# BEAVER DAM DIMENSIONS AND DISTRIBUTION IN NORTHEASTERN NEW MEXICO

by

Rachel M. Cavin, B.S.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science
with a Major in Geography
August 2015

Committee Members:

David R. Butler

Richard W. Dixon

Kimberly M. Meitzen

## ACKNOWLEDGEMENTS

So many people, more than I can possibly name here, have helped, inspired, and if nothing else endured me throughout this research. I feel incredibly lucky to have so many people in my life who give me strength and support.

The person who has invested the most, and inspired the majority of this research is my advisor, Dr. David R. Butler. I owe so many of my successes and accomplishments to his patient and kind mentorship over the past two years. He has been a friend, a teacher, a coauthor, a mentor, a listening ear, a source of inspiration for my own research goals and interests, a kindred spirit, and most of all an unwavering source of support no matter how discouraged, confused, or difficult I was throughout this process. Growing up, I was fascinated by the relationships between animals and their habitat. Dr. Butler taught me that I can continue this lifelong fascination in my research through the study of biogeomorphology. He continues to be an enormous source of encouragement, guidance, and inspiration and I am truly grateful and proud that I have had the opportunity to work with him. Thank you for being my "geography dad," Dr. Butler, and for helping me become the person I've always wanted to be.

Dr. Richard Dixon is a big part of why the sentence "I like math" has ever been uttered by me. He makes math pragmatic and approachable, which is appreciated because it was historically a struggle for me, but my abilities have improved dramatically while I have been his student. More importantly though, Dr. Dixon has been the professor who I

felt I could open up to most when I was having a hard time in graduate school. Dr. Dixon has seen me cry more than anyone else, and he still thinks highly of me despite it! Every time I have ever asked Dr. Dixon a simple question in his office, it has ended up being a thirty minute conversation about my goals, progress, concerns, challenges, or interests. His selfless, genuine approach to advising his students is appreciated and valued, he is a close friend and mentor to me. Thank you, Dr. Dixon, for teaching me how to feel confident using quantitative methods, that even though I'm an emotional wreck I can still accomplish incredible things, and that it's okay if your original plans don't work out, to just try something else and do your best. You've taught me so much more than just statistics.

Dr. Kimberly Meitzen has been a huge role model throughout my master's degree. I look up to her as a young, but brilliant and successful female scientist working in riverine biogeography research, as I would like my career to involve similar work. The time we spent in Congaree National Park together doing field work taught me so much about geography, science, and how to actually use a field map for navigation purposes, which is a skill I was woefully deficient in! Her rigorous research standards are something I aspire to; her input on this project has been invaluable. Thank you Dr. Meitzen, for teaching me that swamps are actually pretty neat, for your tremendous and incredibly helpful guidance in the design of the landscape characteristics portion of this research, and for showing me that even though graduate school is stressful and hard, you

have to prioritize your own needs and interests.

Several other professors have had a profound impact on my development as a researcher, teacher, and scientist, despite not being on the committee for this research project. Drs. Jennifer Jensen, Edwin Chow, Richard Earl, Yongmei Lu, and Colleen Hiner have all had a role in supporting me throughout my graduate studies. I thank each of you for your guidance, understanding, and encouragement throughout my time at Texas State University. The Geography Department staff are all amazing people, and in particular I could not have done this without Allison Glass-Smith and Charles Robinson, thank you both for everything you do.

My mom, Kay Kelso, has always been my biggest supporter, whether it was my love of music, art, or science, she has always encouraged me to explore and experiment with new skills and aspirations. Her support went so far as her volunteering to be my field assistant during the field data collection for this project, and I have some of the best and most hilarious memories of my life from those days. She always knows how to make me laugh, help me through challenges, and cheer me up. My dad, Jim Cavin, has been a source of support and inspiration from a young age. When I was very young, we used to catch lizards and toads together, watch The Crocodile Hunter, and talk about animals all the time. He has been a source of support throughout my studies, and is always happy to hear a geographer's perspective on the weather. John Kelso, my stepdad, has never said no to offering feedback on a draft, though he seldom understands the science, he knows a lot more about proper punctuation than I do! He has always supported me as an aspiring scientist, but especially when it comes to my writing.

To all of my friends who have been there for me throughout this process, thank you. Paul Zunkel, Zoe Zell, Katy Onley, Sam Abbott, Brooke Richardson, Kristen Newcomer, Daffy Gimnich, Tom Shelton, and Ashley Jenkins have made graduate school a truly enjoyable and hilarious experience, I will miss each of you so much and hope we continue to be friends for a very long time. Nina Vadiei has been my best friend since I was a child, and I am so proud of the brilliant, successful people we have grown up to be.

Finally, thank you to the New Mexico State Parks Division for the approval of my research permit related to this study, and for all assistance and advice I received during my field work in the Summer of 2013.

This list is far from exhaustive, thank you everyone who has had a positive place in my life.

## TABLE OF CONTENTS

**Page**

## LIST OF TABLES

## LIST OF FIGURES

**Figure** **Page**

## LIST OF ABBREVIATIONS

| Abbreviation | Description |
|---|---|
| DEM | Digital Elevation Model |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| km | Kilometer |
| m | meter |
| m.y. | Million Years |
| NAIP | National Agriculture Imagery Program |
| NM | New Mexico |
| NMGIS | New Mexico Geographic Information System |
| Spp. | Species |
| US | United States |
| USA | United States of America |
| USDA | United States Department of Agriculture |
| USGS | United States Geological Survey |

# ABSTRACT

The impacts of beaver dams on the geomorphology and ecology of the landscapes on which they are built have grown to become a significant body of literature in recent decades. Additionally, the landscape characteristics most suitable for beaver and dam construction have been modeled, revealing factors important for quality beaver habitat and beaver dam establishment. Beaver dam dimensions, structure, and attributes have not been emphasized in these studies, and little is known about how the landscape influences beaver dam morphology and distribution. The purpose of this study was to examine how beaver dams differ in dimension, structure, and distribution between two New Mexico state parks, then to assess the landscape characteristics spatially associated with these differences. Results indicate that narrow valley widths inhibit beaver dam establishment. High values in stream gradient and sinuosity also appear to inhibit beaver dam establishment. Narrow valley widths, high stream gradients, high sinuosity, and larger upstream catchment areas appear to be most relevant to the incidence of gap flow beaver dams. In particular, beaver dams downstream of narrow valley widths appear to be most vulnerable to breaches. Multithread channels, wider valleys, and low-moderate stream gradients appear advantageous for the establishment of beaver dams. It was difficult to determine patterns related to vegetation and beaver dam establishment, because beavers modify vegetation communities by selective foraging and cutting.

# CHAPTER I

## INTRODUCTION

North American Beavers (*Castor canadensis*) exert tremendous influence on the ecology, hydrology, and geomorphology of the landscapes within their geographic range. In the literature, beavers are commonly described as both zoogeomorphic agents, meaning species that initiate or alter geomorphic processes on landscapes, and ecosystem engineers, referring to species that create new ecosystems on landscapes through natural behaviors (Butler 1995; Wright, Jones, and Flecker 2002). The most conspicuous behavior of the beaver is the construction of dams in rivers, floodplains, deltas, and other environments where water might pool upstream of the dam from surface or hyporheic flow (Figure 1; Dugmore 1914; Gurnell 1998; Butler 2012). These upstream pools, often referred to as beaver ponds, are engineered as safe habitats for the beaver family. Beavers build lodges with underwater entrances in or near these ponds, and forage for food and additional construction materials nearby (Dugmore 1914; Howard and Larson 1985). However, the effects of dam building and pond formation are not limited to the creation of a new habitat suitable for a beaver family. The construction of dams lowers stream velocity and alters discharge, increases channel complexity, raises the water table and saturates nearby soils, accumulates sediments on the pond floor, enhances biodiversity at the landscape scale, and can increase karstification (Cowell 1984; Naiman, Johnston, and Kelley 1988; Viles 1988; Hammerson 1994; Butler 1995). If dams endure multiple decades without being washed away by floodwaters, eventually they infill with accumulated sediments creating a fertile wetland meadow (Ives 1942; Butler and Malanson 1994).

Figure 1: A beaver dam sequence in Coyote Creek State Park, New Mexico.

The various influences beaver have on landscapes have been studied in the literature for decades, and the prevalence of these studies has increased in recent years as understanding and intrigue with the significance of beaver on landscapes has grown. Common in the literature are studies describing the many ecological impacts of beaver activity. Beaver alter and enhance the riparian zone, which provides valuable edge habitat for many species of plants and animals (Apple 1985; Hammerson 1994; Wilkinson 2003; Demmer and Beschta 2008). This is especially important in more arid regions, where riparian habitat is scarce (Apple 1985; Skinner, Smith, Dodd, and Rodgers 1988). Through building dams and impounding water, beavers initiate the creation and maintenance of wetlands, which are critically important to the conservation of many species, such as wood frogs, spotted salamanders, and many species of migratory waterfowl, after decades of wetlands habitat loss in North America (McKinstry, Caffrey, and Anderson 2001; Karraker and Gibbs 2009). Beavers also influence the cycling of nutrients, and increase organic content in streambeds (Naiman, Johnston, and Kelley 1988; Hammerson 1994). The geomorphological effects of beaver activity are another common area of research (Viles 1988; Butler 1995; Gurnell 1998, Westbrook, Cooper, and Butler 2013). Rates of sedimentation in beaver ponds have been described and quantified (Butler and Malanson 1995; Meentemeyer and Butler 1999; Bigler, Butler, and Dixon 2001; Butler and Malanson 2005). Catchment of sediments in the ponds upstream of dams causes decreased turbidity downstream (Hammerson 1994). Sediment deposition occurs in the ponds as a result of beaver dams decreasing stream velocity and sediment capacity by terracing the stream channel and lowering the stream grade (Butler and Malanson 1995). In contrast, the removal or failure of dams can cause increased erosion in the stream channel leading to entrenchment of the river bed (Marston 1994).

All of the previously mentioned landscape and ecosystem alterations begin with the construction of a beaver dam. Researchers have developed models since the 1970s in order to determine landscape characteristics important to beaver habitat and colony establishment. The landscape characteristics that have been found significant for beaver habitat include stream gradient, riparian vegetation communities, aquatic habitat availability, and availability of winter food supplies (Slough and Sadleir 1977; Allen 1983; Howard and Larson 1985; McComb, Sedell, and Buchholz 1990; Nolet, Hoekstra, and Ottenheim 1994; Barnes and Mallik 1997; Suzuki and McComb 1998). None of these studies investigated relationships between landscape characteristics and beaver dam dimensions, or how the landscape influences beaver dam distribution and duration. Angela Gurnell (1998) asserted that a current limitation in beaver dam research is the continued reporting of beaver dam dimensions without seeking to understand the physical factors that may cause those dimensions.

Several studies have inventoried beaver dams and examined changes in beaver colonies through time (Warren 1932; Scheffer 1938; Neff 1959; Woo and Waddington 1990; Zurowski 1992; Demmer and Beschta 2008). Some of these studies reported beaver dam dimensions, especially for dams that reached exceedingly large sizes (Warren 1932; Scheffer 1938; Neff 1959; Woo and Waddington 1990; Demmer and Beschta 2008). Few studies have statistically analyzed beaver dam dimension samples, and those that have are limited to descriptive mean, minimum, and maximum values (Scheffer 1938; Woo and Waddington 1990; Demmer and Beschta 2008). Some studies have examined the distribution of beaver dams, especially by calculating the density of dams over a measure of stream distance (Naiman, Melillo, and Hobbie 1986; Woo and Waddington 1990). Beaver ponds and their associated dams have been mapped using a series of aerial photographs or high resolution satellite imagery over a period of time to assess changes in distribution of dams and ponds (Johnston and Naiman 1990; Christian 2013). However, despite increasing attention to the impacts of beavers on landscapes, mapping of beaver ponds and dams is still scarce in the literature. Beaver populations continue to grow throughout the United States, and without current maps it is difficult to determine the extent of their recovery and recolonization. Past studies have looked for relationships between landscape characteristics and dam site selection by beavers, either through habitat modeling or careful site analysis (Slough and Sadleir 1977; Allen 1983; McComb, Sedell, and Buchholz 1990; Barnes and Mallik 1997). However, no known study specifically examines how beaver dam dimensions and structures differ between two landscapes, and what characteristics of those landscapes may cause those differences.

The objectives of this study were to measure the current beaver dam dimensions, then to explore how landscape characteristics may influence the differences in beaver dam dimensions and distribution, between Cimarron Canyon and Coyote Creek State Parks in northeastern New Mexico. The research questions investigated were 1) What are the dimensions and structures of the beaver dams sampled in the study? How do these dimensions and structures differ between the two study sites? 2) How are the beaver dams distributed throughout the two study sites? 3) What are the landscape characteristics of the two study sites, and how might these characteristics influence the dimensions, structures, and distribution of the beaver dams between the study sites? The results of this thesis contribute new knowledge concerning the dimensions and distribution of beaver dams. The dimensions of beaver dams were compared statistically between two locations for the first time in the known literature, contributing new information regarding beaver dams as structures that may be built differently based on the characteristics of landscapes. The distributions of beaver dams in Cimarron Canyon and Coyote Creek State Parks were mapped, adding new sites to the growing literature body of digitally mapped beaver colonies. And finally, this study found patterns in the differences in beaver dam dimension and distribution based on the landscape characteristics of my two study sites. An increased understanding of landscape scale conditions that influence beaver dams can be important to the management of beavers, especially as their populations continue to grow in North America.

## CHAPTER II

STUDY SITES

Based on field reconnaissance in the summer of 2013, I selected Cimarron Canyon State Park and Coyote Creek State Park as study sites because they contain suitable beaver populations, yet each park contains different landscape characteristics (Figure 2). Both Parks are jointly managed and maintained by the State Park and Recreation Division of the New Mexico Energy, Minerals, and Natural Resources Department and the New Mexico Department of Game and Fish.

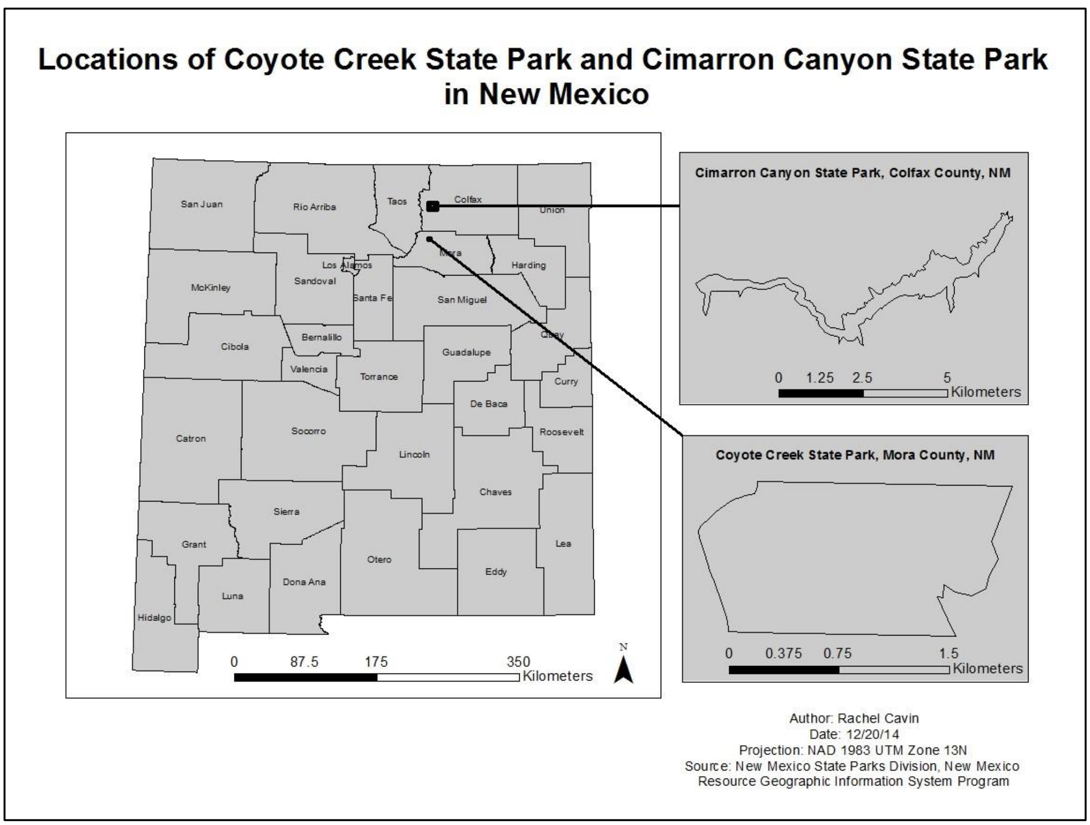


Figure 2: The locations of Coyote Creek and Cimarron Canyon State Parks in New Mexico. Both state parks are located in northeastern New Mexico. Cimarron Canyon State Park is located in Colfax County, and Coyote Creek State Park is located in Mora County.

Regional Climate

Northeastern New Mexico is characterized by mountainous terrain and a semiarid climate. The Köppen Climate Classification of this region is BSk, a semiarid steppe climate (Rohl and Vega 2012). This climate is characterized by a cool, dry climate year round with a mean annual temperature below 18°C (Rohl and Vega 2012).

In the northern mountains, mean annual temperatures can be as low as 4°C. The warmest temperatures of the year often happen in June, despite July being the average warmest month, because thunderstorms in July and August often reduce insolation and afternoon temperatures before they reach their peaks (Figure 3; WRCC 2014). In January, the coldest month, the mean temperatures in the northern mountains of New Mexico can be below 0°C, and temperatures can fall below -17°C, or 0°F, in higher elevations. The freeze-free season can be less than 80 days in the mountainous region of New Mexico, because freezes can occur in the summer months (WRCC 2014).

The northern mountains of New Mexico receive over 50 centimeters mean annual precipitation, however, the annual precipitation totals can vary widely in semiarid climates (WRCC 2014). During the summer months, rain primarily falls during intense afternoon thunderstorms from moisture originating in the Gulf of Mexico that is condensed by orographic lift in the area (WRCC 2014). As much as 30-40% of the precipitation in New Mexico falls during the summer season (WRCC 2014). The summer season carries with it a flash flood risk for many areas of northern New Mexico, because brief but intense storms paired with rough terrain and sparse vegetation characteristic of the region can encourage excessive runoff (WRCC 2014). In contrast, winter is the driest season for the state. Fronts travel eastward from the Pacific Ocean, but much of the moisture falls in the mountains of California, Nevada, Arizona, and Utah prior to reaching New Mexico (WRCC 2014). Much of the precipitation that does fall in winter falls as snow, although some valleys receive rainfall during these months. Some stations in the northern mountains receive over 250 centimeters of snow, with the highest peaks sometimes receiving over 750 centimeters (WRCC 2014).

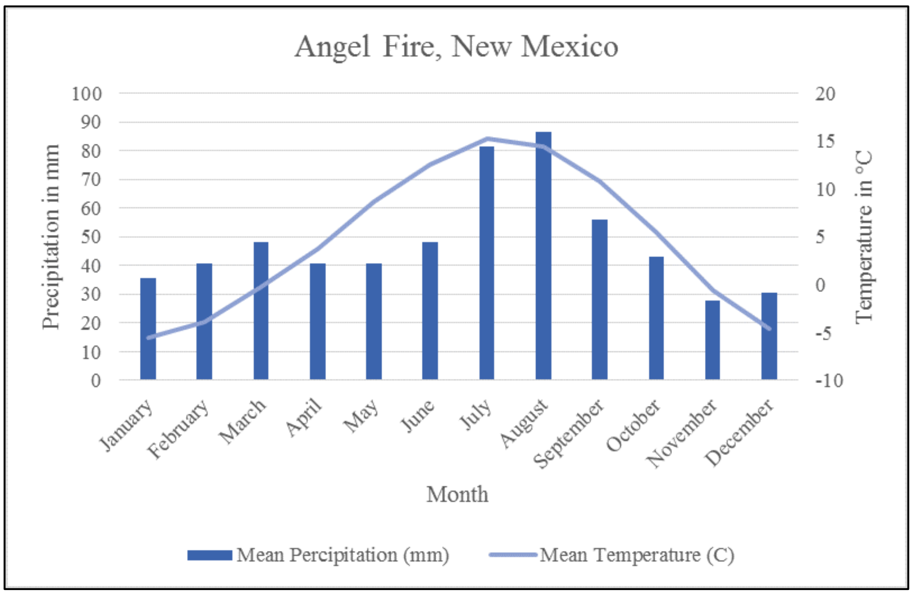


Figure 3: Climograph for Angel Fire, New Mexico.

Cimarron Canyon State Park

Cimarron Canyon State Park is located between Eagle Nest, NM, to the west and Cimarron, NM, to the east. The absolute location of the park is 36°32’01” N, 105°09’57’ W. The Cimarron River flows out of the Eagle Nest Dam, then flows through Cimarron Canyon. Eagle Nest Dam was constructed in 1918 and now holds the lake, and controls the once flood-prone Cimarron River (McLemore 1990). Cimarron Canyon State Park is part of the 33,116 acre Colin Neblett Wildlife Management Area. Cimarron Canyon State Park was opened in 1979, however the Colin Neblett Wildlife Management Area, formerly the Cimarron Canyon Wildlife Area, was acquired by the New Mexico Department of Game and Fish in 1949 (McLemore 1990). The primary land use in the canyon is recreation by park guests. Camping, hiking, and fishing are the main attractions of the park. Fishing and seasonal hunting are allowed in the wildlife area boundaries under New Mexico Department of Game and Fish regulations (New Mexico State Parks Division 2010). US Highway 64 runs through the canyon.

The park is located in the Cimarron Range of the southern Rocky Mountains. The elevations in Cimarron Canyon State Park range from 2250 meters in the valley floor to 3675 meters on Touch-Me-Not Mountain (McLemore 1990). The Fowler Pass fault line bisects the Colin Neblett Wildlife Management Area, dividing the area into two distinct terranes. The northern region is made up of Tertiary rock, with the southern region made up of Proterozoic rock (McLemore 1990). The Palisades were formed as recently as 26 million years ago from fine-grained Tertiary sill intrusions. These cliffs tower over 100 meters above the canyon floor (McLemore 1990).

Cimarron Canyon State Park and the surrounding Colin Neblett Wildlife Management Area are within the South Rocky Mountains Ecoregion. This Ecoregion is typified by woodland and grassland vegetation. In Cimarron Canyon, spruce-fir woodlands occur on north-facing walls and pine-juniper-oak woodlands occupy the south-facing walls. In the riparian corridor the dominant plants are narrowleaf cottonwood (*Populus angustifolia*), alders (*Alnus* spp.), and willows (*Salix* spp.) (New Mexico State Parks Division 2010). The diverse vegetation and availability of water in the canyon make it an excellent habitat for many species of wildlife. Mule deer (*Odocoileus hermionus*), elk (*Cervus elaphus*), bighorn sheep (*Ovis canadensis*), mountain lions (*Puma concolor*), red fox (*Vulpes vulpes*), bobcats (*Lynx rufus*), wild turkeys (*Meleagris gallopavo*), beavers (*Castor canadensis*), raccoon (*Procyon lotor*), porcupine (*Erethizon dorsatum*), bears (*Ursus americanus*), coyotes (*Canis latrans*), chipmunks (*Tamias* spp.), squirrels (*Sciurus* spp.), and as many as 88 species of birds make their home in Cimarron Canyon (McLemore 1990; New Mexico State Parks Division 2010). Brown trout (*Salmo trutta*), cutthroat trout (*Oncorhynchus clarkii*), creek chub (*Semotilus atromaculatus*), longnose dace (*Rhinichthys cataractae*), white sucker (*Catostomus commersoni*), and crayfish (*Orconectes spp. and Procambarus spp.*, both genera are present in New Mexico) inhabit the Cimarron River, in addition to the rainbow trout (*Oncorhynchus mykiss*) that the New Mexico Department of Game and Fish stocks (New Mexico State Parks Division 2010).

