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The Notorious Captain Jack Mill and the Curse It Left Behind

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The Notorious Captain Jack Mill and the Curse It Left Behind

A comparison study of bioaccumulation of heavy metals in streambed sediments, surface water, and benthic macroinvertebrates after the Superfund site remediation of Captain Jack Mill

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Abstract

This study evaluates the state of stream ecosystem health in two creeks in northwestern Boulder County, Colorado. The topic of this research was to evaluate the remediation efforts by the Environmental Protection Agency and local group initiatives of the Captain Jack Mill Superfund site located on Lefthand Creek and the Burlington Mine on Little James Creek. This study evaluated the concentrations of metals present in stream biota, including benthic macroinvertebrates, streambed sediment, and water. The research question of this study sought to understand the effectiveness of the remediation efforts after the major flood event of 2013 in this area by comparing current 2018 research with data from a pre-remediation study conducted in 2004. The hypothesis of this study is that metal concentrations in this area have either remained constant or increased due to the 2013 flood disturbing the area and affecting the metal concentrations in the stream biota in this watershed. The hypothesis was tested by comparing pre-remediation and post-remediation data. The results of this study indicated that levels of metals were overall higher in benthic macroinvertebrates and in the water in Lefthand Creek than the data from 2004 Bautts (2006). These results support the idea that water and benthic macroinvertebrates represent the short-term state of the stream in the years since the 2013 flood. In Little James Creek, metal concentrations were higher in benthic macroinvertebrates and higher in sediment for the metal lead than the data from 2004. These results suggest that remediation efforts were either not effective or that the 2013 flood affected this area by washing built-up sediments downstream. The recommendations of this study include the need for more remediation of both creeks in the future. Without any post-remediation data prior to the 2013 flood, it is hard to determine to what extent the flood affected this watershed. However, this study nonetheless presents the current state of this watershed and is another baseline study to motivate further remediation efforts.
Table of Contents

Abstract ................................................................................................................................. iii
Preface .................................................................................................................................. vii
Introduction ....................................................................................................................... 1
History and Background ...................................................................................................... 4
Overview .............................................................................................................................. Error! Bookmark not defined.
Captain Jack Mill Superfund Site .......................................................................................... 4
Community Involvement and Concern ............................................................................... 5
Remediation Efforts ............................................................................................................ 5
Streamflow and Size of Streams ......................................................................................... 6
Water Quality versus Biological Monitoring ...................................................................... 7
Comparison Study ............................................................................................................... 7

Literature Review ................................................................................................................ 9
Methods and Materials ....................................................................................................... 15
Field Research Area ........................................................................................................... 15
Benthic Macroinvertebrate, Water, and Sediment Sampling Sites .................................... 15
Benthic Macroinvertebrate sampling and analysis ............................................................ 17
Lab Blank Preparation: Macroinvertebrates ...................................................................... 18
Sediment sampling and analysis ....................................................................................... 19
Lab Blank Preparation: Sediment ...................................................................................... 19
Water sampling and analysis ............................................................................................. 20
Lab Blank Preparation: Water ............................................................................................ 20
ICP-MS Machine Detection Limits ................................................................................... 21
EPT/Diptera Ratio Calculation .......................................................................................... 21

Results .................................................................................................................................. 22
Lab Blank Results: Benthic Macroinvertebrates ................................................................. 22
Benthic Macroinvertebrate Results ................................................................................... 22
Lab Blank Results: Sediment ............................................................................................ 28
Sediment Results ................................................................................................................. 28
Water Quality Results ........................................................................................................ Error! Bookmark not defined.

Discussion ........................................................................................................................... 39
Benthic macroinvertebrate vs metal concentrations ......................................................... 39
Water, Macroinvertebrates, & Sediment as Monitors of Stream Health ........................... 45
Comparison from 2004 Data Results and Discussion ...................................................... 57
Further Study and Study Limitations ............................................................................... 69

Conclusion .......................................................................................................................... 71
Recommendations .............................................................................................................. 71
Appendix .............................................................................................................................. 73
References ............................................................................................................................ 79
Preface

Throughout this project, I have had the pleasure of working with individuals who have challenged me and supported me. It has proved to be a challenging yet very rewarding project in the amount of knowledge and experience I have gained throughout. I would like to thank my primary advisor, Joe Ryan, for supporting my decision to take on this project and challenging me with new knowledge and skills. Dale Miller, for supporting and helping me throughout the entire process. I would like to thank Jeff Writer for editing and serving on my committee. I would like to thank Taton Cadwell for helping me collect my samples in the field. I would also like to thank Joe’s graduate student, Holly Miller, for helping me throughout the lab portion of my research and answering many of my questions as we went along. I would also like to send a huge thank you to my family, my brother, dad, and mom for helping me edit, advising me, encouraging me, offering support, and sharing knowledge with me as I completed my thesis. This project would not have been the same without their help.
Introduction

The effects of heavy metals on stream ecosystems and drinking water sources, due to the United States’ mining legacy, emerges as a problem as we learn more about the level of contaminants still present in the streams. Acid mine drainage (AMD) threatens the environmental health of streams and can have impacts on human drinking water. Acid mine drainage occurs when rocks interact with oxygen and water and produce sulfuric acid (Harrington, 2002). This creates a more acidic environment in the stream and causes the dissolution of heavy metals in waste rocks, resulting in more heavy metals leaching into the streams (Harrington, 2002). This side-effect of abandoned mines concerns individuals due to the potential negative effect of acid mine drainage on the aquatic life of the creek and its effect on drinking water quality.

An area in Boulder County, Colorado, that was put on the Environmental Protection Agency’s (EPA) National Priorities List in September 2003 is the Captain Jack Mill, located west of Ward, Colorado on Lefthand Creek. The superfund site includes the Big Five Tunnel, located above the Captain Jack Mill (refer to Map - Figure 1) The tunnel diverts into a settlement pond that then reaches a drainage confluence with Lefthand Creek just before the Captain Jack Mill site. These two areas of concern are located on the stretch of Lefthand Creek known as California Gulch. In the years following the Superfund site declaration, remediation occurred along with mine waste removal and monitoring of pH and heavy metal concentrations by government agencies and local group initiatives.

Of even higher importance and concern for locals is the mining legacy that exists on Little James Creek. Cowart, et al. (2004) discusses the history of the Burlington Mine (Figure 1) located on this creek that underwent voluntary cleanup by the mine owner, Honeywell International Inc. The cleanup began in 2003 and finished in 2004. Goals of the cleanup included constructing diversion channels to control mine drainage, grading, and the permanent closure of adits and shafts. However, the mine still drains
into the creek and mine tailing piles still exist along this creek. Little James Creek is a tributary of Lefthand Creek and therefore affects the entire Lefthand Creek watershed.

Figure 1: Map showing the sampled areas (red) of Lefthand Creek and Little James Creek. The areas of concern where my sample sites were focused are highlighted in yellow. Bautts (2006)

After the government agencies and private owners completed remediation in 2004 at the Burlington Mine, and in 2012 at the Captain Jack Mill superfund site, another event occurred that affected both of the sites in this study. The Boulder Flood that washed through this watershed in September 2013, likely affected the levels of metals in streambed sediment, water, and benthic macroinvertebrates in each stream. The influx of water washed away years of built-up sediments and may have disturbed remediation efforts that took place in the years prior. According to a report published by Agget (2016), Little James Creek is now undergoing flood remediation efforts including tree
plantings near the Burlington Mine site. These efforts have also disturbed the creek and have changed the path of the stream and I will consider this when evaluating this study.

Although mine remediation is complete, the area still evokes concern for many residents downstream of this mining area. Concerns include the mine drainage still entering this watershed and determining how effective the remediation was while also considering the effect the 2013 flood had on the post-remediation status.

The aim of this research is to determine what effects a Superfund declaration and voluntary cleanups had on the stream ecosystem health of Lefthand Creek and Little James Creek while also considering the impact of the 2013 flood that occurred post-remediation. To answer this question, I conducted primary research in the same manner as a previous study that evaluated metal concentrations in benthic macroinvertebrates, sediment, and water present in these creeks. The pre-remediation research took place in 2004, and since then, no studies have evaluated the stream ecosystem health, including the macroinvertebrate community, of both Lefthand Creek and Little James Creek. My objective is to ascertain the state of the stream today compared to 2004 data to determine how metal concentrations have changed since the remediation efforts of the EPA, voluntary cleanup by mine owners, and the 2013 flood.
History and Background

Colorado is known for its mining legacy. Mining activity effects continue to evoke environmental concern across the state today. The mining legacy that flourished in northwestern Boulder County began in the 1860s and continued for many years before closing completely in the early 1990s. Beginning in 1861, the main ores that were sought in California Gulch (refer to Figure 1), where the Big Five Mine and Captain Jack Mill are located, were gold and silver, followed by lead and copper in subsequent years. Fluorite was later found and mined from the Burlington Mine on Little James Creek from 1940-1973. During this time, both the mines still in operation and the abandoned mines were exposed to the environment and severe acid mine drainage was polluting the surrounding watershed.

