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# THE EFFECTS OF *CASTOR CANADENSIS* (NORTH AMERICAN BEAVER) COLONIZATION ON A MINE DRAINAGE IMPACTED STREAM

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# THE EFFECTS OF *CASTOR CANADENSIS* (NORTH AMERICAN BEAVER) COLONIZATION ON A MINE DRAINAGE IMPACTED STREAM

A THESIS APPROVED FOR THE
SCHOOL OF CIVIL ENGINEERING AND ENVIRONMENTAL SCIENCE

BY

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There are many people in my life that deserve a portion of the dedication for this thesis. Firstly, I would like to thank Mrs. Sally Fenska. She was my high school science teacher and the best teacher any student could ask for. She believed in me and pushed me to become the scientist I am today. The hours she spent working with me on my high school science research projects set me on my path to many opportunities, including working with the Oklahoma Conservation Commission and later my education at the University of Oklahoma.

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# Abstract

This study investigated four aspects of North American Beaver (*Castor canadensis*) colonization: (1) retention of metals in-stream due to the presence of dams, (2) metals contamination and leachability of sediments (3) potential for metal mobilization during dam destruction and (4) hydrologic and habitat alterations due to the presence of dams. The study was conducted on an Unnamed Tributary impacted by net alkaline mine drainage since 1979 and was colonized by beaver in late 2013. By the end of 2014, most of the tributary was transformed into a series of impoundments due to beaver dams. By August 2016, the stream had eleven dams impounding water along the one-mile long study reach. The tributary flows into Tar Creek, located within the Tar Creek Superfund Site, which is the Oklahoma portion of the abandoned Tri-State Lead Zinc Mining District. The study found: (1) The presence of beaver dams showed a decrease in Fe and Cd concentrations, with minimal effect on Pb concentrations. The beaver dam with the greatest initial concentrations had mean Fe and Cd removal efficiencies of 57% and 63%, respectively. (2) Stream sediments contained elevated Cd, Pb, and Zn concentrations, with many of the metals concentrations more than five times the EPA site specific guidelines for probable effects concentrations (PEC) of 11.1 mg Cd/kg, 150 mg Pb/kg, and 2,083 mg Zn/kg. Fe concentrations in five of 13 sediment samples exceeded 200,000 mg/kg. The metals had greater concentrations in sediments at the dam outflow compared to the dam inflow. The leachate from a single sediment sample exceeded the Resource Conservation and Recovery Act (RCRA) Cd standard for Toxicity Characteristic Leaching

Procedure (TCLP) with 1.08 mg/L compared to the threshold of 1.0 mg/L. (3) Beaver dam removal caused Fe and Cd concentrations to increase over time and remain elevated for the six-hour sampling period. (4) The EPA rapid habitat assessment in presence of beaver dams had a higher habitat score compared to the absence of dams, however the difference between each category was not statistically significant ($p=0.26$). The presence of beaver dams resulted in a 23% longer mean retention time using a conservative tracer and increased the storage capacity of the stream by 250% (2,500 $m^3$). The study highlights the potentially important role beaver can play in the treatment of mine drainage. As ecosystem engineers, their dam building activities impound water which contributes to decreased metals concentrations.

# Chapter I: Project Introduction and Historical Data

## 1.1 Introduction

*Castor canadensis*, the North American beaver, are known as ecosystem engineers because of their potential to drastically alter both aquatic and terrestrial ecosystems through the construction of dams (Naiman et al., 1986; Snodgrass and Meffe, 1998; Butler and Malanson, 2005; Andersen and Shafroth, 2010; and Hardisky, 2011). The physical alterations due to beaver activity promote greater biodiversity of plant and animal species due to the new habitat that comes with the creation of wetlands. The question of the significance of beaver activity on streams impacted by mine drainage, especially their influence on water quality, has not been extensively studied and is the subject of this research project.

Thousands of miles of waterways are negatively impacted by acid or alkaline mine drainage (AMD) (Hengen et al., 2014). Metal laden sulfuric acid solutions are generated due to biogeochemical processes which occur when sulfide minerals are exposed to the weathering action of air and water (Nordstrom and Alpers, 1999; Gagliano, 2004). AMD can be released from sources such as waste rock piles, mine tunnels, and open pits, and similarly polluted waters, known as acid rock drainage (ARD) can be generated at road cuts or related situations when geological strata are exposed. AMD is often characterized by low pH values, ranging from 2 to 4. However, AMD can also be found where the carbonate geologic formations, such as limestone, contribute alkalinity to the water. The contribution of alkalinity buffers the low pH values seen in AMD and creates a neutral or alkaline discharge, which may still contain elevated metals concentrations (Gagliano, 2004).

## 1.2 Purpose and Scope of Project

This project investigated the effects of North American beaver activity on a stream heavily impacted by AMD. The focus was on evaluating the changes in metals concentrations occurring in the stream due to the presence of beaver dams and the potential for remobilization of metals accumulated in sediments in the event of dam failures. These data were supported by collection of physical water quality parameters, completion of conservative tracer studies and habitat assessments with and without beaver dams, and determination of total and leachable sediment metal concentrations.

## 1.3 Thesis Overview

This thesis is divided into five chapters: (1) Project Introduction and Historical Data, (2) Effects of Beaver Dam Construction on Water and Sediment Quality in a Mine Drainage Impacted Stream, (3) Potential for Metal Remobilization Due to Removal of Beaver Dams in a Mine Drainage Impacted Stream, (4) Comparison of Streams Geomorphic Classification in the Presence and Absence of Beaver Dams Utilizing Rosgen Stream Characterization, USEPA Rapid Habitat Assessment Protocol, and Conservative Tracer Studies, and (5) Conclusions and Future Work. The first chapter is intended as an introductory chapter, and chapters 2-4 are written with the intention of being submitted to various journals for publication. The fifth chapter are brief conclusions, summarizing the stated hypotheses and results, and suggested future work on the topic.

Chapter 1 discusses relevant literature on *Castor canadensis* that applies to each of the remaining chapters and the analysis of a historical dataset that has been regularly collected at the study location since 2004 by the Center for Restoration of Ecosystems and Watersheds (CREW). The trends shown in the historical dataset led to the development of the hypotheses and objectives for this thesis.

Chapters 2-4 share a similar format with an introduction, site description, and methods specific to the hypotheses being investigated. Chapters 2-4 each include results, discussion, and conclusions with respect to the hypotheses the chapter covers.

## 1.4 Literature Review

### *1.4.1 Impacts of Mine Drainage*

Water impacted by active or abandoned mining operations is referred to as acid or alkaline mine drainage (AMD), depending on water quality. AMD initially forms at the exposed, weathering mineral face due to biogeochemical processes including oxidation, hydrolysis, microbial catalysis, precipitation, and dissolution reactions (Nordstrom and Alpers, 1999; Gagliano, 2004). Mine water pollution is formed from the exposure of metal sulfides to oxygen allowing metal sulfides to oxidize, producing dissolved metals, sulfate, and sulfuric acid (Watzlaf et al., 2004). Fe(II) readily forms Fe(III) in the presence of oxygen, is hydrolyzed and precipitates (Babb et al., 1985). Some trace metals, such as Cd and Cu, tend to sorb to the precipitated Fe when the water is exposed to oxygen (Webster et al., 1998).

Thousands of miles of waterways are influenced by AMD around the world, negatively impacting aquatic and nearby terrestrial environments (Hengen et al., 2014). The negative impacts from AMD are largely attributed to the bioaccumulation of toxic metals in biota and effects of precipitation of metals on the benthos (Taylor et al., 2005). A study conducted by DeNicola and Stapleton (2002) investigated the effects of AMD on benthic communities and found caddisflies killed by AMD had higher metal concentrations compared to living caddisflies. The precipitated metals create contaminated stream sediments which can prevent the growth of vegetation and become more susceptible to erosion (Gagliano, 2004).

### *1.4.2 Passive Treatment*

AMD may be treated before it impacts receiving streams through the implementation of active or passive treatment systems (PTS) (Hedin and Nairn, 1994; Fripp et al., 2000, Watzlaf et al., 2004; Cravotta, 2007; Zipper and Skousen, 2010; Hengen et al., 2014, Williams and Turner, 2015; Skousen et al., 2017). Passive treatment is the utilization of ecologically engineered ecosystems to promote physical, biogeochemical, and microbiological processes to remove metals and generate alkalinity (Nairn et al., 2009; Zipper et al., 2011). Passive treatment systems, though constructed, rely on the same processes found in natural wetlands and other ecosystems. Once AMD has been treated and discharged, impacted streams often show significant ecological recovery. Williams and Turner (2015) found increases in species richness and density of fish populations post-restoration of an AMD impacted stream. The study also found significant increases in macroinvertebrate density and biomass (Williams and Turner, 2015). Nelson and Roline (1996) found similar results in a recovering stream in Pennsylvania. The decreased metal concentrations led to immediate macroinvertebrate community increases which were comparable to unaffected reference streams within two years (Nelson and Roline, 1996).

### *1.4.3 Castor canadensis Biology*

*Castor canadensis*, the North American beaver, can be found in the majority of the continent (Figure 1.1). Beaver are the largest rodents found in North America with the average adult weighing 24 to 70 pounds with a total body length of 35 to 53 inches and 10 to 18 inches of tail (Swafford, 2002; Hardisky, 2011). Beaver reach sexual maturity between the ages of 18 to 24 months. Reproduction is characterized by an approximately 100-day gestation period and delivery of 1 to 6 young, known as kits, per litter (Hardisky, 2011). Kits have a substantial survival rate with only 2.7% mortality during the first summer and minimal mortality through the first year (Hardisky, 2011). The average life expectancy for beaver in the wild is up to ten years, with the greatest danger to beaver mortality being humans (Hardisky, 2011).

Beaver reproduction is influenced by anthropogenic activities. Payne (1984) investigated the reproductive rate of beaver colonies that were being trapped versus those that were undisturbed. The study found colonies subject to trapping produce an average of 2.9 kits per female, while those in undisturbed colonies averaged 1.8 kits per female (Payne, 1984). The increased reproduction when threatened is one reason it can be difficult to control beaver populations once they have inhabited an area.

Figure 1.1: Distribution of *Castor canadensis* (Schwartz and Schwartz, 1981)

Beaver tend to construct dams in narrow sections of streams where natural obstacles are already present.  Sticks are initially placed across the stream, followed by vegetation, mud, and rocks to decrease the flow of water though the dam. The dams are constructed for two primary purposes (Hardisky, 2011). The first is to increase water surface area. The increased surface area allows the beaver to access more food sources from the safety of water, as the majority of predation occurs when beaver are out of the water. Beaver are primarily herbivores who consume numerous species of woody and herbaceous vegetation, including quaking aspen (*Populus tremuloides*), willow (*Salix* spp.), duckweed (*Lemna* spp.), and pondweed (*Potamogeton* spp.)

(Hardisky, 2011). Secondly, beaver construct dams to submerge entrances to their dens. The submerged entrance allows the beaver to access their den without the risk of using a terrestrial entrance and decreases the risk of predators entering the den, as the beaver's primary predators are terrestrial.

Beaver tend to live in colonies with an average population of eight beaver of varying ages (Novak, 1977). A single colony typically occupies 0.4 to 0.8 miles of stream channel length and rarely overlaps with other colonies (Hardisky, 2011). One study found two colonies with dens only 0.2 miles apart, but each colony relied on a food source that was in the opposite direction, preventing territory overlap between the colonies (Hardisky, 2011).

A single beaver can cut down 1.5-cm woody stems in a single bite, a 15- cm tree in under 50 minutes, and trunks larger than 25 cm can be brought down in 250 minutes of work (Muller-Schwarze and Sun, 2003). At these rates, beaver have the ability to rapidly construct and repair beaver dams. Coupling their dam construction ability with their reproductive rates, beaver are often viewed as nuisance pests. Another reason they are seen as pests is because man-made stormwater channels are prime locations to construct dams as they are often narrow trenches compared to natural streams. Once established, municipalities have great difficulty preventing beaver from rebuilding dams after they are destroyed and trapping an entire colony is nearly impossible and quite costly (Gerich, 2004; Hardisky, 2011; Taylor and Singleton, 2014). However, the resilience and construction abilities of beaver are the reason they are referred to as ecosystem engineers (Naiman et al., 1986; Snodgrass and Meffe, 1998; Butler and Malanson, 2005; Andersen and Shafroth, 2010; and Hardisky, 2011).

#### 1.4.3.1 Beaver as Ecosystem Engineers

Ecosystem engineers are organisms that significantly modify a habitat through creation, destruction, or alteration of their surroundings (Naiman et al., 1986; Snodgrass and Meffe, 1998; Butler and Malanson, 2005; Andersen and Shafroth, 2010; and Hardisky, 2011). They are typically keystone species in the ecosystems they inhabit. Beaver activity has been shown to decrease flooding, and increase animal and plant species richness through the creation of impoundments behind dams (Hey and Philippi, 1995; Collen and Gibson, 2001; Wright et al., 2002; Bromley and Hood, 2013). The ecosystem improvements are due to the large number of dams constructed over relatively short stretches of stream. Naiman et al. (1986) found a dam density ranging between 8.6 and 16.0 dams/km, with an average of 10.6 dams/km on 4th order and smaller streams. Burchsted and Daniels (2014) stated beaver dams are among the most common and frequent obstructions in rivers.

Hood and Larson (2015) compared the physical characteristics of sixteen boreal wetlands, eight of which were inhabited by beaver. The study found boreal wetlands with beaver activity increased the volume-to-surface area ratio by 50% and the wetland perimeter by 575%. The study also found beaver activity increased connectivity of wetlands, which allowed species migration through previously isolated reaches of boreal wetlands (Hood and Larson, 2015). The connectivity was primarily through the construction of beaver channels between the wetlands with an average width of 1.4 meters and a depth of 0.4 meters (Hood and Larson, 2015). The channels were the primary contributor to the substantial increase in wetland perimeter. The channels averaged 23.4 meters in length with the maximum channel length of 507 meters (Hood and Larson, 2015). The study demonstrated the construction abilities of beaver where it was estimated the beaver channel excavation exceeded 22,000 cubic meters of soil from the Miquelon Lake Provincial Park where the study took place (Hood and Larson, 2015).

There are numerous studies that have investigated the impacts of beaver populations on fish communities (Cunjak, 1996; Snodgrass and Meffe, 1998; Hagglund and Sjoberg, 1999; Snodgrass and Meffe, 1999; Smith and Mather, 2013). Many small streams with intermittent flow may entirely freeze during winter and therefore kill the fish in the stream. Cunjak (1996) found the creation of beaver ponds in small streams provided important winter habitat for fish by increasing depth and preventing the small streams from becoming entirely frozen. In addition, beaver ponds increased habitat heterogeneity in streams by adding lentic habitat to otherwise lotic dominated reaches of streams (Cunjak, 1996; Smith and Mather, 2013). Snodgrass and Meffe (1999) stated the removal of beaver ponds in headwater streams would cut species richness in half. In their study, beaver ponds increased habitat heterogeneity in the stream, supporting eleven species of fish that were considered stream fish and sixteen species considered pond fish (Snodgrass and Meffe, 1998). Destruction of the dams would greatly decrease the habitat of the pond-dwelling fish species, decreasing species richness. In addition, Snodgrass and Meffe (1999) found beaver ponds provided a safe location for fish during high flow events. During base flow, the shallow edges of the beaver ponds provided slow moving water, often with aquatic vegetation that provides important habitat for juvenile fishes (Hagglund and Sjoberg, 1999).

The benefits of beaver dams extend to waterfowl as well. Bromley and Hood (2013) investigated the nesting habits of Canada geese (*Branta canadensis*) in boreal wetlands. The study found active beaver ponds provided open water and the geese would use island beaver lodges for nesting as an additional means of protection against terrestrial predators.

Wright et al. (2002) investigated the impacts that beaver have on vegetative communities. The study found the number of plant species in the riparian zone increased by 33% with the presence of beaver. A later study found beaver meadows nearly doubled the herbaceous species richness compared to the surrounding forest (Anderson et al., 2006). All the studies discussed above indicated beaver colonization positively influences stream and riparian biological communities.

There is also extensive research on the effects of beaver dams on nutrients (Maret et al., 1987; Devito and Dillion, 1993; Margolis et al., 2011; Fuller and Peckarsky, 2011). Despite the numerous articles published on the topic, results are somewhat inconsistent. A study by Fuller and Peckarsky (2011) is an example of how the question “Are beaver dams a nutrient sink or source?” has no simple answer. Fuller and Peckarsky (2011) studied 22 beaver ponds from six different catchments over a period of two years in the Colorado Rocky Mountains. The study found nitrate nitrogen ($NO_3$-N) concentrations increased downstream of beaver ponds, but only during base flow conditions. Soluble reactive phosphorus (SRP) decreased at dams with low-head but increased at dams with higher head. Again, the results occurred at base flow conditions. If discharge was above base flow, both nutrients experienced decreases, attributed to dilution from run-off. Fuller and Peckarsky (2011) also concluded beaver pond morphology did not have an influence on nutrient transport.

In southwestern Wyoming, Maret et al. (1987) investigated nutrient transport seasonally. Samples were collected for two years in the spring and summer over a 12.9 km reach of a second-order stream in and out of beaver ponds. The study found suspended solids (SS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), and $NO_3$-N statistically deceased with beaver ponds during the spring months with no changes during the summer months (Maret et al., 1987). Hill and Duval (2009) conducted a study in southern Ontario, Canada, in an agricultural stream which investigated the nutrient changes before and after the construction of beaver dams over a four-year period. The study found decreases in $NO_3$-N concentrations after the construction of dams, by a factor of 3 to 4. On the other hand, ammonia nitrogen ($NH_4$-N) increased approximately 2.5 times after the construction of beaver dams (Hill and Duval, 2009).

In Appalachian streams, Margolis et al. (2011) compared two sites with beaver activity for a one-year period, analyzing a wide range of parameters. The study found beaver impoundments always decreased $NO_3$-N with greater changes in the summer months at both streams. The decrease in nitrate was attributed to the flooding of soils and the decrease over the entire year suggests vegetation in the impounded water was not a major sink for $NO_3$-N. Sulfate data showed a decrease at one stream and no changes at the other. It was suspected the site with no changes in sulfate lacked the low redox potential necessary to reduce sulfate to sulfide. Margolis et al. (2011) is also one of the few studies that addressed metals concentrations. Al, Fe, and Mn data were collected at both sites, showing beaver impoundments had no effect on Al but acted as a source of Fe and Mn. The authors believe Fe and Mn were mobilized from the soils in the beaver impoundments which contained reduced forms of the metals. It is important to note the concentrations of the metals in the study are between 5 and 150 μg/L. These concentrations are significantly lower than concentrations typically found in AMD.

The numerous studies on beaver dams acting as nutrient sinks or sources have varying and often contradictory conclusions. The contradictions are due to the fact that conditions in stream ecosystems where the beavers impound water are highly complex and site specific. Streams in mountainous regions will have different non-point source run-off contamination compared to streams in agricultural areas. Agricultural streams are likely to have greater initial concentrations due to agricultural runoff, providing more potential for nutrient decreases in and out of beaver dams.

The impact of beaver dams on flood mitigation is another well documented subject (Naiman et al., 1988; Hey and Phillip, 1995; Westbrook et al., 2006; Nyssen et al., 2011; Puttock et al., 2017). Flooding mitigation from beaver dam impoundments is perhaps the most direct contribution beaver have to human society. Flood reduction has the potential to save billions in property damage. Hey and Philippi (1995) focused on the impacts of beaver dam destruction that has occurred in the Mississippi Basin since the 1600s. Over the last 90 years, there has been a massive effort to construct manmade levees in the upper Mississippi Basin to mitigate downstream flooding, yet in the same time span, flood damage increased 140%. Hey and Philippi (1995) attributed the increase in flood damage to the destruction of habitat in the Mississippi Basin watershed. In 1993, a flood hit St. Louis. Missouri causing sixteen billion dollars in damage. Hey and Philippi (1995) stated if beaver dams from the 1600s were unmolested, a volume three times the size of the St. Louis flood could have been stored behind the dams, with little impact downstream.

A more recent study conducted by Nyssen et al. (2011) investigated the impact of a beaver dam system on flow. In this case, a series of six beaver dams were studied where flow measurements were collected every seven days, with continuous depth measurements. The study found the beaver dams retained water during storm events then slowly released the plug over the following days (Nyssen et al., (2011). The slow release resulted in decreased peak flows during the storm event and higher daily flows due to the slow release of water. The dam building creates a stair step gradient and increases the area of flooded soils (Naiman et al., 1988).

In addition to flood storage, beaver dams influence groundwater dynamics. Westbrook et al. (2006) studied a 1.5 km reach of a fourth- order stream in the Rocky Mountains with two beaver dams present. The study found the beaver dams increased inundation during flood events, leading to increased groundwater recharge. As a result, the recharge decreased groundwater table decline on 25% of the study site, even during the summer months. Westbrook et al. (2006) concluded the dams maintained hydraulic flow regimes suitable for the creation and preservation of wetlands.

Beaver dams also decrease the energy and velocity of streams (Johnston and Naiman, 1987). The decreased stream velocities create sediment traps which allow sediments to settle and be stored behind the dam. Naiman et al. (1986) found that a single beaver dam can retain up to 6,500 $m^3$ of sediment.

Butler and Malanson (2005) investigated sediment transport due to the destruction of beaver dams from the 16th to 20th centuries. The study estimated tens to hundreds of billions of cubic meters of sediment were stored in beaver ponds in North America before European colonization. The decline in beaver populations, primarily from over-trapping, since the 16th century has decreased the estimated volume of stored sediment due to beaver dams from tens to hundreds of billions of cubic meters to hundreds of millions of cubic meters (Butler and Malanson, 2005). Over the past century, beaver populations have been recovering. However, even with the partial recovery of beaver colonies in the past century, the density of beaver populations is one-tenth compared to that of the 1500s. The study also found that at locations where dams were removed or failed, revegetation of the accumulated sediments was rapid, preventing the remobilization of the sediments during storm events (Butler and Malanson, 2005).

Thus far, the studies discussed have been conducted under the assumption the dams stay intact during flooding events. Andersen and Shafroth (2010) investigated the impacts of pulse flooding on beaver dam structure. Their study site was unique because numerous beaver dams were established on a large river with an upstream, man-made dam. The dam allowed the researchers to send known plug volumes downstream to test impacts on the dams. The study concluded it was difficult to correlate dam destruction with water velocities/volumes due to the numerous factors that had to be considered. The factors impacting the correlation included dam construction materials, dam activity, flow regimes, and dam height (Andersen and Shafroth, 2010). Dams consisting of herbaceous vegetation, such as cattails (*Typha* spp.), would break under the smallest flood events, while dams consisting of larger woody debris that were also active showed minimal damage during the larger pulse events and immediate reconstruction of weakened sections (Andersen and Shafroth, 2010).

Another study investigated the effects of dam failure on aquatic life. Stock and Schlosser (1991) found that immediately after dam failure, benthic macroinvertebrate density decreased by more than 90%, but 60 days after the failure, riffle benthic macroinvertebrate densities had 62% re-establishment with only an 8% re-establishment of pool benthic invertebrate densities (Stock and Schlosser, 1991). Fish communities downstream showed an influx of species often found in ponds, resulting in a brief increase in diversity and abundance, but after 60 days, the species richness and abundance decreased to levels below the initial population (Stock and Schlosser, 1991).

Dam failures affect more than the aquatic community. Butler and Malanson (2005) cited seven articles from 1984 to 1999 stating that beaver dam failures resulted in thirteen human deaths with numerous injuries. The most notable of the articles discussed by Butler and Malanson (2005) was from 1984 where failed dams produced a plug of water damaging a railroad embankment, causing an Amtrak passenger car to derail, resulting in five deaths.

Despite the potential for negative outcomes, the construction of beaver dams creates more wetlands, impacts water quality, increases species richness and abundance of animals and plants, and has the potential to mitigate flooding. With the documented positive ecosystem services, no studies were found which explicitly investigated the impacts of beaver activity on streams impacted by AMD.

## 1.5 Site Description

The study site is located within the Tar Creek Superfund site, in Northeast Oklahoma. The superfund site covers 40 square miles and is a part of the Tri-State Mining District, contaminated from abandoned lead and zinc mining operations. The mining began in the early 1900's and ended in the 1970s; producing nearly two million tons of lead and nine million tons of zinc (ODEQ, 2006; Nairn et al, 2009).

The study site was a one-mile reach of a first-order tributary located in Commerce, Ottawa County, Oklahoma (Figures 1.2 and 1.3). The watershed for the unnamed tributary (UT) extends into Commerce, OK, with an approximate total area of 0.75 square miles. Within the watershed, there are numerous mine water discharges that have historically contaminated the stream. UT has been impacted for over a century by mining operations with AMD artesian flow starting in 1979. The AMD contains elevated concentrations of iron, lead, cadmium, and zinc. At least two artesian discharges of AMD originally impacted UT. The first AMD source is the start of the study reach of UT, known as UT-Pipe (UT-P) located at the Southeast Commerce Site (SEC), and remained untreated through 2016. SEC discharges an average of 100 gallons per minute (gpm) into UT. Upstream of SEC, UT is an intermittent stream, where storm water is the only contribution. The SEC discharge makes UT a perennial stream for the remaining one mile of stream before it discharges into Tar Creek. The second source, located approximately 0.3 miles downstream from the headwaters, is known as Mayer Ranch (MR). MR location discharges an average of 160 gpm into to UT.

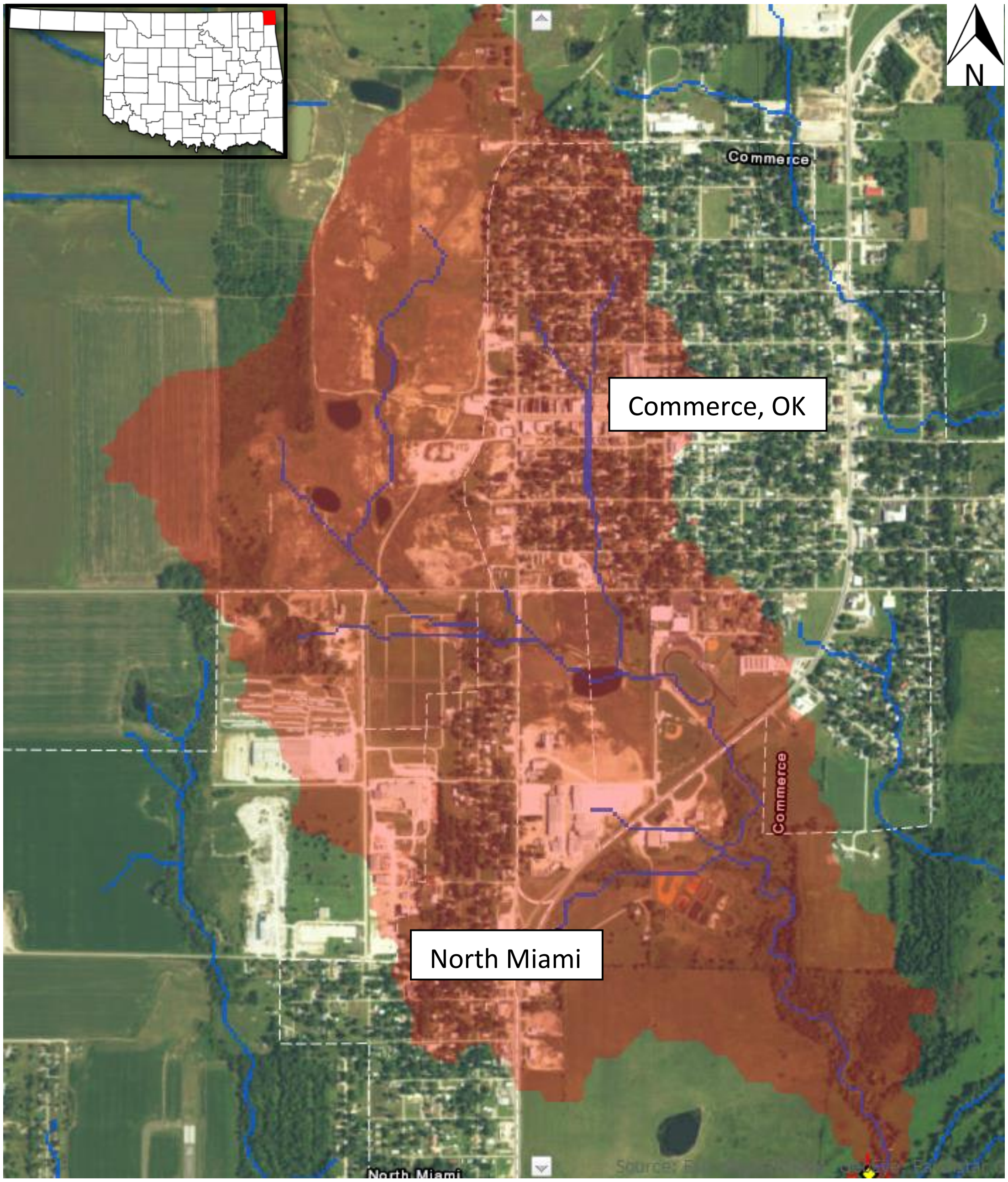

Figure 1.2: The study site location in Commerce, OK. (location of Ottawa County highlighted in inset image), with the UT watershed shaded in red on the aerial image (USGS StreamStats, 2017)

## 1.6 Hypotheses

The hypotheses in this project tested the effect of beaver populations on a stream impacted by mine drainage with respect to water, sediment and stream habitat quality from alterations due to dam construction and subsequent dam destruction.

The hypotheses include:

1. The presence of beaver dams results in a decrease in metals concentrations when compared to historical events that had the potential to impact water quality.
2. The effluent of each beaver dam has lesser metals concentrations than the influent water impounded by the dam.
3. Stream sediment metals concentrations have the greatest concentrations at the most upstream location, with decreasing concentrations downstream.
4. Sediment metal concentrations do not exceed Resource Conservation and Recovery Act (RCRA) Toxicity Characteristic Leaching Procedure (TCLP) criteria and USGS Field Leaching Test (FLT) shows lesser concentrations than TCLP.
5. Total and dissolved aqueous metals concentrations increase immediately after dam destruction, but decrease with respect to decreasing velocity of water flowing through the destroyed dam.
6. Stream complexity and variation, as characterized by rapid habitat assessments and the Rosgen stream classification, increase when beaver dams are not present compared to when the dams are intact, but the resulting habitat score difference between the two is not significant.
7. Residence time of the stream is longer in the presence of beaver dams with lower tracer recovery compared to those with the absence of beaver dams.

## 1.7 Objectives

The objectives of this project were:

1. Determine trends of metal concentrations using a historical dataset.
2. Determine the impacts of beaver dams on water quality.
3. Determine sediment metals concentrations at numerous locations with respect to distance downstream and depth at each location.
4. Determine leachability of stream sediments collected for the previous objective.
5. Determine the impact on water quality in the scenario that beaver dams are destroyed by natural events through collection of timed water quality samples of “flush events” created by destroying the dams.
6. Determine the physical state of the stream using a standard rapid habitat assessment and Rosgen stream characterization with and without beaver dams.
7. Determine retention time and dispersion due to the presence of beaver dams by conducting a conservative tracer study with and without beaver dams.

## 1.8 Historical Data

The University of Oklahoma Center for Restoration of Ecosystems and Watersheds (CREW) is the research team that has been collecting data in the Tar Creek Superfund Site since the 1990s and is the source of the historical dataset used in this section. The repopulation of beaver on UT was initially considered a nuisance by the research team and the City of Commerce.

Beaver colonization resulted in elevated water levels in UT, making water quality sampling difficult at three locations and water quantity measurements impracticable at two of the three locations on UT. The City of Commerce viewed beaver as a nuisance due to elevated water levels in the upstream portion of the stream. Given all the apparent downsides following beaver colonization, a question was raised as to what benefits the beaver may be providing to the stream. This question led to the analysis of the historical dataset on UT collected by CREW from 2004 to 2017.

### *1.8.1 Analysis*

Two historical sampling locations UT-U (Unnamed Tributary-Upstream) and UT-D (Unnamed Tributary-Downstream) were used to determine statistical trends of numerous water quality parameters based on the timing of events that had the potential to impact the stream. “Upstream” and “downstream” site names are in reference to the Mayer Ranch Passive Treatment System (MRPTS) effluent (Figure 1.3). It is important to note that water quality at UT-U was not influenced by the construction of MRPTS because the site is located upstream of the system effluent. MRPTS was constructed in late 2008 and began treating the Mayer Ranch AMD discharges. Summarized MRPTS performance is shown in Table 1.1. The water at UT-U had higher metals concentrations than UT-D during the beaver colonization time period and was therefore the most likely location where the presence of beaver would show an impact on water quality. The historical dataset was divided into four major events, shown below in Table 1.2. Figure 1.4 is a combination of Google Earth images taken at the approximate time of the historical event. The colored circles depict the changes from each aerial image.

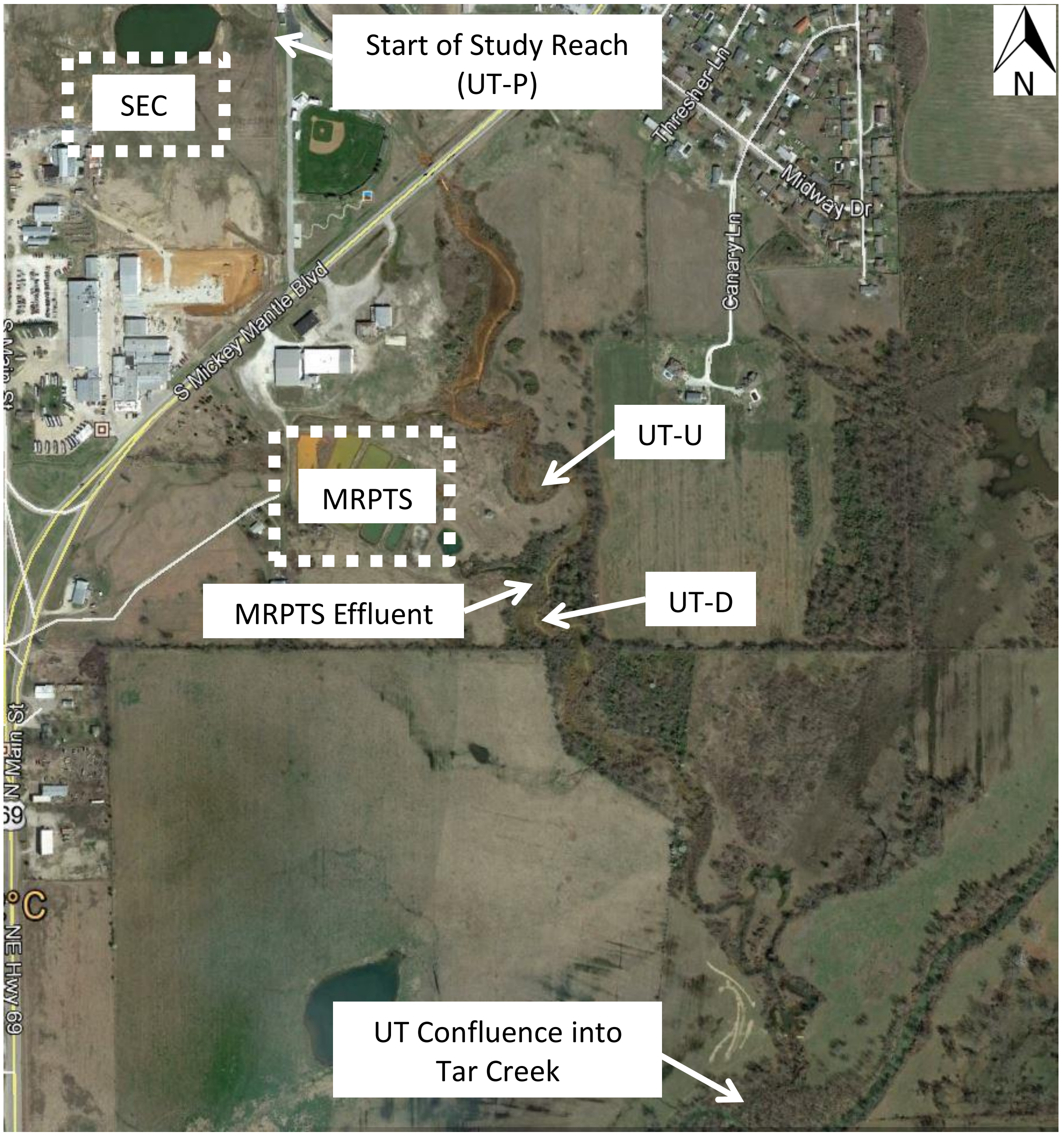

Figure 1.3: CREW site locations used for historic metals trend analysis along UT in Commerce, OK (Google Earth, 2017)

Table 1.1: Average total aqueous metals concentrations of the two contributing AMD groundwater sources (SEC and MR) to UT in Commerce, OK and passive treatment system effluent of the MR source

| | Sample Size | Cd | Fe | Pb | Zn |
|---|---|---|---|---|---|
| | | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| SEC Discharge | 60 | 0.031±0.013 | 133±13 | 0.063±0.011 | 9.71±2.58 |
| MRPTS Inflow[¥] | 184 | 0.016±0.006 | 175±25 | 0.069±0.015 | 8.42±1.42 |
| MRPTS Outflow | 51 | <PQL* | 0.65±0.98 | <PQL* | 0.46±0.85 |

*46 of 51 samples were less than the practical quantitation limit (PQL)

[¥] Values averaged from three discharges

Table 1.2: Dates and descriptions of historical events occurring since 2004 with the potential to impact water quality in UT, located in Commerce, OK

| Event | Start Date | Description |
|---|---|---|
| Initial | Oct-2004 | Start of monthly/quarterly sampling events at each location, before SEC land reclamation. |
| SEC Post-Land Reclamation (LR) | Aug-2006 | Filling of two mine collapse features and subsequent construction of French drain to capture and discharge mine water through an 8" pipe (UT-P) into a 48" stormwater pipe. Note: The stormwater pond visible in aerial image b) 2006 is in no way connected to the French drain. |
| Post-MRPTS | Jan-2009 | Construction of MRPTS, discharging treated AMD |
| Post-Beaver | Jan-2014 | Presence of beaver noted on UT. |

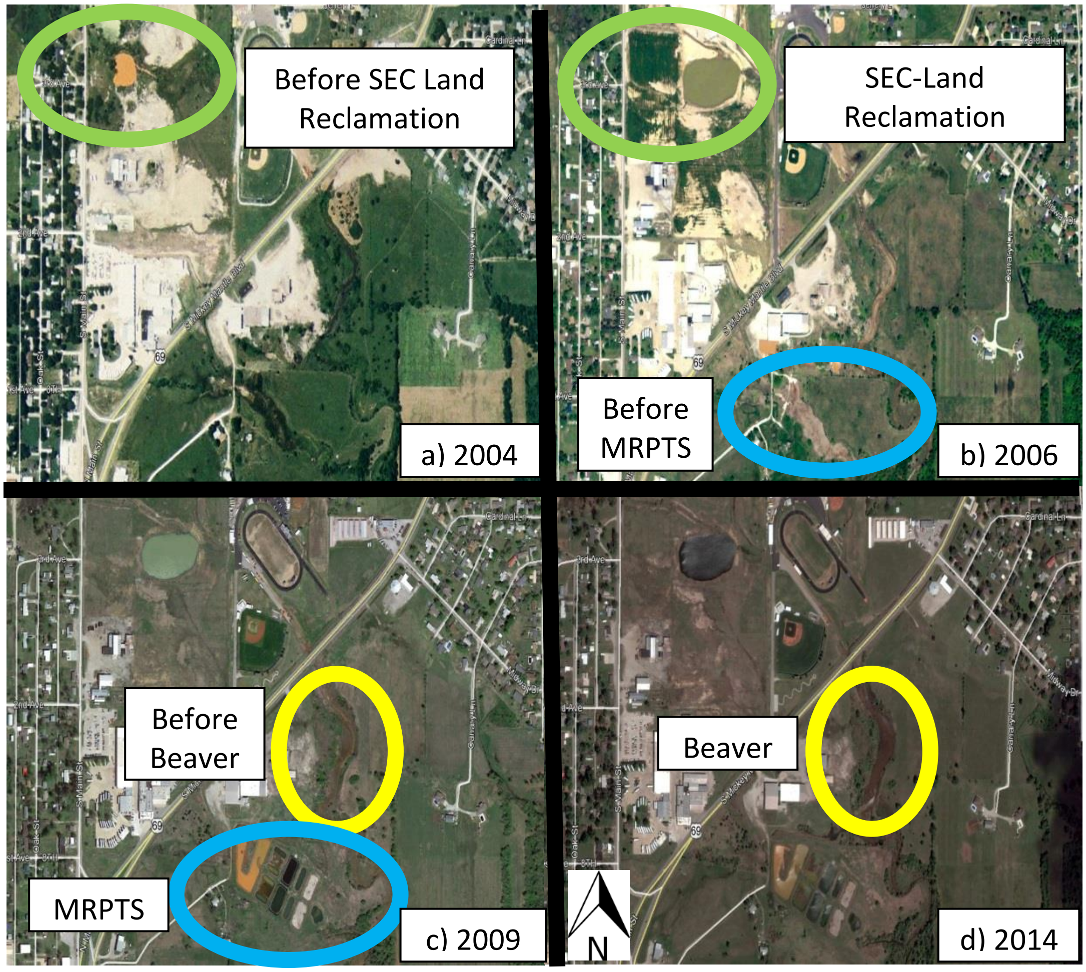

Figure 1.4: Aerial images of historical events with the potential to impact water quality in the UT, located in Commerce, OK, in a) 2004, b) 2006, c) 2009, and d) 2014 with the changes from each event circled and labeled (Google Earth, 2017)

Two collapse features have existed on the SEC site for decades, with AMD discharging from one of the collapse features into a volunteer cattail marsh, where the AMD received natural treatment from the wetland. The post-land reclamation project began in 2006 at the SEC site. The project began with the filling of the two collapse features with mine tailings (chat). These collapse features can be seen as the red and green ponds in Figure 1.4 a). The collapse features where then clay capped. Within a few months, AMD began seeping through the clay cap into a constructed stormwater pond that was not supposed to have any contact with AMD. To prevent the seepage, a French drain system was installed to capture the AMD subsurface and discharge into a 48” stormwater pipe known as the Unnamed Tributary-Pipe (UT-P) site. SEC site before and after the land reclamation is shown in Figures 1.5 and 1.6.