<u>Coyote Creek State Park</u>

Coyote Creek State Park is located off of NM-434, south of Angel Fire, NM, and north of Mora, NM. The absolute location of the park is 36°10’28” N, 105°14’00” W. Coyote Creek runs through the park, from headwaters near Black Lake to the north. Formerly a ranch, Coyote Creek State Park was founded in 1969 after the land was donated to the state of New Mexico (McLemore 1999). Coyote Creek State Park is used for recreation by park guests, and attracts between 20,000 and 30,000 visitors each year for hiking, camping, and fishing (McLemore 1999).

Coyote Creek State Park is located on the floor of Guadalupita Canyon, which was carved out by Coyote Creek. The park grounds are located on a flat, lush meadow between the Rincon Range to the west and La Mesa as the eastern ridge (McLemore 1999). The Rincon Range is made up of Proterozoic metamorphic rocks, whereas La

Mesa contains sedimentary rocks, some as old as the Pennsylvanian and Permian Periods, with more recent (4.2-4.6 m.y.) basalt flows covering the mesa (McLemore 1999). Lava deposits are present in the valley bottom, and Coyote Creek State Park contains many large basalt boulders (McLemore 1999).

The meadow in Coyote Creek State Park is known for its vibrant wildflowers, and along the riparian corridor chinquapin oak (*Quercus muehlenbergii*), chokecherry (*Prunus virginiana*), narrowleaf cottonwood (*Populus angustifolia*), and willows (*Salix* spp.) grow. The slopes adjacent to the meadow are forested with subalpine fir (*Abies lasiocarpa*), blue spruce (*Picea pungens*), Douglas-fir (*Pseudotsuga menziesii*), Engelmann spruce (*Picea engelmannii*), Gambel oak (*Quercus Gambelii*), hairy mountain mahogany (*Cercocarpus montanus*), one-seed juniper (*Juniperus monosperma*), piñon pine (*Pinus edulis*), ponderosa pine (*Pinus ponderosa*), quaking aspen (*Populus tremuloides*), Rocky Mountain juniper (*Juniperus scopulorum*), wavyleaf oak (*Quercus undulata*), and white fir (*Abies concolor*) (McLemore 1999). Deer (*Odocoileus* spp.), elk (*Cervus elaphus*), bears (*Ursus americanus*), turkeys (*Meleagris gallopavo*), beavers (*Castor canadensis*), skunks (*Mephitis mephitis*), coyotes (*Canis latrans*), raccoons (*Procyon lotor*), squirrels (*Sciurus* spp.), and many species of bird are found in Coyote Creek State Park (McLemore 1999; New Mexico State Parks Division 2002).

# CHAPTER III

## LITERATURE REVIEW

### History of North American Beaver Populations

After being hunted to the brink of extinction for their furs by colonial Europeans and early Americans, a change in hat fashions in the 19th century and early conservation efforts in the 20th century allowed North American beaver populations to recover to present day numbers (Naiman, Melillo, and Hobbie 1986; Butler 1995; Butler and Malanson 1995; Wilkinson 2003). Before European contact, the North American beaver population was estimated to have been at least 60 million, and possibly as high as 400 million (Naiman, Melillo, and Hobbie 1986). As of the 21st century, beavers have reoccupied the entirety of their pre-European contact geographic range, but currently at a much lower population density than the pre-contact numbers. It has been estimated there are between 6 and 12 million beavers currently present in North America (Naiman, Melillo, and Hobbie 1986; Butler and Malanson 2005).

The genus *Castor* evolved between 1.8 and 2.4 million years BP, during the late Tertiary or Pleistocene (Westbrook, Cooper, and Butler 2013). Presumably, beavers and related species have been building dams and changing landscapes for thousands of years. The ancient landscapes altered by beaver predate modern long-term scientific observations, but many landscapes still contain remains of past beaver activity (Ruedemann and Schoonmaker 1938; Ives 1942; Polvi and Wohl 2012). Butler and Malanson (2005) used pre- and post-European contact population estimates to calculate potential historic beaver pond numbers across the North American continent. The estimated beaver pond numbers ranged from 15 million to 250 million. Regardless of the true historic number of beaver ponds being closer to the high or low estimations, the land area that was altered by beavers during this time was enormous. Today, the number of ponds is estimated to be somewhere between 1.5 and 7.7 million (Butler and Malanson 2005).

Significance of Beavers: Geomorphological, Hydrological, and Ecological Impacts

Despite the previously mentioned centuries of interaction between humans and beavers in North America, it was not until the 20th century that published works began examining the ability of beavers to transform landscapes. Among the earliest observations were those that contributed to the formation of the beaver meadow hypothesis. The beaver meadow hypothesis, also known as the beaver meadow complex, was formed in the first half of the 20th century as an explanation for the occurrence of vast, flat valleys of fine, alluvial sediments (Ruedemann and Schoonmaker 1938; Ives 1942; Polvi and Wohl 2012). Ruedemann and Schoonmaker (1938) stated that the small meandering streams running across large post-glacial plains in New York were not sufficient to form the extensive alluvial landscapes. The relict terraces and complex drainage patterns of the observed sites led the authors to suspect beavers were actually the agents responsible for the creation of the alluvial fields. The authors mentioned that settlers in the eastern United States refer to such fields as “beaver meadows,” alluding to their possible origins (Ruedemann and Schoonmaker 1938). Ives (1942) came to the same conclusion observing similar post-glacial alluvium valleys in Colorado. Among the sediments making up the vast meadows were decaying woody materials that resembled modern beaver dam sequences (Ives 1942). The recent publication by Polvi and Wohl (2012) investigated these early studies linking beaver dams and sediment accumulation in post-glacial valley environments. By quantifying and dating sediments in the valley, the authors were able to attain the percentage of alluvium that had been accumulated by beaver activity. Their study continued to support the early hypothesis of Ives (1942) and Ruedemann and Schoonmaker (1938) that over hundreds to thousands of years, beaver activity on landscapes encourage fine sediments to accumulate, creating a wet meadow with a complex drainage pattern (Polvi and Wohl 2012). These studies illustrate the long term influences that beaver have had in modifying landscapes throughout the Holocene (Polvi and Wohl 2012).

Whereas the beaver meadow complex develops over hundreds of years, beavers have many more immediate impacts on landscapes. The landscape influences of the beaver begin when they disperse from their natal home, collect woody materials, then build a dam and impound water (Bradt 1938; Naiman, Johnston, and Kelley 1988). Beaver preferentially colonize low order streams, second to fourth order most commonly, as greater flow accumulation can make building and maintaining dams difficult (Naiman, Melillo, and Hobbie 1986). The dam changes the annual stream flow regime, maintaining surface water during dry periods and reducing velocity and erosion during wet periods (Naiman, Johnston, and Kelley 1988, Hammerson 1994; Collen and Gibson 2001). Green and Westbrook (2009) calculated that beaver dams in British Columbia had reduced stream velocity by approximately 81% prior to their removal along Sandown Creek. Water is impounded upstream from the dam, increasing water storage and raising the water table of the surrounding area (Naiman, Johnston, and Kelley 1988; Green and Westbrook 2009). In areas where karstification occurs, beavers can accelerate the process by increasing water availability for karst drainage. Sinkholes can form beneath beaver ponds, draining the pond and forcing the beavers to move elsewhere (Cowell 1984). Beaver dams often cause multi-thread channels downstream. Polvi and Wohl (2012) argue that the increased channel complexity acts as a positive feedback loop that creates additional stream length for beavers to dam, resulting in further landscape impacts from beaver activity. As much as 20-40% of the length of a stream can be impacted by beaver activity (Naiman and Melillo 1984).

Beavers create habitat and niches for other species through damming rivers and creating ponds. By transforming a lotic landscape to a lentic landscape, beaver create valuable ecosystems many species rely on (Hammerson 1994; Butler and Malanson 2005). Beaver impoundments increase biodiversity, and are suitable for many species of waterfowl and furbearers (Hammerson 1994). Beaver ponds can have two to five times the biomass of riffles, with differing invertebrate species from adjacent stream segments (Hammerson 1994). Additionally, through killing trees by flooding and felling, beaver impoundments have higher amounts of open canopy, which impacts the light, nutrients, and sediments entering the impounded stream (Hammerson 1994).

Most beaver dams are temporary structures on landscapes. Although some beaver dams persist and are eventually buried beneath sediments they capture, they often fail, sometimes with catastrophic results (Ives 1942; Butler 1989; Butler and Malanson 2005). Beaver dams are often removed from rivers by humans, as obstructions to stream flow can cause problems such as road creep or flooding (Butler 1989; Marston 1994; Butler and Malanson 2005; Green and Westbrook 2009). Following the loss of a beaver dam, many processes the dam controlled are reversed and the landscape reverts to a pre-dam appearance. The pond that was held by the dam is emptied, sending hundreds to thousands of cubic meters of water downstream (Hillman 1998). The water table drops, and vegetation communities reduce in diversity as a result (Marston 1994). Canopy covers become increasingly closed following the removal of beaver dams and drainage of ponds (Green and Westbrook 2009). Bank erosion, channel entrenchment, and sediment loss as a result of increased transport capacity are additional consequences caused by increased stream power following beaver dam loss (Marston 1994; Green and Westbrook 2009).

### Beaver Dam Morphology

Measured dimensions of beaver dams have been studied in the literature, but are seldom emphasized as a main research purpose. Often, studies report only the most extreme dimensions of beaver dams. Mills (1913) stated that during his 27 year study of beaver colonies all over North America, the largest dam he had seen was located in Montana, and spanned 652 meters in length, with heights up to 4.26 meters. Warren (1932) reported dimensions and approximate dates of construction for multiple dams and associated ponds from his study spanning from 1913 to 1932 in Colorado. Additionally, Warren (1926) surveyed a site that Mills (1913) had studied earlier. Building on previous works, Neff (1959) constructed a seventy year history of a beaver colony that had been studied by both Mills (1913) and Warren (1926), but contributed no beaver dam dimension measurements that hadn’t already been reported in previous works. Using relocated beavers on a site designated by the Soil Conservation Service for flood control and soil conservation, Scheffer (1938) collected data on 22 dams built at the site. The average length of the newly constructed dams was 13 meters and the average height was 0.86 meter. Demmer and Breschta (2008) inventoried beaver dams in central Oregon from 1988-2004, and visually estimated the lengths of 476 beaver dams during their study. They calculated an average length of 8 meters, with estimated dimensions and averages for pond length, depth, surface area, and volume as well.

A unique and important study of beaver dam dimensions as a central focus was conducted by Woo and Waddington (1990). After measuring over 50 dams in the field, dams were categorized into one of eight groups based on morphological characteristics that influence water flow. Four major categories were formed, including overflow dams, gap flow dams, through flow dams, and underflow dams, each containing two subgroups. For each of the four major categories, minimum, maximum, and mean values were reported for dam length, width, and height. The water depth up- and downstream from the dam was also reported, with a calculated difference in those values (Woo and Waddington 1990).

Beaver Dam and Pond Mapping

Aerial photography has been used for location and identification of beaver activity on landscapes for several decades (Neff 1959; Remillard, Gruendling, and Bogucki 1987; Barnes and Mallik 1997; Snodgrass 1997; Green and Westbrook 2009; Morgan, Gergel, and Coops 2010, Butler 2012). Aerial photographs provide one of the most temporally and spatially continuous record for landscape change analysis (Morgan, Gergel, and Coops 2010). Neff (1959) used US Forest Service aerial photographs to combine information from previous researchers into a 70 year history of a beaver colony in Colorado. Remillard, Gruendling, and Bogucki (1997) used historical aerial photographs to analyze how beavers disturb vegetation communities and how those vegetation communities recover following disturbance. From investigating and analyzing the photographs, they determined that plant succession in landscape patches created by beavers is often disturbed within 10-30 years, as beavers are continually abandoning and reoccupying sites. Aerial photographs are often used as a field reconnaissance step to identify areas with a beaver presence before fieldwork begins, then later used for digital mapping (Barnes and Mallik 1997; Snodgrass 1997). Green and Westbrook (2009) used a 36 year sequence of aerial photographs to assess landscape change following the removal of 18 dams along a 3 kilometer stream reach. They determined that the stream had reverted from a multichannel to single channel flow pattern, that canopy cover had dramatically increased, and that an estimated 5-fold increase in velocity had occurred. Butler (2012) used aerial photographs and fieldwork to identify beaver ponds located on deltas in Glacier National Park. Deltaic beaver ponds had never before been analyzed in the literature, with only one previous passing mention by the author (Butler 1991).

The use of GIS and other mapping applications for the identification and classification of beaver ponds and landscape changes is relatively new in the literature (Johnston and Naiman 1990; Johnston, Pastor, and Naiman 1993; Barnes and Mallik 1997; Syphard and Garcia 2001, Wright, Jones, and Flecker 2002). An early study by Johnston and Naiman (1990) determined the changes in hydrology and vegetation of beaver impoundments between 1940 and 1986. They determined that GIS was a superior method for some measurements, and a necessity for others such as classification transition analysis. Johnston, Pastor, and Naiman (1993) investigated the landscape scale zoogeomorphic impacts of both beavers and moose in Voyageurs National Park. Barnes and Mallik (1997) used GIS to identify the spatial locations of their study sites in Ontario, as well as to obtain elevation data for calculation of stream grade. Syphard and Garcia

(2001) conducted change detection analysis using digitized wetlands maps in The Chickahominy River watershed in Virginia. They found that beavers had contributed at least 23% of the wetlands change between 1953 and 1994. Wright, Jones, and Flecker (2002) calculated the proportion of stream length that flows through beaver-modified areas in the Huntington Wildlife Forest, New York. They reclassified wetlands maps to increase reliability, and then determined percentage of total wetlands associated with beaver landscape modifications.

Landscape Influences on Beaver Building Activities

Several important studies have created models or contributed observations to predict and assess the sites on which beavers establish dams. Although many beaver habitat and site selection models have been built using ecological variables with an emphasis on vegetation species, models that encompass multiple variables, such as vegetative, hydrological, and physical landscape characteristics will be considered here. Water is the most essential component of suitable beaver habitat, but the characteristics of the available water on a landscape will govern how beavers will colonize an area (Slough and Sadleir 1977; Gurnell 1998). First to fourth order streams are preferentially colonized by beavers, because higher order streams likely have excessive discharge for dam construction (Naiman, Johnston, and Kelley 1988). In higher stream orders, beaver often dig bank burrows rather than building dams and lodges (Naiman, Melillo, and Hobbie 1986). Apart from river channels, beaver may construct dams and other structures in oxbow lakes, wetlands, meander scrolls, or deltas where they are typically sustained by hyporheic flow rather than surface flow (Butler 2012). Beavers prefer fine soils to coarse or bedrock channel bottoms, likely because fine grain soils make burrow and canal construction easier and encourage stability of dams (Gurnell 1998). Beavers require vegetation for food resources, with the unique additional requirement of woody materials for construction. Beavers require a diet diverse in plant species, but favor species of aspen, willow, alder, maple, and ash (Nolet, Hoekstra, and Ottenheim 1994; Gurnell 1998). Beavers are vulnerable to predation on land, and are believed to travel no more than 100 meters from their home site for food resources (Howard and Larson, 1985).

In an early study, Slough and Sadleir (1977) used multiple regression analysis to quantitatively relate density of beaver colonies to landscape characteristics. With land use by beaver as the dependent variable, the independent variables were length of aspen shoreline, length of swamp shoreline, length of cottonwood shoreline, water level stability (an index value), lake area, lake perimeter, and length of nonproductive brush shoreline. All of the variables associated with the lakes were significant, with the lengths of swamp, unproductive brush, and aspen shorelines being the most significant in predicting beaver colony density. Allen (1983) developed a model for the North American beaver to assess the appropriateness of an area for beaver habitat. The model incorporated several habitat variables that relate to availability of both water and winter food supplies in riverine, lacustrine, and wetlands landscapes, creating specialized habitat suitability indexes for each landscape type. Initially beginning with 22 habitat characteristics measured in the field, McComb, Sedell, and Buchholz (1990) found that bank slope, stream gradient, and hardwood canopy cover best separated beaver occupied and beaver unoccupied sites in their study area. A model was created using these variables to classify sites into occupied and unoccupied sites.

Barnes and Mallik (1997) found that both physical features, including watershed area and stream cross sectional area, and the concentration of mature woody vegetation near the shore influenced beaver dam establishment in Ontario. They emphasized that models should be assessed and adjusted regionally, as a previously published model by McComb, Sedell, and Buchholz (1990) was not accurate in their study area (Barnes and Mallik 1997). Suzuki and McComb (1998) found vegetative and physical landscape features that were both negatively and positively correlated with the presence of beaver dams in the Oregon Coast Range. Decreased alder and shrub cover, with increased grass and sedge cover were found frequently at beaver inhabited sites, however, the authors speculated this may have actually been a result of beaver foraging rather than beaver site selection (Suzuki and McComb 1998). Decreased stream gradients and stream widths, with increased valley widths, were also found to be more suitable conditions for beaver colonization. This was believed to be a result of the lowered stream power of less steep and narrower rivers, and the increased flood retention of larger beaver ponds that can form in wider valleys (Suzuki and McComb 1998). These models are among the most frequently cited and influential, using diverse methods to determine appropriateness of an area for beaver habitation or construction. However, models relating habitat characteristics to the dimensions, attributes, and longevity of beaver dams are much harder to find than those simply determining suitability of a site (Gurnell 1998). Howard and Larson (1985) determined vegetative and physical characteristics that influenced the longevity of beaver colonies, then developed a mathematical model incorporating these characteristics to predict maximum colony density along streams. No known study has specifically studied how landscape variables influence beaver dam dimensions and structures (Gurnell 1998).

# CHAPTER IV

## METHODOLOGY

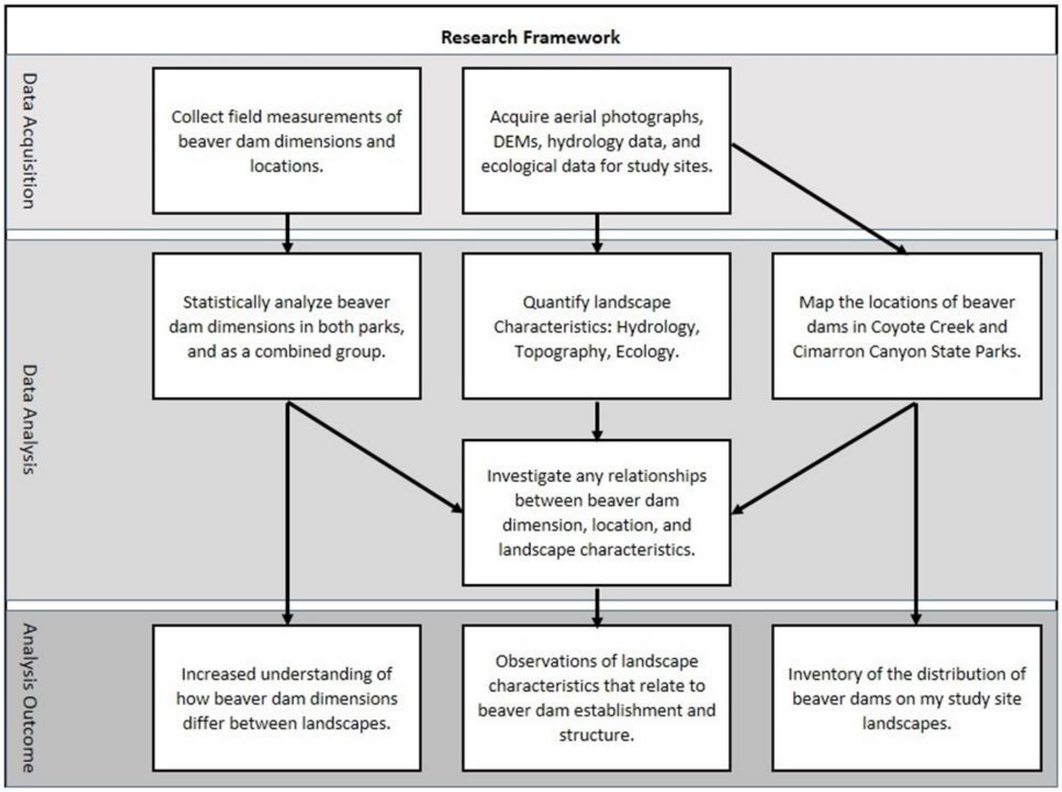


Figure 4: The research framework. The research design will follow a sequence of data acquisition, analysis, and results of analysis.

### Data Acquisition

Both field and digital data were required to complete the analysis for this thesis (Figure 4). Initial data collection took place in Cimarron Canyon and Coyote Creek State Parks, New Mexico. Data collected in the field included beaver dam lengths, heights, left widths, center widths, right widths, GPS coordinates, descriptive characteristics, and 2-10 photographs of each beaver dam (Table 1). Beaver dams were located in the field by following the river course and scouting for beaver dams in or near the river channel. Lengths were measured along the crest of the dam across the channel from bank to bank using a 300 foot measuring tape (Figure 5). Dams that were too large to measure in one single length were measured in multiple segments, and were recombined in a later step of analysis (Figure 6). The three widths of each dam were taken while standing downstream, measuring along the crest of the dam from the front edge to the back edge of the crest (Figure 5). The left and right widths were taken approximately one foot from the ends of the beaver dam length, and the center width was taken at the approximate center of the dam length. The height of each beaver dam was measured using a stadia rod held vertically downstream of each dam, resting on the stream bottom immediately in front of the dam (Figure 5). The height was recorded as the point on the stadia rod perpendicular with the dam crest in the approximate center of the beaver dam length. All dimension measurements were recorded in feet and tenths of feet, then later converted to meters.

Figure 5: Illustrations of the method used to measure each beaver dam dimension. The left image shows the beaver dam length extending across the crest of the dam from bank to bank, and the three widths measured on the crest of the dam. The right image shows the height measured at a perpendicular angle with the beaver dam crest.

In addition to dimension measurements, GPS coordinates were recorded at each beaver dam location using a Garmin GPSMap 62s handheld GPS (Table 1). Photographs were taken of each beaver dam from multiple perspectives in order to classify the beaver dam structure later in analysis. Each beaver dam had between two and ten photographs taken (Table 1). Finally, descriptions of beaver dams were taken whenever an unusual characteristic was observed. Some of these characteristics were relevant to the beaver dam structure classification step.