Captain Jack Mill Superfund Site

According to the Public Health Assessment for Captain Jack Mill (2006), beginning in the 1980s, local, state, and federal agencies began testing the area of the Captain Jack Mill due to environmental concern about the drainage entering Lefthand Creek. In 1986, the Colorado Department of Public Health and Environment (CDPHE) conducted tests near the Captain Jack Mill and found acidic water (pH of 3.3) and elevated heavy metals in the water. The owner of the mine, VanDyke Minerals Inc. filed for bankruptcy in 1987 thus the responsibility of cleanup shifted to government agencies. The EPA began testing this area in the early 1990s to assess the severity of the metal concentrations present as well as the presence of abandoned drums filled with chemicals including cyanide and various acids. The assessment of the site resulted in a Superfund declaration in September 2003, leading to surface and subsurface remediation of the head of California Gulch including the Big Five Tunnel, the Captain Jack Mill, and the White Raven Mine. The cleanup of the area occurred in multiple phases under the direction of both the EPA and the CDPHE. The remediation included removing old buildings and waste rock piles that contaminated the stream.
Community Involvement and Concern

Before government involvement, residents living in this area voiced their concerns and a community effort was formed to address the proposed remediation by the EPA of the Captain Jack Mill as well as other sites along the Lefthand Creek watershed, known as the Lefthand Watershed Oversight Group (LWOG). This community group sought to provide accurate data that warranted the cleanup by the government. Some of the concerns that this group initiative addresses presently include developing a better understanding of the impact of acid mine drainage on the aquatic life in each of the streams and determining the state of current aquatic life or lack thereof, as well as working toward overall health of the watershed. This group has released reports evaluating the total maximum daily load (TMDL) assessments that the Colorado Department of Public Health and Environment (CDPHE) conducted in 2015 of certain metals present in the water, (Wood and Russel, 2005). The results of these reports indicate that the area of Lefthand Creek where I sampled needs improvement in both copper and zinc based on 2015 levels. The area that I tested on Little James Creek needs improvement in the metals cadmium, copper, lead, and zinc. Based on the 2015 water testing, the Lefthand Creek watershed continues to exceed the chronic aquatic life standards in the areas of pH, zinc, and copper, (LWOG, 2016).

Remediation Efforts

The EPA and the CDPHE have conducted remediation efforts on the Captain Jack Mill Superfund Site since 2003 up until 2016 and surface remediation of California Gulch was completed in 2012 (EPA, 2014). The methods used by the EPA to clean up the Captain Jack Mill and surrounding areas include both surface and subsurface remediation. The surface remediation involved removing waste rock piles and excavating the area to remove contaminants of high concern. The subsurface remediation efforts include installing a bulkhead. This concrete device prevents water from flowing downstream from the
mine. The EPA installed the bulkhead in the Big Five Tunnel, which prevented leakage from the tunnel adit (EPA, 2003). The area today looks vastly different than it did 14 years ago. The EPA removed buildings and rock piles in an effort to keep contaminants from leaching into the watershed.

On Little James Creek, the voluntary cleanup by the Burlington Mine owner started in 2003 and finished in 2004. Cowart, et al. (2004) says that the cleanup included limiting future subsidence and reducing safety hazards in this area. This included constructing diversion channels to avoid mine activity and reduce acid mine drainage into Little James Creek as well as permanently closing adits and shafts of this mine. CDPHE (2015) states that the EPA and other agencies completed remediation of other mines on this creek. The Forest Service and EPA performed an emergency response cleanup in 2005 on the Bueno Mine that is located above the Burlington Mine on Little James Creek (see Figure 1). Although Honeywell, Inc. completed the planned cleanup of the Burlington Mine, drainage water from a pond near the mine still discharges into Little James Creek, (CDPHE 2015).

Since the remediation took place, the 2013 flood occurred and likely changed the effectiveness of the efforts. This study will seek to understand the current state of the stream ecosystems while considering this flood event and its effect on the levels of metals present in the water, streambed sediment, and benthic macroinvertebrates in each stream after remediation efforts.

Streamflow and Size of Streams

Lefthand Creek supplies water for a variety of applications including over 20,000 residential and agricultural users through the Lefthand Water District ("Captain Jack Superfund Site and Left Hand Creek’s Legacy of Mining" n.d) The average yearly stream flow of this creek from data from United States Geological Survey (USGS) is 963 L/s, based on USGS data during the monitoring of streamflow of Lefthand Creek. Monitoring of this data of Lefthand Creek’s streamflow started in 1920 and discontinued after 1980 when they removed their water gauge on this creek, (Bautts 2006).
Lefthand Creek is larger than Little James Creek. The discharge of Little James Creek was not available from USGS; however, the discharge of the stream recorded in 2003 was obtained from Wood (2003). This research team determined that the high flow of this creek increased from headwaters to its confluence with James Creek was 110 L/s to 540 L/s, respectively. These two streams are first-order streams because they originate as headwater streams without other tributaries entering them, (Harrel, et al. 1967).

Water Quality versus Biological Monitoring

There are advantages and disadvantages to using either biological monitoring or water quality methods to assess stream health. Bartram and Ballance (1996) discusses the advantages of using water quality methods including the ability to discern the sources of water contamination by testing the specific contaminants in the water. Water quality assessment tells us the state of health of a stream and its effect on human health by comparing the concentrations of metals with TMDL standards. The disadvantages of only testing water quality are that this method cannot fully measure the health of the ecosystem and the impact of water pollution on all the biological life in a stream. Similarly, Bartram and Ballance (1996) discusses the advantages to biological monitoring. This includes the ability to understand how pollution directly affects biological components of a stream through biological monitoring. Some disadvantages to biological monitoring include the unknown factors about the organisms living in the stream such as contamination or pollution. It would be hard to decipher that a certain environmental disturbance caused the observed effects. Chemical sampling of water samples gives scientists a snapshot of the health of the stream, while biological monitoring gives scientists a better long-term understanding of the stream’s health.

Comparison Study
Bautts (2006) conducted a study in 2004 assessing the amount of lead, copper, and zinc present in these streams. Her study focused on determining the amount of metals present in the aquatic characteristics of James Creek, Lefthand Creek, and Little James Creek. Bautts (2006) collected data on metal concentrations in benthic macroinvertebrates, sediment, and water. She compared these three variables in her thesis and presented her evidence of elevated metal concentrations present in each of these streams, with a clear emphasis on Little James Creek. This creek was not noted as an area of concern by the EPA in 2003; instead, the focus of the EPA was primarily on Lefthand Creek where the Captain Jack Mill was located. However, Bautts (2006) presents evidence that both of these streams were considered a stream health risk due to the higher levels of metals present in stream biota, water, and sediment based on data collected in 2004.
Literature Review

The sub-sections within this literature review include research on the use of benthic macroinvertebrates as a monitor for water quality and acid mine drainage effects on these macroinvertebrate communities. I also looked at sediment and water quality studies focusing on metal concentrations present in these variables in areas affected by acid mine drainage. Finally, I researched and read about studies that focused on the effects of remediation by looking at pre and post remediation studies.

*Benthic Macroinvertebrates as an Indicator for Water Quality*

Researchers often use benthic macroinvertebrates to understand the health of a stream. Benthic macroinvertebrates are good indicators for hydrologists to determine the health of various streams ranging from high mountain streams to streams located in urban areas (DeNicola and Stapleton, 2016). The most common taxonomic identification of benthic macroinvertebrates is the order EPT (*Ephemoptera*, *Plecoptera*, and *Trichoptera* – Mayflies, Stoneflies, Caddisflies). These orders of invertebrates live in well-oxygenated, clean water and are considered the most pollution-intolerant of all benthic macroinvertebrates (Stoyanova et al., 2014). These studies have focused on determining the ecological integrity of a stream ecosystem based on the state of benthic macroinvertebrate communities and do so by calculating species richness, diversity, and abundance within a stream. This often involves calculating the ratio between the pollution intolerant species with those that are pollution tolerant (*diptera* – fly larvae).

*Acid Mine Drainage Effect on Macroinvertebrate Species Richness and Diversity*

Studying the benthic macroinvertebrates in a stream is one way to understand the specific effects that acid mine drainage has on the ecological integrity of a stream. DeNicola and Stapleton, (2016), conducted a study to understand the effects of remediation on acid mine drainage. The researcher’s main objective was to determine the effect of passive remediation for acid mine drainage...
and how this form of remediation ultimately affects biological life and overall ecological health of a stream. The methods used in this study for sampling and analysis of macroinvertebrates did not include analysis of metal concentrations. They focused on performing taxonomy on their samples to determine the index of species present in the stream. Their results indicated that the treated areas inhabited slightly more diverse species. They found in their study that the time of year significantly impacts the richness and diversity of macroinvertebrate metrics and that species and genus also determines macroinvertebrates ability to adapt to stream environments. They concluded that to correctly analyze and evaluate remediation efforts, continuous monitoring needs to occur.

Benthic macroinvertebrates offer researchers information about the health of a stream because these organisms are closely integrated with their surrounding ecosystem and are easily impacted by outside factors such as acid mine drainage (Kiffney and Clements, 2002). Several years of monitoring show the effects over time of toxic environments on macroinvertebrates. For instance, Wright and Ryan (2016) found that taxonomic richness was higher at their reference sites, indicating that the areas of the stream directly impacted by acid mine drainage does influence the richness of macroinvertebrates. Farag, et al. (2009) found that concentrations of metals specifically found in macroinvertebrates were higher in sample sites located near or below mine drainage. The macroinvertebrate samples collected had higher concentrations of metals than their reference sites, indicating metals effect on benthic macroinvertebrate communities.

Other research has primarily focused on determining the metal concentrations within stream biota in areas affected by acid mine drainage. Although the methods differ between the hypotheses of these studies are similar. Considering both the taxonomic richness and acid digestions to determine the metal concentrations within macroinvertebrates, can provide more accurate results and provide more thorough information about the effect of metals on macroinvertebrates. For instance, in a study that analyzed various components of stream biota, they found that many of the macroinvertebrate samples...
had higher concentrations of metals at sites located near or below mine drainage (Farag et al., 2007). Both Bautts (2006) and Farag, et al. (2007) digested the macroinvertebrates found with nitric acid and hydrogen peroxide. Farag, et al. (2007) focused on collecting macroinvertebrates, fish, water, colloids, sediment, and biofilm and analyzed the metal concentrations in each of these samples. These researchers digested their samples using nitric acid and hydrogen peroxide. Metals were analyzed using inductively-coupled plasma mass spectrometry (ICP-MS). The results of this study indicate that copper, cadmium, and zinc are easily absorbed by stream biota from the water and sediment present in the stream. The results also indicate that fish in the stream had higher concentrations of these metals due to bioaccumulation through the food chain. Lastly, the study concluded that lead was not absorbed into the stream biota because lead concentrations found in the water were typically below detection limits.