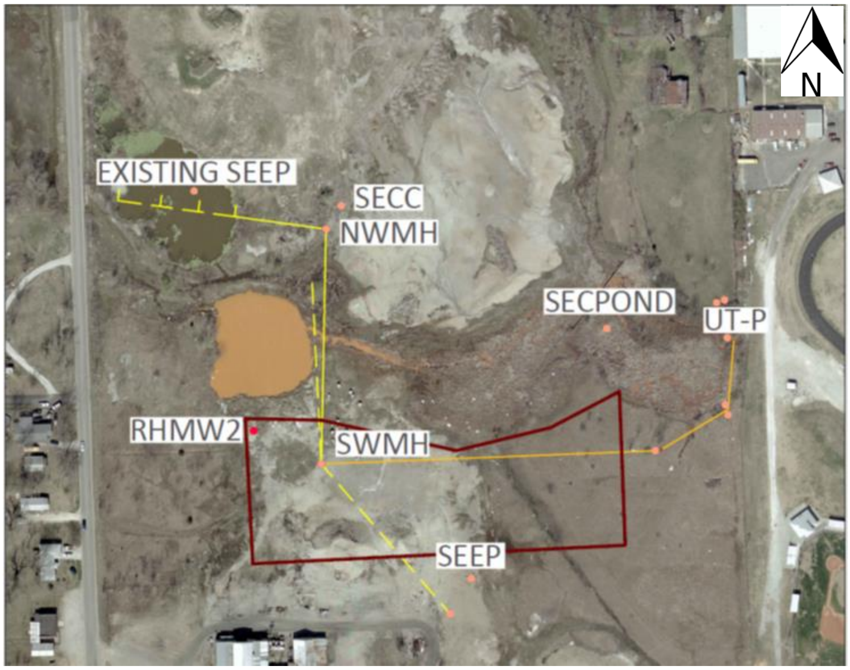

Figure 1.5: SEC pre-land reclamation (2005) aerial image showing two collapse features with the future location of the French drain in yellow and future passive treatment system location in red (Google Earth, 2016)

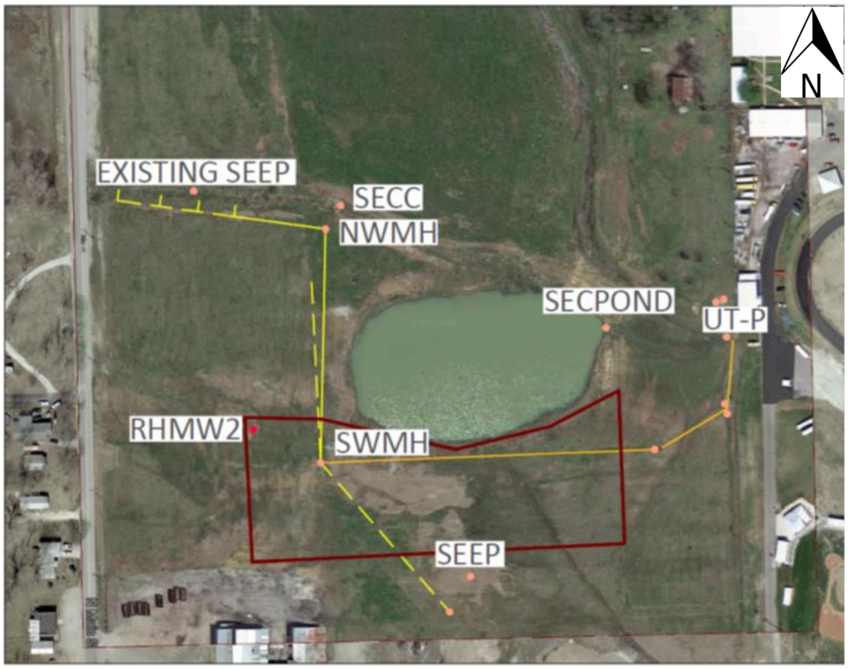

Figure 1.6: SEC post-land reclamation (2015) aerial image with the French drain shown in yellow and future passive treatment system location in red (Google Earth, 2016)

Scatter plots of total metals data were created, and the data fit with linear trend lines for each event date range. Some of the trace metals were below the practical quantitation limit (PQL) set by CREW based on the instrumentation detection limit (IDL) f. The frequency of values below the PQL increased after the implementation of the passive treatment system and beaver colonization. Values below the PQL were considered censored data, following a method published by Hansel and Lee (2006). Since values below the PQL are unknown, it would be incorrect to represent these data points as the PQL or zero. Hansel (2006) found that randomly generating values between *a priori* determined detectable limits and zero produces more realistic results. Once these data were generated using the methods of Hansel (2006), box and whisker plots were created using the censored dataset. The box and whisker plot setup is shown in Figure 1.7

It was hypothesized that the presence of beaver dams on UT resulted in improved water quality and decreases in metals concentrations when compared to historical events that had the potential to impact the water quality of UT. The historical data and statistical analysis are shown in Figures 1.10-1.19.

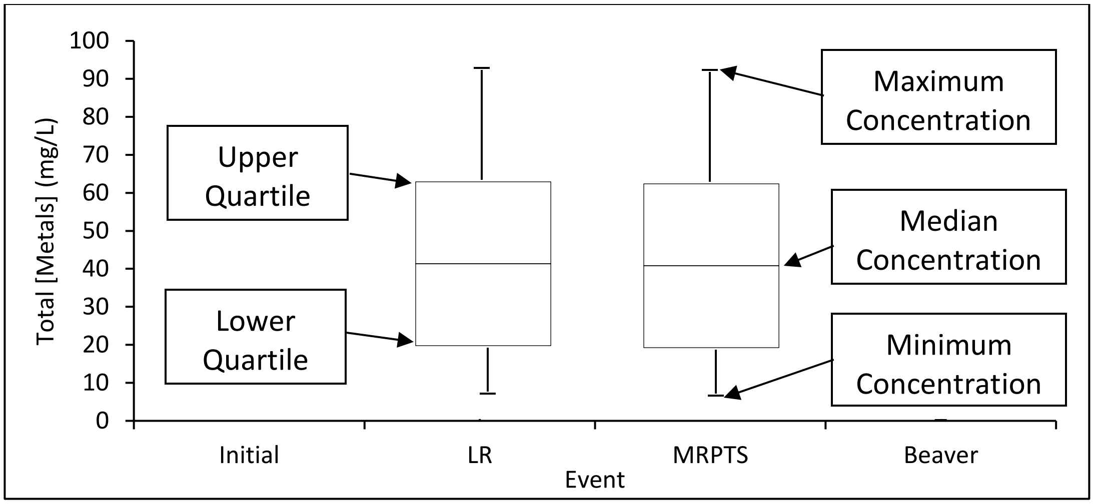

Figure 1.7: Layout of box and whisker plots for historical metals concentrations in UT

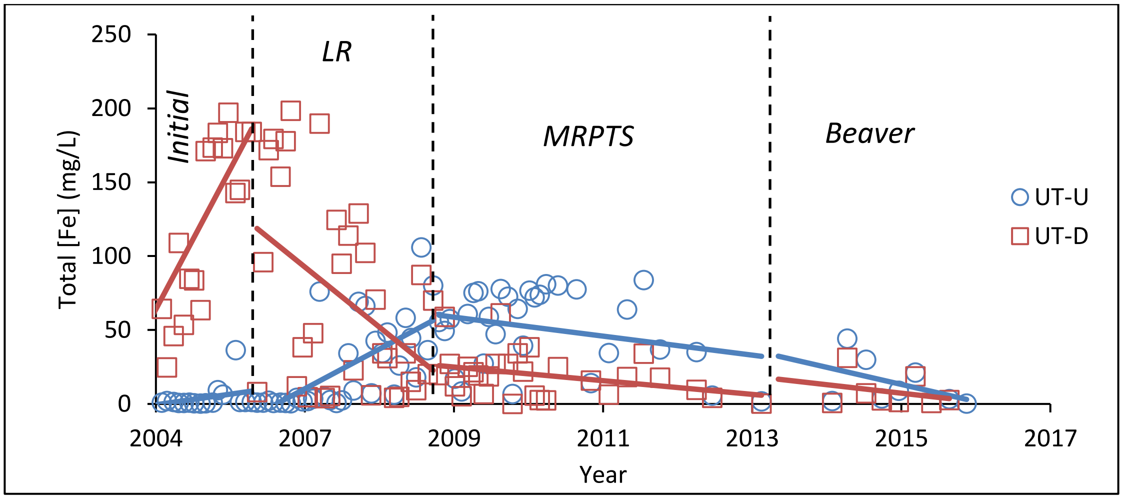

Figure 1.8: Historical total aqueous Fe concentrations at UT-U and UT-D from 2004 to 2017 separated by events that impacted water quality with linear trend lines drawn for each data range

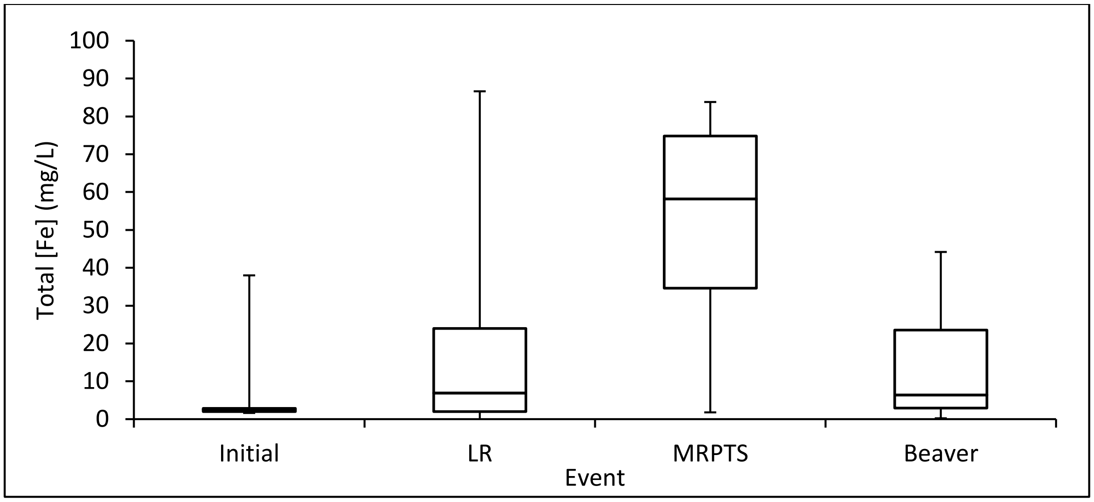

Figure 1.9: Box and whisker plot of historical total aqueous Fe concentrations at UT at UT-U from 2004 to 2017 by event

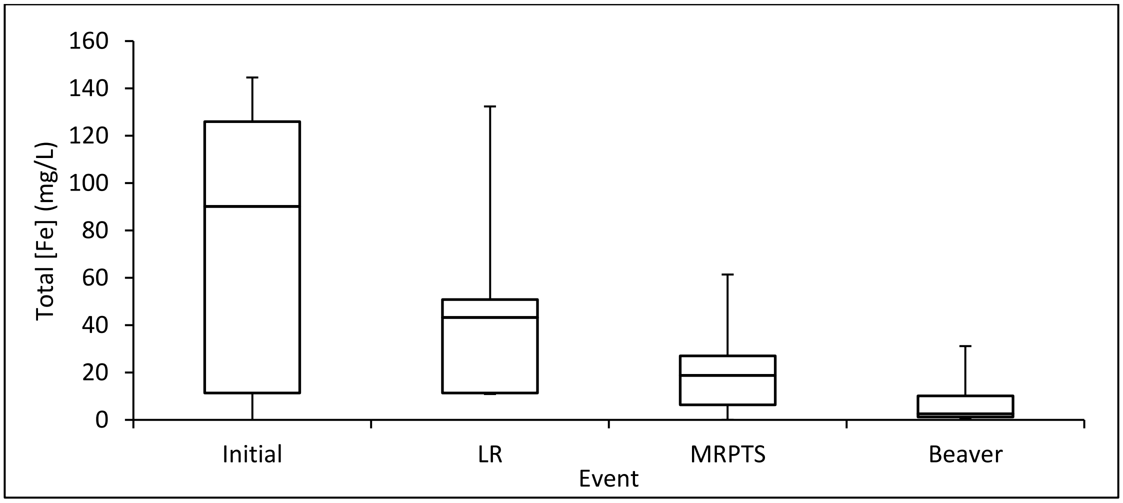

Figure 1.10: Box and whisker plot of historical total aqueous Fe concentrations at UT at UT-D from 2004 to 2017 by event

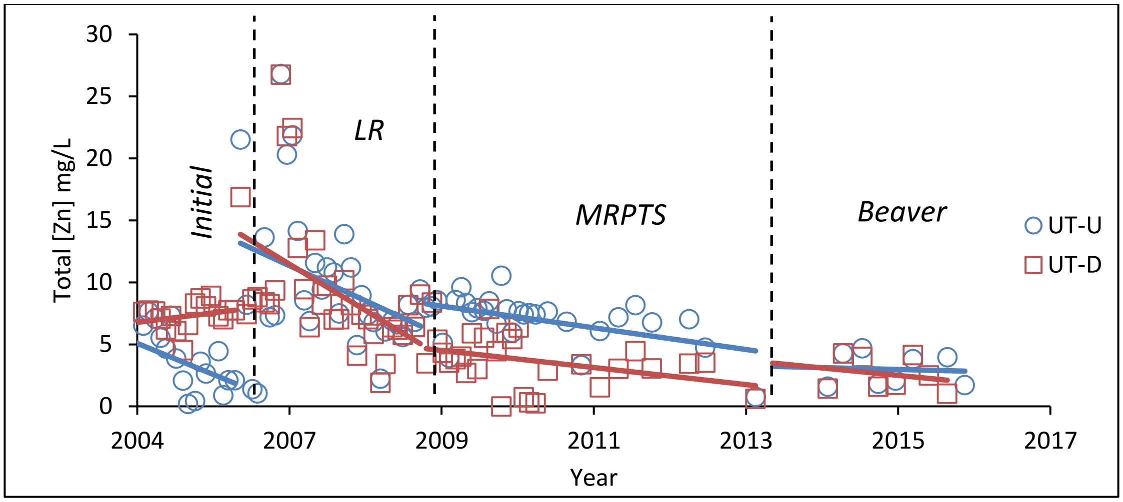

Figure 1.11: Historical total aqueous Zn concentrations at UT-U and UT-D from 2004 to 2017 separated by events that impacted water quality with linear trend lines drawn for each data range

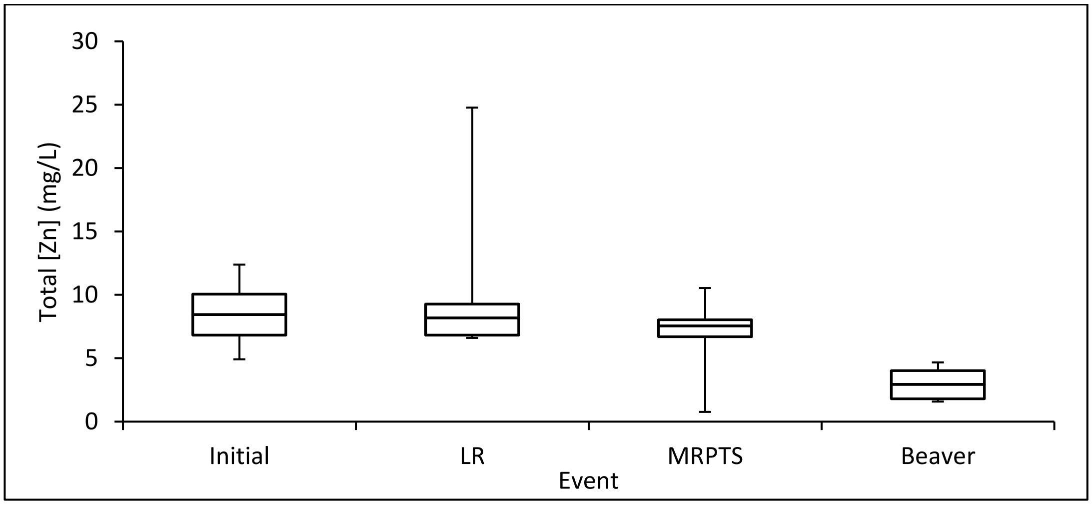

Figure 1.12: Box and whisker plot of historical total aqueous Zn concentrations at UT at UT-U from 2004 to 2017 by event

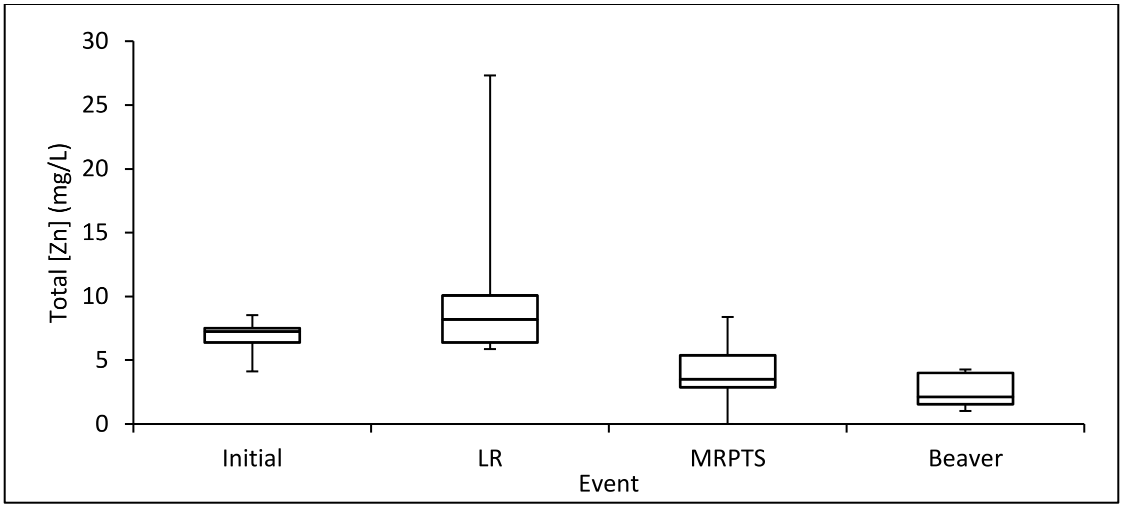

Figure 1.13: Box and whisker plot of historical total aqueous Zn concentrations at UT at UT-D from 2004 to 2017 by event

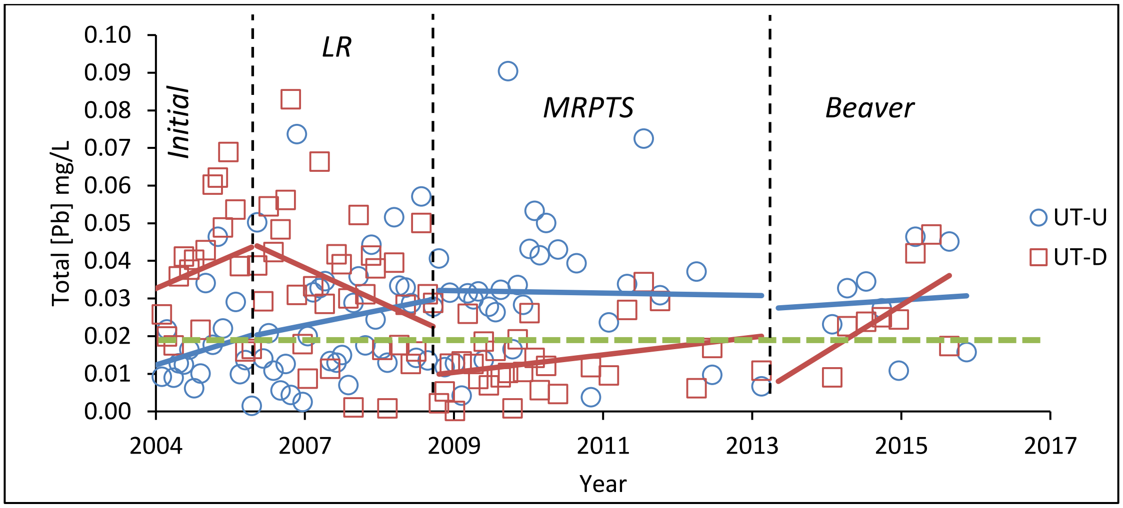

Figure 1.14: Historical total aqueous Pb concentrations at UT-U and UT-D from 2004 to 2017 separated by events that impacted water quality with linear trend lines drawn for each data range; lead PQL (0.019 mg/L) is denoted by horizontal dashed line

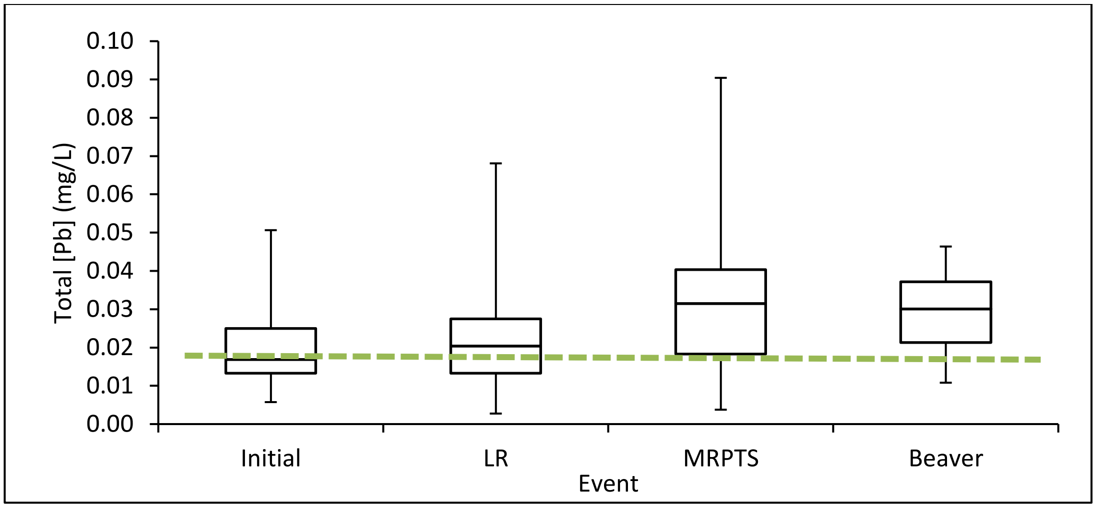

Figure 1.15: Box and whisker plot of historical aqueous Pb concentrations at UT and UT-U from 2004 to 2017 by event; lead PQL (0.019 mg/L) is denoted by horizontal dashed line

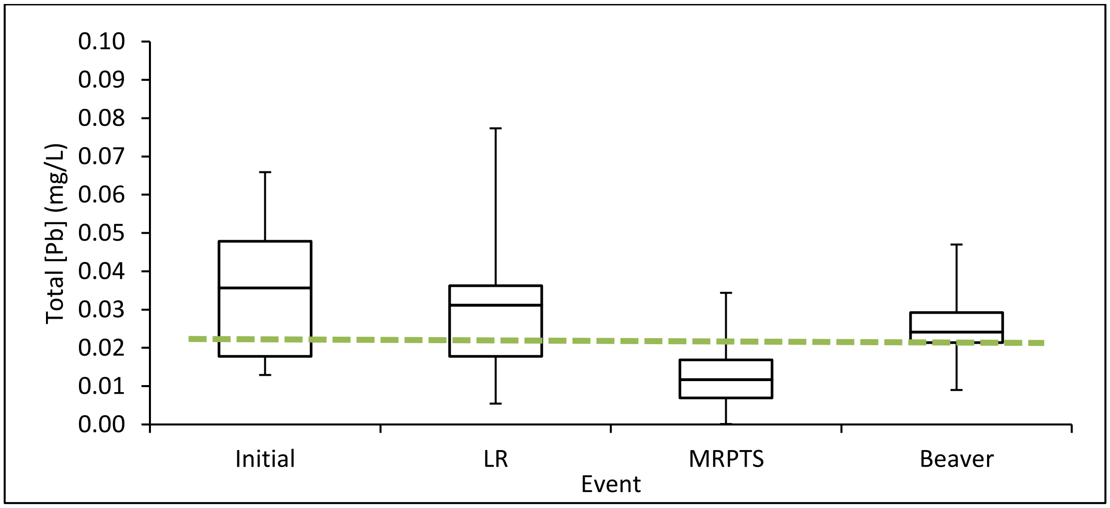

Figure 1.16: Box and whisker plot of historical aqueous Pb concentrations at UT and UT-D from 2004 to 2017 by event; lead PQL (0.019 mg/L) is denoted by horizontal dashed line

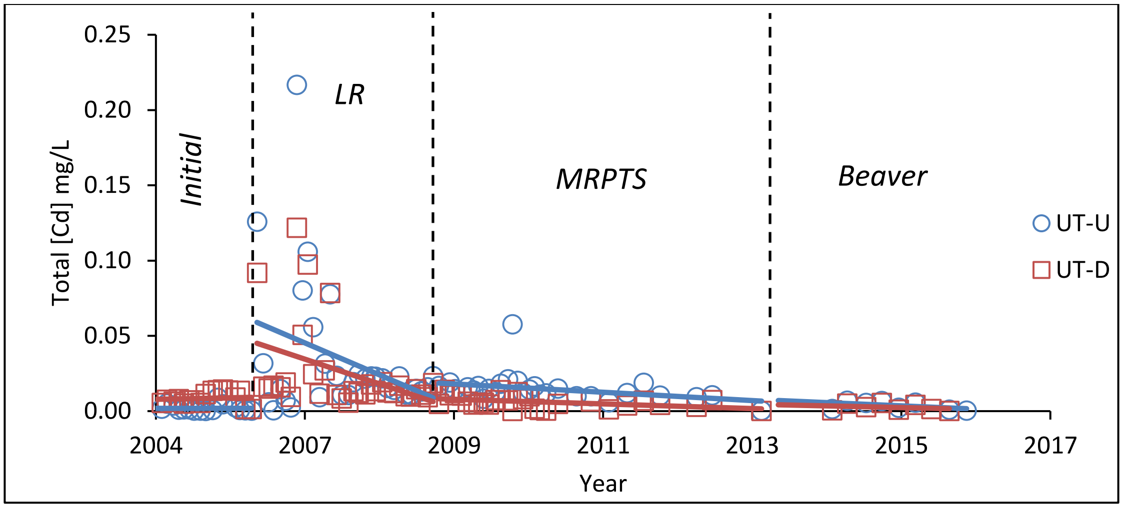

Figure 1.17: Historical total aqueous Cd concentrations at UT-U and UT-D from 2004 to 2017 separated by events that impacted water quality with linear trend lines drawn for each data range

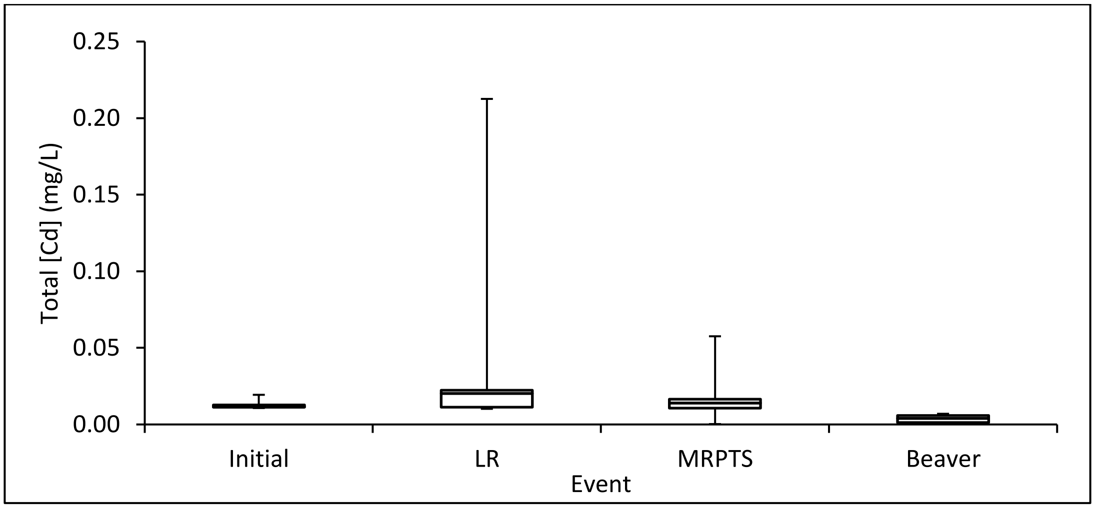

Figure 1.18: Box and whisker plot of historical total aqueous Cd concentrations at UT at UT-U from 2004 to 2017 by event

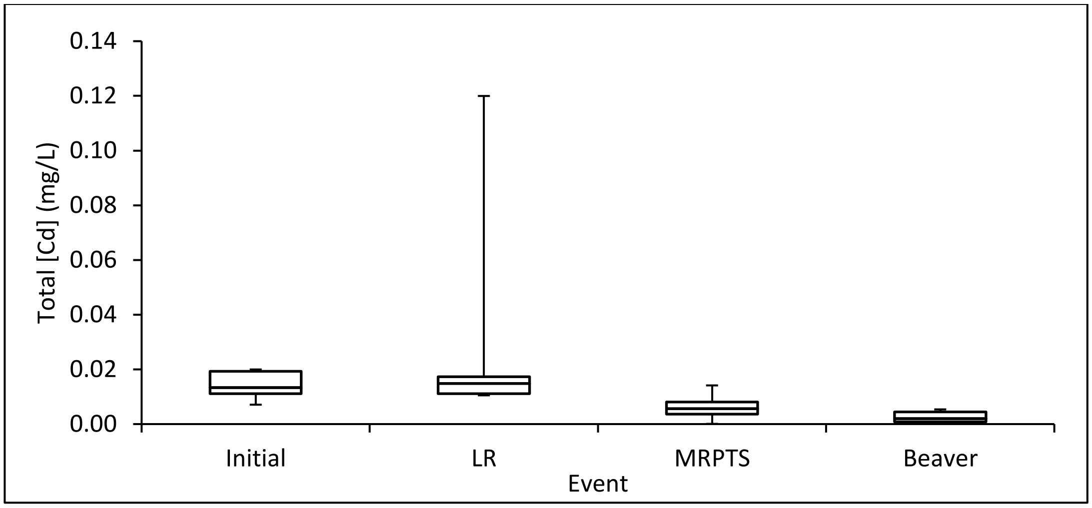

Figure 1.19: Box and whisker plot of historical total aqueous Cd concentrations at UT at UT-D from 2004 to 2017 by event

### *1.8.2 Discussion*

Although background is not a specific "event" that impacts the stream, the background time period was used as the baseline for metals concentrations. It must be noted that the stream was impacted by mining operations and various reclamation activities for at least a century prior the start of these data collection efforts, so background data do not reflect a "no impact" scenario, but rather the conditions prior to the beginning of this study. The background time period was used to be able to make comparisons to changes after the first true event, land reclamation and the installation of the French drain at SEC. For the background to land reclamation event transition, UT-U is nearest to the disturbance and therefore more likely to be impacted. Before the installation of the SEC French drain, untreated AMD discharged from a collapse feature (shown in Figure 1.4 a) 2004) and entered a volunteer cattail marsh which likely provided partial natural treatment, at least through oxidation of Fe.

The effects of the partial natural treatment are shown by the low Fe and Cd concentrations found at UT-U during the background time period. The French drain eliminated the natural filtration by capturing the water subsurface and flowing it directly into a stormwater pipe. The lack of aeration and filtration from the cattail marsh and the filling of the two collapse features with chat can be seen by the abrupt increase in Fe and Cd concentrations immediately following the French drain construction. These data points skew the box and whisker plots, particularly for Cd, but they are an important representation of the impacts of the land reclamation and French drain installation. During the post-land reclamation time period, MRPTS was not yet constructed and was therefore flowing AMD not treated by a PTS that was partially treated through another volunteer cattail marsh before impacting the stream at the UT-D site. The lack of effective treatment by MRPTS is likely the reason for the elevated Fe concentrations seen at UT-D during the 2004 to 2009 time period.

When viewing the event transition period between the land reclamation/ French drain installation and MRPTS, it is clear MRPTS had a positive influence on UT-D. All target metal concentrations were decreased and, in the case of Pb, 24 of the 29 samples collected during the MRPTS-only time period had Pb concentrations lower than the PQL. In the same time period, Fe concentrations at UT-U began to plateau at approximately 50 mg/L (Figure 1.8). MRPTS became a source of dilution water for the untreated AMD from the French drain, diluting it down to approximately 10 mg/L at the UT-D site. It is during the time period of the French drain operation that the linear trend lines for Fe at the UT-U and UT-D sites cross (Figure 1.8). MRPTS began to decrease Fe concentrations during the construction phases in late 2008 while the French drain increased Fe concentrations at UT-U until its plateau in 2008. MRPTS also decreased Zn and Cd concentrations at UT-D.

Unlike the previous events, the colonization of beaver is not an anthropogenically driven event. Rather, the beaver colonization is a natural event and is a slow process that likely had a gradual impact on the stream based on numerous factors including the size of the beaver colony, the availability of building material, the trapping of beaver, and flooding or anthropogenic events that destroyed dams. The gradual manifestation made it difficult to pinpoint a specific date of the beaver colonization event and it likely extends into a portion of the MRPTS time period, as beaver activity was noted but not considered a nuisance during the MRPTS time. The small metals concentrations at UT-D due to the construction of MRPTS limited the potential for the beaver dams to have an impact on water quality at UT-D. The greater metals concentrations seen at UT-U made that location the most likely to be able to detect and analyze the impacts of beaver colonization. The establishment of beaver impounded water showed a decrease in median Fe values from approximately 50 mg/L during the MRPTS event to less than 10 mg/L after beaver colonization (Figure 1.8).

At UT-D, Fe concentrations show a decrease during the MRPTS time to beaver event transition period. The decrease is likely due to the lower Fe concentrations coming from upstream, meaning the MRPTS effluent did not have to dilute as much Fe. Zn and Cd showed a similar trend to Fe where the beaver colonization decreased concentrations at UT-U with subsequently lower concentrations at UT-D (Figures 1.12, 1.13, 1.18, and 1.19). Pb is the only metal showing no change at UT-U due to beaver colonization and an increase in median concentrations at UT-D above the PQL (Figures 1.15 and 1.16). The beaver impoundments may have little effect on Pb since the impoundments are expected to oxidize the water where Pb is more likely to precipitate under sulfate reducing conditions as a sulfide.

Analysis of the historical dataset supports the hypothesis that the presence of beaver dams will decrease metals concentrations, with the exception of Pb concentrations. The presence of beaver dam impounded water showed a decrease in median Fe, Zn, and Cd concentrations at UT-U. In addition, the historical data suggests that the French drain caused an increase in metals concentrations at UT-U and MRPTS effluent decreased all metals concentrations at UT-D after it was constructed; diluting the raw AMD from the SEC French drain.

The historical dataset suggests the land reclamation had a negative impact on water quality, shown by the increase in median Fe, Pb, and Cd concentrations compared to the background time period and the maximum metals concentrations of the dataset at UT-U (Figures 1.9, 1.12, 1.15, and 1.18). MRPTS showed a decrease in metals concentrations at the UT-D location where the treated effluent diluted the higher metals concentrations seen at UT-U over the same time period (Figures 1.9-1.19). Beaver colonization resulted in lower concentrations of Fe, Zn, and Cd at UT-U compared to the land reclamation event, partially supporting the hypothesis that beaver colonization will decrease metals concentrations in a net alkaline mine drainage impacted stream (Figures 1.9, 1.12, 1.18).

# Chapter II: Effects of Beaver Dam Construction on Water and Sediment Quality in a Mine Drainage Impacted Stream

## 2.1 Introduction

### *2.1.1 Impacts of Mine Drainage and Implementation of Passive Treatment Systems*

Thousands of miles of waterways are negatively impacted by acid or alkaline mine drainage (AMD) around the world, harming aquatic and nearby terrestrial environments (Hengen et al., 2014). AMD initially forms at the exposed, weathering mineral face due to biogeochemical processes including oxidation, hydrolysis, microbial catalysis, precipitation, and dissolution reactions (Gagliano, 2004). Mine water pollution is formed from the exposure of metal sulfides to oxygen allowing metal sulfides to oxidize, producing dissolved metals, sulfate, and sulfuric acid (Watzlaf et al., 2004). Fe(II) readily forms Fe(III) in the presence of oxygen, is hydrolyzed at pH >4.5 and precipitates (Babb et al., 1985). The precipitated metals create highly contaminated stream sediments which can prevent the growth of vegetation and become more susceptible to erosion (Gagliano, 2004).

AMD may be treated before it impacts receiving streams through the implementation of active or passive treatment systems (PTS) (Hedin and Nairn, 1994; Fripp et al., 2000, Watzlaf et al., 2004; Cravotta, 2007; Zipper and Skousen, 2010; Hengen et al., 2014, Williams and Turner, 2015; Skousen et al., 2017). Passive treatment is the utilization of ecologically engineered ecosystems to promote physical, biogeochemical, and microbiological processes to remove metals and generate alkalinity (Nairn et al., 2009; Zipper et al., 2011). These systems, while constructed, rely on the same processes found in natural wetlands and other ecosystems. Once AMD has been treated and discharged, impacted streams often show significant ecological recovery. Williams and Turner (2015) found increases in species richness and density of fish populations post-restoration of an AMD impacted stream. The study also found significant increases in macroinvertebrate density and biomass (Williams and Turner, 2015). Nelson and Roline (1996) found similar results in a recovering stream in Pennsylvania. The decreased metal concentrations led to immediate macroinvertebrate community increases which were comparable to unaffected reference streams within two years (Nelson and Roline, 1996). This study investigated the effects of *Castor canadensis* on a mine drainage impacted stream.

### *2.1.2 Castor canadensis*

*Castor canadensis*, the North American Beaver, are ecosystem engineers. Their natural distribution covers the majority of North America. Ecosystem engineers are organisms with the potential to significantly modify their surroundings. In the case of beaver, they modify their surroundings through the creation of ponds and wetlands due to the damming of waterways (Naiman et al., 1986; Snodgrass and Meffe, 1998; Butler and Malanson, 2005; Andersen and Shafroth, 2010; Hardisky, 2011; Law et al., 2016, and Puttock et al., 2017). The alteration of the ecosystem has been shown to increase plant and animal species richness (Collen and Gibson, 2001; Cunjak, 1996; Snodgrass and Meffe, 1998; Hagglund and Sjoberg, 1999; Snodgrass and Meffe, 1999; Wright et al., 2002; Bromley and Hood, 2012; Smith and Mather, 2013). The increase in species richness is often attributed to the increase in habitat heterogeneity, particularly in headwater streams. Snodgrass and Meffe (1999) found beaver impounded waters provide lentic zones to an otherwise lotic dominated environment. The newly created lentic zones attracted pond dwelling fish that would otherwise not inhabit the stream. The impounded water also provides shallow, slow moving water with aquatic vegetation that is important habitat for juvenile fishes (Hagglund and Sjoberg, 1999). With respect to vegetation, Wright et al. (2002) found a 33% increase in plant species in the riparian zone compared to areas with no history of beaver populations. A second study conducted by Anderson et al. (2006) found herbaceous species richness nearly doubles in beaver meadows compared to the surrounding forest.

#### 2.1.2.1 Impact of *Castor canadensis* on nutrient concentrations

The impacts of beaver dam impoundments in AMD have not been studied, but there is extensive literature on the impacts of beaver dams on nutrient concentrations, which provide insight to the complexities and potentially site-specific results that may apply to AMD impacted streams. The literature investigating nutrient concentrations is highly variable. An in-depth study conducted by Fuller and Peckarsky (2011) investigated 22 beaver ponds located in six different catchments located in the Colorado Rocky Mountains over a two-year period. The study concluded beaver impoundments do not have predictable effects on downstream nutrient concentrations. Rather, the results varied based on a range of parameters including pond morphology and annual hydrologic fluctuations. Nitrate concentrations significantly increased downstream of the beaver dams, but only when the stream was at base flow. It is also important to note the nitrate concentration in the stream was low, with values typically less than 50 μg/L (Fuller and Peckarsky, 2011). The same study found soluble reactive phosphorus (SRP) was a function of flow and the hydraulic head of each beaver dam. Downstream SRP increased with high-head beaver dams and decreased with low-head dams, but only during base flow conditions. If conditions were above base-flow, both nitrate and phosphate would show a decrease in concentration that was attributed to dilution due to runoff (Fuller and Peckarsky, 2011).

Maret et al. (1987) investigated seasonal nutrient transport in southwest Wyoming for two years in the spring and summer over a 12.9 km reach of stream. Samples were collected in and out of the numerous beaver dams located on the stream and the authors found suspended solids (SS), total phosphorus (TP), total Kjeldahl nitrogen (TKN), and $NO_3$-N statistically decreased in and out of beaver ponds during the spring months with no changes during the summer months (Maret et al., 1987). Maret et al. (1987) did not report the head of each beaver dam, so it is hard to make a comparison to Fuller and Peckarsky (2011) in terms of TP. However, the results contradict Fuller and Peckarsky (2011) in terms of $NO_3$-N at base flow conditions. A later study, supporting Maret et al. (1987), conducted in southern Ontario, Canada on an agricultural stream over a four-year period found a decrease in $NO_3$-N concentrations after dam construction by a factor of 3 to 4. The study also reported an increase in ammonia nitrogen ($NH_4$-N) by a factor of 2.5 after beaver dam construction, which was not a measured parameter in Maret et al. (1987).

Margolis et al. (2011) investigated beaver impoundments in the Appalachian Mountains. The study found no statistical difference between beaver impounded and unaffected reaches of two separate streams (Margolis et al., 2011).

The studies discussed above show there is not a consensus in terms of $NO_3$-N being retained or exported through beaver impounded water, with Fuller and Peckarsky (2011) reporting an increase in $NO_3$-N concentrations at base flow conditions, Maret et al (1987), along with Hill and Duval (2009), reporting a decrease in $NO_3$-N concentrations, and Margolis et al. (2011) reporting no statistical difference.

#### 2.1.2.2 Impact of *Castor canadensis* on Metals Concentrations

Despite the ample literature on nutrients, there is minimal work investigating metal retention in beaver impounded water. Margolis et al. (2011) measured a few select metals, but the concentrations of all reported values were less than 0.5 mg/L. The metals concentrations presented by Margolis et al. (2011) are substantially lower than the metal concentrations found in AMD impacted streams, such as the one that is the focus of this study.

This study investigated the impacts of impounded water due to beaver dam construction in an AMD impacted stream. It was hypothesized that 1) the effluent of each beaver dam will have lesser metals concentrations than the influent water impounded by the presence of the beaver dam, 2) sediment metals concentrations will have the greatest concentrations at the most upstream location, with decreasing downstream concentrations, 3) sediment metal concentrations will not exceed Resource Conservation and Recovery Act (RCRA) Toxicity Characteristic Leaching Procedure (TCLP) criteria and 4) USGS Field Leaching Test (FLT) will show lesser concentrations than the TCLP results.

