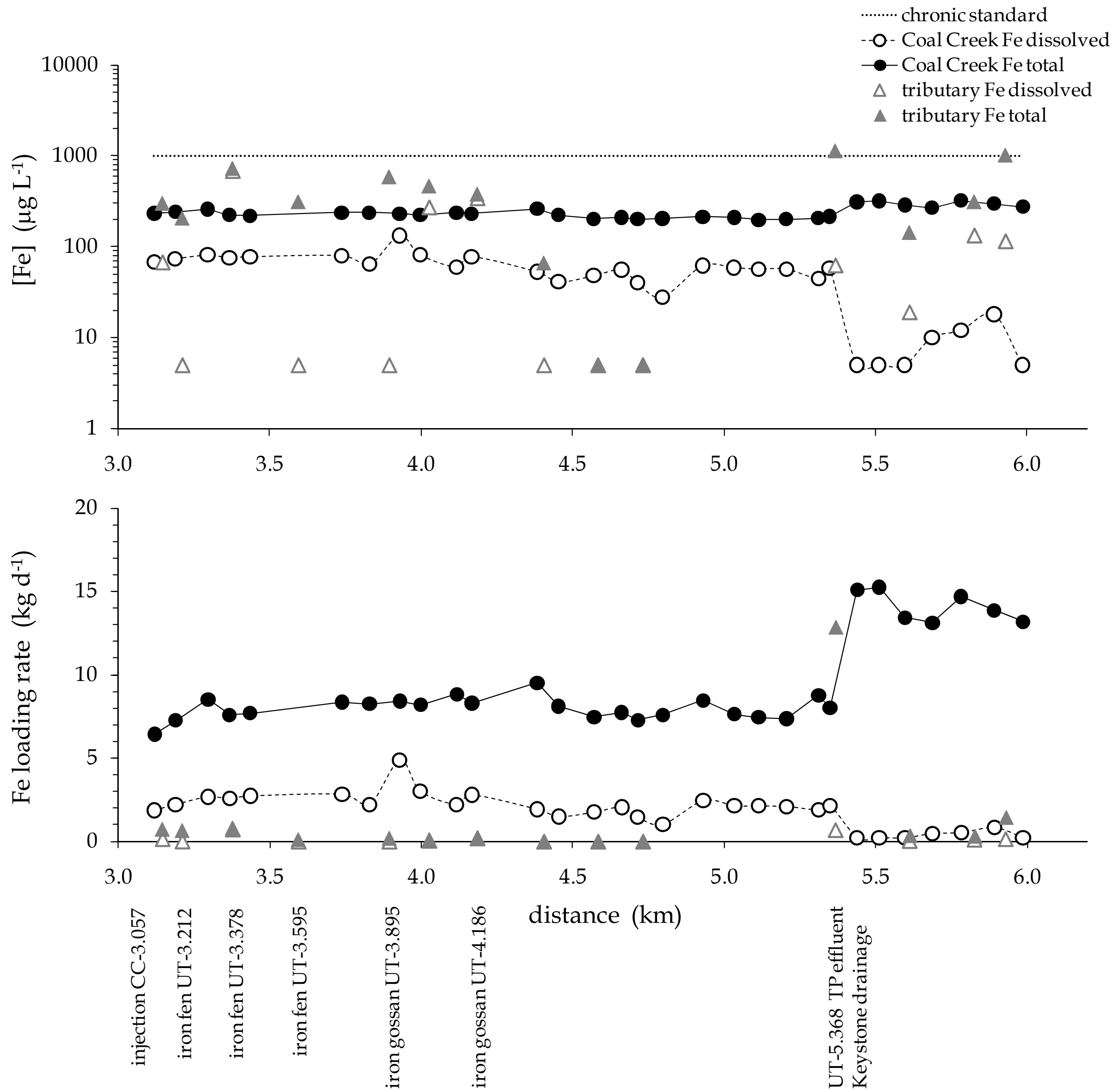

Figure 25. Stream and tributary iron concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 µm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

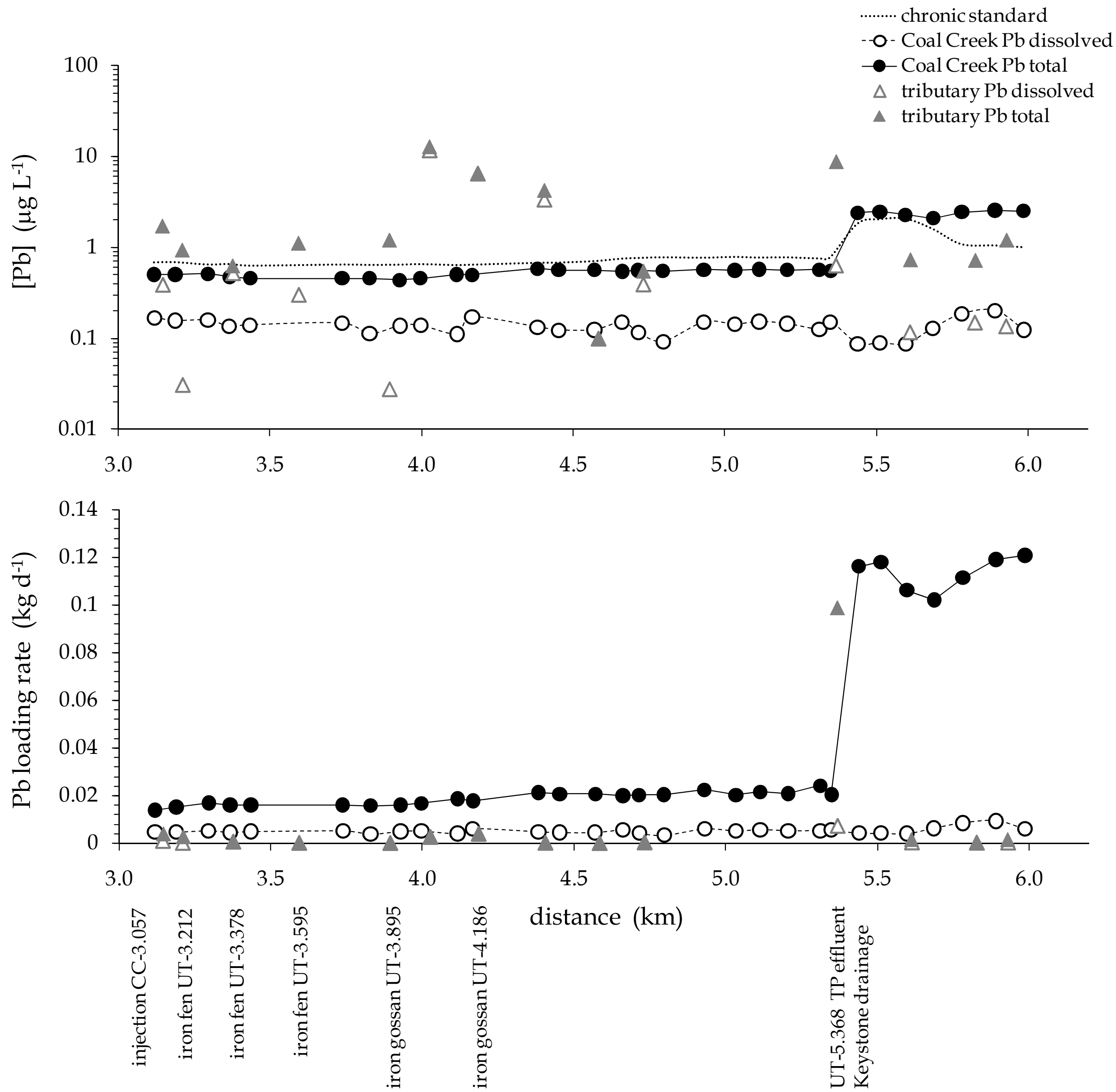

Figure 26. Stream and tributary lead concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 µm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The hardness-based chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

Manganese. Over the Coal Creek reach examined in this metal loading tracer dilution test, the total concentration of manganese increased from 25 to 460 μg L^{-1} and the dissolved concentration decreased from 20 to 460 μg L^{-1} (Figure 27). The concentrations of manganese increased just downstream of the iron gossan tributary at 4.186 km and the Mount Emmons treatment plant effluent. Most of the tributaries contained concentrations of manganese that were higher than the concentrations of manganese in the stream. With the exception of a few tributaries, the total and dissolved manganese concentrations were similar, which indicates that the manganese was not present in the colloidal fraction.

The dissolved manganese concentrations in Coal Creek never exceeded the hardness-based chronic aquatic life toxicity standard. In contrast, the 30-day drinking water supply standard, 50 μg L^{-1} for dissolved manganese (CDPHE, 2008), was exceeded from CC-4.167 to the downstream end of the reach.

The main contributors of manganese to Coal Creek are UT-4.186, the iron gossan tributary (15%); UT-4.733, a tributary draining the western part of the Keystone Mine property (19%); and the Mount Emmons treatment plant effluent (59%).

Nickel. The total concentrations of nickel ranged from 0.7 to 3.5 μg L^{-1} and the dissolved concentrations were similar; therefore, very little of the nickel was in the colloidal phase (Figure 28). The highest concentration of nickel was found at the upstream end of the reach. Increases in nickel concentration occurred just downstream of the iron gossan tributary at 4.186 km and the Mount Emmons treatment plant effluent. Most of the tributaries contained concentrations of nickel that were higher than the concentrations of nickel in the stream.

The dissolved nickel concentrations in Coal Creek never exceeded the hardness-based chronic aquatic life toxicity standard or the 30-day drinking water supply standard, 100 μg L^{-1} for dissolved nickel (CDPHE, 2008).

The main contributors of manganese to Coal Creek are UT-4.186, the iron gossan tributary (15%); UT-4.733, a tributary draining the western part of the Keystone Mine property (19%); and the Mount Emmons treatment plant effluent (59%).

Zinc. Over the reach of Coal Creek examined in this metal loading tracer dilution test, the total concentration of zinc increased from 80 to 780 μg L^{-1} (Figure 29). The dissolved zinc concentrations were 5-10% lower than the total zinc concentrations, which indicates that a small fraction of the zinc was in the colloidal phase. Most of the tributaries over the upper 2 km of the reach contained higher concentrations of zinc than Coal Creek. Downstream of the Mount Emmons treatment plant effluent, the zinc concentrations in the tributaries draining the eastern Keystone Mine property were lower than those in Coal Creek.

Throughout this reach of Coal Creek, the dissolved zinc concentration exceeded the chronic aquatic life standard. Zinc did not exceed the 30-day drinking water supply standard of 5,000 μg L^{-1} in the study reach (CDPHE, 2008).

The main zinc contributor was the Mount Emmons treatment plant effluent (50%). The iron gossan tributary at 4.186 km contributed 24% of the zinc to Coal Creek.

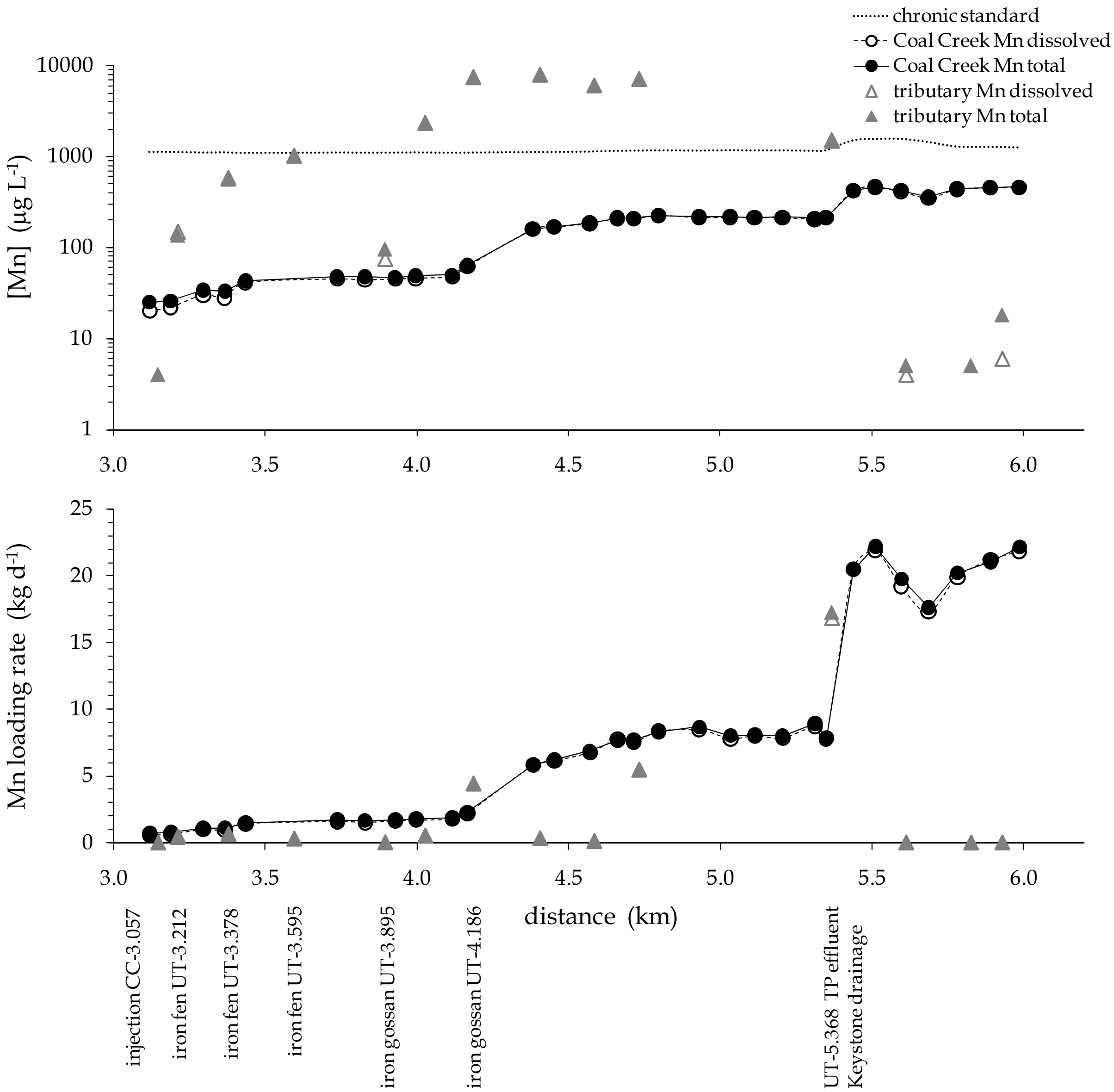

Figure 27. Stream and tributary manganese concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 µm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The hardness-based chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

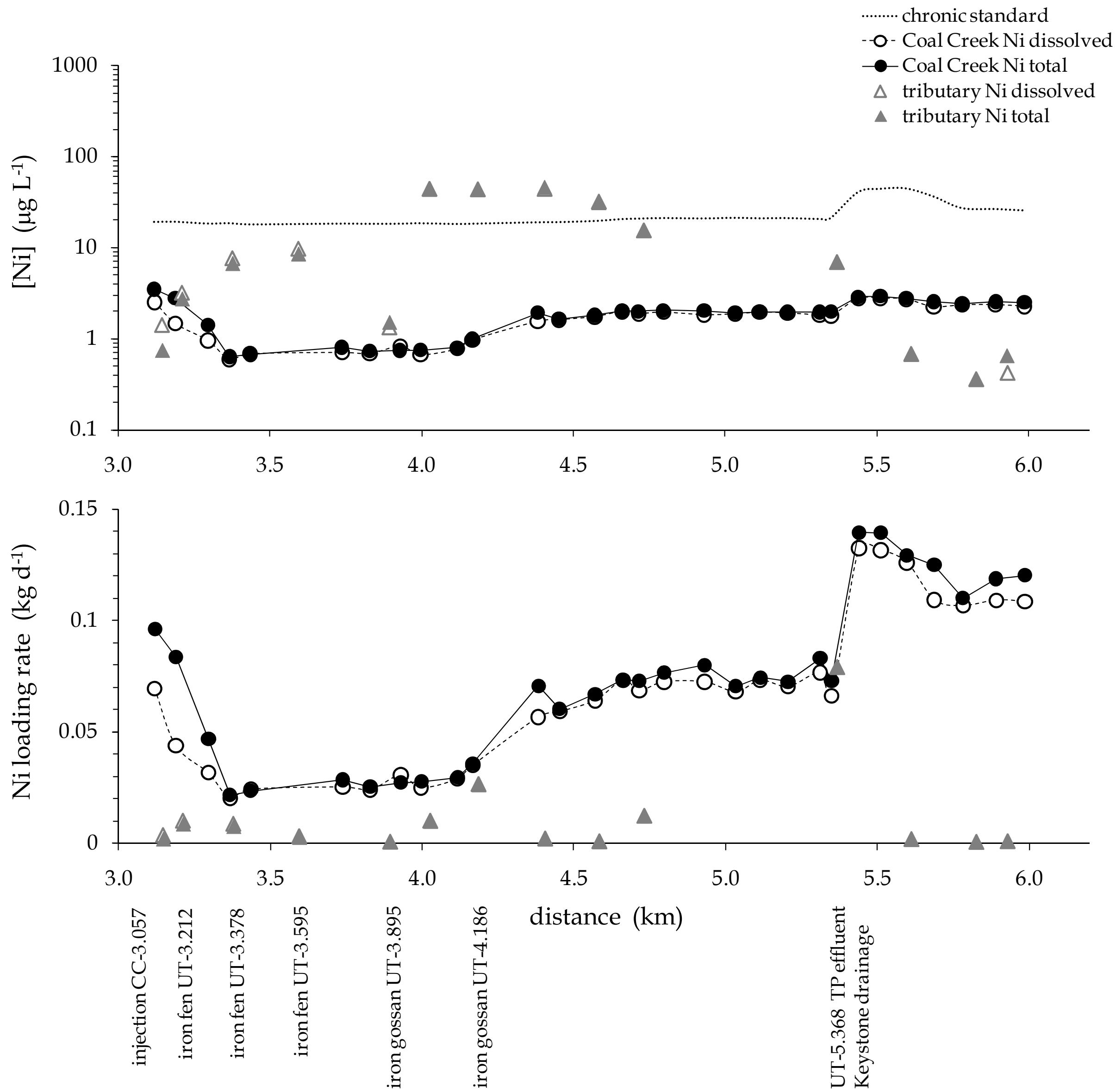

Figure 28. Stream and tributary nickel concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 µm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The hardness-based chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

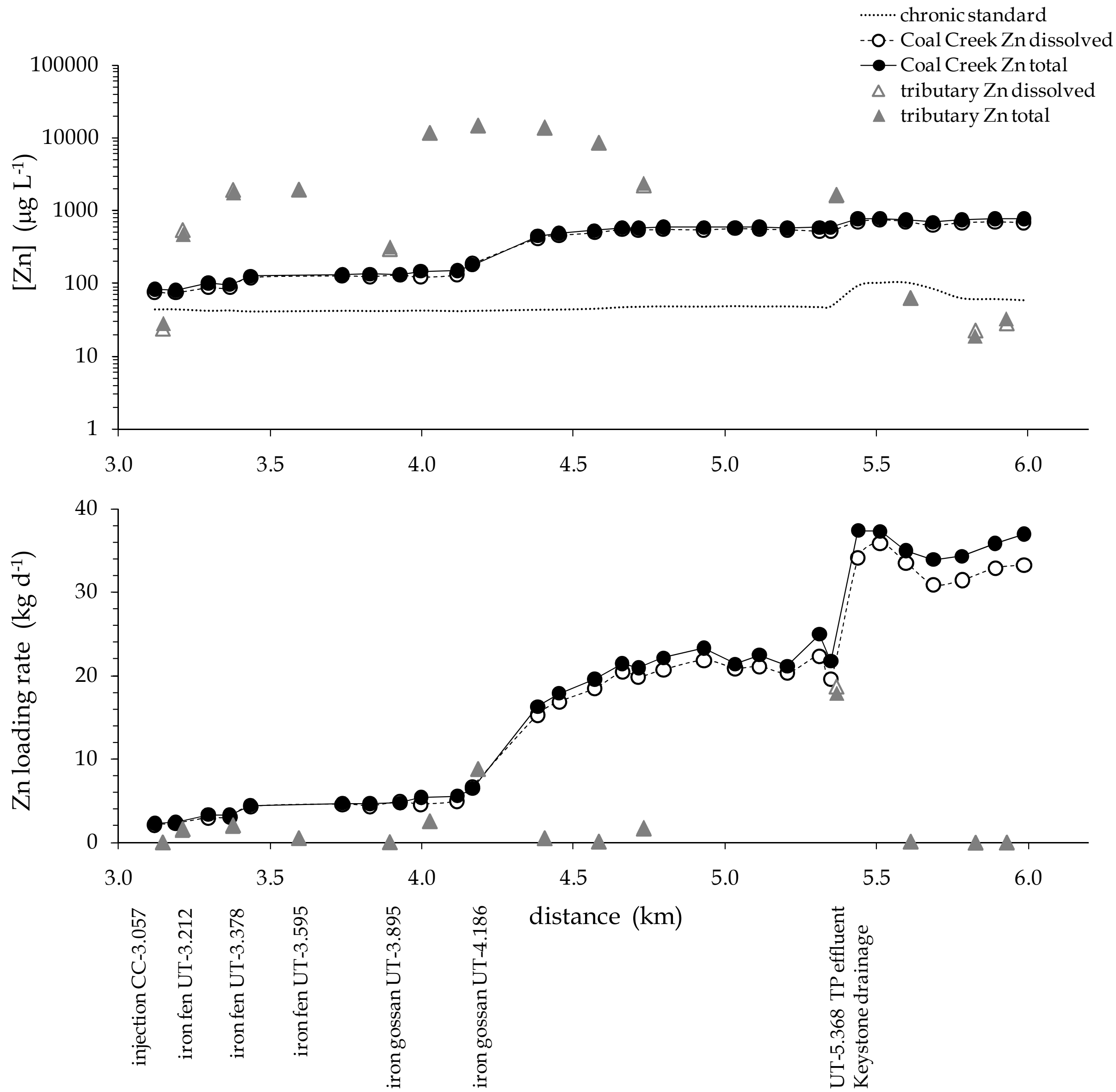

Figure 29. Stream and tributary zinc concentrations (upper) and loading rates (lower) as a function of distance in Coal Creek during the metal loading tracer dilution test in April 2007. Dissolved concentrations operationally defined by 0.45 µm membrane filtration. The concentrations are displayed on a logarithmic axis. The stream concentrations are connected by lines. The hardness-based chronic standard for toxicity to aquatic life (CDPHE, 2008) is shown on the concentration graph.