Site- specific studies include benthic macroinvertebrate monitoring in high altitude streams in the United States. Yang (1995) conducted research on a Colorado stream to determine the effect acid mine drainage has on nesting tree swallows that consume benthic macroinvertebrates as one of their food sources. This study determined metal concentrations in benthic macroinvertebrates directly affect nesting swallows throughout the food chain. The results of this study demonstrate a correlation between metal concentrations in benthic macroinvertebrates and nesting occupancy in this location.

Loayza-Muro, et al. (2010) also focused their research on the effect of metals on benthic macroinvertebrates in high altitude streams. This researcher specifically discusses how increased acidity and increased metal concentrations affect invertebrate abundance and species richness. Indirect effects such as smothering of streambed substrate by metal precipitates reduces fauna habitat and changes functional feeding group interactions. This study shows that low pH conditions increase the bioavailability of metals and decreasing pH levels coincides with decreased abundance and richness of macroinvertebrates.
Sediment and Acid Mine Drainage

Researchers often analyze streambed sediments when looking at metal concentrations present in stream ecosystems. For many benthic macroinvertebrates, sediment is part of their scavenging diet. Farag et al. (2007), found elevated levels of metals in the sediment in certain areas of the stream that corresponds to the location of mines. They discussed how sediment’s transport and ability to retain elements can be the pathway for lead, specifically, to other biological components of a stream ecosystem. Axtmann et al. (1997) shows in their study of metals in sediments and benthic insects that concentrations in benthic macroinvertebrates showed correlation with metals found in sediments. The researchers concluded that macroinvertebrate exposure to metals depend partially on metals bound to sediments in the stream.

Water Quality

Along with stream biota and sediment, water quality assessments also help researchers understand the state of a stream affected by acid mine drainage. De la Torre, et al. (2015), assessed the effect of acid mine drainage on the pH of a stream. They found that water with low pH and high levels of heavy metals decreased biodiversity and contaminated soil. This study concluded that a decrease in metals results in a rise in pH of water in the area.

Pre- and Post-Remediation Studies

Wei, et al. (2011) discussed the impact of coal mining on water quality and the effect of remediation on these impacts. The study concluded that reclamation was beneficial and improved water quality; however, as years passed, acid mine drainage effects were still present in the stream ecosystem and were above safe levels. Common indicators of a stream affected by acid mine drainage includes low pH and high metal concentrations. This study indicates that effects are still present after 7 years of close monitoring of water quality, though metal concentrations have decreased since remediation efforts have taken place.
Runkel et al. (2009) also discussed the impact of acid mine drainage on water quality in Mineral Creek, a mountain stream in Colorado. The results indicate that concentrations of a variety of common metals found in acid mine drainage are higher post-remediation and continue to exceed the chronic aquatic-life standards established by the state of Colorado. Overall, the study concludes that remediation has had a positive impact on water quality of Mineral Creek; however, it is stated that temporal variability should always be considered. Due to the remaining high concentrations of metals in this stream, these researchers recommended continued remediation efforts on the stretches of this stream.

Another study stressed the importance of obtaining pre- and post-remediation data on areas surrounded by abandoned mines, (Williams and Turner, 2015). This study sampled macroinvertebrates and preserved them in ethanol to later identify taxa to the genus species. They then calculated the taxonomic richness of their samples. They used the method that determines EPT% (mean percent of total individuals comprised of *Ephemeroptera, Plecoptera, and Trichoptera* genus) (Williams and Turner 2015). This study found that since 1967, when mining was taking place in the area, compared to 2011, the macroinvertebrate community density, regional richness, and EPT taxa significantly increased. This indicates that the water quality in this area has improved and allowed for more macroinvertebrates to thrive.

Unruh et al. (2009) demonstrated the effectiveness of remediation efforts on Boulder River watershed in Montana. They saw the greatest improvements in areas where removal of large amounts of waste rock occurred. This action significantly reduced cadmium and zinc concentrations in the water and sediment; however, acidic water continues to leak from mine adits. The researchers stressed that waste removal must be addressed first before improvements will be seen regarding the aquatic habitat of the stream.
Methods and Materials

In my methods, I have seven sub-sections. I first focus on and introduce the area where I researched including the sample sites and my reasoning for choosing them. I then give an overview of how I sampled benthic macroinvertebrates, sediment, and water in the field. I then outline my procedure for analysis of these three variables in the lab, including lab blank analysis. I discuss the machine detection limits for the spectrometer used in my analysis and the methods used for calculation the EPT/diptera ratio.

Field Research Area

Using the descriptions provided in Bautts (2006), I chose sample sites along Lefthand Creek and Little James Creek. I chose these specific creeks because I found that these two creeks were of the most concern in terms of higher concentrations of metals in sediment and benthic macroinvertebrates. I reduced the number of sites to 24 compared to the 32 sites sampled by Bautts (2006). I focused on concentrating my sampling in the problem areas found in 2004 by Bautts (2006) by sampling only the areas directly above, at, or below the Captain Jack Mill and the Burlington Mine (Figures 2 and 3).

Benthic Macroinvertebrate, Water, and Sediment Sampling Sites

Figures 2 and 3 show the sampling sites for Lefthand Creek and Little James Creek. I collected samples of benthic macroinvertebrates, water, and sediment during one day on Lefthand Creek on October 21st, 2017. There were no storm events in the days prior to testing on this day. I collected the samples from Little James Creek on the following weekend October 29th, 2017. The weather was cooler prior to testing but no rainfall occurred prior to or during testing.
Figure 2. A map of Lefthand Creek samples sites and landmarks.
Benthic Macroinvertebrate sampling and analysis

The methods used for benthic macroinvertebrate sampling followed the procedure outlined in Farag et al. (2007) and Bautts (2006). At each site, I selected three riffles for sampling. Benthic macroinvertebrates were released into a rectangular kicknet by turning over rocks and kicking sediment in the riffle. I dumped the contents of the kicknet into a plastic tray by rinsing the kicknet with stream water to ensure release of all the invertebrates collected and attached to the net. I transferred the invertebrates to acid-washed conical tubes by plastic spoons. I put the samples on ice and transferred them to a freezer in the lab until further analysis.

In the lab, I thawed the macroinvertebrates and put the contents into petri dishes so they could be counted and taxonomically identified by class *Ephemeroptera, Trichoptera, Plecoptera*, and *Diptera*. I
rinsed each sample with de-ionized water to ensure that metal-contaminated water was not present on the exoskeleton of the invertebrates. The specific conductivity and water quality of this de-ionized water is unknown. This method might be a reason for discrepancies in data presented. I transferred the invertebrates to small beakers to prepare for drying at 60°C in the lab oven. I dried the samples in a lab oven for 24 h at 60°C. I put the dried samples into the same acid-washed conical tubes used for collection and prepared them for acid digestion. I added a combined total of 15 mL of water, trace metal-grade nitric acid, and 30% hydrogen peroxide to the conical tubes of each sample. I added 10 mL of deionized water, 2.5 mL of 30% hydrogen peroxide, and 2.5 mL of trace metal-grade nitric acid. I shook the samples by hand, end over end, to thoroughly mix and allowed them to settle overnight for 12 h (+/- 2 h). I put the samples into a water shaker bath at 60°C for 2 h and allowed them to settle overnight for 12 h (+/- 2 h). I removed the supernatant using a different disposable glass pipette for each sample and put the supernatant into acid-washed sample bottles. I sent the prepared samples to Lab for Environmental and Geological Science (LEGS), located in the Department of Geological Sciences at the University of Colorado, Boulder. The LEGS lab analyzed these samples for zinc, copper, and lead concentrations by Inductively-coupled plasma mass spectrometry (ICP-MS).

Lab Blank Preparation: Macroinvertebrates

I prepared two lab blanks using the exact methods for digestion as my other samples following Bautts (2006) outlined procedure. I prepared these blanks to ensure that the reagents (nitric acid and hydrogen peroxide) and the water did not skew the results from the ICP-MS analysis. I added 10 mL of de-ionized water, 2.5 mL of trace metal grade nitric acid, and 2.5 mL of 30% hydrogen peroxide for a total of 15mL of liquid. The blanks did not contain any macroinvertebrate bodies. I shook the samples by hand, end over end, to thoroughly mix and allowed them to settle overnight for 12 h (+/- 2 h). I put the samples into a water shaker bath at 60°C for 2 h and allowed them to settle overnight for 12 h (+/- 2 h). I
removed the supernatant using a different disposable glass pipette for each sample and put the supernatant into acid-washed sample bottles. I sent the prepared samples to LEGS for analysis.

Sediment sampling and analysis

I collected sediment samples in pool areas of the creeks at each sample site and followed procedures outlined in Farag et al. (2007) and Bautts (2006). I collected 50 mL of sediment using a plastic spoon to ensure minimal metal contamination from outside sources. I put my samples of sediment into acid-washed conical tubes. I put the samples on ice and then stored them in a laboratory refrigerator for 20 days until further analysis. I allowed the samples to air dry in the acid-washed plastic conical tubes for 12 h. I transferred the samples into ceramic bowls to ensure quicker and even drying in the oven. I placed the samples in a drying oven at 65°C for 12 h. I dry-sieved the sediment samples sieved through two sieves by hand. I weighed the samples prior to sieving, then passed them through a 2 mm metal sieve and weighed each sample. I then shook the samples through a 1 mm metal sieve and weighed each sample afterwards. I transferred the samples back into acid-washed conical tubes and weighed each sample out to a consistent weight of 2 g (±0.1 g).