## 2.2 Methods and Materials

### *2.2.1 Site Description*

Unnamed tributary (UT) is a first-order tributary of Tar Creek located in Commerce, Oklahoma, shown below in Figure 2.1. The UT stream has been impacted by AMD from abandoned lead and zinc operations for at least a century. At base flow, the stream has primarily two continuous artesian-flowing groundwater sources of AMD. UT and these contributing sources are regularly monitored for water quality by the University of Oklahoma Center for Restoration of Ecosystems and Watersheds (CREW). All historical data were provided by CREW. The first artesian source, which is the start of the study reach, is where UT becomes a perennial stream, known as Southeast Commerce (SEC), discharging 100 gpm. The second artesian source is located approximately 0.3 miles downstream, and is known as Mayer Ranch (MR) where a passive treatment system (MRPTS) discharges 160 gpm of treated AMD into UT. The treated AMD from MRPTS dilutes the metals concentrations of all locations downstream of the MRPTS effluent. The metals concentrations of the two AMD sources and performance of MRPTS is shown in Table 2.1. In 2013, the presences of beaver in the UT were noted. By the end of 2014, approximately half of UT was influenced with elevated water levels due to the presence of beaver dams.

Table 2.1: Average total aqueous metals concentrations of the two contributing AMD groundwater sources (SEC and MR) to UT in Commerce, OK and passive treatment system effluent of the MR source

| | Sample Size | Cd | Fe | Pb | Zn |
|---|---|---|---|---|---|
| | | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| SEC Discharge | 60 | 0.031±0.013 | 133±13 | 0.063±0.011 | 9.71±2.58 |
| MRPTS Inflow[¥] | 184 | 0.016±0.006 | 175±25 | 0.069±0.015 | 8.42±1.42 |
| MRPTS Outflow | 51 | <PQL* | 0.65±0.98 | <PQL* | 0.46±0.85 |

*46 of 51 samples were less than the practical quantitation limit (PQL)

[¥] Values averaged from three discharges

### *2.2.2 Water and Sediment Sample Collection and Analysis*

Water and sediment samples were collected at the inflow and outflow of each beaver dam impoundment along UT. The parameters analyzed are shown in Table 2.2. Inflow into beaver impounded water was identified as the location where water levels at base flow remained at or above the bankfull elevation or were impounded above bankfull to the next upstream beaver dam with positive head. The outflow for water quality sampling was defined at the location where the water spills over the dam, and that for sediment sampling was defined at the location immediately upstream of the beaver dam where sediments used to construct the dam were not present. Sampling locations were chosen based on site inspections the day of each sampling event. The sampling began at Unnamed tributary-Robinson site (UT-R) because it is the furthest downstream location. The samples were collected sequentially upstream to the location where water exits UT-Pipe (Figure 2.1) Water samples were collected at each site from the bank, using an extended sampling pole with a bottle to prevent disturbance of the water column. Then, water quality measurements were collected using a YSI 600QS multiparameter datasonde.

After water quality sampling was completed, sediments were collected at the sampling locations using a stainless-steel shovel. Depths of obvious sediment layer changes were recorded, and a representative sample of each layer collected and placed into a sealable plastic bag. The objective of sediment sample collection was to find native streambed and collect a representative sample. Sampling events occurred on three separate occasions:  August 2016, November 2016, and January 2017.

Total reactive phosphorus and nitrate-N were collected and analyzed during the August sampling event, however the results were below the detectable limits (0.1 mg/L NO3-N and 0.01 mg/L TRP), so these two parameters were not included in the November 2016 or January 2017 events.  Dissolved metals were collected during two of the three sampling events, August 2016 and January 2017.

Also, it is important to note that not every dam was present for each sampling event. Some dams were anthropogenically destroyed for another portion of this study and not reconstructed and others were constructed by beaver after the first sampling event. Over the entire one-mile length of the UT study reach, six beaver dams were sampled in one or more of the sampling events. In addition to the beaver dams, historical sampling locations and a man-made, concrete low water crossing were sampled (Figure 2.1). The low water crossing (LWC) is a concrete road that acts like a beaver dam and has been in place for decades.

Table 2.2: Water quality and sediment sampling parameters and methods used to assess impacts of beaver dams along UT, located in Commerce, OK

| | Method/Instrumentation | Volume/Mass |
|---|---|---|
| *Water Quality Parameters* | | |
| Total Metals | USEPA 3015a and 6010c | 250 mL |
| Dissolved Metals | USEPA 3015a and 6010c | 250 mL |
| Physical Parameters | YSI 6920 V2 multiparameter datasonde following CREW and YSI SOPs | N/A |
| Temperature | | |
| Specific Conductance | | |
| Conductivity | | |
| Resistivity | | |
| Dissolved Oxygen (DO) (%) | | |
| DO Concentration (mg/L) | | |
| Total Dissolved Solids | | |
| pH | | |
| Chlorophyll-a | | |
| Total Reactive Phosphorus | USEPA 365.3 | 100 mL |
| Nitrate-N | USEPA 352.1 | 100 mL |
| Turbidity | Hach 2100P Turbidimeter | 30 mL |
| Alkalinity | Hach Method 8203 | 100 mL |
| *Sediment Quality Parameters* | | |
| Particle Size | ASTM 2488 | ≥200 g |
| Total Metals | USEPA 3051a and USEPA 6010c | 0.5 g dry |
| Field Leaching Test | USGS TM 5-D3 | 50 g dry |
| Toxicity Characteristic Leaching Procedure | USEPA 1311, USEPA 3015a, USEPA 6010c | 100 g |

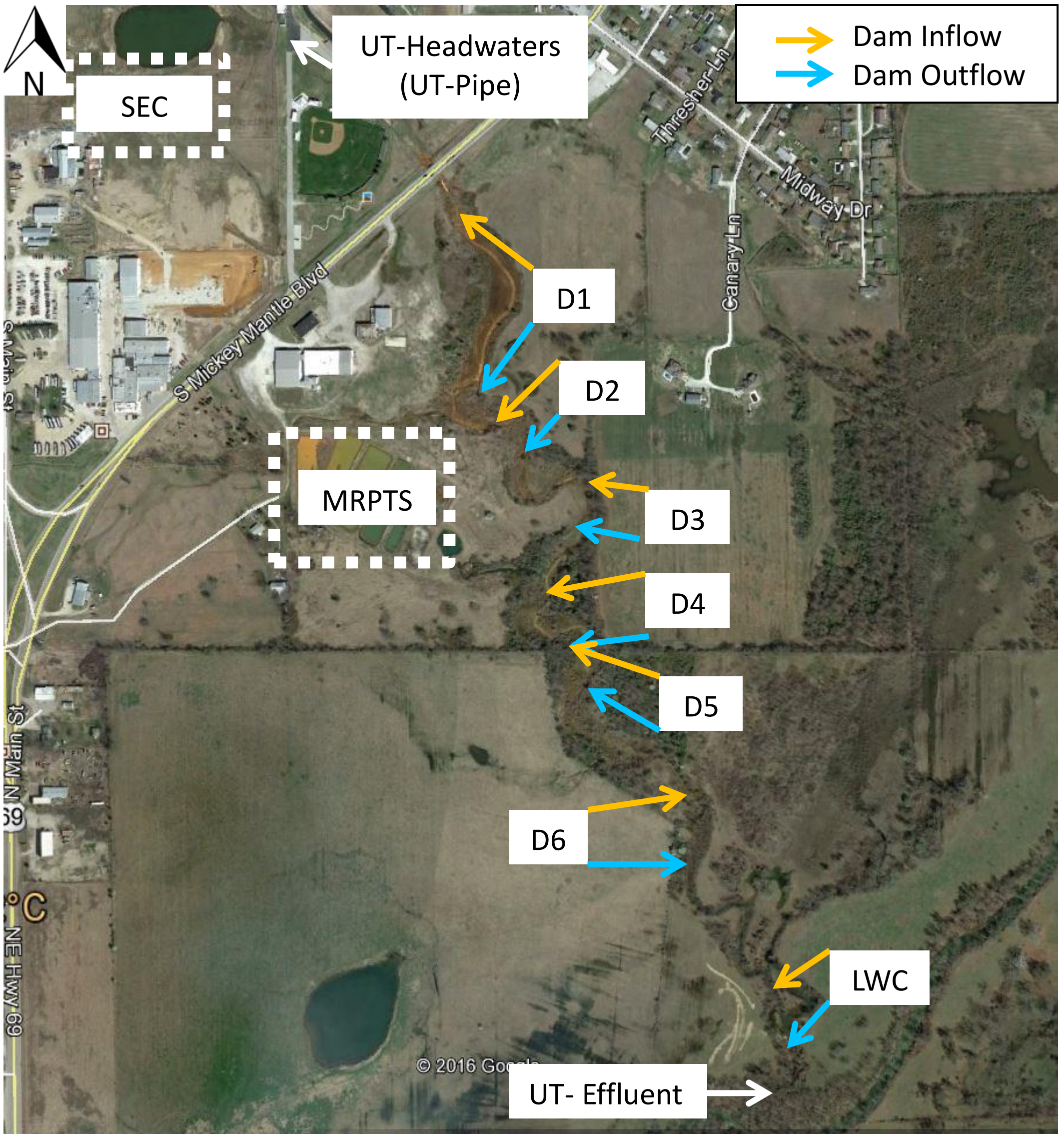

Figure 2.1: Beaver dam locations along UT in Commerce, OK, with arrows indicating inflow and outflow of each impoundment from beaver dam construction (Google Earth, 2017)

## 2.3 Results and Discussion

### *2.3.1 Water quality in and out of Beaver Dams*

Total metals concentrations data collected at the three separate sampling events are shown in Table 2.3 and Figures 2.2-2.7. The dissolved metals data are shown in Table 2.4. Dam 1 (D1) through dam 3 (D3) are located upstream of the MRPTS effluent. The upstream sites have greater concentrations due to the lack of dilution from the treated effluent of MRPTS. The upstream locations contained detectable Cd concentrations in the water, where concentrations were less than the practical quantitation limit (PQL) at the downstream dams.

In these data collected for this experiment, numerous gaps exist for each event where dams were not sampled. As discussed in the methods, some dams were created or destroyed over the period of the sampling events. During the first sampling event in August 2016, four dams were selected because they impounded the largest amount of water. However, only one of the dams (D1) was located upstream of the MRPTS effluent. In another portion of this study, during the August sampling event, all beaver dams on UT were manually destroyed. Many of the dams showed signs of reconstruction within two days of being destroyed. By the November sampling event, the beaver had begun constructing new dams upstream, allowing for two more sampling locations (D2 and D3) upstream of MRPTS. D5 and D6, two of the largest dams on UT, were not reconstructed during the November 2016 sampling event. By January 2017, D5 was re-established to the same elevation or higher compared to the August 2016 sampling event, while D6 was not reconstructed. In Figures 2.2, 2.3, and

2.5 decreasing Fe, Cd, and Zn concentrations can be seen in for each of the three sampling events. The impounded water from the beaver dams acted as an oxidation pond (as those designed for use in a PTS), allowing for Fe to precipitate and settle as iron oxyhydroxides. The decrease in Cd was likely due to sorption of the Cd to the iron precipitates, which is a process seen in the oxidation pond of the MRPTS (Nairn et al., 2009). The sorption of Cd to Fe is likely the reason Cd and Fe concentrations show nearly identical trends (Figures 2.2 and 2.3). The beaver dams had minimal impact on Pb concentrations in the water (Figure 2.4). Pb is removed in PTS vertical flow bioreactors via bacterial sulfate reduction in an anoxic environment (Nairn et al., 2009). A reducing environment that the water flows through is not likely to be present in a beaver impoundment, which is supported by the lack of Pb removal in the beaver dam impoundments studied. Reducing conditions may be present in the sediments, but the water is not forced through this environment as it is in a passive treatment system's vertical flow bioreactor.

The initial concentrations of all metals seen at D1 inflow vary based on the condition of the stream at the time the sample was collected. Conditions that potentially influenced the collected samples were the time period since the previous storm event and severity of the storm event. Additionally, during the January 2017 sampling event, the MRPTS oxidation pond bypass was open. The bypass discharged partially treated water into UT immediately after D2 inflow, causing an abrupt increase in metals concentrations. The increase is particularly evident in Figure 2.2 where the Fe concentration increases from 6.22 mg/L to 21.8 mg/L. The water flowing out of the bypass in January 2017 had not gone through the complete set of treatment ponds designed to remove other metals and is likely the reason Zn concentrations are elevated compared to the two previous sampling events (Figure 2.5). Some water quality parameters, such as alkalinity and specific conductivity, were collected as stated in the methods section but are not present because there are no trends of interest.

Table 2.3: Total aqueous metals concentrations in and out of six water impoundments due to the construction of beaver dams and a low water crossing (LWC) along UT, located in Commerce, OK

| Site | Aug. Sampling Event | | | | Nov. Sampling Event | | | | Jan. Sampling Event | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cd | Fe | Pb | Zn | Cd | Fe | Pb | Zn | Cd | Fe | Pb | Zn |
| | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| D1 In | 0.015 | 66.1 | 0.053 | 5.49 | 0.013 | 22.6 | 0.036 | 8.10 | 0.007 | 46.4 | 0.055 | 5.53 |
| D1 Out | 0.005 | 40.8 | 0.044 | 4.23 | 0.005 | 4.71 | 0.022 | 5.73 | 0.002 | 21.7 | 0.042 | 4.35 |
| D2 In | - | - | - | - | 0.004 | 3.75 | 0.022 | 5.04 | 0.002 | 6.22 | 0.043 | 4.58 |
| D2 Out | - | - | - | - | 0.002 | 1.30 | 0.019 | 3.77 | 0.002 | 21.8 | 0.046 | 3.96 |
| D3 In | - | - | - | - | 0.002 | 1.67 | 0.025 | 3.92 | 0.002 | 18.8 | 0.042 | 4.02 |
| D3 Out | - | - | - | - | 0.001 | 1.49 | 0.021 | 3.88 | 0.002 | 15.4 | 0.041 | 3.98 |
| D4 In | <PQL* | 0.839 | 0.029 | 0.270 | 0.001 | 0.927 | 0.026 | 3.45 | 0.001 | 9.58 | 0.041 | 4.44 |
| D4 Out | <PQL* | 0.512 | 0.030 | 0.087 | <PQL* | 0.980 | 0.023 | 2.93 | 0.001 | 8.60 | 0.035 | 3.95 |
| D5 In | <PQL* | 2.25 | 0.034 | 0.172 | - | - | - | - | 0.001 | 7.54 | 0.037 | 3.94 |
| D5 Out | <PQL* | 0.893 | 0.032 | 0.093 | - | - | - | - | <PQL* | 6.26 | 0.035 | 3.87 |
| D6 In | <PQL* | 0.489 | 0.034 | 0.087 | - | - | - | - | - | - | - | - |
| D6 Out | <PQL* | 0.486 | 0.026 | 0.091 | - | - | - | - | - | - | - | - |
| LWC In | <PQL* | 0.245 | 0.029 | 0.113 | <PQL* | 0.347 | 0.017 | 1.66 | <PQL* | 1.36 | 0.039 | 3.57 |
| LWC Out | <PQL* | 0.240 | 0.036 | 0.109 | <PQL* | 0.300 | 0.019 | 1.59 | <PQL* | 0.637 | 0.021 | 3.70 |

* Practical quantitation limit (PQL)

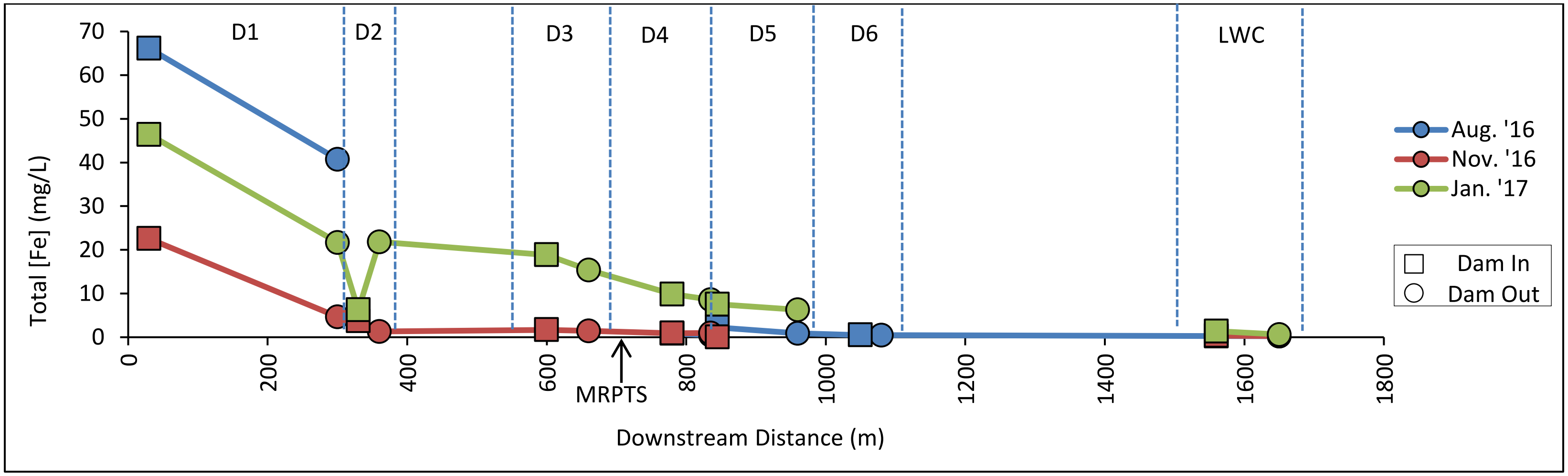

Figure 2.2: Total aqueous Fe concentrations in and out of beaver impounded water due to dams along UT versus distance on a one-mile study reach, with MRPTS arrow indicating the location of MRPTS effluent into UT

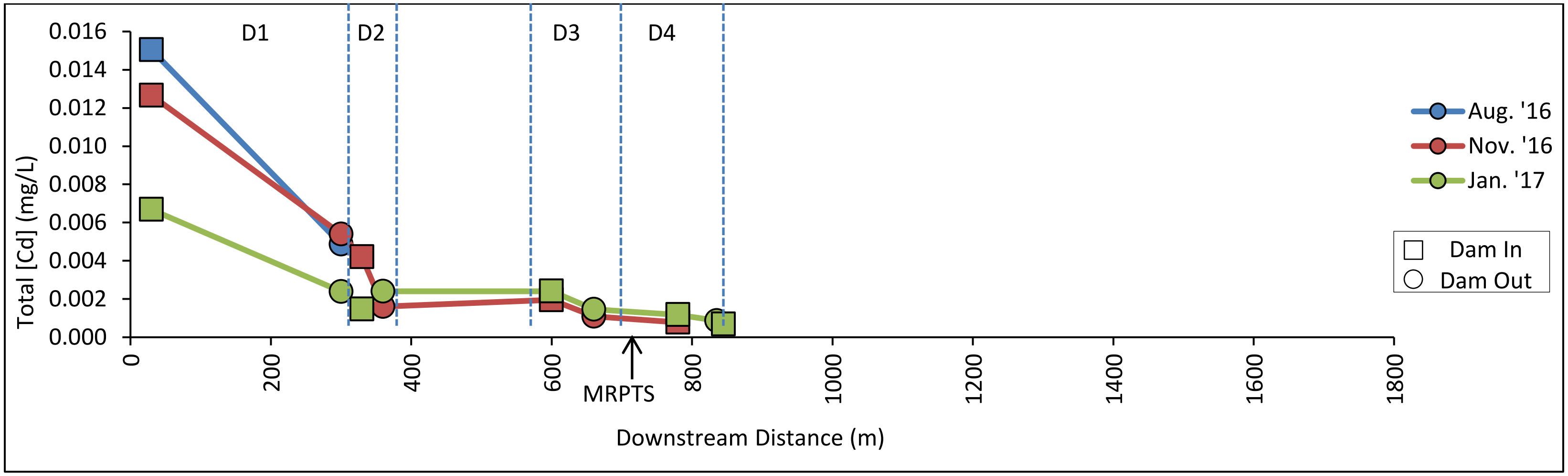

Figure 2.3: Total aqueous Cd concentrations in and out of beaver impounded water due to beaver dams along UT versus distance on a one-mile study reach, with MRPTS arrow indicating the location of MRPTS effluent into UT

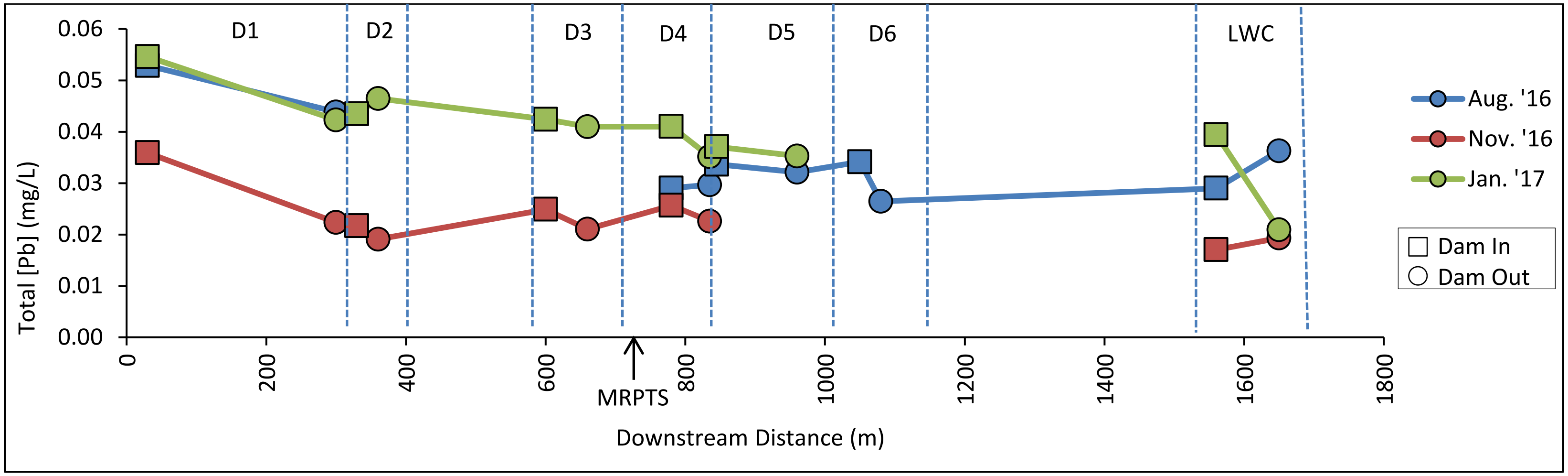

Figure 2.4: Total aqueous Pb concentrations in and out of beaver impounded water due to dams along UT versus distance on a one-mile study reach, with MRPTS arrow indicating the location of MRPTS effluent into UT

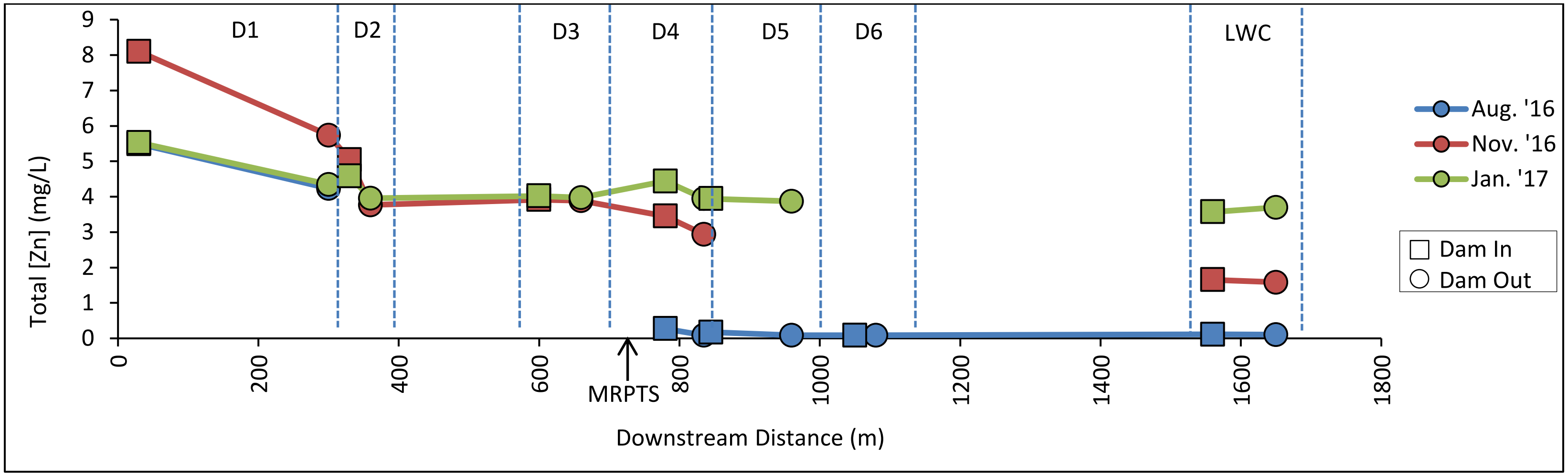

Figure 2.5: Total aqueous Zn concentrations in and out of beaver impounded water due to dams along UT versus distance on a one-mile study reach, with MRPTS arrow indicating the location of MRPTS effluent into UT

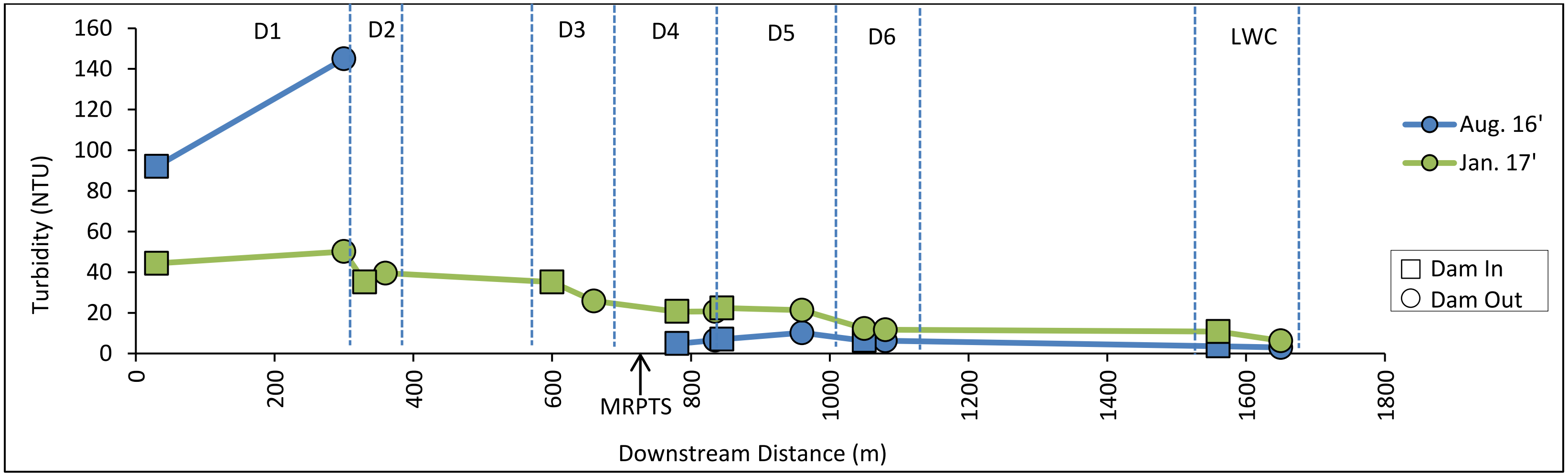

Figure 2.6: Turbidity in and out of beaver impounded water due to beaver dams along UT versus distance on a one-mile study reach, with MRPTS arrow indicating the location of MRPTS effluent into UT

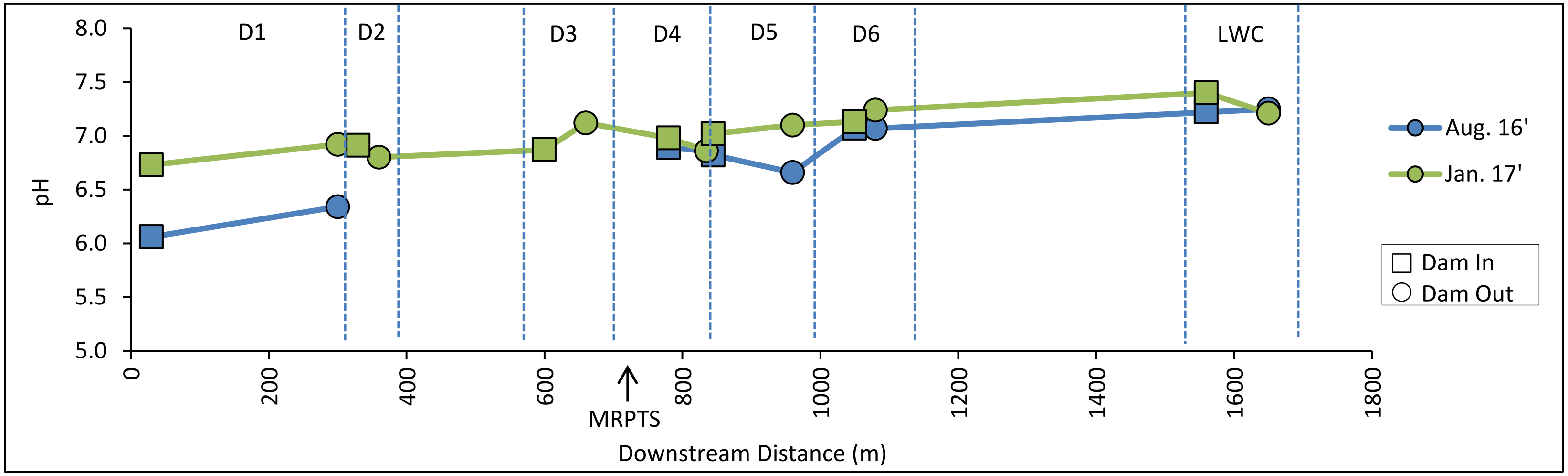

Figure 2.7: pH in and out of beaver impounded water due to dams along UT versus distance on a one-mile study reach, with MRPTS arrow indicating the location of MRPTS effluent into UT

Table 2.4: Dissolved aqueous metals concentrations in and out of six water impoundments due to the construction of beaver dams and a low water crossing (LWC) along UT, located in Commerce, OK

| Site | Aug. 2016 | | | | Jan. 2017 | | | |
|---|---|---|---|---|---|---|---|---|
| | Cd | Fe | Pb | Zn | Cd | Fe | Pb | Zn |
| | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| D1 In | 0.006 | 43.9 | 0.044 | 4.596 | 0.010 | 44.9 | 0.029 | 5.836 |
| D1 Out | 0.004 | 27.8 | 0.045 | 4.127 | 0.009 | 20.9 | 0.020 | 5.03 |
| D2 In | - | - | - | - | 0.008 | 4.05 | 0.026 | 4.83 |
| D2 Out | - | - | - | - | 0.009 | 21.1 | 0.020 | 4.34 |
| D3 In | - | - | - | - | 0.008 | 16.1 | 0.019 | 4.34 |
| D3 Out | - | - | - | - | 0.008 | 12.7 | 0.028 | 4.30 |
| D4 In | <PQL | 0.041 | 0.024 | 0.287 | 0.007 | 8.04 | 0.025 | 4.26 |
| D4 Out | <PQL | 0.108 | 0.031 | 0.099 | 0.011 | 6.17 | 0.023 | 4.29 |
| D5 In | <PQL | 0.023 | 0.035 | 0.098 | 0.008 | 5.27 | 0.020 | 4.19 |
| D5 Out | <PQL | 0.040 | 0.027 | 0.075 | 0.008 | 4.18 | 0.019 | 4.17 |
| D6 In | <PQL | 0.040 | 0.028 | 0.073 | <PQL | 2.35 | 0.019 | 4.13 |
| D6 Out | <PQL | 0.110 | 0.032 | 0.074 | 0.008 | 2.17 | 0.018 | 4.10 |
| LWC In | <PQL | 0.025 | 0.036 | 0.105 | 0.008 | 0.271 | 0.020 | 3.76 |
| LWC Out | <PQL | 0.033 | 0.021 | 0.102 | <PQL | 0.233 | <PQL | 3.60 |

* Practical quantitation limit (PQL)

Samples were collected at only three dams for all three events (D1, D4, and LWC). The remaining dams had samples from two of the three events. For a statistical comparison, the dams with three samples were used, and one of these three dams, D1, was located upstream of MRPTS effluent. Another of the three is the man-made low water crossing (LWC) site, resulting in only two beaver dams being used to determine statistical significance.  The dams with three or more sampling events (D1, D4, and LWC) were analyzed using a paired, one-tailed T-test to determine if the outflow metals concentrations were statistically lower than the inflow metals concentrations. A summary of the statistical analysis is shown in Table 2.5.

D1 showed statistically significant ($p < 0.05$) decreases in metals concentrations for all four metals, while the remaining dams did not show significant decreases in concentrations, with the exception of Zn in D4. The significant decrease in metals at D1 is likely do to the elevated initial concentrations, where-as D4 and LWC experienced much lesser metals concentrations due to the inflow of clean water from MRPTS and extended retention time in the stream allowing precipitation and sorption of the metals.

Table 2.5: Resulting p-values from a 1-tailed, paired T-test comparing total aqueous metals concentrations in and out of two water impoundments due to the construction of beaver dams and a low water crossing (LWC) along UT, located in Commerce, OK

| Site | Cd | Fe | Pb | Zn |
|---|---|---|---|---|
| D1 | 0.025 | 0.006 | 0.007 | 0.026 |
| D4 |  | 0.150 | 0.140 | 0.032 |
| LWC |  | 0.189 | 0.372 | 0.387 |

Since D1 was the only location to show significant decreases in Fe concentrations, it was chosen to determine an iron removal rate for the pond behind the dam for each of the three sampling events. From a habitat assessment conducted for a separate portion of this project, the surface area of D1 was determined to be approximately 3,000 $m^2$ with a total estimated volume of 1,500 $m^3$. Using the change in Fe concentrations between the inflow and outflow of D1 for each sampling event and an average flow rate from SEC discharge of 100 gpm, Fe removal rates were calculated (Table 2.6). The values were compared to a 20 g Fe $m^{-2}$ $day^{-1}$ design removal rate that is used for the design of oxidation ponds for passive treatment systems (Nairn et al., 2009). The beaver impounded water at D1 performed at approximately 20% to 25% of the designed removal rate for passive treatment system oxidation ponds. Beaver impoundments experience more environmental fluctuations than a designed oxidation pond and therefore were not be expected to work at the same efficiency. Beaver impoundments promote the growth of numerous types of aquatic vegetation that can lead to large changes in DO over a 24-hour period. During a separate sampling event, a multiparameter datasonde was deployed for a 24-hour in UT, collecting data every thirty minutes. At night, the DO fell below 40% saturation. The lack of available DO during the night hours may be a hindrance on Fe oxidation and therefore potentially decrease the daily Fe removal rates in the beaver impounded waters. There is also literature showing that lower initial Fe concentrations result in lower removal rates. Hedin (2008) reported decreasing removal rates with lower initial concentrations of Fe through a large passive treatment system. In that study, with an initial total Fe concentration 26 mg/L, the oxidation rate of Fe was 18 g Fe $m^{-2}$ $day^{-1}$. In the following unit, the initial total Fe concentration was 10.5 mg/L with an Fe removal rate reported as >1.4 g Fe $m^{-2}$ $day^{-1}$ (Hedin, 2008).

Hedin (2008) also reported the cost of Fe removal for the Marchand passive treatment system, which treats net alkaline mine drainage, at approximately \$0.238 per kg Fe. The cost of treatment was based on the capital cost and operational cost with a 25-year system life time and assuming Fe sludge management will be offset by Fe recovery. The value of \$0.238 per kg Fe removed was applied to D1 removal efficiency, which had an average decrease in total Fe of 22.6 mg/L and flow rate of 378 liters per minute. The flow rate was the average from the CREW historical dataset.

$$\frac{22.6\, mg\ Fe\ removed}{1\, L} \times \frac{378\, L}{1\, min} \times \frac{1440\, min}{1\, day} \times \frac{1\, kg}{1{,}000{,}000\, mg} \times \frac{\$0.238}{1\, kg\ Fe\ removed} = \$2.93$$

D1 removed an average of 12.3 kg of Fe per day, resulting in D1 having a treatment value of \$2.93 per day or \$1,070 per year. The value calculated is a conservative value because it does not consider the removal value of other metals or the benefits beaver dams provide beyond AMD treatment.

Table 2.6: Iron removal rates of a beaver dam located on an AMD impacted stream in Commerce, OK compared to a passive treatment system designed removal rate

| | Fe Removal Rate (g Fe $m^{-2}$ $day^{-1}$) |
|---|---|
| PTS Design Removal | 20.0 |
| D1 August 2016 | 4.62 |
| D1 November 2016 | 3.25 |
| D1 January 2017 | 4.50 |

### *2.3.2 Metals Concentrations in Sediments*

Sediment samples were collected during the August 2016 sampling event immediately after the water quality samples were collected. Four beaver dams (D1, D4, D5, and D6) and the LWC were sampled. At each site, a representative sample of each sediment layer was collected if distinct layers were identified. Three locations had stratification and all of them were at the outflow of the beaver dams. The outflow dam locations showed higher Fe, Cd, and Zn concentrations in sediments than the inflow locations at the majority of the dams, (Table 2.7, Figures 2.8 and 2.9). Pb did not show a similar trend to the other metals, (Figure 2.9).

The Tri-State Mining District has probable effects concentrations (PEC) established by Ingersoll et al. (2009) for Cd, Pb, and Zn. The PEC was determined by performing a toxicity assessment using amphipods and sediments from the Tri-State Mining District. Two of the thirteen samples (D4 Out 10” - 14” and D5 In) were below the PEC of 2,083 mg/kg for Zn. D5 In was the only sample with Cd and Pb values below the PEC of 11.1 mg/kg and 150 mg/kg, respectively. Five of 13 samples had Fe concentrations exceeding 200,000 mg/kg. It was assumed that Fe in the sediments was in the form of iron oxides which suggests >30% of the mass of the sediments samples was iron oxides.

The elevated metals concentrations in the sediments found at the outflow were likely due to the metals precipitating in the beaver impoundments, but remaining suspended in the water column until settling at the shallow waters nearest the beaver dam.