Metal contributions from Tributary UT-5.368. The tributary UT-5.368 is a combination of three drainages: (1) the effluent from the Mount Emmons treatment plant, (2) a roadside ditch draining the north side of County Road 12 west of the treatment plant effluent channel, and (3) a channel draining part of the eastern half of the Keystone Mine property (Figure 30). The treatment plant effluent contained the highest concentrations of aluminum, cadmium, manganese, nickel, and zinc (Figure 31). The roadside ditch contained the highest concentrations of arsenic, barium, and chromium, which are all present at low concentrations. The Keystone mine drainage contained the highest concentrations of copper, iron, and lead.

The flow rate of UT-5.368 was measured as 131 L s^{-1}. The samples collected from the effluent, roadside ditch, and drainage did not contain any added bromide and were not measured for any constituents that would work well as conservative tracers. At the pH of these waters, however, calcium and magnesium are expected to be adequately conservative. Using the calcium and magnesium concentrations of the three sources and the total flow rate, the flow rates of the three sources were estimated (Table 5) by finding a unique trio of flow rates that satisfied the following equations:

$$[\mathrm{Ca}]_{METP} Q_{METP} + [\mathrm{Ca}]_{ditch} Q_{ditch} + [\mathrm{Ca}]_{KM} Q_{KM} = [\mathrm{Ca}]_{5.368} Q_{5.368} \tag{10}$$

$$[\mathrm{Mg}]_{METP} Q_{METP} + [\mathrm{Mg}]_{ditch} Q_{ditch} + [\mathrm{Mg}]_{KM} Q_{KM} = [\mathrm{Mg}]_{5.368} Q_{5.368} \tag{11}$$

$$Q_{METP} + Q_{ditch} + Q_{KM} = Q_{5.368} \tag{12}$$

where Q is the flow rate and the subscripts *METP*, *ditch*, *KM*, and *5.368* refer to the Mount Emmons treatment plant effluent, the roadside ditch, the Keystone Mine drainage, and the combined tributary UT-5.368, respectively. The Mount Emmons treatment plant effluent contains a high concentration of calcium because lime (CaO) is used to form metal hydroxide solids at high pH. The roadside ditch contains a high concentration of magnesium because of the use of magnesium chloride for de-icing and dust suppression on County Road 12. The differences in the calcium and magnesium concentrations between the three drainages allowed identification of a unique trio of flow rates.

Table 5. Dissolved calcium and magnesium and measured and estimated flow rates for the tributary UT-5.368 and the three drainages that combine to form UT-5.368. The flows were estimated using Equations 10, 11, and 12. The estimated flows are shown in italic font for the three drainages.

designation:	tributary	dissolved [Ca] (mg L^{-1})	dissolved [Mg] (mg L^{-1})	flow rate (L s^{-1})
UT-5.368:	combined tributary at 5.368 km	97.5	4.04	131.0
METP:	Mount Emmons treatment plant effluent	179	5.86	*69.30*
ditch:	roadside ditch	42.5	13.78	*2.45*
KM:	Keystone Mine drainage	6.00	1.50	*59.25*

Figure 30. Photographs of the drainages combining to make up the tributary UT-5.368: (upper left) view from the south side of County Road 12 where the oval culvert in left background drains the road-side ditch and the cast-iron pipes drain the treatment plant effluent and the Keystone Mine drainage; (upper right) view of the road-side ditch on the north side of County Road 12 which drains through the oval culvert; (lower left) close-up view of the Mount Emmons treatment plant effluent; and (lower right) the Keystone Mine drainage which is joined by the treatment plant effluent at the blue arrow.

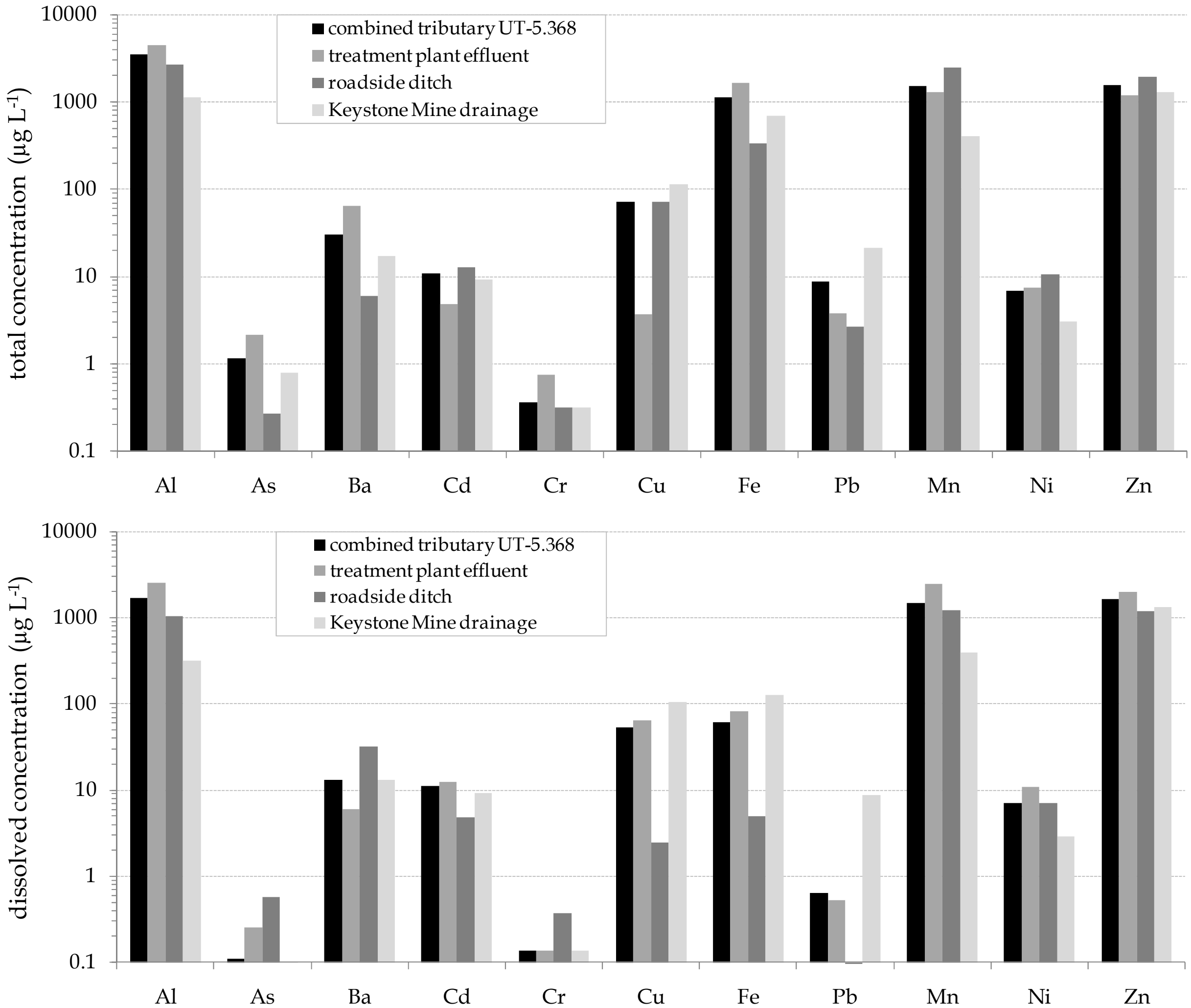

Figure 31. Total (upper) and dissolved (lower) metal concentrations for the three sources that combine to form the tributary UT-5.368. The concentrations are shown on logarithmic axes. The combined tributary is formed by the confluence of (1) the Mount Emmons treatment plant effluent, (2) the roadside ditch along County Road 12, and (3) a Keystone Mine drainage.

Summary of Metal Loading Contributions in Coal Creek

To quantify the contribution of each tributary to the overall Coal Creek metal loading, tributary loading rates were expressed as percentages of the cumulative loading rates for total and dissolved metals using Equation 7. The metal loading contributions are presented in Table 6.

The tributary UT-5.368 was a major source of all of the metals measured as total, and a major source of all but two of the metals measured as dissolved (0.45 µm-filtered). For dissolved chromium and iron, this tributary was a minor source. Three drainages combined to make this tributary to Coal Creek – the treatment plant effluent, the roadside ditch, and a Keystone Mine drainage. On its own, the treatment plant effluent was a major source of aluminum, cadmium, copper, manganese, and nickel. The roadside ditch was a trace source for all of the metals measured. The Keystone Mine drainage was a major source of barium, copper, and lead and total arsenic and iron.

The iron gossan tributary UT-4.186 was a minor metal source for cadmium, manganese, nickel, and zinc in the total and dissolved forms and aluminum and lead in the dissolved form. The low pH of UT-4.186 (3.61) resulted in dissolved metal concentrations approximately equal to total metal concentrations for nearly all of the metals, even those that were found predominantly in the colloidal form in other tributaries and in Coal Creek.

In addition to the major metal contributions from UT-5.368 (the treatment plant effluent and the Keystone Mine drainage) and UT-4.186, the iron gossan drainage, a few other tributaries made minor contributions to the metal loading in Coal Creek.

- UT-3.146, the first tributary sampled downstream of the injection, was a minor contributor of dissolved arsenic and chromium;
- UT-3.212, the first iron fen tributary, was a minor contributor of dissolved barium and total chromium;
- UT-3.378, the second iron fen tributary, was a major contributor of dissolved iron;
- UT-4.027, a tributary south of the iron gossan, was a minor contributor of dissolved lead;
- UT-4.733, a tributary draining the western part of the Keystone Mine property, was a minor contributor of manganese; and
- UT-5.930, a tributary draining the eastern part of the Keystone Mine property, was a minor contributor of dissolved arsenic.

Table 6. Total ("Tot") and dissolved ("Diss") metal loading rates expressed as percentages of the cumulative total metal loading rate for Coal Creek as determined by Equation 7. Percentages between 12% and 33% are highlighted in italic font ("minor" sources); percentages greater than 33% are highlighted in bold font ("major" sources). Percentages of less than 0.1% are shown as blank entries. Percentages are shown in grey for the three sources that combine to form the tributary UT-5.368. The cumulative total loading rate is shown on the final line of the table.

Source / Tributary	**Tot Al (%)**	**Tot As (%)**	**Tot Ba (%)**	**Tot Cd (%)**	**Tot Cr (%)**	**Tot Cu (%)**	**Tot Fe (%)**	**Tot Pb (%)**	**Tot Mn (%)**	**Tot Ni (%)**	**Tot Zn (%)**
UT-3.146	2.6	6.1	2.7		*14.5*	0.2	4.0	3.4		1.2	0.2
UT-3.212 1st iron fen	4.1	2.4	7.1	2.9	*16.5*	0.3	3.6	2.4	1.4	5.5	4.0
UT-3.378 2nd iron fen	4.9	0.5	3.4	4.1	5.9	0.2	4.5	0.6	2.1	4.9	5.3
UT-3.595 3rd iron fen	2.1	0.7	1.3	0.9	1.2	0.1	0.5	0.3	1.0	1.7	1.6
UT-3.895 1st iron gossan	0.6	1.2	0.9	0.2	1.5		1.0	0.3	0.1	0.3	0.3
UT-4.027	5.1	0.4	1.4	7.9	0.9	0.5	0.6	2.4	1.7	6.4	7.1
UT-4.186 2nd iron gossan	11.4	1.0	1.6	*23.8*	2.1	4.3	1.3	3.3	*15.0*	*17.1*	*24.4*
UT-4.406 west Keystone Mine	0.4	0.2	0.1	1.5	0.2	0.6		0.1	1.1	1.2	1.6
UT-4.584 west Keystone Mine	0.1		0.1	0.2	0.1				0.4	0.4	0.4
UT-4.733 west Keystone Mine	2.8	0.9	2.2	4.1	1.0	2.0		0.4	*18.5*	8.0	5.0
UT-5.368 combined tributary	**58.9**	**74.2**	**65.4**	**54.4**	**37.7**	**91.1**	**72.9**	**83.5**	**58.5**	**51.5**	**49.6**
treatment plant effluent	**41.3**	*19.5*	*17.2*	**33.3**	*19.4*	**39.0**	*24.5*	10.6	**50.5**	**40.6**	*31.0*
roadside ditch	2.5	5.5	6.6	0.5	1.6	0.1	4.3	0.5	0.9	1.0	0.7
Keystone Mine drainage	*15.1*	**49.2**	**41.6**	*20.7*	*16.7*	**52.0**	**44.1**	**72.3**	7.1	9.9	*17.9*
UT-5.613 east Keystone Mine	0.8	2.7	2.7	0.1	6.1	0.3	1.9	1.4		1.1	0.4
UT-5.827 east Keystone Mine	0.6	3.6	1.8		4.0	0.1	1.7	0.6		0.2	
UT-5.930 east Keystone Mine	5.6	6.2	9.1		8.3	0.2	8.1	1.4	0.1	0.6	0.1
Cumulative total load (kg d^{-1})	**68.1**	**0.02**	**0.52**	**0.22**	**0.01**	**0.88**	**17.7**	**0.17**	**29.5**	**0.15**	**36.1**

Source / Tributary	**Diss Al (%)**	**Diss As (%)**	**Diss Ba (%)**	**Diss Cd (%)**	**Diss Cr (%)**	**Diss Cu (%)**	**Diss Fe (%)**	**Diss Pb (%)**	**Diss Mn (%)**	**Diss Ni (%)**	**Diss Zn (%)**
UT-3.146	0.4	*14.5*	3.3		*31.8*	0.3	7.2	5.6		2.1	0.2
UT-3.212 1st iron fen	6.2	5.4	*14.0*	2.9	6.9	0.4	0.7	0.6	1.6	6.3	4.5
UT-3.378 2nd iron fen	8.5	1.6	6.1	4.3	7.9	0.3	**33.4**	3.5	2.2	5.4	5.7
UT-3.595 3rd iron fen	3.2	0.7	2.2	0.8	2.5	0.2	0.1	0.5	1.0	1.8	1.5
UT-3.895 1st iron gossan	0.1	1.1	0.6	0.2	0.6		0.1		0.1	0.2	0.2
UT-4.027	8.6	1.4	2.5	7.6	2.5	0.6	2.7	*15.8*	1.8	6.3	7.0
UT-4.186 2nd iron gossan	*19.4*	5.0	3.1	*23.6*	3.2	5.7	9.1	*23.6*	*15.2*	*16.8*	*23.7*
UT-4.406 west Keystone Mine	0.6	0.5	0.2	1.4	0.2	0.8		0.8	1.1	1.2	1.5
UT-4.584 west Keystone Mine	0.1	0.2	0.1	0.2	0.1				0.4	0.4	0.4
UT-4.733 west Keystone Mine	4.7	2.8	4.0	3.9	1.7	2.5	0.2	1.9	*18.8*	7.7	4.6
UT-5.368 combined tributary	**47.5**	**36.0**	**51.4**	**54.9**	*25.4*	**88.7**	*31.8*	**43.9**	**57.8**	**50.3**	**50.2**
treatment plant effluent	**42.4**	*25.5*	*16.9*	**33.4**	*13.0*	**37.2**	*13.8*	2.8	**50.0**	**40.2**	*31.7*
roadside ditch	0.6	2.0	3.2	0.5	1.3				0.9	0.9	0.7
Keystone Mine drainage	4.5	8.6	**31.3**	*21.0*	11.1	**51.4**	*18.0*	**41.1**	6.9	9.2	*17.9*
UT-5.613 east Keystone Mine	0.1	7.5	4.0	0.1	5.2	0.4	2.0	1.7		1.0	0.4
UT-5.827 east Keystone Mine	0.2	10.7	2.0		8.8	0.1	5.6	0.9		0.2	0.1
UT-5.930 east Keystone Mine	0.3	*12.7*	6.3		3.1	0.2	7.2	1.2		0.4	0.1
Cumulative total load (kg d^{-1})	**40.0**	**0.003**	**0.29**	**0.23**	**0.006**	**0.69**	**2.21**	**0.016**	**29.2**	**0.16**	**37.3**

DISCUSSION

Measurement of Flow Rate in Coal Creek

Suitability of bromide as a tracer in Coal Creek. Bromide was used as the tracer in this April 2007 metal loading tracer dilution test to avoid the problems encountered with lithium and chloride in the previous tests (Shanklin and Ryan, 2006; Ryan and Bevan, 2009). An appropriate tracer must be (1) conservative (non-reactive, non-sorbing), (2) present at concentrations several times greater than background concentrations, (3) cost-effective, and (4) safe (no risk to human health or aquatic life) (Bencala et al., 1990). Bromide and chloride have been shown to be conservative over a wide range of conditions, but lithium was not conservative in Coal Creek (Shanklin and Ryan, 2006). The addition of bromide and lithium resulted in stream concentrations much greater than concentrations in the tributaries. Bromide, added as sodium bromide, was more expensive than sodium chloride, but less expensive than lithium chloride. Bromide, lithium, and chloride were all considered to be safe at the concentrations resulting from injection in Coal Creek. For bromide, there was initial concern about oxidation into bromate (BrO_3^-), a carcinogen, during chlorination in the Town of Crested Butte's drinking water treatment plant, but calculation of the bromide dilution in Coal Creek and in the town's drinking water reservoir indicated that no risk was present even if all of the bromide were oxidized to bromate.

Steady-state conditions for bromide injection in Coal Creek. During a metal loading tracer dilution test, the tracer concentration must reach steady-state concentrations for the tracer dilution method to properly work. For this April 2007 test, the results indicated that steady-state bromide concentrations were achieved in Coal Creek. The bromide solution was injected at a fairly constant flow rate and concentration (Table 1, Figure 11) and the bromide concentration at the downstream end of the reach achieved a clear plateau (Figure 12).

Mount Emmons Treatment Plant Effluent and Hardness

The Mount Emmons treatment plant adds lime (CaO) during the treatment process to achieve a pH greater than 10 (John Perusek, personal communication, July 15, 2005). The pH is increased to precipitate and remove cadmium and manganese in the plant's flotation process. Cadmium and manganese require higher pH for precipitation than most other metals. The calcium is released to Coal Creek with the treatment plant effluent as part of tributary UT-5.368. The release of effluent is not steady; it varies from 0 to 79 L s^{-1} over each day and concludes at 16:00 (John Perusek, personal communication, July 15, 2005). During the synoptic sampling conducting for this April 2007 metal loading tracer dilution test, the treatment plant was discharging effluent at a flow rate estimated at 69.3 L s^{-1} (Table 5). The variation in effluent release also results in differences in calcium concentration along the length of Coal Creek. During this test, the calcium concentration downstream of UT-5.368 was about 3 times greater than the upstream calcium concentration, and just about 400 m downstream of UT-5.368, the calcium concentration decreased by a factor of about two relative to the peak calcium concentration (Figure 16). The decrease in calcium concentration may be attributed to either calcium removal by geochemical processes in the stream or to variations in the effluent release.

The hourly variation in calcium concentration in Coal Creek results in hourly variation in hardness and, hence, the protection of hardness for uptake of toxic metals by aquatic life. When treatment plant effluent is being discharged to Coal Creek, aquatic life is afforded greater protection from toxic metals. When effluent is not being discharged, aquatic life is at greater risk from toxic metals. According to CDPHE (2008), hardness-based toxicity standards should be calculated using the hardness corresponding to "the lower 95 per cent confidence limit of the mean hardness value at the periodic low flow criteria as determined from a regression analysis of site-specific data." The aquatic toxicity standards shown for the metals in the Results section were calculated using the hardness measured during the synoptic sampling. For a permit effluent calculation for the Mount Emmons treatment plant, the periodic input of calcium and hardness could not be used to lessen the stringency of the toxicity standards.

Aquatic Life Toxicity and Drinking Water Supply Standard Exceedances

During the early spring runoff in April 2007, concentrations of aluminum, cadmium, copper, and zinc exceeded the CDPHE chronic aquatic life toxicity standards in the reach of Coal Creek examined during the metal loading tracer dilution test (Table 7). The CDPHE drinking water supply standards were not exceeded by any of the metals or arsenic, although the arsenic concentrations did exceed the CDPHE human health-based standard for drinking water (0.02 µg L^{-1}) throughout Coal Creek.

Table 7. Coal Creek distances over which metals and arsenic exceed the Colorado chronic aquatic life toxicity standards (CDPHE, 2008).

metal	chronic toxicity standard exceeded
aluminum	3.435 to 5.439 km
arsenic	none
barium[1]	--
cadmium	4.167 km to end
chromium	none
copper	5.349 km to end
iron	none
lead	none
manganese	none
nickel	none
zinc	entire reach

[1] No aquatic life toxicity standard.

Sources of Metals Exceeding Aquatic Life Toxicity Standards

For the metals that exceeded the chronic toxicity standard for aquatic life – aluminum, cadmium, copper, and zinc – the major, minor, and trace sources are presented in Table 8. "Major" sources were classified as sources that caused water quality standard exceedances or contributed more than 33% of the cumulative tributary metal loading rate. "Minor" sources were classified as sources that contributed 12-33% of the cumulative tributary metal loading rate. "Trace" sources were classified as sources that contributed 5-12% of the cumulative tributary metal loading rate.

During early spring runoff in April 2007, the major sources of toxic metal contamination in Coal Creek were the Mount Emmons treatment plant effluent and a Keystone Mine drainage that combined to form unnamed tributary UT-5.368.

The treatment plant effluent was a major contributor of aluminum, cadmium, and copper and a minor contributor of zinc. The treatment plant effluent is a major contributor to the metal loading rate in Coal Creek because the lime/flotation treatment process does not achieve complete metal removal and because the effluent flow rate is high.