I digested the sediment samples by following the procedures outlined in Bautts (2006). I added 0.2 mL of 30 % hydrogen peroxide and 20 mL of trace metal-grade nitric acid to each sample. I capped the samples shook them by hand, end over end, to ensure thorough mixing. I allowed the samples to settle overnight for 12 h (+/- 2 h) and then put them into a shaking water bath at 60°C for 2 h. After the shaken samples settled overnight for 12 h (+/- 2 h), I removed the supernatant using a new disposable glass pipette for each sample. I transferred the prepared samples to LEGS lab for metal concentration analysis of zinc, copper, and lead.

Lab Blank Preparation: Sediment
I prepared two lab blanks for the sediment samples in my study. I used the same methods for the sediment sample preparation. I added 0.2 ml of 30% hydrogen peroxide to an acid-washed plastic conical tube. I then added 20 mL of trace metal-grade nitric acid to each of the blanks. I capped the samples shook them by hand, end over end, to ensure thorough mixing. I allowed the samples to settle overnight for 12 h (+/- 2 h) and then put them into a shaking water bath at 60°C for 2 hours. After the shaken samples settled overnight for 12 h (+/- 2 h), I removed the supernatant using a new disposable glass pipette for each sample. I transferred the prepared samples to LEGS lab for metal concentration analysis of zinc, copper, and lead.

Water sampling and analysis

I collected water samples from each site along Lefthand Creek and Little James Creek. I collected 50 mL of water from a riffle area of my sample area in a 50 mL acid-washed plastic conical tube. I put the samples on ice and transported them to a freezer until further analysis.

In the lab, I set the samples out to thaw to room temperature in the lab overnight for 12 h (+/- 2 h). Once the samples reached room temperature, I transferred the samples to acid-washed plastic bottles for analysis. To prepare my samples for inductively-coupled plasma mass spectrometer analysis, I added 63 µL of trace metal-grade nitric acid to my water samples to lower the pH of the samples to 1.0 and to ensure accurate readings by the spectrometer analysis. I used an auto-pipette to extract 10mL of water from each sample and transfer it to acid-washed plastic sample bottles. I used a different pipette for each sample to ensure cross-contamination did not occur. I added 63 µL of nitric acid to each of my samples. I capped the bottles and transported them to the LEGS lab for further analysis.

Lab Blank Preparation: Water
I prepared one lab blank for water for analysis at LEGS lab. I used de-ionized water and added 63 µL of trace metal-grade nitric acid to the bottle. I sent this sample along with the other samples to LEGS for analysis of zinc, copper, and lead.

ICP-MS Machine Detection Limits

Table 1 shows the machine detection limits for benthic macroinvertebrates, sediment, and water. I first sent 41 samples to LEGS for analysis of metal concentrations. One week later I sent 10 more samples to LEGS for analysis. Lastly, I sent 26 water samples to LEGS for analysis of zinc, copper, and lead. All of the low concentrations found in the sample results were much higher than the machine detection limits in this study. Tables in the Appendix show the comparison of these values with the specific site they correspond with in more detail.

Table 1. Machine Detection limits for each set of samples sent to LEGS lab for analysis of zinc, copper, and lead.

<table>
<thead>
<tr>
<th></th>
<th>Zinc (ppb)</th>
<th>Copper (ppb)</th>
<th>Lead (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Machine Detection Limit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>for 41 samples: Sediment</td>
<td>0.57</td>
<td>0.18</td>
<td>0.01</td>
</tr>
<tr>
<td>and Benthic Macroinvertebrates</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|                           | 1.901      | 0.209        | 0.316      |
| Machine Detection Limit   |            |              |            |
| for 10 samples: Sediment  |            |              |            |
| and Benthic Macroinvertebrates |

| Machine Detection Limit   | 3.42       | 1.10         | 0.08       |
| For 26 Water Samples      |            |              |            |

EPT/Diptera Ratio Calculation

As part of my results and discussion, I calculated the EPT/Diptera ratio of benthic macroinvertebrates to determine the effect of metals in the assemblages of the macroinvertebrates on species richness. I added the number of each species, *Ephemoptera*, *Plecoptera*, and *Trichoptera* to receive a total sum of the pollution tolerant species present in the stream. I then divided these numbers by the number of *diptera*, or pollution intolerant organisms in the stream.
Results

The results section includes the raw data that I found for each of my variables, including benthic macroinvertebrates, sediment, and water. There are six sub-sections in my results. The results of these three variables also include the lab blank results. For benthic macroinvertebrates, I have presented the results of the number of organisms and classification in this results section as well.

Lab Blank Results: Benthic Macroinvertebrates

To ensure that the constituents I used for my digestion methods were accurate and did not contain trace metals that I was analyzing my samples for, I sent two lab blanks to also be analyzed. I prepared the blanks using the same methods for digestion as my other samples following Bautts (2006) outlined procedure. I added 10 mL of de-ionized water, 2.5 mL of trace metal grade nitric acid, and 2.5 mL of 30% hydrogen peroxide. The levels in these blanks were higher than expected. However, the results of the true samples were all much higher than the values of these blanks. The higher sample values compared to these blank values indicates that the samples were not altered heavily by the reagents used in the digestion analysis. The blank results were close to the machine detection limit for these samples, with the exception of Blank 3 BM of zinc (35.3 ppb).

Table 2. Table showing the values in ppb of the benthic macroinvertebrate blanks sent to the lab for analysis of metals. *DL indicates that levels were below the machine detection limit.

<table>
<thead>
<tr>
<th></th>
<th>Zinc  (ppb)</th>
<th>Copper (ppb)</th>
<th>Lead  (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank 1 BM</td>
<td>2.15</td>
<td>1.24</td>
<td>DL*</td>
</tr>
<tr>
<td>Blank 2 BM</td>
<td>1.96</td>
<td>3.40</td>
<td>0.66</td>
</tr>
<tr>
<td>Blank 3 BM</td>
<td>35.3</td>
<td>2.4</td>
<td>DL*</td>
</tr>
<tr>
<td>Machine Detection Limit for 46 samples</td>
<td>1.900</td>
<td>0.209</td>
<td>0.316</td>
</tr>
<tr>
<td>Machine Detection Limit for 10 samples</td>
<td>3.42</td>
<td>1.10</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Benthic Macroinvertebrate Results
The benthic macroinvertebrate results include both the taxonomy found in both creeks as well as the amount of metals found in the macroinvertebrate bodies at each site. The trend found in my results of taxonomy on Lefthand Creek indicate that higher numbers of benthic macroinvertebrates were found on either end of my testing area (Figure 4). The results of taxonomy indicate that the order Plecoptera invertebrate was the most commonly found organism on this stretch of sampling of Lefthand Creek. I found low numbers of macroinvertebrates in the stretch of creek after the Big Five Tunnel discharge into the creek and just below the Captain Jack Mill (1-1.47 km).

![Figure 4: Bar graph of benthic macroinvertebrate taxonomy found in Lefthand Creek. *Notice break in axis from 2km to 22km.](image)

Taxonomy of Little James Creek indicates elevated levels of organisms at the last site (LJ11), which was further downstream than the other sites. The sites nearest the Burlington Mine (LJ6-LJ10, 1.05-1.37 km downstream) have the lowest count of total organisms. The graph also indicates that order
Trichoptera invertebrate was the most commonly found organism in the entire stretch of sampling on Little James Creek.

![Bar graph of benthic macroinvertebrate taxonomy found in Little James Creek](image)

Figure 5: Bar graph of benthic macroinvertebrate taxonomy found in Little James Creek

Table 3 shows the background concentrations of benthic macroinvertebrates in areas void of mining activity. I took the background site samples for Lefthand Creek at the Peak-to-Peak Highway (refer to Figure 1) intersection with the creek. The concentrations of zinc and copper in Lefthand Creek are relatively high at the background sites, because mines do exist above this point; however, these sites served as a baseline for the mines that exist downstream. The background sites for Little James Creek were sampled above the Argo Mine (refer to Figure 1) and away from other mine activity. The site of LJ2 had much higher concentrations than LJ1. This result may be because other mined exist above these background sites and may affect the metal concentrations.
Table 3. Benthic Macroinvertebrate background concentrations from areas void of mining activity

<table>
<thead>
<tr>
<th>Creek</th>
<th>Site Name</th>
<th>Zinc (µg/g)</th>
<th>Copper (µg/g)</th>
<th>Lead (µg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lefthand Creek</td>
<td>LH1</td>
<td>588.87</td>
<td>500.6</td>
<td>48.1</td>
</tr>
<tr>
<td>Lefthand Creek</td>
<td>LH2</td>
<td>315.1</td>
<td>131.1</td>
<td>4.2</td>
</tr>
<tr>
<td>Little James Creek</td>
<td>LJ1</td>
<td>285.62</td>
<td>57.68</td>
<td>9.32</td>
</tr>
<tr>
<td>Little James Creek</td>
<td>LJ2</td>
<td>435.29</td>
<td>317.96</td>
<td>375.48</td>
</tr>
</tbody>
</table>

The highest level of zinc on Lefthand Creek was at site LH8 (918.1 µg/g). The highest level of copper concentration in Lefthand Creek was at site LH6 (3550 µg/g) this site is below the Big Five Mine drainage point and above the Captain Jack Mill area. The next highest concentration of copper on Lefthand Creek was at site LH8 (993.1 µg/g), which is located just downstream of the Captain Jack Mill. The highest concentration of lead found in Lefthand Creek was sample site LH8 (67.5 µg/g).

When collecting samples in the field, I did not find many benthic macroinvertebrates in the stretch from sites LJ6-LJ10. I made the decision to combine these sites for benthic macroinvertebrate testing due to their close proximity to one another. The highest level of copper concentration in Little James Creek came from the combined sites of LJ6-LJ10 (3365 µg/g). The highest levels of lead came from site LJ1 (375.48 µg/g). The highest zinc concentrations came from site LJ4 (612.8 µg/g).