Table 2.7: Metals concentrations in UT sediments collected at the inflow and outflow of impounded water due to beaver dams compared to the PEC for the Tri-State Mining District, published by Ingersoll et al. (2009)

| Site | Depth | Al | As | Cd | Fe | Pb | Zn |
|---|---|---|---|---|---|---|---|
| | (Inches) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) | (mg/kg) |
| PEC* | - | - | - | 11.1 | - | 150 | 2,083 |
| D1 In | 0-24 | 4,100 | 8.17 | 75.4 | 204,000 | 500 | 9,240 |
| D1 Out | 0-20 | 3,880 | 39.9 | 88.6 | 167,000 | 377 | 10,300 |
| D4 In | 0-8 | 6,230 | 11.9 | 146 | 122,000 | 522 | 10,600 |
| D4 Out | 10-14 | 6,140 | 7.21 | 11.6 | 19,900 | 1,360 | 1,460 |
| D4 Out | 0-10 | 4,500 | 57.2 | 70.2 | 228,000 | 477 | 9,400 |
| D5 In | 0-18 | 6,780 | 5.30 | 8.38 | 14,000 | 28.8 | 863 |
| D5 Out | 8-20 | 3,810 | 10.1 | 21.7 | 51,000 | 419 | 2,500 |
| D5 Out | 0-8 | 3,990 | 53.8 | 137 | 266,000 | 384 | 21,400 |
| D6 In | 0-6 | 5,770 | 5.44 | 20.3 | 26,100 | 628 | 2,2400 |
| D6 Out | 3-12 | 5,360 | 18.6 | 120 | 149,000 | 626 | 1,4700 |
| D6 Out | 0-3 | 6,350 | 18.5 | 234 | 252,000 | 538 | 13,000 |
| LWC In | 0-12 | 5,700 | 4.08 | 21.2 | 9,560 | 192 | 2,930 |
| LWC Out | 0-18 | 6,100 | 23.8 | 93.2 | 221,000 | 360 | 13,500 |

*PEC for Tar Creek Superfund Site from (Ingersoll et al., 2009)

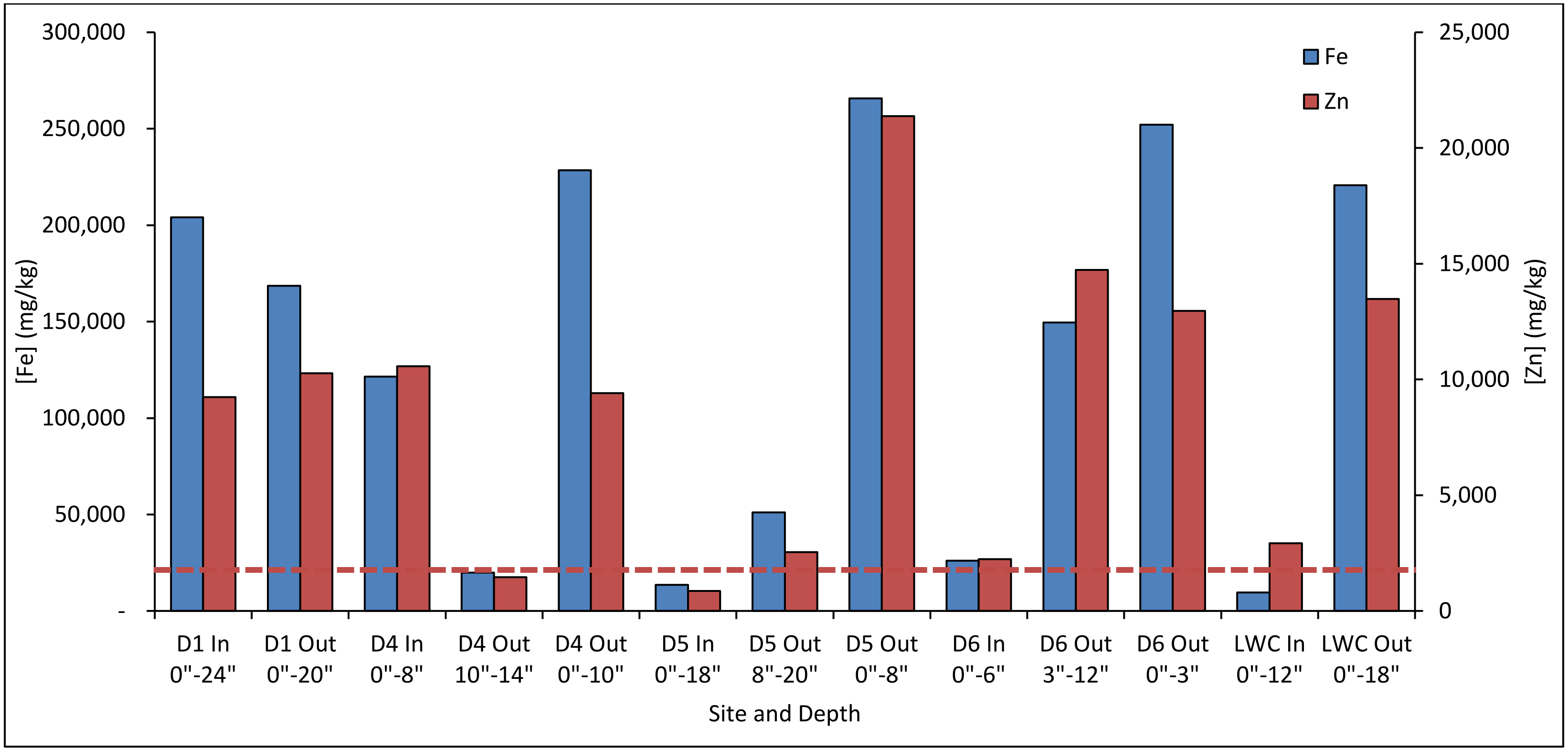

Figure 2.8: Fe and Zn concentrations of each identifiable profile with associated depth in UT sediments at each beaver dam location compared to the Zn PEC (2,083 mg/kg) for the Tri-State Mining District represented by the red horizontal dashed line

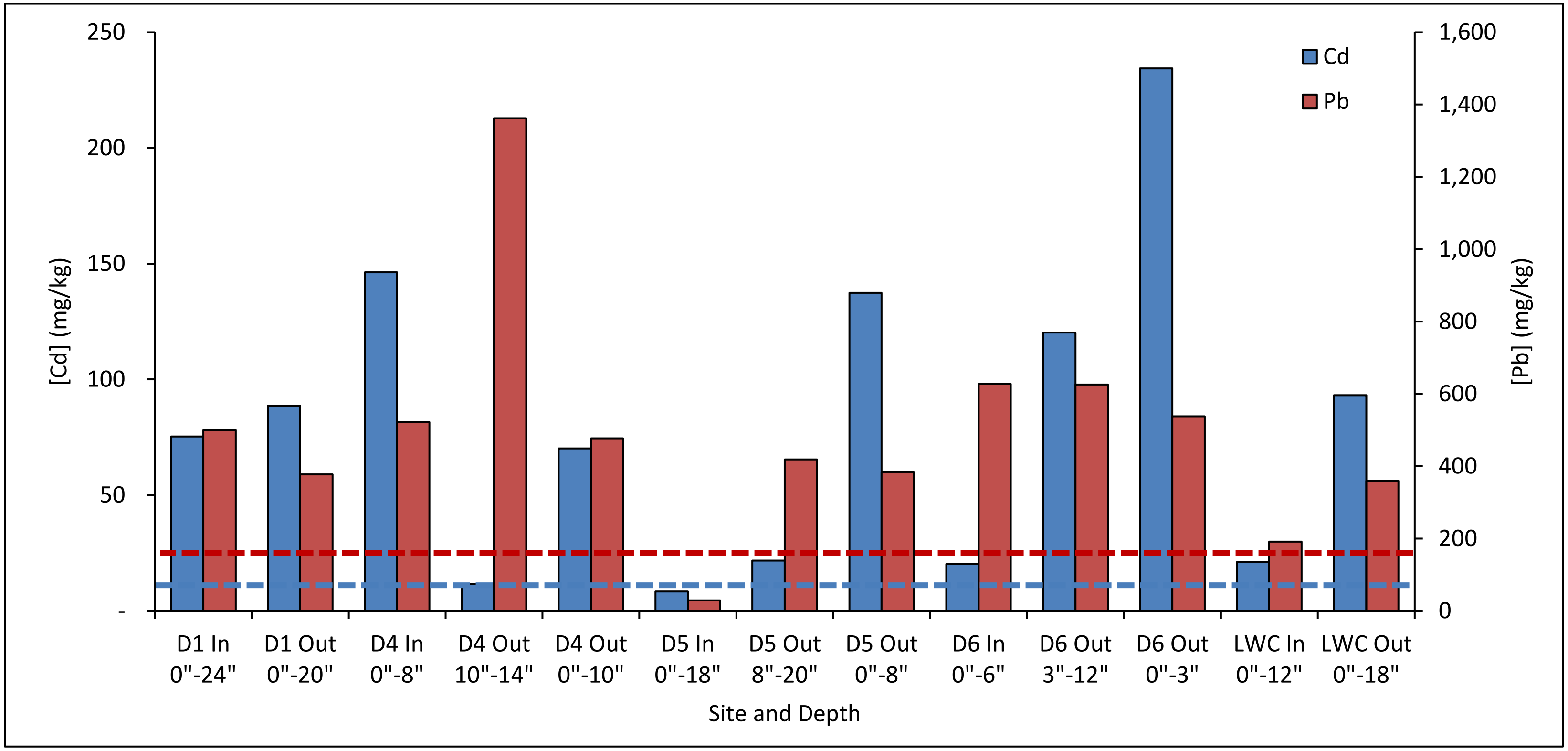

Figure 2.9: Cd and Pb concentrations of each identifiable profile with associated depth in UT sediments at each beaver dam location compared to the Cd PEC (11.1 mg/kg), represented by the blue horizontal dashed line, and Pb PEC (150 mg/kg), represented by the red horizontal dashed line, for the Tri-State Mining District

The metals concentrations in the sediments were statistically analyzed to determine if values at the inflow of beaver impounded waters were statistically lower than the outflow locations. A 1-tailed, paired, T-Test compared the sediment metals concentration of the inflow and top layer of the outflow of each beaver dam to determine if the outflow sediment metals concentrations were statistically higher than the inflow sediment metals concentrations. Fe and Zn showed significantly greater ($p=0.023$ and $p=0.049$, respectively) concentrations in the sediments when comparing the top layer of the outflow locations to the inflow sediment locations. Cd and Pb did not show statistical significance. The statistical analysis supports the premise that Fe is remaining suspended in the water column until it approaches the location of the beaver dam. However, Cd would be expected to follow the same trend since it typically sorbs to the iron oxides to precipitate.

When comparing the metals concentrations of the sediment layers at D4, D5, and D6, Cd and Fe concentrations were significantly greater in the top layer ($P=0.018$ and $p=0.020$, respectively). In these cases, Cd follows the same trend as Fe, which is to be expected if Cd is sorbing to the iron oxides. The lesser metals concentrations in the bottom layer suggest any accumulation of metals in the bottom of the stream does not persist for an extended period of time and is likely mobilized during high flow events.

### *2.3.3 Metals Leachability in Sediments*

The results from the FLT are shown in Table 2.8. Half of the FLT samples had Cd concentrations below PQL of 0.6 μg/L, and Pb concentrations for the FLT did not exceed 1 mg/L. These data support that the FLT can be a good initial method to identify potentially contaminated locations.

Table 2.8: USGS field leaching test results from UT sediments collected at the inflow and outflow of impounded water due to beaver dams

| Site | Depth | Cd | Pb | Zn |
|---|---|---|---|---|
| | (Inches) | (mg/L) | (mg/L) | (mg/L) |
| D1 In | 0-24 | 0.003 | 0.108 | 2.16 |
| D1 Out | 0-20 | 0.038 | 0.032 | 166.62 |
| D4 In | 8-10 | 0.002 | 0.045 | 0.90 |
| D4 In | 0-8 | 0.023 | 0.235 | 7.59 |
| D4 Out | 10-14 | 0.054 | 0.043 | 11.07 |
| D4 Out | 0-10 | <PQL* | 0.025 | 0.27 |
| D5 In | 0-18 | <PQL* | 0.040 | 1.45 |
| D5 Out | 8-20 | <PQL* | 0.033 | 0.19 |
| D5 Out | 0-8 | 0.022 | 0.170 | 12.08 |
| D6 In | 0-6 | 0.013 | 0.750 | 2.52 |
| D6 Out | 3-12 | <PQL* | 0.026 | 1.58 |
| D6 Out | 0-3 | <PQL* | 0.023 | 3.99 |
| LWC In | 0-12 | <PQL* | 0.019 | 2.51 |
| LWC Out | 0-18 | <PQL* | 0.018 | 0.07 |

* Practical quantitation limit (PQL)

TCLPs were performed on the samples which showed the greatest concentrations from the FLT and total metals concentrations from Table 2.7. No samples exceeded the RCRA standard for Pb (5 mg/L). The greatest Pb TCLP concentration was 2.8 mg/L. A single site, D4 In, exceeded the RCRA standard of 1 mg Cd /L with a concentration of 1.08 mg Cd /L (Table 2.9). The next greatest TCLP Cd concentration was 0.465 mg/L, which is less than half the RCRA standard. The TCLP results are shown in Figure 2.10.

Table 2.9: USEPA toxicity characteristic leaching procedure results on selected sites based on USGS field leaching test and metals concentrations from UT sediments collected at the inflow and outflow of impounded water due to beaver dams

| Site | Depth | As | Cd | Pb | Zn |
|---|---|---|---|---|---|
| | (Inches) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| RCRA Standards | | 5.0 | 1.0 | 5.0 | - |
| D4 In | 0-8 | 0.026 | 1.083 | 1.800 | 106.0 |
| D4 Out | 10-14 | 0.022 | 0.273 | 0.768 | 88.64 |
| D4 Out | 0-10 | 0.019 | 0.033 | 0.100 | 49.47 |
| D5 Out | 0-8 | | 0.008 | 0.119 | |
| D6 In | 0-6 | 0.019 | 0.465 | 2.806 | 75.23 |
| D6 Out | 3-12 | 0.017 | 0.258 | 1.641 | 41.30 |
| D6 Out | 0-3 | 0.018 | 0.094 | 0.220 | 82.86 |

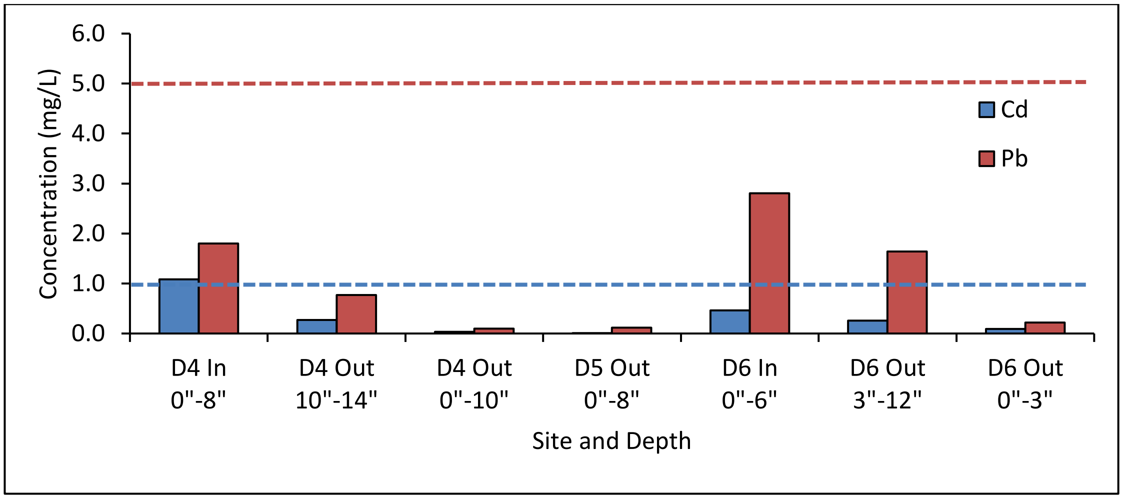

Figure 2.10: USEPA toxicity characteristic leaching procedure results for selected samples from UT stream sediments collected at the inflow and outflow of impounded water due to beaver dams, based on USGS field leaching test and sediment metals concentrations, compared to RCRA standards for Pb (5.0 mg/L) and Cd (1.0 mg/L)

The samples chosen for TCLP analysis where then compared to the results of the FLT, (Table 2.10). The TCLP metals concentrations were on average 28 times greater than the FLT metals concentrations. Figure 2.11 represents the differences in concentrations.

Table 2.10: Comparison of USEPA toxicity characteristic leaching procedure and USGS field leaching test results from UT stream sediments collected at the inflow and outflow of impounded water due to beaver dams

| | | TCLP | | | | FLT | | |
|---|---|---|---|---|---|---|---|---|
| Site | Depth | As | Cd | Pb | Zn | Cd | Pb | Zn |
| | (Inches) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| RCRA Standards | | 5.0 | 1.0 | 5.0 | - | | | |
| D4 In | 0-8 | 0.026 | 1.083 | 1.800 | 106.0 | 0.023 | 0.235 | 7.585 |
| D4 Out | 10-14 | 0.022 | 0.273 | 0.768 | 88.64 | 0.054 | 0.043 | 11.065 |
| D4 Out | 0-10 | 0.019 | 0.033 | 0.100 | 49.47 | <PQL* | 0.025 | 0.275 |
| D5 Out | 0-8 | <PQL* | 0.008 | 0.119 | <PQL* | 0.022 | 0.170 | 12.08 |
| D6 In | 0-6 | 0.019 | 0.465 | 2.806 | 75.23 | 0.013 | 0.750 | 2.522 |
| D6 Out | 3-12 | 0.017 | 0.258 | 1.641 | 41.30 | <PQL* | 0.026 | 1.576 |
| D6 Out | 0-3 | 0.018 | 0.094 | 0.220 | 82.86 | <PQL* | 0.023 | 3.991 |

* Practical quantitation limit (PQL)

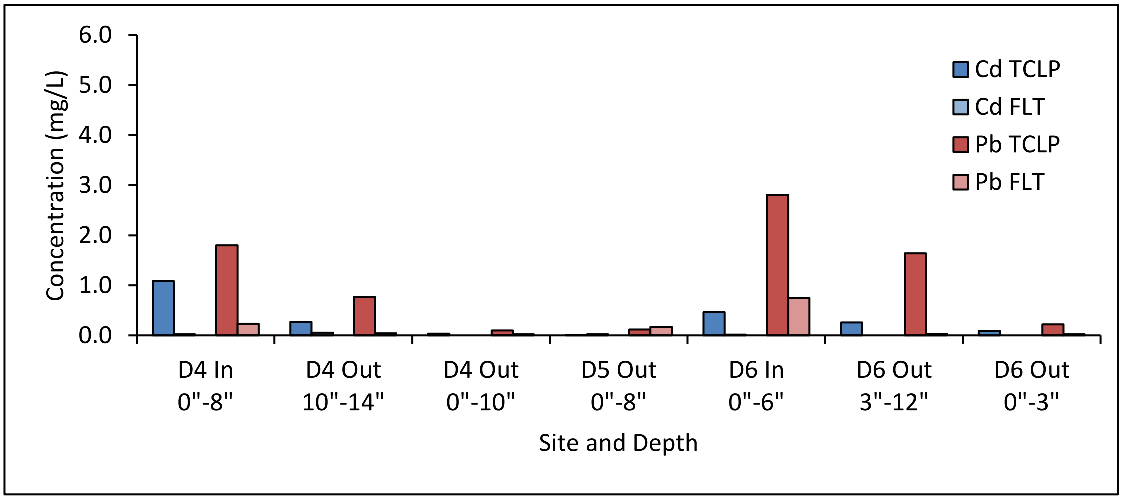

Figure 2.11: Comparison of USEPA toxicity characteristic leaching procedure and USGS field leaching test samples, from UT stream sediments, collected at the inflow and outflow of impounded water due to beaver dams

## 2.4 Conclusions

The results show that the presence of beaver dams decreases metals concentrations in an AMD impacted stream, with a significant decrease in Cd, Fe, Pb, and Zn at the upper reaches of the impacted stream where metals concentrations were greatest. The impounded water behind a beaver dam functions like an oxidation pond. The increased water surface area and hydraulic retention time create the correct conditions for oxidation and precipitation of Fe. However, the beaver impounded water has little impact on Pb, because Pb is typically removed via bacterial sulfate reduction in PTS.

The sediment metals concentration did not have a decreasing trend from upstream to downstream as hypothesized. Rather, the sediments at the beaver dams had significantly greater metals concentration than the inflow locations. In addition, the top layer of sediment had greater metals concentrations than the lower layer at the beaver dam outflows, with significantly higher concentrations of Cd and Fe.

The hypothesis that the TCLP results would exceed the FLT metals concentrations was supported. The TCLP results averaged a metals concentration 28 times higher than the FLT. The second hypothesis that all sediment samples would remain below RCRA standards was rejected. A single sample exceeded the RCRA standard of 1.0 mg/L with a concentration of 1.08 mg/L. All other samples were well below the RCRA standards for Cd and Pb.

The results from this study suggests that beaver should be viewed as a valuable species in an AMD impacted stream rather than as a nuisance. Beaver are ecosystem engineers and the construction of their dams and subsequent creation of wetlands is a monetarily free contribution to the partial treatment of net alkaline mine drainage.

Although the AMD in UT is net alkaline, these results prompt future work in net acidic mine drainage. In acidic waters, elevated metals concentrations are much more bioavailable, due to the lack of hardness and increased solubility of certain metals species. Future work could quantify the effectiveness of beaver dams with respect to other metals and net acidic mine drainage and might include an evaluation of ecotoxicity. Beaver may have the potential to decrease the costs associated with mine water treatment, and their presence should have an ecosystem services value associated with the treatment they provide.

# Chapter III: Potential for Metal Remobilization Due to Removal of Beaver Dams in a Mine Drainage Impacted Stream

## 3.1 Introduction

Acid or alkaline mine drainage (AMD) negatively impacts thousands of miles of waterways around the world, harming the aquatic and nearby terrestrial environments (Hengen et al., 2014). In chapter 2, it was shown beaver may be assisting in the treatment of AMD through the impoundment of water behind beaver dams. Another objective of this study was to investigate the potential for remobilization of the metals captured behind the beaver dams in the event the dams are destroyed.

*Castor canadensis*, the North American Beaver, are ecosystem engineers (Naiman et al., 1986; Snodgrass and Meffe, 1998; Butler and Malanson, 2005; Andersen and Shafroth, 2010; Hardisky, 2011; Law et al., 2016, and Puttock et al., 2017). Beaver dams have the ability to 1) alter stream channel geomorphology, 2) establish and maintain wetland environments 3) increase retention of sediments, 4) and influence the downstream transportation of water and other materials (Hillman, 1998). Beaver create dams to increase the surface area and depth of water in streams. The increased surface area allows beaver to access food and building supplies from the safety of the water, as the majority of predation occurs when beaver are on land (Hardisky, 2011).

However, beaver dams are not permanent structures. Beaver dam failure can be caused by a variety of factors such as storm events, unmaintained and weakened dams, and active dam removal by humans. Beaver dams may be abandoned due to a reduction in food supply, or if the beaver have been removed by humans (Rosell et. al., 2005). When dams are abandoned, the slow erosion caused by streamflow will begin to dislodge the building materials, making the dams more likely to fail.

A study conducted by Andersen and Shafroth (2010) investigated the impacts of pulse floods on beaver dam structural integrity. The study was conducted at a location where beaver had constructed dams immediately downstream of a man-made dam on a perennial stream with a base flow of 2.6 $m^3$/sec. The man-made dam allowed the research team to release known pulse volumes of water towards the beaver dams to test their resilience based on dam activity, construction material, and dam height. It was found that herbaceous dams, consisting primarily of *Typha* spp. (cattails), failed even under the smallest releases of water, 37 $m^3$/sec peak discharge. The dams constructed with larger woody debris showed minimal damage during the largest pulses, 65 $m^3$/sec peak discharge. Due to the minimal amount of damage, active dams constructed of large woody debris were immediately repaired following the damage (Andersen and Shafroth, 2010).

Regardless of the reasons dams fail, the rapid release of the stored water may have a drastic impact on both the aquatic community and humans. Stock and Schlosser (1991) found that beaver dam failure caused a 90% decrease in benthic macroinvertebrate density immediately after failure. Sixty days later, the benthic macroinvertebrate population experienced a 62% reestablishment. With respect to humans, Butler and Malanson (2005) cited seven articles from 1984 to 1999 stating that beaver dam failures resulted in thirteen deaths with numerous injuries. The most notable of the articles is from 1984 where failed dams produced a pulse of water damaging a railroad embankment, causing an Amtrak passenger car to derail, resulting in five deaths (Butler and Malanson, 2005). Hillman (1998) reported a beaver dam failure on a second order stream resulted in peak flows 3.5 times the maximum discharge recorded in a 23-year period for the stream.

Hydrologic impacts are only a portion of the consequences of dam failure. A literature gap exists in the investigation of water quality impacts due to the failure of beaver dams, in particular with respect to the potential for metal remobilization. This portion of the study investigated the potential for metal remobilization due to beaver dam destruction on a mine drainage impacted stream, where metal concentrations are expected to initially increase with the increase in stream velocity after dam removal, but return to the original base concentration as velocities decrease.

## 3.2 Methods and Materials

### *3.2.1 Site Description*

Unnamed Tributary (UT) is a stream located in Commerce, OK that is impacted by AMD from abandoned lead and zinc mining operations. UT has primarily two continuous groundwater inputs before it enters Tar Creek. UT and the contributing sources of water are regularly monitored for water quality by The Center for Restoration of Ecosystems and Watersheds (CREW). All historical data was provided by CREW. The studied stream reach is approximately one mile long, with the start of the one-mile reach being the first groundwater discharge flowing at approximately 100 gpm. The first discharge, known as UT-Pipe (UT-P) located at the Southeast Commerce site (SEC), remained untreated through the entirety of this study with metals concentrations of 60 samples averaging 133 mg Fe /L, 9.71 mg/L Zn, 0.063 mg/L Pb, 0.031 mg/L Cd, and 0.037 mg/L As. The second discharge is located approximately 0.3 miles downstream flowing at approximately 160 gpm and has been captured and treated by the Mayer Ranch passive treatment system (MRPTS). Since 2008, the average metals concentrations of 51 samples at the MRPTS effluent are: 0.65 mg Fe /L, 0.46 mg Zn /L, with As, Cd, and Pb below detectable limits. Mine drainage passive treatment is the utilization of ecologically engineered ecosystems to promote physical, biogeochemical, and microbiological processes to remove metals and generate alkalinity (Nairn et al., 2009; Zipper et al., 2011). The MRPTS effluent dilutes contaminant concentrations in the stream for the remaining 0.7 miles. In 2013, the presence of beaver were first noted, with the majority of the stream being impacted by beaver dams by the end of 2014. Figure 3.1 shows historic sampling locations, locations of the groundwater discharges, and location of beaver dams that were destroyed in this study.

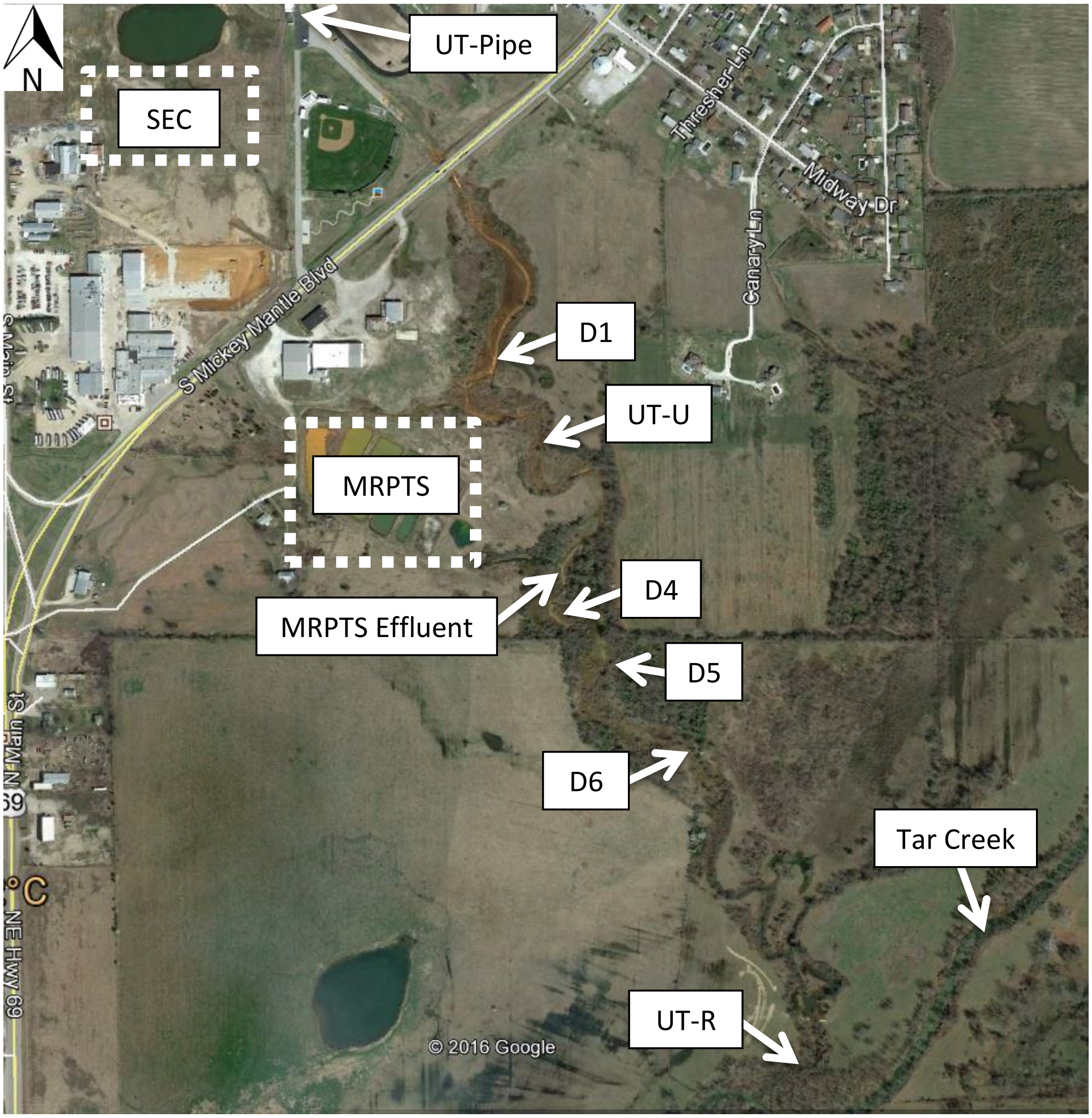

Figure 3.1: Aerial image of UT, located in Commerce, OK, with sampling locations labeled and sources of mine drainage boxed (Google Earth, 2017)

### *3.2.2 Flush Events Sampling and Analysis*

The induced flushing events are the result of the beaver dams being manually destroyed during base flow conditions, causing a pulse of water to move downstream. The manual destruction of dams began at the most downstream dam and worked upstream. Every dam was destroyed to a base elevation consistent with the upstream bed elevation that was determined to be unaffected by the dam. During the destruction events, it was noted that many additional dams were submerged until downstream dams were destroyed. These submerged dams were destroyed, but not sampled because each flush sampling event took at least one hour, and the entire stream needed to be sampled the same day due to the potential for beaver construction activity over night. In total, eleven dams were destroyed, with four of the eleven being sampled. Water quality of the released pulses was characterized using a multiparameter datasonde (YSI 600QS with YSI 650MDS) and grab samples collected at each broken dam. An additional data-recording multiparameter datasonde (YSI 6920 V2) was placed at the UTR site, taking measurements every five minutes to characterize the downstream water quality before it reached Tar Creek.

At each broken dam, water quality of each pulse was determined every five minutes using a multiparameter datasonde, for one hour. Three grab samples for total and dissolved metals were collected at each sampled dam. The initial metals samples were collected at a time of 5 minutes, rather than at time zero, to allow time for complete dam removal. Grab samples were initially collected when the water flowing through the dam was clear and not noticeably influenced by mobilized sediments. Additional grab samples were collected at 35 minutes and 65 minutes after the dam was destroyed.

A single dam (D1) was selected for installation of a flow measuring device (Sontek Argonaut Acoustic Doppler Velocimeter), recording multiparameter water quality datasonde (YSI 6920 V2), and autosampler (Sigma 900 Max Portable Sampler).

All units were deployed at the location before the dam was broken. The flow-measuring device averaged five minutes of continuous flow measurements for every 30-minute interval, and the autosampler collected a grab sample every thirty minutes for twelve hours. The collected water samples were analyzed for total metals, and the resulting concentrations were plotted to examine relationships of water velocity and remobilization of metals during the destruction event. Another portion of this study involved habitat assessments conducted with and without beaver dams, where stream cross-sections were measured every 30 meters for the entire length of the study reach. The habitat assessment data were used to determine approximate water volumes held behind each beaver dam. The volumes and mean total metals concentrations were used to determine the estimated mass of metals mobilized at each of the destroyed dams.

## 3.3 Results

### *3.3.1 Sequential Dam Removals*

The sequential dam removal event took place in August 2016, beginning at the most downstream location. Eleven dams were removed. At four of the eleven dams, water quality data were collected immediately following dam destruction. Total and dissolved metals concentrations are shown in Table 3.1. Fe concentrations increased following dam removal (Figure 3.2). Zn concentrations did not follow the same trend. At D1, Zn concentrations decreased with respect to time after dam removal, while at D5 and D6, Zn concentrations remained unchanged over the one-hour sampling time (Figure 3.3). Pb showed a slight increase in concentration with respect to time at D1, but remained unchanged at the three remaining dams during the sequential destruction event (Figure 3.4).

D1 had much greater metals concentrations than the remaining dams due to its location upstream of the MRPTS effluent that diluted the untreated mine drainage from SEC. The greater metals concentrations likely resulted in more accumulation which provided greater potential for metal remobilization. At D1, Fe precipitates were visible on the bottom of the stream. However, particulate Fe did not appear to contribute to the majority of the metals remobilized because dissolved Fe concentrations accounted for over two thirds of the total iron at each time interval. D4 was the only dam to show a decreasing trend in specific conductivity with time while the remaining dams did not show any notable changes (Figure 3.5). DO demonstrated an increasing trend at D4 and D5 with respect to time until plateauing near 110%. DO at D1 and D6 did not show notable changes, remaining near 70%. DO values at D4 and D5 responded as expected because the destruction of the dams caused turbulent flow through the destroyed section and aerated the water (Figure 3.6).

The sequential dam removal event attempted to collect data on as many beaver dams as possible in a single day to limit potential alteration of the results due to environmental factors that may have changed if the sampling was extended over numerous days. However, collecting only three grab samples per dam over a one-hour period did not allow for development of long term trends. The sequential dam removal events partially confirmed the hypotheses that metals are remobilized upon dam destruction, as shown by the increasing concentrations of Fe and Cd. Pb and Zn did not support the hypothesis with the majority of results remaining unchanged over the one-hour sampling period at each dam. Pb likely did not show a change in concentration over time because, as shown in the previous chapter, Pb concentrations do not decrease when the dams are intact, so there is likely minimal Pb accumulation available for remobilization.

Table 3.1: Total and dissolved metals concentrations for sequential beaver dam removal event along UT, located in Commerce, OK, at four separate beaver dam locations

| Dam # | Time | Tot. Cd | Diss. Cd | Tot. Fe | Diss. Fe | Tot. Pb | Diss. Pb | Tot. Zn | Diss. Zn |
|---|---|---|---|---|---|---|---|---|---|
| | (Min) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) | (mg/L) |
| D1 | 5 | 0.0039 | 0.0033 | 22.7 | 14.7 | 0.037 | 0.034 | 4.55 | 4.35 |
| | 35 | 0.0071 | 0.0052 | 43.0 | 32.5 | 0.039 | 0.038 | 3.83 | 3.32 |
| | 65 | 0.0099 | 0.0080 | 60.4 | 50.3 | 0.049 | 0.043 | 3.23 | 2.77 |
| D4 | 5 | <PQL* | <PQL* | 1.04 | 0.51 | 0.029 | 0.025 | 0.211 | 0.093 |
| | 35 | <PQL* | <PQL* | 1.75 | 0.58 | 0.032 | 0.032 | 0.356 | 0.332 |
| | 65 | <PQL* | <PQL* | 2.41 | 1.50 | 0.035 | 0.026 | 0.519 | 0.529 |
| D5 | 5 | <PQL* | <PQL* | 0.763 | 0.380 | 0.031 | 0.026 | 0.102 | 0.113 |
| | 35 | 0.0006 | <PQL* | 0.785 | 0.193 | 0.025 | 0.031 | 0.074 | 0.076 |
| | 65 | <PQL* | <PQL* | 1.91 | 0.265 | 0.028 | 0.035 | 0.092 | 0.069 |
| D6 | 5 | <PQL* | <PQL* | 0.750 | 0.131 | 0.032 | 0.027 | 0.106 | 0.075 |
| | 35 | <PQL* | <PQL* | 0.599 | 0.103 | 0.030 | 0.031 | 0.090 | 0.102 |
| | 65 | <PQL* | <PQL* | 1.00 | 0.667 | 0.028 | 0.025 | 0.079 | 0.085 |

* Practical quantitation limit (PQL)

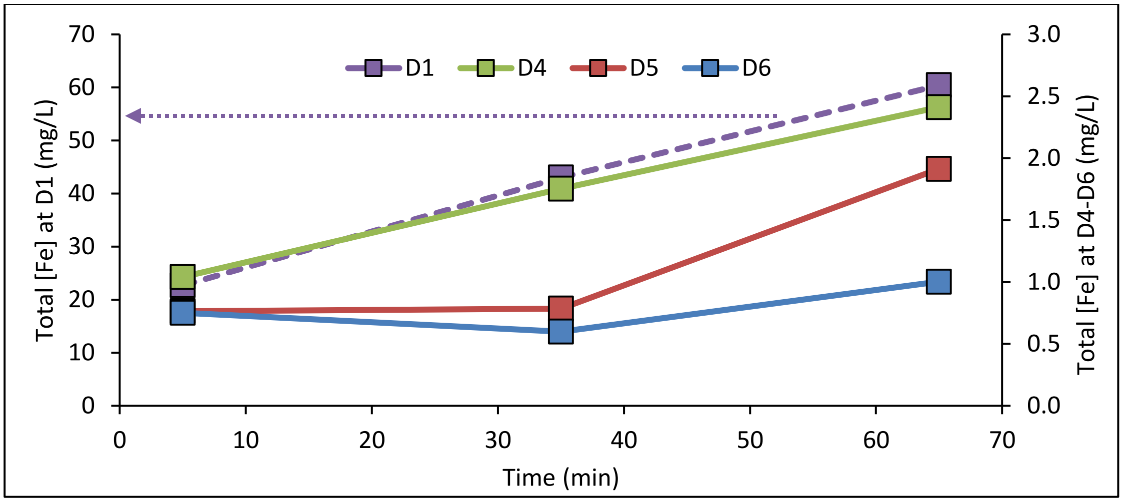

Figure 3.2: Total aqueous Fe concentrations for sequential beaver dam removal event along UT at four separate beaver dam locations with the purple dotted arrow indicating D1 corresponds to the left axis and D4-D6 correspond to the right axis

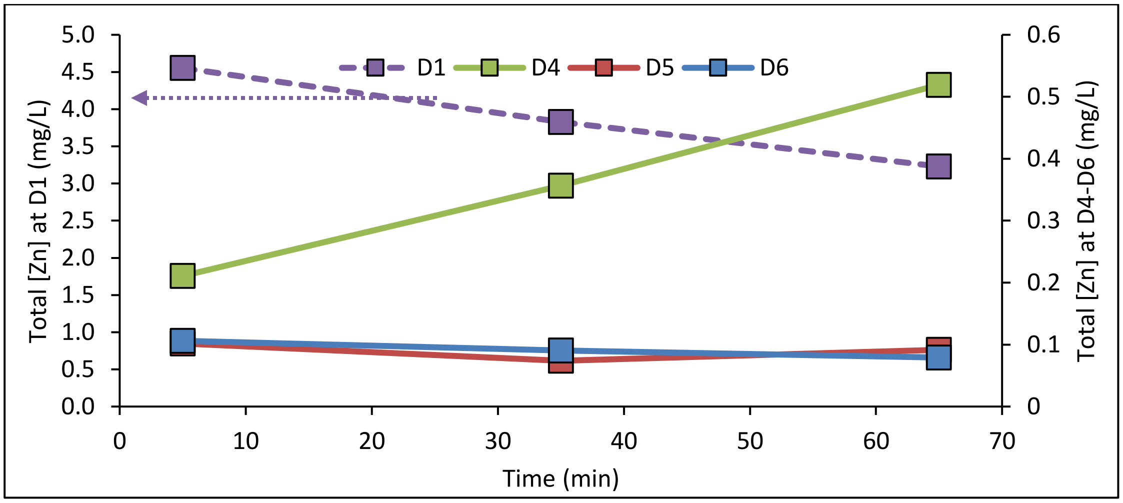

Figure 3.3: Total aqueous Zn concentrations for sequential beaver dam removal event along UT at four separate beaver dam locations with the purple dotted arrow indicating D1 corresponds to the left axis and D4-D6 correspond to the right axis

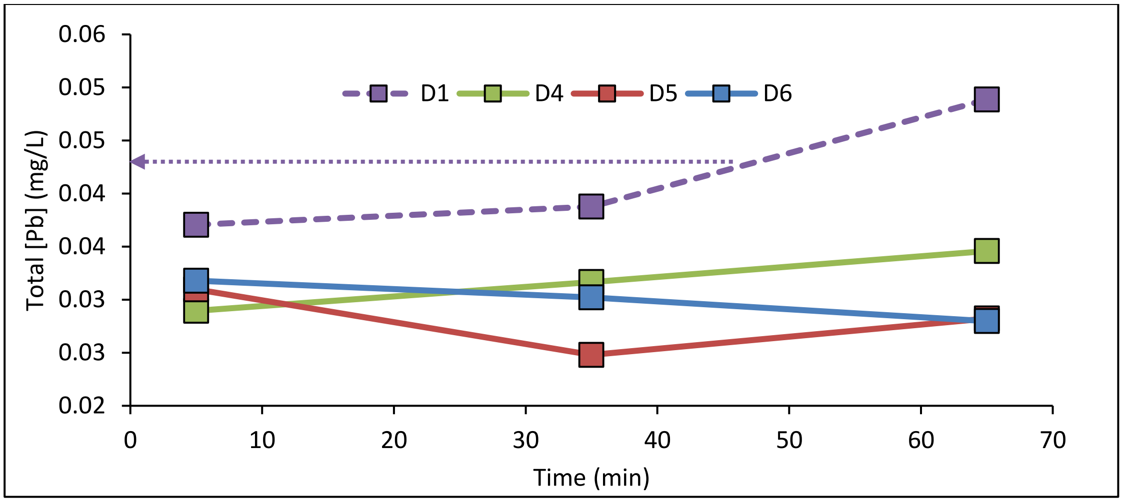

Figure 3.4: Total aqueous Pb concentrations for sequential beaver dam removal event along UT at four separate beaver dam locations with the purple dotted arrow indicating D1 corresponds to the left axis and D4-D6 correspond to the right axis

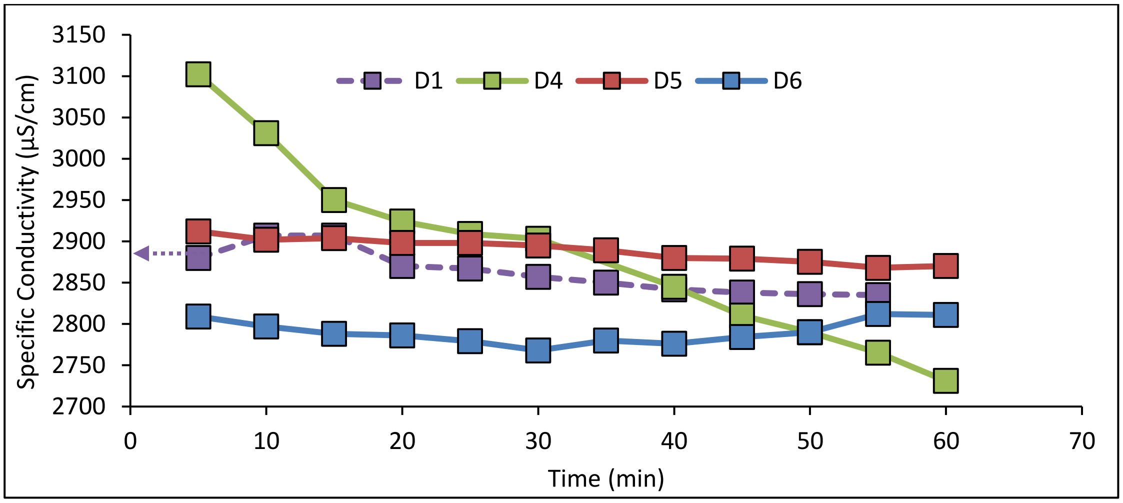

Figure 3.5: Specific conductivity for sequential dam removal event along UT at four separate beaver dam locations with the purple dotted arrow indicating D1 corresponds to the left axis and D4-D6 correspond to the right axis

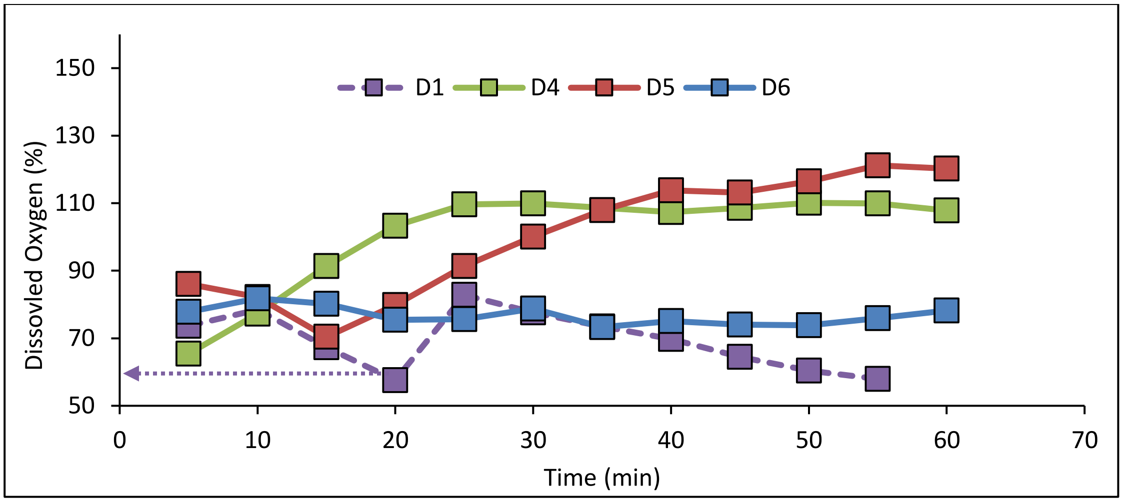

Figure 3.6: Dissolved oxygen for sequential beaver dam removal event along UT at four separate beaver dam locations with the purple dotted arrow indicating D1 corresponds to the left axis and D4-D6 correspond to the right axis

Total metals concentrations (Table 3.2) where used to estimate the mass of metals mobilized. The estimated volume of water behind each beaver dam was calculated from the rapid habitat assessment and multiplied by the mean metals concentrations at each dam. The averaged values are likely an underestimate because the metals concentrations after one hour show increasing trends with no indication of a plateau. The habitat assessments include three depth measurements and water width measurements that were used to calculate and approximate area, then multiplied by the transect length of 30 meters. The calculation was repeated for each transect within the impounded water of each dam. The difference between the habitat assessment with and without beaver dams for each transect was determined to be the storage volume. The resulting mobilized metals masses are shown in Table 3.2 and Figure 3.7. The metals mass data reinforces the supposition that the majority of the mobilized metals occur upstream of MRPTS effluent, where D1 contributed 55.2 kg of the 56.4 kg total mobilized Fe mass. However, since the dams were destroyed beginning downstream, the study does not address how far downstream the metals remained mobilized. The distance the metals remain mobilized will be dependent on many factors, including if the dams were anthropogenically destroyed, as they were in this study, or if they were washed out by a rain event.