The Keystone Mine drainage that forms part of the flow in unnamed tributary UT-5.368 appears to drains an area containing the grit chamber and equalization pond associated with the Mount Emmons treatment plant (Figure 32). The exact area drained by this tributary was not determined because access to the Keystone Mine property is controlled. Further reconnaissance is needed to determine the source of toxic metals in this drainage.

Figure 32. Photographs of the grit chamber (left) and equalization pond (right) used by the Mount Emmons treatment plant. The chamber and pond are located above the Keystone Mine drainage that forms part of unnamed tributary UT-5.368.

The unnamed tributary UT-4.186 that drains the iron gossan and possibly the western part of the Keystone Mine property was a minor source of aluminum and zinc and a trace source of cadmium and copper. The exact source of the metal-contaminated water in this tributary is not clear. Most of the water appeared to be flow into the tributary from the iron gossan to the west, but seepage and runoff from the exposed terrain of the Keystone Mine could also be a source. Further examination of the source of this water with high metal concentrations and low pH is recommended.

Unnamed tributaries draining the iron fen (UT-3.212, UT-3.378) and the iron gossan (UT-4.027) were trace contributors of toxic metals. Because of the low pH in the iron fen water, the tributaries UT-3.212 and UT-3.378 were trace contributors of dissolved aluminum. Metals are more soluble in waters of low pH and high dissolved organic matter concentration. The unnamed tributary UT-4.027 drains an area south of the iron gossan. We did not observe a direct connection between the gossan and this tributary, but we assume it is fed by water draining over the iron gossan.

Table 8. Major, minor, and trace sources of metals that exceeded the chronic toxicity standards for aquatic life in Coal Creek. Sources classified as "major" include those that caused water quality standard exceedances or contributed more than 33% of the cumulative metal loading rate; those classified as "minor" contributed 12-33% of the cumulative metal loading rate; and those classified as "trace" contributed 5-12% of the cumulative metal loading rate.

metal	major sources	minor sources	trace sources
aluminum, total	UT-5.368 (Mount Emmons treatment plant effluent)		UT-4.027 (iron gossan?) UT-4.186 (iron gossan) UT-5.368 (Keystone Mine drainage) UT-5.930 (Keystone Mine east)
aluminum, dissolved	UT-5.368 (Mount Emmons treatment plant effluent)	UT-4.186 (iron gossan)	UT-3.212 (iron fen) UT-3.378 (iron fen) UT-4.027 (iron gossan?)
cadmium, total	UT-5.368 (Mount Emmons treatment plant effluent)	UT-5.368 (Keystone Mine drainage)	UT-4.027 (iron gossan?) UT-4.186 (iron gossan)
cadmium, dissolved	UT-5.368 (Mount Emmons treatment plant effluent)	UT-5.368 (Keystone Mine drainage)	UT-4.027 (iron gossan?) UT-4.186 (iron gossan)
copper, total	UT-5.368 (Mount Emmons treatment plant effluent) UT-5.368 (Keystone Mine drainage)		
copper, dissolved	UT-5.368 (Mount Emmons treatment plant effluent) UT-5.368 (Keystone Mine drainage)		UT-4.186 (iron gossan)
zinc, total		UT-4.186 (iron gossan) UT-5.368 (Mount Emmons treatment plant effluent) UT-5.368 (Keystone Mine drainage)	UT-3.378 (iron gossan) UT-4.027 (iron gossan?) UT-4.733 (Keystone Mine west)
zinc, dissolved		UT-4.186 (iron gossan) UT-5.368 (Mount Emmons treatment plant effluent) UT-5.368 (Keystone Mine drainage)	UT-3.378 (iron gossan) UT-4.027 (iron gossan?)

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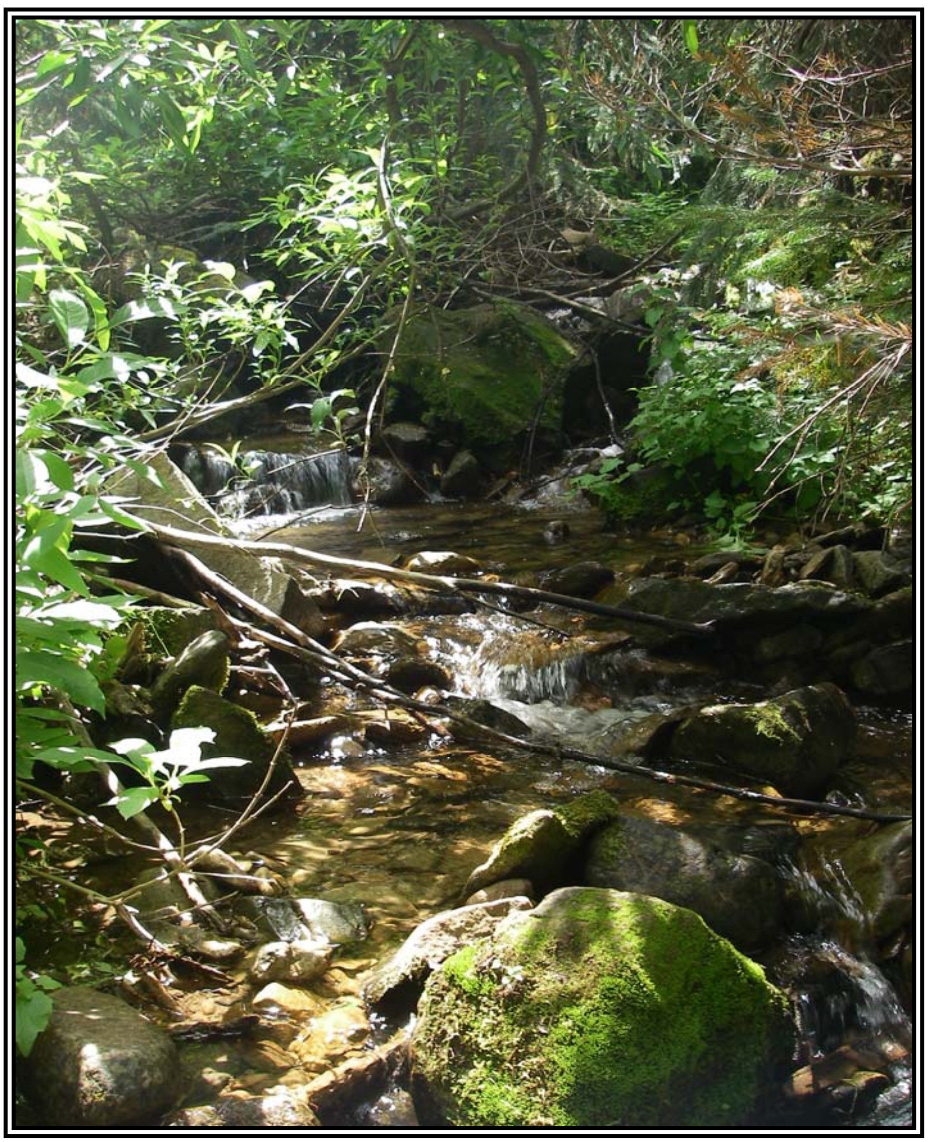
Coal Creek Watershed Coalition

Protect and Restore

Coal Creek Watershed Water Quality Report 2008



Executive Summary

Where We Are: It's been five years since the Coal Creek Watershed Coalition (CCWC) formed in 2003. Since then we've made major strides in understanding the contaminant sources affecting water quality in Coal Creek and have made plans to start remediating these sources to help improve water quality. Though our sampling indicates treated drinking water is safe to drink, we know cadmium and zinc remain the most troublesome of the "bad actors" in the watershed. These contaminants, along with other metals, exceed the standards established for aquatic life in the watershed.

Levels of metals in Coal Creek currently do not allow for sensitive species of trout and other aquatic life to utilize Coal Creek as habitat. This report focuses largely on standards developed for aquatic life, called "Table Value Standards" (see Section 3 of this report for more information). It is our hope that efforts being made throughout the watershed will allow more sensitive species of aquatic life to inhabit Coal Creek while protecting this drinking water source for the Town of Crested Butte.

The Colorado Division of Reclamation, Mining, and Safety is directing an effort to better characterize the contaminant contributions of abandoned and inactive mines in the Coal Creek Watershed. This information (to be released in the summer of 2009), combined with data from our monitoring program, will be used to develop a Watershed Restoration Plan. This plan will identify the sources of contaminants and will provide direction for any agencies, municipalities, and individuals who are interested in protecting and restoring this valuable headwater region.

The CCWC has been tracking the efforts of the Standard Mine reclamation work being performed by the United States Environmental Protection Agency (EPA) through the Superfund Program. We have been pleased with their efforts and their engagement of the community to ensure their cleanup efforts are consistent with the community's needs. The EPA has made significant progress at the Standard Mine over the past three summers, the most significant of these efforts being the removal of all waste rock and tailings materials from the site. In 2008, the EPA finalized the removal of approximately 44,000 cubic yards of contaminated materials. The site has undergone a dramatic "face-lift," with Elk Creek no longer flowing through wastes abandoned a generation ago. The site has been revegetated with native plant species and three new wetlands have been created. There is still much to do at the site, as the draining adit of the mine is still releasing metals-rich waters into Elk Creek. A final remediation plan is in the works and the CCWC and its technical advisors will continue to ensure the best remedy for the site is implemented.

The public is always encouraged to be a part of our efforts. Send us an email at coordinator@coalcreek.org or visit our site to find out when we'll be meeting again.

1. Introduction

TABLE OF CONTENTS

Is it possible to overstate the importance of water? Life in the Upper Gunnison, like almost every society, depends on water. Our tourism-based economy relies heavily on clean and abundant waters. Whether it enables downhill skiing on early-season man-made snow or rafting or fishing the scenic waters of the Upper Gunnison basin, it's hard to imagine the impacts to our recreation if there weren't such bountiful waters in our basin. Ranching and agriculture in this arid environment would be a largely fruitless effort without the benefit of irrigation fed by our rivers' waters. Waters from Coal Creek serves, in some small part, in almost all of these roles. Add drinking water to this mix of uses, and it's not hard to consider Coal Creek as one of the more important of the creeks of the Upper Gunnison.

This report includes results from sampling conducted by the EPA and the CCWC over the spring, summer, and fall of 2008. It will also present the major findings of the CCWC's water quality monitoring program. This report will discuss the known sources of contaminants in Coal Creek and its tributaries, assess the health of different areas in the watershed, identify threats to healthy streams, and discuss local efforts to protect and restore water quality in the watershed. For more up to date information visit our website at www.coalcreek.org. In addition to newsletters, reports, and water quality data, our website includes a glossary of terms and the Water Quality Monitoring Reports for 2006 and 2007.

2. Water Quality Data Collection

From February through October 2008, the CCWC collected 366 water samples from 28 different sites throughout the watershed using staff, volunteers, and automated sampling equipment. Additional samples were collected by the EPA and the United States Geological Survey ("USGS"). CCWC sampling locations are shown on Map A and a narrative description with GPS coordinates is included in the Appendices Section. To guarantee consistent, high-quality data, the CCWC uses the quality assurance and quality control checks outlined in the organization's Sampling and Analysis and Quality Assurance Plans developed by Stantec Consulting, Ltd.

In 2008, the CCWC began to focus on metal loading to Coal Creek. Loading is a measure of a stream's total metal content, calculated by multiplying the metals concentration at a site by the flow at that site. This is particularly helpful when trying to compare the contribution of metals from different sources such as tributaries. There are limitations of this type of examination of the data, since the CCWC uses single grab samples and instantaneous flows. Both methods still only represent the flow and metals concentrations for a specific period in time and should be viewed as a snapshot of conditions in the watershed with the potential for considerable variation and error. Since the CCWC cannot always collect the flow data needed to calculate loading due to field conditions (such as low-flow or snow), it will still report concentrations when necessary.

3. Contaminants of Concern and Standards

The CCWC monitors a variety of physical, biological, and chemical parameters, many of which are currently not deemed a problem. This section describes the pollutants known to impact water quality within the Watershed and those being given greater consideration by our organization, the EPA and State agencies.

Metals are currently considered the primary contaminant of concern for both human and aquatic life in the Coal Creek Watershed. The State of Colorado sets aquatic life standards for dissolved metals, which are based on the levels of calcium and magnesium present in the water (referred to as the water's "hardness"). Metals in waters with higher hardness are less toxic to aquatic organisms, and therefore the standard for used in one stream can differ dramatically from another nearby stream.

Standards: Three numerical standards are referred to in this report. The "Chronic Table Value Standard" or "Chronic TVS" is the highest water concentration of a toxicant to which organisms can be exposed to indefinitely without causing chronic toxicity. Chronic toxicity is a negative stimulus that lingers or continues for a long period of time, often one-tenth of the organism's life span or more. Chronic effects may also include mortality, reduced growth, reproduction impairment, harmful changes in behavior, or other nonlethal effects. Chronic water quality standards are set for individual pollutants at a level designed to protect the aquatic community from any long-term effects. The aquatic community includes humans and wildlife that consume aquatic organisms.

Another numerical standard, the "Acute Table Value Standard" or "Acute TVS", refers to a standard where the introduction of a substance at concentrations equal to or exceeding the standard will cause effects severe enough to induce a rapid response. In toxicity tests, a response is normally observed in 96 hours or less. Acute effects are often measured in terms of mortality or other debilitating effects. Acute water quality standards are set for individual pollutants at a level designed to protect 95 percent of the species in an aquatic community from acute effects, 95 percent of the time.

The third standard is called a "Temporary Modification," and refers to temporary standard set by the State of Colorado for impaired streams. Temporary Modifications establish numeric limits for any man-made discharges in an impaired segment of a stream until it can be determined whether the underlining standards can be met. If not, a site-specific standard will be developed for this segment. There are two temporary modifications for the segment of Coal Creek near the historic Keystone mine: cadmium and zinc temporary modifications are in place until December 31, 2011. A Total Maximum Daily Load (TMDL) process is required for impaired segments. The purpose of doing a TMDL is to allocate the loading between natural and human causes of contamination. If the impairment is being caused by natural sources, then site-specific standards for discharges will be needed.

Metals of Concern: Cadmium, copper, iron, lead, manganese, and zinc are considered the most likely threats to the health of human and aquatic life in the Coal Creek Watershed, though none are likely to cause severe human health effects at their current levels. Other water quality constituents of concern are microbes like E. coli, nutrients, and suspended solids. The Town of Crested Butte's water treatment plant removes most contaminants of concern, with the exception of most metals. Manganese is the only metal actively removed at the facility, although other metals are incidentally removed through the treatment process.

For detailed information on the potential health effects of any of these contaminants please download our 2006 Water Quality Monitoring Report at www.coalcreek.org/filesandpublications or visit the EPA's website for information on groundwater and drinking water: http://epa.gov/safewater.

4. Macroinvertebrate Data Summary

Figure 1. Mayflys like the Green Drake (*Drunella doddsii*), shown above, are a typical macroinvertebrate used in bio-monitoring.

Background: In 2008, our VISTA member, Logan Reese, was awarded a grant by the Colorado Watershed Protection Fund (now called the Colorado Healthy River Fund) allowing the Wendy Brown of Bugs Unlimited to collect and analyze samples at more sites than in the past. In this report, we will present an overview of these findings. The full analysis of the macroinvertebrate data will be available on our website in the near future.

The bio-monitoring data from the macroinvertebrate community of the Coal Creek drainage complements the physical and water chemistry data the CCWC collects at those same sites. For the purposes of this report the term "macroinvertebrate" includes only aquatic insects though other species of non-insect invertebrates, such as mites, flatworms and other types of worms are also considered macroinvertebrates.

Update: The near flood-stage runoff from the large snowpack of the 2007-08 winter was the most obvious change in Coal Creek's conditions from previous years. High runoff in sub-alpine watersheds, like the Coal Creek watershed, wash out sediment and roll cobbles and rocks onto stream bottoms. Mountain stream insects are adapted to this and prefer less sediment in most of their habitat. However, high spring runoffs, like 2008's, can scour algae off of rocks and wash away detritus,, temporarily reducing food availability for the stream fauna. High current speeds in the creek also force insects to seek refuge so they are not washed downstream. As a result, many predators are under-nourished for portions of the spring runoff. All of these elements affect the aquatic insects by delaying their life cycles during years with higher than usual runoff. In 2008, samples were collected on the same calendar day as in 2007. However, the data make it seem as if the samples were collected several weeks earlier. By collecting "earlier," we caught insect larvae that would have already emerged as adults during the same time periods in 2007 and 2006. This "time delay" increased species richness, among other things, which can contribute to stream quality, as shown in Figure 2.

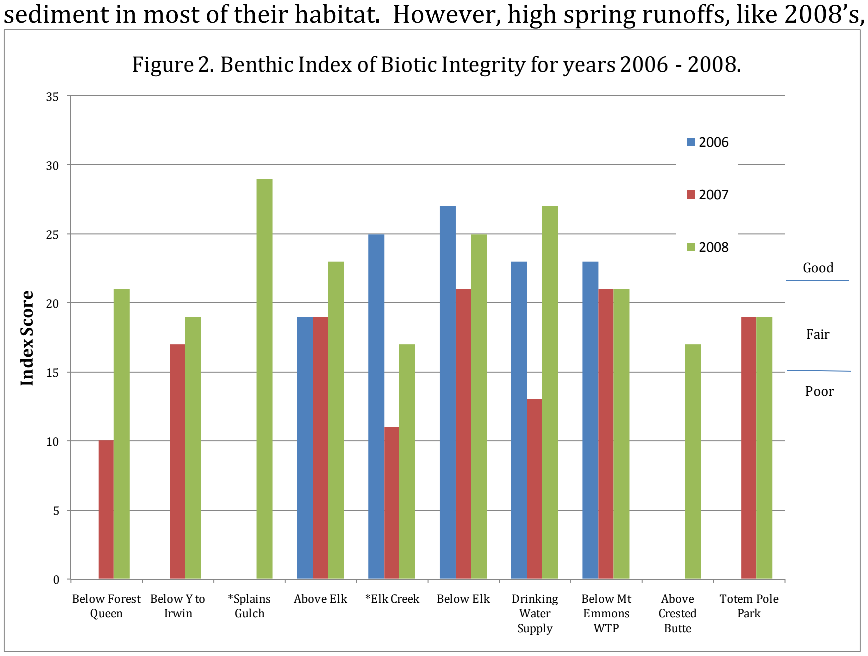


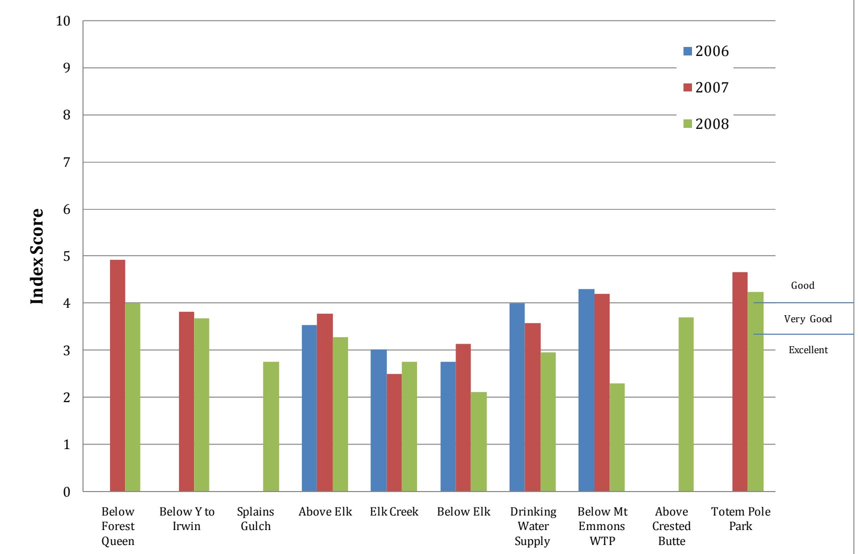
Figure 2. Benthic Index of Biotic Integrity for years 2006 - 2008.

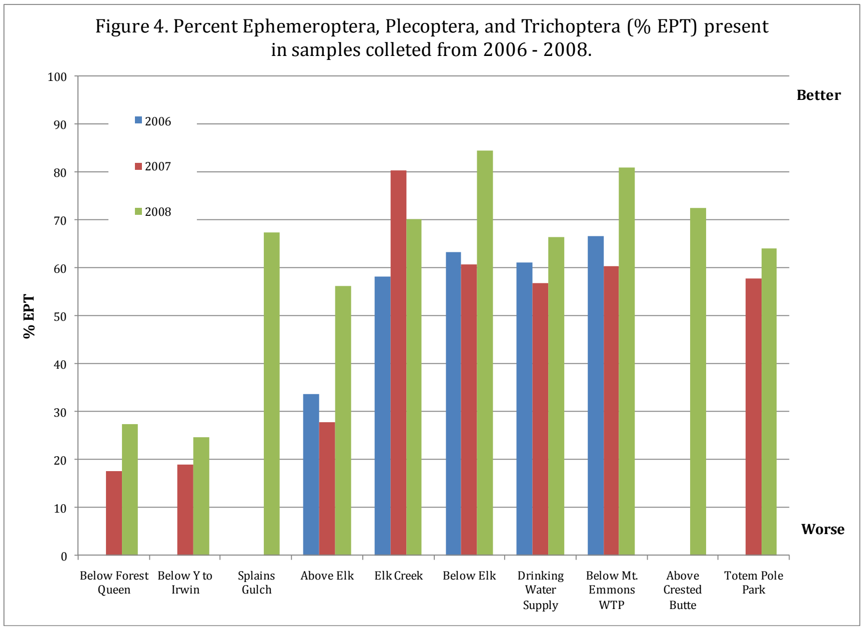
The best news the 2008 bio-monitoring data revealed was the partial recovery of Elk Creek and Coal Creek. This was due to the Standard Mine Superfund site remediation. In the summer of 2008, the EPA re-aligned Elk Creek into a newly constructed stream segment, creating riparian wetlands as a part of this process. The EPA finished reclaiming the Standard Mine site with soil amendments and revegetation with native plants. The CCWC's water quality monitoring shows improvements in Elk Creek and data shows that the macroinvertebrate community responded accordingly.