Table 1: Data acquired both in the field and in digital formats from online sources. These data were utilized further during processing and analysis.

| **Data Acquired** | | |
|---|---|---|
| **Field Data** | **Digital Data** | |
| **At each dam Site:** | **For each study site:** | **Source:** |
| Length | Digital Elevation Model (DEM) | USGS |
| Height | Recent NAIP Aerial Photographs | USDA |
| Left Width | NM State Park Boundaries | NMGIS |
| Center Width | NM County Boundaries | NMGIS |
| Right Width | | |
| GPS Coordinate | | |
| 2-10 Photographs | | |
| Dam Characteristics | | |

After returning from the field, several digital data products were acquired from government data clearinghouses (Table 1). To create a map of the study site locations, a map of New Mexico counties and state park boundaries was acquired. For later analysis of landscape characteristics, a digital elevation model, and 2009 NAIP aerial photographs were also acquired.

Data Analysis

Following data collection, some data required processing before it could be used in analysis. In the field, some dams were measured in multiple segments because of excessive length. When these measurements were taken, each segment contained height and width (left, middle, right) measurements as if they were individual dams. In order to perform statistical analysis, these dam segments had to be combined and treated like a single dam again (Figure 6). To do this, the length of all segments was summed to get the total dam length. To find a height that reflects the entire dam, a weighted mean was calculated. Two equations were used, depending on the number of segments the dam was measured in. $Height_{\mu}$ is the mean height of the dam segments, $Height_A$ is the dam segment that contained the center of the total dam length, and $Height_B$ and $Height_C$ are the segments that did not contain the center of the total dam length (Figure 6). The width measurements also needed to be adjusted in order to combine dam segments into full dams ready for statistical analysis. The left-most and right-most widths became the values for the left and right widths of the combined dam, whereas the mean of the two center-most widths became the middle width value.

Two Dam Segments:

$$Height_{\mu} = \frac{3(Height_A)+2(Height_B)}{5}$$

Three Dam Segments:

$$Height_{\mu} = \frac{3(Height_A)+2(Height_B)+2(Height_C)}{7}$$

Figure 6: The weighted mean equation used in the calculation of heights for segmented dams. There are two equations, one for two dam segments, and the other for three dam segments.

In order to determine whether there were differences in the dimensions of beaver dams between Coyote Creek and Cimarron Canyon State Parks, the Mann-Whitney U Test was used. This test was chosen because it is suitable for samples sizes greater than ten and it is a nonparametric test (Cangelosi, Taylor, and Rice 1976). The Mann-Whitney U Test works by hierarchically ranking the values from each group, if the two samples come from the same population, or two populations with equal means, the means of the group ranks will be equal. If the groups have high concentrations of either high or low ranks, the group means will not be equal. The null hypothesis was that no difference in beaver dam dimensions exists between study sites. The alternate hypothesis was that a difference in beaver dam dimensions exists between the study sites (Figure 7). Each dimensional measurement (length, height, width left, middle, and right) in both parks were tested using the Mann Whitney U Test. Some dams were excluded from statistical analysis because of absent dimension measurements. For example, dams that burst were not measured for height or widths, because the center of the dam was missing.

$$H_0: Cimarron\ Canyon\ Dam\ U = Coyote\ Creek\ Dam\ U$$

$$H_A: Cimarron\ Canyon\ Dam\ U \neq Coyote\ Creek\ Dam\ U$$

Figure 7: The null hypothesis and alternate hypothesis used in the Mann-Whitney U Test. The level of significance for the test was $\alpha = 0.05$.

Beaver dams were mapped in GIS as point data, with the locational aspect originally derived from GPS coordinates in the field. New fields were added to the attribute table of the dam layer that helped identify patterns in their distribution, and aided in the later step of relating those patterns to landscape characteristics. Added attributes included a dam structure classification system (Woo and Waddington 1990), length, height, and the dam widths (right, center, left). The beaver dam structures are overflow (where the water plunges over the beaver dam crest), gap flow (where the water flows through a breach in the beaver dam), through flow (where the water seeps through the beaver dam), and underflow (where the water flows under the beaver dam either through seeping or hyporheic flow). The beaver dam layer was mapped over recent NAIP aerial photographs for visualization purposes, and for later analysis of landscape characteristic patterns.

The final analysis step was to synthesize the attributes of beaver dams and the characteristics of the landscapes in which they were located to make speculations as to what characteristics of landscapes might influence beaver dam dimensions. Previous studies have determined that valley width, stream gradient, canopy cover, aquatic habitat availability, stream order, and bank slope are relevant to beaver dam establishment (Slough and Sadleir 1977; Allen 1983; Howard and Larson 1985; McComb, Sedell, and Buchholz 1990; Barnes and Mallik 1997; Suzuki and McComb 1998). This study measured the following characteristics of each study area: valley area, average valley width, surveyed stream length, stream gradient, percent cover (forest canopy, riparian forest canopy, vegetated, and developed), stream sinuosity, upstream catchment area, beaver dam relative density, and the length of stream between beaver dams. Variables were measured for the entire study area, then for smaller segments of each park as well. Descriptions of the methodology and motivation for measuring each variable are described below:

*Valley Area*

The Valley Area is the area occupied by the active floodplain in each park, and the lateral spatial extent for the following steps. In order to determine the extent of this area, the lowest areas of a 10 meter Digital Elevation Model were traced as a polygon in ArcGIS. These areas represent the areas beyond the stream banks most likely to be laterally connected to the river. The area of this polygon was calculated in the attribute table using Calculate Geometry. After the initial polygon was digitized, additional segments of the valley area were traced at natural breaks in the geomorphology to serve as the study area segments for the following project steps. Measuring valley area is important to this project because it served as the spatial extent for other variables, but also because mountain valleys serve as habitat for beavers and the riparian vegetation species they use for food and building material. Beavers have relatively small home ranges and are central place foragers (Howard and Larson 1985), however, they have been shown to preferentially build in larger, wider valleys (Suzuki and McComb 1998).

### *Average Valley Width*

The average valley width was obtained using the previously digitized valley area and a fishnet grid in ArcGIS. The fishnet was clipped to the extent of the valley area, and then the grid lines that cross the valley were measured and a mean width was calculated for both the whole valley and each individual segment. Whether the valleys are wider or narrower and more confined have important implications for the fluvial geomorphology of the valley and the availability of habitat for riparian floral species that beavers use as food and building material (Slough and Sadlier 1977; McComb, Sedell, and Buchholz 1990; Barnes and Mallik 1997; Suzuki and McComb 1998). Wider valleys have been shown to be preferentially colonized by beavers (Suzuki and McComb 1998), because of additional area and building material for beaver dams. Wider valleys have a greater lateral extent, therefore beaver ponds, and possibly beaver dams, can reach larger sizes. This not only provides additional habitat for the beaver family, but can also increase the potential for flood retention on the landscape, reducing the chance of damage to beaver dams (Suzuki and McComb 1998).

### *Surveyed Stream Length*

The surveyed stream length was measured as the length of the river course starting from 100 meters upstream of the farthest upstream dam to 100 meters downstream of the furthest downstream dam. The surveyed stream length serves as the longitudinal extent for the other landscape variables. This variable is primarily important for the calculation of other variables, such as the beaver dam relative density and stream gradient, but it does indicate the potential area for beaver dam construction, although the entire stream length may not be suitable for beaver dams.

*Stream Gradient*

The stream gradient of each study site used the previously measured surveyed stream length, as well as a 10 meter Digital Elevation Model. Using the identify tool, the elevation at the end points of the surveyed stream length were obtained for the entire park and the stream length in each segment. The difference between these points was calculated and divided by the stream length between the points. The gradient is reported in meters per kilometer. Higher stream gradients cause increased stream power, which could lead to more frequent beaver dam breaches. Beaver dams may be built differently in areas with higher gradients in order to withstand the higher stream power, such as by increasing height or width of the dam, however when gradients are too high no beaver dams are built at all (Suzuki and McComb 1998).

*Percent Cover (Forest, Riparian, Vegetated, Developed)*

Using a 2009 NAIP aerial photograph of each park, the land covers for each park were classified and traced as polygons in ArcGIS. The classification categories are barren, developed, herbaceous, pine/upland forest, riparian forest, and river. Once the entire surface of the study area was categorized, “calculate geometry” was used to obtain the area of each polygon in the attribute table. Polygons were split as necessary so each was contained in only one segment, and the number of the segment that each polygon fell within was added to the attribute table. The attribute table for each park was exported to Microsoft Excel, where the polygons were combined into their classification categories, first as the full park and then as separate segments. The area occupied by vegetation (herbaceous, pine forest, and riparian forest), riparian forest, forest (pine forest and riparian forest), and developed were individually divided by the total area of the study site. This gave the percentage of the area in each site or segment occupied by each of the cover classifications. Studies have found that beaver dams tend to be located in areas with higher herbaceous vegetation cover, however it is unclear if this is actually because of alteration by beaver because they selectively forage riparian vegetation for construction material and food (Suzuki and McComb 1998). Areas located near beaver dams with large dimensions, or dams that need repairs frequently might potentially have lower riparian cover, and greater herbaceous cover, because of increased beaver foraging. Developed cover can influence vegetation distribution, increase localized runoff, discourage colonization by beavers because of nearby humans, and increase the likelihood of beaver dams being removed because of hazards they may pose to structures or roads.

*Stream Sinuosity*

For each study area, a straight-line valley length was drawn that began at the furthest upstream stream point, and ended at the furthest downstream stream point. This process was repeated at the start and end points of the stream in each segment of the study sites. The length of each valley length polyline was calculated in the attribute table using calculate geometry. The sinuosity ratio of the stream was then calculated by dividing the surveyed stream length of each site and segment by the corresponding valley length. The sinuosity of streams influences the distribution of flow velocities, deposition, and erosion in the channel at fine scales. Beaver dam dimensions, such as width on one side of the dam, may be influenced by more sinuous streams because of the differences in flow, deposition, or erosion across the full beaver dam length. Sinuosity may also influence the beaver dam length because of the gradual erosion of cut banks in river meanders.

*Upstream Catchment Area*

The flow direction for each park was generated using the flow direction tool and a 10 meter digital elevation model in ArcGIS. The flow direction layer was then input into the delineate watershed tool to determine the extent of the watershed of each river. The downstream point of the surveyed stream length was used as the pour point. The watershed layers were converted to vector format, then the area of each polygon was calculated using calculate geometry in the attribute table. A larger catchment area indicates a larger area of land collecting water from precipitation and snow melt that flows into the stream system. This can indicate higher flows in the stream from the water flowing into the stream overland and through tributaries, which could potentially influence beaver dam dimensions and structures.

*Beaver Dam Relative Density*

To determine the number of beaver dams per kilometer in each park, the surveyed stream length was first converted to kilometers from meters by dividing the value by 1000. Then the number of beaver dams in each park and segment was divided by the number of kilometers. This value is commonly reported for beaver dams in the literature to give a simple indication of their spacing throughout the study area. Landscape variables, such as stream gradient and riparian vegetation communities, have been shown to influence beaver dam distribution (Slough and Sadleir 1977; Howard and Larson 1985;

McComb, Sedell, and Buchholz 1990; Barnes and Mallik 1997; Suzuki and McComb 1998). The density of beaver dams may also influence beaver dam dimensions. For example, there may be differences in the dimensions of dams located immediately downstream of other dams, or dams that are isolated from other dams. Having additional dams nearby may reduce the likelihood that dams will be breached, therefore influencing beaver dam structure as well.

### *Stream Length between Beaver Dams*

For every beaver dam, the distance upstream and downstream to the nearest adjacent dam was drawn using the editor tool. The river course was traced between beaver dams as a polyline using a 2009 NAIP aerial photograph. For beaver dams not located in the main stream channel, additional lines were drawn from the nearest adjacent dam, following the direction of in- or out flow for the dam. Some beaver dams did not have both in- and out flow, and therefore may be missing up- or downstream values. This is similar, yet yields more specific information about the beaver dams, than the previous relative density variable. For example, because the in- and out flow are drawn for dams, it can be determined whether the dams are part of a densely spaced sequence of dams or not, which may have impacts on the dimensions or structures of those dams.

## Limitations of this Study

Each of the previously mentioned methodologies contains limitations. During field data collection, some data was subject to error. In particular, height measurements may be imprecise because of the method used to collect them. Holding a stadia rod vertically and visually lining up the measurement with the height of the dam crest, which is angled away from the vertical stadia rod, may have introduced small amounts of error in each measurement. Additionally, handheld GPS units have consistent accuracy problems. Each GPS measurement was subject to up to 3 meters of potential horizontal inaccuracy. During data processing the segmented dams were mathematically recombined, but the recombination of the dam segments was a mathematical approximation based on weighted averages of the sums of segments, rather than actual measurements. Seven of the thirty-eight dams were affected by this, and the data that went into the weighted averages is based on field observations.

The final step in analysis of assessing the relationship between landscape characteristics and beaver dam attributes was a comparison of two sets of landscape characteristics measurements to find possible reasons for the differences in beaver dam dimensions and structures between and within the two parks. Although the information gathered will be useful, it was based on interpretation and will not yield any definitive causative reason for the beaver dam dimensions differing between parks. Some variables are not measured in this study, such as stream velocity, bank slope, and channel substrate. The shapefiles, imagery, and measurements used with the field measurements may have limitations of their own. File metadata was read prior to analysis to account for any limitations in the data obtained from secondary sources.

# CHAPTER V

## RESULTS

The results chapter is organized into multiple sub-sections in order to separate results related to different analysis tasks. The chapter begins with the beaver dam dimensions results, first with Coyote Creek State Park, then with Cimarron Canyon State Park, followed by a comparison of the min, max, range, median, and average measurements for each dimension. The second section presents the results of the Mann-Whitney U Test that was run on beaver dam dimensions between the study sites. Beaver dam structure classifications in each study site are the third section, with percentages of beaver dams which were classified in each structure type. A brief section follows, which describes and maps the way in which study sites were partitioned into segments to maintain variability within each study site when calculating results. Beaver dam distributions are the focus of the fourth section, it is presented with a series of maps which show the dimensions and structures of each beaver dam in the study sites. This allows for visualization of patterns in the distribution of beaver dams of different dimensions and structures, in addition to the distribution of the dams themselves. The chapter concludes with a section that covers the results related to the individual landscape characteristics.

### Beaver Dam Dimensions

#### *Coyote Creek State Park*

A total of 19 potential beaver dams were measured during field work in Coyote Creek State Park, however three were later reclassified as woody debris piles and eliminated from analysis, leaving a total of 16 beaver dams (Table 2). For every beaver dam, six variables were analyzed in order to characterize the dimensions of the beaver dams in Coyote Creek State Park: structure classification, length, left width, center width, right width, and height.

Table 2: The raw field measurements in meters of beaver dam structure classifications and dimensions for Coyote Creek State Park.

| Coyote Creek Beaver Dam Dimensions | | | | | | |
|---|---|---|---|---|---|---|
| **Dam ID** | **Structure** | **Length** | **Left Width** | **Center Width** | **Right Width** | **Height** |
| **A101** | Gap flow | 6.29 | 4.36 | 2.65 | 0.94 | 0.70 |
| **A102** | Through flow | 18.76 | 0.96 | 0.58 | 1.04 | 1.07 |
| **A103** | Through flow | 22.25 | 1.69 | 0.55 | 0.43 | 1.43 |
| **A104** | Overflow | 2.37 | 0.42 | 0.75 | 0.44 | 0.53 |
| **A105** | Through flow | 9.97 | 0.52 | 0.55 | 0.41 | 0.82 |
| **A106** | Overflow | 4.51 | 0.34 | 0.34 | 0.06 | 0.47 |
| **A107** | Through flow | 47.00 | 0.79 | 0.88 | 0.40 | 0.42 |
| **A108** | Through flow | 12.04 | 0.27 | 0.87 | 0.26 | 0.61 |
| **A109** | Through flow | 10.87 | 0.77 | 0.61 | 0.30 | 0.76 |
| **A110** | Through flow | 10.09 | 0.21 | 1.40 | 0.67 | 0.94 |
| **A111** | Overflow | 12.18 | 0.18 | 0.85 | 0.34 | 0.55 |
| **A112** | Through flow | 7.23 | 0.30 | 0.77 | 0.54 | 0.85 |
| **A113** | Through flow | 3.39 | 0.19 | 0.33 | 0.15 | 0.18 |
| **A114** | Gap flow | 10.18 | 0.00 | 0.00 | 0.00 | 0.00 |
| **A115** | Overflow | 10.21 | 0.97 | 0.49 | 0.46 | 0.82 |
| **A116** | Underflow | 30.73 | 0.15 | 0.22 | 0.12 | 0.61 |

*Cimarron Canyon State Park*

A total of 19 potential beaver dams were measured during field work in Cimarron Canyon State Park, however, like in Coyote Creek, three were reclassified as woody debris and eliminated from analysis, leaving a total of 16 beaver dams (Table 3). For every beaver dam, six variables were analyzed in order to characterize the dimensions of the beaver dams in Cimarron Canyon State Park: structure classification, length, left width, center width, right width, and height.

Table 3: The raw field measurements in meters of beaver dam structure classifications and dimensions for Cimarron Canyon State Park.

| Cimarron Canyon Beaver Dam Dimensions | | | | | | |
|---|---|---|---|---|---|---|
| **Dam ID** | **Structure** | **Length** | **Left Width** | **Center Width** | **Right Width** | **Height** |
| **B101** | Gap flow | 7.66 | 0.00 | 0.00 | 0.00 | 0.00 |
| **B102** | Gap flow | 9.75 | 0.70 | 1.37 | 1.37 | 1.37 |
| **B103** | Gap flow | 19.96 | 0.00 | 0.00 | 0.00 | 0.00 |
| **B104** | Gap flow | 9.51 | 0.00 | 0.00 | 0.00 | 0.00 |
| **B105** | Underflow | 1.86 | 0.12 | 0.49 | 0.34 | 0.34 |
| **B106** | Gap flow | 6.08 | 0.00 | 0.00 | 0.00 | 0.00 |
| **B107** | Through flow | 2.13 | 0.40 | 0.52 | 0.58 | 0.98 |
| **B108** | Underflow | 4.11 | 0.18 | 0.30 | 0.70 | 0.34 |
| **B109** | Through flow | 11.77 | 1.58 | 1.68 | 1.40 | 1.01 |
| **B110** | Gap flow | 3.05 | 0.00 | 0.00 | 0.00 | 0.00 |
| **B111** | Gap flow | 13.56 | 0.79 | 0.91 | 1.22 | 0.61 |
| **B112** | Through flow | 22.80 | 4.32 | 0.16 | 0.27 | 0.04 |
| **B113** | Through flow | 31.94 | 0.46 | 0.64 | 0.43 | 1.07 |
| **B114** | Underflow | 8.84 | 0.49 | 1.28 | 0.49 | 0.82 |
| **B115** | Through flow | 15.85 | 0.88 | 1.37 | 0.67 | 0.94 |
| **B116** | Gap flow | 15.88 | 0.00 | 0.00 | 0.00 | 0.00 |

*Coyote Creek and Cimarron Canyon State Parks*

The overall average length of beaver dams was 12.59 meters, with a median length of 10.13 meters (Table 4). The longest beaver dam was 47.00 meters long, whereas the shortest was just 1.86 meters in length, making the overall range in beaver dam lengths 45.14 meters (Figure 8, Table 4). The beaver dams in Coyote Creek tended to be slightly longer than those in Cimarron Canyon. The average beaver dam length in

Coyote Creek was 13.63 meters, with a median of 10.20 meters, whereas beaver dams in Cimarron Canyon averaged 11.55 meters long with a median length of 9.63 meters (Table 4). Coyote Creek contained the longest beaver dam measured at 47.00 meters long, and the shortest beaver dam in the park was 2.37 meters in length, making the range 44.63 meters (Figure 8, Table 4). The longest dam measured within Cimarron Canyon was 31.94 meters in length, and the shortest was 1.86 meters long, making the range of length measurements 30.08 meters in the park (Figure 8, Table 4).

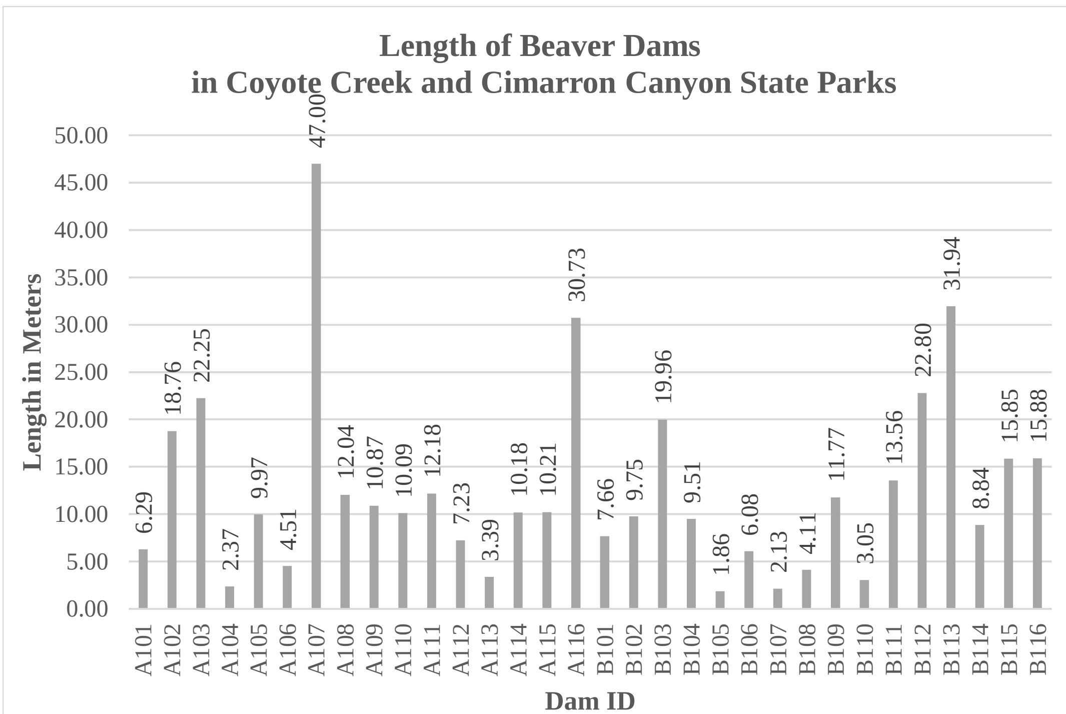


Figure 8: The length of beaver dams in meters in both Coyote Creek and Cimarron Canyon State Parks. All Dam ID values that start with A are located in Coyote Creek, whereas Dam ID values that start with B are located in Cimarron Canyon.

The overall average left width was 0.88 meters, with a median left width value of 0.49 meters. The widest left width value was 4.36 meters, and the narrowest left width was 0.12 meters, making the overall range 4.24 meters (Figure 9, Table 4). Cimarron

Canyon had the higher left width values, with an average of 0.99 meters and a median of 0.6 meters. The average left width in Coyote Creek was 0.81 meters and the median value was 0.42 meters. The widest left width in Cimarron Canyon was 4.32 meters and the narrowest was 0.12 meters, making the total range of values in Cimarron Canyon 4.2 meters (Figure 9, Table 4). Coyote Creek had a value of 4.36 meters as the widest left width, and 0.15 meters as the narrowest, making the range of values in Coyote Creek 4.21 meters (Figure 9, Table 4).