The data reported are the results of anthropogenic dam removal. The concentrations experienced during a large rain event may be much lesser due to the increased volume of contributing runoff, but increased velocities may have the potential to mobilize larger masses of metals and keep them suspended for longer time periods. Rain events were not sampled in this study due to the lack of control, the inability to guarantee dam removal and safety concerns in sampling during such an event large enough to cause likely dam destruction. Any sampling during rain events can be difficult because the work relies on being present during the event, the potential of losing expensive equipment due to high flows, and the danger of manually collecting valid samples during high flows. The flows produced from the rain event would have to be great enough to destroy the beaver dams and therefore likely great enough to destroy any instrumentation that would be used to collect data.

Table 3.2: Volume and Mass of metals mobilized at four beaver dam locations during sequential beaver dam removal event along UT, located in Commerce, OK

| Dam # | Volume | Cd | Fe | Pb | Zn |
|---|---|---|---|---|---|
| | (m$^3$) | (g) | (g) | (g) | (g) |
| D1 | 1315 | 9.161 | 55,276 | 54.66 | 4,577 |
| D4 | 296 | | 513.0 | 9.380 | 93.98 |
| D5 | 503 | | 580.4 | 14.08 | 44.81 |
| D6 | 96 | | 75.53 | 2.890 | 8.852 |
| Summed Mass | | 9.161 | 56,445 | 81.0 | 4,725 |

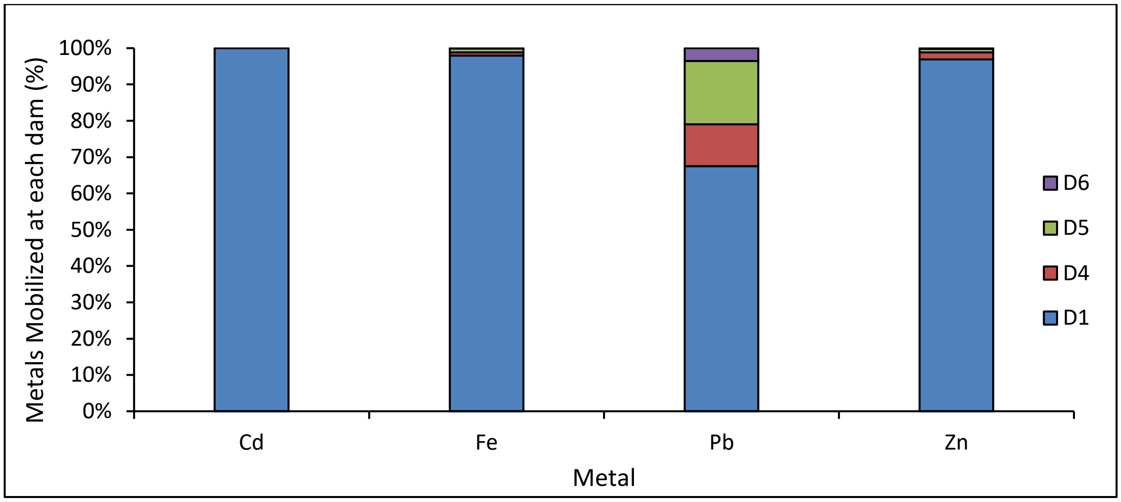

Figure 3.7: Normalized distribution of metals mobilized at four separate beaver dams during sequential beaver dam removal event along UT, located in Commerce, OK

### *3.3.2 Single Dam Removal with Extended Monitoring*

After completing the sequential dam removal in August 2016, D1 was selected for a single dam removal event in January 2017. D1 had the greatest metals concentrations and therefore was the most likely to show noticeably substantial trends. The idea behind destroying a single dam was to collect more data over a twelve-hour period to determine if decreasing velocities would result in decreased remobilization by a decrease in metals concentrations. A Sigma Max 900 autosampler was deployed to collect a sample every 30 minutes for twelve hours. However, after six hours of sampling, the water levels were below the intake line of the autosampler that was set three inches off the bottom of the stream. The YSI 6920 V2 multiparameter datasonde began to show signs of sensors being out of the water column at two and a half hours. The sensors were determined to be out of the water when the DO jumped from 33.3% to 95% and remained between 95% and 99% until the datasonde was collected twelve hours later when it was found to be fully out of the water.

Table 3.3 shows the water quality parameters of interest for the single dam removal. Pb and Zn concentrations did not change over the six-hour period (Figure 3.8). The velocity of the pulse did not correlate to the metals concentrations. Fe and Cd concentrations increased through the first two-hours, with flatter slopes shown between the second and fifth hours (Figure 3.9). Velocity decreased until it was below the detection limits of the flow sensor, Sontek Argonaut, after two hours when the velocities were reported as negative values (Figure 3.10). It is hypothesized that increased velocities experienced upstream due to the pulse caused by dam removal re-suspended accumulated metals and the six-hour sampling period was insufficient for metals to settle. The settling rate of iron sludges has been reported between 0.2 cm/min and 1.9 cm/min (Dempsey and Jeon, 2001; Dietz and Dempsey, 2002). Deitz and Dempsey (2002) reported an iron sludge settling rate of 1.8 cm/min in passive treatment systems. These studies indicated that any disturbance caused by falling water levels and increased velocities would have the potential to suspend Fe precipitates for hours after dam removal.

Despite the potential for resuspension, iron oxidation rates in streams have been shown to be higher than in ponds (Dempsey et al., 2001). A study found the mass transfer coefficient for $O_2$ was 2 cm/hr for an oxidation pond and 4 to 40 cm/hr for a stream, resulting in Fe removal rates of 18 g $m^{-2}$ $d^{-1}$ and 42 g $m^{-2}$ $d^{-1}$, respectively (Dempsey et al., 2001). It was reported the rate of Fe removal increased with increasing water velocity. The study site had velocities > 6 meters/min in the stream and 0.006 m/min in the pond (Dempsey et al., 2001). By comparison, data from a tracer study conducted on UT in the presence of beaver dams showed an estimated stream velocity of 0.18 m/min. The stream velocity on UT is not high enough to facilitate higher Fe oxidation rates shown by Dempsey et al. (2001) but are at least one order of magnitude greater than the pond velocities.

Within minutes to hours of a beaver dam being removed, either anthropogenically or via flooding, it is likely that the oxidation mass transfer rate and subsequent Fe removal rate will increase with increased stream velocities. However, with the presence of beaver dams in UT, the system more closely resembles that of a pond or wetland with lower velocities and large surface areas.

Dissolved oxygen and turbidity showed decreasing trends vs. time (Figure 3.11). The results were unexpected because the turbulence created as water velocities increase was expected to increase DO and suspend solids, causing turbidity to increase. Since an autosampler was used to collect the samples for metals analyses, dissolved metals data were not able to be collected. It is possible the majority of the Fe in the samples was in the dissolved form as it was in the sequential dam removal experiment, therefore not notably contributing to the turbidity.

Table 3.3: Water quality results for single beaver dam removal event along UT located in Commerce, OK with extended six-hour sampling with samples collected every 30 minutes, but datasonde sensors, turbidity and DO, were above the water level after 2.5 hours

| Time (min) | Cd (mg/L) | Fe (mg/L) | Pb (mg/L) | Zn (mg/L) | Turbidity (NTU) | DO (%) |
|---|---|---|---|---|---|---|
| 30 | 0.0050 | 25.4 | 0.060 | 3.78 | 189.5 | 84.8 |
| 60 | 0.0023 | 19.6 | 0.039 | 3.32 | 29.2 | 76.6 |
| 90 | 0.0025 | 22.0 | 0.036 | 2.75 | 24.0 | 55.9 |
| 120 | 0.0038 | 34.5 | 0.042 | 2.61 | 28.9 | 41.0 |
| 150 | 0.0058 | 46.0 | 0.045 | 2.71 | 34.7 | 33.3 |
| 180 | 0.0058 | 49.0 | 0.041 | 2.74 | - | - |
| 210 | 0.0060 | 51.6 | 0.047 | 2.69 | - | - |
| 240 | 0.0065 | 54.0 | 0.053 | 2.68 | - | - |
| 270 | 0.0074 | 57.9 | 0.054 | 2.64 | - | - |
| 300 | 0.0074 | 57.8 | 0.055 | 2.64 | - | - |
| 330 | 0.0055 | 45.4 | 0.049 | 2.59 | - | - |
| 360 | 0.0073 | 56.3 | 0.049 | 2.78 | - | - |

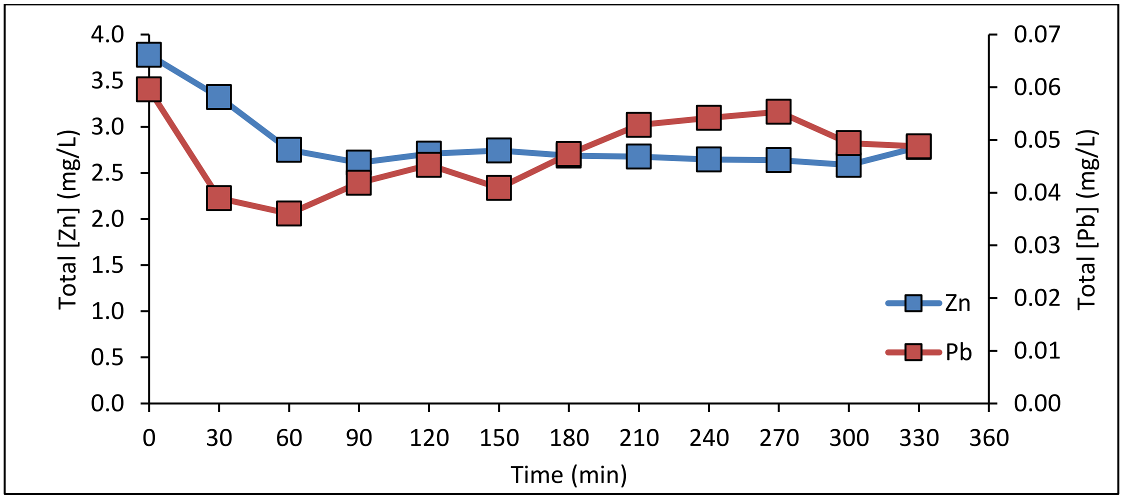

Figure 3.8: Total aqueous Zn and Pb concentrations for single beaver dam removal event along UT with extended six-hour sampling

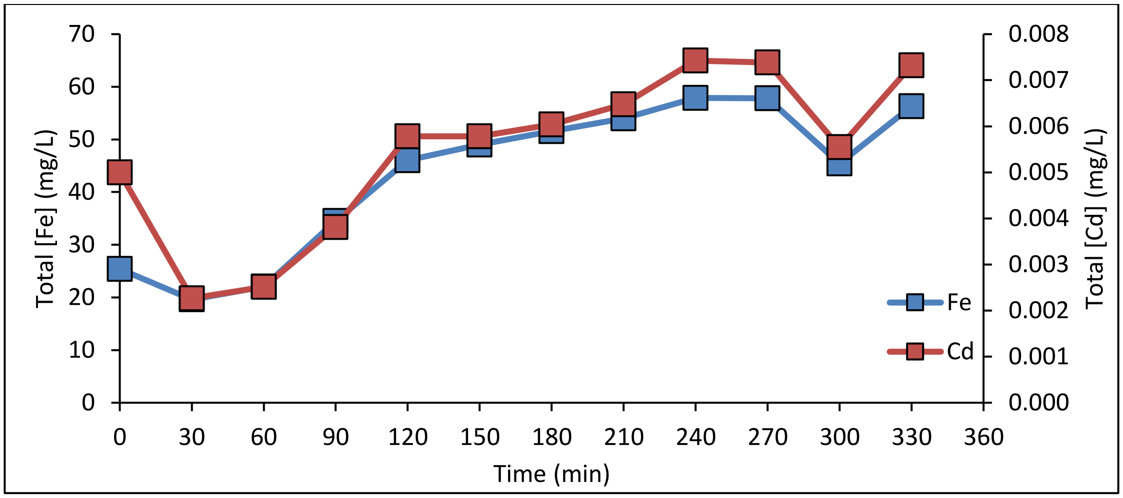

Figure 3.9: Total aqueous Fe and Cd concentrations for single beaver dam removal event along UT with extended six-hour sampling

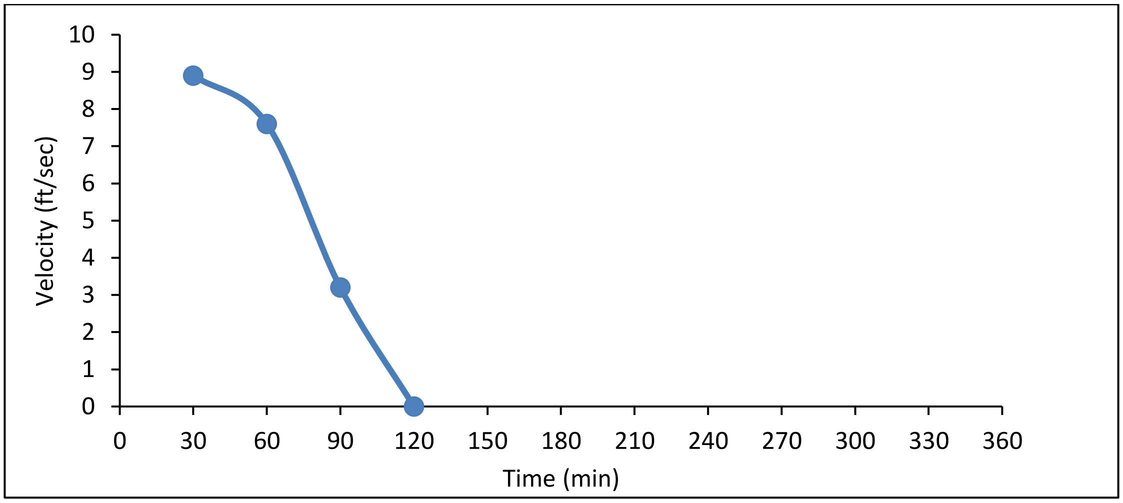

Figure 3.10: Velocity of water during the single beaver dam removal event along UT with extended six-hour sampling, where the velocity was below the instrument sensitivity after two hours

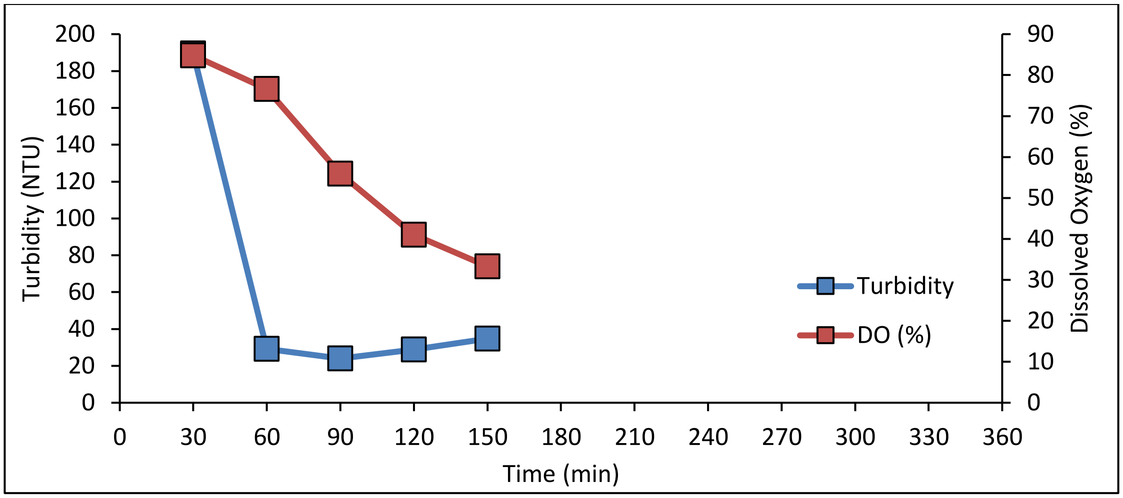

Figure 3.11: Turbidity and dissolved oxygen for single dam removal event along UT with extended six-hour sampling, where the sensors were out of the water after 2.5 hours

## 3.4 Conclusions

Beaver dam failure is well documented in the literature (Stock and Schlosser, 1991; Hillman, 1998; Butler and Malanson, 2005; Rosell et. al., 2005; Andersen and Shafroth, 2010). It is not a matter of if a beaver dam will fail, it is a matter of when and how. This e study investigated beaver dam failure in a mine drainage impacted stream and the potential for metals remobilization. The sequential dam removal experiment partially supported the hypothesis that metals were remobilized following beaver dam removal. Fe and Cd concentrations showed an increasing trend, but Zn and Pb concentrations did not show a noticeable change. The second hypothesis, which stated metals concentrations would track the trends of velocity, was rejected because the recorded velocities during the single dam removal experiment continually decreased and Fe and Cd concentrations showed an increasing trend. The increasing Fe and Cd concentrations were believed to be due to the initial remobilization of metals upstream that did not have adequate time to settle even after the stream velocities decreased below the detectable limits of the sensor.

From the previous chapter, Pb concentrations did not show clear trends with the presence of beaver dams. The lack of change in Pb concentrations during the dam removal experiments suggest that if Pb concentrations were not decreasing in and out of the beaver dams, then there is minimal Pb present that can be remobilized in the event of dam failure.

The results reflect anthropogenic beaver dam destruction, which likely represents mobilization of the minimal mass of metal. A rain event capable of destroying a beaver dam will come with higher stream velocities, creating more turbulent flow and occurring for longer duration than any anthropogenic activity. The force of the water will likely mobilize more material, including metals, and keep the material suspended for a greater distance downstream.

# Chapter IV: Comparison of Streams Geomorphic Classification in the Presence and Absence of Beaver Dams Utilizing Rosgen Stream Classification, USEPA Rapid Habitat Assessment Protocol, and Conservative Tracer Studies

## 4.1 Introduction

This study investigated the use of two common methods of stream physical classification, in the presence and absence of beaver dams. Both methods serve important, but distinct roles. The first is the Rosgen stream classification. It is a widely used method of classifying waterways based on their physical states. Rosgen stream classification uses a four-level approach: 1) geomorphic characterization, 2) morphological description, 3) stream “state” or condition, and 4) field validation (Rosgen, 1996). Rosgen stream classification is designed for lotic systems and is not intended for classifying portions of streams that are lentic, as is the case in the presence of beaver dams. The second method is the habitat assessment portion of the United States Environmental Protection Agency (USEPA) Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers (USEPA, 1999). The USEPA rapid habitat assessment protocol scores the physical habitat of a stream from the perspective of aquatic life. The habitat assessment incorporates a more detailed analysis of the available habitats and their variety than the Rosgen stream classification.

*Castor canadensis*, the North American beaver, are known as ecosystem engineers. An ecosystem engineer is an organism with the potential to drastically alter their surroundings. With beaver, the alterations are due to the construction of beaver dams (Naiman et al., 1986; Snodgrass and Meffe, 1998; Butler and Malanson, 2005; Andersen and Shafroth, 2010; Hardisky, 2011; and Puttock et al., 2017). The dams are constructed for the safety of the beaver. The majority of predation occurs when beaver are on land (Hardisky, 2011). Therefore, the increased water surface area provided behind the beaver dams allows the beaver to access their food supply without leaving the safety of the water. Secondly, the increased depth of the water ensures the entrances to their dens are submerged (Hardisky, 2011).

The literature supporting beaver activity as a benefit to both aquatic and terrestrial life is substantial, but there are few studies that attempt to classify streams with beaver activity (Burksted and Daniels, 2014). Beaver dams create changing and challenging conditions. A beaver colonized stream can have characteristics of both flowing streams and wetlands, which limits the use of classification systems designed for either lentic or lotic environments. Juracek and Fitzpatrick (2003) investigated limitations of the Rosgen stream classification system and found many of the limitations are characteristics associated with wetland environments. Juracek and Fitzpatrick (2003) stated that a Rosgen Level II classification, morphological description, can be limited by:

> *"(1) time dependence, (2) uncertain applicability across physical environments, (3) difficulty in identification of a true equilibrium*

> *condition, (4) potential for incorrect determination of bankfull elevation, and (5) uncertain process significance of a classification criteria."*

Many of the Rosgen stream classification limitations stated by Juracek and Fitzpatrick (2003) apply to streams with beaver impoundments. The dams create a time-dependent nature where dams can be constructed and destroyed on a scale of a few weeks or less. With the potential for rapid changes in stream morphology come difficulties in identifying a base flow equilibrium state and bankfull elevations, as bankfull may be submerged when dams impound water. The same difficulties and uncertainties are applicable to the USEPA habitat assessment method. The method is designed to identify potential habitat for in-stream life which may change day by day based on the ever-changing heights of downstream beaver dams. Beaver activity at a dam can change the width and depth of the impounded water. Increased stream width due to beaver impounded water can dilute the existing channel conditions before beaver dam development with what is initially recently flooded terrestrial vegetation. An example is if a streambed that is 100% gravel has an increased water width into the floodplain due to beaver dams, the floodplain composition would decrease the 100% gravel bed to 25% gravel and 75% clay. The otherwise lotic stream becomes a lentic wetland, which promotes different species of aquatic life. Snodgrass and Meffe (1998) provided an example of beaver dams promoting new species documenting that habitat heterogeneity in a headwater stream, created through the construction of beaver dams, supported eleven species of fish typically found in lotic environments and sixteen species found in lentic systems. While there are methods of classifying wetlands such as the index of biological integrity (IBI), these methods were not used because the methods could not be applied to the stream in the absence of beaver dams.

Despite the difficulties of classifying streams under the influence of beaver, beaver are a keystone species because they alter hydrology, stream geomorphology, and biogeochemical pathways, and increase community productivity (Naiman et al., 1986). Naiman et al. (1986) found beaver dams significantly alter the geomorphology of a stream through the impoundment of sediment and water. Much of beaver activity was found to occur on 2nd to 4th order streams where sediment volume impounded was correlated with surface area following the equation:

$$Sediment\ volume\ (m^3) = 47.3 + 0.39 \times Surface\ area\ (m^2) \qquad (4.1)$$

with a $p<0.01$ (Naiman et al., 1986). Pollock et al. (2007) conducted a similar study, investigating the aggradation rate of sediment due to beaver dams located in incised streams. The study found young beaver dams, less than a year old, aggraded up 0.5 meters of sediment per year (Pollock et al., 2007). The natural aggrading and dynamic equilibrium phase of stream succession can take anywhere from tens to hundreds of years, while beaver dams have been shown to return streams to dynamic equilibrium in as little as twenty years (Pollock et al., 2014). Beaver typically construct between 8.6 and 16.0 dams per stream km (Naiman et al., 1986). The impoundments lead to the creation of step pools over the profile of the river where the diversion of water, attenuation of floods, and reduction in downstream hydraulic energy become the driving forces in shaping stream geomorphology (Gurnell, 1998).

Nyssen et el. (2011) investigated the impacts of beaver dams on the hydrology of small mountain streams and found that the dams assisted in producing more consistent flow downstream. During storm events, the dams would accumulate water, decreasing peak flows experienced downstream. In dry periods, the leaky dams would maintain low flow conditions downstream that would likely not occur in the absence of the dams (Nyssen et al., 2011).

Another study conducted by Majerova et al. (2015) found the mean residence time in a 1st order mountain stream tripled due to the presence of beaver dams. It was noted that sites with the greatest influence on mass recovery of the conservative tracer contained large beaver dams and multiple side channels (Majerova et al. 2015). Gurdak et al. (2002) found similar results in a mountain stream where the travel time of a conservative tracer in May ranged from 2.5 to 3.45 hours. In September, the travel time of the conservative tracer reached 15.33 hours, attributed in part, to the construction of beaver dams (Gurdak et al., 2015). However, Majerova et al. (2015) and Gurdak et al. (2002) did not report the mass percent recovery of the tracer. Jin et al. (2009) conducted a study using rhodamine WT dye as a conservative tracer and recorded the lowest reported mass recovery of rhodamine in streams with beaver influence found in the literature at 89%. The loss of mass was attributed to sorption to streambed materials, photodegradation and the lengthy stream reach of 2,365 m (Jin et al., 2009).

At the site of this study, mine drainage is also a factor in potentially decreasing the mass recovery of rhodamine. Fe-rich waters strongly attenuate rhodamine (Kill Eagle et al., 2009). The attenuation is amplified in low pH waters, pH <5, causing rhodamine to be considered a non-conservative tracer in these conditions (Kill Eagle et al., 2009).

For this study, it was hypothesized that 1) stream complexity and variation characterized by a rapid habitat assessment and Rosgen stream classification is expected to increase when the beaver dams are not present compared to when the dams are intact, but the resulting habitat score between the two will not be significant, 2) the presence of beaver dams will increase the stream hydraulic retention time, with lower tracer recovery compared to that in the absence of beaver dams.

## 4.2 Methods and Materials

### *4.2.1 Site Description*

Unnamed Tributary (UT) is located in Commerce, Oklahoma and is impacted by MD from abandoned lead and zinc mining operations (Figure 4.1). The headwaters of UT are an intermittent stream where flows are storm event driven. The stream becomes a perennial stream due to two continuous groundwater sources before it reaches its confluence with Tar Creek. UT and the contributing groundwater sources are regularly monitored for water quality by the University of Oklahoma (OU) Center for Restoration of Ecosystems and Watersheds (CREW). All historical data were provided by CREW. The first artesian MD source was located near the headwaters of the stream and contributes approximately 100 gpm. This discharge was untreated

AMD, known as UT-Pipe (UT-P), located at the Southeast Commerce (SEC), with approximate metals concentrations, from the historical dataset of 50 samples, of 133 Fe mg/L, 9.71 mg Zn /L, 0.063 mg Pb /L, 0.031 mg Cd /L, and 0.037 mg As /L. The second discharge was a collection of three seeps approximately 0.3 miles downstream of SEC, flowing at a combined average rate of 160 gpm and was treated by a passive treatment system, known as Mayer Ranch (MRPTS). The effluent of MRPTS from the historical data has average metals concentrations of 0.65 mg Fe, /L 0.46 mg Zn /L, with As, Cd, and Pb below detectable limits. The addition of the treated water dilutes in-stream contaminant concentrations for the remaining 0.7 miles of stream, at UT-Robinson location (UT-R) where UT effluents into Tar Creek. In late 2013, the presence of beaver was noted in the CREW field books, with approximately half of the stream influenced by the construction of beaver dams by the end of 2014.

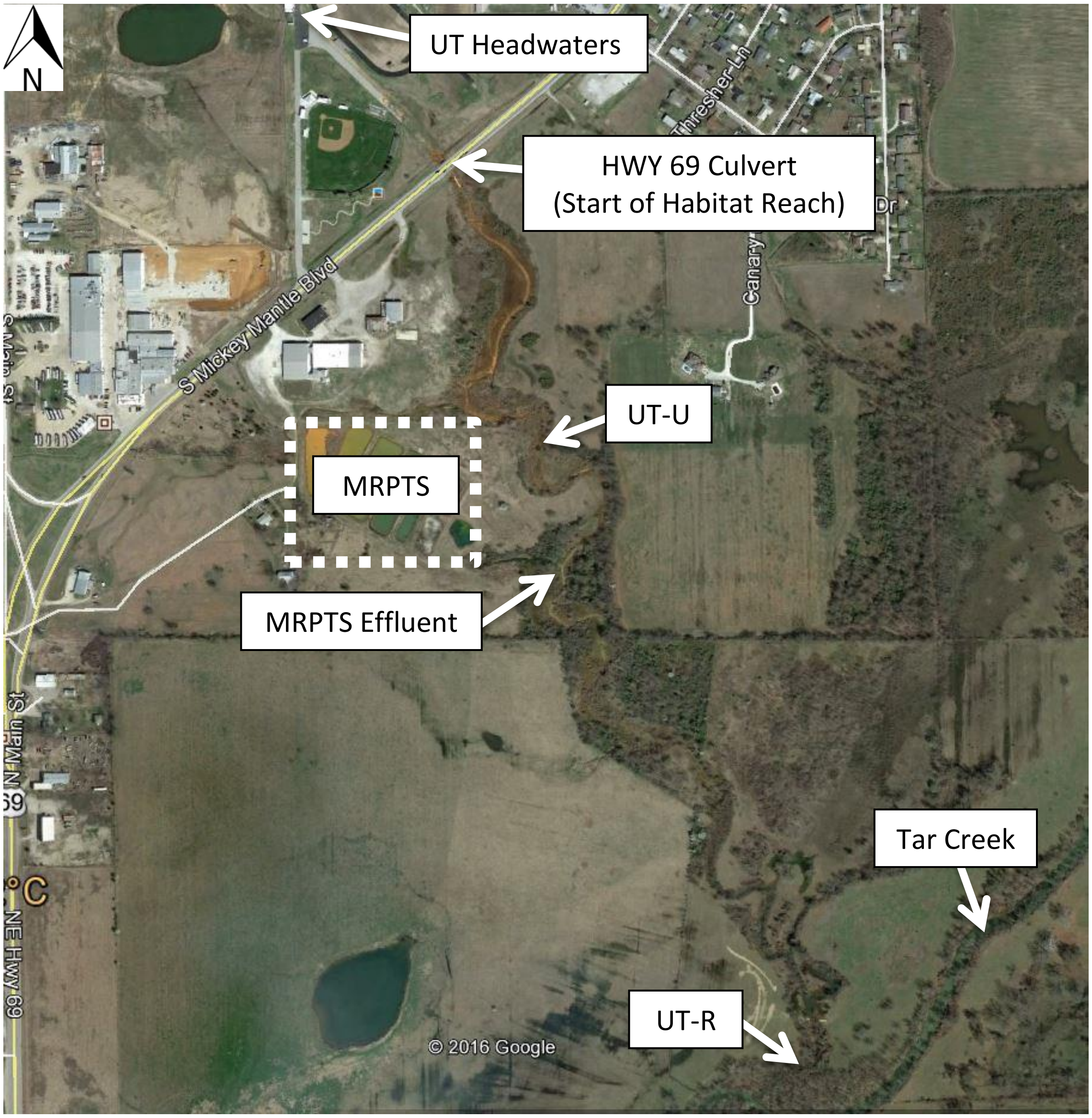

Figure 4.1: Site locations along UT in Commerce, OK, and existing passive treatment system (MRPTS) with the start location of the habitat assessment marked (Google Earth, 2017)

### *4.2.2 Stream Classification*

The stream was categorized in August 2016 using i) the Rosgen classification system, and ii) the USEPA rapid habitat assessment procedure, both with and without beaver dams (beaver dams were manually destroyed to provide for this assessment). Many of the metrics are shared between the classification methods. A project-specific habitat assessment document (Figure 4.2) was used to evaluate UT that gathered the appropriate information for both classifications. The definitions used for each category of the habitat assessment sheet may be found in Appendix A. Station locations are 30 meters apart following the stream thalweg. This distance was chosen to maximize the detail of the assessment while still completing the assessment within a single field day.

Rosgen (1996) classifies streams using a four-level identification scheme. Each level and its defined parameters are shown in Figure 4.3. The Rosgen stream classification is useful in quantifying the state of the stream in terms of its physical characteristics. The stream classification information becomes useful when comparing different streams and when considering the need for stream restoration. Because of inherent heterogeneity, classification of UT was not limited to a single Rosgen classification. The classification changed when the defined parameters appeared to differ from the previous station of the assessment.

| Station (Dist) | Lat. Long. (center) | | Depth (m) | | | Bank full depth (m) | | | Width | | | Substrate at transect (add up to 100%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lat | Long | L1/4 | C | R1/4 | L1/4 | C | R1/4 | Water | Bankfull | Flood prone | Silt/Clay | Sand | Gravel | Cobble | Boulder | Bedrock | Ang | POM | HPC |
| 30 | | | | | | | | | | | | | | | | | | | | |
| 60 | | | | | | | | | | | | | | | | | | | | |

| Habitat Type | | | | In-Stream Cover (% area) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rif | Run | Pool | Dry | UCB | LWD | SWD | Roots | BRL | SAV | EAV | Terr. Veg. | CBG | Embed | % Can. Cov. | Pt. Bar | D&S | Bank Veg. | Dom. Veg. |
| | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | |

| % Eroded Bank | | Ht. Eroded | | Deg. Slope | | Rip. Width | | Rip. Condition | |
|---|---|---|---|---|---|---|---|---|---|
| Left | Right | Left | Right | Left | Right | Left | Right | Left | Right |
| | | | | | | | | | |
| | | | | | | | | | |

| Tributary | | | | | Cattle | | | |
|---|---|---|---|---|---|---|---|---|
| # Trib/Bank | Width | D: L1/4 | D: C | D: R1/4 | %Tram. | # CP | Trail | Class |
| | | | | | | | | |
| | | | | | | | | |

| Beaver | | | | | Comments |
|---|---|---|---|---|---|
| # Dams | Dam Width | Dam Ht. | WTR Ht. | Active? | |
| | | | | | |
| | | | | | |

Figure 4.2: Project-specific habitat assessment form based on USEPA's Rapid Bioassessment protocol (USEPA, 1999)

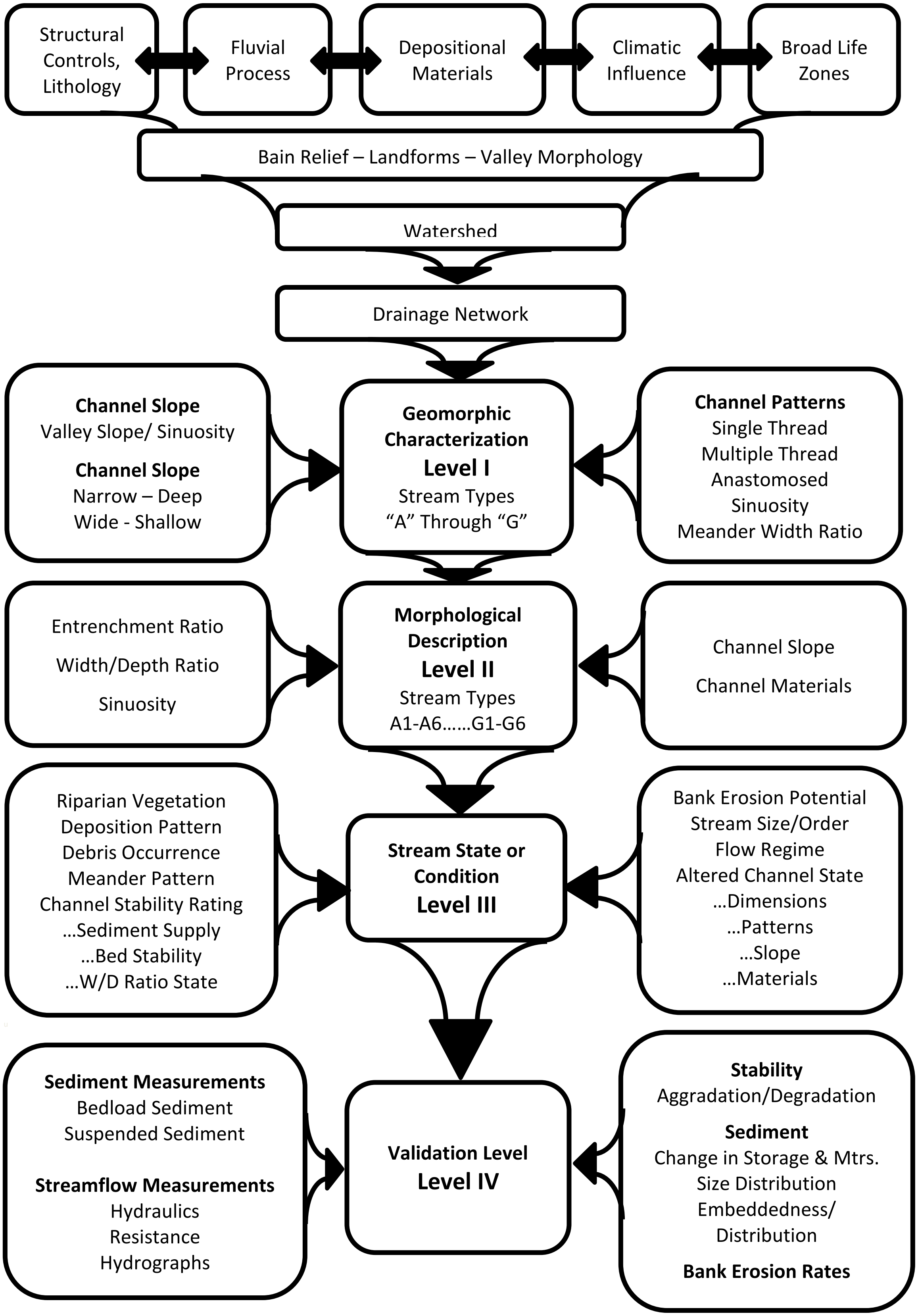

Figure 4.3: Rosgen (1996) stream classification hierarchy recreated

### *4.2.3 Conservative Tracer Studies*

The first conservative tracer study was representative of UT with beaver dams intact. The historic flow data were used to determine the amount of Rhodamine (Equation 4.2) to inject following USGS (1982) protocols. The method utilizes both flow and velocity to determine the volume of Rhodamine needed to be added for a successful tracer analysis. Therefore, the area for the entire stream was estimated using the rapid habitat assessment information.

Equation 4.2: Volume of Rhodamine

$$V_R = 3.4 \times 10^{-4} \times \left(\frac{Q_M \times L}{vel.}\right)^{0.94} \times C_p \tag{4.2}$$

Flow ($Q_M$) was assumed to equal 0.61 cfs from the historical CREW dataset, length (L) was one mile, and desired downstream concentration ($C_p$) was 50 µg/L. The downstream concentration was chosen based on the range of the rhodamine sensor detectable limits.

The YSI OMS datasondes with attached Rhodamine sensors were two-point calibrated with a zero standard and a 150 µg/L Rhodamine standard. Rhodamine was injected at the UT-Pipe site in order to capture the full flow path of the mine discharge from the SEC site. The datasondes were deployed at least one hour before the Rhodamine injection to acquire background concentrations, and measurement were recorded every 30 minutes. The 30-minute time-frame was chosen to allow the sonde to collect data for up to ten days without changing batteries or filling the memory.

After it had been determined that the Rhodamine had fully passed the last sensor on the tributary, the datasondes were removed and data analyzed.

The Rhodamine study was conducted a second time to represent base flow conditions without beaver manipulation. All beaver dams on UT were manually removed in a single day and the Rhodamine was again added at UT-Pipe immediately after dam removal. The quantity of Rhodamine injected for each of the tests was different because the average cross-sectional area with beaver dams was assumed to be greater than without beaver dams. Estimates based on average cross-sections throughout the entire reach of UT were used. The two conservative tracer tests assisted in comparing the storage capacity and travel time of the stream with and without the presence of beaver dams.

Each of the datasets was analyzed to determine measured retention time (Equation 4.3), variance (Equation 4.4), normalization (Equation 4.5Equation 4.), dispersion coefficient (Equation 4.6), dead volume per bulk volume (Equation 4.7), and index of short circuiting (Equation 4.8) (Levenspeil, 1999). These parameters were used to support the tracer study results, such as short circuiting of beaver impounded water, resulting in short retention times despite larger volumes of water in the presence of beaver dams.

Equation 4.3: Measured retention time of conservative tracers

$$\bar{t} = \frac{\int_0^\infty tC\,dt}{\int_0^\infty C\,dt} \tag{4.3}$$

$\bar{t} = measured\ retention\ time\ (hours)$
$C = mass\ concetration\ \left({}^{mg}/_{L}\right)$

Equation 4.4: Conservative tracer variance

$$\sigma^2 = \frac{\int_0^\infty t^2 C\, dt}{\int_0^\infty C\, dt} - \overline{t^2} \tag{4.4}$$

$t = time\ (hours)$
$\sigma^2 = Concentration\ variance\ of\ conservative\ tracer$

Equation 4.5: Conservative tracer normalization

$$N = \frac{\overline{t^2}}{\sigma^2} \tag{4.5}$$

Where *N=1* indicates a completely mixed flow pattern and *N*=∞ indicates that the flow pattern reflects ideal plug flow.

Equation 4.6: Dispersion number of conservative tracers

$$D = v \times L \times d \tag{4.6}$$

$d = dispersion\ number, d = N \times 0.5$
$D = dispersion\ coesfficent\ ({}^{m^2}/_{s})$
$v = average\ linear\ velocity\ ({}^{m}/_{s})$
$L = length\ from\ influent\ to\ effluent\ (m)$

Equation 4.7: Dead bulk volume per bulk volume using conservative tracers

$$Vf = \left(1 - \frac{\bar{t}}{\tau}\right) \times 100 \tag{4.7}$$

$Vf = \frac{dead\ volume}{bulk\ volume}$

$\tau = theoretical\ retention\ time\ (hours)$

Equation 4.8: index of short circuiting in surface waters using conservative tracers

$$\alpha_s = \left(\frac{\bar{t} - t_p}{\bar{t}}\right) \tag{4.8}$$

## 4.3 Results

### *4.3.1 Stream Classification*

#### 4.3.1.1 USEPA Rapid Habitat Assessment

The USEPA rapid habitat assessments showed that the presence of beaver dams results in a higher combined habitat score than in the absence of dams (Table 4.1, Figures 4.4 and 4.5). However, the differences of each category in the habitat assessments with and without beaver dams were not significant, with a p-value of 0.26. The raw data for both habitat assessments are in Appendix B.

