Short-Term Benthic Macroinvertebrate Response to Fire and Hydrologic Event-Induced Changes in Stream Bed Sediment in the Colorado Front Range

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TABLE OF CONTENTS

Contents

ABSTRACT

The effect of wildfires on forests and aquatic environments in the Colorado Front Range is relatively well understood. However, the way in which macroinvertebrate community structures change in the six months after a fire is an aspect currently lacking consensus. This study evaluates the response of benthic macroinvertebrates in the Cache la Poudre to the High Park Fire of 2012, and emphasizes the change in sediment sizes in the stream bed and how food sources may be affected. Changes in stream health and its potential impact on water quality are also considered. Comparisons were made between invertebrate communities in Boulder Creek, an unburned reference stream, and the Cache la Poudre from 2003 and 2012 to determine how taxa distributions changed. Sediment sizes were measured in both streams in November 2012, and these data were compared to sediment size data from a study conducted after the Hayman Fire of 2002. Macroinvertebrate diversity decreased in the Cache la Poudre after the fire, and stream health was slightly degraded. Sediment sizes decreased overall, and most likely impacted the availability of food for invertebrates, which may have contributed to their reduced diversity and poorer stream health.

PREFACE

The summer of 2012 left much of the Colorado landscape charred and the air smoky for weeks on end. At various times throughout the season, fires burned in places that I was personally attached to. I experienced the haze from the High Park Fire in Fort Collins during a summer school class, and breathed smoky air from the Little Sand fire during my father's wedding in Pagosa Springs. I watched a plume of smoke form from an area behind Boulder's Flatirons, and I got daily updates from friends and relatives about the growing number of structure losses, evacuations, and burned acres of forests and neighborhoods in my hometown of Colorado Springs during the Waldo Canyon fire. During a class at the CU Mountain Research Station, we were told to be ready to evacuate at a moment's notice at all times if a fire started nearby. It seemed that everywhere I traveled in Colorado last summer was somehow affected by a fire.

At the time, these huge, destructive forces threatened the physical intactness of places I knew, and safety of people I loved. Because of this, I regarded these fires as nuisances that should be stopped. I found it difficult to keep in mind that fire was a natural disturbance that was healthy for ecosystems while I witnessed the destruction of peoples' homes and acres of wilderness.

Another defining aspect of the summer of 2012 was my time spent at the Mountain Research Station, taking the field course Lake and Stream Ecology with Dr. Dev Niyogi from the Missouri University of Science and Technology. Since I started at the University of Colorado at Boulder, I had been looking forward to taking a freshwater biology course. This course surpassed all of my expectations, and is by far the best class I have taken in college. This experience inspired me to apply what I had learned in an honors thesis. Part of our course was spent doing group projects on topics of our choice. I worked with two other students assessing the impact of nutrients and anthropogenic influence on Boulder Creek by sampling benthic macroinvertebrates and analyzing water samples. The nature of this work was new to me, and I loved doing it.

My newfound expertise and excitement about limnology made me wonder about what was going on in these systems when fires burned around them. I knew that erosion was one of the biggest problems after a fire occurred, but that was the extent of my hydrological knowledge involving such intense disturbances. In an ecology class, we discussed succession in forests after they burned, but I wondered if succession was also a phenomenon that took place in streams. My research focus was born from this idea.

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INTRODUCTION

Disturbance is a natural phenomenon that may have dramatic effects on an ecosystem. While it may initially seem devastating, it becomes apparent at some point after the disturbance occurs that it was the basis for a process of renewal. The structure of communities of organisms might change completely after a disturbance. The effects of a disturbance in terrestrial ecosystems can be more noticeable than the effects on an aquatic ecosystem because of the enhanced visibility of terrestrial organisms by humans. Because of this, changes aquatic environments might go overlooked and seem unimportant in understanding the extent to which a disturbance affects a region.

Aquatic communities have a unique importance to humans. Many of the habitats occupied by aquatic organisms serve as a water source in some capacity. Because of this, the persistence and survival of these organisms is crucial for knowing the relative quality of a water resource. Water habitats, specifically those in rivers and streams, are home to a multitude of life forms. Benthic macroinvertebrates are insects, typically larvae, that live among the sediment at the bottom of a stream. These organisms can serve as good indicators of a stream's overall response to a disturbance because their existence and characteristics can be tied to observed changes in populations of higher consumers, water chemistry, food sources, and habitat features.