<u>Fore's Benthic Index of Biotic Integrity:</u> This metric was developed to evaluate the impact of heavy metals on aquatic insect populations. Our bio-monitoring indicates that Splains Gulch is the least impacted tributary, making it a good representative site to represent a healthy macroinvertebrate community in the Coal Creek Watershed. In Figure 3 lower scores indicate a decline in habitat quality in Elk Creek, as well as in several stations downstream in 2007. This could potentially be due to the disturbance of the site's conditions during the EPA's efforts to remediate the site (see Section 8 for details on these activities). The insect community appears to be healthier upstream of the Crested Butte drinking water supply intake in 2008. Due to the hardness added to the discharge from the Mt Emmons Water Treatment Plant, the site below the old Keystone Mine is very consistent for the aquatic insects. Additional hardness mitigates the effects of heavy metals on aquatic macroinvertebrates. However, downstream of the Keystone Mine, and towards the Town of Crested Butte, the quality of habitat declines slightly. The CCWC is still investigating whether this decline is due to a dilution of hardness downstream from the Mt. Emmons Water Treatment Plant or to pollution from another source.

<u>Hilsenhoff's Biotic Index:</u> The Hilsenhoff Biotic Index is used to determine if a stream is impacted by organic pollutants, such as those found in untreated human waste. Organic pollution often leads to a reduction in dissolved oxygen which can impair the ability of aquatic life to survive. Therefore, this metric indirectly measures the impacts of reduced levels of dissolved oxygen and of increased levels of nutrients such as nitrogen and phosphorus-based compounds. For this metric, a low score is better, while higher scores indicate worse conditions. Figure 3 demonstrates that the watershed is in generally very good to excellent condition and that organic pollutants do not significantly impact the watershed. These results are normal for a sparsely populated subalpine drainage. However, the site below the Forest Queen Mine, which is also just below the Town of Irwin, along with sites near Crested Butte, are only in good condition. This could possibly indicate slight effects from increased human activity. Overall, the sites' scores were healthier in 2008 than in 2006 and 2007.

Figure 3. Scores from the Hilsenhoff Biotic Index analysis of samples from the Coal Creek Watershed from 2006 - 2008.

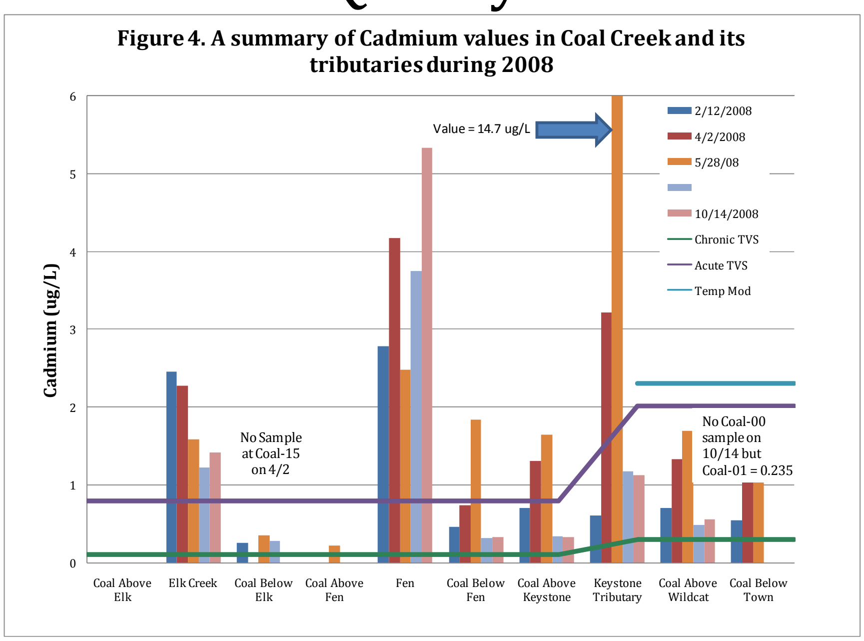




Percent EPT: This metric looks at some of the aquatic insects people are most familiar with, namely Mayflies (Ephemeroptera), Stoneflies (Plecoptera) and Caddisflies (Trichoptera). Once again, all sites show signs of improved water quality in 2008 (Figure 4). Based on this metric, the sites below the Forest Queen Mine and near the fork in Kebler Pass below Ohio Pass (labeled as the "Y" to Irwin in some charts) are in the worst condition of all sites sampled. Additional investigation is needed to determine the cause of this phenomenon.

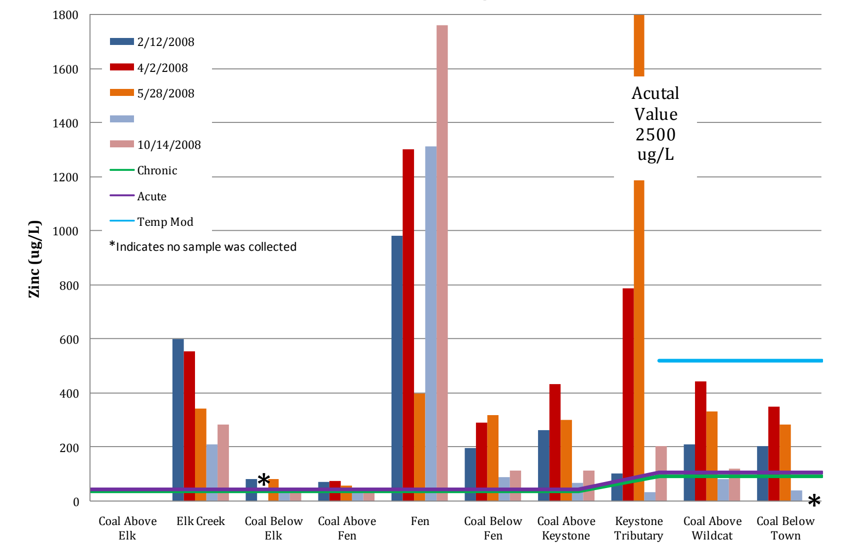
Conclusions: Bio-monitoring with aquatic insects has established some excellent baseline data on the condition of Coal Creek, Elk Creek and Splains Gulch. This data has led the CCWC to look for sources of contaminants near the Forest Queen Mine, the Irwin town site, and Crested Butte and will help shape future cleanup efforts in the watershed. We can also see that the Mt. Emmons Water Treatment Plant is essential to protecting stream fauna from the historic mining impacts in the area. Data analysis of both water quality and macroinvertebrate populations reveals the first examples of the recovery of the watershed from the Standard Mine Superfund cleanup. The Coal Creek Watershed Coalition website, http://coalcreek.org/, includes a full presentation of all of our macroinvertebrate analyses. Additional indices and analyses will be included as more data becomes available**.**

5. An Overview of Water Quality



Background: The CCWC expanded its sampling efforts in 2006 after hiring Coordinator Anthony Poponi to organize the CCWC's efforts. The CCWC began sampling in June of 2006 and followed this effort with sampling in August and October. Later in 2006, the EPA presented data from samples collected in April of 2006, which showed abnormally high metals concentrations in Coal Creek. Based on the April 2006 results, the CCWC expanded its efforts to include sampling in March and April 2007. Prior to these sampling events in February of 2007, the CCWC collected eleven samples over a fifteen-day period at a site downstream of the Town of Crested Butte at the Butte Avenue Bridge. These samples indicated that cadmium and zinc concentrations exceeded the chronic and acute standards, as well as the temporary modifications for this segment of Coal Creek. These acute TVS exceedances indicate Coal Creek's waters are capable of leading to acute toxicity and possible death of sensitive aquatic life during spring flushing events, if these conditions are maintained for a sustained period. The source of these metals could not be determined by the limited nature of the sampling effort and therefore could be linked to any or all of the known sources in the watershed. The CCWC continued to sample in 2007 during the peak flow in May and during lower-flow conditions in August and October. The EPA also collected samples at some of the CCWC's locations during June and September.

Figure 5. A summary of Zinc values in Coal Creek and its tributaries during 2008



Update: On February 12th and April 2nd of 2008 the U.S. Forest Service and CCWC representatives conducted sampling at several locations in the watershed to verify the findings of the 2007 sampling. The CCWC also sampled throughout the watershed in May, August and October and the EPA collected samples at some of the CCWC locations in June and September.

Figure 4 & 5 present cadmium concentrations collected from sites throughout the watershed in 2008. No metals were measured in any samples collected in Coal Creek immediately upstream of Elk Creek, but samples further upstream contain metals that are likely diluted by tributaries in Splains Gulch. Cadmium and zinc in Elk Creek, near the confluence of Coal and Elk Creek, consistently exceeded the chronic and acute standards for these metals. Metals concentrations slightly decreased in Elk Creek during 2008. For the first time, no cadmium was detected in samples collected in October below the confluence of Elk and Coal Creeks, possibly indicating that remediation efforts completed by the EPA during 2008 are leading to improved water quality. These findings will be discussed in more detail in Section 8 of this report.

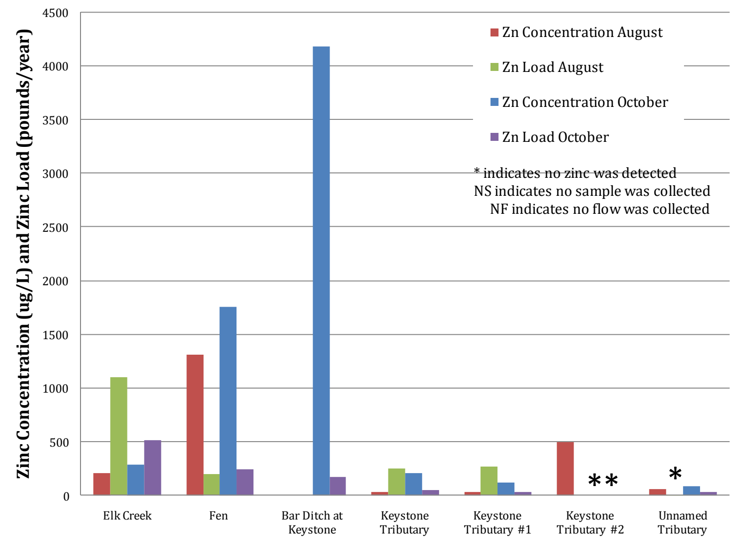
Metals concentrations from the main fen tributary are consistently high year-round and exceeded both standards in all samples collected. Water quality in the reach of the fen and Keystone Mine intermittently (February & April) increased below all known sources of metals associated with the fen. Metals in April and May samples, collected from a site receiving combined storm water and wastewater discharges, were higher than in any other month. The source of these metals has not been confirmed, but could be a combination of man-made and natural sources. These findings are discussed further in Sections 9 & 10 below. There are no known sources of cadmium and zinc downstream of the Keystone Mine and these metals' values decrease minimally as one moves downstream. Extensive water quality data including metal concentrations are available on our website.

Future Actions:

In 2009, the CCWC will be collecting more samples to better understand the results of the February and April 2008 sampling events. Other more specific actions will be discussed in other sections of this report.

6. Tributary Loading to Coal Creek

Figure 4. Zinc concentrations and loading to Coal Creek from samples collected in August and October 2008.



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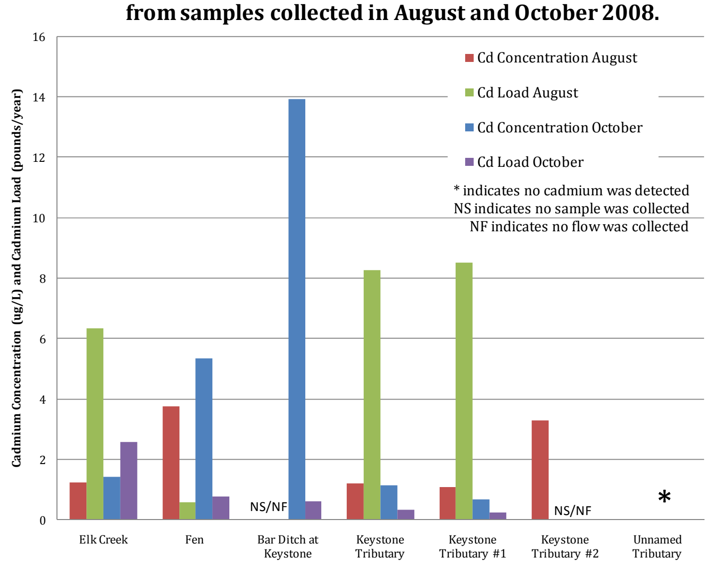
Many of the metals delivered to Coal Creek come directly from tributaries and from diffuse sources adjacent to Coal Creek. Figure 3 and Figure 4 show cadmium and zinc concentrations and loading from tributaries known to contribute metals to Coal Creek. Cadmium concentrations in these tributaries and amount of metals loaded to Coal Creek not always consistently mimic each other in individual tributaries. For example, Elk Creek had lower metals concentrations compared to other tributaries in the watershed. However, due to the volume of Elk Creek, it contributed a much higher amount of cadmium to Coal Creek than the bar ditch adjacent to the Keystone Mine, even though concentrations in the bar ditch are nearly ten times higher. Similarly, the main fen tributary contributes less cadmium and zinc to Coal Creek than Elk Creek due to flow. Other tributaries like Splain's Gulch, Wildcat Creek, and "Unnamed Tributary" (downstream of all Keystone tributaries) have not been documented to have significant concentrations of metals. Regardless of source, cadmium values in waters in Coal Creek at almost all sites downstream of the confluence of Elk Creek continue to exceed the chronic standard established by the State of Colorado.

Figure 3. Cadmium concentrations and loading to Coal Creek from samples collected in August and October 2008.



__Future Actions:__ Understanding the quantities of metal loading from each tributary source helps clarify where the largest reduction in metals loading could be achieved. The CCWC will continue to verify the loading estimates presented in this section. Elk Creek remains the largest contributor of cadmium and zinc; efforts to remedy the draining adit at the Standard Mine should remain a priority since adit discharges are the sole remaining source of metals affecting Elk Creek. Further discussion of these findings will be addressed in the relevant sections in this report.

7. Forest Queen Mine

Background: The EPA's Assessment Team collected water and sediment samples from the Forest Queen Mine in the spring and summer of 2006, to assess the impacts of the Forest Queen Mine and adjacent mine related contaminants. Water quality results indicated metals concentrations were elevated downstream of the site but did not present a considerable risk to aquatic or human uses. However, sediments at the site frequently exceed the guidelines established as thresholds for aquatic life.

Update: In September of 2008, the CCWC with the aid of Steve Renner and Tara Tafi from the State of Colorado's Division of Reclamation Mining and Safety conducted a survey of waste piles and other contaminant sources. The intent was to measure the volume of waste piles and to collect samples from any draining adits on site. Twelve waste piles were measured and volumes were estimated. Approximately twenty industrial batteries associated with other recent mine related equipment, debris, and refuse were found near the Forest Queen adit. Water samples were collected from four sites during September of 2008 (Figure 5). Samples were analyzed for 22 metals commonly found in surface waters in the Watershed. Only arsenic was present at levels of any concern in these samples. Lead, manganese, and zinc were detected in surface waters at levels not warranting much concern.

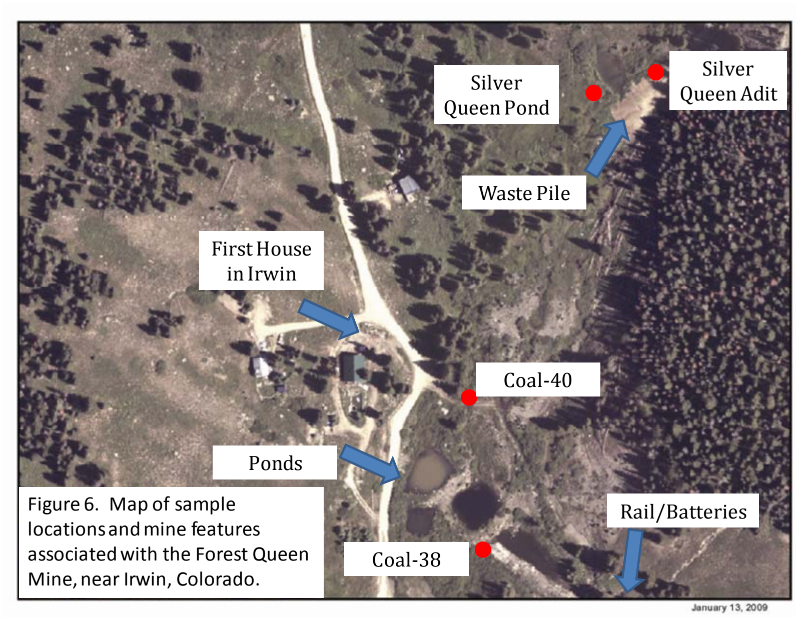


Figure 6. Map of sample locations and mine features associated with the Forest Queen Mine, near Irwin, Colorado.

To refine our understanding of the Mine's impact on water quality, the CCWC added a water sampling site downstream of all known potential sources of contamination associated with the Forest Queen Mine. Throughout 2008, two samples were collected at this site and only arsenic was present at levels of concern to human uses, such as drinking water. Of the six contaminants of concern for the Coal Creek Watershed, only manganese was detected in 2008 and at levels well below applicable water quality standards. The EPA has set a maximum contaminant level (MCL) for levels of arsenic in raw drinking water sources. The MCL was exceeded in Coal Creek downstream of the Forest Queen site on the two occasions it was measured in 2007, but not in either of the samples collected in 2008. Arsenic has never exceeded the MCL at the Town's drinking water diversion in any of the sixteen samples the CCWC has collected dating back to 2006. The chronic and acute aquatic life standards have never been approached in any of the samples collected from this site.

Contaminated sediments remain the primary concern at the Forest Queen Mine: arsenic levels in sediments collected at and around the site exceed the guidelines established for these metals. Sediment samples were collected from Coal Creek and from pond and wetland features adjacent to the Forest Queen Mine. Impacts to Coal Creek and these wetland features are discussed below. The discussion does not include the effects below the confluence with Elk Creek, since impacts from the Standard Mine Superfund Site affect sediment quality in Elk Creek and Coal Creek sites downstream of the confluence of these two streams.

During both high-flow and low-flow conditions, arsenic concentrations in sediments collected in Coal Creek downstream of the Forest Queen Mine and in wetland features adjacent to the mine consistently exceed the probable affects level (PEL) and interim sediment quality guidelines (ISQG). The exceedances are found at locations in Coal Creek as far downstream as the next known source of metals contamination in the Watershed, Elk Creek. Arsenic values at these sites approach or exceed the Severe Effects Limit (SEL) for benthic dwelling organisms. Cadmium concentrations in sediments do not consistently exceed the ISQG. The PEL and SEL for cadmium were not exceeded in any sites impacted by the Forest Queen Mine. Copper does not exceed any of the established standards. Lead, mercury, and zinc frequently exceed the ISQGs and the outflow of one wetland exceeds the PEL. (NOTE: These sediment guidelines can be reviewed by visiting (NOTE: These sediment guidelines can be reviewed by visiting NOAA's website where the guidelines are discussed in detail.)

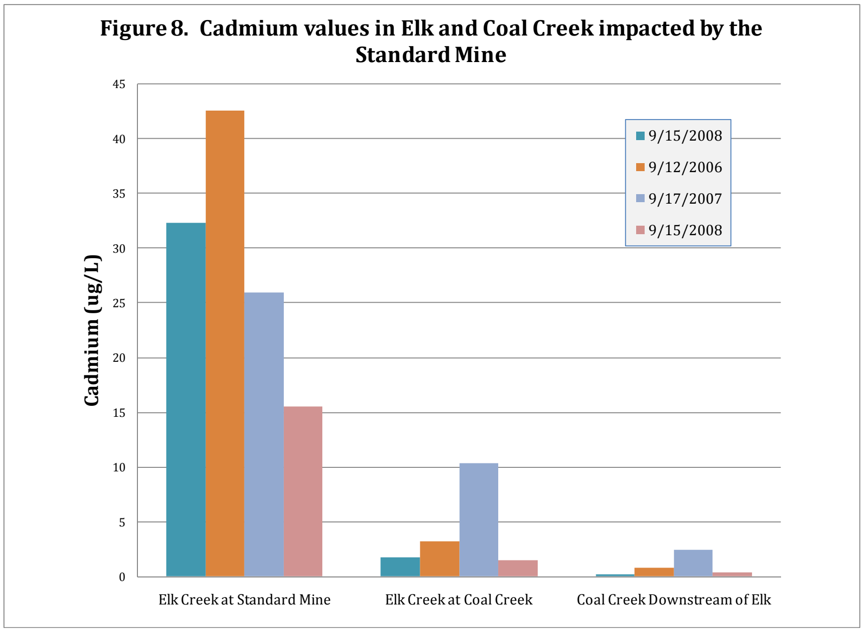
Future Actions: Considering the findings from the 2008 water samples and their consistency with historic EPA data, the focus for 2009 and beyond will be on sediments. The Division of Reclamation Mining and Safety has secured funds to assess sediments and waste piles and also to remove and dispose of industrial batteries left at the Forest Queen Mine site. Both efforts will be conducted in the spring and summer of 2009. Results from the sediment sampling will be used to determine if future removal of contaminated sediments or waste piles is warranted.

NOTE: Information on the Forest Queen Mine and other abandoned mines will be presented in greater detail in the near future as a separate report.

8. Standard Mine Remediation

Update: In 2008, the EPA Superfund Program completed its third year of remediation work at the Standard Mine site in the Elk Creek Basin. In 2007, a portion of the waste rock and tailing materials from the site were removed and placed in a permanent repository isolated from surface water sources to reduce acid mine drainage production. In 2008, the remainder of these materials were relocated to the repository and a permanent cap was placed on the site. A cap prevents water from reaching the waste materials and thus prevents acid mine drainage from being produced. In all, over 44,000 cubic yards of contaminated materials were moved off site. Level 1 of the Standard Mine, where most of the waste materials were removed, was re-graded and vegetated with native seeds. Elk Creek historically flowed through contaminated waste materials and into a tailings pond full of metals-rich mill tailings. In 2008, the Creek was rechanneled to mimic a natural stream and re-vegetated with native plants appropriate for the climate and hydrology of the site (Figure 7). Cadmium and zinc values in Elk Creek near the Standard Mine were dramatically

Figure 7. A view of the new Elk Creek with fallen trees, rock features, and vegetation incorporated into the design to mimic a natural creek.



reduced in 2008 (Figure 8). Contributions of clean water by several springs and lake outfalls reduce the overall concentrations of metals as Elk Creek approaches its confluence with Coal Creek. Zinc concentrations did not consistently show a reduction in 2008 when compared to previous years (Figure 8). Cadmium and zinc concentrations in the adit discharge at Level 1 of the site are frequently over 100 ug/L for cadmium and over 25,000 ug/L for zinc and this discharge remains a considerable source of metals in Elk Creek considering the chronic standards of 0.1 ug/L and 52 ug/L for cadmium and zinc, respectively.