Figure 6 shows that the levels of metals spike in the distance downstream between 1 and 1.4 km. This reach begins at the discharge point of the Big Five Tunnel and ends downstream of the remnants of the Captain Jack Mill. In this reach, the Big Five Tunnel drainage meets at a confluence with Lefthand Creek. Levels of each metal decline after the spike in Lefthand Creek. The levels of the metals zinc and lead spike at the distance of 1.2-1.4 km in Lefthand Creek. The spike in copper occurred at the distance of 1.0-1.2 km. These two locations between the drainage of the Big Five Tunnel drainage into Lefthand Creek and the area of creek located adjacent to the Captain Jack Mill.

The trend of metal concentrations in Little James Creek that drains into Lefthand Creek (Figure 7). Zinc and lead concentrations both spike at a distance downstream of 0.5-0.8 km. This location
is the distance downstream above the Burlington Mine drainage but after the Argo Mine tailings located on this stretch of stream. The sampling in this area for benthic macroinvertebrates was more difficult than other areas due to the flood remediation that was taking place at this time on this stretch of Little James Creek.
Figure 6. Line graph of the concentrations of zinc, copper, and lead in benthic macroinvertebrates as a function of distance in Lefthand Creek.
Figure 7. Line graph showing the metal concentrations of zinc, copper, and lead consecutively of macroinvertebrates found in Little James Creek.

Lab Blank Results: Sediment

Table 3 shows the values for the lab blanks for sediment. These low values indicate that levels were low in the nitric acid, hydrogen peroxide, and laboratory methods used were amenable to the fact that metals were being analyzed in each of the samples, therefore they did not affect the results of my samples. The blanks were close to the values of the machine detection limit, with the exception of Blank 1 of zinc (13.55 ppb).

Table 3. Values for sediment lab blanks sent to the lab to be analyzed. *DL indicates that levels were below the machine detection limit. Detection limits of both sets of samples are also shown in this table.

<table>
<thead>
<tr>
<th>Blank</th>
<th>Zinc (ppb)</th>
<th>Copper (ppb)</th>
<th>Lead (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank1 SED</td>
<td>13.55</td>
<td>3.13</td>
<td>DL*</td>
</tr>
<tr>
<td>Blank 2 SED</td>
<td>4.28</td>
<td>DL*</td>
<td>0.80</td>
</tr>
<tr>
<td>Blank 3 SED</td>
<td>DL*</td>
<td>DL*</td>
<td>2</td>
</tr>
<tr>
<td>Machine Detection Limit for 46 samples</td>
<td>1.900</td>
<td>0.209</td>
<td>0.316</td>
</tr>
<tr>
<td>Machine Detection Limit for 10 samples</td>
<td>3.42</td>
<td>1.10</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Sediment Results

Table 4 displays the metal concentrations for the background sites where I collected sediment along Lefthand Creek and Little James Creek. These levels of metal concentrations are far lower than the benthic macroinvertebrate results that I obtained from sites surrounding the mines. The highest of these background sites was found at site LJ1 with a lead concentration of 17.7 µg/g.

Table 4. Sediment background concentrations from areas void of mining activity.

<table>
<thead>
<tr>
<th>Creek</th>
<th>Site Name</th>
<th>Copper (µg/g⁻¹)</th>
<th>Lead (µg/g⁻¹)</th>
<th>Zinc (µg/g⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lefthand Creek</td>
<td>LH1</td>
<td>8.99</td>
<td>3.55</td>
<td>6.85</td>
</tr>
<tr>
<td>Lefthand Creek</td>
<td>LH2</td>
<td>8.09</td>
<td>2.84</td>
<td>3.08</td>
</tr>
<tr>
<td>Little James Creek</td>
<td>LJ1</td>
<td>8.63</td>
<td>17.76</td>
<td>8.32</td>
</tr>
<tr>
<td>Little James Creek</td>
<td>LJ2</td>
<td>7.69</td>
<td>10.44</td>
<td>3.6</td>
</tr>
</tbody>
</table>
The highest levels of copper found in the sediment of Lefthand Creek come from site LH9 (246 µg/g) which is located downstream of the Captain Jack Mill area but above the White Raven Mine. The highest levels of lead found in sediment was found at site LH12 (125.07 µg/g), which is located below all mines at the intersection of Saw Mill Road (refer to map - Figure 1). The highest concentration of zinc was at site LH9 (86.0 µg/g) as well.

In Little James Creek, the highest levels of copper were at site LJ6 (140.6 µg/g), which is the intersection of the Burlington Mine water drainage. The highest levels of lead are found at site LJ7 (242.5 µg/g), which is located just below the confluence of acid mine drainage from the Burlington Mine. The highest levels of zinc were found at site LJ4 (103.8 µg/g), located upstream of the Burlington Mine discharge.

Figure 8 shows the graphical representation of metal concentrations for zinc, copper, and lead in sediment for Lefthand Creek. These concentrations are plotted against the distance downstream based on my sample sites. These graphs show that there were low levels of metals in the background sites of each sample location. These sites are at the Peak-to-Peak Highway on Lefthand Creek, and above the Burlington Mine, away from mine drainage on Little James Creek. Lefthand Creek shows a similar trend followed by each metal analyzed in the sediment of this creek. Zinc, copper, and lead all follow similar trend, peaking slightly at a distance of 1 km which the area of creek where the Big Five Mine drains into Lefthand Creek. Zinc and copper both reach their highest concentration at a distance of 1.4km downstream which is the site located just below the Captain Jack Mill. The results indicate a clear decrease in concentration in metals at the last sample site on Lefthand Creek where the Lefthand Water District intake (Haldi Headgate) is located.
Figure 8. Line graph showing the concentrations of zinc, copper, and lead in the sediment of Lefthand Creek.
Concentrations of metals in sediment in Little James Creek conversely do not follow similar trends. Zinc spikes at the distance downstream between 0.5-0.8 km. This is the location upstream of both the Argo Mine discharge and the Burlington Mine discharge. Copper metal concentrations spike in the distance downstream from 0.8 km to 1.2 km. This location is upstream of the Burlington Mine but below the discharge of the Argo Mine. Lead concentrations spike in the location downstream of the Burlington Mine discharge about 0.2 km.
Figure 9. Line graph showing the concentrations of zinc, copper, and lead in the sediment of Little James Creek.
Lab Blank Results: Water

Table 5 shows the results for the lab blank of water. The levels are low in both zinc and lead; however, copper is unusually high in this sample. The higher levels of copper and zinc in this lab blank may be due to the quality of the de-ionized water used or the bottle the water was stored in, therefore, impacting the levels of metals in the lab blank. The samples collected in close proximity to the mines were well above the blank values presented in this table.

Table 5. Values represent the levels present in the lab blank for water. *DL indicates levels were below machine detection limit.

<table>
<thead>
<tr>
<th></th>
<th>Zinc (ppb)</th>
<th>Copper (ppb)</th>
<th>Lead (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank 1 Water</td>
<td>2.27</td>
<td>11.3</td>
<td>*DL</td>
</tr>
<tr>
<td>Machine Detection</td>
<td>3.42</td>
<td>1.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Limits for 26 water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>samples</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Water Results

Table 6 shows the background concentrations of water in areas void of mining activity on both creeks. The levels are very low, many were below the ICP-MS detection limit, denoted as DL (detection limit) in the table. The highest level found at background sites was from site LH2 with 2.11 µg/g of zinc.

Table 6. Water background concentrations from areas void of mining activity for Lefthand Creek and Little James Creek. *DL indicates levels were below machine detection limit.

<table>
<thead>
<tr>
<th>Creek</th>
<th>Site Name</th>
<th>Copper (µg/g)</th>
<th>Lead (µg/g)</th>
<th>Zinc (µg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lefthand Creek</td>
<td>LH1</td>
<td>DL*</td>
<td>DL*</td>
<td>0.7</td>
</tr>
<tr>
<td>Lefthand Creek</td>
<td>LH2</td>
<td>0.39</td>
<td>0.01</td>
<td>2.11</td>
</tr>
<tr>
<td>Little James Creek</td>
<td>LJ1</td>
<td>1.02</td>
<td>DL*</td>
<td>DL*</td>
</tr>
<tr>
<td>Little James Creek</td>
<td>LJ2</td>
<td>1.01</td>
<td>0.06</td>
<td>1.58</td>
</tr>
</tbody>
</table>

The highest levels of copper found in water samples that I collected from Lefthand Creek was at site LH4 (332.5 µg/g). This site is located at the drainage confluence of the Big Five Mine adit. The
highest concentration of lead found on Lefthand Creek was site LH7 (2.1 µg/g) which is located at the Captain Jack Mill site. The highest levels of zinc found on this creek was at site LH4 (523.2 µg/g) as well.

At Little James Creek, the highest levels of copper found were from site LJ7 (21.9 µg/g). This site is located directly below the drainage confluence of the Burlington Mine. The highest concentration of lead that I found was at site LJ7 (6.7 µg/g) also. The highest levels of zinc found was from site LJ10, which is located downstream of the drainage confluence of the Burlington Mine discharge.

Figure 10 shows the metal concentrations found in the water of Lefthand Creek plotted against the distance of the sample sites of each of my sampling locations. Metals found in water concentrations of Lefthand Creek all follow a similar trend. All three metals spike in the distance where the Big Five Tunnel discharge enters the stream (1km downstream). Copper and zinc slightly increase in concentration in the stretch of creek located across from the Captain Jack Mill site. However, lead reaches its highest concentration at this same point in the creek where the Captain Jack Mill is, (1.2 km downstream). The three metals gradually decrease and reach low levels once more at the end of the testing sites at the Haldi Headgate, where the Lefthand Creek outtake is located.
Figure 10. Line graph showing the concentrations of zinc, copper, and lead in the water of Lefthand Creek.
Figure 11 shows the line graph of metals present in the water of Little James Creek. The metal concentrations in Little James Creek water also follow a very similar trend. All three metals spike at the location of the Burlington Mine discharge as well as the distance downstream where site LJ 10. They decrease slightly downstream of the Burlington Mine discharge. The levels of metals all increase again at the LJ 10 site. This site is about 0.2 km downstream of the Burlington Mine confluence with Little James Creek. Similar to Lefthand Creek, the levels in all three metals decrease again to low levels just before the Little James confluence with James Creek.
Figure 11. Line graph showing the concentrations of zinc, copper, and lead in the water of Little James Creek.