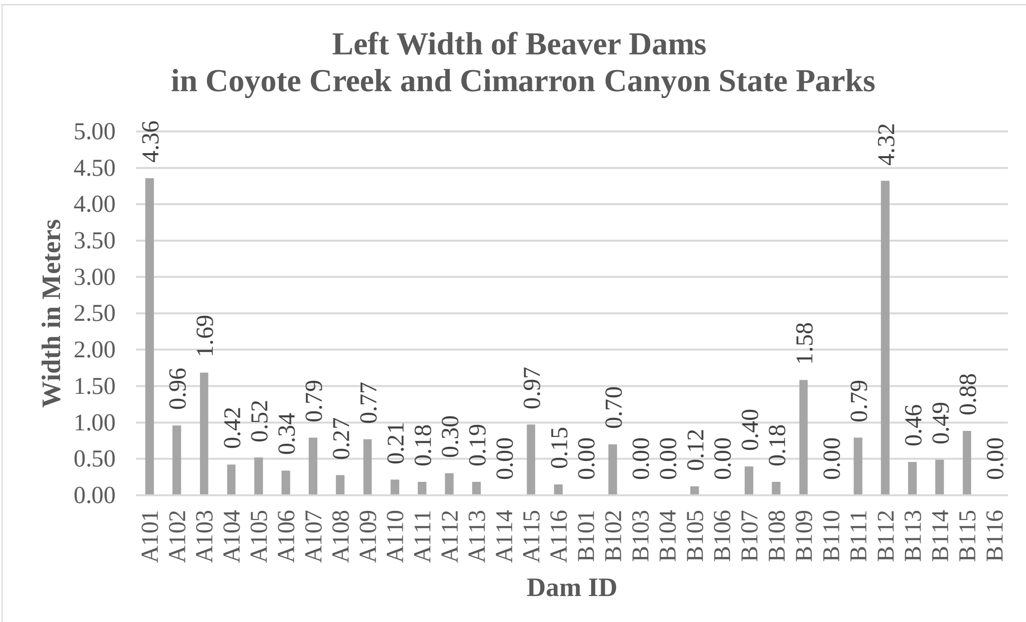


Figure 9: The left width of beaver dams in meters in both Coyote Creek and Cimarron Canyon State Parks. All Dam ID values that start with A are located in Coyote Creek, whereas Dam ID values that start with B are located in Cimarron Canyon.

The overall average center width value for both parks is 0.82 meters, with a median value of 0.49 meters. The widest center width was 2.65 meters, and the lowest was 0.22 meters, making the overall range of values 2.43 meters (Figure 10, Table 4). The center widths were higher in Cimarron Canyon overall, the park average value was

0.87 meters with a median value of 0.78 meters. The average center width value in Coyote Creek was 0.79 meters with a median of 0.61 (Figure 10, Table 4). The widest center width in Cimarron Canyon was 1.68 meters, and the narrowest was 0.3 meters, making the range of values 1.38 meters. Coyote Creek had a widest center width value of 2.65 meters, a narrowest value of 0.22, and a range of 2.43 meters (Figure 10, Table 4).

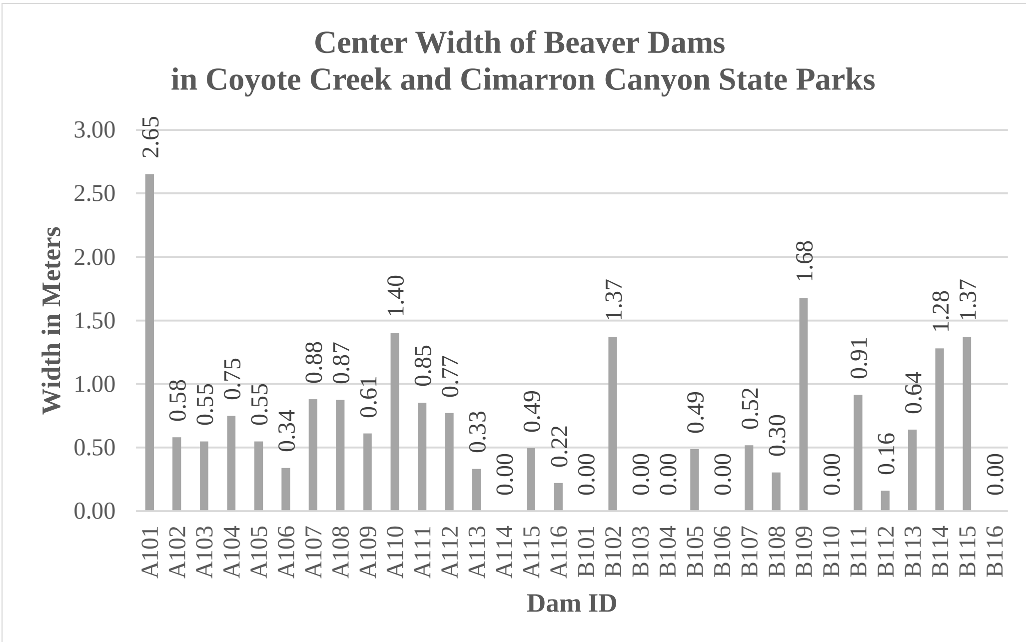


Figure 10: The center width of beaver dams in meters in both Coyote Creek and Cimarron Canyon State Parks. All Dam ID values that start with A are located in Coyote Creek, whereas Dam ID values that start with B are located in Cimarron Canyon.

The overall average beaver dam right width for both parks was 0.56 meters, with a median value of 0.44 meters. The widest right width of any beaver dam was 1.37 meters, and the narrowest was 0.12 meters, making the overall range 1.25 meters (Figure 11, Table 4). The average right width in Cimarron Canyon was slightly higher than those in Coyote Creek, the average value was 0.75 meters with a median of 0.63 meters. Coyote Creek had an average right width of 0.44 meters and a median of 0.41 meters

(Figure 11, Table 4). The widest right width in Cimarron Canyon was 1.37 meters, and the narrowest 0.27 meters, making the range in that park 1.1 meters. In Coyote Creek, the widest right width value was 1.04 meters, and the narrowest was 0.12 meters, giving the park a range of 0.92 meters (Figure 11, Table 4).

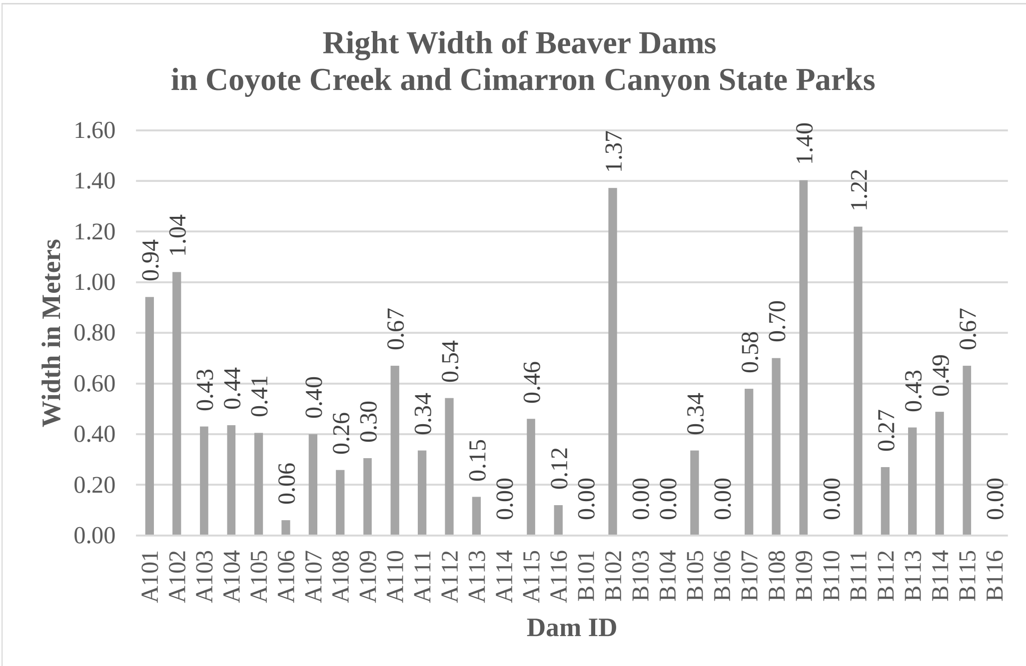


Figure 11: The right width of beaver dams in meters in both Coyote Creek and Cimarron Canyon State Parks. All Dam ID values that start with A are located in Coyote Creek, whereas Dam ID values that start with B are located in Cimarron Canyon.

The overall average beaver dam height was 0.73 meters, with a median height of 0.76 meters. The tallest beaver dam was 1.43 meters and the shortest beaver dam was 0.04 meters, making the range of beaver dam heights 1.39 (Figure 12, Table 4). Cimarron Canyon had slightly taller beaver dams, with an average value of 0.75 meters and a median value of 0.88 meters. Coyote Creek had an average value of 0.72 meters with a median value of 0.70 meters (Figure 12, Table 4). The tallest beaver dam in Cimarron

Canyon was 1.37 meters, and the shortest was 0.04 meters, making the range of beaver dam heights in the park 1.33 meters. In Coyote Creek, the tallest beaver dam was 1.43 meters and the shortest was 0.18 meters, making the range of beaver dam heights 1.25 meters (Figure 12, Table 4).

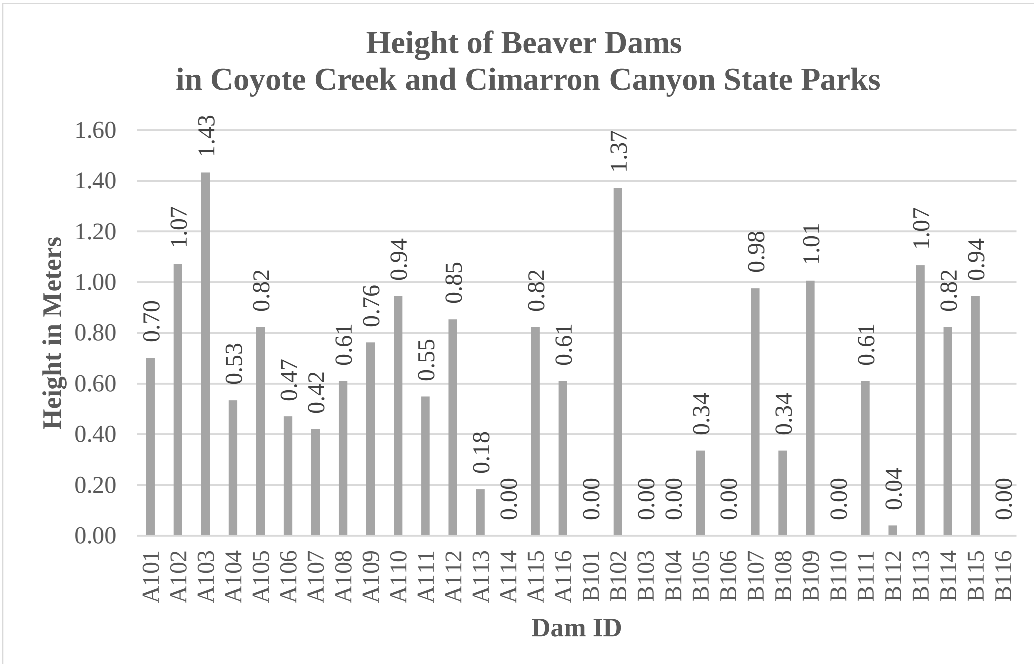


Figure 12: The height of beaver dams in meters in both Coyote Creek and Cimarron Canyon State Parks. All Dam ID values that start with A are located in Coyote Creek, whereas Dam ID values that start with B are located in Cimarron Canyon.

Table 4: The descriptive statistics of each beaver dam dimension in meters in each park and as a full sample group. Beaver dams with missing dimensions (0.00 in tables and graphs) were not used in statistics.

| Beaver Dam Dimension Descriptive Statistics | | | |
|---|---|---|---|
| | **Total** | **Coyote Creek** | **Cimarron Canyon** |
| **Length** | | | |
| Mean | 12.59 | 13.63 | 11.55 |
| Median | 10.14 | 10.20 | 9.63 |
| High | 47.00 | 47.00 | 31.94 |
| Low | 1.86 | 2.37 | 1.86 |
| Range | 45.14 | 44.63 | 30.08 |
| **Left Width** | | | |
| Mean | 0.88 | 0.81 | 0.99 |
| Median | 0.49 | 0.42 | 0.60 |
| High | 4.36 | 4.36 | 4.32 |
| Low | 0.12 | 0.15 | 0.12 |
| Range | 4.24 | 4.21 | 4.2 |
| **Center Width** | | | |
| Mean | 0.82 | 0.79 | 0.87 |
| Median | 0.64 | 0.61 | 0.78 |
| High | 2.65 | 2.65 | 1.68 |
| Low | 0.22 | 0.22 | 0.3 |
| Range | 2.43 | 2.43 | 1.38 |
| **Right Width** | | | |
| Mean | 0.56 | 0.44 | 0.75 |
| Median | 0.44 | 0.41 | 0.63 |
| High | 1.37 | 1.04 | 1.37 |
| Low | 0.12 | 0.12 | 0.27 |
| Range | 1.25 | 0.92 | 1.1 |
| **Height** | | | |
| Mean | 0.73 | 0.72 | 0.75 |
| Median | 0.76 | 0.70 | 0.88 |
| High | 1.43 | 1.43 | 1.37 |
| Low | 0.04 | 0.18 | 0.04 |
| Range | 1.39 | 1.25 | 1.33 |

Statistical Tests of Beaver Dam Dimensions

The Mann-Whitney U Test was used to test the beaver dam dimensions in Cimarron Canyon and Coyote Creek State Parks to determine if a statistically significant difference exists between the two groups of beaver dams. Beaver dams that were missing a measurement for a dimension were not included in the analysis for that dimension. Every dimension had a p value greater than 0.05, meaning that there were no significant differences in beaver dam dimensions between the two study sites (Table 5).

Table 5: The results of the Mann-Whitney U Test between the study sites. Both the U value and p values are provided. $\alpha = 0.05$.

| **Mann-Whitney Test of Beaver Dam Dimensions** | | |
|---|---|---|
| | **Mann-Whitney U** | **Asymp. Sig (2-tailed)** |
| **Length** | 114.0 | 0.6 |
| **Left Width** | 67.5 | 0.68 |
| **Center Width** | 68.0 | 0.7 |
| **Right Width** | 39.0 | 0.46 |
| **Height** | 67.0 | 0.68 |

Beaver Dam Structure Classifications

Each of the 32 measured beaver dams were classified into a structure category based on the system developed by Woo and Waddington (1990). In Coyote Creek State Park, the majority of beaver dams, 56%, were classified as through flow (Figure 13). These beaver dams are intact, and water flows through small spaces between the building materials. The next largest category of dams in Coyote Creek State Park was overflow dams, with a quarter of all dams, 25%, classified into this category (Figure 13). Water flows over the crest of overflow dams, creating a plunging flow downstream. Both gap flow and underflow classifications had smaller numbers of beaver dams categorized into them, with 13% and 6% of the total beaver dams in Coyote Creek, respectively (Figure 13). Gap flow dams have a breach that allows water to flow directly through a hole in the dam, whereas underflow dams either have a gap at the bottom of the dam that allows flow near the channel bed, or the downstream flow is sustained through hyporheic flow beneath the dam.

In Cimarron Canyon State Park, the beaver dam structure classifications were distributed quite differently. Rather than through flow, the highest number of beaver dams were gap flow in Cimarron Canyon, with 50% of the total dams (Figure 14). These dams made up just 13% of the dams in Coyote Creek, so Cimarron Canyon had many more breached dams. Through flow dams were the next largest category, with 31% of the total beaver dams in Cimarron Canyon (Figure 14). Underflow contained 19% of the dams in Cimarron Canyon, and there were zero dams classified as overflow in the park (Figure 14).

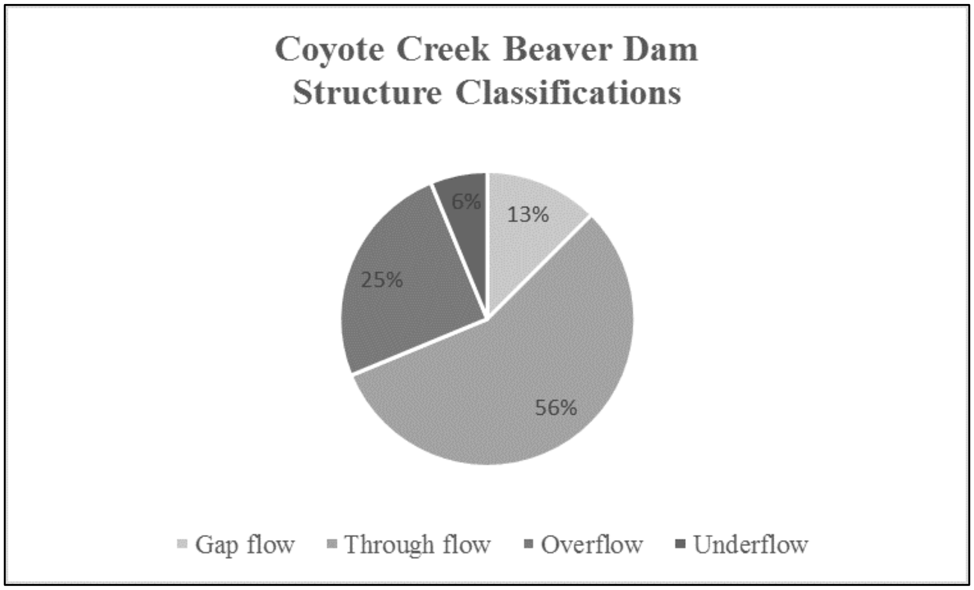


Figure 13: The percentage of beaver dams assigned to each structure classification in Coyote Creek State Park.

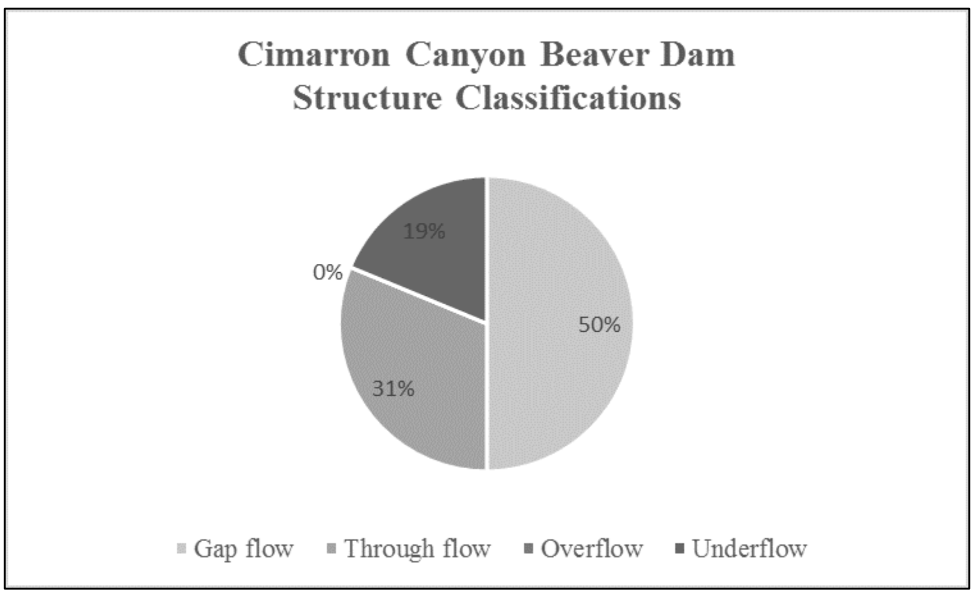


Figure 14: The percentage of beaver dams assigned to each structure classification in Cimarron Canyon State Park.

Study Site Segments

In order to maintain variability in beaver dam dimensions and structures, as well as the landscape characteristics between and within the parks, these variables were measured for the entire study site area, as well as within smaller subsets of each study site called segments (Figures 15-16). Coyote Creek was measured in three segments, the boundaries of these segments are based on changes in both the valley width and the sinuosity of Coyote Creek. In segment two there is an extension to the west in the valley, and the stream splits into several channels. In segment three there is another westward extension in the valley width, and the stream anastomoses (Figure 15).

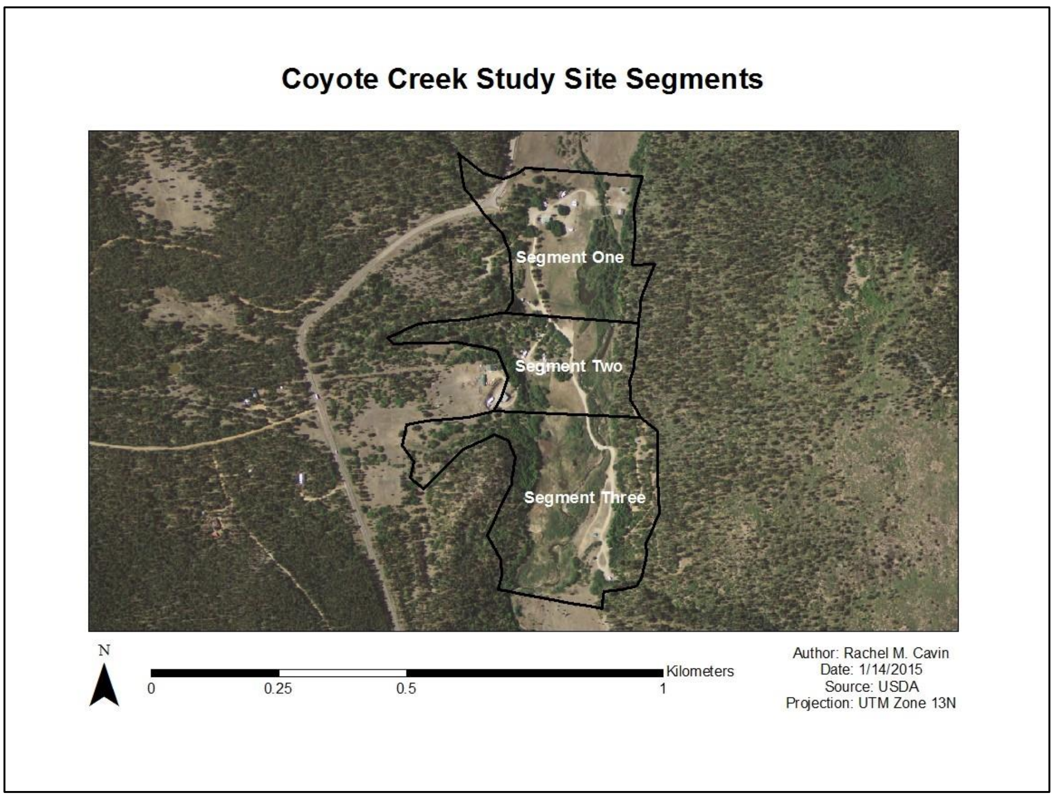


Figure 15: The segments of the study area in Coyote Creek State Park.

In Cimarron Canyon there were four study site segments. These segment boundaries were primarily based on major river meanders and changes in the orientation of the valley. Segment one is the furthest upstream, and contains a fairly straight stream segment with a west to east valley orientation. Segment two contains the straightest stream segment, with the valley continuing in its west to east orientation. Segment three contains a major meander where the valley begins orienting itself more southward. And segment four contains another river meander and the most southward segment of the valley (Figure 16).