Wildfire is an increasingly common disturbance in the western United States as average annual precipitation decreases and fuel sources continually build in forests (Westerling et al. 2006). Fire suppression is mostly done to protect cities and human populations. Suppression has reached its height in the 20th century, and is contributing to some of the highest recorded stand densities and fuel accumulations in human history (Veblem, Kitzberger, and Donnegan 2000). Fires affect streams directly and indirectly. Direct effects that occur up until the first significant runoff event include increased water temperature, nutrient addition, and input of ash, charcoal, and ammonia. Indirect effects happening after the first significant runoff event are increased erosion, sediment transport and deposition, and increased turbidity (Minshall 2003, Pettit and Naiman 2007). Hydrologic disturbances involving an abrupt, considerable change in discharge are thought to be the most prevalent factor in the alteration of invertebrate communities after a fire (Gore, Layzer, and Mead 2001, Arkle, Pilliod, and Strickler 2010).

After a fire burns an area, vegetative cover and soil permeability decrease due to the presence of hydrophobic compounds coating the soil surface. Any water that falls over the area now flows over the soil instead of infiltrating it, and this phenomenon is what contributes to the input of sediment from a slope into a stream (Pettit and Naiman 2007). This addition of sediment causes fluctuation in invertebrate communities due to species being physically removed, primary productivity and food sources decreasing, or invertebrates being intolerant of fine sediment (Gore, Layzer, and Mead 2001, Arkle, Pilliod, and Strickler 2010).

Studies have been conducted to characterize the responses of benthic macroinvertebrate communities to wildfires and consequent hydrologic disturbances. These studies have largely compared invertebrates in unburned reference streams to invertebrates in streams that burned for variable durations or at different intensities. There is a general consensus that severely-burned streams experience variation in macroinvertebrate diversity and community composition for up to 10 years after a fire due to prolonged sediment input (Ryan and Dwire 2012). However, there have been different findings about the short- term (pre-spring runoff) effects on invertebrates. While one study found that invertebrate density decreased by over 95% and diversity was reduced by at least 50% (Rinne 1997), another found that within a similar amount of time, no significant changes in taxa richness occurred (Minshall et al. 1997). This measured divergence in invertebrate diversity presents an opportunity to further investigate macroinvertebrate diversity in the months following a wildfire.

The objective of this study is to investigate changes in invertebrate diversity in the Cache la Poudre, a stream in the Front Range of Colorado that burned in the High Park Fire in the summer of 2012. Boulder Creek is an unburned reference stream that would be used to compare changes in an undisturbed invertebrate community. Macroinvertebrate samples were collected from both streams in mid November of 2012. These samples were compared to samples taken by the Colorado Department of Public Health and Environment (CDPHE) in 2003, which was the most recent year they were available. The differences between these samples were analyzed using a biological diversity metric and metrics accounting for the sensitivity of invertebrate taxa to pollution. Using the Wolman pebble count method, average sediment size was determined. Because no data about the size of sediments in these streams before the fire, changes in sediment size were interpolated from literature addressing changes in stream sedimentation after other Colorado Front Range fires. The occurrence of hydrologic disturbances was determined by looking at hydrographs and precipitation data from both Boulder Creek and the Cache la Poudre.

This study was designed to be able to relate changes in benthic macroinvertebrate community structure to changes in average sediment size. The overall question addressed in this thesis is: How do changes in stream sediment following a fire affect the composition of benthic macroinvertebrate communities? Additionally, what does this change in composition suggest about the relative health of the stream? The hypothesis is that the average size of stream sediment will drastically decrease within the first six months after a fire because of the input of fine sediment from hillside erosion adjacent to a stream. This will cause invertebrate communities to become less diverse because the availability of food sources will be altered, and as a result stream health will decrease.