The wetland conditions created due to the beaver dams promoted the growth of emergent and submergent aquatic vegetation that was not well represented in the absence of the beaver dams, which resulted in higher epifaunal substrate/available cover score (Table 4.1). Channel flow status was the other major category that resulted in a higher score in the presence of beaver dams compared to that with the lack of beaver dams. Channel flow status is the degree to which water fills the channel. The presence of beaver dams maintained water levels that were at or above bankfull for most of the stream reach. When the dams were removed, the lowered water levels did not reach lower terraces of the banks and left exposed substrate where the impounded water had established lentic environments. There was also a portion of the stream that was only wet in the presence of beaver dams which created a slightly higher sinuosity.

The lack of beaver dams did reveal important riffle and run habitats at numerous locations along UT that were otherwise pool habitats in the presence of beaver dams. The addition of lotic habitats in the absence of dams resulted in higher scores in the assessment because of changes in the frequency of riffles, embeddedness, and velocity/depth combination categories compared to the habitat assessment in the presence of beaver dams (Figures 4.4 and 4.5). Many studies have shown the importance of beaver dams in providing heterogenous habitat in streams by creating lentic environments (Cunjak, 1996; Snodgrass and Meffe, 1998; Hagglund and Sjoberg, 1999; Snodgrass and Meffe, 1999; Smith and Mather, 2013). However, in many cases, the streams in these studies were miles long; Snodgrass and Meffe (1999), Hagglund and Sjoberg (1999), and Smith and Mather (2013) examined streams > 15, > 5 and 45 miles long, respectively. The UT study reach is only one mile long, so the presence of beaver dams created a more homogenous stream by creating a solely lentic environment which may limit the presence of aquatic organisms that thrive in lotic environments.

In many categories, the two habitat assessments scored identically (Table 4.1). These categories primarily related to bank characteristics such as streambank cover and stability, and riparian zones. The bankfull depth and width parameters of the habitat assessment should not change between the two assessments and therefore can be a good tool to verify consistency between the assessments. Bankfull is a geomorphic state of the stream and is not influenced by the depth of water. Table 4.2 shows a comparison of the average bankfull values for the 57 transects with and without beaver dams. The averaged depth parameters have less than a five-centimeter difference between the assessments and the bankfull widths were 5% different.

Table 4.1: USEPA rapid habitat assessment scoring results of UT, located in Commerce, OK, with and without beaver dams

| Category | Maximum Score | With Dams | Without Dams |
|---|---|---|---|
| *Stream Complexity Parameters* | | | |
| Epifaunal Substrate/Available Cover | 20 | 12 | 8 |
| Embeddedness | 20 | 0 | 1 |
| Pool Substrate Characterization | 20 | 12 | 9 |
| Velocity/Depth combinations | 20 | 6 | 8 |
| Pool Variability | 20 | 10 | 6 |
| Sediment Deposition | 20 | 9 | 9 |
| Channel Flow Status | 20 | 20 | 13 |
| Channel Alteration | 20 | 11 | 11 |
| Frequency of Riffles | 20 | 0 | 3 |
| Channel Sinuosity | 20 | 7 | 6 |
| *Stream Bank Parameters* | | | |
| Bank Stability (Right Bank) | 10 | 10 | 10 |
| Bank Stability (Left Bank) | 10 | 10 | 10 |
| Bank Vegetation (Right Bank) | 10 | 6 | 6 |
| Bank Vegetation (Left Bank) | 10 | 7 | 8 |
| Riparian Vegetative Zone Width (Right) | 10 | 10 | 10 |
| Riparian Vegetative Zone Width (Left) | 10 | 10 | 10 |
| *Total* | 260 | 140 | 128 |

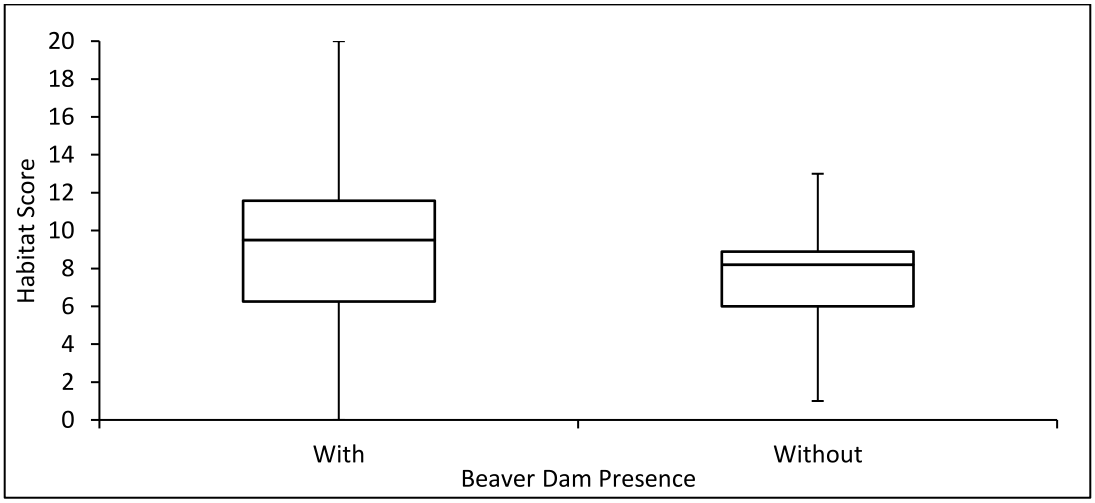

Figure 4.4: Box and whisker plot of USEPA habitat assessment stream complexity parameters comparison with and without beaver dams along UT, located in Commerce, OK

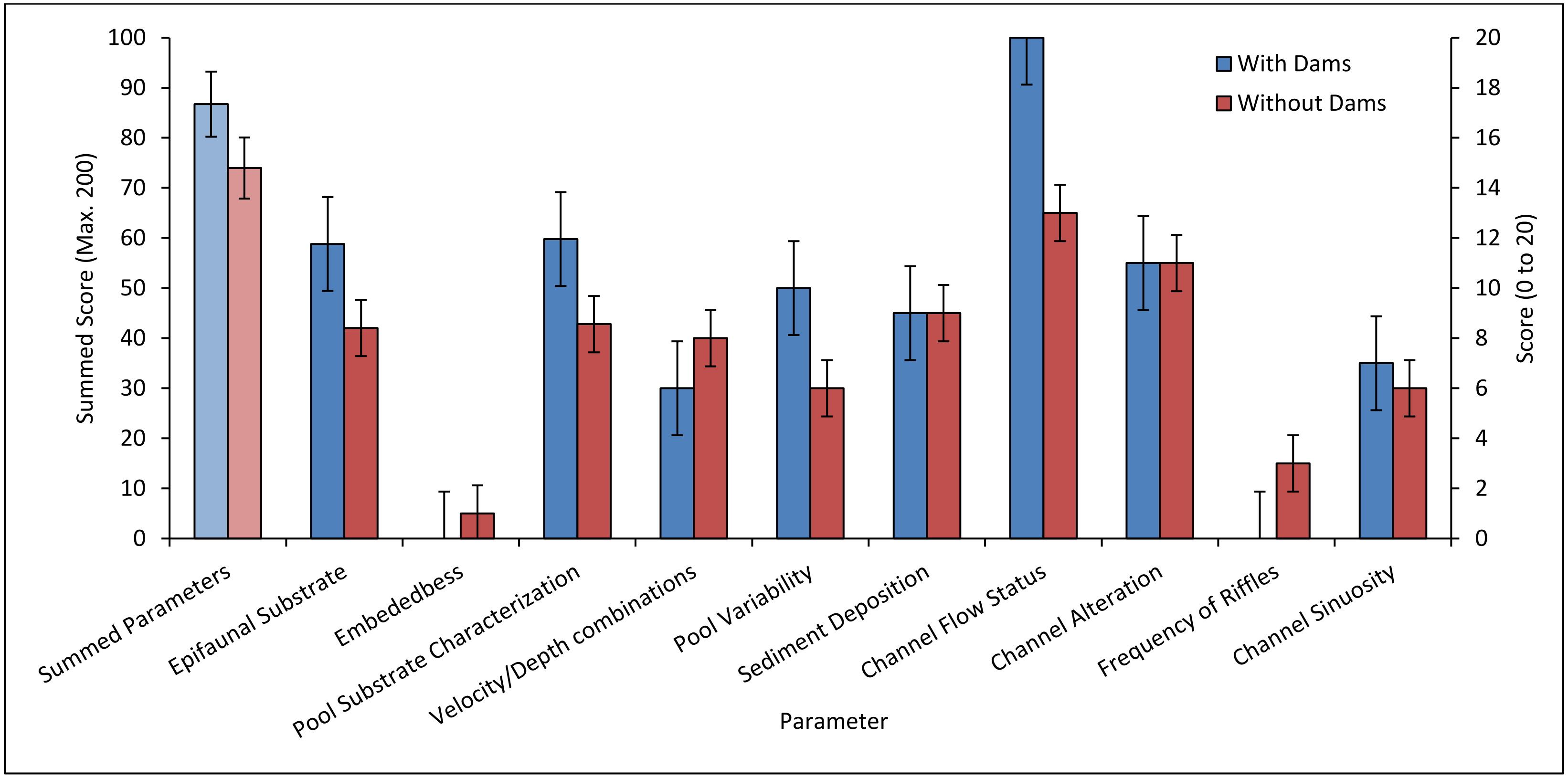

Figure 4.5: USEPA habitat assessment stream complexity parameters comparison with and without beaver dams along UT, located in Commerce, OK

Table 4.2: USEPA rapid habitat assessment bankfull comparison with and without beaver dams along UT, located in Commerce, OK

| | Depth (m) | | | Width (m) | |
|---|---|---|---|---|---|
| | Left | Center | Right | Water | Bankfull |
| With Beaver Dams | 0.90 | 1.06 | 0.90 | 7.74 | 22.5 |
| Without Beaver Dams | 0.86 | 1.02 | 0.87 | 3.26 | 23.7 |

#### 4.3.1.2 Estimating Storage Capacity of Beaver Dams

All of the beaver dams stored approximately 2,500 $m^3$ (2 acre-ft) of water, which was 250% more storage capacity than UT in the absence of beaver dams (Table 4.3). The storage value was estimated from the difference in water depths and widths from the two habitat assessments. Downstream of UT's confluence with Tar Creek is a USGS stream gage station (Station 07185095: Tar Creek at 22nd St. Bridge in Miami, OK) that was also used to estimate the storage behind the beaver dams. The data from this USGS station were compared to an upstream gage station (Station 07185090: Tar Creek at Highway 69 near Commerce, OK) to determine if any elevated flow at the downstream station was due to beaver dam removal, and not a precipitation event. The area under the curve at Tar Creek 22nd St., excluding base flow volume, resulted in 2.6 ac-ft of water passing the station due to beaver dam removal (Figure 4.6). The two methods of determining storage provided similar results given the large approximations and assumptions assisted with each.  A similar study conducted by Puttock et al., (2017) supports the findings of this study, where thirteen beaver dams stored approximately 1,000 $m^3$, resulting in a 30% decrease in peak discharges and 34% decrease in total discharge during rain events.

Table 4.3: Estimated volume of water stored by six separate beaver dams and a low water crossing along UT, located in Commerce, OK

| Dam | Distance* (Meters) | With Dams ($m^3$) | Without Dams ($m^3$) | Difference ($m^3$) |
|---|---|---|---|---|
| D1 | 30 to 300 | 1,557 | 242 | 1,315 |
| D2 | 300 to 360 | 97.50 | 21 | 77 |
| D2a | 360 to 450 | 240 | 49 | 191 |
| D3 | 600 to 660 | 104 | 80 | 24.38 |
| D4 | 780 to 840 | 364 | 68 | 296 |
| D5 | 840 to 960 | 631 | 128 | 503 |
| D6 | 1,050 to 1,080 | 122 | 25 | 96 |
| LWC | 1,560 to 1,620 | 459 | 431 | 27 |
| Summed Volume | | 3,753 | 1,044 | 2,530 |

*Distance from HWY 69 culvert shown in Figure 4.1

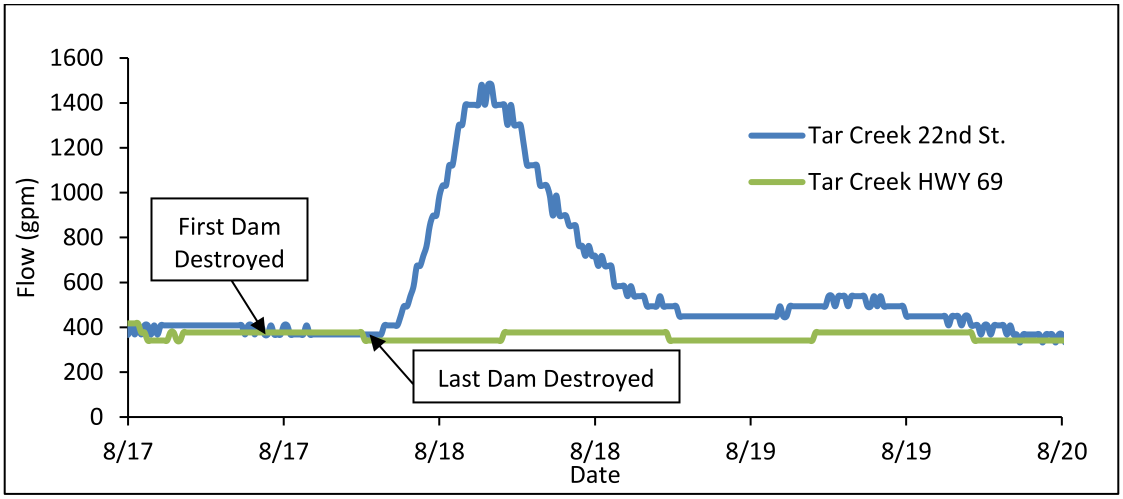

Figure 4.6: USGS stream gage stations upstream and downstream of UT confluence during beaver dam removal event

#### 4.3.1.3 Rosgen Stream Classification

The Rosgen stream classification was completed with both the habitat assessment data and nine surveyed cross-sections, the locations of which are identified by the stars on Figure 4.7. The summarized Rosgen stream classifications are shown in Tables 4.4, and 4.5, with the raw data in Appendix C.

The habitat assessment resulted in a more detailed stream classification per length of stream since it was conducted on 30-meter intervals, but each transect had low resolution with only three water depth measurements and rough field estimates for bankfull width and flood prone area. The survey data targeted all the potentially different stream types along the length of UT with more points per transect, allowing for higher resolution per transect, but was conducted at only nine transects over the length of the stream compared to 57 for the habitat assessment.

Data obtained from the rapid habitat assessment resulted in the same stream classification as the survey on five of the nine cross-sections (CS). Two of the four CS that did not match, CS 6 and CS 7, were completed in areas of high beaver activity that resulted in no classification (NC) for the habitat assessment. However, the survey had more data points across each CS, allowing for the stream to be classified as an E classification at CS 6 and CS 7. CS 1 occurred at a bridge on the northern most location on UT which influenced the stream classification (Figure 4.7). CS 1 was an E6 classification because the bridge caused a lower bankfull width/mean bankfull depth (W/D) ratio than that recorded 30 meters downstream, where the first transect of the habitat assessment was conducted. The first rapid habitat assessment transect, located at the 30-meter station, was determined to be a C6 classification.

CS 5, located upstream of D4, was the only transect where the classifications overlapped and were different. The survey produced an E6 classification and the habitat produced a C6 classification. As stated above, the difference in the two locations is the W/D ratio where the survey has more detailed information and better identified the thalweg when the water was clearly elevated due to the D5 beaver dam.

The Rosgen stream classification, completed using the rapid habitat assessment sheet (Figure 4.2), was influenced by beaver activity at 19 of the 57 transects and for 14 of the 19 transects UT was not classifiable due to extensive beaver impoundments. The transects were unclassifiable when the water width was above the bankfull elevation where the system more closely resembled a wetland than a stream.  The habitat assessment produced five different level I classifications and two additional level II classifications (Table 4.4).

The primary reason for changes in classification was due to decreased stream incision from accumulation of sediments from beaver. UT is primarily a C channel for 21 of the 57 transects, or an E channel for 13 of 57 transects. Many of the classification changes occurred on the upstream portion of UT where most beaver activity was reported. C and E classifications differ with respect to the W/D ratio that can be directly influenced by accumulation of sediments in the thalweg. There was also a portion of UT that flows through a dense section of trees where the roots created a multi-channel stream, resulting in D and $D_A$ stream classifications. A single transect was determined to be a level I F classification where the inflow of a stormwater tributary created a low entrenchment ratio. Nine of the 57 transects had gravel dominated bed material primarily from mining waste (Locally known as “chat”) which resulted in a “4” level II classification. All other transects were a “6” level II classification with silt-clay or particulate organic matter (POM) being the dominant bed material. The stream classifications from Tables 4.4 and 4.5 are shown on the aerial image of UT shown in Figure 4.7.

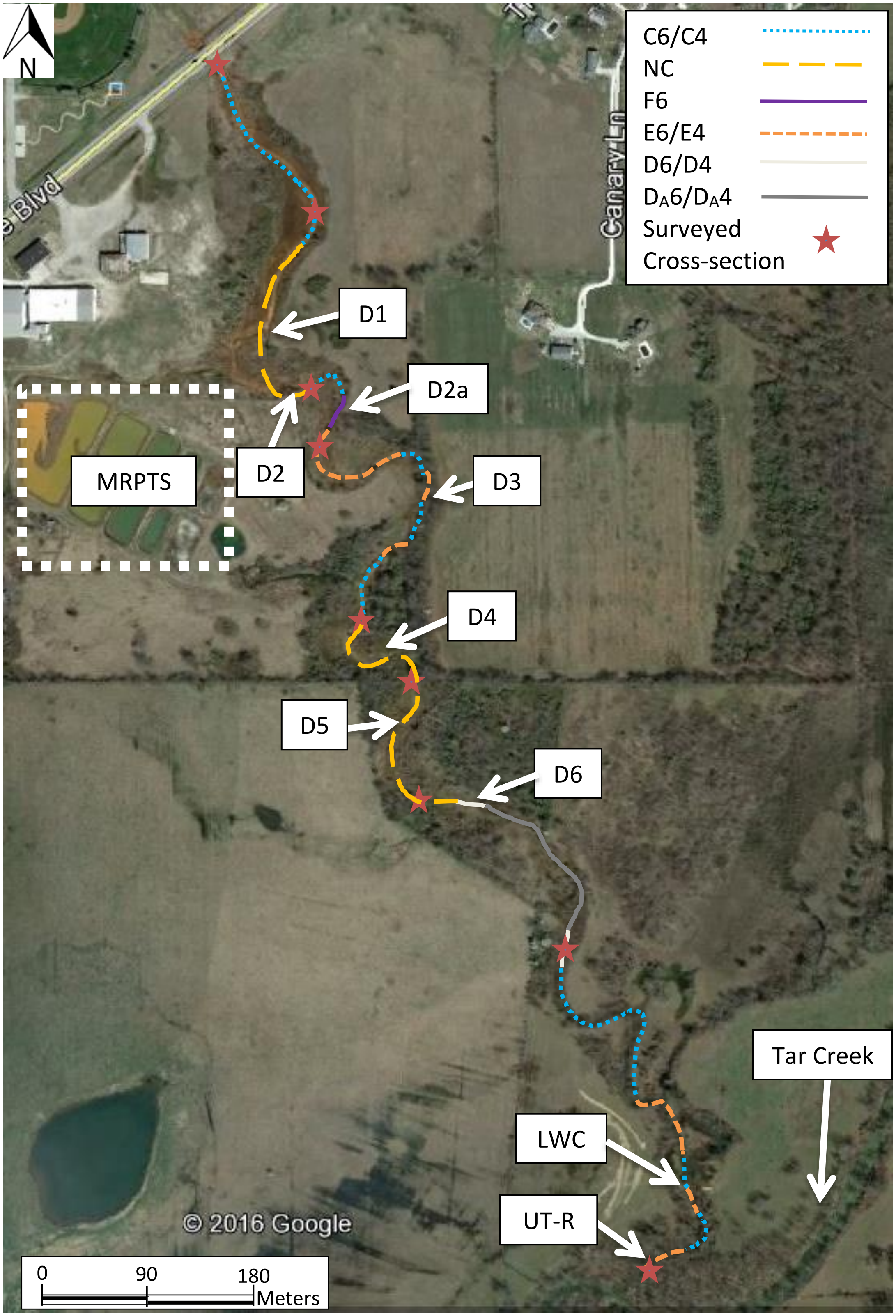

Figure 4.7: Rosgen stream classifications for each 30-meter reach labeled along UT aerial image (Google Earth, 2017)

Table 4.4: Rosgen stream classification conducted every 30 meters along UT starting at Highway 69 culvert and ending the UT and Tar Creek Confluence

| Station (m) | Bankfull Width (m) | Flood-Prone Width (m) | Mean BF Depth (m) | Maximum BF Depth (m) | Entrenchment Ratio | W/D Ratio | Primary Bed Material | Rosgen Stream Classification |
|---|---|---|---|---|---|---|---|---|
| 30 to 210 | 30.05 | >40.00 | 0.84 | 0.96 | >2.2 | 20.71 | Silt/Clay | C6 |
| 210 to 360 | 30.00 | 30.83 | 0.81 | 1.05 | 1.00 | 34.28 | Silt/Clay | NC* |
| 360 to 390 | 20.00 | 25.00 | 1.10 | 1.20 | >2.2 | 18.18 | Silt/Clay | C6 |
| 390 to 420 | 20.00 | 25.00 | 1.10 | 1.20 | 1.25 | 18.18 | Silt/Clay | F6 |
| 420 to 510 | 7.00 | >40.00 | 1.34 | 1.42 | >2.2 | 5.23 | Silt/Clay and POM | E6 |
| 510 to 540 | 18.00 | >40.00 | 0.98 | 1.10 | >2.2 | 18.31 | POM | C6 |
| 540 to 570 | 9.00 | >40.00 | 1.17 | 1.20 | >2.2 | 7.71 | POM | E6 |
| 570 to 630 | 19.50 | >40.00 | 1.02 | 1.18 | >2.2 | 19.07 | Silt/Clay and POM | C6 |
| 630 to 660 | 8.00 | >40.00 | 1.23 | 1.40 | >2.2 | 6.49 | POM | E6 |
| 660 to 810 | 21.20 | >40.00 | 1.11 | 1.30 | >2.2 | 19.54 | POM | C6 |
| 810 to 1050 | 35.33 | >40.00 | 0.80 | 1.04 |  | 29.78 | Silt/Clay | NC* |
| 1080 to 1110 | >40.00 | >40.00 | 0.30 | 0.30 | MC** | >40 | Silt/Clay | DA6 |
| 1110 to 1140 | >40.00 | >40.00 | 0.97 | 1.10 | MC** | <40 | Gravel | DA4 |
| 1140 to 1170 | >40.00 | >40.00 | 0.47 | 0.70 | MC** | >40 | Gravel | D4 |
| 1170 to 1200 | 18.00 | >40.00 | 1.08 | 1.35 | MC** | 16.62 | Gravel | DA4 |
| 1200 to 1290 | 20.00 | >40.00 | 1.03 | 1.15 | MC** | 19.74 | Silt/Clay | DA6 |
| 1290 to 1380 | 17.00 | 36.67 | 0.91 | 1.17 | 2.37 | 19.13 | Gravel | DA4 |
| 1380 to 1410 | 5.00 | 9.00 | 0.70 | 0.83 | 1.80 | 7.15 | Gravel | E4 |
| 1410 to 1440 | 3.50 | 15.00 | 1.06 | 1.22 | 4.29 | 3.32 | Silt/Clay | E6 |
| 1440 to 1470 | 9.00 | >40.00 | 0.99 | 1.11 | >2.2 | 9.11 | Gravel | E4 |
| 1470 to 1530 | 7.75 | 32.00 | 1.06 | 1.25 | 3.69 | 7.34 | Silt/Clay | E6 |
| 1530 to 1590 | 18.00 | >40.00 | 1.15 | 1.37 | >2.2 | 16.05 | Silt/Clay | C6 |
| 1590 to 1620 | 20.00 | >40.00 | 1.55 | 1.86 | >2.2 | 12.92 | Silt/Clay | E6 |
| 1620 to 1650 | 21.00 | >40.00 | 0.70 | 0.77 | >2.2 | 30.02 | POM | C6 |
| 1650 to 1680 | 13.00 | 18.00 | 0.49 | 0.55 | 1.38 | 26.45 | Gravel | C4 |
| 1680 to 1710 | 5.75 | 26.50 | 0.98 | 1.04 | 4.60 | 5.99 | Silt/Clay | E6 |

*No classification due to extensive impacts from beaver activity

**Multiple channels

Table 4.5: Rosgen stream classification at nine surveyed cross-sections along UT, located in Commerce, OK

| | Station (m) | Entrenchment Ratio | Width/Depth Ratio | Sinuosity | Slope | Rosgen Stream Classification |
|---|---|---|---|---|---|---|
| CS 1 | 0 | >2.2 | 4.37 | 1.43 | 0.0034 | E6 |
| CS 2 | 170 | 5.4 | 31.08 | 1.43 | 0.0034 | C6 |
| CS 3 | 360 | 8.41 | 11.34 | 1.43 | 0.0034 | C6 |
| CS 4 | 450 | 2.5 | 10.07 | 1.43 | 0.0034 | E6 |
| CS 5 | 780 | 5.25 | 3.08 | 1.43 | 0.0034 | E6 |
| CS 6 | 930 | 5.09 | 9.64 | 1.43 | 0.0034 | E6 |
| CS 7 | 1020 | 3.51 | 8.59 | 1.43 | 0.0034 | E6 |
| CS 8 | 1290 | 17.84 | 93.22 | 1.43 | 0.0034 | D6 |
| CS 9 | 1710 | >2.2 | 6.81 | 1.43 | 0.0034 | E6 |

### *4.3.2 Conservative Tracer Studies*

The first tracer study was conducted in July 2016. The mass of rhodamine injected was determined using USGS guidelines for the measurement of time of travel in streams by dye tracing (USGS, 1982). The rhodamine concentration peaked at 17 µg/L at UT-U, and after ten days, the rhodamine did not appear to reach the final rhodamine sensor at UT-R. An additional YSI equipped with a rhodamine sensor was then used take point data while walking in the stream length to find the plug of rhodamine. There were no measurable signs of rhodamine in UT, suggesting the beaver impoundments and water/sediment chemistry diluted and/or retarded the rhodamine concentrations below detectable limits of the sensor (0.5 µg/L).

The initial calculated mass from the USGS equation was then multiplied by ten and injected a few weeks later in August 2016. The same multiplication factor was applied to the calculated mass of rhodamine without beaver dams. Table 4.6 summarizes the results of these two successful tracer studies. As hypothesized, the presence of beaver dams increased the retention time in the stream. The presence of beaver dams extended the mean retention time (MRT) by 23%, with most of the retention occurring in the downstream portion of UT. The results reported in this study are lower than those found in other studies. Majerova et al. (2015) found a 230% increase in mean retention time after the colonization of beaver and Jin et al. (2009) reported travel times of conservative tracers three times larger due to transient storage zones partially created by beaver dams.

Short circuiting through beaver impounded waters may be one possibility for the smaller difference in retention time between the presence and absence of beaver dams compared to other studies. The presence of beaver dams did not increase the retention time between UT-P and UT-U, the upstream portion of UT, as shown in Table 4.6. In the upstream portion at UT-U, the presence of beaver dams was four hours faster (48.0 hours) than without dams (52.2 hours). This upstream stretch of UT had two of the eleven beaver dams present, one of which is the largest by volume (Table 4.6 The small differences in retention time upstream of UT-U suggests the large beaver dam (D1) has a preferential flow path through the impounded water. The low calculated dispersion coefficient and high dead bulk volume support the idea that the upstream portion of UT may be impounding large volumes water, but it is not necessarily increasing the retention time of water. Figures 4.8 and 4.9 show impounded water occurring due to the construction of D1 had a large amount of backwater that likely did not contribute to the retention time of the stream.

Table 4.6: Conservative tracer studies using rhodamine along UT, located in Commerce, OK, using two sensors, located at UT-U and UT-R, conducted with and without beaver dams

| | With Dams | | Without Dams | |
|---|---|---|---|---|
| Parameter | UT-U | UT-R | UT-U | UT-R |
| Total mass of rhodamine injected (g) | 697 | | 374 | |
| Total mass of rhodamine recovered (g) | 60.04 | 63.79 | 106.36 | 87.78 |
| Recovery (%) | 8.61 | 9.15 | 28.47 | 23.50 |
| Time from injection to sensor (hrs.) | 27.0 | 72.5 | 29.0 | 62.5 |
| Total time until pulse passes (hrs.) | 79.0 | 242.5 | 113.5 | 177.0 |
| Mean retention time (hrs. after injection) | 48.0 | 155.0 | 52.2 | 126.0 |
| Mean retention time (MRT) (pulse start) | 19.5 | 74.0 | 41.5 | 63.5 |
| Calculated retention time | 102.6 | 244.5 | 19.9 | 68.2 |
| Dispersion number | 0.24 | 34.92 | 2.70 | 8.59 |
| Dispersion coefficient ($m^2/s$) | 0.14 | 20.87 | 1.61 | 5.13 |
| Dead volume per bulk volume | 53.2 | 36.6 | -162.3 | -84.8 |
| Index of short circuiting | -0.21 | 0.85 | 0.46 | 0.27 |

Figure 4.8: Aerial image (2011) of UT pre-beaver colonization at Dam 1 with a white box identifying the backwater storage location (Google Earth, 2017)

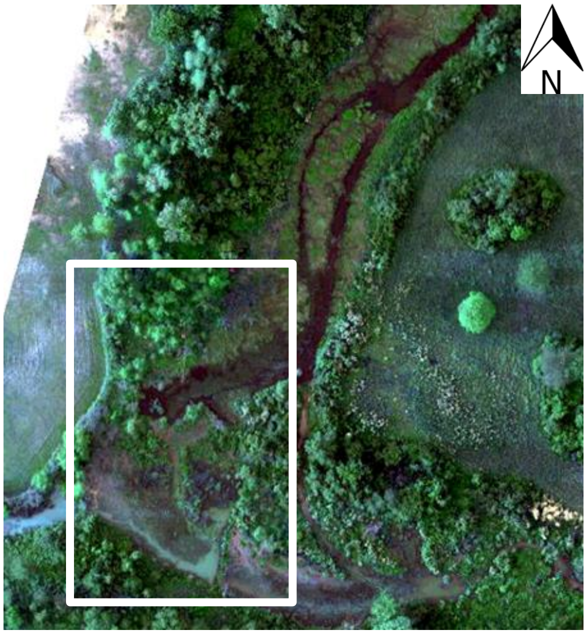

Figure 4.9: Aerial image of UT post beaver colonization at Dam 1 with a white box identifying the backwater storage location, taken in 2017 with an unmanned aerial system

Beaver activity immediately following dam removal is a second potential cause for the small difference in MRTs between the two tracer studies. Although beaver activity on the tributary after dam removal could not by quantified, beaver dam reconstruction was noted at numerous dams. UT-U was the only location with a depth sensor. The depth data shown in Figure 4.10 suggest a destroyed beaver dam downstream of UT-U was at least partially reconstructed and retaining water. The water level before the dams were removed was approximately 0.9 ft and dropped to under 0.6 ft after dam removal occurred, shown in Figure 4.10. The low depth only lasted four hours before beaver activity apparently began impounding water. The water continued to accumulate over the next four days to a new height of 1.4 ft. It is important to note the dam downstream of UT-U was a small dam that was not sampled, however it was the only dam with which a depth sensor was associated. With similar activity noted at other dam locations, it is likely the immediate reconstruction activity of beaver influenced the MRT for the supposed absence of beaver dam tracer study. Similar reconstruction activity was reported by Cook (1943), where following a flood event that removed a dam, it was repaired and enlarged immediately.

The majority of the retention time due to beaver dams is occurring between UT-U and UT-R where the dispersion coefficients increased from 0.14 $m^2$/sec to 21 $m^2$/sec, respectively. The dead volume per bulk volume decreased by approximately 45% at UT-R compared to UT-U (Table 4.6). Figures 4.11 and 4.12 show the retention of rhodamine occurring in the downstream portion of UT where the MRT at UT-R occurs much later in the presence of beaver dams.

The recovery of rhodamine was much lower in the presence of beaver dams, where it was less than 10% of the calculated mass at both sites. The tracer study conducted without beaver dams had rhodamine recovery near 25%, which is lower than many values reported in similar studies. Rhodamine recovery has been shown to be affected by beaver activity, but not to the extent found in this study. As discussed in the introduction, Jin et al. (2009) reported rhodamine recovery as low as 89%. In other studies, low rhodamine recovery has been attributed to sorption to organics (Sabatini et al., 1999; Dierberg and DeBusk, 2005). The additional loss of rhodamine in UT was largely attributed to the mine drainage where rhodamine will sorb to iron oxides. According to Sabatini et al. (1999), fluorescent dyes have the potential to sorb to oppositely charged surfaces, which includes iron oxide surfaces.

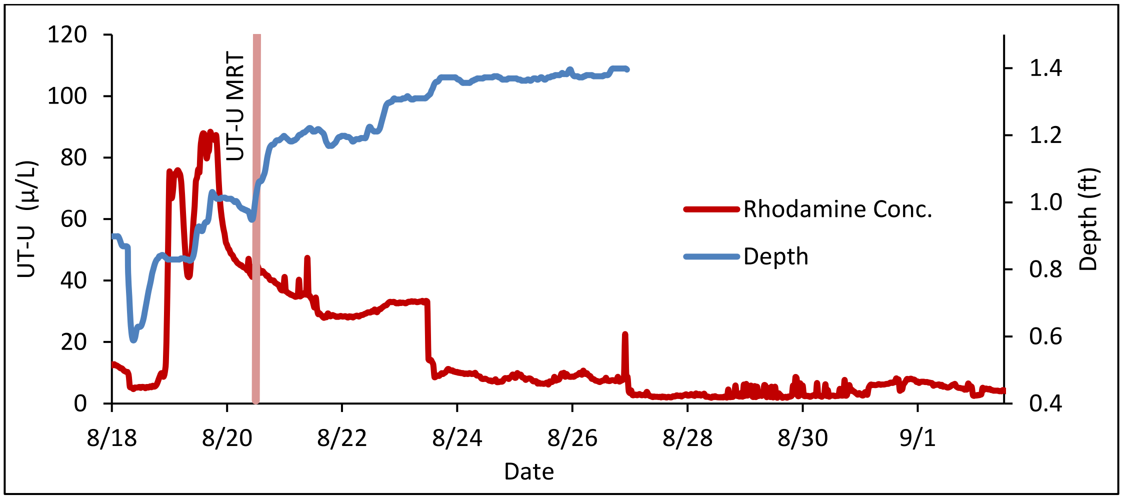

Figure 4.10: Conservative tracer study using rhodamine conducted in the absence of beaver dams at UT-U with tracer concentrations and depth measurements showing dam reconstruction

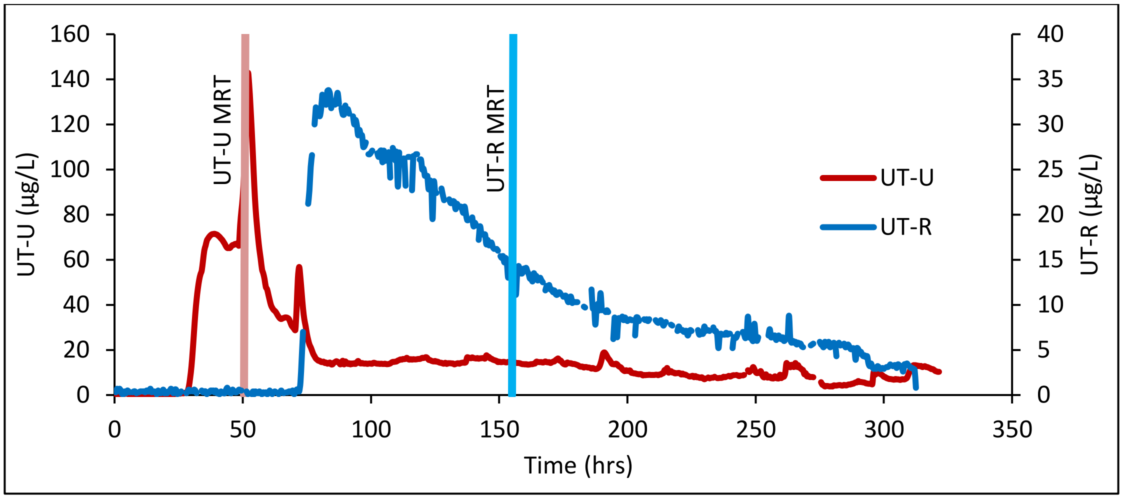

Figure 4.11: Conservative tracer study using rhodamine conducted in the presence of beaver dams along UT at two locations, UT-U and UT-R with mean retention times labeled for each location

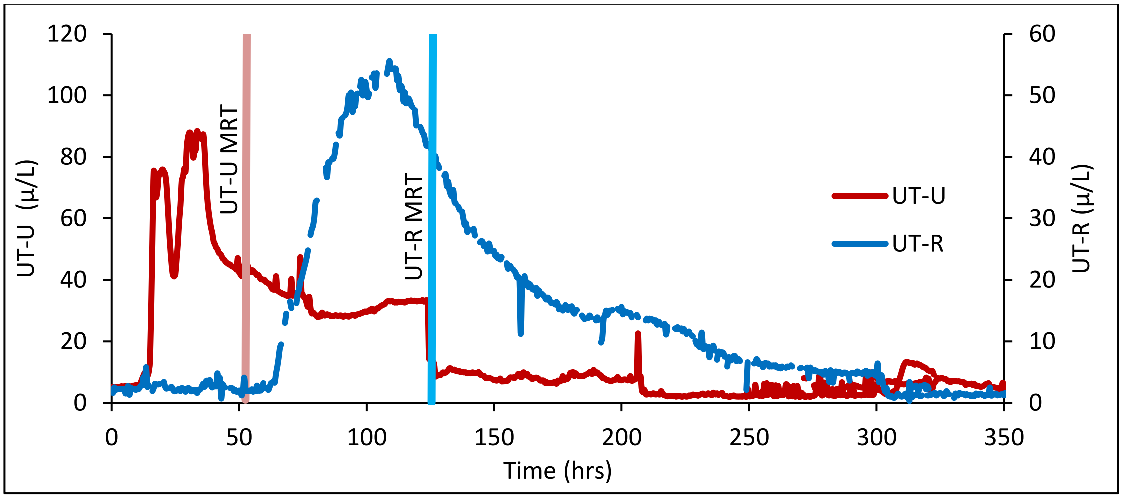

Figure 4.12: Conservative tracer study using rhodamine conducted in the absence of beaver dams along UT at two locations, UT-U and UT-R with mean retention times labeled for each location

## 4.4 Conclusions

The first hypothesis, which stated the USEPA rapid habitat assessment in the absence of beaver dams would result in a higher score than the presence of beaver dams, but the two assessments would not be statically significant, was partially accepted because the presence of beaver resulted in a higher overall habitat score but there was no statistical difference ($p>0.05$) in the individual categories of the habitat assessments with and without beaver dams. The beaver dams created wetland areas that promoted a variety of in-stream cover due to aquatic vegetation, and maintained elevated water levels. However, the lack of riffles in the presence of beaver dams created a homogenous environment that was not favorable compared to that in the absence of beaver dams. The combined habitat assessments show approximately 2,500 $m^3$ of water were stored behind the beaver dams, a 250% increase in stream capacity compared to that in the absence of beaver dams.

The Rosgen stream classification was greatly influenced by beaver activity where 14 of the 57 stations were not classifiable due to extensive beaver alterations to the stream. The stream was classified primarily as a C6, with intermittent sections of E classifications on more incised reaches of the stream. The rapid habitat assessment classifications were mostly supported by the surveyed cross-sections despite having far fewer points. The UT study reach had five different level classifications along the entire one-mile length. A single station was a level I F classification and six stations had multiple channels, resulting in D and $D_A$ level I classifications. The abundance of mining waste material (chat) in the stream sediments at nine transects resulted in a gravel-dominated bed material level II classification. The remaining transects were silt-clay dominated.

The conservative tracer studies supported the hypothesis that beaver dams would increase retention time and decrease rhodamine recovery. The majority of the retention time occurred in the lower portion of UT, despite the largest dam (D4) that stores the majority of the water being located in the upstream portion. Rhodamine recoveries without beaver dams were approximately 25% while the presence of beaver dams had recoveries <10%. The lower recovery was likely due to higher dispersion coefficients, and sorption to Fe and organics due to the extended retention times.

Beaver are ecosystem engineers, providing valuable services to streams due to the construction of beaver dams (Naiman et al., 1986; Snodgrass and Meffe, 1998; Butler and Malanson, 2005; Andersen and Shafroth, 2010; Hardisky, 2011; Law et al., 2016, and Puttock et al., 2017). On UT, the colonization of beaver improved habitat by establishing wetland conditions that provided a wide variety of cover and substrate. The beaver impoundments are expected to decrease peak flows and discharge because of the 250% increased storage capacity. The positive services provided by beaver far out-weigh the draw backs associated with elevated water levels.

# Chapter V: Conclusions and Future Work

## 5.1 Conclusions

### *5.1.2 Unnamed Tributary Mine Drainage Sources Summary*

A small tributary located in Commerce, OK that flows into Tar Creek has been historically impacted by untreated net alkaline mine drainage (AMD) from two locations along the one-mile long tributary study reach. In 2008, water quality at the larger of the two mine drainage locations, located 0.3 miles from the headwaters of UT and flowing at approximately 160 gpm, was addressed using passive treatment. The implementation of Mayer Ranch Passive Treatment System (MRPTS) improved the water quality of UT downstream of the MRPTS effluent by diluting the untreated AMD coming from upstream. It is likely the primary factor leading to the colonization of beaver into UT.