Future Actions: Addressing metals concentrations in the adit discharge remains the most important remaining piece of the remediation of the Standard Mine. The Colorado Division of Reclamation, Mining, and Safety, in conjunction with the United States Geological Survey, conducted a study of the surface and groundwater flow patterns associated with the Micawber fault, which runs through much of the Standard Mine. The study's goal was to understand the movement of water along the fault and to try to predict how flows entering the fault zone could be controlled. Clean water enters the fault zone and can become contaminated if it comes in contact with mineralized areas underground. Controlling these sources of clean water could prevent contamination and reduce adit discharges.

The EPA continued to collect samples from the sulfate-reducing bioreactor, passive wetland system installed by the EPA in 2007. This man-made wetland is still being explored as a method to remove metals from the adit discharge. It currently removes some metals at ratios exceeding 90%. More results on the effectiveness of this system and the Chito-REM system being employed for the same purpose are expected in 2009.

The CCWC will continue its water quality monitoring along Coal and Elk Creeks to document improvements in water quality as a result of the EPA's remediation work. The Standard Mine Technical Advisory Group (formed by members of the CCWC) will continue to monitor progress at the Standard Mine site to ensure the EPA's remediation goals are consistent with the needs of the community and the watershed's wildlife. More information on the Standard Mine Superfund Site can be found on the EPA's website: http://www.epa.gov/region8/superfund/co/standard/.

9. Fen Contributions to Water Quality

Background: Fens are unique types of wetland found throughout the world. The fen in the Coal Creek Watershed is estimated to be over 8,000 years old and supports many species rare to Colorado, including certain species of dragonflies, fungi and a carnivorous plant called the Roundleaf Sundew. This species of sundew had been documented as occurring in only one other location in Colorado. The fen is also unique in that the groundwater sources feeding the fen come in contact with mineralized materials, creating acid rock drainage similar to acid mine drainage. Acid rock drainage differs from acid mine drainage in that the mineralization of the water occurs naturally and is not due to human activities, such as mining. These mineralized waters enter Coal Creek through several tributaries, though one main perennial tributary

Figure 10

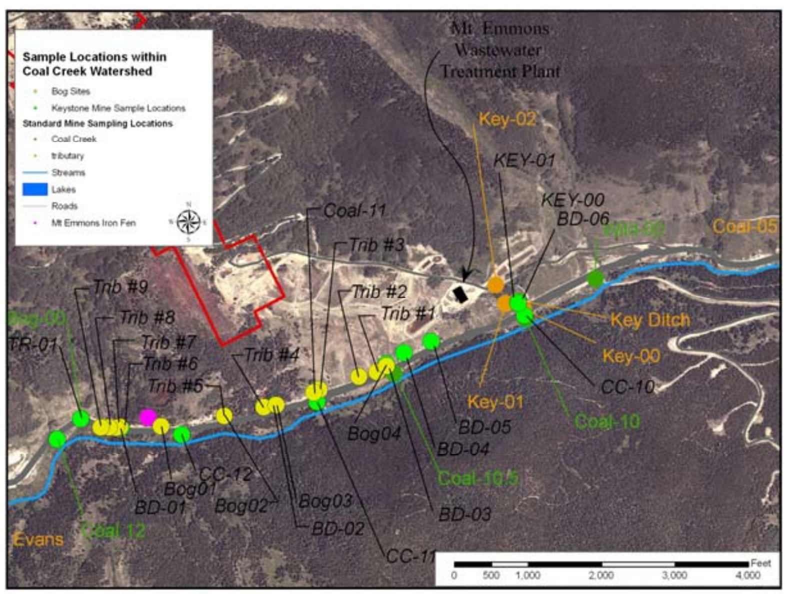
Figure 9. One of nine tributaries found adjacent to the fen. Note the red discoloration, which indicates potential acid rock or acid mine drainage.

delivers the bulk of the flows and metals to Coal Creek. Other seasonal tributaries deliver metals-rich waters to Coal Creek in the spring.

Update: Figures 3 and 4 show the fen does load metals to Coal Creek, although not at levels as great as other sources in the watershed. The CCWC collects samples in Coal Creek to characterize water quality conditions both upstream and downstream of the fen. During the sampling conducted in February and April 2008, water quality is slightly degraded at the sample sites downstream of all fen sources ("Coal Above Keystone", Figures 1 and 2). These results suggest another unknown source of metals, such as groundwater or a seasonal tributary, is affecting water quality.

In the spring of 2007, the CCWC conducted sampling to characterize water quality conditions as the first pulse of snowmelt started reaching Coal Creek. During this time, the CCWC noticed these seasonal tributaries. In 2008, the CCWC set out to characterize these tributary sources to ensure that it had properly located the sampling site downstream of all know fen contributions (named "Coal-11" or "Coal Below Fen" in charts). In May of 2008, nine different tributaries were located upstream of the site called "Coal Below Fen". Flows from these nine tributaries reach Coal Creek via five culverts. The CCWC collected samples and physical characteristics, such as flow and water chemistry, from each of the culverts as shown in the map below.

Table 1 shows the results of monitoring conducted during May of 2008. Tributary flows reaching Coal Creek through the Bog-01 culvert accounted for 76% of the cadmium and 74% of the zinc loading delivered to Coal Creek downstream of the perennial tributary Bog-00. Although the perennial tributary Bog-00 was suspected of contributing the most flow and loading to Coal Creek, the flow data for this site was not recorded and therefore leaves open the possibility of this being the largest contributor of metals along this reach of Coal Creek.



Future Actions: It is possible that remediation efforts at the Standard Mine will dramatically reduce metals concentrations in upstream segments of Coal Creek and bring these segments into compliance with applicable standards for water quality. This remediation could allow Coal Creek to assimilate the fen's metal contributions without causing exceedances downstream. The EPA and the community will work to establish realistic remediation goals based on achievable results over the summer of 2009. The final remediation goals could play a significant role in reducing the overall impacts of other metals sources downstream such as the fen.

Table 1. Loading calculations from sampling conducted by the Coal Creek Watershed Coalition on May 28, 2008.

	Flow (cfs)	Gallons Per Minute	Cadmium (ug/L)	Cadmium Loading (lbs/day)	% Of Load	Zinc (ug/L)	Zinc Loading (lbs/day)	% Of Load	pH
Bog-00	NF	NF	2.48	0	NF	398	NF	0%	5.36
Bog-01	0.71	320	15.8	0.06	19%	2440	9.4	19%	3.95
Bog-02	0.12	55	0.847	0	0%	246	0.2	0%	6.01
Bog-03	0.43	195	102	0.24	76%	15300	35.9	74%	3.55
Bog-04	0.18	79	13.4	0.01	4%	3430	3.3	7%	4.86
Total Load to Coal Creek				**0.31**			**48.8**		

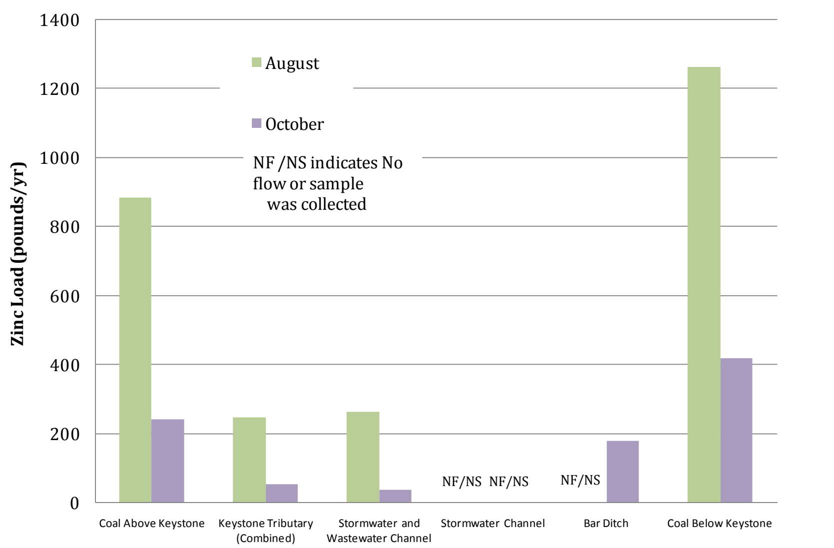
NF = indicates flow was not measured.

Beyond determining the loading from each tributary, the source of these metals remains unknown. Are these tributaries derived from surface or groundwater associated with the fen, Keystone Mine workings or tailings, other natural sources, or some combination of all three? This question needs to be answered to help guide where the efforts of the CCWC can best be applied. In 2009, the CCWC will collect samples at all of the nine tributaries it located in 2008 in order to characterize the contributions from each of these sources. Each tributary will be traced to its source, with the intent of determining the origin of the flow wherever possible.

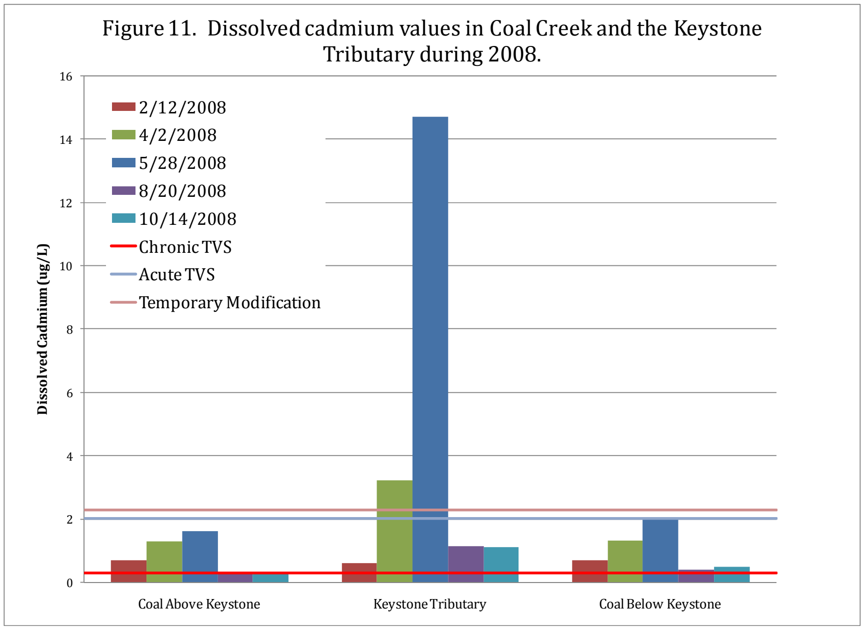
The historic flow patterns of the fen were altered at some point and could be contributing to higher surface water flows entering Coal Creek. The CCWC will investigate the possible restoration of historic surface flows near the fen to see if this would reduce metals loading to Coal Creek.

10. Historic Keystone Mine

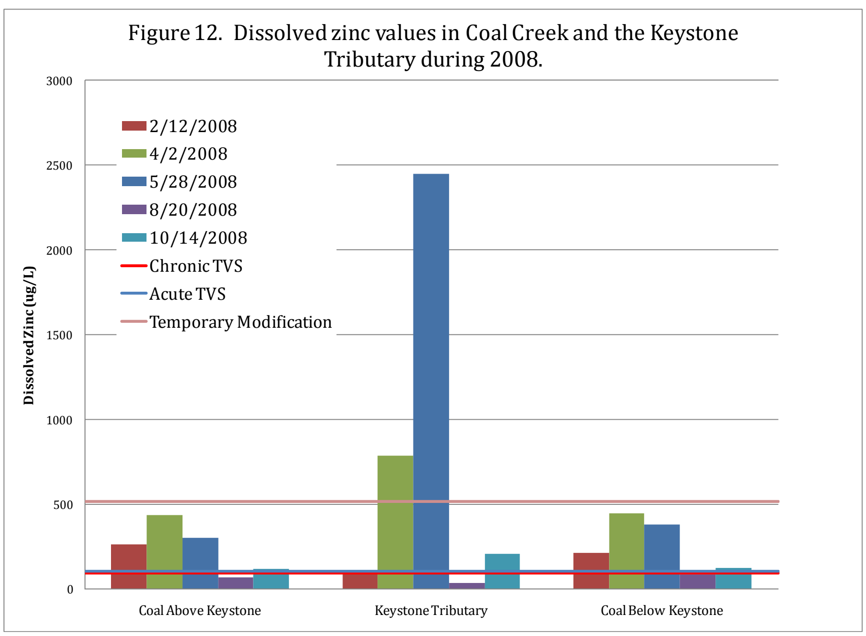
Figure 10. A summary of zinc loading from tributaries associated with the Keystone Mine in August and October of 2008.



Background: In April of 2006, the EPA collected samples from six sites in the Watershed. The results from the sampling indicated that in spring conditions tributaries leaving the Keystone Mine had levels of metals elevated above those seen at other times of the year. In 2007, the CCWC conducted sampling in the watershed to refine its understanding of water quality conditions and found similar impairments of water quality conditions in storm water leaving the historic mine area. Whether the sources of these metals are natural, man-made, or some combination of both sources has yet to be determined.



Update: In February, April, and May of 2008, the CCWC again sampled throughout the watershed to document low-flow conditions during the winter and conditions when temperatures and snowmelt start increasing in the spring. Figure 10 shows zinc loading from tributary sources in segments of Coal Creek adjacent to the historic Keystone Mine. Flows from the "Stormwater and Wastewater Channel" and "Stormwater Channel" combine to form the tributary labeled "Keystone Tributary." The "Bar Ditch" flows down Kebler Pass Road and joins with Keystone Tributary flows downstream of Kebler Pass Road. The Bar Ditch was flowing in October but not in August, indicating snowmelt is not the only source of these intermittent flows. However, as Figure 10 shows, the zinc loading to Coal Creek during October was significant even though the flows from the Keystone Tributary were five times greater than in the Bar Ditch. Hardness values in the Bar Ditch hint at subsurface connectivity to the Stormwater and Wastewater Channel, but cadmium and zinc values are orders of magnitude higher than in what is measured in this channel. This indicates there is likely another source of metals affecting water quality in the ditch. The source of any of the metals associated with the tributaries in Figure 10 has not been determined. The result is that Coal Creek is becoming further degraded due to metals inputs from these undetermined sources.



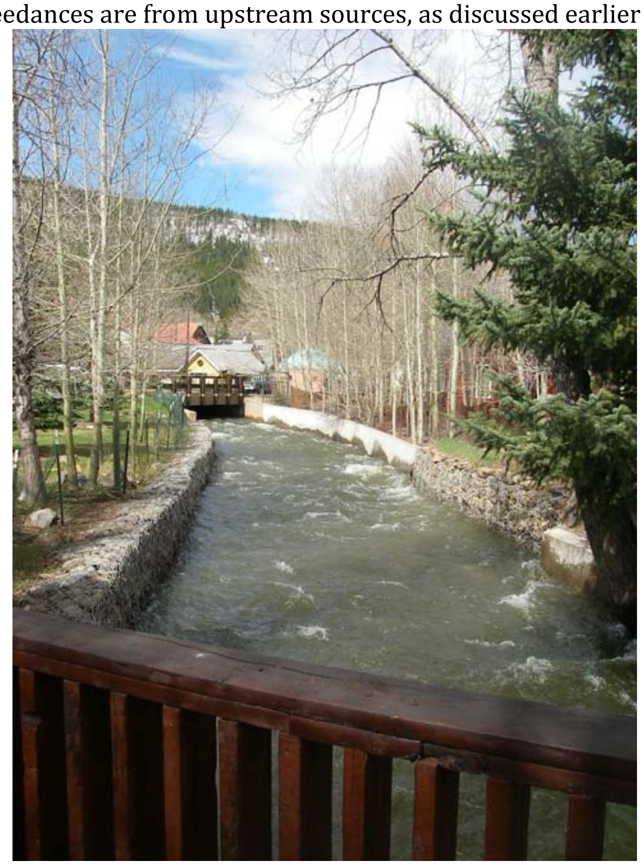
Figures 11 and 12 show cadmium and zinc values near the historic Keystone Mine during 2008. (NOTE: Samples collected in February and April were taken at Coal-05 and not at Coal-06). Cadmium and zinc values typically increase slightly downstream of the Keystone Mine. Standards and the temporary modification values continue to be exceeded downstream of the mine, even despite the fact that these standards are higher than in other segments of Coal Creek.

Future Actions:

The CCWC will continue to work towards determining if the source or sources of contamination in storm water are present during the winter season. In the spring of 2009, the CCWC will conduct more detailed sampling throughout this stretch of the watershed in order to refine our understanding of water quality impairments. The CCWC will continue to discuss findings with the proponents of the molybdenum mine on Mt. Emmons Project to determine the source(s) of contamination and determine remedies where appropriate.

11. Town of Crested Butte

Update: The Town of Crested Butte diverts and treats water from Coal Creek to be used as drinking water. The CCWC continued to monitor water quality upstream and downstream of the Town of Crested Butte to characterize the Town's contribution to water quality issues in Coal Creek. Past sampling indicates the Town of Crested Butte does not contribute cadmium and zinc to Coal Creek. However, at times water quality in this stretch of Coal Creek exceeds the chronic TVS for cadmium and both the chronic and acute standards for zinc. These exceedances are from upstream sources, as discussed earlier in this document in Sections 8.



Future Actions: Storm water's effect on water quality in Coal Creek forms the main concern in this reach of Coal Creek. Such contributions may include contaminants like suspended solids (such as sand, grit and dirt), residentially applied pesticides and fertilizers, pet waste, and automobile byproducts. Such contaminants are thought to be delivered to Coal Creek through the Town's storm water collection system as well as through other dispersed sources. With funding from the State's Non-Point Source Program, the CCWC is collaborating with the Office for Resource Efficiency and Colorado State University's Extension Office to implement a program to reduce household contaminants entering local waterways. The Water Wise workshop was offered in May of 2009 to educate residents on the impacts of residential sources of non-point sources. As part of the Workshop, "Home Kits" will be provided to participants to help prevent future contamination from these sources. Water diversions downstream of Totem Pole Park in Crested Butte may also affect water and habitat quality.

12. Nutrients

Background: The long-term historical data available for Coal Creek is limited to one point on Coal Creek downstream of the Town of Crested Butte. This data indicates nitrate-nitrite and phosphorus is not trending upward in Coal Creek as we move downstream or from year-to-year. Typically, lab results do not detect these nutrients in the samples or detect them at levels only slightly above the detection limits (Nitrate-Nitrite =0.05 mg/L and Total Phosphorus = 0.020 mg/L) for the analytical instruments employed in the analysis. Low levels of nutrients are expected in a subalpine watershed like the Coal Creek Watershed.

Update: Samples collected in 2007 and 2008 detected phosphorous at two sites: one at a location downstream of the town site of Irwin and another just upstream of the Keystone Mine.

Future Actions: The CCWC will continue to monitor phosphorus levels in Coal Creek and work towards remediating any sources so detected. To this end, the CCWC will collaborate with Gunnison County's Environmental Health Office to refine our sampling program to identify the sources of these contaminants.

13. Microbes

Background: Harmful microbes, like E. coli, Cryptosporidium and Giardia, are removed from drinking water through treatment processes, but can be ingested through contact during common recreational activities. In the case of Coal Creek, these harmful microbes are introduced naturally by wildlife as well as by humans, through improper waste disposal from camping and potentially from individual sewage disposal systems.

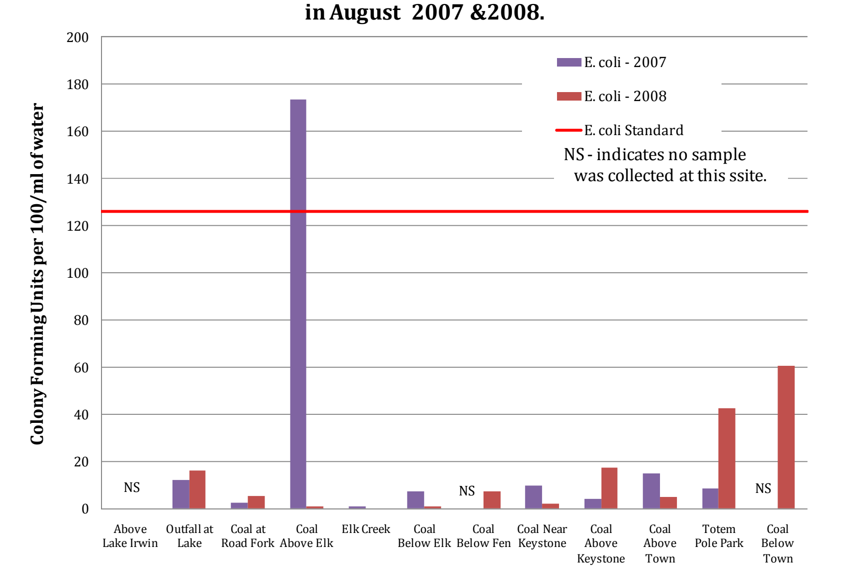


Figure 13. Total coliform and fecal coliform data from sampling in August 2007 &2008.

Update: None of the samples collected in 2008 reported E. coli values exceeding the standard for E. coli. Sampling results from 2008 indicated some increases in E. coli along the stretch of Coal Creek that travels through the Town of Crested Butte (Figure 13). Sampling results were not available downstream of the Town in 2007 due to diversions that dried the Creek.

Future Actions: With funding from the State's Non-Point Source Program, the CCWC has entered into a collaborative effort with the Office for Resource Efficiency and the Colorado State University Extension Office to implement a program to reduce household contaminants entering local waterways. A workshop was offered in May of 2009 to educate residents on the impacts of residential sources of non-point sources. As part of the event, a "Home Kit" will be provided to help prevent future contamination from these sources. The CCWC has also entered into a cooperative agreement with the Gunnison County Environmental Health Office to collaborate on monitoring water quality in the townsite of Irwin and to address any water quality issues arising from that effort.