LITERATURE REVIEW

Fire as a Disturbance

Since the 1980s, wildfires in the United States have become more frequent and longer lasting, especially in forests of the northern Rocky Mountains, where there has been a roughly 60% increase in the occurrence of large fires. Rising spring and summer temperatures and earlier spring snowmelt can be partially explained by abnormal precipitation patterns brought on by the effects of El Niño, El Niña, and droughts. More frequent, severe wildfires are being attributed to the combined effects of precipitation deficits and excess fuel in forests (Westerling et al. 2006). The incidence of fires in the forests of the western United States is important because of the role these landscapes play in the nation's carbon sequestration. With increased burning comes increased carbon release, which could substantially contribute to climate change as atmospheric carbon dioxide also increases (Westerling et al. 2006).

Though incredibly destructive, fire is considered a crucial natural and healthy process in ecosystems (Malison and Baxter 2010). Studies of streams in Yellowstone National Park (YNP) acknowledge the difference between the direct and indirect effects of fires on lotic systems. Direct effects take place while the fire burns until the first significant runoff event, which can be during or after a fire. Increases in water temperature, nutrients, ash, charcoal, and ammonia are all considered direct effects. Indirect effects, occurring after the first significant runoff event, include increased erosion, transport and deposition of sediment, modification to channel shapes/directions, changes in nutrient cycling, and increased turbidity (Minshall 2003, Pettit and Naiman 2007). Fires also affect external inputs to streams, typically destroying riparian vegetation and overloading the stream with ash and charcoal, which deplete exploitable food resources (Minshall 2003).

Ecological disturbances to streams theoretically occur as a probability outcome in which factors of regional climate, topographical features, and vegetation interact to influence stream networks (Benda et al., 2003). While large-scale disturbances may seem catastrophic, they are necessary for the maintenance of an ecosystem's stability (Pettit and Naiman 2007). Low diversity is prevalent when a single taxon dominates. This is a result of periodic variation in community structures and consequently, a dynamic equilibrium. Disturbances combined with species interactions allow for a dynamic equilibrium to occur, with regular changes being made to the community composition as a result (Arkle, Pilliod, and Strickler 2010). In lotic systems, human activity typically results in the simplification of channels and physical homogeneity. When a stream reaches this point, disturbances can help to replenish biological and physical diversity (Benda et al., 2003).

Studying lotic ecosystems after fire is beneficial because the physical and chemical influences of a fire are most apparent at this junction where water and land interact (Minshall 2003). As members of a stream ecosystem, benthic macroinvertebrates serve as food sources for fish, and organic material and nutrient processors (Gore, Layzer, and Mead 2001). Communities of invertebrates are most notably altered by occasional hydrologic disturbances, which can contribute to the displacement or lethal injury of individuals (Arkle, Pilliod, and Strickler 2010). Studies have shown that most macroinvertebrates cannot, and largely do not return to areas from which they have been displaced. Hydrologic disturbances often involve an abrupt or substantial fluctuation in discharge, which may also cause changes in community composition because of invertebrates' general intolerance to changes in discharge (Gore, Layzer, and Mead 2001).

Fire Regimes Along the Colorado Front Range

A fire regime for a specific region is defined as "a summary description of the salient characteristics of fire occurrence and effects" (Graham 2003). Ultimately, the occurrence of wildfires is controlled by "availability of biomass to burn, ignition sources, and weather conditions suitable for fire initiation and spread" (Gartner et al. 2012). Before the 20th century, fires occurred more frequently than they currently do along the Colorado Front Range in the montane zone (Veblen, Kitzberger, and Donnegan 2000). When Euro-American settlers began inhabiting the land in this area, fire suppression became a common practice (Graham 2003). Suppressing fires as a means of protecting peoples' property greatly increased the risk of catastrophic or severe fires, especially in ponderosa pine forests. Fuels were also allowed to accumulate, leading to unprecedented stand densities (Veblen, Kitzberger, and Donnegan 2000). Less frequent fires beginning around this time also allowed for the spread of ponderosa pines, Douglas firs, and lodgepole pine into grasslands at lower elevations (Gartner et al. 2012). It has been estimated that fire occurs every 10-25 years in the western United States' coniferous forests on average throughout all elevations (Arkle, Pilliod, and Strickler 2010), though areas with ponderosa pines, Douglas firs, and lodgepole pines experience less fires than regions containing only ponderosa pines. Fire is also known to occur more often at lower elevations than higher elevations (Veblen, Kitzberger, and Donnegan 2000).