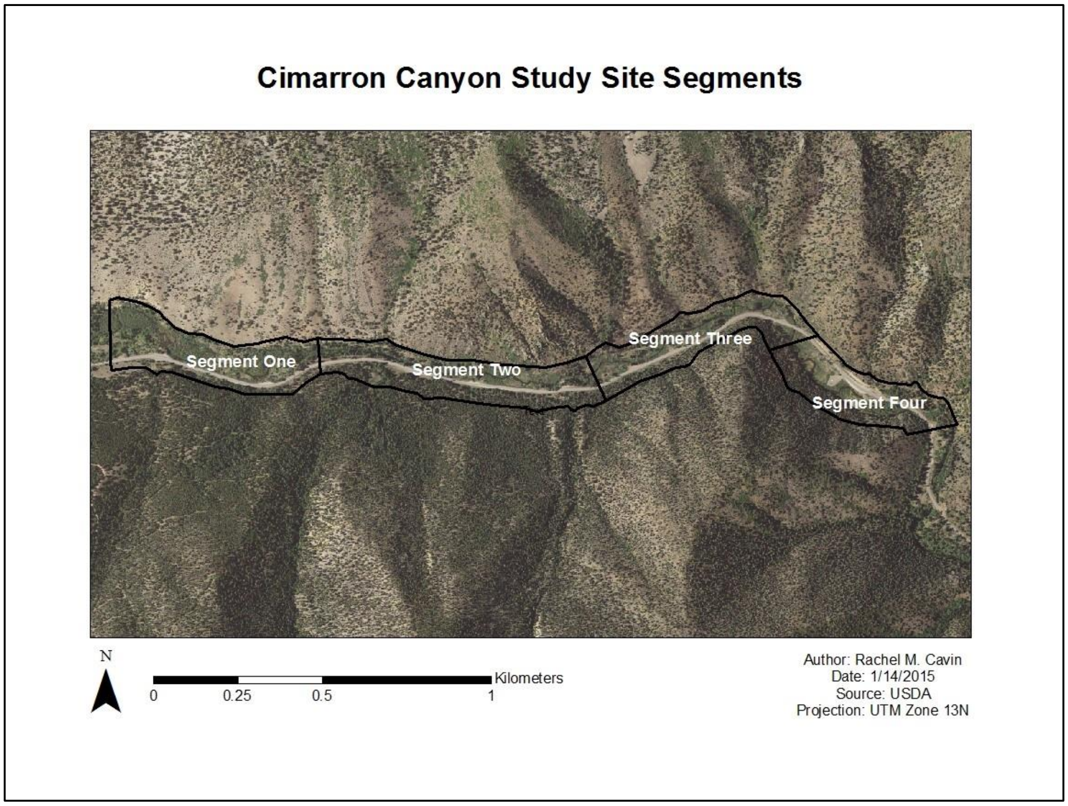


Figure 16: The segments of the study area in Cimarron Canyon State Park.

Beaver Dam Dimension and Structure Maps

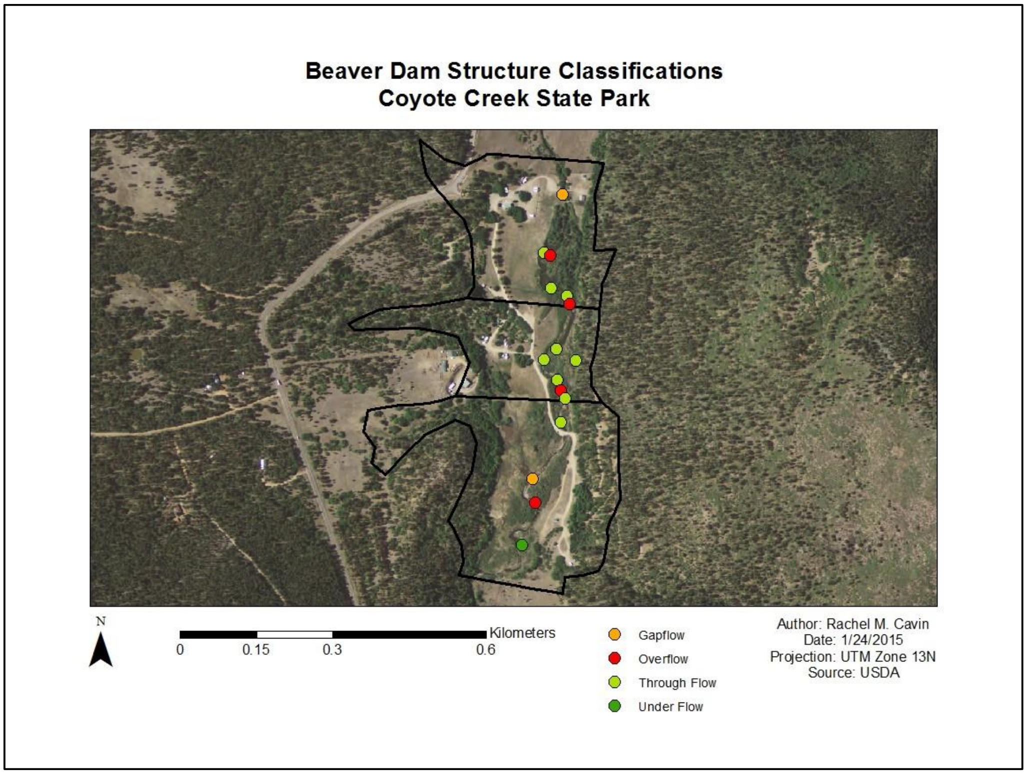


Figure 17: The distribution of beaver dam structure classifications in Coyote Creek State Park.

In Coyote Creek, through flow dams were the largest category with 9 beaver dams (56%). There were also 4 overflow dams (25%), 2 gap flow dams (13%) and 1 underflow dam (6%) in Coyote Creek (Figure 17, Table 6). Segment one of Coyote Creek contained six beaver dams. Three of these dams were through flow (50%), two were overflow (33%), one was gap flow (17%), and there were zero underflow dams. Coyote Creek segment two had 5 through flow dams (83%), one overflow dam (17%), and no gap flow or underflow dams. Segment three in Coyote Creek had one through flow dam (25%), 1 gap flow dam (25%), one overflow dam (25%), and one underflow dam (25%) (Figure 17, Table 6).

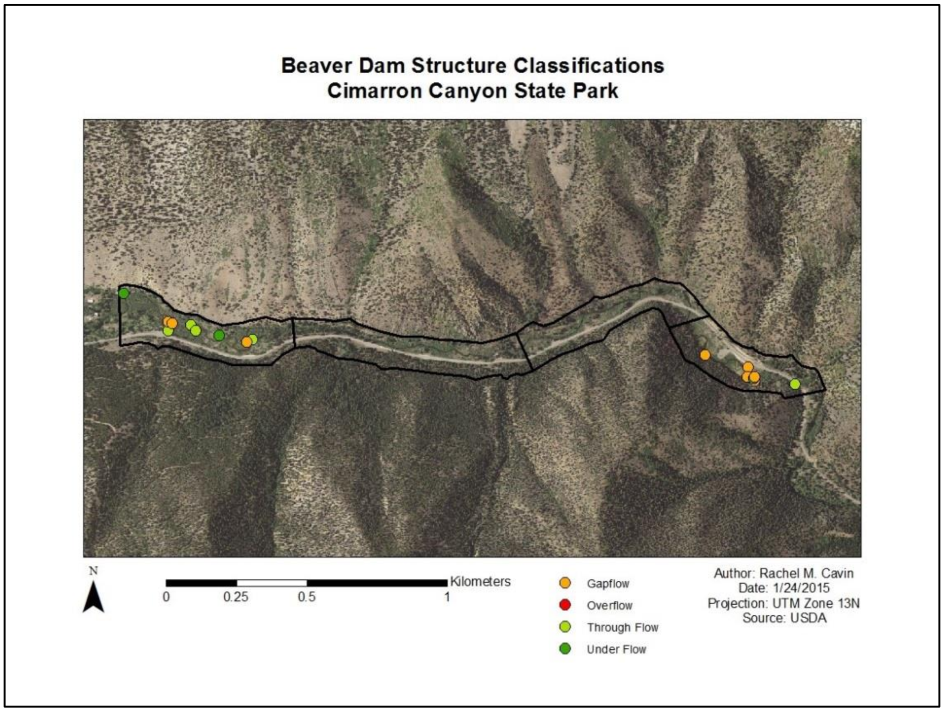


Figure 18: The distribution of beaver dam structure classifications in Cimarron Canyon State Park.

Cimarron Canyon State Park contained eight gap flow dams (50%), five through flow dams (31%), three underflow dams (19%), and zero overflow dams (Figure 18, Table 6). The majority of beaver dams in Cimarron Canyon were classified as gap flow. In segment one, there were four through flow dams (44%), three gap flow dams (33%), 2 underflow dams (22%), and zero overflow dams. Segments two and three in Cimarron Canyon contained no beaver dams. Segment four had five gap flow dams (71%), 1 underflow dam (14%), 1 through flow dam (14%), and zero overflow dams (Figure 18, Table 6).

Table 6: Averages or Percentages of Dimensions and Beaver Dam Structure Classifications.

| Beaver Dam Dimensions | Coyote Creek Total | Coyote Creek Segment 1 | Coyote Creek Segment 2 | Coyote Creek Segment 3 | |
|---|---|---|---|---|---|
| Average Length | 13.63 meters (Longer) | 10.69 meters | 16.57 meters | 13.63 meters | |
| Average Left Width | .76 meters (Longer) | 1.38 meters | .42 meters | .33 meters | |
| Average Center Width | .74 meters (Longer) | .90 meters | .90 meters | .26 meters | |
| Average Right Width | .41 meters (Shorter) | .55 meters | .42 meters | .18 meters | |
| Average Height | .67 meters (Longer) | .84 meters | .69 meters | .40 meters | |
| Structure Classifications | 9 Through Flow (56%) 4 Overflow (25%) 2 GapFlow (13%) 1 Underflow (6%) | 3 Throughflow (50%) 2 Overflow (33%) 1 Gapflow (17%) 0 Underflow (0%) | 5 Throughflow (83%) 1 Overflow (17%) 0 Gapflow (0) 0 Underflow (0%) | 1 Through Flow (25%) 1 Gapflow (25%) 1 Overflow (25%) 1 Under Flow (25%) | |
| **Beaver Dam Dimensions** | **Cimarron Canyon Total** | **Cimarron Canyon Segment 1** | **Cimarron Canyon Segment 2** | **Cimarron Canyon Segment 3** | **Cimarron Canyon Segment 4** |
| Average Length | 11.55 meters (Shorter) | 14.19 meters | | | 8.14 meters |
| Average Left Width | .62 meters (Shorter) | .97 meters | | | .17 meters |
| Average Center Width | .55 meters (Shorter) | .70 meters | | | .34 meters |
| Average Right Width | .47 meters (Longer) | .57 meters | | | .33 meters |
| Average Height | .47 meters (Shorter) | .54 meters | | | .38 meters |
| Structure Classifications | 8 Gap Flow (50%) 5 Through Flow (31%) 3 Underflow (19%) 0 Overflow (0%) | 4 Through Flow (44%) 3 Gapflow (33%) 2 Under Flow (22%) 0 Overflow (0%) | 0 Through Flow (0%) 0 Gapflow (0%) 0 Under Flow (0%) 0 Overflow (0%) | 0 Through Flow (0%) 0 Gapflow (0%) 0 Under Flow (0%) 0 Overflow (0%) | 5 Gapflow (71%) 1 Under Flow (14%) 1 Through Flow (14%) 0 Overflow (0%) |

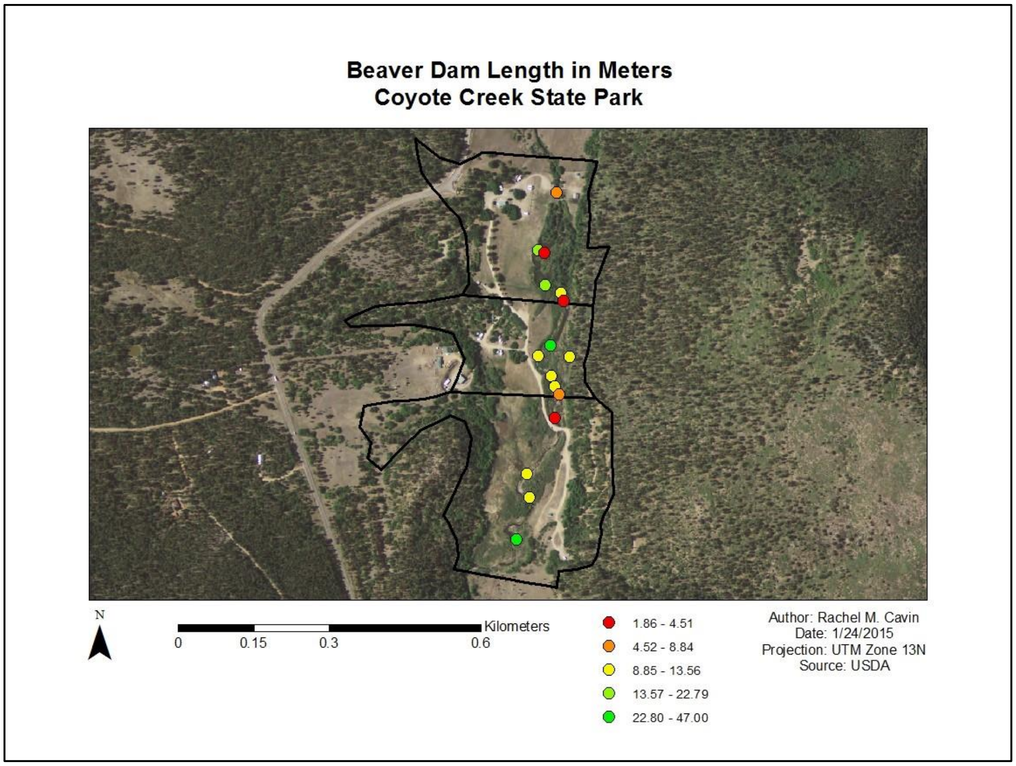


Figure 19: The distribution of beaver dam length measurements in Coyote Creek State Park.

The overall average beaver dam length in Coyote Creek was 13.63 meters. In segment one the average length was 10.69 meters, in segment two the average length was 16.57 meters, and in segment three the average length was 13.63 meters (Figure 19, Table 6). Segment two had the highest average, whereas segment one had the lowest average.

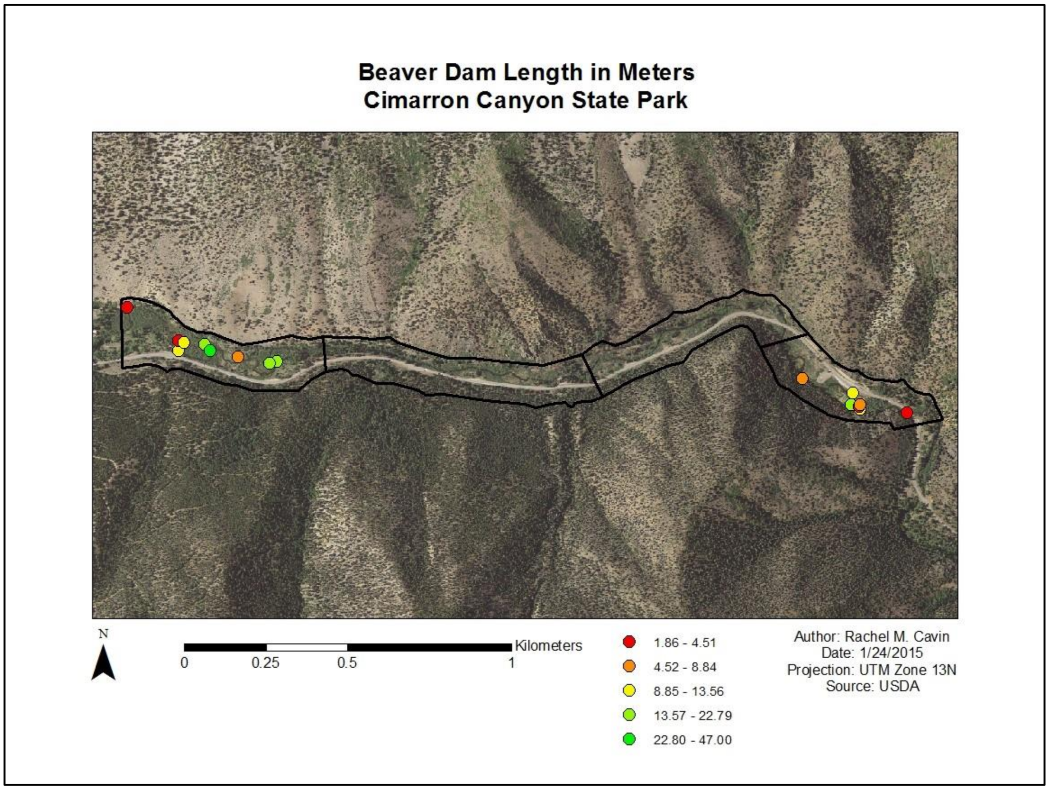

Figure 20: The distribution of beaver dam length measurements in Cimarron Canyon State Park.

In Cimarron Canyon the overall average beaver dam length was 11.55 meters, segment one had an average length of 14.2 meters, segments two and three contained no beaver dams, and segment four had an average length of 8.14 meters (Figure 20, Table 6). Segment one had the highest average length and segment four had the lowest average length.

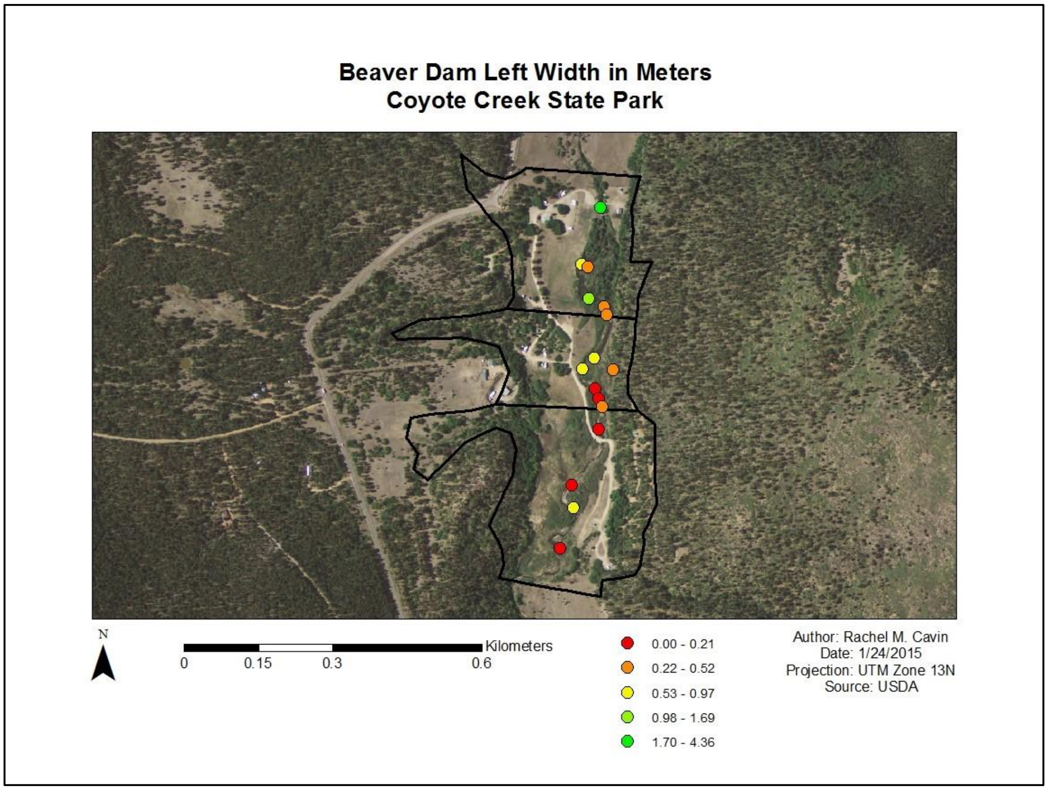


Figure 21: The distribution of beaver dam left width measurements in Coyote Creek State Park.

The average left width measurement in Coyote Creek was 0.88 meters. In segment one, the average left width was 1.38 meters, segment two had an average left width of 0.42 meters, and segment three had an average left width value of 0.44 meters (Figure 21, Table 6). Segment one had the highest average left width and segment two had the lowest.

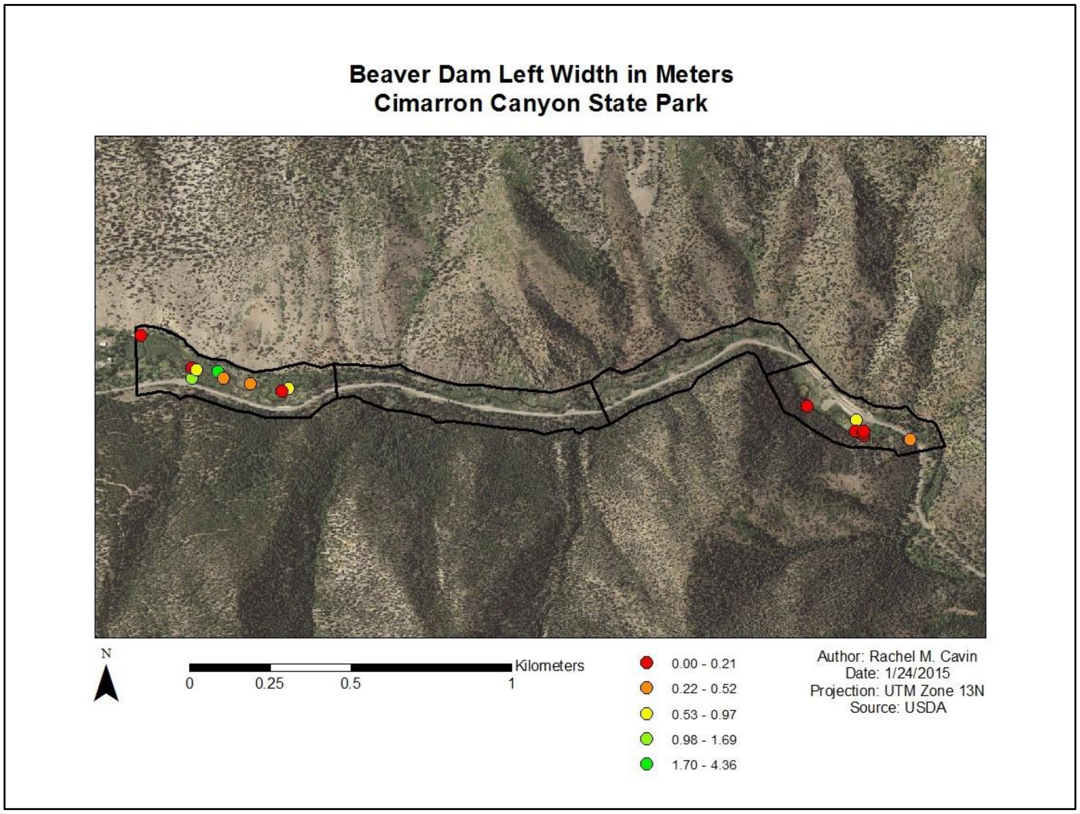


Figure 22: The distribution of beaver dam left width measurements in Cimarron Canyon State Park.