Near the headwaters of UT, the smaller untreated source of MD known as SEC flowing at approximately 100 gpm year around negatively impacted the water and sediment quality, and biota in UT. This AMD source remained untreated throughout this study. The data collection for this study concluded in January 2017. That was in part because a new passive treatment system, the Southeast Commerce Passive Treatment System (SECPTS) became fully functional in February 2017. The implementation of SECPTS is now treating the last major source of AMD, resulting in no major sources of AMD flowing into UT as of February 2017.

### *5.1.3 Historical Water Quality in the Unnamed Tributary*

The Center for Restoration of Ecosystems and Watersheds (CREW) is a research team from the School of Civil Engineering and Environmental Science at the University of Oklahoma. CREW began working in the Tar Creek Superfund Site in the late 1990s. CREW has regularly monitored UT at three locations since 2004. The use of CREW's historical dataset was the first step in identification of the impacts of *Castor canadensis*. The historic dataset dating back to 2004 was used to determine if beaver had any notable impact on UT water quality. The historical data were divided into four groups based on events believed to have impacted water quality: 1) background, 2) SEC French drain installation, 3) MRPTS construction, and 4) beaver colonization. The installation of the SEC French drain, at the headwaters of UT, resulted in maximum concentrations of Cd, Fe, Pb, and Zn at UT-U and Cd, Pb, and Zn at UT-D (Figures 1.10-1.19). For the UT-U location, the elevated metals concentrations during the MRPTS time period are still attributed to the installation of the French drain. The UT-U site name is in reference to being upstream of the MRPTS effluent, therefore the construction of MRPTS was expected to have no impact on UT-U. At UT-D, however, MRPTS construction resulted in consistently lesser metals concentrations than the French drain event dates. In the case of Pb, the majority of the samples were below the detectable limits of the analytical instrumentation (0.019 mg/L) (Figure 1.14). MRPTS was effectively acting as a dilution source for the untreated water flowing from SEC.

Because of the improved water quality downstream of MRPTS before beaver colonization, it pushed the focus of evaluating beaver impacts to the UT-U site. The greater concentrations of metals at UT-U compared to UT-D provided potential for metal removal due to the presence of beaver dams. At UT-U, the beaver impoundments decreased Fe concentrations from an average of 50 mg/L to approximately 10 mg/L between the MRPTS and Beaver events (Figure 1.8). The average Zn concentrations over the same time periods were approximately halved, decreasing from 7 mg/L to 3 mg/L (Figure 1.11). Cd concentrations at UT-U showed a decrease in concentration and had a smaller spread of concentrations due to beaver activity on UT (Figure 1.17). The beaver had minimal impact on Pb concentrations at UT-U. Pb is typically removed in passive treatment in anaerobic conditions, which are not promoted by the beaver dams. Rather, the beaver dams appear to act as a large oxidation pond, supported by the oxidation of Fe that typically precipitates as iron oxides. Cd then sorbs to the iron oxides (Nairn et al., 2009). The data led to partially accepting the hypothesis that beaver dams would result in a positive influence on water quality through the decrease in metals concentrations.

### *5.1.4 Impacts of Beaver Dams*

Once the historical data established beaver colonization had a positive impact on AMD impacted streams, the next step was quantifying the impacts of individual dams. The impacts were quantified by analyzing water and sediment samples at the inflow and outflow of each beaver dam. The inflow was defined as the location where water impounded by a given dam was no longer at or above bankfull elevation. The outflow locations for water quality were where the water flowed over the dam. The sediments at the outflow location were upstream of the given dam where materials used to construct the dam were no longer present. Sampling events occurred in August 2016, November 2016, and January 2017. The dams sampled at each event were not always the same. In some cases, new, larger dams were created after the first event, while others were destroyed and not re-established. The inability to consistently sample all dams resulted in limited statistical analysis.

In general, all beaver dams showed a decrease in Fe and Cd concentrations, with no discernable changes in Pb concentrations (Table 2.4). Zn showed decreases at upstream locations, with less drastic changes below the MRPTS effluent. The data resulted in partially accepting the hypothesis that the effluent of beaver dams would have lesser metals concentrations than the influent water. The most upstream dam (D1), which was also the dam impounding the most water, showed statistically significant removal of all metals (Cd P=0.025, Fe, P=0.006, Pb P=0.007, and Zn P=0.026). The remaining dams that were used in the statistical analysis did not show statically significant metal removal, which was attributed to the lower initial concentrations of all metals because the dams were downstream of MRPTS effluent. D1 was also used to calculate an Fe removal rate that averaged 4.1 g $m^{-2}$ $day^{-1}$. The Fe removal rate is approximately 20% to 25% of the designed Fe removal rate of 20 g $m^{-2}$ $day^{-1}$ utilized in oxidation ponds of passive treatment systems (Nairn et al., 2009).

The sediments in UT had statistically greater Fe and Zn concentrations (P=0.0023 and P=0.049, respectively) at the outflow of the dam compared to the inflow. The metals data led to the rejection of the hypothesis that the metals concentrations would continually decrease from upstream to downstream. Five of 13 samples had elemental Fe concentrations exceeding 200,000 mg/Kg (Table 2.7). The metals accumulation at the outflow of the beaver dams is likely related to the precipitation of metals in the impounded water of each dam. The Fe is being oxidized throughout the impounded water, but the Fe particle settling likely occurs nearest the beaver dams. Three of the outflow locations (D4, D5, and D6) showed a distinct separation in the sediment profile, which was collected and analyzed as separate samples. Cd and Fe concentrations were significantly higher ($P=0.018$ and $P=0.020$, respectively) in the top layer of sediment. The lesser metals concentrations in the bottom layer of sediment suggest metals that precipitate and accumulate are relatively recent and are likely remobilized during high flow events.

The sediments were hypothesized to not exceed Resource Conservation and Recovery Act (RCRA) criteria for Toxicity Characteristic Leaching Procedure (TCLP) and that the USGS field leaching test (FLT) would yield lower concentrations than the TCLP. The TCLP concentrations were, on average, 28 times higher than the FLT concentrations. The FLT was an excellent tool to identify candidates for the TCLP. The FLT was a much quicker and cheaper process compared to the TCLP. Seven samples were chosen to perform the TCLP. A single location (D4 In) exceeded the USEPA guidelines for TCLP. The sample had a Cd concentration of 1.08 mg/L compared to the allowable concentration of 1.00 mg/L. All other samples were less than a third of the allowable Cd concentration. The highest Pb concentration (D6 In) for TCLP was 2.81

mg/L compared to the allowable Pb concentration of 5.0 mg/L. The majority of TCLP samples were below 1 mg/L Pb (Table 2.9).

### *5.1.5 Beaver Dam Removal*

The beaver dams have been shown to be a benefit to AMD impacted streams, but the dams do not last forever. The failure of the dams on UT has happened in the past and will likely happen in the future, leading to questions about the fate of the metals that have been removed behind beaver dams. The beaver dam removal study was broken into a sequential dam removal event and a single dam removal event. The sequential dam removal event showed Fe and Cd were remobilized, with increasing trends between the three data points collected at each dam over a one-hour period. Most of the mobilized mass occurred at the most upstream dam (D1), where 55.2 Kg of the total 56.4 Kg Fe mobilized (Table 3.2). Pb and Zn appeared to be unaffected by the dam removal. The flush events data led to the partial support of the hypothesis that metals concentrations would increase immediately after dam destruction.

The single dam removal event was performed to further establish trends by sampling for six hours after dam removal. D1 was selected since it had the greatest concentrations of all metals and therefore would be more likely to show trends. It was hypothesized the metals concentrations would decrease with decreasing stream velocities following dam removal. The hypothesis was not supported because Fe and Cd concentrations showed a rising trend for two hours, before plateauing near 55 mg/L Fe and 0.007 mg/L Cd, while velocities decrease over the same time period (Figures 3.9 and 3.10). The initially high velocity of the water after dam removal likely resuspended the metals, and the six-hour sampling period was insufficient for the metals to settle and return to the original metals concentrations. Pb and Zn did not show any changes in concentration over the six-hour sampling event (Figure 3.8).

The two dam removal events are characteristic of anthropogenic dam removal which likely represents the minimum amount of metals mobilized due to dam removal. If the dams were washed out due to high flow, the high velocities would be more likely to suspend settled metals over the entire length of the stream. The high flow would also keep the metals suspended for longer distances compared to anthropogenic dam removal.

### *5.1.6 Stream Classification and Conservative Tracer Studies*

The USEPA rapid habitat assessment supported the hypothesis that the absence of beaver dams would have a higher habitat scored compared to the stream in the presence of beaver dams, but the difference in the scores for each category was not significantly different (P=0.26). The beaver impoundments created wetland conditions throughout UT, which provided more diverse habitat from increased vegetation and substrate than the absence of dams. However, without the beaver dams, riffles and runs were established which is important habitat for benthic macroinvertebrates and some fish species. From the habitat assessment, the presence of beaver dams on UT stored approximately 2,500 m$^3$ (2 acre-ft) more than in the absence of dams, a 250% increase in storage capacity.

UT underwent geomorphic categorization using the Rosgen stream classification from raw data collected during the USEPA rapid habitat assessment and surveyed transects. The USEPA rapid habitat assessment has far less detail at each transect, but it allowed for completing a transect every 30 meters along the entire length of UT in a single day, resulting in 57 transects. The surveyed transects had a much higher resolution at each transect, with up to 23 data points per transect, which produced more precise data than the habitat assessment.

The USEPA rapid habitat assessment resulted in a level I classification of a C for 21 of 57 transects, and an E classification for 13 of 57 transects. The two classifications often alternated in the upstream portion where most beaver dams are present. C and E classifications differ with respect to the W/D ratio that can be directly influence by sedimentation in the thalweg due to beaver activity. Nineteen of the 57 transects were marked as heavily influenced by beaver activity and 14 of the 19 were not classifiable. The unclassifiable transects often occurred where the stream more closely resembled a wetland than a stream (Table 4.4 and Figure 4.7).

The surveyed transects overlapped with the USEPA habitat assessment in eight locations. Of the eight locations, two of the transects (CS 6 and CS 7) were in lengths of the stream that the habitat assessment could not classify, both of which the survey determined were E6 classifications. Five of the transects (CS 2, 3, 4, 8, and 9) resulted in the same classification as the habitat assessment. Only a single location did not match (CS 5) where the habitat assessment had a C6 classification while the survey resulted in E6. The difference was the higher W/D ratio produced by the habitat assessment compared to the survey data, where the increased number of points from the survey better captured the stream under the beaver impounded water and produced a more accurate W/D ratio.

The tracer studies results were consistent with the hypothesis that the residence time in the presence of beaver dams would be longer than in the absence of beaver dams with decreased rhodamine recovery. The presence of beaver dams increased the mean retention time by 23% over the full length of UT. The majority of the water retained by beaver dams (1,315 $m^3$ of 2,530 $^3$) occurred at D1, the most upstream beaver dam located between the headwaters and UT-U, but the MRT was not affected by D1. The MRT without beaver dams had a 4-hour longer retention time than with beaver dams at the UT-U location. Therefore, the majority of the MRT was occurring on the downstream side of UT-U behind the other beaver dams. Rhodamine recovery for both studies was much lower than many reported values, at 25% without dams and <10% with dams, respectively. The lower recovery was attributed to sorption of rhodamine to iron oxides present in the stream.

### *5.1.7 Closing Statements*

The colonization of beaver in a net alkaline mine drainage impacted stream has been shown to benefit the water quality of the stream. The beaver may appear to be a nuisance by creating high water and making sampling difficult (sometimes impossible) at established sampling locations, but their presence should be viewed as a valuable contribution through the remediation of AMD and flood attenuation. The beaver are ecosystem engineers, providing a much-needed service to UT (Naiman et al., 1986; Snodgrass and Meffe, 1998; Butler and Malanson, 2005; Andersen and Shafroth, 2010;

Hardisky, 2011; Law et al., 2016, and Puttock et al., 2017). Despite the two sources of AMD now being treated with passive treatment, (MRPTS and SECPTS) the beaver will still be valuable to UT. The beaver will continue to provide flood attenuation, and valuable polishing of stormwater, PTS effluent, and occasional PTS bypass water which will promote increased vegetation, macroinvertebrate, and fish diversity in UT (Maret et al., 1987; Hey et al., 1995; Cunjak, 1996; Snodgrass and Meffe, 1998; Hagglund and Sjoberg, 1999; Collen and Gibson, 2001; Wright et al., 2002; Jin et al., 2009; Hardisky, 2011; Nyssen et al., 2011; Smith and Mather, 2013; Hood and Larson, 2015; Law et al., 2016; and Puttock et al., 2017).

## 5.2 Future Work

Beaver colonization in a mine drainage impacted stream provides opportunities for extensive future work due to minimal published literature on the subject. Beginning with future work on the UT site, additional tracer studies should be conducted to create statistical significance and perhaps capture the ever-changing retention time because of the continuous beaver activity. To better address variations between tracer studies in the future, a rapid habitat assessment should be conducted to determine approximate changes in volume, dam locations, and dam sizes. Now that the majority of the water at base flow is treated AMD, the rhodamine recoveries should increase, resulting in more accurate data. If periodically collected, the rapid habitat assessments and surveying transects would be an excellent tool to establish the rate which beaver promote stream succession at UT.

Beaver colonization needs to be investigated in as many locations as possible to establish effectiveness on different water quality, metals, and metals concentrations. Other types of AMD will likely yield different results than this study. The beaver impoundments are essentially oxidation ponds and polishing wetlands, therefore low pH AMD may not be influenced by beaver impoundments until the pH of the water is increased.

The impacts of dam removal require more work to better establish metal remobilization from both anthropogenic and flooding events. This study established metal remobilization is likely occurring, but it was unable to address how far downstream the metals were mobilized, or the length of time the metals remained suspended due to anthropogenic removal. As discussed in Chapter 3, sampling storm events capable of washing out beaver dams would be difficult, timely, and potentially expensive because of the likelihood of lost or damaged equipment. However, it is an important area as it likely mobilizes settled metals and contaminated sediments for longer times and distances compared to anthropogenic removal.

Chapter two discussed the possibility that diurnal fluctuations may be influencing the lower Fe removal rate compared to PTS oxidation ponds. Exploring the impacts of diurnal fluctuations on AMD may be an influential study that can be applied to any treatment wetland in addition to beaver impoundments.

Finally, the largest selling point for nearly any idea becoming successful in society is the cost benefit. Evaluating the ecosystem services provided by beaver colonization on a mine drainage impacted stream could be the driving force for the public and private sector to accept the work created by these ecosystem engineers as a valuable service that can save time and money in restoration projects.

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## Appendix A

Appendix A: USEPA Rapid Habitat Assessment Parameter Definitions

# Stream Characterization

## Definitions used during stream characterization and habitat assessment

***Depth:***

Left quarter (L1/4), right quarter (R1/4), center(C): measurement from top of solid streambed material to water height.

Solid streambed material is defined as the location the measuring device rests without applied forces.

***Bank full:***

"The bankfull state corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics" (Rosgen, 1996).

Bank full indicators:

(a) Presence of a floodplain at the elevation of initial flooding

(b) Break in slope of the banks and/or a change in particle size distribution

(c) Evidence of an inundation feature

(d) Staining of rocks

(e) Exposed root hairs below an intact soil layer indicating exposure to erosive flow

Source: Rosgen, 1996.

***Bank full depth (max depth):***

Left quarter (L1/4), right quarter (R1/4), center(C): measured from top of solid streambed material to water height.

***Flood-prone area:***

The elevation that occurs at two times the max depth, then applied to find the width of stream at defined elevation (Rosgen, 1996)

***Substrate at transect:***

Silt/clay – less than 0.1 mm

Sand – 0.1 mm to 2 mm

Gravel – 2 mm to 50 mm

Cobble – 50 mm to 250 mm

Boulder - >250 mm

POM – particulate organic matter (rotten leaves, stick and log fragments)

HPC – hardpan clay

Source: Oklahoma Conservation Commission, 2002.

***Habitat type:***

Habitat present at transect line

Riffle – surface of water disrupted by small waves, usually making a sound

Run – obvious current, surface may be slightly broken, and does not make noise

Pool – smooth surface with little to no current

Source: Oklahoma Conservation Commission, 2002.

***In stream cover:***

Categories will sum to 100%

LWD – large woody debris in water >10cm diameter

SWD – small woody debris in water ≤10cm diameter

Roots – submerged root wads of trees

TV – terrestrial vegetation that is currently underwater

CBG – cobble bolder gravel

***Embedded:***

Degree to which boulders, cobble, and gravel have been surrounded by sediments

***Percent Canopy Cover (CAN):***

The measurement, in percent, of shade cover at each station, adjusted to the time when the sun is directly overhead (Oklahoma Conservation Commission, 2002).

***Point Bar (PT. Bar):***

The recent accumulation of materials above the water's surface with little to no vegetation (Oklahoma Conservation Commission, 2002).

***Deposition and Scouring (D+S):***

This is a measurement related to habitat destruction. Scouring can be identified by visible roots, and siltation accumulation in the stream. Orange roots are a sign of recent/active scouring. Deposition will be recorded if deposited materials are recent enough to support little to no vegetation (Oklahoma Conservation Commission, 2002).

***Bank Vegetative Cover (BVC):***

Estimate of the area of combined left and right bank that is protected from erosion by perennial vegetation (Oklahoma Conservation Commission, 2002).

***Dominant Vegetation (DV):***

The most dominant vegetation on the banks that provide ground protection. There are three options i) Grasses/forbs (G) ii) shrubs (S) iii) Trees (T). Shrubs are considered woody plants with trunks ≤10 cm. Mixture can be recorded if the bank cover is at least twenty percent of each category (Oklahoma Conservation Commission, 2002).

***Percent Eroded Banks:***

Percent eroded bank is separated into left and right bank. Record the average percent of actively eroding bank for each side. The erosion is measured from the edge of the lower bank to the upper bank, which is usually defined by the floodplain (Oklahoma Conservation Commission, 2002).

***Average Height of the Eroding Banks:***

The height of eroding banks is measured from lower bank to the upper bank, which is usually defined by the floodplain (Oklahoma Conservation Commission, 2002).

***Average Slope:***

Degree of the slope is measured for the same area as height and cover. A vertical bank is recorded as 90 degrees, while everything less than vertical is less than 90 degrees (Oklahoma Conservation Commission, 2002).

### *Riparian Zone Width and condition:*

Record the average width of the riparian area which is defined as the distance until land is managed by humans. This is where the land is not plowed, mowed, or influenced by human practices. The riparian area will then be categorized using the table below (Oklahoma Conservation Commission, 2002).

Table A1: USEPA rapid habitat assessment categorization of riparian zone conditions

| Rank | Description | % cover |
|---|---|---|
| 1A | Stable forest | <1% bare soil |
| 2B | Moderately used forest | 1-10% bare soil |
| 1C | heavily used forest | >10% bare soil |
| 2A | Good condition grassland | <1% bare soil |
| 2B | Fair condition grassland | 1-5% bare soil |
| 2C | poor condition grassland | 5-20% bare soil |
| 2D | Bad condition grassland | >20% bare soil |
| W | Wetland | at least 5m is wetlands |

Source: Oklahoma Conservation Commission, 2002.

### *Cattle*

The cattle category is an addition of the habitat assessment made by the Oklahoma Conservation Commission due to the high percentage of streams that are affected by farming practices. This category is divided into four groups i) percent trampled (% tram) which is an estimate of percent bare land due to livestock in a two-meter section ii) Trail, is the number of livestock trails observed on both banks for the entire segment iii) number of cow pies (#CP) is the number of cow pies in the same two meters iv) Class trails is the width of each trail, each trail should be listed and separated by a comma (Oklahoma Conservation Commission, 2002)

# Appendix B

Appendix B: USEPA Rapid Habitat Assessment Raw Data

## USEPA Rapid Habitat Assessment Raw Data With Beaver Dams

Table B1: USEPA rapid habitat assessment raw data in presence of beaver dams

| | |
|---|---|
| **Site Name: UT** | **Start Point: Highway** |
| **Site Date: 8-3-2016** | **End Point: UTR** |
| **Site Time: 1430** | **Sinuosity: 1.42** |

| Station (Dist) | Depth (m) | | | Bnk full depth (m) | | | Width | | | Substrate at transect (add up to 100%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L1/4 | C | R1/4 | L1/4 | C | R1/4 | Water | BF | FP | Silt/Clay | Sand | Gravel | Cobble | Boulder | POM | HPC |
| 30 | 0.50 | 0.80 | 0.40 | 0.90 | 1.20 | 0.80 | 3.10 | 11.0 | + | 85% | 10% | 5% | | | | |
| 60 | 0.55 | 0.60 | 0.45 | 0.85 | 0.90 | 0.75 | 3.80 | 9.3 | + | 90% | | 10% | | | | |
| 90 | 0.60 | 0.70 | 0.55 | 0.90 | 1.00 | 0.85 | 4.05 | 54.0 | + | 90% | | 10% | | | | |
| 120 | 0.50 | 0.60 | 0.70 | 0.80 | 0.90 | 1.00 | 6.50 | 46.0 | + | 70% | 10% | 5% | | | 15% | |
| 150 | 0.10 | 0.30 | 0.30 | 0.40 | 0.60 | 0.60 | 12.60 | 35.0 | + | 60% | 5% | 35% | | | | |
| 180 | 0.55 | 0.70 | 0.55 | 0.85 | 1.00 | 0.85 | 5.70 | 36.0 | + | 90% | | 10% | | | | |
| 210 | 0.35 | 0.70 | 0.55 | 0.65 | 1.00 | 0.85 | 6.00 | 33.0 | 33.0 | 40% | | 10% | | | | |
| 240 | 0.60 | 0.80 | 0.30 | 0.90 | 1.10 | 0.60 | 19.00 | 21.0 | 21.0 | 90% | | 10% | | | | |
| 270 | 0.60 | 0.80 | 0.70 | 0.90 | 1.10 | 1.00 | 17.00 | 21.0 | 21.0 | 90% | | 10% | | | | |
| 300 | 0.90 | 0.20 | 0.20 | 1.20 | 0.50 | 0.50 | 22.00 | 30.0 | 30.0 | 90% | | 10% | | | | |

+Width exceeded 40 meters

Table B1 Continued: Page 2, 30m to 300m

| Station (Dist) | Habitat Type | | | | In-Stream Cover (% area) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rif | Run | Pool | Dry | UCB | LWD | SWD | Roots | BRL | SAV | EAV | Terr. Veg. | CBG | % Can. Cov. | Pt. Bar | D&S | Bank Veg. | Dom. Veg. |
| 30 | | | X | | | | | | | | | 15 | | 20 | | | Stable | M |
| 60 | | | X | | | | | | | | | 15 | | 20 | | | Stable | G |
| 90 | | | X | | | | | | | | | 10 | | 10 | | | Stable | G |
| 120 | | | X | | | | 1 | | | | | 15 | | 15 | | | Stable | G |
| 150 | | | X | | | | | | | | | 5 | | 5 | | | Stable | G |
| 180 | | | X | | | | | | | | | 8 | | 8 | | | Stable | G/WL |
| 210 | | | X | | | | | | | | | 7 | | 7 | | | Stable | G/WL |
| 240 | | | X | | | | | | | | | 65 | | 65 | | | Stable | G/WL |
| 270 | | | X | | | | | | | | | 70 | | 70 | | | Stable | G/WL |
| 300 | | | X | | | | | | | | | 70 | | 70 | | | Stable | G/WL |

Table B1 Continued: Page 3, 30m to 300m

| Station (Dist) | % Eroded Bank | | Ht. Eroded | | Deg. Slope | | Rip. Width | | Rip Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right |
| 30 | | | | | 90 | 90 | 3 | 3 | G | G/WL |
| 60 | | | | | 2 | 2 | 10 | 10 | G | M |
| 90 | | | | | 1 | 2 | 15 | 15 | G | M |
| 120 | | | | | 1 | 2 | 15 | 15 | M | M |
| 150 | | | | | 1 | 1 | 18 | 18 | G | M |
| 180 | | | | | 1 | 1 | 35 | 35 | G | G/WL |
| 210 | | | | | 4 | 1 | 25 | 25 | M | G/WL |
| 240 | | | | | 5 | 1 | 15 | 15 | S | G/WL |
| 270 | | | | | 1 | 1 | 25 | 25 | G | M |
| 300 | | | | | 5 | 1 | 10 | 10 | G | M |

Table B1 Continued: Page 4, 30m to 300m

| Station (Dist) | Tributary | | | | | Cattle | | | |
|---|---|---|---|---|---|---|---|---|---|
| | # trib/bank | Width | D: L1/4 | D: C | D: R1/4 | %Tram. | # CP | Trail | Class |
| 30 | | | | | | | | | |
| 60 | | | | | | | | | |
| 90 | | | | | | | | | |
| 120 | | | | | | | | | |
| 150 | | | | | | | | | |
| 180 | | | | | | | | | |
| 210 | | | | | | | | | |
| 240 | | | | | | | | | |
| 270 | | | | | | | | | |
| 300 | | | | | | | | | |

Table B1 Continued: Page 5, 30m to 300m

| Station (Dist) | Beaver | | | | | Comments |
|---|---|---|---|---|---|---|
| | # dams | Dam Width | Dam Ht. | WTR Ht. | Active? | |
| 30 | | | | | | Not Flagged |
| 60 | | | | | | Wetland like, Soft Bottoms |
| 90 | | | | | | Wetland like, Soft Bottoms |
| 120 | | | | | | Wetland like, Soft Bottoms |
| 150 | | | | | | Wetland like, Soft Bottoms |
| 180 | | | | | | Wetland like, Soft Bottoms |
| 210 | | | | | | Widening |
| 240 | | | | | | |
| 270 | | | | | | |
| 300 | 2 | 6,6 | 0.3,0.4 | | y,y | Split into threads (B-4-Out) |

Table B1 Continued: Page 1, 330m to 1020m

| Station (Dist) | Depth (m) | | | Bnk full depth (m) | | | Width | | | Substrate at transect (add up to 100%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L1/4 | C | R1/4 | L1/4 | C | R1/4 | Water | BF | FP | Silt/Clay | Sand | Gravel | Cobble | Boulder | POM | HPC |
| 330 | 0.10 | 0.00 | 0.40 | 0.60 | 0.50 | 0.90 | 17.00 | 45.0 | 90.0 | 90% | | 10% | | | | |
| 360 | 0.50 | 0.00 | 0.30 | 1.00 | 0.50 | 0.80 | 13.00 | 35.0 | + | 90% | | 10% | | | | |
| 390 | 0.50 | 0.60 | 0.70 | 1.00 | 1.10 | 1.20 | 7.70 | 20.0 | 25.0 | 100% | | | | | | |
| 420 | 0.40 | 0.50 | 0.45 | 1.30 | 1.40 | 1.35 | 1.60 | 10.0 | + | 50% | | | | | 50% | |
| 450 | 0.20 | 0.40 | 0.20 | 1.30 | 1.50 | 1.30 | 1.60 | 5.0 | + | 50% | | | | | 50% | |
| 480 | 0.35 | 0.45 | 0.40 | 1.25 | 1.35 | 1.30 | 2.75 | 6.0 | + | 30% | | | | | 70% | |
| 510 | 0.35 | 0.50 | 0.30 | 0.95 | 1.10 | 0.90 | 2.30 | 18.0 | + | 40% | | | | | 60% | |
| 540 | 0.60 | 0.60 | 0.50 | 1.20 | 1.20 | 1.10 | 1.90 | 9.0 | + | 30% | | 20% | | | 50% | |
| 570 | 0.30 | 0.30 | 0.12 | 0.80 | 0.80 | 0.62 | 3.40 | 14.0 | + | 20% | | 30% | | | 50% | |
| 600 | 0.30 | 0.85 | 0.65 | 1.00 | 1.55 | 1.35 | 6.00 | 25.0 | + | 50% | | | | | 50% | |
| 630 | 0.50 | 0.60 | 0.20 | 1.30 | 1.40 | 1.00 | 2.90 | 8.0 | + | 40% | | 10% | | | 40% | |
| 660 | 0.45 | 0.50 | 0.40 | 1.35 | 1.40 | 1.30 | 3.70 | 20.0 | + | 50% | | 10% | | | 65% | |
| 690 | 0.50 | 0.35 | 0.05 | 1.20 | 1.05 | 0.75 | 5.40 | 20.0 | + | 30% | | 5% | | | 65% | |
| 720 | 0.30 | 0.60 | 0.30 | 0.90 | 1.20 | 0.90 | 5.00 | 24.0 | + | 30% | | 5% | | | 65% | |
| 750 | 0.60 | 0.70 | 0.30 | 1.30 | 1.40 | 1.00 | 6.50 | 22.0 | + | 30% | | | | | 65% | |
| 780 | 0.50 | 0.90 | 0.25 | 0.90 | 1.30 | 0.65 | 6.00 | 20.0 | + | 65% | 10% | | | | 25% | |
| 810 | 0.50 | 0.80 | 0.50 | 0.80 | 1.10 | 0.80 | 12.00 | 30.0 | + | 70% | 5% | | | | 25% | |
| 840 | 0.20 | 1.20 | 0.40 | 0.50 | 1.50 | 0.70 | 16.00 | 18.0 | + | 60% | | 15% | | | 25% | |
| 870 | 0.35 | 1.00 | 0.45 | 0.75 | 1.40 | 0.85 | 5.10 | 40.0 | + | 50% | 15% | 25% | | | 10% | |
| 900 | 0.30 | 0.50 | 0.75 | 0.80 | 1.00 | 1.25 | 14.00 | + | + | 35% | 5% | | | | 60% | |
| 930 | 0.25 | 0.70 | 0.10 | 0.45 | 0.90 | 0.30 | 17.00 | + | + | 70% | | 5% | | | 25% | |
| 960 | 0.70 | 0.30 | 0.20 | 1.00 | 0.60 | 0.50 | 18.00 | + | + | 30% | | | | | 70% | |
| 990 | 0.00 | 0.00 | 0.00 | 0.30 | 0.30 | 0.30 | 38.00 | + | + | 60% | 15% | 10% | | | 15% | |
| 1020 | 0.55 | 0.60 | 0.55 | 0.95 | 1.00 | 0.95 | 2.75 | + | + | 80% | | 5% | | | 15% | |

+Width exceeded 40 meters

Table B1 Continued: Page 2, 330m to 1020m

| Station (Dist.) | Habitat Type | | | | In-Stream Cover (% area) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rif | Run | Pool | Dry | UCB | LWD | SWD | Roots | BRL | SAV | EAV | Terr. Veg. | CBG | % Can. Cov. | Pt. Bar | D&S | Bank Veg. | Dom. Veg. |
| 330 | | | X | | | | | | | | | 18 | | 18 | | | Stable | G/WL |
| 360 | | | X | | | | | 5 | | | | 60 | | 8 | | | Stable | G/WL |
| 390 | | | X | | | | | 8 | | | | 65 | | 80 | | | Stable | G/WL |
| 420 | | | X | | | | | 10 | | | | 10 | | 90 | | | Stable | G/WL |
| 450 | | | X | | | 15 | 15 | 10 | | | | 25 | | 80 | | | Stable | G/WL |
| 480 | | | X | | | | 28 | 5 | | 5 | | 15 | | 35 | | | Stable | G |
| 510 | | | X | | | | 5 | 1 | | | | 10 | | 15 | | | Stable | G |
| 540 | | | X | | | | 10 | | | 10 | 12 | 10 | | 20 | | | Stable | G |
| 570 | | | X | | | | 15 | | | 8 | 10 | 5 | | 30 | | | Stable | G |
| 600 | | | X | | | | 10 | | | 30 | 10 | 5 | | 25 | | | Stable | G |
| 630 | | | X | | | | 8 | | | 35 | 15 | 5 | | 20 | | | Stable | G |
| 660 | | | X | | | | 20 | | | 45 | 20 | 5 | | 70 | | | Stable | G |
| 690 | | | X | | | | 20 | | | 45 | 20 | 5 | | 30 | | | Stable | G |
| 720 | | | X | | | | 5 | | | 60 | 10 | 5 | | 70 | | | Stable | G |
| 750 | | | X | | | | 10 | | | 15 | 70 | 10 | | 70 | | | Stable | G |
| 780 | | | X | | | 2 | 12 | | | 20 | 50 | 10 | | 70 | | | Stable | G |
| 810 | | | X | | | 1 | 15 | | | 10 | 80 | 5 | | 25 | | | Stable | G |
| 840 | | | X | | | | 10 | | | 10 | 70 | 5 | | 35 | | | Stable | G |
| 870 | | | X | | | 30 | 15 | | | 10 | 90 | 3 | | 20 | | | Stable | G |
| 900 | | | X | | | | 10 | | | 15 | 65 | 15 | | 10 | | | Stable | G |
| 930 | | | X | | | 2 | 5 | | | 15 | 90 | 5 | | 5 | | | Stable | G |
| 960 | | | X | | | 15 | 30 | | | 35 | 95 | | | 25 | | | Stable | G |
| 990 | | | X | | | 5 | 5 | | | 10 | 55 | 20 | | 12 | | | Stable | G |
| 1020 | | | X | | | | 15 | | | | 20 | 5 | | 5 | | | Stable | G |

Table B1 Continued: Page 3, 330m to 1020m

| Station (Dist.) | % Eroded Bank | | Ht. Eroded | | Deg. Slope | | Rip. Width | | Rip Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right |
| 330 | | | | | 2 | 4 | 16 | 16 | G | M |
| 360 | | | | | 5 | 1 | 10 | 10 | M | M |
| 390 | | | | | 1 | 15 | + | + | M | M |
| 420 | | | | | 1 | 1 | + | + | M | M |
| 450 | | | | | 25 | 25 | + | + | G | G |
| 480 | | | | | 10 | 1 | + | + | M | G |
| 510 | | | | | 2 | 2 | + | + | G | G |
| 540 | | | | | 1 | 5 | + | + | G/WL | G |
| 570 | | | | | 2 | 40 | + | + | G/WL | G |
| 600 | | | | | 1 | 8 | + | + | G/WL | G |
| 630 | | | | | 4 | 1 | + | + | G | G |
| 660 | | | | | 15 | 2 | + | + | M | G |
| 690 | | | | | 5 | 2 | + | + | M | G |
| 720 | | | | | 8 | 3 | + | + | M | G |
| 750 | | | | | 7 | 4 | + | + | M | G |
| 780 | | | | | 4 | 2 | + | + | M | M |
| 810 | | | | | 1 | 1 | + | + | M | M |
| 840 | | | | | 1 | 2 | + | + | G | G |
| 870 | | | | | 1 | 4 | + | 30 | M | M |
| 900 | | | | | 3 | 5 | + | + | M | M |
| 930 | | | | | 6 | 1 | 18 | + | T | M |
| 960 | | | | | 4 | 3 | 16 | + | T | M |
| 990 | | | | | 1 | 7 | + | 15 | T | T |
| 1020 | | | | | 2 | 4 | + | 10 | G | M |

+Width exceeded 40 meters

Table B1 Continued: Page 4, 330m to 1020m

| Station (Dist.) | Tributary | | | | | Cattle | | | |
|---|---|---|---|---|---|---|---|---|---|
| | # trib/bank | Width | D: L1/4 | D: C | D: R1/4 | %Tram. | # CP | Trail | Class |
| 330 | | | | | | | | | |
| 360 | Right | 12 | 0.2 | 0.4 | 0.2 | | | | |
| 390 | | | | | | | | | |
| 420 | | | | | | | | | |
| 450 | | | | | | | | | |
| 480 | | | | | | | | | |
| 510 | | | | | | | | | |
| 540 | | | | | | | | | |
| 570 | | | | | | | | | |
| 600 | | | | | | | | | |
| 630 | | | | | | | | | |
| 660 | | | | | | | | | |
| 690 | | | | | | | | | |
| 720 | | | | | | | | | |
| 750 | | | | | | | | | |
| 780 | | | | | | | | | |
| 810 | Right | 7 | 0.3 | 0.65 | 0.3 | | | | |
| 840 | | | | | | | | | |
| 870 | | | | | | | | | |
| 900 | right | 14 | 0.5 | 0.6 | 0.3 | | | | |
| 930 | | | | | | | | | |
| 960 | | | | | | | | | |
| 990 | | | | | | | | | |
| 1020 | | | | | | | | | |

Table B1 Continued: Page 5, 330m to 1020m

| Station (Dist.) | Beaver | | | | | Comments |
|---|---|---|---|---|---|---|
| | # dams | Dam Width | Dam Ht. | WTR Ht. | Active? | |
| 330 | | | | | | MRPTS Storm water channel |
| 360 | 1 | 16 | 0.4 | | y,y | MRPTS Thread dammed, Not Flagged |
| 390 | 1 | 10 | 0.4 | | y,y | Recombined |
| 420 | 1 | 5 | 0.3 | | y,y | |
| 450 | | | | | | |
| 480 | | | | | | UTU |
| 510 | | | | | | UTU |
| 540 | | | | | | |
| 570 | 1 | 4 | 0.2 | | y | |
| 600 | | | | | | |
| 630 | | | | | | |
| 660 | | | | | | |
| 690 | | | | | | |
| 720 | | | | | | |
| 750 | | | | | | |
| 780 | | | | | | |
| 810 | | | | | | MRPTS Effluent |
| 840 | | | | | | UTD |
| 870 | | | | | | |
| 900 | 1 | 8 | 0.3 | | y | Backwater at martin property,B-3-Out, MD left (40 ft diameter) |
| 930 | | | | | | |
| 960 | | | | | | Martin Fence line |
| 990 | 1 | 60 | 0.4 | | y | B-2-Out (big old dam w/ beaver deceiver) |
| 1020 | | | | | | |

Table B1 Continued: Page 1, 1050m to 1710m

| Station (Dist) | Depth (m) | | | Bnk full depth (m) | | | Width | | | Substrate at transect (add up to 100%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L1/4 | C | R1/4 | L1/4 | C | R1/4 | Water | BF | FP | Silt/Clay | Sand | Gravel | Cobble | Boulder | POM | HPC |
| 1050 | 0.35 | 0.50 | 0.45 | 0.75 | 0.90 | 0.85 | 7.50 | 30.0 | + | 45% | 30% | 10% | | | 15% | |
| 1080 | 0.40 | 0.70 | 0.70 | 0.80 | 1.10 | 1.10 | 8.20 | 23.0 | + | 45% | | 10% | | | 45% | |
| 1110 | 0.30 | 0.50 | 0.60 | 0.80 | 1.00 | 1.10 | 12.00 | + | + | 25% | | 50% | | | 25% | |
| 1140 | 0.00 | 0.40 | 0.10 | 0.30 | 0.70 | 0.40 | 2.00 | + | + | 10% | | 55% | | | 35% | |
| 1170 | 0.20 | 0.65 | 0.30 | 0.90 | 1.35 | 1.00 | 2.75 | 18.0 | + | 30% | 10% | 60% | | | | |
| 1200 | 0.55 | 0.65 | 0.55 | 1.15 | 1.25 | 1.15 | 3.85 | 18.0 | + | 70% | | 10% | | | 20% | |
| 1230 | 0.65 | 0.40 | 0.20 | 1.15 | 0.90 | 0.70 | 14.00 | 22.0 | + | 60% | 5% | 10% | | | 25% | |
| 1260 | 0.45 | 0.50 | 0.55 | 0.95 | 1.00 | 1.05 | 4.80 | 20.0 | + | 70% | | 10% | | | 20% | |
| 1290 | 0.10 | 0.50 | 0.00 | 0.70 | 1.10 | 0.60 | 4.00 | 21.0 | + | | 30% | 70% | | | | |
| 1320 | 0.10 | 0.30 | 0.50 | 0.80 | 1.00 | 1.20 | 4.00 | 14.0 | + | | 30% | 70% | | | | |
| 1350 | 0.15 | 0.25 | 0.60 | 0.75 | 0.85 | 1.20 | 7.30 | 16.0 | 30.0 | 10% | 25% | 65% | | | | |
| 1380 | 0.56 | 0.73 | 0.50 | 0.66 | 0.83 | 0.60 | 3.96 | 5.0 | 9.0 | 20% | 20% | 50% | | | 10% | |
| 1410 | 0.59 | 0.82 | 0.55 | 0.99 | 1.22 | 0.95 | 2.47 | 3.5 | 15.0 | 45% | 15% | 30% | | | 10% | |
| 1440 | 0.43 | 0.61 | 0.43 | 0.93 | 1.11 | 0.93 | 7.10 | 9.0 | + | 10% | 25% | 50% | | | 5% | |
| 1470 | 0.30 | 0.98 | 0.70 | 0.70 | 1.38 | 1.10 | 5.27 | 6.5 | 24.0 | 70% | 10% | 15% | | | 5% | |
| 1500 | 0.67 | 0.82 | 0.76 | 0.97 | 1.12 | 1.06 | 5.82 | 9.0 | + | 60% | | 15% | | | 25% | |
| 1530 | 0.34 | 0.70 | 0.61 | 0.64 | 1.00 | 0.91 | 7.19 | 15.0 | + | 75% | | | | | 25% | |
| 1560 | 0.91 | 1.34 | 0.91 | 1.31 | 1.74 | 1.31 | 5.85 | 21.0 | + | 50% | | | | | | 50% |
| 1590 | 1.10 | 1.46 | 0.88 | 1.50 | 1.86 | 1.28 | 5.85 | 20.0 | + | 90% | 5% | 3% | | | 2% | |
| 1620 | 0.67 | 0.61 | 0.52 | 0.77 | 0.71 | 0.62 | 7.92 | 21.0 | + | 5% | | 5% | | | 90% | |
| 1650 | 0.15 | 0.00 | 0.12 | 0.55 | 0.40 | 0.52 | 3.35 | 13.0 | 18.0 | 10% | 25% | 55% | | 25% | | |
| 1680 | 0.34 | 0.27 | 0.15 | 0.94 | 0.87 | 0.75 | 4.36 | 6.0 | 29.0 | 12% | 60% | 28% | | | | |
| 1710 | 0.12 | 0.15 | 0.06 | 1.12 | 1.15 | 1.06 | 2.07 | 5.5 | 24.0 | 15% | 55% | 30% | | | | |