The montane zone of the Colorado Front Range occurs between 1800 and 2800 m above sea level. This zone receives an average of 45.6cm of precipitation annually, and experiences annual average temperatures of 6.65°C. Slope aspect is a determinant of vegetation because of the effect it has on insolation and soil moisture. North-facing slopes in the montane zone typically have a relatively dense population of Douglas fir trees and ponderosa pines, while south-facing slopes contain primarily more sparsely-placed ponderosa pines (Gartner et al. 2012).

Benthic Macroinvertebrate Ecology

A macroinvertebrate is an organism that can be caught in a net with a mesh size of up to 250 µm. In streams in the Colorado Front Range, these organisms are typically arthropods (Alba-Tercedor 2006). The life cycles of these organisms is principally controlled by temperature because of its effect on invertebrate metabolisms ("Structure and Function of Stream Ecosystems" 1974). Dominance of differing groups is based on the most available energy sources and which invertebrates can exploit these most effectively. Because of the dynamic nature of these energy sources, invertebrates that have more versatile and facultative morpho-behavioral feeding habits have a larger niche and can thrive in a larger variety of habitats (Cummins and Klug 1979).

Invertebrate community structures and are determined by stream bank profile and structure and substrate characteristics (Armitage 2006, "Aquatic Insect-Substratum" 1984). Described by Vannote, insect community distribution is related to power distribution and changes in discharge and channel shape of a stream (Vannote 1980). The rough shape and dimensions of a habitat are determined by hydrologic processes, while fluid determinants create the microscale structure and more refined environmental characteristics of an insect's surroundings (Newbury 1984). Two of the most common subhabitats that are formed by hydrological and fluid determinants are riffles and pools. Riffles, or erosional subhabitats, are areas of relatively shallow, fast moving water. Depositional subhabitats, or pools are basically the opposite; relatively deeper sections with slower moving water. Riffles have been shown to support a wider diversity of invertebrates than pools. The size, stability, heterogeneity, porosity, and silt and organic matter content of a stream's substratum are all factors influenced by a system's flow regime. These factors affect invertebrates' survivability by impacting the insects' ability to cling or burrow, escape predation, find protection, construct casings, or lay eggs. The ideal substratum composition of a stream bed is one with mixed sizes and complexities of sediment because this setting can support more insects and niches ("Aquatic Insect-Substratum" 1984).

Substratum is arranged or sorted by the water current. Fine particles, classified as sand or silt, are also subject to this process. Introduction of silt can change water movement patterns, food availability or quality, availability of oxygen, and inter-sediment spaces. Silt and sand can be transported and deposited in such a way that it "blanket[s] the surface of the bed, thereby restricting algal growth…diluting the organic content of the food supply, as well as directly impeding the movement, feeding activities, or respiration of the insects". These adverse effects typically result in decreased species abundance and richness, though there are few macroinvertebrate species that prefer fine-sediment conditions. Overall, studies have found that when silting occurs, a stream experiences a reduction in productivity. Organic matter also breaks down much less frequently and efficiently on silt than on other substratum ("Aquatic Insect-Substratum" 1984).

Macroinvertebrates can be categorized in terms of their adaptations for feeding. These organisms derive nutrition from a system that varies temporally and spatially in production and storage of food resources. The most common feeding group designations among benthic macroinvertebrates are shredders, collectors, scrapers, and predators (Cummins and Klug 1979). Shredders include herbivores and detritivores among the orders Trichoptera, Coleoptera, Diptera, and Lepidoptera ("Trophic Relations" 1973). Coarse particulate organic matter (CPOM), detritus, dropped leaves and needles from trees, and other non-woody plant parts serve as food sources for shredders. These invertebrates have been found to prefer CPOM that has been "well colonized by microorganisms". Life cycle timing is correlated with food supply abundance, with shredders' major growth period occurring between fall and spring, when input of deciduous foliage is greatest (Cummins and Klug 1979).