In Cimarron Canyon State Park, the overall average left width was 0.99 meters. Segment one had an average left width of 1.24 meters, segments two and three had no beaver dams, and segment four had an average left width measurement of 0.41 meters (Figure 22, Table 6). Segment one had the highest average left width value, and segment four had the lowest.

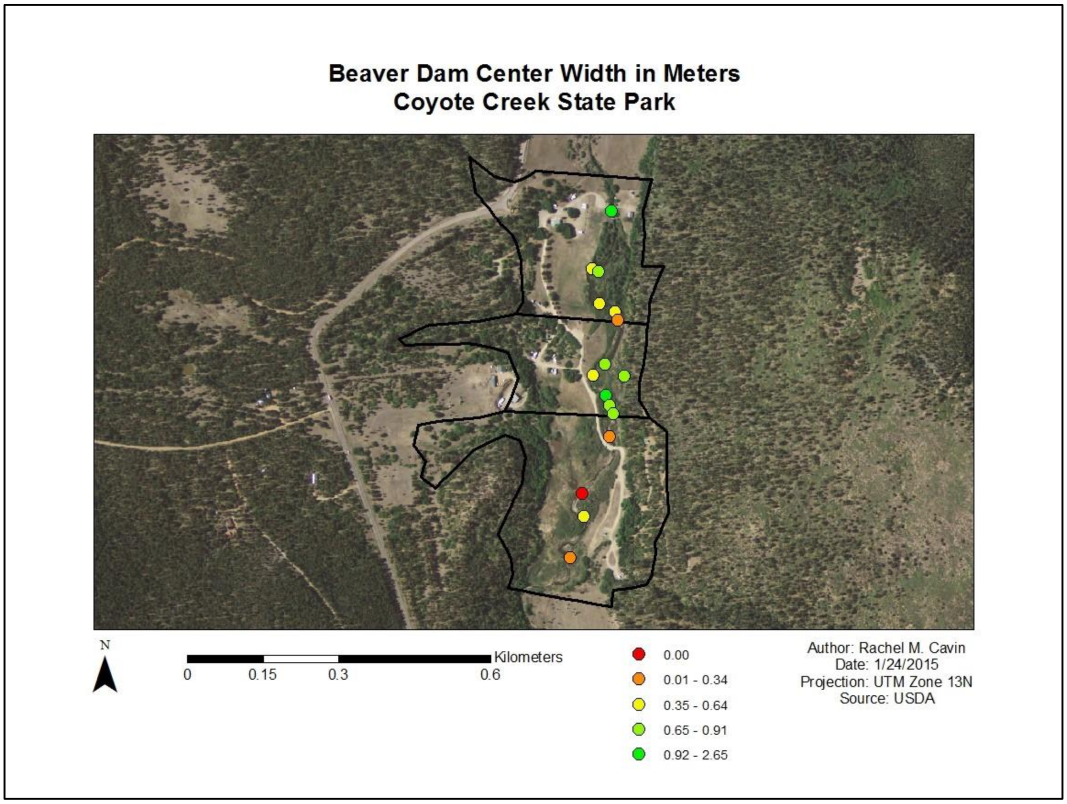


Figure 23: The distribution of beaver dam center width measurements in Coyote Creek State Park.

The overall average center width measurement in Coyote Creek State Park was 0.82 meters. Segment one had an average center width of 0.90 meters, the average of segment two was 0.90 meters, and the average of segment three was 0.35 meters (Figure 23, Table 6). Segments two and three both had the highest average center widths, and segment three had the lowest.

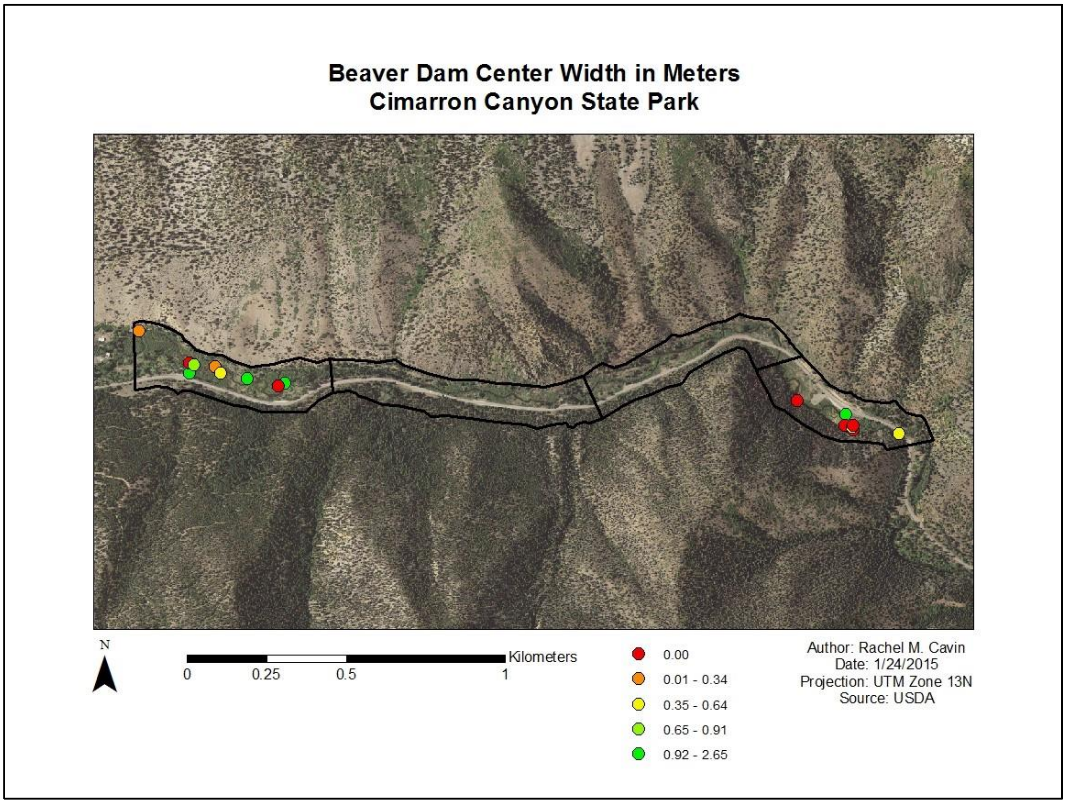


Figure 24: The distribution of beaver dam center width measurements in Cimarron Canyon State Park.

In Cimarron Canyon State Park, the average center width was 0.87 meters. Segment one had an average center width of 0.91 meters, segments two and three had no beaver dams, and the average center width in segment four was 0.79 meters (Figure 24, Table 6). Segment one had the highest average center width and segment four had the lowest.

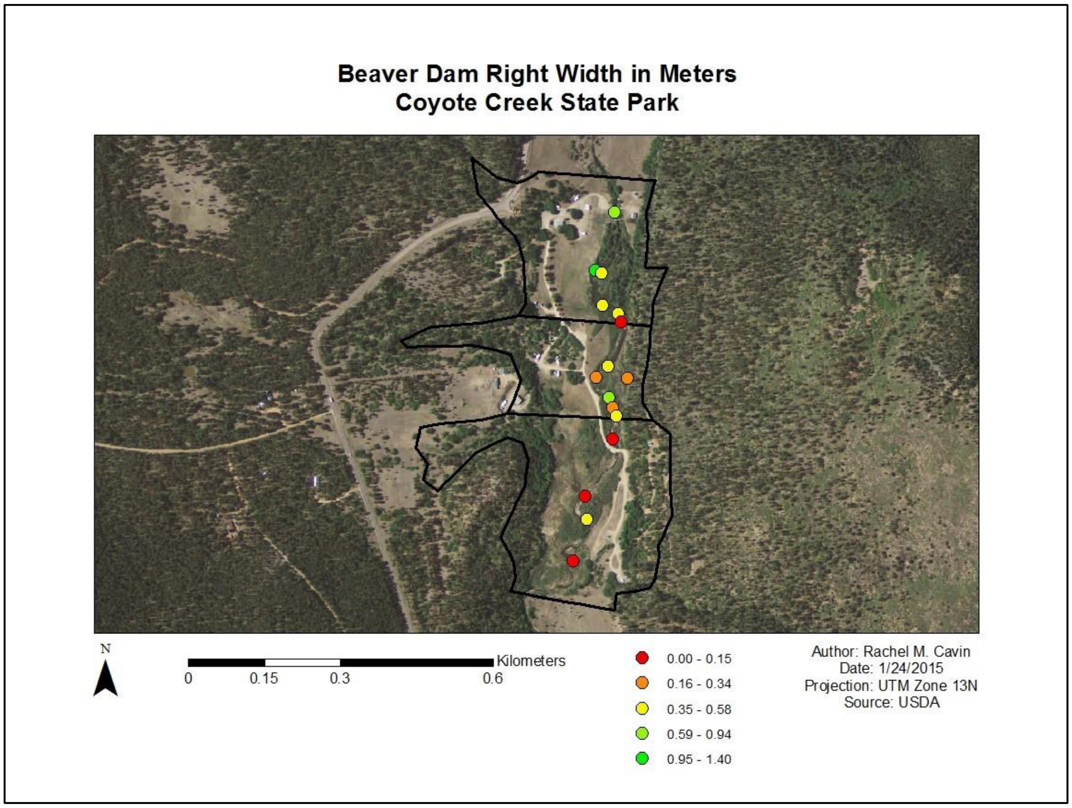

Figure 25: The distribution of beaver dam right width measurements in Coyote Creek State Park.

Coyote Creek had an overall average right width of 0.56 meters. Segment one had an average right width of 0.55 meters, segment two had an average of 0.42, and the third segment had an average right width of 0.24 (Figure 25, Table 6). Segment one had the highest average right width, and segment three had the lowest.

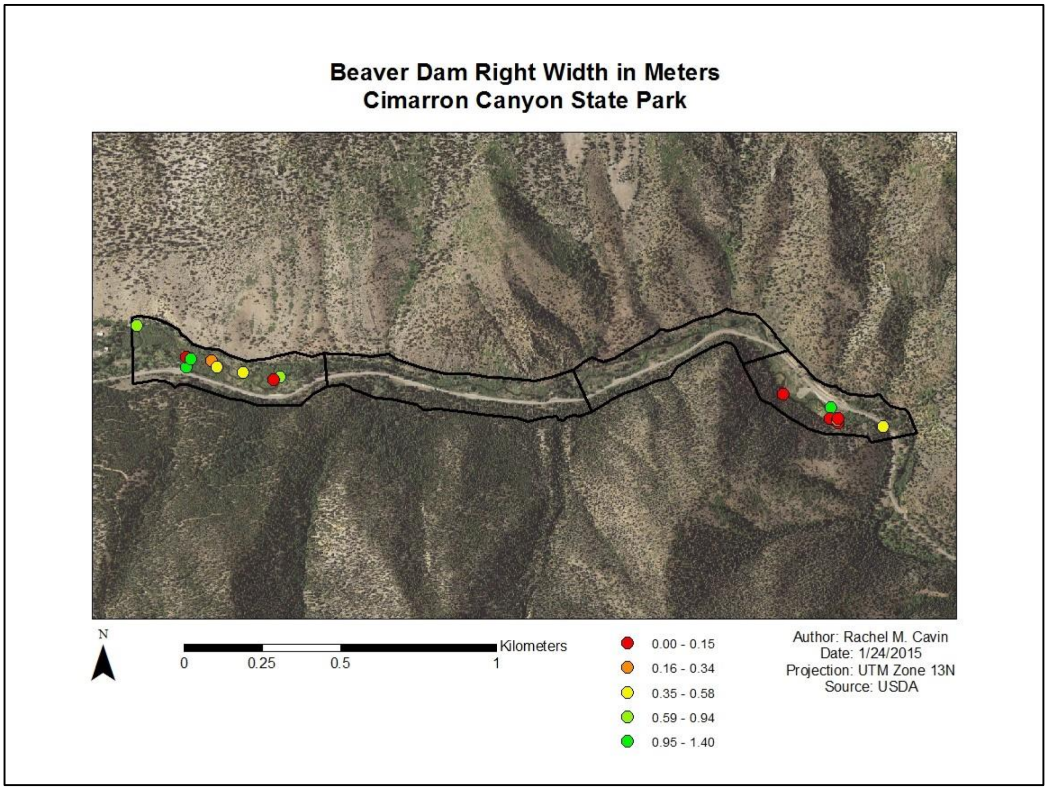


Figure 26: The distribution of beaver dam right width measurements in Cimarron Canyon State Park.

In Cimarron Canyon, the average right width was 0.75 meters. Segment one had an average right width of 0.74 meters, segments two and three contained no beaver dams, and segment four had an average right width of 0.76 meters (Figure 26, Table 6). Segment three had the highest average right width, and segment one had the lowest.

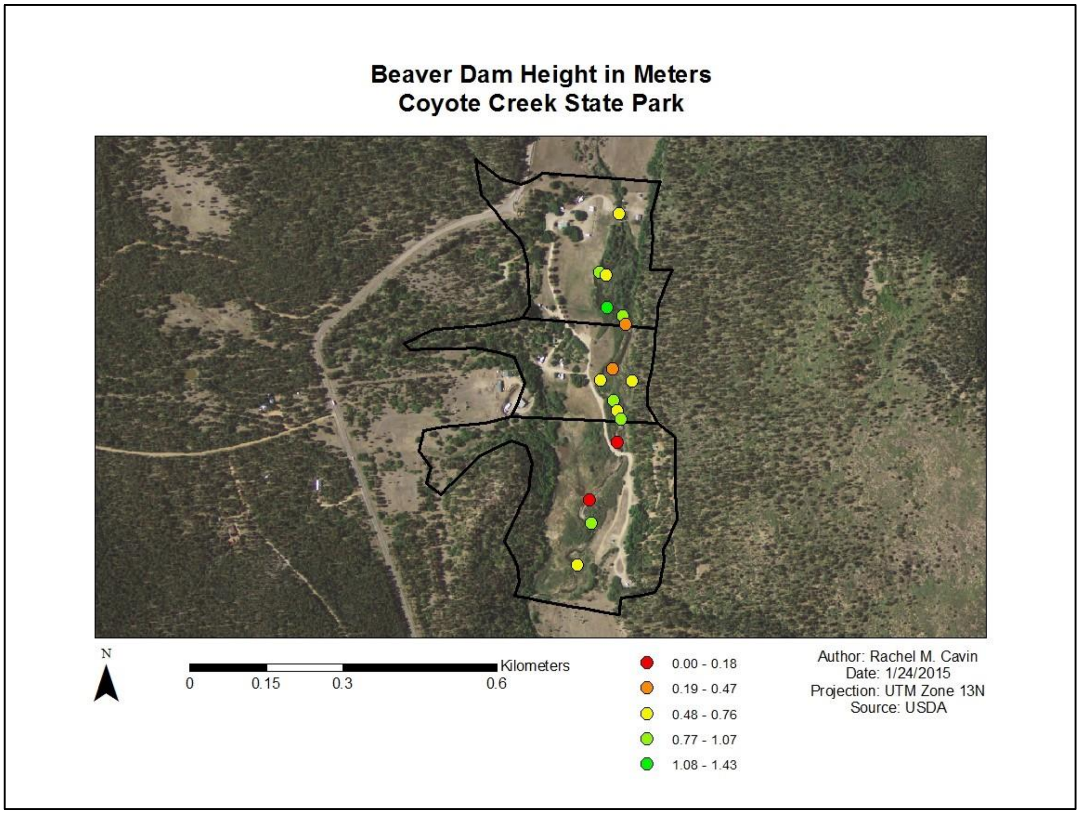


Figure 27: The distribution of beaver dam height measurements in Coyote Creek State Park.

The average height of beaver dams in Coyote Creek State Park was 0.73 meters. In segment one the average height was 0.83 meters, in segment two the average height was 0.69 meters, and segment three had an average height of 0.54 meters (Figure 27, Table 6). Segment one had the highest average beaver dam height and segment three had the lowest.

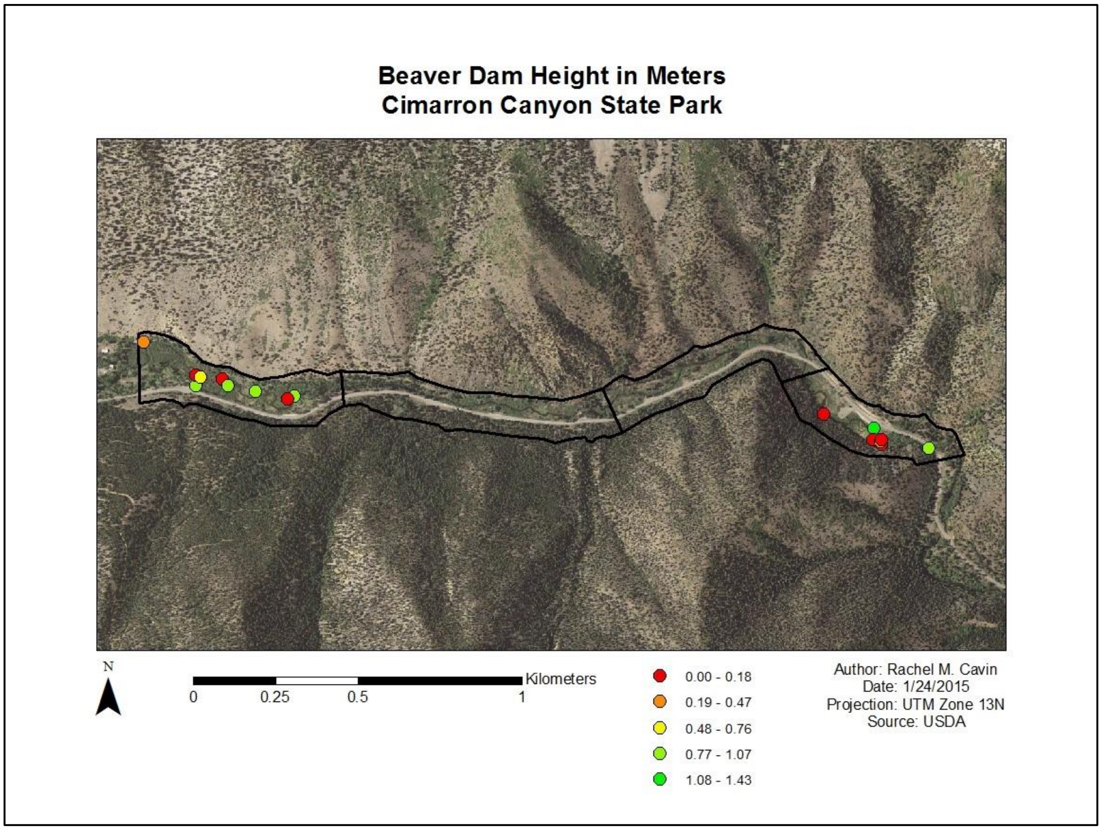


Figure 28: The distribution of beaver dam height measurements in Cimarron Canyon State Park.

Cimarron Canyon had an average beaver dam height of 0.75 meters. In segment one the average height was 0.69 meters, segments two and three had no beaver dams, and segment four had an average height of 0.90 meters (Figure 28, Table 6). Segment four had the highest average height of 0.90 meters, and segment one had the lowest average height at 0.69 meters.

<u>Landscape Characteristics of Coyote Creek and Cimarron Canyon State Parks</u>

This section contains the results related to the landscape characteristics of Coyote Creek State Park and Cimarron Canyon State Park. The landscape characteristics presented here are upstream catchment area, valley area, beaver dam relative density, surveyed stream length, stream gradient, average valley width, stream sinuosity, percent cover (canopy, riparian, vegetated, developed), and stream length between beaver dams.

*Upstream Catchment Area*

Cimarron Canyon had the largest upstream catchment area, with an area of 518 square kilometers. Coyote Creek had a smaller upstream catchment area of 196 square kilometers (Table 7).

*Valley Area*

Cimarron Canyon had a greater valley area of 355,889 square meters. Segment one was 96,336 square meters in size, segment two was 102,076 square meters, segment three was 82,385 square meters, and segment four had an area of 75,092 square meters (Table 7). Coyote Creek was smaller at 257,692 square meters. Segment one was 80,006 square meters, segment two was 58,418 square meters, and segment three was 119,268 square meters (Table 7).

*Beaver Dam Relative Density*

Cimarron Canyon and Coyote Creek both contained 16 beaver dams. The relative density of beaver dams in Coyote Creek was highest, at 15.8 beaver dams per kilometer. Segment one had a relative density of 16.3 beaver dams per kilometer, segment two had a relative density of 28.7 beaver dams per kilometer, and segment three had a relative density of 9.2 beaver dams per kilometer (Table 7). Cimarron Canyon had a lower beaver dam relative density of 5.1 beaver dams per kilometer. Segment one had a relative density of 9.7 beaver dams per kilometer, segments two and three contained no beaver dams and therefore had a relative density of zero beaver dams per kilometer, and segment four had a relative density of 11.9 beaver dams per kilometer (Table 7). When the stream length of segments two and three was removed from the calculation of beaver dam relative density, Cimarron Canyon had a relative density of 10.58 beaver dams per kilometer (Table 7)

*Surveyed Stream Length*

Cimarron Canyon had a longer surveyed stream length at 3129 meters. Segment one had 925 meters, segment two had 850 meters, segment three had 767 meters, and segment four had 587 meters of surveyed stream length (Table 7). Coyote Creek had 1012 meters of surveyed stream length. Segment one contained 367 meters, segment two had 209 meters, and segment three had 436 meters of surveyed stream length (Table 7).

*Stream Gradient*

Coyote Creek had a higher stream gradient overall, at 12.75 meters per kilometer. Segment one had a gradient of 14.17 meters per kilometer, segment two had a gradient of 11.96 meters per kilometer, and segment three had a gradient of 11.93 meters per kilometer (Table 7). Cimarron Canyon had a lower overall stream gradient of 8.9 meters per kilometer. Segment one had a stream gradient of 6.81 meters per kilometer, segment two had a gradient of 10.70 meters per kilometer, segment three had a gradient of 4.95 meters per kilometer, and segment four had a gradient of 14.82 meters per kilometer (Table 7).

*Average Valley Width*

Coyote Creek had a wider valley width of 293.93 meters. Segment one had a width of 246.53 meters, segment two had a width of 253.65 meters, and segment three had a width of 320.04 meters (Table 7). Cimarron Canyon had a narrower valley width of 141.45 meters. Segment one had a width of 149.58 meters, segment two had a width of 120.78 meters, segment three had a width of 117.81 meters, and segment four had a width of 136.43 meters (Table 7).

*Stream Sinuosity*

The Cimarron River had the highest sinuosity of 1.26 throughout the full study site. In segment one the sinuosity was 1.26, in segment two the sinuosity was 1.49, in segment three the sinuosity was 1.28, and in segment four the sinuosity was 1.13 (Table 7). Coyote Creek had a sinuosity of 1.21 throughout the study site. Segment one had a sinuosity of 1.23, segment two had a sinuosity of 1.12, and segment three had a sinuosity of 1.15 (Table 7).