+Width exceeded 40 meters+

Table B1 Continued: Page 2, 1050m to 1710m

| Station (Dist.) | Habitat Type | | | | In-Stream Cover (% area) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rif | Run | Pool | Dry | UCB | LWD | SWD | Roots | BRL | SAV | EAV | Terr. Veg. | CBG | % Can. Cov. | Pt. Bar | D&S | Bank Veg. | Dom. Veg. |
| 1050 | | | X | | | 2 | 10 | | | 8 | 35 | 5 | | 45 | | | Stable | T |
| 1080 | | | X | | | 5 | 19 | | | 10 | 65 | | | 65 | | | Stable | T |
| 1110 | | | X | | | 25 | 28 | | | 15 | 50 | 5 | | 85 | | | Stable | T |
| 1140 | | | X | | 5 | 15 | 30 | | | 5 | 30 | | | 80 | | | Stable | M |
| 1170 | | x | X | | | 5 | 55 | | | | 10 | 5 | | 40 | | | Stable | T |
| 1200 | | | X | | | | 15 | | | 5 | 50 | | | 25 | | | Stable | M |
| 1230 | | | X | | | | 5 | | | | 60 | | | 80 | | | Stable | G |
| 1260 | | x | X | | | 1 | 8 | | | 5 | 45 | 3 | | 100 | | | Stable | G |
| 1290 | | x | X | | | | 18 | | | | 5 | | 30 | 100 | | | Stable | T |
| 1320 | | x | X | | | 3 | 20 | | | | | | | 100 | | | Stable | T |
| 1350 | | | X | | | | 29 | | | | | | | 95 | | | Stable | T |
| 1380 | | | X | | | | 5 | 10 | | | 40 | 5 | 10 | 30 | | | Stable | T |
| 1410 | | | X | | | | 10 | 5 | | | 20 | 2 | 15 | 65 | | | Stable | M |
| 1440 | | | X | | | | 5 | 10 | | | 10 | | 10 | 45 | | | Stable | M |
| 1470 | | | X | | | | | | | | 10 | | | 35 | | | Stable | T |
| 1500 | | | X | | | | | 5 | | | | | | 20 | | | Stable | M |
| 1530 | | | X | | | 2 | 10 | | | | | | | 25 | | | Stable | M |
| 1560 | | | X | | | 5 | 15 | 8 | | 15 | 3 | | | 40 | | | Stable | T |
| 1590 | | | X | | | | 5 | | | 10 | 5 | | | 70 | | | Stable | T |
| 1620 | | | X | | | | 10 | | | 15 | 60 | | | 18 | | | Stable | M |
| 1650 | | | X | | | 2 | 8 | 3 | | 28 | 65 | | 15 | 25 | | | Stable | T |
| 1680 | | | X | | | 5 | 25 | 8 | | 5 | | | 5 | 60 | | | Stable | T |
| 1710 | | | X | | | 15 | 30 | 10 | | | | | | 85 | | | Stable | T |

Table B1 Continued: Page 3, 1050m to 1710m

| Station (Dist.) | % Eroded Bank | | Ht. Eroded | | Deg. Slope | | Rip. Width | | Rip Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right |
| 1050 | | | | | 2 | 10 | + | 8 | G | M |
| 1080 | | | | | 1 | 5 | + | 18 | G/WL | T |
| 1110 | | | | | 1 | 2 | + | 12 | M | T |
| 1140 | | | | | 2 | 9 | + | 8 | M | T |
| 1170 | | | | | 3 | 5 | + | + | G | G |
| 1200 | | | | | 9 | 4 | 20 | 30 | M | G |
| 1230 | | | | | 2 | 1 | 10 | 8 | G | G |
| 1260 | | | | | 5 | 3 | 28 | 30 | G | G |
| 1290 | | | | | 12 | 10 | + | 10 | M | T |
| 1320 | | | | | 25 | 12 | + | 8 | G | M |
| 1350 | | | | | 7 | 30 | 28 | 8 | G | M |
| 1380 | | | | | 6 | 3 | 1 | 10 | G | G |
| 1410 | | | | | 6 | 20 | 3 | 6 | G | G |
| 1440 | | | | | 8 | 4 | 10 | 1 | T | G |
| 1470 | | | | | 4 | 3 | 20 | 30 | G | G |
| 1500 | | | | | 3 | 5 | 18 | 17 | M | M |
| 1530 | | | | | 1 | 3 | 40 | 1 | M | G |
| 1560 | | | | | 6 | 3 | 10 | 10 | M | G |
| 1590 | | | | | 10 | 5 | 12 | 15 | M | M |
| 1620 | | | | | 1 | 5 | 18 | 6 | G/WL | M |
| 1650 | | | | | 60 | 35 | 7 | 4 | T | T |
| 1680 | | | | | 40 | 10 | 8 | 35 | M | M |
| 1710 | | | | | 70 | 18 | + | 10 | T | M |

+Width exceeded 40 meters

Table B1 Continued: Page 4, 1050m to 1710m

| Station (Dist.) | Tributary | | | | | Cattle | | | |
|---|---|---|---|---|---|---|---|---|---|
| | # trib/bank | Width | D: L1/4 | D: C | D: R1/4 | %Tram. | # CP | Trail | Class |
| 1050 | | | | | | | | | |
| 1080 | | | | | | | | | |
| 1110 | | | | | | | | | |
| 1140 | | | | | | | | | |
| 1170 | | | | | | | | | |
| 1200 | | | | | | | | | |
| 1230 | | | | | | | | | |
| 1260 | | | | | | | | | |
| 1290 | | | | | | | | | |
| 1320 | | | | | | | | | |
| 1350 | | | | | | | | | |
| 1380 | | | | | | | | | |
| 1410 | | | | | | | | | |
| 1440 | | | | | | | | | |
| 1470 | | | | | | | | | |
| 1500 | | | | | | | | | |
| 1530 | | | | | | | | | |
| 1560 | Left | 11 | 0.4 | 0.45 | 0.4 | | | | |
| 1590 | | | | | | | | | |
| 1620 | | | | | | | | | |
| 1650 | | | | | | | | | |
| 1680 | | | | | | | | | |
| 1710 | | | | | | | | | |

Table B1 Continued: Page 5, 1050m to 1710m

| Station (Dist.) | Beaver | | | | | Comments |
|---|---|---|---|---|---|---|
| | # dams | Dam Width | Dam Ht. | WTR Ht. | Active? | |
| 1050 | 1 | 2 | | 0.2 | no | Submerged dam |
| 1080 | | | | | | |
| 1110 | | | | | | |
| 1140 | 1 | 32 | 0.5 | | y | MD seep below dam, threaded stream in trees, B-1-Out |
| 1170 | | | | | | |
| 1200 | | | | | | Animal Trail left (2m) |
| 1230 | | | | | | |
| 1260 | 1 | 3 | 0.4 | | n | Past fence perpendicular to UTR (drove ATVs through gate) |
| 1290 | | | | | | |
| 1320 | | | | | | MD |
| 1350 | | | | | | |
| 1380 | | | | | | |
| 1410 | | | | | | |
| 1440 | | | | | | |
| 1470 | | | | | | |
| 1500 | | | | | | |
| 1530 | | | | | | |
| 1560 | | | | | | LWC-In |
| 1590 | | | | | | |
| 1620 | | | | | | |
| 1650 | | | | | | LWC- Out/Seep after LWC |
| 1680 | | | | | | |
| 1710 | | | | | | UTR |

## USEPA Rapid Habitat Assessment Raw Data Without Beaver Dams

Table B2: USEPA rapid habitat assessment raw data in absence of beaver dams

| | |
|---|---|
| **Site Name: UT** | **Start Point: Highway** |
| **Site Date: 8-18-2016** | **End Point: UTR** |
| **Site Time: 1350** | **Sinuosity 1.38** |

| Station (Dist) | Depth (m) | | | Bnk full depth (m) | | | Width | | | Substrate at transect (add up to 100%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L1/4 | C | R1/4 | L1/4 | C | R1/4 | Water | BF | FP | Silt/Clay | Sand | Gravel | Cobble | Boulder | POM | HPC |
| 30 | 0.4 | 0.7 | 0.4 | 0.6 | 0.9 | 0.6 | 3.0 | 3 | 15 | 60 | 5 | 35 | | | | |
| 60 | 0.1 | 0.3 | 0.1 | 0.4 | 0.6 | 0.4 | 2.9 | 5 | 24 | 85 | | 15 | | | | |
| 90 | 0.5 | 0.4 | 0.1 | 1.0 | 0.9 | 0.6 | 3.1 | 28 | + | 40 | | 55 | | | 5 | |
| 120 | 0.1 | 0.4 | 0.1 | 0.6 | 0.9 | 0.6 | 4.2 | 34 | + | 60 | 25 | 15 | | | | |
| 150 | 0.1 | 0.2 | 0.5 | 0.5 | 0.6 | 0.9 | 1.5 | 24 | + | 10 | 10 | 80 | | | | |
| 180 | 0.2 | 0.5 | 0.2 | 0.5 | 0.8 | 0.5 | 2.6 | 32 | + | | 20 | 80 | | | | |
| 210 | 0.5 | 0.5 | 0.1 | 0.9 | 0.9 | 0.5 | 3.1 | 27 | + | 60 | | 38 | | | 2 | |
| 240 | 0.1 | 0.4 | 0.3 | 0.5 | 0.8 | 0.7 | 2.9 | 21 | + | 100 | | | | | | |
| 270 | 0.4 | 0.7 | 0.4 | 0.8 | 1.1 | 0.8 | 3.7 | 30 | + | 90 | | | | | 10 | |
| 300 | 0.1 | 0.1 | 0.1 | 0.8 | 0.8 | 0.8 | 1.3 | 2 | + | 75 | | | | | 5 | |

+Width exceeded 40 meters

Table B2 Continued: Page 2, 30m to 300m

| Station (Dist) | Habitat Type | | | | In-Stream Cover (% area) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rif | Run | Pool | Dry | UCB | LWD | SWD | Roots | BRL | SAV | EAV | Terr. Veg. | CBG | % Can. Cov. | Pt. Bar | D&S | Bank Veg. | Dom. Veg. |
| 30 | | | x | | | | | | | | | 4 | | 15 | | | S | M |
| 60 | | | x | | | | 5 | | | | | 5 | | 8 | | | S | G |
| 90 | | | x | | | | 2 | | | | | 2 | | 1 | | | S | G/WL |
| 120 | | | x | | | | | | | | | 4 | | 2 | | | S | G/WL |
| 150 | | x | | | | | 5 | | | | | 2 | | 1 | 1 | | S | G/WL |
| 180 | | | x | | | | 4 | | | | | 2 | | 2 | 1 | | S | G/WL |
| 210 | | x | | | | | | | | | | 5 | | 4 | | | S | G/WL |
| 240 | | | x | | | | 5 | | | | | 3 | | 4 | | | S | G/WL |
| 270 | | | x | | | | 2 | | | | | 1 | | 5 | | | S | G/WL |
| 300 | | x | | | | 2 | 15 | | | | | | | 50 | | | S | S |

Table B2 Continued: Page 3, 30m to 300m

| Station (Dist) | % Eroded Bank | | Ht. Eroded | | Deg. Slope | | Rip. Width | | Rip Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right |
| 30 | | | | | 12 | 6 | 10 | 20 | M | M |
| 60 | | | | | 3 | 2 | 15 | 15 | M | M |
| 90 | | | | | 1 | 5 | 22 | 15 | G/WL | M |
| 120 | | | | | 2 | 4 | 15 | 15 | G/WL | M |
| 150 | | | | | 2 | 3 | 12 | 15 | G/WL | G/S |
| 180 | | | | | 5 | 2 | + | 35 | G | G/WL |
| 210 | | | | | 6 | 1 | 24 | 22 | G | G/WL |
| 240 | | | | | 7 | 2 | 15 | 26 | G | M |
| 270 | | | | | 4 | 1 | 10 | 25 | G | G/WL |
| 300 | | | | | 10 | 25 | 10 | + | S | S/WL |

Table B2 Continued: Page 4, 30m to 300m

| Station (Dist) | Tributary | | | | | Cattle | | | |
|---|---|---|---|---|---|---|---|---|---|
| | # trib/bank | Width | D: L1/4 | D: C | D: R1/4 | %Tram. | # CP | Trail | Class |
| 30 | | | | | | | | | |
| 60 | | | | | | | | | |
| 90 | | | | | | | | | |
| 120 | | | | | | | | | |
| 150 | | | | | | | | | |
| 180 | | | | | | | | | |
| 210 | | | | | | | | | |
| 240 | | | | | | | | | |
| 270 | | | | | | | | | |
| 300 | | | | | | | | | |

Table B2 Continued: Page 5, 30m to 300m

| Station (Dist) | Beaver | | | | | Comments |
|---|---|---|---|---|---|---|
| | # dams | Dam Width | Dam Ht. | WTR Ht. | Active? | |
| 30 | | | | | | |
| 60 | | | | | | |
| 90 | | | | | | |
| 120 | | | | | | |
| 150 | 1 | 1 | 0.1 | 0.05 | | Pile of beaver wood exposed. Not blocking entire channel |
| 180 | | | | | | |
| 210 | | | | | | |
| 240 | | | | | | |
| 270 | | | | | | |
| 300 | 1 | Broken | | | | Did not connect MRPTS loop. No water path. Lost 2 transects |

Table B2 Continued: Page 1, 330m to 1020m

| Station (Dist) | Depth (m) | | | Bnk full depth (m) | | | Width | | | Substrate at transect (add up to 100%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L1/4 | C | R1/4 | L1/4 | C | R1/4 | Water | BF | FP | Silt/Clay | Sand | Gravel | Cobble | Boulder | POM | HPC |
| 330 | 0.2 | 0.5 | 0.3 | 0.7 | 1.0 | 0.8 | 4.0 | 19 | + | 95 | | | | | 5 | |
| 360 | 0.2 | 0.3 | 0.2 | 0.6 | 0.7 | 0.6 | 1.0 | 1 | + | 90 | | | | | 10 | |
| 390 | 0.1 | 0.3 | 0.1 | 0.7 | 0.9 | 0.7 | 1.7 | 7 | + | 70 | | | | | 30 | |
| 420 | 0.3 | 0.5 | 0.2 | 0.9 | 1.1 | 0.8 | 2.4 | 30 | + | 70 | | | | | 30 | |
| 450 | 0.3 | 0.5 | 0.3 | 0.9 | 1.1 | 0.9 | 1.5 | 50 | + | 90 | | | | | 10 | |
| 480 | 0.7 | 0.7 | 0.7 | 1.2 | 1.2 | 1.2 | 1.7 | 50 | + | 95 | | | | | 5 | |
| 510 | 0.4 | 0.2 | 0.1 | 0.9 | 0.7 | 0.6 | 2.4 | 35 | + | 70 | | | | | 30 | |
| 540 | 0.3 | 0.8 | 0.2 | 0.9 | 1.4 | 0.8 | 2.8 | 28 | + | 90 | | | | | 10 | |
| 570 | 0.4 | 0.6 | 0.2 | 0.8 | 1.0 | 0.6 | 3.3 | + | + | 75 | | | | | 10 | |
| 600 | 0.6 | 0.6 | 0.4 | 1.6 | 1.6 | 1.4 | 4.5 | 40 | + | 70 | | | | | 30 | |
| 630 | 0.2 | 0.7 | 0.5 | 0.6 | 1.1 | 0.9 | 3.0 | 40 | + | 70 | | | | | 30 | |
| 660 | 0.2 | 0.4 | 0.2 | 0.7 | 0.9 | 0.7 | 1.5 | 25 | + | 40 | | | | | 60 | |
| 690 | 0.4 | 0.5 | 0.4 | 1.1 | 1.2 | 1.1 | 2.6 | 35 | + | 40 | | | | | 60 | |
| 720 | 0.4 | 0.7 | 0.5 | 0.8 | 1.1 | 0.9 | 2.7 | 25 | + | 60 | | | | | 40 | |
| 750 | 0.3 | 0.4 | 0.4 | 0.8 | 0.9 | 0.9 | 2.9 | 30 | + | 60 | | | | | 40 | |
| 780 | 0.3 | 0.9 | 0.6 | 0.9 | 1.5 | 1.2 | 2.0 | 28 | + | 40 | | | | | 60 | |
| 810 | 0.3 | 0.9 | 0.4 | 0.8 | 1.4 | 0.9 | 2.5 | 38 | + | 60 | | | | | 40 | |
| 840 | 0.3 | 0.4 | 0.3 | 0.9 | 1.0 | 0.9 | 2.8 | 40 | + | 50 | | | | | 50 | |
| 870 | 0.3 | 0.3 | 0.2 | 0.7 | 0.7 | 0.6 | 2.5 | + | + | 80 | | | | | 20 | |
| 900 | 0.6 | 0.4 | 0.6 | 1.2 | 1.0 | 1.2 | 4.9 | 25 | + | 50 | | | | | 50 | |
| 930 | 0.1 | 0.3 | 0.3 | 0.8 | 1.0 | 1.0 | 0.7 | 10 | + | 70 | | | | | 30 | |
| 960 | 0.3 | 0.4 | 0.3 | 0.9 | 1.0 | 0.9 | 2.1 | 25 | + | 65 | | 25 | | | 10 | |
| 990 | 0.1 | 0.2 | 0.2 | 0.6 | 0.7 | 0.7 | 2.5 | 35 | + | 50 | | | | | 50 | |
| 1020 | 0.2 | 0.4 | 0.3 | 0.7 | 0.9 | 0.8 | 5.0 | 35 | + | 25 | | 5 | | | 70 | |

+Width exceeded 40 meters

Table B2 Continued: Page 2, 330m to 1020m

| Station (Dist.) | Habitat Type | | | | In-Stream Cover (% area) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rif | Run | Pool | Dry | UCB | LWD | SWD | Roots | BRL | SAV | EAV | Terr. Veg. | CBG | % Can. Cov. | Pt. Bar | D&S | Bank Veg. | Dom. Veg. |
| 330 | | | x | | | | 5 | | | | 2 | | | 25 | | | S | M |
| 360 | | x | | | | 4 | 15 | 5 | | | | | | 45 | | | S | M |
| 390 | | | x | | | 5 | 25 | 3 | | | | 5 | | 15 | | | S | S |
| 420 | | | x | | | 2 | 35 | 8 | | | | 4 | | 35 | | | S | M |
| 450 | | | x | | | | 10 | 8 | | | | 6 | | 15 | | | S | G |
| 480 | | | x | | | | 5 | 4 | | | 3 | 7 | | 5 | | | S | G |
| 510 | | | x | | | | 18 | 3 | | | | | | 25 | | | S | M |
| 540 | | | x | | | | 12 | 5 | | | 3 | | | 20 | | | S | S |
| 570 | | | x | | | | 28 | | | | 10 | 2 | | 8 | | | S | G |
| 600 | | | x | | | 2 | 25 | 3 | | | 5 | 6 | | 35 | | | S | M |
| 630 | | | x | | | | 15 | 6 | | | 10 | 4 | | 65 | | | S | M |
| 660 | | | x | | | | 10 | | | | 40 | 2 | | 16 | | | S | M |
| 690 | | | x | | | | 10 | 3 | | | 75 | 3 | | 15 | | | S | M |
| 720 | | | x | | | 5 | 15 | 4 | | | 65 | | | 18 | | | S | M |
| 750 | | | x | | | | 5 | 5 | | | 70 | 2 | | 10 | | | S | T |
| 780 | | | x | | | | 3 | 1 | | | 70 | 1 | | 20 | | | S | T |
| 810 | | | X | | | | 10 | | | | 90 | | | 80 | | | S | G |
| 840 | | | X | | | 5 | 45 | | | | 50 | | | 75 | | | S | M |
| 870 | | | X | | | 2 | 18 | | | | 75 | 2 | | 90 | | | S | G |
| 900 | | | X | | | 6 | 29 | | | | 85 | 5 | | 85 | | | S | M |
| 930 | | X | | | | 2 | 15 | 10 | | | 60 | | | 60 | | | S | G |
| 960 | | X | X | | | 6 | 30 | | | | 25 | 1 | | 30 | | | S | S |
| 990 | | X | | | | | 15 | 20 | | | 40 | 3 | | 60 | | | S | T |
| 1020 | | | X | | | 35 | 20 | | | | 60 | | | 80 | | | S | T |

Table B2 Continued: Page 3, 330m to 1020m

| Station (Dist) | % Eroded Bank | | Ht. Eroded | | Deg. Slope | | Rip. Width | | Rip Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right |
| 330 | | | | | 7 | 2 | + | + | G | M |
| 360 | | | | | 1 | 1 | + | + | G | G |
| 390 | | | | | 12 | 2 | + | + | G | G |
| 420 | | | | | 3 | 1 | 18 | + | G | G |
| 450 | | | | | 2 | 4 | + | + | M | G |
| 480 | | | | | 1 | 3 | + | + | S | G |
| 510 | | | | | 2 | 25 | + | + | G | G |
| 540 | | | | | 1 | 29 | + | + | M | G |
| 570 | | | | | 4 | 1 | 25 | + | M | G |
| 600 | | | | | 20 | 1 | 10 | + | T | G |
| 630 | | | | | 4 | 2 | 8 | + | T | G |
| 660 | | | | | 6 | 1 | 10 | + | T | G |
| 690 | | | | | 20 | 2 | 25 | + | T | G |
| 720 | | | | | 2 | 6 | + | + | T | M |
| 750 | | | | | 4 | 5 | + | + | T | T |
| 780 | | | | | 2 | 2 | + | + | M | M |
| 810 | | | | | 2 | 2 | 35 | 15 | M | M |
| 840 | | | | | 1 | 3 | + | + | M | T |
| 870 | | | | | 4 | 2 | 18 | + | T | T |
| 900 | | | | | 6 | 2 | 10 | + | T | T |
| 930 | | | | | 4 | 5 | 15 | 25 | T | T |
| 960 | | | | | 6 | 2 | + | 30 | M | M |
| 990 | | | | | 3 | 7 | + | 8 | S | M |
| 1020 | | | | | 2 | 6 | + | 20 | S | T |

+Width exceeded 40 meters

Table B2 Continued: Page 4, 330m to 1020m

| Station (Dist) | Tributary | | | | | Cattle | | | |
|---|---|---|---|---|---|---|---|---|---|
| | # trib/bank | Width | D: L1/4 | D: C | D: R1/4 | %Tram. | # CP | Trail | Class |
| 330 | 1R | 1.4 | 0.15 | 0.2 | 0.3 | | | | |
| 360 | | | | | | | | | |
| 390 | | | | | | | | | |
| 420 | | | | | | | | | |
| 450 | | | | | | | | | |
| 480 | | | | | | | | | |
| 510 | | | | | | | | | |
| 540 | | | | | | | | | |
| 570 | | | | | | | | | |
| 600 | | | | | | | | | |
| 630 | | | | | | | | | |
| 660 | | | | | | | | | |
| 690 | | | | | | | | | |
| 720 | | | | | | | | | |
| 750 | | | | | | | | | |
| 780 | | | | | | | | | |
| 810 | | | | | | | | | |
| 840 | | | | | | | | | |
| 870 | | | | | | | | | |
| 900 | 1L | 2 | 0 | 0 | 0 | | | | |
| 930 | | | | | | | | | |
| 960 | | | | | | | | | |
| 990 | | | | | | | | | |
| 1020 | | | | | | | | | |

Table B2 Continued: Page 5, 330m to 1020m

| Station (Dist) | Beaver | | | | | Comments |
|---|---|---|---|---|---|---|
| | # dams | Dam Width | Dam Ht. | WTR Ht. | Active? | |
| 330 | | | | | | Effluent MRPTS Bypass trib |
| 360 | 1 | Broken | | | | 420 Transect from Habitat 1 |
| 390 | 1 | Broken | | | | |
| 420 | | | | | | 480 Transect from habitat 1 |
| 450 | | | | | | utu |
| 480 | | | | | | |
| 510 | | | | | | |
| 540 | | | | | | |
| 570 | | | | | | |
| 600 | | | | | | |
| 630 | | | | | | |
| 660 | 1 | 14 | | 0.6 | No | Dam Uncovered when water dropped |
| 690 | | | | | | |
| 720 | | | | | | |
| 750 | | | | | | |
| 780 | | | | | | |
| 810 | | | | | | |
| 840 | 1 | Broken | | | | B3 |
| 870 | | | | | | |
| 900 | | | | | | Drainage by beaver dens |
| 930 | 1 | Broken | | | | B2 |
| 960 | | | | | | |
| 990 | 1 | Broken | | | | |
| 1020 | | | | | | |

Table B2 Continued: Page 1, 1050m to 1650m

| Station (Dist) | Depth (m) | | | Bnk full depth (m) | | | Width | | | Substrate at transect (add up to 100%) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L1/4 | C | R1/4 | L1/4 | C | R1/4 | Water | BF | FP | Silt/Clay | Sand | Gravel | Cobble | Boulder | POM | HPC |
| 1050 | 0.2 | 0.3 | 0.2 | 0.9 | 1.0 | 0.9 | 2.7 | 15 | + | 25 | | 75 | | | | |
| 1080 | 0.1 | 0.2 | 0.1 | 1.1 | 1.2 | 1.1 | 0.9 | 20 | 40 | 40 | 50 | 10 | | | | |
| 1110 | 0.1 | 0.4 | 0.1 | 0.8 | 1.1 | 0.8 | 2.5 | 19 | 38 | 70 | | 15 | | | 15 | |
| 1140 | 0.2 | 0.5 | 0.3 | 0.8 | 1.1 | 0.9 | 3.9 | 12 | + | 70 | | | | | 30 | |
| 1170 | 0.3 | 0.5 | 0.3 | 0.7 | 0.9 | 0.7 | 3.1 | 30 | + | 30 | | | | | 70 | |
| 1200 | 0.4 | 0.4 | 0.5 | 1.0 | 1.0 | 1.1 | 4.3 | 19 | + | 60 | | | | | 40 | |
| 1230 | 0.2 | 0.0 | 0.1 | 0.7 | 0.5 | 0.6 | 1.7 | 25 | + | | | 95 | | | 5 | |
| 1260 | 0.3 | 0.3 | 0.3 | 0.7 | 0.7 | 0.7 | 3.3 | 17 | + | 25 | 5 | 70 | | | | |
| 1290 | 0.3 | 0.2 | 0.8 | 0.8 | 0.7 | 1.3 | 6.0 | 12 | 35 | 15 | 10 | 75 | | | | |
| 1320 | 0.6 | 0.8 | 0.6 | 1.0 | 1.2 | 1.0 | 4.2 | 8 | 15 | 25 | | 75 | | | | |
| 1350 | 0.6 | 0.7 | 0.8 | 1.7 | 1.8 | 1.9 | 4.4 | 18 | 25 | 50 | | 50 | | | | |
| 1380 | 0.3 | 0.8 | 0.6 | 0.7 | 1.2 | 1.0 | 7.3 | 12 | 20 | 20 | | 70 | | | 10 | |
| 1410 | 1.1 | 1.1 | 0.4 | 1.5 | 1.5 | 0.8 | 5.3 | 12 | 25 | 50 | | 50 | | | | |
| 1440 | 0.6 | 0.9 | 0.6 | 0.9 | 1.2 | 0.9 | 5.0 | 12 | 18 | 45 | | 40 | | | 15 | |
| 1470 | 0.5 | 0.8 | 0.5 | 0.8 | 1.1 | 0.8 | 0.8 | 10 | 20 | 100 | | | | | | |
| 1500 | 0.9 | 1.4 | 0.9 | 1.1 | 1.6 | 1.1 | 6.2 | 35 | + | 90 | | | | | 10 | |
| 1530 | 0.8 | 1.2 | 0.9 | 1.1 | 1.5 | 1.2 | 6.1 | 17 | + | 85 | | | | | 15 | |
| 1560 | 0.6 | 0.6 | 0.4 | 0.7 | 0.7 | 0.5 | 8.0 | 35 | + | 25 | | | | | 75 | |
| 1590 | 0.3 | 0.2 | 0.1 | 0.7 | 0.6 | 0.5 | 5.2 | 8 | + | | 15 | 70 | 10 | | 5 | |
| 1620 | 0.4 | 0.3 | 0.2 | 1.7 | 1.6 | 1.5 | 5.2 | 10 | 15 | | 15 | 60 | | | 25 | |
| 1650 | 0.1 | 0.2 | 0.2 | 1.3 | 1.4 | 1.4 | 2.0 | 20 | 35 | 40 | 10 | 35 | | | 15 | |

+Width exceeded 40 meters

Table B2 Continued: Page 2, 1050m to 1650m

| Station (Dist) | Habitat Type | | | | In-Stream Cover (% area) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rif | Run | Pool | Dry | UCB | LWD | SWD | Roots | BRL | SAV | EAV | Terr. Veg. | CBG | % Can. Cov. | Pt. Bar | D&S | Bank Veg. | Dom. Veg. |
| 1050 | | | X | | | 20 | 20 | | | | 30 | | | 45 | | | S | M |
| 1080 | | X | | | | 3 | 35 | 20 | | | 10 | 5 | | 69 | | | S | T |
| 1110 | | X | | | | | 15 | | | | | 5 | | 75 | | | S | T |
| 1140 | | | X | | | | 5 | | | | 65 | 3 | | 80 | | | S | M |
| 1170 | | | X | | | 2 | 5 | 3 | | | 60 | | 20 | 85 | | | S | M |
| 1200 | | | X | | | 1 | 10 | | | | 20 | | | 60 | | | S | M |
| 1230 | | X | | | | 2 | 15 | | | | 5 | | | 75 | | | S | T |
| 1260 | | X | | | | | 20 | 10 | | | | 4 | | 65 | | | S | T |
| 1290 | | | X | | | | 5 | 7 | | | 3 | | | 70 | | | S | T |
| 1320 | | | X | | | 1 | 5 | | | | 50 | | | 45 | | | S | T |
| 1350 | | | X | | | | 10 | | | | 5 | | | 60 | | | S | T |
| 1380 | | | X | | | | | 5 | | | 20 | | | 45 | | | S | T |
| 1410 | | | X | | | | 5 | | | | 25 | | | 35 | | | S | T |
| 1440 | | | X | | | | 5 | | | | 20 | | | 30 | | | S | T |
| 1470 | | | X | | | | 3 | | | | 68 | | | 85 | | | S | T |
| 1500 | | | X | | | | 5 | | | | 40 | | | 65 | | | S | T |
| 1530 | | | X | | | | 10 | | | | 2 | | | 55 | | | S | T |
| 1560 | | | X | | | | 10 | | | | 25 | | | 40 | | | S | T |
| 1590 | | | X | | | 2 | 8 | 10 | | | | | | 15 | | | S | T |
| 1620 | | | X | | | | | | | | 2 | | | 35 | | | S | T |
| 1650 | | | X | | | 4 | 10 | 15 | | | | | | 60 | | | S | T |

Table B2 Continued: Page 3, 1050m to 1650m

| Station (Dist) | % Eroded Bank | | Ht. Eroded | | Deg. Slope | | Rip. Width | | Rip Condition | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Left | Right | Left | Right | Left | Right | Left | Right | Left | Right |
| 1050 | | | | | 4 | 9 | + | 20 | M | T |
| 1080 | | | | | 2 | 6 | + | 18 | S | T |
| 1110 | | | | | 3 | 15 | + | 30 | M | T |
| 1140 | | | | | 2 | 4 | 10 | * | T | M |
| 1170 | | | | | 1 | 1 | 15 | 25 | M | G |
| 1200 | | | | | 6 | 2 | 40 | 20 | M | G |
| 1230 | | | | | 4 | 3 | + | 15 | M | M |
| 1260 | | | | | 12 | 5 | 20 | 18 | M | T |
| 1290 | | | | | 3 | 15 | 25 | 12 | G | T |
| 1320 | | | | | 10 | 7 | 20 | 1 | G | T |
| 1350 | | | | | 5 | 30 | 25 | 10 | G | M |
| 1380 | | | | | 4 | 5 | 25 | 35 | T | M |
| 1410 | | | | | 6 | 5 | 25 | 25 | T | M |
| 1440 | | | | | 8 | 4 | 18 | 12 | M | T |
| 1470 | | | | | 4 | 2 | 20 | 1 | M | G |
| 1500 | | | | | 1 | 2 | 8 | 5 | T | T |
| 1530 | | | | | 1 | 1 | 10 | 12 | T | M |
| 1560 | | | | | 1 | 1 | 1 | 10 | T | M |
| 1590 | | | | | 40 | 25 | 2 | 2 | T | T |
| 1620 | | | | | 25 | 35 | 8 | 20 | T | M |
| 1650 | | | | | 70 | 8 | + | 18 | T | M |

+Width exceeded 40 meters

Table B2 Continued: Page 4, 1050m to 1650m

| Station (Dist) | Tributary | | | | | Cattle | | | |
|---|---|---|---|---|---|---|---|---|---|
| | # trib/bank | Width | D: L1/4 | D: C | D: R1/4 | %Tram. | # CP | Trail | Class |
| 1050 | | | | | | | | | |
| 1080 | | | | | | | | | |
| 1110 | | | | | | | | | |
| 1140 | | | | | | | | | |
| 1170 | | | | | | | | | |
| 1200 | | | | | | | | | |
| 1230 | | | | | | | | | |
| 1260 | | | | | | | | | |
| 1290 | | | | | | | | | |
| 1320 | | | | | | | | | |
| 1350 | | | | | | | | | |
| 1380 | | | | | | | | | |
| 1410 | | | | | | | | | |
| 1440 | | | | | | | | | |
| 1470 | | | | | | | | | |
| 1500 | | | | | | | | | |
| 1530 | | | | | | | | | |
| 1560 | 1L | 12 | 0.2 | 0.4 | 0.3 | | | | |
| 1590 | | | | | | | | | |
| 1620 | | | | | | | | | |
| 1650 | | | | | | | | | |

Table B2 Continued: Page 5, 1050m to 1650m

| Station (Dist) | Beaver | | | | | Comments |
|---|---|---|---|---|---|---|
| | # dams | Dam Width | Dam Ht. | WTR Ht. | Active? | |
| 1050 | | | | | | |
| 1080 | 1 | Broken | | | | B1 |
| 1110 | | | | | | |
| 1140 | | | | | | |
| 1170 | | | | | | |
| 1200 | 1 | Broken | | | | First dam we broke the day before |
| 1230 | | | | | | |
| 1260 | | | | | | |
| 1290 | | | | | | |
| 1320 | | | | | | |
| 1350 | | | | | | |
| 1380 | | | | | | |
| 1410 | | | | | | |
| 1440 | | | | | | |
| 1470 | | | | | | |
| 1500 | | | | | | |
| 1530 | | | | | | |
| 1560 | | | | | | |
| 1590 | | | | | | |
| 1620 | | | | | | |
| 1650 | | | | | | |

# Appendix C

Appendix C: Rosgen Stream Classification Raw Data

## Rosgen Stream Classification: Raw Data

Table C1: Rosgen stream classification raw data for UT

| 3 | | Width (m) | | | Depth (m) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Notes | Station (m) | Water | Bankfull | Flood-Prone | Mean BF | Maximum | Entrenchment Ratio | W/D Ratio | Primary Bed Material | Rosgen Classification |
| B4 In | 30 | 3.1 | 11 | + | 0.97 | 1.2 | >2.2 | 11.3 | Silt/Clay | C6 |
| | 60 | 3.8 | 9.3 | + | 0.83 | 0.9 | >2.2 | 11.2 | Silt/Clay | C6 |
| | 90 | 4.05 | + | + | 0.92 | 1 | >2.2 | >12 | Silt/Clay | *C6 |
| | 120 | 6.5 | + | + | 0.90 | 1 | >2.2 | >12 | Silt/Clay | *C6 |
| | 150 | 12.6 | + | + | 0.53 | 0.6 | >2.2 | >12 | Silt/Clay | *C6 |
| | 180 | 5.7 | + | + | 0.90 | 1 | >2.2 | >12 | Silt/Clay | *C6 |
| | 210 | 6 | 33 | 33 | 0.83 | 1 | 1 | 39.6 | Silt/Clay | Not Classifiable |
| | 240 | 19 | 21 | 21 | 0.87 | 1.1 | 1 | 24.2 | Silt/Clay | Not Classifiable |
| | 270 | 17 | 21 | 21 | 1.00 | 1.1 | 1 | 21 | Silt/Clay | Not Classifiable |
| B4 Out | 300 | 22 | 30 | 30 | 0.73 | 1.2 | 1 | 40.9 | Silt/Clay | Not Classifiable |
| B7 in | 330 | 17 | + | + | 0.67 | 0.9 | >2.2 | | Silt/Clay | Not Classifiable |

*Severely impacted by beaver activity; Shaded indicates parameters were higher than 40 meters

Table C1 Continued

| | | Width (m) | | | Depth (m) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Notes | Station (m) | Water | Bankfull | Flood-Prone | Mean BF | Maximum | Entrenchment Ratio | W/D Ratio | Primary Bed Material | Rosgen Classification |
| B7 out/B6 in | 360 | 13 | 35 | + | 0.77 | 1.0 | >2.2 | 45.7 | Silt/Clay | *C6 |
| | 390 | 7.7 | 20 | 25 | 1.10 | 1.2 | 1.25 | 18.2 | Silt/Clay | F6 |
| | 420 | 1.6 | 10 | + | 1.35 | 1.4 | >2.2 | 7.4 | Silt/Clay and POM | C6 |
| B6 out | 450 | 1.6 | 5 | + | 1.37 | 1.5 | >2.2 | 3.7 | Silt/Clay and POM | *C6 |
| | 480 | 2.75 | 6 | + | 1.30 | 1.4 | >2.2 | 4.6 | POM | E6 |
| | 510 | 2.3 | 18 | + | 0.98 | 1.1 | >2.2 | 18.3 | POM | C6 |
| | 540 | 1.9 | 9 | + | 1.17 | 1.2 | >2.2 | 7.7 | POM | E6 |
| | 570 | 3.4 | 14 | + | 0.74 | 0.8 | >2.2 | 18.9 | Silt/Clay pom | C6 |
| B5 in | 600 | 6 | 25 | + | 1.30 | 1.6 | >2.2 | 19.2 | Silt/Clay pom | C6 |
| | 630 | 2.9 | 8 | + | 1.23 | 1.4 | >2.2 | 6.5 | POM | E6 |
| B5 out | 660 | 3.7 | 20 | + | 1.35 | 1.4 | >2.2 | 14.8 | POM | *C6 |
| | 690 | 5.4 | 20 | + | 1.00 | 1.2 | >2.2 | 20.0 | POM | C6 |
| | 720 | 5 | 24 | + | 1.00 | 1.2 | >2.2 | 24.0 | POM | C6 |
| | 750 | 6.5 | 22 | + | 1.23 | 1.4 | >2.2 | 17.8 | POM | C6 |
| B3 in | 780 | 6 | 20 | + | 0.95 | 1.3 | >2.2 | 21.1 | Silt/Clay | C6 |
| | 810 | 12 | 30 | + | 0.90 | 1.1 | | 33.3 | Silt/Clay | Not Classifiable |
| B3 out/B2 in | 840 | 16 | 18 | + | 0.90 | 1.5 | | 20.0 | Silt/Clay | Not Classifiable |
| | 870 | 5.1 | + | + | 1.00 | 1.4 | | | Silt/Clay | Not Classifiable |
| | 900 | 14 | + | + | 1.02 | 1.3 | | | POM | Not Classifiable |
| | 930 | 17 | + | + | 0.55 | 0.9 | | | Silt/Clay | Not Classifiable |
| B2 out | 960 | 18 | + | + | 0.70 | 1.0 | | | POM | Not Classifiable |
| | 990 | 38 | + | + | 0.30 | 0.3 | MC | >40 | Silt/Clay | D6 |
| | 1020 | 2.75 | + | + | 0.97 | 1.0 | MC | <40 | Silt/Clay | DA6 |
| B1 in | 1050 | 7.5 | 30 | + | 0.83 | 0.9 | MC | 36.0 | Silt/Clay | DA6 |
| B1 out | 1080 | 8.2 | 23 | + | 1.00 | 1.1 | MC | 23.0 | Silt/Clay pom | DA6 |

Table C1 Continued

| | | Width (m) | | | Depth (m) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Notes | Station (m) | Water | Bankfull | Flood-Prone | Mean BF | Maximum | Entrenchment Ratio | W/D Ratio | Primary Bed Material | Rosgen Classification |
| | 1110 | 12.0 | + | + | 0.97 | 1.1 | Multiple Channels | <40 | Gravel | DA4 |
| | 1140 | 2.0 | + | + | 0.47 | 0.7 | Multiple Channels | >40 | Gravel | D4 |
| | 1170 | 2.8 | 18 | + | 1.08 | 1.4 | >2.2 | 16.6 | Gravel | C4 |
| | 1200 | 3.9 | 18 | + | 1.18 | 1.3 | >2.2 | 15.2 | Silt/Clay | C6 |
| | 1230 | 14.0 | 22 | + | 0.92 | 1.2 | >2.2 | 24.0 | Silt/Clay | C6 |
| | 1260 | 4.8 | 20 | + | 1.00 | 1.1 | >2.2 | 20.0 | Silt/Clay | C6 |
| | 1290 | 4.0 | 21 | + | 0.80 | 1.1 | >2.2 | 26.3 | Gravel | C4 |
| | 1320 | 4.0 | 14 | + | 1.00 | 1.2 | >2.2 | 14.0 | Gravel | C4 |
| | 1350 | 7.3 | 16 | 30 | 0.93 | 1.2 | 1.9 | 17.1 | Gravel | C4 |
| | 1380 | 4.0 | 5 | 9 | 0.70 | 0.8 | 1.8 | 7.1 | Gravel | E4 |
| | 1410 | 2.5 | 3.5 | 15 | 1.06 | 1.2 | 4.3 | 3.3 | Silt/Clay | E6 |
| | 1440 | 7.1 | 9 | + | 0.99 | 1.1 | >2.2 | 9.1 | Gravel | E4 |
| | 1470 | 5.3 | 6.5 | 24 | 1.06 | 1.4 | 3.7 | 6.1 | Silt/Clay | E6 |
| | 1500 | 5.8 | 9 | + | 1.05 | 1.1 | >2.2 | 8.6 | Silt/Clay | E6 |
| | 1530 | 7.2 | 15 | + | 0.85 | 1.0 | >2.2 | 17.7 | Silt/Clay | C6 |
| LWC in | 1560 | 5.9 | 21 | + | 1.46 | 1.7 | >2.2 | 14.4 | Silt/Clay | C6 |
| | 1590 | 5.9 | 20 | + | 1.55 | 1.9 | >2.2 | 12.9 | Silt/Clay | E6 |
| LWC out | 1620 | 7.9 | 21 | + | 0.70 | 0.8 | >2.2 | 30.0 | POM | C6 |
| | 1650 | 3.4 | 13 | 18 | 0.49 | 0.6 | 1.4 | 26.5 | Gravel | C4 |
| UTR | 1680 | 4.4 | 6 | 29 | 0.85 | 0.9 | 4.8 | 7.0 | Silt/Clay | E6 |
| | 1710 | 2.1 | 5.5 | 24 | 1.11 | 1.2 | 4.4 | 4.9 | Silt/Clay | E6 |