Metal Concentrations in Water: Little James Creek

Zinc (µg/L)

Copper (µg/L)

Lead (µg/L)

Distance Downstream (km)
Overall, the results from this study indicate that laboratory procedures did not significantly impact the research by misconstruing the data, based on the lab blanks I prepared. The background concentrations of metals in water were lower than background concentrations of metals in benthic macroinvertebrates and sediment at each creek. I will analyze these results in the next section by looking at the correlation between the three variables that I tested and also comparing my data to the 2004 data from Bautts (2006).
Discussion

In this discussion section, I have three sub-sections. The first sub-section discusses the relationship between benthic macroinvertebrate metal concentrations and the EPT/diptera ratio that I found. The next section discusses the varying effects of the three variables of macroinvertebrates, sediment, and water on each other. Lastly, I discuss the comparison results between my data and the data from 2004.

Benthic macroinvertebrate vs metal concentrations

To understand the relationships between the metal concentrations present in the benthic macroinvertebrates and the abundance and species richness of benthic macroinvertebrates found in the stream, I plotted the EPT/Diptera ratio index against the metals found in the macroinvertebrates at each site. The interpretation of the significance of the ratio is that a higher ratio found indicates better stream water quality, (Scott and McCord, 2015). This includes lower levels of heavy metals and higher dissolved oxygen. I did not monitor other water quality aspects such as dissolved oxygen content or periphyton in the stream to better understand the health of the stream and the health of the benthic macroinvertebrate community. However, from the data I did collect, I can infer some relationship between the ratio of pollution sensitive organisms to pollution tolerant organisms and the levels of metals present in these organisms.

Zinc

Figure 12 shows the levels of zinc present in the benthic macroinvertebrates and its relationship to the EPT/Diptera ratio for Lefthand Creek. The levels of zinc in the macroinvertebrates are shown in blue and the trend of the EPT/Diptera is represented as a line graph plotted against distance. In Lefthand Creek, the results indicate that the EPT/Diptera ratio supports my hypothesis because a higher ratio is found at the background sites of Lefthand Creek, indicating better water quality. These areas
were void of mining activity away from the areas found downstream at the Big Five Tunnel confluence and Captain Jack Mill site.

Figure 12. EPT/Diptera Ratios plotted against metal concentration of Zinc within the macroinvertebrates found in Lefthand Creek. * Note that a denominator of at least 1 diptera was used in the calculation of this value to provide a non-zero answer.

Figure 13 shows the EPT/Diptera Ratio versus the concentration of zinc in macroinvertebrates in Little James Creek. This graph has missing data due to the inability to find enough macroinvertebrates in the area surrounding the Burlington Mine discharge. The ratio does not have a clear trend except for a few correlations at sample sites that have high levels of zinc have lower ratios of EPT/Diptera. The sites located at 1.05 km to 1.47 km downstream show the lowest ratios of zinc. These results support the fact that zinc tends to stay in the water rather than adsorb to organisms or sediment (Kimball et al., 1995; Farag et al., 1998).
Figure 13. EPT/Diptera Ratios plotted against metal concentration of Zinc within the macroinvertebrates found in Little James Creek. *Note that a denominator of at least 1 diptera was used in the calculation of this value to provide a non-zero answer.

Copper

Figure 14 shows the EPT/Diptera ratio and concentration of copper in macroinvertebrates in Lefthand Creek. This graph has a clearer relationship between these two variables than zinc did. Where levels of benthic macroinvertebrates EPT/Diptera ratio are high, indicating better water quality and less heavy metals, the metals found within these macroinvertebrates were very low. A decline in the ratio at the location near the Big Five Tunnel discharge and the Captain Jack Mill is also evident based on this figure. These are the areas where the metals concentration of copper was the highest in benthic macroinvertebrates in Lefthand Creek.
Figure 14. EPT/Diptera Ratios plotted against metal concentration of copper within the macroinvertebrates found in Lefthand Creek. * Note that a denominator of at least 1 diptera was used in the calculation of this value to provide a non-zero answer.

Figure 15 shows the EPT/Diptera ratio and copper concentration trend for Little James Creek. As with the zinc graph representing Little James Creek, it is hard to draw many conclusions from this graph due to a lack of macroinvertebrates found in the stretch near the Burlington Mine drainage confluence. This graph shows at the location of 1.05 km downstream, site LJ 6 (upstream of Burlington Mine discharge, below CR-87) the level of copper is high and the ratio of benthic macroinvertebrates is low. The data also shows that at the last sample spot that I found benthic macroinvertebrates at LJ 11 (just before confluence with James Creek) the level of copper is very low and the ratio of macroinvertebrates is the highest at this site location. This indicates that the water entering James Creek from Little James Creek, according to EPT/Diptera ratio and metal concentrations has a higher water quality than any other stretch of Little James Creek.
Figure 15. EPT/Diptera Ratios plotted against metal concentration of copper within the macroinvertebrates found in Little James Creek. * Note that a denominator of at least 1 diptera was used in the calculation of this value to provide a non-zero answer.

Lead

Figure 16 shows the lead concentrations and EPT/Diptera ratio found in benthic macroinvertebrates in Lefthand Creek. This graph shows a low ratio of macroinvertebrates at the location 1.11 km downstream to 1.32 km downstream. This location corresponds with the sites LH 6 to LH 8. These sites represent the location ranging from upstream of the Captain Jack Mill to just below the Captain Jack Mill. Metal concentration of lead is also the highest at the area just downstream of the Captain Jack Mill at site LH8 (1.32 km).
Figure 16. EPT/Diptera Ratios plotted against metal concentration of lead within the macroinvertebrates found in Lefthand Creek. * Note that a denominator of at least 1 diptera was used in the calculation of this value to provide a non-zero answer.

Figure 17 shows the EPT/Diptera ratios and concentration of lead in macroinvertebrates in Little James Creek. The ratio is the highest at the site located just before the confluence of Little James Creek with James Creek. The level of lead in macroinvertebrates is also low at this location. The high level of lead found at the background site may be because of the mines that lie above this watershed and above the background site. This may be a reason because there is a medium ratio of macroinvertebrates found in this area, yet the level of lead is very high for a background site. Other factors that may have affected the levels of lead in the lab include the transportation of the macroinvertebrates into the drying oven.
Overall, my study shows that the metal copper shows the strongest correlation between EPT/Diptera ratio and metal concentration within macroinvertebrates in both streams. Due to lack of data from Little James it is hard to draw any solid conclusions from the relationship and impact of metals on benthic macroinvertebrate communities. In all three metals and two creeks, the relationship between high ratios and low metal concentrations at either end of the testing sites is clear. This corresponds to my hypothesis that metals do have an impact on the health and existence of benthic macroinvertebrate communities. However, I can infer that the results support the fact that zinc tends to stay in the water while lead is the most-likely to adsorb to other constituents in the stream including benthic macroinvertebrates and sediment.

Water, Macroinvertebrates, & Sediment as Monitors of Stream Health

Benthic macroinvertebrates and sediment are good for long-term monitoring of stream health, while water is best used as a short-term indicator and monitor of stream health (Hare et al., 1991). Based on this knowledge, I ran regression analyses using RStudio on my variables to determine if there...
was any correlation between certain variables. I chose to look at the impact that both metals in the sediment and metals in the water have on the concentration of metals in the benthic macroinvertebrates. I also sought to understand how the metals in the sediment impacted the metals in the water.

Table 7 shows the statistical values of $r^2$ determined from the regression analysis of benthic macroinvertebrates versus sediment. I found two higher $r^2$ values showing a positive correlation between these two variables in Little James Creek in copper in macroinvertebrates and copper in sediment ($r^2=0.49$). This indicates that the regression model explained about 50% of the positive correlation between these two variables. The other positive correlation found in this table is the $r^2$ value showing a slight positive correlation in Lefthand Creek in the lead in macroinvertebrates and in the sediments ($r^2=0.13$). Overall, I found stronger correlations between benthic macroinvertebrates and sediment in Little James Creek. This may be due to the low flow present in this creek during the testing affecting the levels of metal in the sediment, because little water was disturbing the sediment in this area sediment could have had the chance to build up more and retain more metals. It could also be because of the general lack of benthic macroinvertebrates compared to Lefthand Creek.
Figure 18 and 19 shows the regression analysis and graphical correlation between the metals found in macroinvertebrates and the metals found in sediment in both sample site locations. The correlation between these two variables is not very strong, except as previously noted in copper in Little James Creek. There are areas where metals rise in both sediments and macroinvertebrates; however, we can conclude that there is no positive correlation between sediments and macroinvertebrates in these two locations.

Bautts (2006) also examined the correlation between sediment and macroinvertebrates and found that there were strong positive correlations for copper ($r^2=0.80$) and lead ($r^2=0.84$). Lack of a strong correlation between benthic macroinvertebrates and sediment between my study and Bautts (2006), may be due to lower concentrations of metals in sediment in my data than they were Bautts (2006) analysis. These lower levels of metals in sediment could be because the flood washed away the sediment that was in the creek for many years and had built up metals in it.