Table 7: The Landscape Characteristics of Coyote Creek and Cimarron Canyon.

| | **Coyote Creek** | **Cimarron Canyon** |
|---|---|---|
| **Upstream Catchment Area** | 196 $km^2$<br>76 $mi^2$ | 518 $km^2$<br>200 $mi^2$ |
| **Valley Area** | **257,692 $m^2$** | **355,889 $m^2$** |
| **Segment 1** | 80,006 $m^2$ | 96,336 $m^2$ |
| **Segment 2** | 58,418 $m^2$ | 102,076 $m^2$ |
| **Segment 3** | 119,268 $m^2$ | 82,385 $m^2$ |
| **Segment 4** | | 75,092 $m^2$ |
| **Number of Beaver Dams** | 16 | 16 |
| **Beaver Dam Rel. Density** | **15.8/km** | **5.1/km** *(10.58/km)* |
| **Segment 1** | 16.3/km | 9.7/km |
| **Segment 2** | 28.7/km | 0/km |
| **Segment 3** | 9.2/km | 0/km |
| **Segment 4** | | 11.9/km |
| **Surveyed Stream Length** | **1012 m** | **3129 m** |
| **Segment 1** | 367 m | 925 m |
| **Segment 2** | 209 m | 850 m |
| **Segment 3** | 436 m | 767 m |
| **Segment 4** | | 587 m |
| **Stream Gradient** | **12.75 m/km** | **8.9 m/km** |
| **Segment 1** | 14.17 m/km | 6.81 m/km |
| **Segment 2** | 11.96 m/km | 10.70 m/km |
| **Segment 3** | 11.93 m/km | 4.95 m/km |
| **Segment 4** | | 14.82 m/km |
| **Average Valley Width** | **293.93 m** | **141.45 m** |
| **Segment 1** | 246.53 m | 149.58 m |
| **Segment 2** | 253.65 m | 120.78m |
| **Segment 3** | 320.04 m | 117.81 m |
| **Segment 4** | | 136.43 m |
| **Stream Sinuosity** | **1.21** | **1.26** |
| **Segment 1** | 1.23 | 1.49 |
| **Segment 2** | 1.12 | 1.04 |
| **Segment 3** | 1.15 | 1.28 |
| **Segment 4** | | 1.13 |

*Percent Canopy Cover*

Percent canopy cover included both riparian and pine/upland forests. Cimarron Canyon had the higher percent canopy cover at 71.2% coverage (Table 8, Figure 30). Segment one had 71.2% coverage, segment two had 73.4% coverage, segment three had 73.0% coverage, and segment four had 66.4% coverage (Table 8). Coyote Creek had slightly less canopy cover at 60.3% (Table 8, Figure 29). Segment one had 52.7%, segment two had 67.3%, and segment three had 86.6% canopy coverage (Table 8).

*Percent Riparian Cover*

Cimarron Canyon had a higher riparian forest coverage of 41.9% (Table 8, Figure 30). Segment one had 52.8% riparian coverage, segment two had 38.5%, segment three had 45.3%, and 27.3% of segment four had riparian forest coverage (Table 8). Coyote Creek had 23.1% riparian forest coverage (Table 8, Figure 29). Segment one had 17.4% coverage, segment two had 16.5%, and segment three had 34.5% riparian forest coverage (Table 8).

*Percent Vegetated Cover*

Vegetated cover includes riparian, pine/upland, and herbaceous vegetation types. Coyote Creek had a higher vegetation cover percentage of 84.7% (Table 8, Figure 29). Segment one had 82.4% vegetated cover, segment two had 86.2% vegetated cover, and segment three had 63.3% vegetated cover (Table 8). Cimarron Canyon had a lower vegetated cover percentage of 77.2% (Table 8, Figure 30). Segment one had 77.0% vegetated cover, segment two had 79.2%, segment three had 80.8%, and segment four had 70.8% vegetated cover (Table 8).

*Percent Developed Cover*

Developed cover included buildings, roads, and campsites. Coyote Creek had the most developed cover at 10.5% (Table 8, Figure 29). Segment one had 14.3% developed cover, segment two had 9.3% cover, and segment three had 7.3% developed cover (Table 8). Cimarron Canyon had 9.1% developed cover (Table 8, Figure 30). Segment one had 8.0% developed cover, segment two had 9.7% cover, segment three had 9.7% cover, and segment four had 8.5% developed cover (Table 8).

*Stream Length between Beaver Dams*

Table 9 contains the stream length both up and downstream of each individual beaver dam, as well as park averages. Coyote Creek had an average upstream distance of 72.50 meters, and an average downstream distance of 70.29 meters (Table 9). Cimarron Canyon had an average upstream distance of 246.39 meters, or 95.40 meters when the 2058 meter gap between beaver dam B115 and B101 was removed, and the average downstream distance was 261.70 meters, or 112.00 meters without the gap (Table 9).

Table 8: The percentage of Coyote Creek and Cimarron Canyon that were covered by forest canopy, riparian forest, vegetation, and developed cover.

| | **Coyote Creek** | **Cimarron Canyon** |
|---|---|---|
| **Percent Canopy Cover** | **60.3%** | **71.2%** |
| **Segment 1** | 52.7% | 71.2% |
| **Segment 2** | 67.3% | 73.4% |
| **Segment 3** | 86.6% | 73.0% |
| **Segment 4** | | 66.4% |
| **Percent Riparian Cover** | **23.1%** | **41.9%** |
| **Segment 1** | 17.4% | 52.8% |
| **Segment 2** | 16.5% | 38.5% |
| **Segment 3** | 34.5% | 45.3% |
| **Segment 4** | | 27.3% |
| **Percent Vegetated Cover** | **84.7%** | **77.2%** |
| **Segment 1** | 82.4% | 77.0% |
| **Segment 2** | 86.2% | 79.2% |
| **Segment 3** | 63.3% | 80.8% |
| **Segment 4** | | 70.8% |
| **Percent Developed Cover** | **10.5%** | **9.1%** |
| **Segment 1** | 14.3% | 8.0% |
| **Segment 2** | 9.3% | 9.7% |
| **Segment 3** | 7.3% | 8.5% |
| **Segment 4** | | 10.2% |

Table 9: The stream length in meters up- and downstream from each beaver dam to the nearest beaver dam. Each park also has an average; the average for Cimarron Canyon was calculated both with and without the 2058 meter gap between dam B101 and B115.

| | **Upstream Distance** | **Downstream Distance** |
|---|---|---|
| **Coyote Creek** | | |
| 101 | | 137 m |
| 102 | 137 m | 80 m |
| 103 | 80 m | 37 m |
| 104 | 132 m | 74 m |
| 105 | 37 m | 20 m |
| 106 | 20 m | 98 m |
| 107 | 98 m | 38 m |
| 108 | 45 m | |
| 109 | 38 m | 63 m |
| 110 | 63 m | 23 m |
| 111 | 23 m | 19 m |
| 112 | 19 m | 60 m |
| 113 | 60 m | 141 m |
| 114 | 141 m | 72 m |
| 115 | 72 m | 122 m |
| **116** | **122 m** | |
| **Average:** | 72.50 m | 70.29 |
| Cimarron **Canyon** | | |
| 101 | 2058 m | 178 m |
| 102 | 178 m | 38 m |
| 103 | 38 m | 27 m |
| 104 | 7 m | |
| 105 | 27 m | 7 m |
| 106 | 7 m | 163 m |
| 107 | 163 m | |
| 108 | | 215 m |
| 109 | 38 m | 129 m |
| 110 | 215 m | 38 m |
| 111 | 17 m | |
| 112 | | 29 m |
| 113 | 129 m | 304 m |
| 114 | | 194 m |
| **115** | **22** m | **2058** m |
| **116** | **304** m | **22** m |
| **Average:** | **246.39** | **261.70** |
| **Average (Without Gap):** | *95.40* | *112.00* |

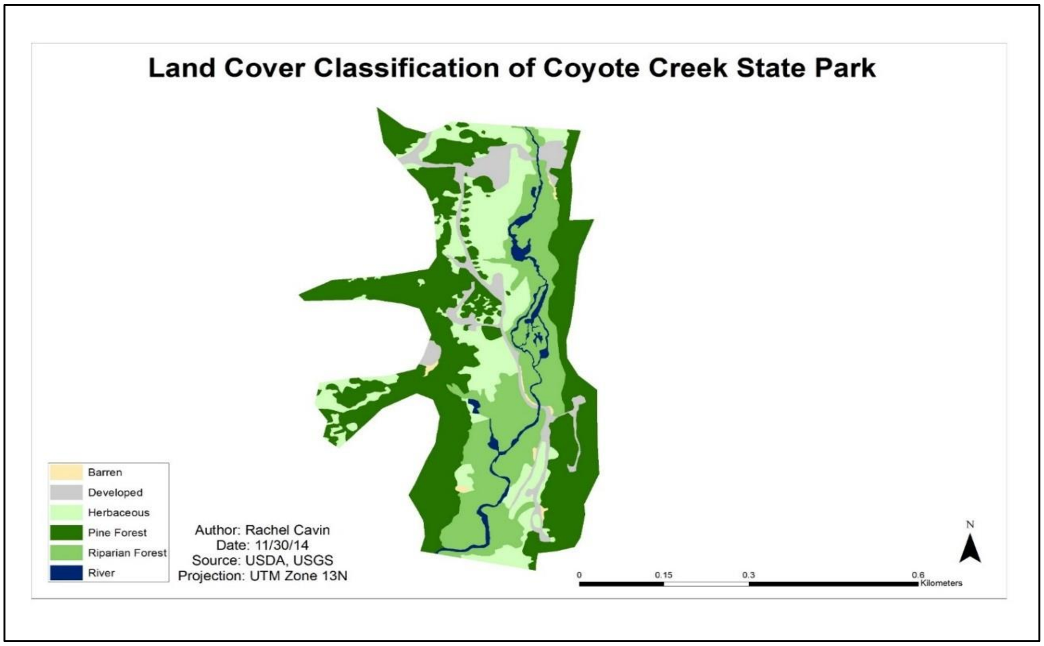


Figure 29: A map of barren, developed, herbaceous, pine forest, riparian forest, and river land covers in Coyote Creek State Park.

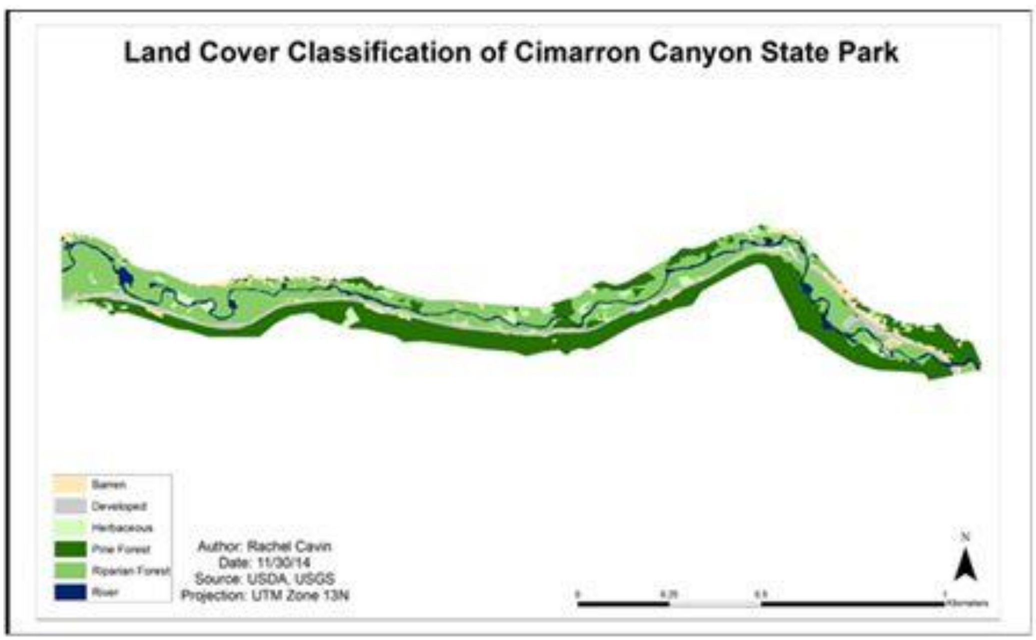


Figure 30: A map of barren, developed, herbaceous, pine forest, riparian forest, and river land covers in Cimarron Canyon State Park.

# CHAPTER VI

## DISCUSSION

Similar to the results chapter, this discussion chapter is organized into several subsections. It will begin with a discussion of the beaver dam dimensions, their differences and similarities between study sites as tested with the Mann-Whitney U Test, and comparisons with beaver dam dimension studies that took place in other regions. Beaver dam structure classifications will follow, with beaver dam distributions as the third section, each with comparisons between Cimarron Canyon and Coyote Creek, as well as to the wider beaver dam literature similarly to that in the first section. The final section is a synthesis which seeks to discuss how differences and similarities in beaver dam dimensions, structures, and distributions relate to the landscape characteristics of the study sites and their segments.

### Beaver Dam Dimensions

Despite small differences in the descriptive statistics of beaver dam dimensions in Cimarron Canyon and Coyote Creek State Parks (Table 6), the Mann Whitney U Test indicated that no statistically significant difference in beaver dam dimensions exists between Coyote Creek and Cimarron Canyon (Table 5). Furthermore, within each study site the average beaver dam dimensions across each segment did not have noteworthy variability either (Table 6). The beaver dam dimensions reported in this study are within reasonable range of those reported in multiple literature sources, although mean values in this study tend to be slightly higher than many measured and reported in past studies (Table 10). This suggests that variation in beaver dam dimensions might not be significant across different regions. If this is the case, then beaver dams are built to the same sizes and shapes, regardless of the characteristics, climate, or flow regime of the surrounding landscape. Considering the extent and variability of conditions contained within the geographic range of the North American beaver, this would suggest that beaver dams are versatile structures, requiring no alterations in construction apart from those needed to fit each dam to the morphology of the river channel.

Table 10: A list of beaver dam dimensions reported in the literature. Beaver dam dimensions measured in this study in bold. * Indicates a single beaver dam dimension reported in a study, rather than statistics on a sample.

| **Length** | **Study Site** | **Mean** | **Min** | **Max** | **Method of Measurement** |
|---|---|---|---|---|---|
| Mills (1913) | Montana, USA | | | 652* | Not Specified |
| Scheffer (1938) | Washington, USA | 13.06 | | | Not Specified |
| Townsend (1953) | Montana, USA | | 0.60 | 13.00 | Field Measurement |
| Woo and Waddington (1990) - Overflow | Ontario, Canada | 15.54 | 2.40 | 67.70 | Field Measurement |
| Woo and Waddington (1990) - Gap Flow | Ontario, Canada | 11.24 | 1.00 | 40.50 | Field Measurement |
| Woo and Waddington (1990) - Underflow | Ontario, Canada | 11.52 | 2.50 | 35.80 | Field Measurement |
| Woo and Waddington (1990) - Throughflow | Ontario, Canada | 4.64 | 0.50 | 18.50 | Field Measurement |
| Butler (1995) | Montana, USA | | 15.00 | 70.00 | Field Measurement |
| Demmer and Breschta (2008) | Oregon, USA | 8.00 | | | Field Visual Estimation |
| **Coyote Creek State Park** | **New Mexico, USA** | **13.63** | **2.37** | **47.00** | **Field Measurement** |
| **Cimarron Canyon State Park** | **New Mexico, USA** | **11.55** | **1.86** | **31.94** | **Field Measurement** |
| **Height** | | | | | |
| Scheffer (1938) | Washington, USA | 0.85 | | | Not Specified |
| Townsend (1953) | Montana, USA | | 0.10 | 1.50 | Field Measurement |
| Woo and Waddington (1990) - Overflow | Ontario, Canada | 0.15 | 0.05 | 0.75 | Field Measurement |
| Woo and Waddington (1990) - Gap Flow | Ontario, Canada | 0.15 | 0.03 | 0.40 | Field Measurement |
| Woo and Waddington (1990) - Underflow | Ontario, Canada | 0.15 | 0.02 | 0.40 | Field Measurement |
| Woo and Waddington (1990) - Throughflow | Ontario, Canada | 0.02 | 0.01 | 0.10 | Field Measurement |
| **Coyote Creek State Park** | **New Mexico, USA** | **0.72** | **0.18** | **1.43** | **Field Measurement** |
| **Cimarron Canyon State Park** | **New Mexico, USA** | **0.75** | **0.04** | **1.37** | **Field Measurement** |
| **Width** | | | | | |
| Woo and Waddington (1990) - Overflow | Ontario, Canada | 0.63 | 0.20 | 1.70 | Field Measurement |
| Woo and Waddington (1990) - Gap Flow | Ontario, Canada | 0.80 | 0.26 | 2.00 | Field Measurement |
| Woo and Waddington (1990) - Underflow | Ontario, Canada | 0.79 | 0.40 | 1.55 | Field Measurement |
| Woo and Waddington (1990) - Throughflow | Ontario, Canada | 0.47 | 0.15 | 0.95 | Field Measurement |
| Butler (1995) | Montana, USA | | 1.00 | 2.00 | Field Measurement |
| **Coyote Creek State Park - Left Width** | **New Mexico, USA** | **0.81** | **0.15** | **4.36** | **Field Measurement** |
| **Coyote Creek State Park - Center Width** | **New Mexico, USA** | **0.79** | **0.22** | **2.65** | **Field Measurement** |
| **Coyote Creek State Park - Right Width** | **New Mexico, USA** | **0.44** | **0.12** | **1.04** | **Field Measurement** |
| **Cimarron Canyon State Park - Left Width** | **New Mexico, USA** | **0.99** | **0.12** | **4.32** | **Field Measurement** |
| **Cimarron Canyon State Park - Center Width** | **New Mexico, USA** | **0.87** | **0.30** | **1.68** | **Field Measurement** |
| **Cimarron Canyon State Park - Right Width** | **New Mexico, USA** | **0.75** | **0.27** | **1.37** | **Field Measurement** |

Beaver Dam Structure Classifications

Although the beaver dam dimensions were similar between the two study sites, there were observable differences in beaver dam structures between the locations. No statistical test was used to determine the statistical significance of these differences, however, the frequency of the structures was very different between the two parks (Figures 13-14, Table 6, Table 11). Coyote Creek had a much higher frequency of through flow and overflow beaver dams, whereas Cimarron Canyon had a higher frequency of gap flow and through flow beaver dams. The structure classifications in Coyote Creek were more uniform across all three segments, however in Cimarron Canyon the upstream first segment was mostly through flow dams and the downstream fourth segment was mostly gap flow dams. Compared to the frequencies of the classifications reported in Woo and Waddington (1990), the frequencies in this study were less evenly distributed throughout the four categories. Both Cimarron Canyon and Coyote Creek had a single structure classification that contained at least half of all the beaver dams sampled in that site, gap flow and through flow, respectively. My study sites also had secondary large classifications, through flow in Cimarron Canyon and overflow in Coyote Creek, with lower classification frequencies in the third and fourth classes. Underflow dams were relatively scarce in my sites, similar to the findings from Woo and Waddington (1990), although nearly 20% of the dams in Cimarron Canyon were in this class. Cimarron Canyon also had no overflow dams, which is unusual in comparison with both Coyote Creek and Woo and Waddington's (1990) findings (Table 11). Paired with the lack of significant differences in beaver dam dimensions, it is likely that although beaver dams start out similar in their construction, differences in structure appear over time because of differences in the surrounding landscapes that may increase incidence and likelihood of beaver dam breaches, and variability in flow that may cause differences in the frequency of overflow, through flow, and underflow dams.

Table 11: A list of beaver dam structure classifications reported in the literature. The values from this study are bolded, and compared to those reported by Woo and Waddington (1990) in their study sites in Ontario, Canada.

| | Study Site | Through Flow | Overflow | Gap flow | Underflow | Method of Measurement |
|---|---|---|---|---|---|---|
| Woo and Waddington (1990) | Ontario, Canada | 15 (28%) | 20 (37%) | 15 (28%) | 4 (7%) | Field Measurement |
| **Coyote Creek State Park** | **New Mexico, USA** | **9 (56%)** | **4 (25%)** | **2 (13%)** | **1 (6%)** | Photographic Evidence |
| **Cimarron Canyon State Park** | **New Mexico, USA** | **5 (31%)** | **0 (0%)** | **8 (50%)** | **3 (19%)** | Photographic Evidence |

Beaver Dam Distribution

In Coyote Creek State Park, beaver dam distributions varied, but no major gaps existed between dams (Table 9). Segment one of Coyote Creek had a relative density of 16.3/km, segment two had the highest density at 28.7/km, and segment three had a low density at 9.2/km (Table 7). Cimarron Canyon had a much more uneven beaver dam distribution, with a 2058 meter gap that extended two full segments (Table 9). Segment one had an average beaver dam relative density of 14.2/km, and segment four had an average relative density of 8.14/km, however segments two and three had no beaver dams at all (Table 7). Compared with relative density values in the literature, Coyote Creek State Park had an intermediate, but somewhat high beaver dam relative density of 15.8/km (Table 12). Cimarron Canyon had a relatively low relative density when calculated with the gap between beaver dams at 5.1/km, but when calculated without the gap in beaver dams the relative density was more intermediate, at 10.58/km (Table 12).

Table 12: A list of relative densities, or beaver dams per kilometer, as reported in the literature. The values reported in this study are bolded, and the parenthesis indicate a relative density calculated to avoid large gaps between dams that skew the results.

| | Study Area | Relative Density | Method of Measurement |
|---|---|---|---|
| Naiman, et al. (1986) | Quebec, Canada | 10.6/km | Field Data |
| Naiman, et al. (1988) | Minnesota, USA | 2.5/km | Not Specified |
| McComb et al (1990) | Oregon, USA | 0.14/km | Field Data |
| Woo and Waddington (1990) | Ontario, Canada | 14.3/km | Field Data |
| Butler and Malanson (1994) | Montana, USA | 25/km | Field Data |
| MacCracken and Lebovitz (2005) | Washington, USA | 3/km | Field Data |
| **Coyote Creek State Park** | **New Mexico, USA** | **15.8/km** | **Field Data in GIS** |
| **Cimarron Canyon State Park** | **New Mexico, USA** | **5.1/km (10.58/km)** | **Field Data in GIS** |

Beaver Dam Structures and Distribution, and Landscape Characteristics

Although the beaver dam dimensions were similar between the two study sites, the beaver dam structures and distributions did have differences between Cimarron Canyon and Coyote Creek. In order to find explanations for why these differences might have occurred, patterns and relationships between the beaver dam structures and distributions, and the characteristics of the two study site landscapes were assessed.

In Coyote Creek the beaver dam structures and distributions were relatively uniform throughout the study area, without expansive gaps between dams or major differences in beaver dam structures between segments. Coyote Creek had the higher beaver dam relative density, which was highest in the central segment of the park, segment two. In this study site segment, the stream split into a complex multithread channel, and the high beaver dam relative density in this particular segment of the stream may be an example of the argument expressed by Polvi and Wohl (2012) that beaver dams can create a positive feedback loop, whereas they increase channel complexity and therefore create more stream length to dam (Figure 29). Despite the channel complexity of channel two, Coyote Creek had a lower stream sinuosity of 1.21, compared with 1.26 in Cimarron Canyon. Coyote Creek was the smaller study site, with a valley area of 257,692 square meters and a surveyed stream length of 1,012 meters (Table 7). Although despite its smaller size, it contained the same number of beaver dams. The average upstream and downstream distance between beaver dams was lower in Coyote Creek, even whenever the Cimarron Canyon values were calculated without the gap in segments two and three (Table 9).