For more information please visit our website: www.coalcreek.org

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15. Acknowledgements

Special thanks go out to all of the volunteer board members and advisory committee members of the Coal Creek Watershed Coalition and the organizations, agencies, businesses, and municipalities they represent. Their individual commitment to the efforts of the CCWC and their dedication to the restoration of the Coal Creek Watershed are critical to the organization's success.

These agencies have provided invaluable aid to our organization, both in funds and in-kind services:

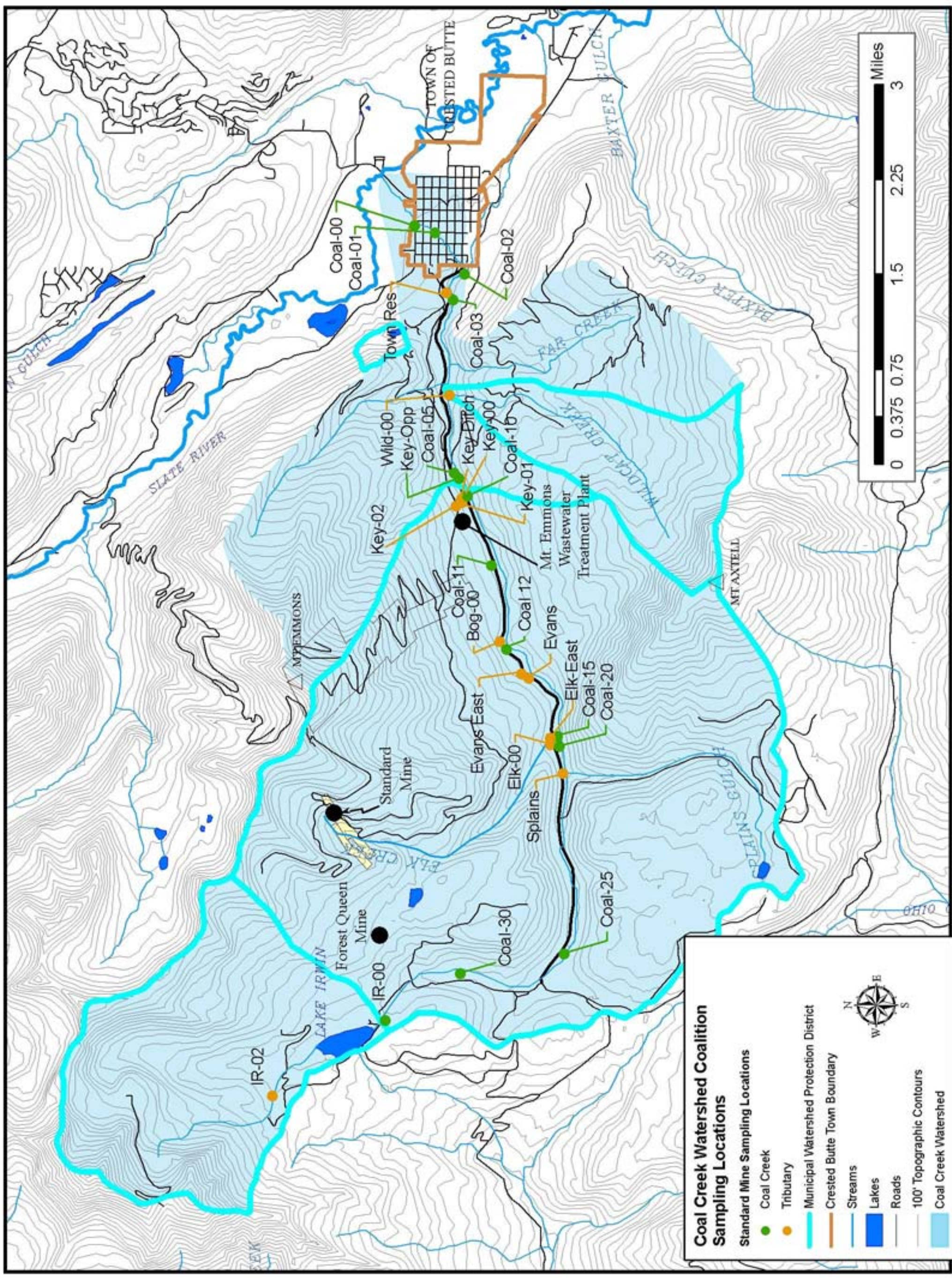
High Country Citizens' Alliance helped organize the Coal Creek Watershed Coalition in 2003 and remains a valuable partner. The State of Colorado's Division of Reclamation Mining and Safety Inactive Mines Reclamation Program provides one-half the stipend for the Americorps*VISTA member to work with the Coal Creek Watershed Coalition and other staff and financial support. Rock Mountain Biological Laboratory helps the Coalition with aspects of identification of problem areas and scientific data needed for remediation. Gunnison County provides the Coalition with GIS assistance and expertise on County regulations. The U.S. Forest Service commissioned the first evaluation of the Standard Mine, owns most of the land in the watershed and is heavily involved in the cleanup at the Standard Mine. The Mt. Emmons Project is a project cooperator on sampling efforts and attends our meetings.

Funding for the CCWC comes largely from the State of Colorado's Non-Point Source Program, Town of Crested Butte, Upper Gunnison River Water Conservancy District, Gunnison County, and the Colorado Healthy Rivers Fund. The Town of Crested Butte provides office and meeting spaces, fiscal and administrative services, reporting services for the grant, and project oversight.

The U.S. Environmental Protection Agency generously donates water sample laboratory analysis services and assists in water sampling training and field measurements. The Colorado Department of Public Health and the Environment assists in water sampling training and field measurements. Thanks also go out to Dr. Joseph Ryan at the University of Colorado and his crews for their work within the watershed and to the University of Colorado's Community Outreach Program for their funding of this program. Matt Mallick of the National Park Service and his staff also provide invaluable assistance to CCWC's sampling program in the form of equipment and labor. Additionally, Western State College provides office space for the organization in Kelly Hall.

16. Appendices

Appendix A: MAP A - Coal Creek Watershed Coalition sampling locations.



Appendix B: GPS Locations and Narrative Descriptions of Sampling Site Locations

Site Name	Latitude	Longitude	Description:
Coal-00	38 52 24.2 N	106 59 02.9 W	Sample just upstream of pedestrian bridge on Butte Ave. Access the site by crossing over to the north side of the bridge and head west.
Coal-01	N/A	N/A	Totem Pole Park in Crested Butte near the intersection of 3rd Ave and Maroon Ave. Sample downstream of bridge to allow for mixing of storm water discharge at the bridge.
Coal-02	38 52 03.33630 N	106 59 28.11882 W	Coal Creek upstream of town of Crested Butte on Kebler Pass Road. Before crossing a bridge on County Road 12 make a left onto a dirt pull off just before the bridge. Creek access point is about 100 meters from the paved road.
Coal-03	38 52 07.9 N	106 59 41.7 W	Upstream of irrigation ditches from Coal02. Access the same way as Coal02 but continue past the first metal diversion and to the second wooden diversion.
Town Res	38 52 10.7 N	106 59 38.2 W	The site is located along the south side of Kebler Pass Road with the water pooling on the north side of the road and reappearing on the south side with no culvert visible in the area. Sample on the south side of the road.
Wild-00	38 52 08.7383624 N	107 00 32.0216044 W	Follow Kebler Pass Road out of Crested Butte past mile marker 31. Look on left hand side of road (south side) for a drainage culvert and parking pullout (small) about eight-tenths of a mile past marker 31 on the right. Wildcat Creek comes in from the south. Hike down from the parking area and walk upstream 50 meters.
Coal-05	38 52 06.3 N	107 01 13.3 W	Coal Creek approximately 10 meters downstream of Wildcat Trail bridge. Access site at junction of Wildcat Trail Road and County Rd. 12. Park at pull off alongside Wildcat Trail Road and hike down to site.
Key-Opp	N/A	N/A	Tributary upstream of Coal-05 and Wildcat Trail bridge. Enters Coal Creek from the north but is downstream of the winter trailhead and all "Key" tributaries.
Key-00	38 52 02.1009279 N	107 01 25.6221196 W	Aprroximately 3 meters upstream of Kebler Pass Road below the confluence of Key01 and Key02 flows.
Key Ditch	38 52 03.1 N	107 01 26.7 W	While sampling at Key00, which flows under Kebler Pass Road via two black culverts, another metal culvert was noticed just a few feet to the west. It's flows come from the west via a bar ditch and travel under the road where they spill out and join with the Key00 flows.

Appendix B Continued.

Key-01	38 52 02.8 N	107 01 28.7W	Key00 flows separate into two flows about 15 meters up the hillside from Kebler Pass Road. The left fork (western) segment of the stream (named Key01) contains the discharge from the plant. The right fork was sampled from a culvert crossing under the road to the waste water treatment plant (Key02).
Key-02	38 52 05.3 N	107 01 30.5 W	Key00 flows separate into two flows about 15 meters up the hillside from Kebler Pass Road. The left fork (western) segment of the stream (named Key01) contains the discharge from the plant. The right fork was sampled from a culvert crossing under the road to the waste water treatment plant (Key02).
Coal-10	38 52 00.7538097 N	107 01 25.1594691 W	Coal Creek approximately 100 meters upstream of Keystone Mine WWTF outfall. Access site in the same way as Coal-05. Look for two yellow-colored poles with blue tops that mark the drinking water intake.
Coal-11	38 51 50.4 N	107 02 01.5 W	Stake along roadside 50 meters upstream of 4x4 road heading down to creek. This site is downstream of 3rd outfall possibly receiving inputs from the fen. Use 4X4 road for access. (Site formerly called Bog-01)
Bog-00	38 51 46.4086067 N	107 02 41.4463833 W	Iron bog outfall at Kebler Pass Road. The site is 800 ft. downstream of mile marker 28. Look for the culvert jutting out from side of road below beaver pond segment of creek.
Coal 12	38 51 43.5 N	107 02 45.6 W	One tenth of a mile upstream of Bog00 outfall. There is a parking area on the left (south) side of road. Follow small trail down to water. Look for two dead clusters of trees on south bank of stream.
Evans East	38 51 37.2 N	107 02 58.3 W	Flows go under Kebler Pass Road via a culvert marked by tall green metal stake markers. This culvert gets flows from the west coming along the bar ditch and from flows running down the hillside above the culvert.
Evans	38 51 34.2 N	107 03 00.6 W	This tributary's flows originate up the hillside flowing under the pedestrian bridge and do not receive flows from bar ditch. This site is ~100m east of the Evans site but west of the road to the gravel pit.
Coal-15	38 51 21.9172275 N	107 03 31.0521244 W	Coal Creek 100 meters downstream of Elk Creek confluence. Sample where water is well-mixed. Look for 4X4 trail leaving parking lot to the south and east. Look for stake by stream.
Elk-00	38 51 24.8466503 N	107 03 35.3476869 W	Elk Creek at CO-12 crossing approximately 100 meters upstream of confluence with Coal Creek just above Kebler Pass Road.

Elk-East	N/A	N/A	Tributary in the small basin east of Elk Creek. Enters Coal Creek from the north. Samples collected just above the road where the culvert delivers water under Kebler Pass Road.
Coal-20	38 51 21.1913996 N	107 03 36.4514664 W	From parking lot walk upstream past Elk Creek then head towards Coal Creek. A stake is in an opening approximately 20 meters upstream of a cluster of conifers at the confluence of Elk and Coal. Look for the stake near a fir leaning across creek.
Splains	38 51 19.5327688 N	107 03 50.6560663 W	Sample 15 meters upstream of the mouth of the strea where it is not braided.
Coal-25	38 51 17.6119073 N	107 05 25.4994864 W	Coal Creek downstream from Independence and Anthracite/Ruby confluence. Access site before right-hand turn to Irwin Lake. Look for a short road that ends at a dirt mound that heads toward Coal Creek from CO-12. Sample approximately 15 meters upstream of culverts.
Coal-30	38 52 0.3648 N	107 5 37.068 W	Coal Creek downstream of Irwin and the Forest Queen mine workings. Park along the roadside near the clump of trees adjacent to the sample site.
IR-00	38 52 30.8936644 N	107 06 02.3429267 W	Lake Irwin outfall approximately 75 meters downstream of pump house. Access site by driving up Irwin Townsite road. The road will make a sharp left-hand turn about 50 meters down gradient of the lake shoreline. Park across from the pumphouse along the trees' edge and walk about 50 meters east along the trees to find the flume.
IR-02	38 53 16.65412 N	107 06 43.34314 W	Inflow to Irwin Lake upstream of all mining activity and the lake. Take road toward Irwin Lake Lodge until you reach an Irwin Lake inflow culvert just upstream of a small stream crossing. If you get to the winter cabin you've gone too far.

Appendix D: Summary of Colorado Department of Public Health and Environment Table Value Standards for Coal Creek.

Segment	Description	Mean Hardness	Cadmium		Copper		Lead		Manganese		Zinc	
			Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute	Chronic	Acute
9	Mainstem of Coal Creek above the conflunce with Elk Creek.*	36	0.2	1.1	3.7	5.1	0.8	20.9	1174	2124	52	60
11	Mainstem of Coal Creek below the confluence with Elk Creek.	24	0.1	0.79	2.6	3.5	0.5	13.3	1025	1856	37	42
12	Mainstem of Coal Creek below the drinking water diversion.**	70	0.3	2.01	6.6	9.6	1.7	43.7	1465	2651	92	106

Note: All TVS are in micrograms per Liter (ug/L). Hardness is presented as miligrams per Liter (mg/L).

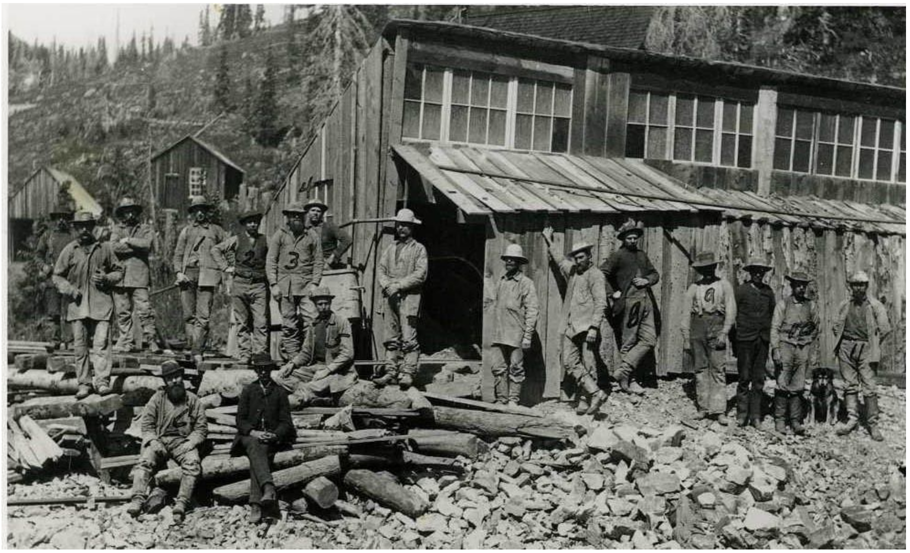
*The State does not have hardness data for Coal Creek and its tributaries upstream of the confluence with Elk Creek (Segment 9). Through 2007 the CCWC dataset includes 40 samples in this segment with an average hardness of 36.4 mg/L which is used above to calculate the Table Value Standards for this segment.

**Due to existing conditons in Segment 12 of Coal Creek the State of Colorado has put Temporary Modifications in place for cadmium (2.3 ug/L) and zinc (598 ug/L) which are used as the temporary standard in lieu of the underlying TVS. The Temporary Modification will expire on 12/31/2011 at which time the underlying TVS will apply for this segment.

Welcome to the Coal Creek Watershed!

Headwaters and History

Coal Creek's headwaters begin with the outflows from Lake Irwin. From its start in this old mining camp, the creek continues on a nine mile course through the Town of Crested Butte before ending at its confluence with the Slate River. Along its route, Coal Creek serves as the municipal drinking water source for the town of Crested Butte. After the discovery of ore deposits in the summer of 1879, prospectors swarmed the Ruby Mining District and the town of Irwin sprang to life.



Miners in the old town site of Irwin. Image from the Crested Butte Mountain Heritage Museum.

However, by 1884, silver prices fell and some ore deposits were exhausted. The difficulty of transporting supplies and minerals to and from Irwin's remote location also contributed to the town's decline. In spite of this, the people and infrastructure that mining attracted to the area formed the basis for continued growth in Crested Butte and the Gunnison Valley.

Today, Irwin hosts approximately 30 off-the-gird residences, as well as the remains of the Forest Queen and Forest King mines. Along with the Standard Mine and Keystone Mine, these old mine workings generate acid mine drainage, leaching metals that impair Coal Creeks' ability to support sensitive aquatic life. Water bodies throughout Colorado and the West face degradation from acid mine drainage; without remediation efforts, high acidity and elevated levels of metals threaten wildlife and prevent people from using these waterways for recreation, drinking water, and other purposes.

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Coal Creek Watershed Coalition — Protect and Restore

www.coalcreek.org
To restore and protect the environmental integrity of the Coal Creek Watershed.

Slide 1

AW1 How about: and impair human uses of these waters like recreation and use as drinking water.
Amy Weinfurter, 10/26/2009

Welcome to the Coal Creek Watershed!

Paradise Divide rises above the confluence of Coal Creek and the Slate River.

Coal Creek's Wetlands

The Butte Avenue bridge arrived in Crested Butte in 1995, one of several recycled pieces of a larger bridge that previously spanned the Colorado River during the construction of the Hanging Lake Tunnel near Glenwood Canyon. Pieces of the bridge now stand over smaller tributaries to the Colorado River in small mountain communities throughout the state. After flowing east under Butte Avenue Bridge, Coal Creek joins the Slate River and eventually merges with the East River near Crested Butte South.

Looking towards Mt. Crested Butte, you may notice the wetlands that form around the Slate River and Coal Creek's confluence, creating an important ecosystem that feeds groundwater aquifers, traps sediments, and recycles nutrients. This reduces the amount of sediment that would otherwise be transported into larger water systems. Wetlands also play an important ecological role locally, providing unique habitat for local wildlife that require a high water table or saturated soils. Many mammals, fish, amphibians, invertebrates, birds and fauna thrive in these unique high-moisture habitats. Elk herds will frequent these wetlands in the late summer and early fall – keep an ear out for their distinctive bugle calls as you wander through the area.

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Slide 2

ACP2 did you find out where?
acpoponi, 10/20/2009

Welcome to the Coal Creek Watershed!

The Creation of Totem Pole Park

"By late afternoon, the sculpture [totem pole] was up, and it was actually a kind of a momentous moment, seeing it towering above us, with a weathervane on top trying to find the wind. A moment out of time, who one feels things ending, or beginning, or just pausing in transit for a moment, in appreciation."

- George Sibley, "The Trouble With Money," from Dragons in Paradise

Totem Pole Park gets its name from its towering totem pole sculpture, which five local artists created in August 1973 as a capstone to Crested Butte's third community arts festival. Each artist carved a section of the large spruce log in their own style at the site that was then an abandoned lot, and is now Totem Pole Park. "A case of beer and an appreciation of fine art"[1] led the ski area to lend a crane to help lift the pole into place.

Totem Pole Park is also the site where a portion of the Town's storm water enters Coal Creek. Reducing the amount of contaminants in runoff from sources like gardens, lawns, pet waste, and streets and sidewalks helps support sensitive aquatic life, such as aquatic insects and trout. Preventing contaminants from entering the watershed can include everything from picking up after a pet to washing cars with ecologically-friendly soaps.

[1]From *The Crested Butte News*, August 1973.

Coal Creek winds through Crested Butte's historic district before joining the Slate River outside of town.

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Slide 3

ACP3 Put text next to the arrow "Coal Creek"
acpoponi, 10/20/2009

Welcome to the Coal Creek Watershed!

Armoring and Stream Habitat

You have to look closely to find the only evidence that my faded red love was once on Elk Avenue…Right where the front door had been, you'll see my now weatherworn initials, SLC, and 1975, the year I scratched my mark in the wet concrete of the newly poured sidewalk.

– Sandra Cortner, former editor of the Crested Butte Pilot, on one of the buildings relocated to Creekside Plaza, in "From Barber Shop to Bagel Place." Reprinted with permission from the Crested Butte Magazine.

As you follow Coal Creek's path throughout town, you may notice "armoring," the strategic use of rock gabions and concrete walls to stabilize the river's course and prevent erosion along its banks. In Crested Butte, the beginning of armoring and the rise of some of the buildings that necessitated it can be traced to the late 1970's and early 1980's.

During this period, the town employed a prison work program to stabilize the river's course in an attempt to prevent damage to community dwellings during high water events. Although often necessary in the town limits to protect infrastructure and property, this channelization alters habitat along stream banks by removing vegetation along the creek's corridors. In areas where armoring is not needed, alders and willows stabilize stream banks.

Armoring the creek protected three historical buildings that a group of local businessmen had relocated to create "Creekside Plaza" along the stream. These structures include an old mining dwelling, an atrium donated by the Union Congregational Church, along with structure that was home to an early town newspaper, *The Crested Butte Pilot*. A walkway was also installed to make it easier for residents and visitors to explore the newly created plaza and get a close look at these unique town features.

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Welcome to the Coal Creek Watershed!

The Evolution of City Hall

The City Hall building was originally built in 1883, to house the town's business offices, volunteer fire department, and town meeting hall. It was rebuilt in 1893 after a winter fire destroyed part of the building. In those times, frozen pipes prevented fire fighters from using water to stop the fire; instead, they used dynamite to stop the flames' spread.

Town residents in front of City Hall's original location. Image from the Crested Butte Mountain Heritage Museum.

In this case, the over-zealous explosion shattered windows within a four-block radius. While the man in charge of the dynamite job left town that spring, the City Hall building continued to evolve with the town. In 1991, the structure was temporarily relocated while a new foundation and a flood-protection wall were built to stabilize its position on the stream bank.