<table>
<thead>
<tr>
<th>Lefthand Creek</th>
<th>Benthic Macroinvertebrates vs. Sediment</th>
<th>Little James Creek</th>
<th>Benthic Macroinvertebrates vs. Sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>r2</td>
<td>0.002</td>
<td>Zinc</td>
</tr>
<tr>
<td></td>
<td>r2</td>
<td>r2 0.041</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>r2</td>
<td>0.005</td>
<td>Copper</td>
</tr>
<tr>
<td></td>
<td>r2</td>
<td>r2 0.494</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>r2</td>
<td>0.1379</td>
<td>Lead</td>
</tr>
<tr>
<td></td>
<td>r2</td>
<td>r2 0.077</td>
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</tr>
</tbody>
</table>
Figure 18. Metals in benthic macroinvertebrates as a function of metals in the sediments of Lefthand Creek. Linear regressions shown as blue lines.
Figure 19. Regression analysis graph showing how the metals in the sediment impact the metals in benthic macroinvertebrates of Little James Creek. Copper shows a positive correlation.
Table 8 shows the statistical values of $r^2$ regression analysis of these two variables, benthic macroinvertebrates and water. The $r^2$ values are used to determine how well the line fits the regression model, thus how correlated these two variables are. The strongest positive correlation that was found was between copper in benthic macroinvertebrates and copper in water Little James Creek ($r^2 = 0.36$). The $r^2$ for lead was low (0.05) in Little James Creek and (0.03) in Lefthand Creek. The other $r^2$ values that were a result of the regression analysis between benthic macroinvertebrates and water were very low. From these $r^2$ values, I can conclude that the relationship between metal concentrations in benthic macroinvertebrates and water is not a strong positive correlation in my study. Overall, by looking at all three metals in each of the two streams, Little James Creek appears to have a stronger positive correlation between benthic macroinvertebrates and water in the creek. This might be explained by the low flow impacting the levels of metal in the water present in this stream, resulting in a more concentrated metal water environment that the macroinvertebrates were living in.

Table 8. Table representing $r^2$ values for metals in benthic macroinvertebrates vs water in Lefthand Creek and Little James Creek.

<table>
<thead>
<tr>
<th></th>
<th>Benthic Macroinvertebrates vs. Water</th>
<th>Little James Creek</th>
<th>Benthic Macroinvertebrates vs. Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lefthand Creek</strong></td>
<td>Zinc</td>
<td>r2</td>
<td>0.0005</td>
</tr>
<tr>
<td><strong>Copper</strong></td>
<td>0.002</td>
<td>r2</td>
<td>0.363</td>
</tr>
<tr>
<td><strong>Lead</strong></td>
<td>0.035</td>
<td>r2</td>
<td>0.054</td>
</tr>
</tbody>
</table>

Figure 20 and 21 show the correlation graph of metals found in the macroinvertebrates and the metals found in the water of Lefthand Creek and Little James Creek. The Lefthand Creek results show no correlation between these two variables. The graph that shows the clearest correlation between metals in benthic macroinvertebrates and metals in water is the Little James Creek graph showing the concentration of copper in Figure 21. The level of copper in macroinvertebrates was high in Lefthand Creek overall and this graph does show a positive correlation between these two variables. For these
graphs, the macroinvertebrate total from the combined sites of LJ6-10 were represented by taking the average of the water concentrations from these sites and comparing them as one site.

Bautts (2006) found one positive correlation in the element copper ($r^2=0.74$) in Little James Creek when she compared metals in the water and metals in benthic macroinvertebrates in her study. This result suggests that metals in water do not have a strong effect on metals in benthic macroinvertebrates, except for copper in Little James Creek. This might be explained by the fact that concentrations of copper were higher in benthic macroinvertebrates in Little James Creek than in Lefthand Creek.
Figure 20. Regression analysis graphs how the metals in the water impact the metals in benthic macroinvertebrates in Lefthand Creek. No correlations were found.
Figure 21. Regression analysis graphs showing the impact of metals in the water on the metals in the benthic macroinvertebrates of Little James Creek. Copper shows a positive correlation.
Table 9 shows the $r^2$ values for the regression analysis of sediment vs water for the metals copper, lead, and zinc in Lefthand Creek and Little James Creek. These values show that copper and lead in Little James Creek both have higher $r^2$ values than the values for Lefthand Creek, indicating that the values explain almost the entire model. The strong positive correlations for how metals in the water affect metals in the sediment Little James Creek were copper ($r^2=0.90$) and lead ($r^2=0.91$). The highest $r^2$ value for Lefthand Creek was for lead ($r^2=0.04$). The lowest value for $r^2$ was also in Lefthand Creek in copper ($r^2 = 0.001$). Overall, sediment and water in Little James Creek alone have the strongest relationship than any of the other sets of variables.

<table>
<thead>
<tr>
<th>Lefthand Creek</th>
<th>Sediment vs. Water</th>
<th>Little James Creek</th>
<th>Sediment vs. Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc</td>
<td>$r^2$ = 0.008</td>
<td>Zinc</td>
<td>$r^2$ = 0.085</td>
</tr>
<tr>
<td>Copper</td>
<td>$r^2$ = 0.001</td>
<td>Copper</td>
<td>$r^2$ = 0.901</td>
</tr>
<tr>
<td>Lead</td>
<td>$r^2$ = 0.042</td>
<td>Lead</td>
<td>$r^2$ = 0.911</td>
</tr>
</tbody>
</table>

Figure 22 and 23 show how metals in the water affect metals in the sediment. Metals in the water do show a positive correlation to the metals in the sediment in Little James Creek only. However, the relationship between the metals in the water and the metals in the sediment in Lefthand Creek is mostly negative. This correlation is likely due to the extensive remediation efforts that have already taken place on Lefthand Creek as opposed to the lack of extensive remediation efforts on Little James Creek.
Figure 22. Regression analysis graphs examining whether metals in water impact the metals in sediment in Lefthand Creek. No correlations were observed.
Figure 23. Regression analysis of concentration of metals in sediment vs the concentration of metals in water in Little James Creek. All three metals show a positive correlation.
Comparison from 2004 Data Results and Discussion

*Macroinvertebrates*

Figure 24 shows the graphical representation of my metal concentrations in the macroinvertebrates compared to the previous data found in 2004 by Bautts (2006) in Lefthand Creek. The red color denotes my data and the gray color is Bautts (2006) prior data. For benthic macroinvertebrates, all levels of metals were higher in my 2018 data than they were in 2004. This graph shows a strong relationship between the two sets of data from different years. The data I obtained follows a very close pattern in all of the metals to the pre-remediation and pre-flood data from Bautts (2006).
Figure 24. Line graph showing the comparison between 2004 data and current data for the concentrations of metals in macroinvertebrates of Lefthand Creek. Graph indicates that levels of metals were higher in current data.
Figure 25 shows the comparison between 2004 data and my 2018 data of metals in macroinvertebrates in Little James Creek. Metals are higher in my data of copper and lead and slightly less in zinc than Bautts (2006) data. The missing points in each of the graphs of the metals show that I found very few macroinvertebrates in this stretch of Little James Creek, so I combined the samples I did find and represented those as one single sample in my data and graphs. Bautts (2006) also struggled to find many macroinvertebrates in this stretch of creek in 2004, so there are also missing data points represented in her data.
Figure 25. Line graph showing the comparison between 2004 data and current data for the concentrations of metals in macroinvertebrates in Little James Creek. Graph indicates that levels of metals were higher in current data. Missing data was due to no macroinvertebrates found in this stretch of the creek.
Sediment

Figure 26 shows the comparison between the data in 2004 and my data of sediment in Lefthand Creek. These graphs show that the levels of sediment were much higher in 2004 than in my data from 2018. This large difference in levels of sediment is likely due to the 2013 flood washing out the previous sediment that was present in this area. In 2013, the flood washed through Lefthand Canyon in part of its major destruction in Boulder County. The sediments that were present in the stream were likely very different from the sediments tested in 2004 by Bautts (2006).
Figure 26. Line graph showing the comparison between 2004 data and current data for the concentrations of metals in sediment in Lefthand Creek. Graph shows that levels of metals in sediment were higher in 2004.
Figure 27 shows the comparison of metals in the sediment in Little James Creek between 2004 data and my data. This graphical representation shows that levels in sediment were higher in both copper and zinc in 2004 rather than today. However, levels of lead were higher in my data rather than in 2004. These results support the fact that of these three metals, zinc tends to stay dissolved in the water, copper tends to be in both organisms and sediment and lead tends to bind to sediments and benthic macroinvertebrates, (Kimball et al, 1995; Farag et al. 1998). The lower levels of zinc and copper in the sediment of Little James Creek could mean that the flood event of 2013 had an impact on washing away the sediments that were present when Bautts (2006) took her samples. However, the lead concentrations are slightly higher today than in 2004 which also supports the understanding that lead clings to sediment and benthic macroinvertebrates more, which is representative in the continually elevated levels of lead in the sediment found in my data.
Figure 27. Line graph of the comparison between 2004 data and current data for the concentrations of metals in sediment in Little James Creek. Graph shows higher levels today in lead than in 2004, but lower levels of zinc and copper today.
Figure 28 shows the comparison between my data and 2004 data of metal concentrations in water of Lefthand Creek. The metal concentrations in water in Lefthand Creek were higher today than in 2004. However, the metal concentrations of zinc and copper in water in Little James Creek were higher in 2004 than today. These results indicate a much higher spike in concentrations of metals in water at the area where the Big Five Tunnel drainage meets Lefthand Creek. The levels of lead present in Lefthand Creek closely resembles the data from 2004.
Figure 28. Line graph comparison of 2004 data and current data for the concentrations of metals in water. Graph indicates that levels of metals were higher in present data than in 2004.
Figure 2 shows the comparison between 2004 and my data for metals in water in Little James Creek. This graphical representation of the comparison data shows that levels of metals were higher in 2004 than today. The higher levels in the water in 2004 might be because of the much lower flow in Little James Creek at the time that I did my testing. The flow of Little James Creek was uncharacteristically low during the sampling that I did in October. These results could also mean that the remediation was not sufficient in this area and needs to continue in the years to come.
Figure 29. Line graph comparison of 2004 data to current data for the concentrations of metals in water in Little James Creek. Graph indicates levels of metals in water were higher in 2004.
Further Study and Study Limitations

In this section, I discuss three sub-sections that discuss the effects from the 2013 flood, the effects of low flow, and finally the effects of diverse methods.