Coyote Creek had a wider valley width of 293.93 meters (Table 7), which beavers have been shown to prefer for building beaver dams (Suzuki and McComb 1998). Coyote Creek also had a smaller upstream catchment area of 196 square kilometers. Smaller basins have less area contributing to stream flow, therefore Coyote Creek likely experiences lower flows than Cimarron River, and when the water is backed up there is a wider valley width for that water to inundate. This can spread floodwaters over a larger area, discouraging velocities in the stream from reaching points which may breach beaver dams (Suzuki and McComb 1998). The lower overall sinuosity for the park also means less variation exists in velocity across the lateral length of the stream, and there may be an associated lack of diversity in streambed substrate as a result. This would make beaver dams more stable, because of a more even water pressure across the full length of the dam. Although Coyote Creek did have the higher overall stream gradient of 12.75 m/km (Table 7), the lower sinuosity paired with the wider valley width likely lessen the impact of this on the beaver dam structures. These variables help explain why Coyote Creek had only two gap flow dams, whereas Cimarron Canyon had eight. The landscape characteristics of Coyote Creek are less likely to test the structural integrity of a beaver dam, and therefore gap flow dams were infrequent, with more dams categorized as through flow and overflow (Table 6, Figure 31). Coyote Creek also had a lower percentage of riparian coverage, yet a higher total vegetated cover area that was mostly herbaceous vegetation. Although it is difficult to be certain, this could be the result of more active cutting of beavers in this park for beaver dam construction and maintenance (Suzuki and McComb 1998). Though Coyote Creek had slightly more developed cover, it is concentrated at the park entrance, rather than throughout the park (Table 8, Figure 29).

Figure 31: A through flow beaver dam in Coyote Creek State Park. The flow seeps through the face of the dam, rather than flowing over the dam crest, under the dam, or through any breaches in the beaver dam.

Cimarron Canyon was the larger study area, with a surveyed stream length of 3129 meters and a valley area of 355,889 square meters. Cimarron Canyon had more variability throughout the park in beaver dam structures, distributions, and the landscape characteristics. Despite the larger size of the Cimarron Canyon study area, it contained the same number of beaver dams as Coyote Creek, at a lower relative density along the river course (Table 7). Cimarron Canyon had a low beaver dam relative density of 5.1/km (Table 7). This low relative density is partially a result of the 2058 meter gap between beaver dam clusters in Cimarron Canyon, however even whenever that distance is removed from the relative density calculation, the adjusted beaver dam relative density of 10.58/km is still lower than the density in Coyote Creek. The average upstream distance between beaver dams was 246.39 meters (95.40 meters when calculated without the 2058 meter gap in segments 2 and 3) and the average downstream distance between beaver dams was 261.70 (112.0 when calculated without the gap), considerably lower than that of Coyote Creek, even when calculated without the gap (Table 9).

Several relevant factors could explain the lack of beaver dams in Cimarron Canyon segments 2 and 3, and the lower beaver dam relative density overall in this study site. Cimarron Canyon has a lower valley width of 141.45 meters overall (Table 7). The width narrows in segments two and three, to 120.78 meters in segment two and 117.81 meters in segment three (Table 7). This confinement of the valley and stream could create a nozzle effect which would force the water through this stream section at higher velocities than the rest of the stream reach (Kieffer, 1989). Along with valley confinement, the stream gradient in segment two is 10.70 m/km, which is moderately steep. Though it decreases in segment three to just 4.95 m/km, it rises once more downstream in segment four to 14.82 m/km, the highest gradient throughout both study sites (Table 7). Valley confinement with occasionally high stream gradients would likely make beaver dams unstable in these areas, which increases water pressure behind beaver dams as the water moved quickly downstream. This could also explain the higher incidence of gap flow dams downstream of these two segments, as the fast moving water entering segment four from segments two and three will likely continue to move quickly because of the high stream gradient of segment four (Table 7). The upstream catchment area of Cimarron Canyon was larger, at 518 $km^2$ (Table 7).

The beaver dam structures in Cimarron Canyon differed from Coyote Creek in that they were primarily gap flow dams (Table 6, Figure 32). The majority of the gap flow dams were also located further downstream, with the upstream section of the stream reach primarily containing through flow beaver dams (Table 6). Segment one has a relatively low stream gradient of 8.9 m/km, a moderate valley width of 149.58 meters, a high sinuosity of 1.49, which nearly crosses the 1.5 threshold into a meander channel, and an abundant riparian coverage at 52.80% coverage (Table 7, Table 8). Although the high sinuosity could cause some stability problems for beaver dams, the other characteristics of segment one are appropriate for beaver dam construction (Howard and Larson 1985; Gurnell 1998; Suzuki and McComb 1998). The suitability of segment one for beaver dams may explain why they are generally in better condition, and more likely to be classified as through flow. Segment four is located downstream of segments two and three, which contain no beaver dams. As previously mentioned, it appears water may be accelerated through segments two and three, though the lack of velocity measurements in this study make it impossible to be certain. The acceleration of water through this segment likely continues into segment four to some extent because of the high stream gradient of 14.82 m/km in segment four, the highest observed in any of the segments (Table 7). The valley width of segment four is still relatively narrow at 136.43 meters, compared with the width of 149.58 meters in segment one, and this area has the least riparian cover of the Cimarron Canyon segments at 27.30% coverage (Table 7, Table 8). These factors together make this area harsher compared with segment one, as the high stream gradient and narrow valley width would continue to accelerate flow, and when beaver dams are breached there is less woody riparian cover to use as building material for repairs. These landscape characteristics together help to explain the high incidence of gap flow dams throughout segment four, as compared to segment one (Table 6, Table 7, Table 8).

Complicating factors in Cimarron Canyon include periodic trapping of beavers by the New Mexico Game and Fish Department and a recent wildfire in 2010 that affected beaver dams in segment four (personal communication with park staff 2012, 2013). Because US Highway 64 runs through Cimarron Canyon, beavers are trapped and beaver dams are destroyed if the beaver ponds begin to pose a hazard to the highway and motorists traveling through the park. The removal of beavers could cause beaver dams to degrade over time, and eventually breach. A wildfire also burned an area adjacent to the stream in 2010, and according to a park ranger a beaver lodge and at least one beaver dam was destroyed in the fire (personal communication with park staff 2012).

Figure 32: A breached, gap flow beaver dam in segment four of Cimarron Canyon. The entire central portion of the dam was destroyed, leaving remnants of the dam only on the river banks.

# CHAPTER VII

## CONCLUSIONS

Although publications on beavers and their beaver dams have existed for over a century (Mills 1913; Dugmore 1914), no previous publications have specifically examined the role of landscape characteristics in determining the dimensions or structures of beaver dams (Gurnell 1998). The purpose of this study was to measure beaver dam dimensions, distribution, and structure classifications in Coyote Creek and Cimarron Canyon State Parks, New Mexico, then to find relationships between characteristics of beaver dams and the characteristics of the surrounding landscapes.

The results of this study suggest that beaver dam dimensions did not vary between the two study sites, and that there is actually very little variation in beaver dam dimensions across multiple regions (Table 5, Table 10). This finding suggests that beavers likely build dams according to stream cross sectional dimensions, rather than to account for any characteristics beyond the stream banks. The lack of variation in beaver dams in a variety of different settings is a testament to the adaptability of the structures in a variety of different conditions. Although some landscape characteristics, such as high stream gradient, high stream order, or a lack of riparian vegetation can make a landscape unsuitable for beaver dam construction, it seems that beaver dams are constructed similarly in any site that meets suitability requirements.

Previous studies had investigated beaver dam distribution and landscape characteristics (Gurnell 1998), and this study contributed to that continuing discussion in the literature. Considerable variance has been observed in beaver dam distributions in previous studies, and this study is no different in that regard (Table 11). Although Coyote

Creek had a higher beaver dam relative density of 15.8/km, lower average upstream and downstream distances between beaver dams of 72.5 meters and 70.29 meters, respectively, with the highest relative density in segment two where the stream split into multiple channels (Table 7), Cimarron Canyon had a very different beaver dam distribution pattern. Cimarron Canyon had a lower beaver dam relative density of 5.1/km, higher average upstream and downstream distances between beaver dam values of 246.39 meters and 261.70 meters, respectively, and a very uneven distribution of beaver dams because of a 2058 meter gap between beaver dam clusters in segments one and four (Table 7, Table 9). Even when calculated without the gap between beaver dam clusters, the distribution of beaver dams in Cimarron Canyon is still more spaced than that of Coyote Creek (Table 9).

Woo and Waddington (1990) published the only previous study to classify beaver dams into through flow, gap flow, overflow, and underflow structure categories. Their classification system was adopted in this study, and this study was the first to compare structure classifications between two study sites. The results of this study indicated that the structures of beaver dams can vary greatly between two study sites. Coyote Creek was primarily through flow and overflow, Cimarron Canyon was mostly gap flow and through flow. Cimarron Canyon had variation in the distribution of beaver dam structure classifications along the stream reach. In the upstream first segment, the dams were primarily through flow and gap flow, whereas the downstream section was almost entirely gap flow dams (Table 6). These findings suggest that landscape characteristics do influence the structure of beaver dams. Though beaver dams are constructed to similar dimensions on differing landscapes, it appears that the landscape then effects the duration and durability of the dams over time.

When the distributions and structures of beaver dams were compared with the landscape characteristics of each study site and study site segment, several patterns emerged. The findings of this study agree with findings of previous studies in that stream gradients above a certain point appear to be a limiting factor for beaver dam construction (Gurnell 1998). However, it appears that in addition to lowering beaver dam density, high stream gradients can increase the number of dams that are breached and classified as gap flow. Narrow valleys also appear to inhibit beaver dam establishment by creating a nozzle effect that accelerates water through the stream at higher velocities than less confined areas of the same stream (Kieffer 1989). Areas downstream of confined stream sections may also experience a higher rate of beaver dam breaches. Areas larger upstream catchment areas appear to be more likely to have low beaver dam relative densities and high beaver dam breach rates. However, beaver trapping and wildfires may also be factors contributing to beaver dam breaches. The coincidence of the highest beaver dam relative density occurring in the stream segment of Coyote Creek with the most channel complexity supports the statement made by Polvi and Wohl (2012) that beaver dams increase channel complexity, and therefore create additional stream length to be dammed.

In summary, although beaver dam dimensions do not appear to be significantly affected by the surrounding landscape characteristics, the distribution and structure of beaver dams does appear to vary depending on landscape characteristics. In this study, valley widths that were too narrow appear to be the most inhibitive condition of those measured to beaver dam establishment. High values in stream gradient, sinuosity, and upstream catchment area also appear to be inhibiting to beaver dam establishment. However, stream velocity, channel substrate, and cross sectional dimensions could be additional relevant factors that were not measured in this study. Narrow valley widths, high stream gradients, high sinuosity, and larger upstream catchment areas appear to be most relevant to the incidence of gap flow beaver dams. In particular, beaver dams downstream of narrow valley widths appear to be most vulnerable to breaches.

# CHAPTER VIII

## FUTURE RESEARCH

Beaver dam dimensions are a topic that have been reported frequently, but seldom analyzed. Future projects should continue to seek patterns and processes that impact, control, or limit the dimensions and structures of beaver dams. Beyond the research in this thesis, extensive field research should be done, particularly with stream width, stream depth, bank slope, channel substrates, and velocities near beaver dams as landscape variables measured in the field. Those variables were lacking from this study, and it would be beneficial for another study to investigate their influences on beaver dam dimensions.

Mapping beaver dams could be improved beyond the method used in this study by collecting the aspect of each beaver dam in the field. This would enable the dams to be mapped as linear features in ArcGIS, with the line length equivalent to the beaver dam length measured in the field.

Beaver dams are not static landscape features, they are constantly built, destroyed, and repaired again. However, of the studies cited in this thesis that measured beaver dams, not a single one of those studies reported any repeated measurements over multiple months or years. It is not understood how beaver dams change through time, whether through a beaver family's maintenance or from natural processes degrading, and eventually destroying them over time. An interesting future study could measure beaver dams over a series of several years to see what changes occur in that time frame.

Because of the abundance of beaver dam dimensions reported in the literature, a future study could use the existing measurements to examine beaver dam dimensions across different regions of North America, and perhaps parts of Europe with reported Eurasian beaver dam dimensions.

Many questions still remain related to beaver dam dimensions and structures, however, once more is understood about why beaver dams take the forms they do the existing information in the literature can be used in new ways. Future researchers should endeavor to pose questions and collect data that might enable the use of previous beaver dam measurements, because so few studies in the past have included any analysis of the measurements they provide.

## REFERENCES

Allen, A.W. 1983. *Habitat suitability index models: beaver*. Western Energy and Land Use Team, Division of Biological Service, Research and Development, Fish and Wildlife Service, US Department of the Interior.

Apple, L.L. 1985. *Riparian habitat restoration and beavers*. United States Forest Service General Technical Report. RM-GTR-120:489-490.

ArcGIS, 10.1, ESRI, Redlands/California/United States.

Barnes, D.M. and A.U. Mallik. 1997. Habitat factors influencing beaver dam establishment in a northern Ontario watershed. *Journal of Wildlife Management* 61(4):1371-1377.

Bigler, W., D.R. Butler, R.W. Dixon. 2001. Beaver-pond sequence morphology and sedimentation in northwestern Montana. *Physical Geography* 22:531 – 540.

Bradt, G.W. 1938. A study of beaver colonies in Michigan. Journal of Mammalogy 19(2):139-162.

Butler, D.R. 1989. The failure of beaver dams and resulting outburst flooding: a geomorphic hazard in the southeastern piedmont. *The Geographical Bulletin* 31(1):29-38.

Butler, D. R. 1991. Beavers as agents of biogeomorphic change: a review and suggestions for teaching exercises. *Journal of Geography* 90(5):210-217.

Butler, D.R. 1995. *Zoogeomorphology - Animals as Geomorphic Agents*. Cambridge University Press: New York.

Butler, D.R. 2012. Characteristics of beaver ponds on deltas in a mountain environment. *Earth Surface Processes and Landforms* 37:876-882.

Butler, D.R. and G.P. Malanson. 1994. Beaver landforms. *The Canadian Geographer* 38(1):76-79.

Butler, D.R. and G.P. Malanson. 1995. Sedimentation rates and patterns in beaver ponds in a mountain environment. *Geomorphology* 71:48-60.

Butler, D.R. and G.P. Malanson. 2005. The geomorphic influences of beaver dams and failures of beaver dams. *Geomorphology* 71(1):48-60.

Cangelosi, V.E., P.H. Taylor, and P.F. Rice. 1976. *Basic statistics: a real world approach*. West Publishing Company: New York.

Christian, T.A. 2013. A study of beaver pond morphology and site characteristics after disturbance in eastern Glacier National Park, Montana. Master's Thesis. Texas State University. 75 pp.

Collen, P. and R.J. Gibson. 2001. The general ecology of beavers (*Castor spp*.), as related to their influence on stream ecosystems and riparian habitats, and the subsequent effects on fish – a review. *Reviews in Fish Biology and Fisheries* 10: 439-461.

Cowell, D.W. 1984. The Canadian beaver, *Castor canadensis*, as a geomorphic agent in karst terrain. *Canadian Field Naturalist* 98(2):227-230.

Demmer R. and R. Breschta. 2008. Recent history (1988-2004) of beaver dams along Bridge Creek in central Oregon. *Northwest Science* 82(4):309-318.

Dugmore, A.R. 1914. *The romance of the beaver; being the history of the beaver in the western hemisphere*. J.B. Lippincott Company: Philadelphia.

Green, K.C. and C.J. Westbrook. 2009. Changes in riparian area structure, channel hydraulics, and sediment yield following loss of beaver dams. *BC Journal of Ecosystems and Management* 10(1):68-79.

Gurnell, A.M. 1998. The hydrogeomorphological effects of beaver dam-building activity. *Progress in Physical Geography* 22(2):167-189.

Hammerson, G.A. 1994. Beaver (*Castor canadensis*): ecosystem alterations, management, and monitoring. *Natural Areas Journal* 14(1):44-57.

Hillman, G.R. 1998. Flood wave attenuation by a wetland following a beaver dam failure on a second order boreal stream. *Wetlands* 18(1):21-34.

Howard, R.J. and J.S. Larson. 1985. A stream habitat classification system for beaver. *Journal of Wildlife Management* 49:19-25.

Indicators of Hydrologic Alteration, 7.1, The Nature Conservancy, Arlington/Virginia/United States.

Ives, R.L. 1942. The beaver-meadow complex. *Journal of Geomorphology* 5(3):191-203.

Johnston, C.A. and R.J. Naiman. 1990. The use of a geographic information system to analyze long-term landscape alteration by beaver. *Landscape Ecology* 4(1):5-19.

Johnston, C.A., J. Pastor, and R.J. Naiman. 1993. Effects of beaver and moose on boreal forest landscapes. In: Haines-Young, R., D.R. Green, S. Cousins (eds.) *Landscape Ecology and Geographic Information Systems*. Taylor and Francis: London, United Kingdom.

Karraker, N.E., and J.P. Gibbs. 2009. Amphibian production in forested landscapes in relation to wetland hydroperiod: a case study of vernal pools and beaver ponds. *Biological Conservation* 142:2293-2303.

Kieffer, S.W. 1989. Geologic nozzles. *Reviews in Geophysics* 27(1):3-38.

Marston, R.A. 1994. River entrenchment in small mountain valleys of the western USA: influence of beaver, grazing, and clearcut logging. *Revue de Geographie de Lyon* 69(1):11-15.

McComb, W.C., J.R. Sedell, and T.D. Buchholz. 1990. Dam-site selection by beavers in an eastern Oregon USA basin. *Great Basin Naturalist* 50:272-282.

McLemore, V.T. 1990. Cimarron Canyon State Park and Colin Neblett Wildlife Area. *New Mexico Geology* 12:66-71.

McLemore, V.T. 1999. Coyote Creek. *New Mexico Geology* 21:18-21.

McKinstry, M.C., P. Caffrey, and S.H. Anderson. 2001. The importance of beaver to wetland habitats and waterfowl in Wyoming. *Journal of the American Water Resources Association* 37(6):1571-1577.

Meentemeyer, R.K. and D.R. Butler. 1999. Hydrogeomorphic effects of beaver dams in Glacier National Park, Montana. *Physical Geography* 20(5):436-446.

Mills, E.A. 1913. *In Beaver World*. Houghton Mifflin Company: New York.

Morgan, J.L., S.E. Gergel, and N.C. Coops. 2010. Aerial Photography: a rapidly evolving tool for ecological management. *BioScience* 60(1):47-59.

Müller-Schwarze, D. and L. Sun. 2003. *The beaver: natural history of a wetlands engineer*. Cornell University Press: New York.

Naiman, R.J. and J.M. Melillo. 1984. Nitrogen budget of a subarctic stream altered by beaver (*Castor canadensis*). *Oecologia* 62:150-155.

Naiman, R.J., J.M. Melillo, and J.E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). *Ecology* 67(5):1254-1269.

Naiman, R.J., C.A. Johnston, and J.C. Kelley. 1988. Alteration of North American streams by beaver. *BioScience* 38(11):753-762.

Neff, D.J. 1959. A seventy-year history of a Colorado beaver colony. *Journal of Mammalogy* 40(3):381-387.

New Mexico State Parks Division. 2002. Coyote Creek State Park management and development plan 2002-2006. New Mexico State Parks Division, New Mexico Energy, Minerals, and Natural Resources Department.

New Mexico State Parks Division. 2010. Cimarron Canyon State Park management plan 2010. New Mexico State Parks Division, New Mexico Energy, Minerals, and Natural Resources Department.

Nolet, B.A., A. Hoekstra, and M.M. Ottenheim. 1994. Selective foraging on woody species by the beaver (*Castor fiber*) and its impact on a riparian willow forest. *Biological Conservation* 70(2):117-128.

Polvi, L.E. and E.E. Wohl. 2012. The beaver meadow complex revisited: the role of beavers in post-glacial floodplain development. *Earth Surface Processes and Landforms* 37:332-346.

Remillard, M.M., G.K. Gruendling, and D.J. Bogucki. 1987. Disturbance by beaver (Castor canadensis Kuhl) and increased landscape heterogeneity. In: M.G. Turner (ed.), *Landscape Heterogeneity and Disturbance*. Springer-Verlag: New York, NY.

Rohli, R.V. and A.J. Vega. 2011. *Climatology*. Jones and Bartlett Learning: Burlington, MA.

Ruedemann, R. and W. Schoonmaker. 1938. Beavers as geologic agents. *Science* 88:523-525.

Scheffer, P.M. 1938. The beaver as an upstream engineer. *Soil Conservation* 3(7):175-181.

Skinner, Q.D., M.D. Smith, J.L. Dodd, and J.D. Rodgers. 1988. Reversing desertification of riparian zones along cold desert streams. In: Whitehead, E.E., C.F. Hutchinson, B.N. Timbermann, and R.G. Varady (Eds.) *Arid Lands Today and Tomorrow*. Westview Press: Boulder, CO.

Slough, B.G. and R.M.F.S. Sadleir. 1977. A land capability classification system for beaver (*Castor canadensis* Kuhl). *Canadian Journal of Zoology* 55:1324-1335.

Snodgrass, J.W. 1997. Temporal and spatial dynamics of beaver-created patches as influenced by management practices in a south-eastern North American landscape. *The Journal of Applied Ecology* 34(4):1043-1056.

Suzuki, N., and W.C. McComb. 1998. Habitat classification models for beaver (Castor canadensis) in the streams of the central Oregon coast range. *Northwest Science* 72(2):102-110.

Syphard, A.D. and M.W. Garcia. 2001. Human and beaver-induced wetland changes in the Chickahominy River watershed from 1953 to 1994. *Wetlands* 21(3):342-353.

Townsend, J.E. 1953. Beaver ecology in western Montana with special reference to moevements. *Journal of Mammalogy* 34:459-479.

Viles, H.A. (ed). 1988. *Biogeomorphology*. Blackwell: New York.

Warren, E.R. 1926. Notes on the beaver in Estes Park, Colorado. *Roosevelt Wildlife Annals* 1:193-234.

Warren, E.R. 1932. The abandonment and reoccupation of pond sites by beavers. *Journal of Mammalogy* 13(4):343-346.

Westbrook, C.J., D.J. Cooper, and D.R. Butler. 2013. Beaver hydrology and geomorphology. In: Butler, D.R. and C.R. Hupp (Eds.) *Treatise on Geomorphology*, Volume 12: *Ecogeomorphology*. Academic Press: San Diego, CA.

Western Regional Climate Center. 2014. Climate of New Mexico. Available at http://www.wrcc.dri.edu/narratives/newmexico/

Wilkinson, T. 2003. The benefits of beavers. *National Parks* 77(1-2):30-35.

Woo, M. and J.M. Waddington. 1990. Effects of beaver dams on subarctic wetland hydrology. *Arctic* 43(3):223-230.

Wright, J.P., C.G. Jones, A.S. Flecker. 2002. An ecosystem engineer, the beaver, increases species richness at the landscape scale. *Oecologia* 132:96-101.

Zurowski, W. 1992. Building activity of beavers. *Acta Theriologica* 37(4):403-411.