Though the stream bottom in the creek might appear to be a lifeless pile of rocks and cobble, this habitat supports aquatic insects such as mayflies, stoneflies, and caddisflies. These insects serve as critical components in the food web. Changes in the structure of insect communities can indicate changes in the overall health of the watershed.

A winged adult stonefly, *Megarcys signata.*

Coal Creek Watershed Coalition

Protect and Restore

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Slide 5

ACP4 This picture appears to be stetched oddly. Try insertig the original file again.
acpoponi, 10/20/2009

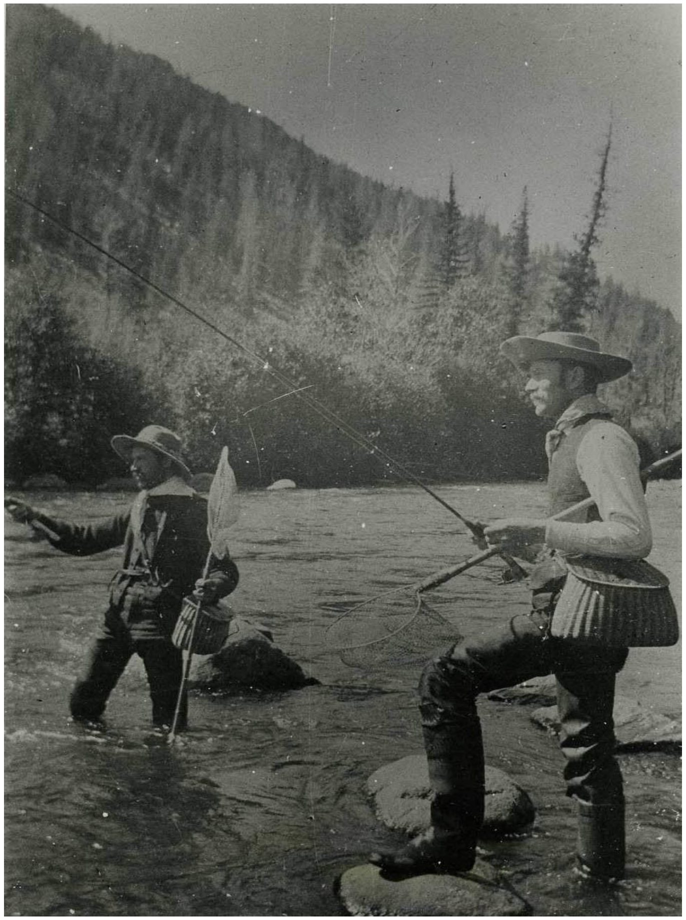
You're in the Coal Creek Watershed!

The Course and Characteristics of Coal Creek

The Coal Creek Watershed begins approximately eight miles west of town. Its headwaters are located at the town site of Irwin, a former mining town that now hosts a small, off-the-grid community of some two dozen residents. Coal Creek flows adjacent to Kebler Pass Road as it makes its way to town, providing key riparian habitat for fish, aquatic insects, birds, and mammals. Drinking water for the town of Crested Butte also comes from Coal Creek.

Three major abandoned mines – the Standard Mine, the Keystone Mine, and the Forest Queen Mine – lie within the watershed's boundary. Along with natural sources of mineralization, these abandoned mines contribute heavy metals such as cadmium and zinc to the watershed through a process called acid mine drainage. In watersheds where acid mine drainage is severe, high concentrations of these metals have the potential to threaten the health of the animals and people who drink the water.

Non-point source pollution – defined as pollution from many diffuse sources – can also threaten aquatic life. It may originate from runoff from road surfaces or lawns, and can contribute sediments, excess nutrients, and other contaminants to the watershed.



In addition to utilizing the watershed for mineral extraction and drinking water, Crested Butte residents of all eras have enjoyed the recreational opportunities it provides. Image from the Crested Butte Mountain Heritage Museum.

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Slide 6

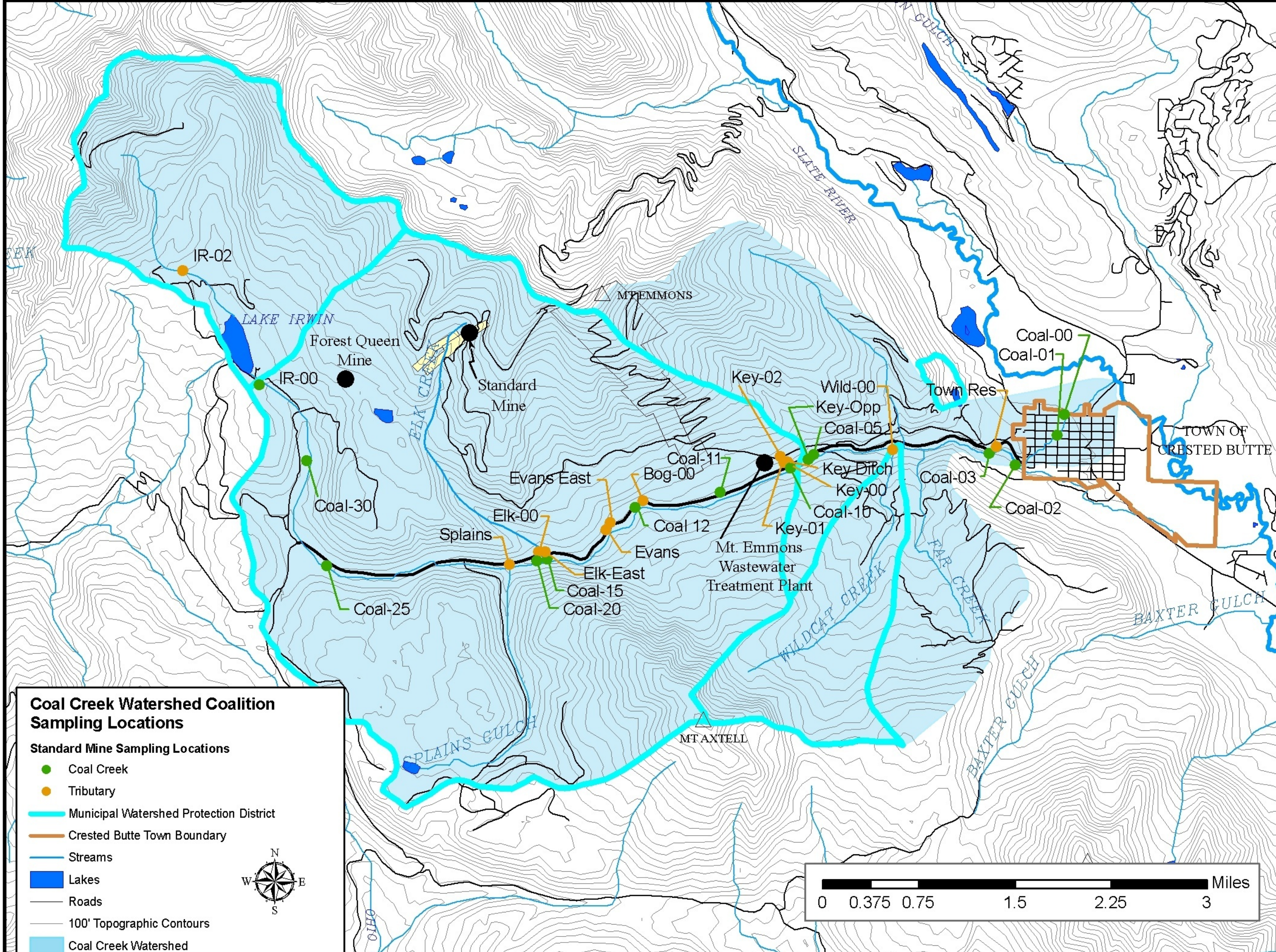
ACP5 How do you like this?
acpoponi, 10/20/2009

Coal Creek Watershed Coalition 2006-2008 Macroinvertebrate Samples

Wendy Brown
Bugs Unlimited, LLC

2008 Sample Locations

Coal 00	Coal Creek at Butte Ave Bridge
Coal 01	Coal Creek at Totem Pole Park
Coal 02	Coal Creek Above Crested Butte
Coal 05	Coal Creek Below Mt Emmons Water Treatment Plant
Coal 10	Crested Butte Drinking Water Supply
Coal 15	Coal Creek Below Elk Creek
Coal 20	Coal Creek Above Elk Creek
Coal 25	Coal Below Irwin and Kebler Pass Y
Coal 30	Coal Creek Below Forest Queen
IR00	Coal Creek Below Irwin Pump House
SP00	Splains Above Confluence with Coal Creek
Elk 00	Elk Creek above Kebler Pass Road

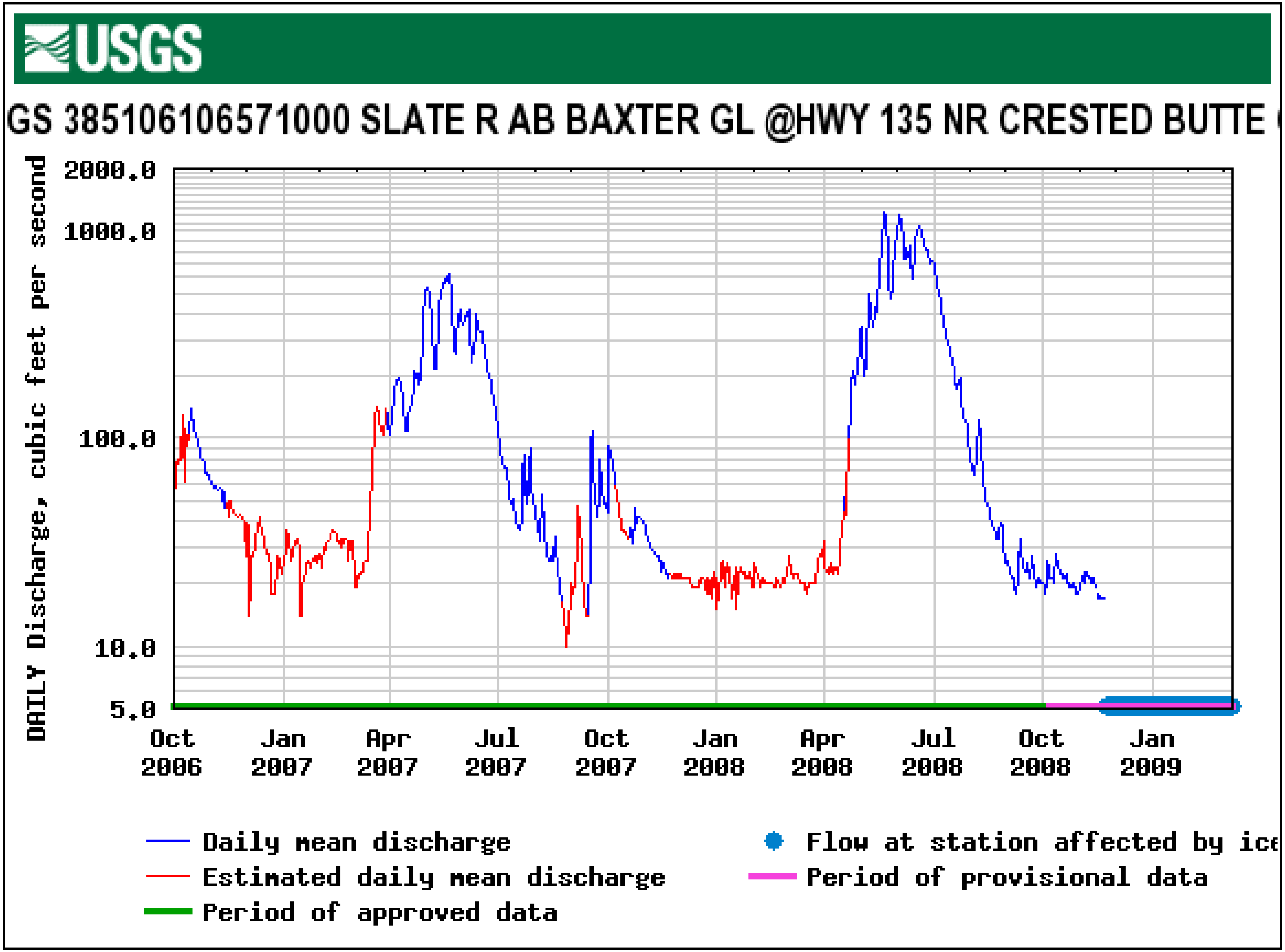


January 28, 2008

Watch for these Trends in the macroinvertebrate data

- High runoff in spring of 2008 generally helped.
- Elk and Coal Creeks have partially recovered from cleaning up the Standard Mine Superfund site.
- Below Forest Queen site appears damaged.
- The new Below Irwin Lake site is not a good stream site.
- Both Irwin/Forest Queen Mine and Crested Butte have slightly negative effects on the stream.

Closest USGS gaging station to Coal Creek, 2007-2008



% EPT

Mayflies, Stoneflies and Caddisflies

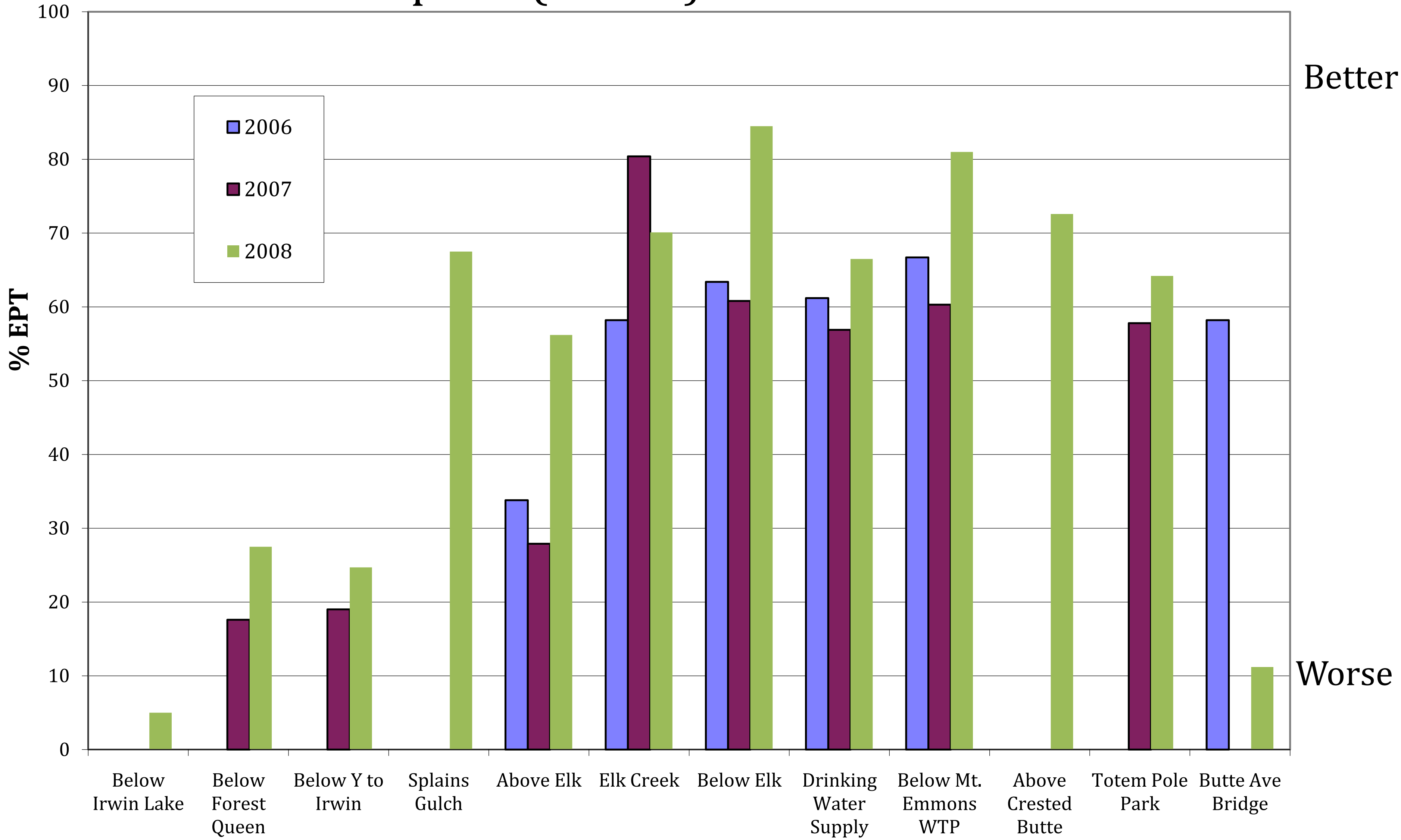
All are intolerant of organic pollution

This mayfly (Baetis or Blue Winged Olive) is most tolerant of heavy metals of the animals on this slide.

This is a stonefly (Hesperophylax or Golden Stone)

This caddis (Rhyacophila or Green Rock Worm) is very sensitive to heavy metals and is among the first to disappear below mines.

Figure 1: % Ephemeroptera, Plecoptera, and Trichoptera (% EPT) from 2006 – 2008.



Fore’s Benthic Index of Biotic Integrity B-IBI

Used for evaluating metal impacted streams

- *Based on data from many streams in Colorado.*
- *Higher numbers are better.*

- Species richness - Total Taxa
- # Mayfly taxa
- # Stonefly taxa
- # Caddisfly taxa
- # Metal Intolerant taxa
- # Clinger Taxa
- % Heptageniidae

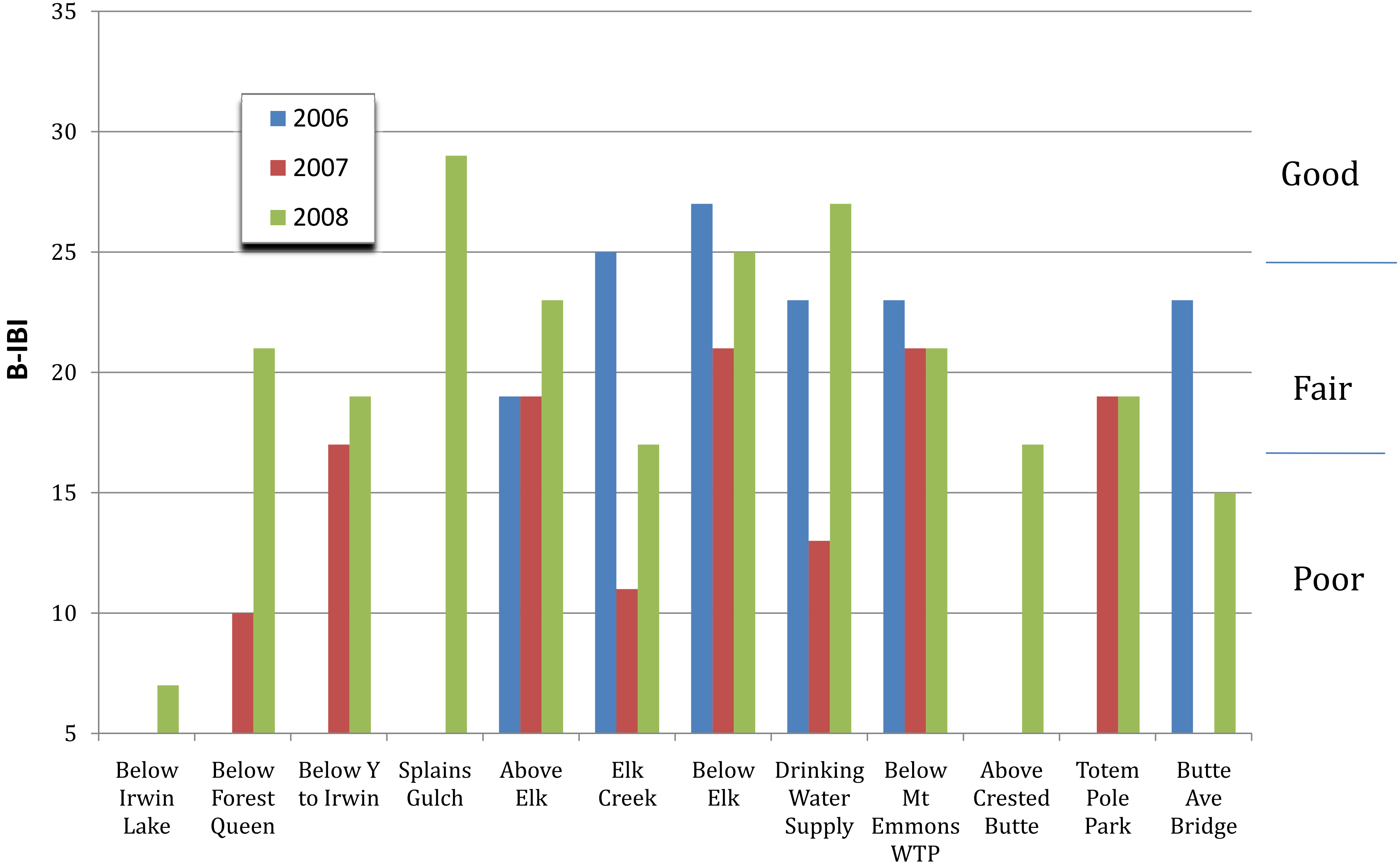
All these are combined to create the B-IBI

Fore,LS 2002 Biological assessment of mining disturbance on stream invertebrates in mineralized areas of Colorado. In: Biological Response Signatures: Indicator Patterns Using Aquatic Communities. Ed: Simon,TP CRC Press, Boca Raton, FL, 347-370.

Standard Mine in August 2005

Standard Mine in September 2009

Figure X. Fore's Benthic Index of Biotic Integrity for the Coal Creek Watershed for 2006 – 2008.