Impacts of 2013 Flood

To better understand the difference in data between 2004 and 2018, we can look to the 2013 Boulder County Flood for an explanation in my data. This flood affected the region of Lefthand Creek Watershed and ultimately could have had drastic consequences for the transportation and disturbance of metals in this area. Byrne, et al. (2017) discusses the detrimental impact that even annual storm events can have on abandoned mines. The researchers of this study found that during storm events, metals present in the mine waste flushed downstream and increased the concentrations to levels above water quality guidelines. Walton-Day and Mills (2015) pre-remediation and post-remediation comparison study shows that after the installation of a bulk-head in a mine in Colorado, input of heavy metals decreased by 97%. However, they found that water quality problems continued to persist in excess during high-flow events and years with heavy rainfall. Although the EPA removed much of the mine waste near the Captain Jack Mill before the flood event of 2013, the intense flood event likely had an affected both creeks. The 2013 flood could be a reason why I saw higher levels of metals in the macroinvertebrates at each creek. The flood could also be why I saw elevated levels of metals in water and benthic macroinvertebrates in Lefthand Creek but not sediment, due to the flood disturbing the flow regime and washing away years of built-up sediment in the area.

Impacts of Low Flow

One possible factor that may have affected my results in contrast to Bautts (2006) results, would be the low flow present in Little James Creek. The creek was undergoing flood restoration and remediation efforts during the time that I tested and sampled in this area. The stream had very little flow and machinery had disturbed the soil in the process of remediation for flooding that occurred there
in 2013. The agitated flow regime could have had an impact on the lack of benthic macroinvertebrate communities in this area. USGS scientist Kirk Nordstrom (2009) discussed the impact of climate change on acid rock drainage. The researcher learned that metal concentrations tend to increase gradually during dry months and then decrease during discharge peak. This is a concern for the area where I tested because the dry periods of summer are continuing to lengthen. The study states that flood events rather demonstrate a sudden increase in levels of metals surrounding mines. The study concludes that remediation efforts must consider the impact of climate change on acid mine drainage. This includes an increase in budget for remediation in order to properly increase the size and effectiveness of these efforts, (Nordstrom, 2009). Based on this study, climate change could have affected the areas of both Lefthand Creek and Little James Creek. The low flow of Little James Creek should be a concern to those continuing to remediate the area due to the impact of dry climate and low flow on acid mine drainage.

**Impacts of Diverse Methods**

Other reasons why my results may have been different from Bautts (2006) results from 2004 include the diverse methods that I used for my research versus Bautts (2006) research in 2004. One method I did not follow was weighing the macroinvertebrates in the field to obtain a weight of 5g. I chose to not weigh the macroinvertebrates in the field because I collected my samples on a smaller scale in a concentrated area. The areas in which I pulled samples from were also highly contaminated which would make it difficult to find that many macroinvertebrates in my particular sample sites. The heaviest dry weight of macroinvertebrates that I found was 0.03 g from L J 3, above the Argo Mine. Another method that I did not follow precisely was the sieving of sediment to 64 µm. Bautts (2006) sieved each of her sediment samples to this smaller particle size, however, I only sieved my sediment samples to a particle size of 1 mm. This choice likely affected the comparison results and the conclusions I could draw from them because metals are easier to obtain from smaller size particles than larger particles, (Yao, et al. 2015) Davis and Atkins (2001) reported in their study that metal concentrations in
the 64 µm size sediment were about 10 times higher than sediment sieved to a size of 2 mm. Based on this, my 1 mm sieved sediment metal concentration results might differ from Bautts (2006) data by a factor of 10.

Conclusion

<table>
<thead>
<tr>
<th>Overall Results</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lefthand Creek</strong></td>
</tr>
<tr>
<td>Benthic Macroinvertebrates</td>
</tr>
<tr>
<td>Sediment</td>
</tr>
<tr>
<td>Water</td>
</tr>
<tr>
<td><strong>Little James Creek</strong></td>
</tr>
<tr>
<td>Benthic Macroinvertebrates</td>
</tr>
<tr>
<td>Sediment</td>
</tr>
<tr>
<td>Water</td>
</tr>
</tbody>
</table>

I can conclude from this study that the state of each creek studied requires further remediation. Throughout Lefthand Creek, I saw an increase in metals in water and benthic macroinvertebrates compared to the data from 2004. In Little James Creek, I saw an increase or stagnation overall in metals in benthic macroinvertebrates. These two stream constituents are good short-term monitors of stream health. My results represent the short-term state of the streams in the years since the 2013 flood. Based on these indicators, I can conclude that the state of the stream health after remediation and the 2013 flood requires attention and further remediation and monitoring. Because there are no studies evaluating the metal concentrations after remediation and prior to the flood, the true effects of this event are unknown. However, this study is a new baseline study showing the current state of each stream and the metal concentrations present in each stream.

Recommendations

Based on the results of my study, I would recommend that further remediation efforts take place on both Lefthand Creek and Little James Creek. The Captain Jack Mill and the area of the Big Five
Tunnel were a large concern for the EPA in 2003 and many efforts took place on this creek for several years. I would expect that levels of metals had decreased due to the extensive remediation in this area. However, the remediation efforts, based on my study, were not effective. The ineffectiveness of these remediation efforts might also be due to the 2013 flood releasing even more metals and disturbing the remediated land before it had a chance to settle completely. The area surrounding the Burlington Mine on Little James Creek also needs further remediation in the future. The only remediation that has occurred in this area was the voluntary cleanup by Honeywell. Therefore, my recommendation would be to continue remediation and to also consider the impacts of climate change when planning for the future remediation in this area.
## Appendix

### Sample Site Descriptions

<table>
<thead>
<tr>
<th>Sample Site Name</th>
<th>Sample Site Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LEFTHAND CREEK</strong></td>
<td></td>
</tr>
<tr>
<td>LH1</td>
<td>at the Peak-to-Peak Highway</td>
</tr>
<tr>
<td>LH2</td>
<td>at the Peak-to-Peak Highway (2nd Background)</td>
</tr>
<tr>
<td>LH3</td>
<td>upstream of Big Five Tunnel drainage confluence</td>
</tr>
<tr>
<td>LH4</td>
<td>at of Big Five Tunnel drainage confluence</td>
</tr>
<tr>
<td>LH5</td>
<td>downstream of Big Five Tunnel drainage confluence</td>
</tr>
<tr>
<td>LH6</td>
<td>Upstream of Captain Jack</td>
</tr>
<tr>
<td>LH7</td>
<td>At Captain Jack</td>
</tr>
<tr>
<td>LH8</td>
<td>Downstream of Captain Jack</td>
</tr>
<tr>
<td>LH9</td>
<td>Downstream of CJ (upstream of White Raven)</td>
</tr>
<tr>
<td>LH10</td>
<td>Downstream of CJ (At White Raven)</td>
</tr>
<tr>
<td>LH11</td>
<td>Downstream of CJ (Downstream of White Raven)</td>
</tr>
<tr>
<td>LH12</td>
<td>at Sawmill Road</td>
</tr>
<tr>
<td>LH13</td>
<td>at Haldi Head gate, Left Hand Water District intake</td>
</tr>
<tr>
<td>Station</td>
<td>Notes</td>
</tr>
<tr>
<td>---------</td>
<td>-------</td>
</tr>
<tr>
<td>LJ1</td>
<td>upstream of Argo mine and tailings (background)</td>
</tr>
<tr>
<td>LJ2</td>
<td>upstream of Argo mine and tailings (background)</td>
</tr>
<tr>
<td>LJ3</td>
<td>upstream of small tailings pile and Argo</td>
</tr>
<tr>
<td>LJ4</td>
<td>upstream of Argo discharge, upstream of Burlington Mine</td>
</tr>
<tr>
<td>LJ5</td>
<td>downstream of Argo discharge, upstream of Burlington</td>
</tr>
<tr>
<td>LJ6</td>
<td>Upstream of Burlington Mine Discharge, below CR-87</td>
</tr>
<tr>
<td>LJ7</td>
<td>At Burlington Mine Discharge</td>
</tr>
<tr>
<td>LJ8</td>
<td>downstream of Burlington Mine (in front of culvert at Fike Driveway)</td>
</tr>
<tr>
<td>LJ9</td>
<td>downstream of Burlington Mine (on other side of culvert)</td>
</tr>
<tr>
<td>LJ10</td>
<td>downstream of Burlington Mine</td>
</tr>
<tr>
<td>LJ11</td>
<td>upstream of confluence with James Creek</td>
</tr>
</tbody>
</table>
Number of Benthic Macroinvertebrates found: Order Ephemoptera, Plecoptera, Trichoptera, Diptera and EPT/Diptera ratio.

<table>
<thead>
<tr>
<th>Lefthand Creek: Distance Downstream (km)</th>
<th>Total</th>
<th>Ephemoptera</th>
<th>Plecoptera</th>
<th>Trichoptera</th>
<th>Diptera</th>
<th>EPT/Diptera Ratio</th>
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</thead>
<tbody>
<tr>
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<table>
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<th>Total</th>
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<th>Trichoptera</th>
<th>Diptera</th>
<th>EPT/Diptera Ratio</th>
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Benthic Macroinvertebrate dry weights

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<th>Total Dry Weight (mg)</th>
<th>Weight of bugs (g)</th>
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75
### Raw data of 46 samples sent to LEGS for analysis: includes blanks and machine detection limits for this set of samples. SED=sediment, BM=benthic macroinvertebrates

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<th>Pb (ppb)</th>
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Raw data of 10 samples sent to LEGS for analysis.
Row data of 26 water samples sent to LEGS for analysis of zinc, copper, and lead.

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Machine Detection Limit | 0.57 | 0.18 | 0.01
References


Captain Jack Superfund Site and Left Hand Creek’s Legacy of Mining.” n.d LWOG, lwog.org/home/captain-jack/.