Conclusions from the B-IBI

•*Splains Gulch is the cleanest steam we've sampled ☺*

•*Elk Creek and downstream in Coal Creek were damaged by disturbance during the Standard Mine superfund cleanup in 2007 and recovered somewhat in 2008. ☺*

•*The Crested Butte drinking water supply looks better in 2008 ☺*

•*Below Forest Queen down to Above Elk Creek are in Poor to Fair condition .*

•*The Butte Avenue Bridge site looks impacted, possibly by drying or runoff from town?*

US Environmental Protection Agency (EPA)
Biological Assessment Tools for Colorado

Based on statewide stream samples, including many rivers affected by cities or farmland. The metrics used include:

- Species Richness
- % Oligochaetes (aquatic worms)
- % Trichoptera which are Hydropsychidae
- % Clingers

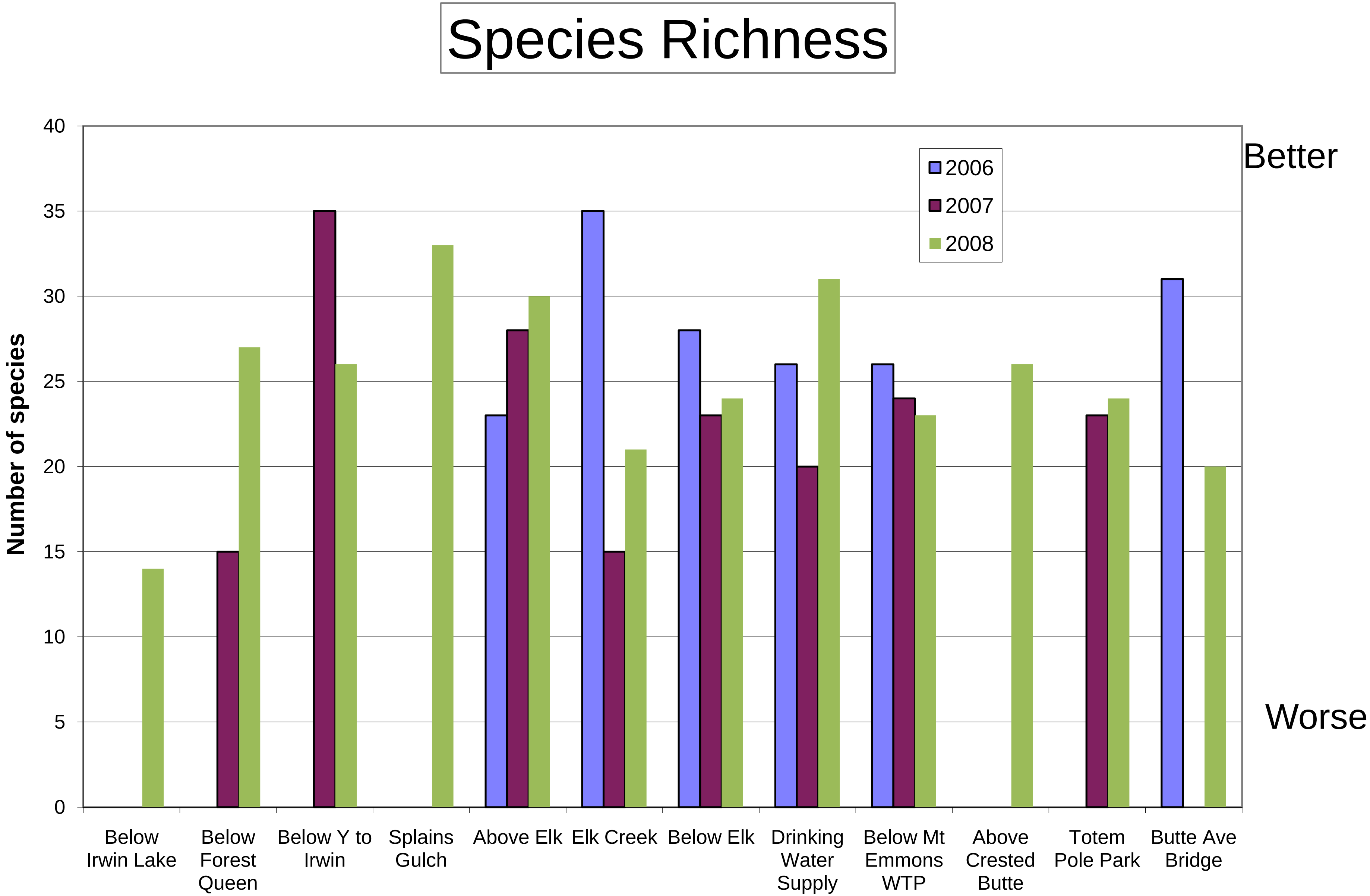
http://www.epa.gov/region08/water/monitoring/documents.html

Species Richness

is the number of different species in a sample

More is better.

Species change over the summer as they leave the water and emerge as adults entering the terrestrial habitat.

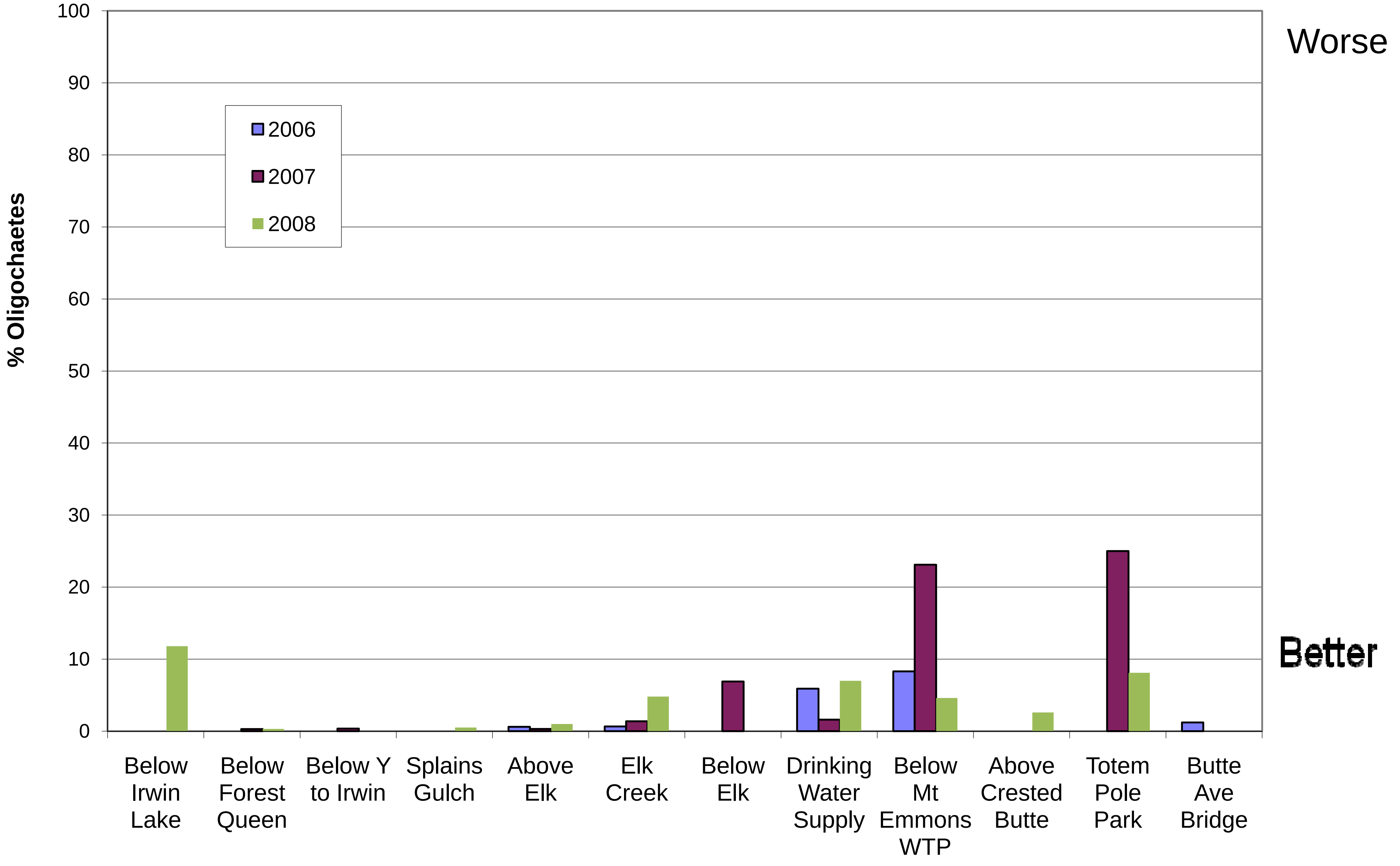


Species Richness
Number of species
40
35
30
25
20
15
10
5
0
2006
2007
2008
Better
Worse
Below Irwin Lake
Below Forest Queen
Below Y to Irwin
Splains Gulch
Above Elk
Elk Creek
Below Elk
Drinking Water Supply
Below Mt Emmons WTP
Above Crested Butte
Totem Pole Park
Butte Ave Bridge

Oligochaetes are aquatic worms.

Present in small numbers in all rivers,
a large population indicates pollution from sewage, fertilizer or sediment.

% Oligochaetes
(aquatic worms)

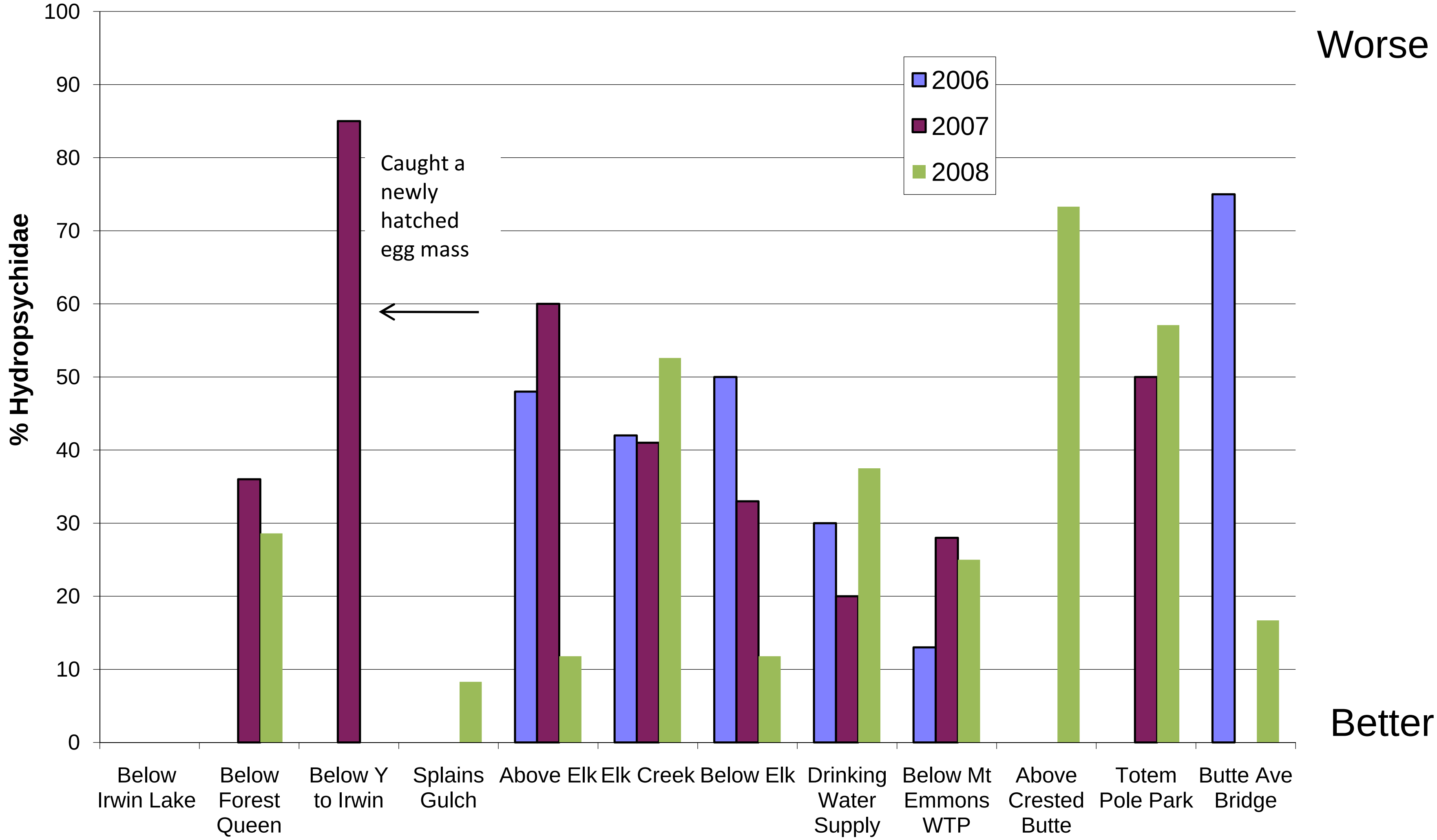


Hydropsychidae are “Net spinner” caddisflies

They are tolerant of many types of pollution.

Notice the net on the retreat on the right. Living off the bottom and filtering food from the current may give these caddisflies less exposure to toxic sediments.

% Hydropsychidae of all Caddis
Net Spinning Caddisflies

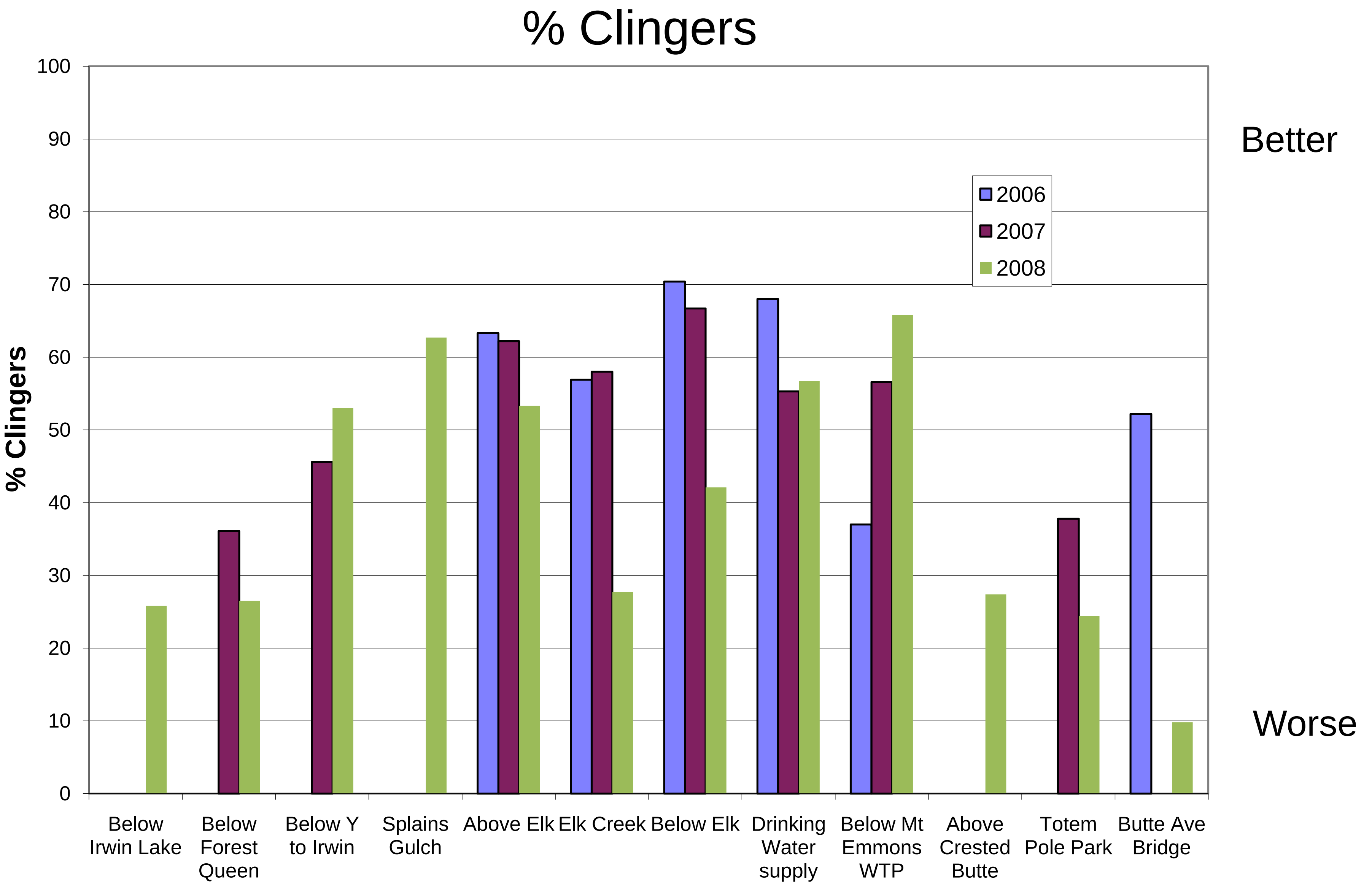


% Clingers

- Clingers attach themselves firmly to the substrate through a fixed retreat, strong claws or various suction devices.

- This is not the best metric for our area since bugs have to be clingers to live in rocky, high gradient streams like Coal Creek and tributaries.

- However, clingers decrease with increased sedimentation and so monitor for land disturbance in the watershed.

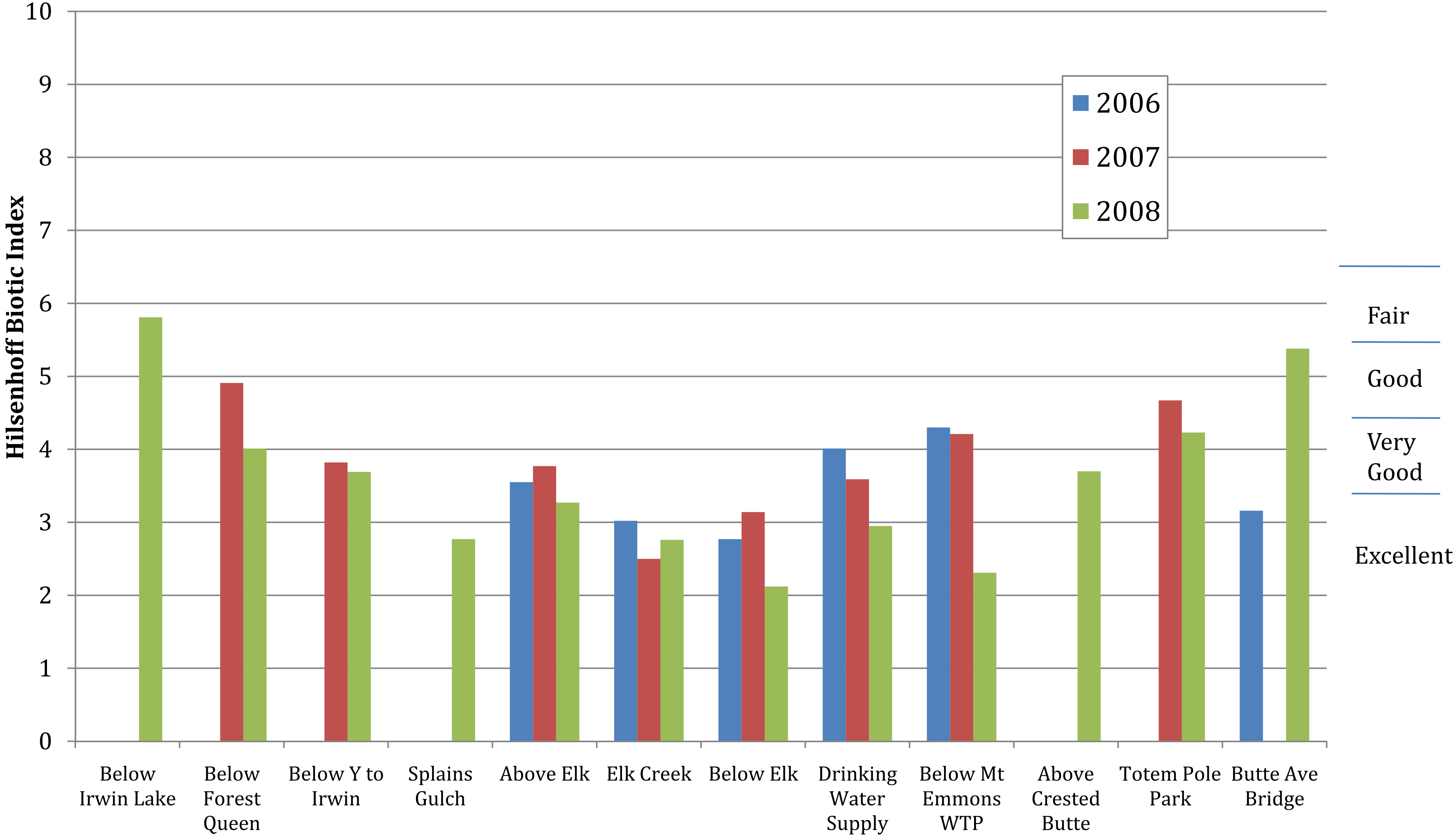

% Clingers
100
90
80
70
60
50
40
30
20
10
0
% Clingers
Better
Worse
2006
2007
2008
Below Irwin Lake
Below Forest Queen
Below Y to Irwin
Splains Gulch
Above Elk
Elk Creek
Below Elk
Drinking Water supply
Below Mt Emmons WTP
Above Crested Butte
Totem Pole Park
Butte Ave Bridge

Hilsenhoff Biotic Index (HBI)

- Used to decide if a stream is impacted by sewage or fertilizer.
- Assigns tolerance values based on genus or species
- An HBI of less than 5 is good. Higher numbers are worse.

- *Near the Irwin townsite and Crested Butte are slightly impaired.*

Figure X. Hilsenhoff Biotic Index for the Coal Creek Watershed for the years 2006 – 2008.



Conclusions from Coal Creek Macroinvertebrates 2006-2008

- Coal Creek Below Forest Queen appears impacted.
- Elk and Coal Creeks are recovering from the Standard Mine superfund cleanup.
- The Mt. Emmons water treatment plant provides a stable environment for the aquatic macroinvertebrates downstream.
- The huge runoff of spring 2008 probably helped Coal Creek and it's tributaries. Sediments washed downstream.
- Both Irwin/Forest Queen and Crested Butte have slightly negative effects on Coal Creek

Confounding Facts

- The big snowpack and large runoff year moved the life cycles later in the year so we caught slightly different insects than in 2006 and 2007.
- The Below Irwin Lake site was too close to the pipe and needs to be moved downstream.
- All metrics at the Butte Ave Bridge site were affected by the large numbers of Tanytarsini midge larvae.