Collectors are invertebrates that feed on suspended particulate, or particulate that has been deposited on the stream bed. This group includes Ephemeroptera, Trichoptera, Lepidoptera, Diptera, Hemiptera, and Coleoptera ("Trophic Relations of Aquatic Insects" 1973). Collection of fine particulate organic matter or ultrafine particulate organic matter (FPOM or UPOM) is done via filtering or gathering (Cummins and Klug 1979, Vannote et al. 1980). FPOM includes any soft plant pieces, woody fragments, feces of other invertebrates, individualized microbial cells, sloughed algae, or mineral particles within organic films. UPOM is comprised of leaf, needle, and woody fragments, flocculated material and clay particles, and any organic films that have adsorbed onto these particles. It has been hypothesized that the essence of the collector strategy is to "pass a comparatively low quality food through the gut rapidly" (Cummins and Klug 1979). Collectors become more important and dominant as stream size increases and detrital particles decrease in size (Vannote et al. 1980).

Scrapers can belong to the orders Ephemeroptera, Trichoptera, Lepidoptera, Coleoptera, Diptera, or Hemiptera. Members of this trophic group feed on both mineral and organic matter ("Trophic Relations" 1973). These invertebrates have special morphological adaptations such as scoop-shaped mandibles that enable them to graze on periphyton or other food that has adhered to a surface. Periphyton refers to any attached, living algal cells, such as diatoms, green or bluegreen algae, or flagellated algae forms. They are usually able to maintain their position in fast-moving water because of the ability to flatten their body or attach it to a surface using a sucker or multiple suckers. In general, the diets of collectors, scrapers, and shredders consume a larger quantity of low quality food due to its relatively poor nutritional value. To combat this lack of nutrition, macroinvertebrates may employ several feeding strategies. Symbiotic relationships with microbes are also common among invertebrates to help supplement this deficiency (Cummins and Klug 1979).

Predators are the final trophic classification among benthic macroinvertebrates. There are many orders that include predators, such as Odonata, Plecoptera, Megaloptera, Trichoptera, Coleoptera, Diptera, and Hemiptera. This group includes both predators and piercers ("Trophic Relations" 1973). The role that these invertebrates play in streams is one of particle converters and "controllers of nonpredator populations" ("Structure and Function of Stream Ecosystems" 1974). Predators feed on other macroinvertebrates, while piercers pierce and feed on the fluids of an individual algal cell. Though predators feed almost exclusively on other invertebrates, members of other trophic groups may occasionally feed on another invertebrate to increase their protein intake at a crucial point in their life cycle (Cummins and Klug 1979).

Currents in which invertebrates live impact the ability of these insects to gather food, avoid competition or predation, leave poor habitats, and colonize ideal habitats ("Aquatic Insect-Substratum" 1984). The force exerted on invertebrates is variable because of the variation in water velocity from the top to the stream bed. Velocity is highest at the top of the water surface, then decreases as water depth increases to the point of the boundary layer, where velocity declines to almost zero (Alba-Tercedor 2006). Benthic macroinvertebrates have morphological adaptations that enable them to survive in this current. Flattening the body makes some mayflies able to move between substrate at the bottom of a channel, where the water velocity is relatively low. Reducing projecting structures is another adaptation, commonly found in mayflies, that increases the individual's resistance to a current. Suckers allow invertebrates to attach themselves to surfaces and are most common among the order Diptera. Members of the orders Diptera, Ephemeroptera, and Plecoptera often have hooks at the ends of their appendages which help them to cling to stones. Ballasting is common among the order Trichoptera, which includes caddisflies. These invertebrates increase their weight, thereby making it more difficult to sweep them away, by building cases around their bodies. Lastly, the use of friction pads or marginal contact keeps the bodies of Ephemeroptera close to substrate, and increases their frictional resistance (Alba-Tercedor 2006).

Macroinvertebrates are commonly used as indicators of stream health for several reasons. They are found in most lotic systems and fill different ecological niches within a stream ecosystem . Because most species do not migrate very far during their time in a stream, conditions at specific locations are appropriately represented by the presence and health of these creatures (Barbour et al. 1999). Their mostly sedentary nature is also helpful because it can help determine the source of a pollutant (Alba-Tercedor 2006). Most benthic invertebrates have complex life cycles in which the larval or nymph stages of their lives are spent in a stream and, once mature, they leave the stream to live on land once mature ("Structure and Function of Stream Ecosystems" 1974). Under stress, invertebrates at sensitive stages of life respond more quickly and intensely, signifying changes in water quality soon after stress occurs (Barbour et al. 1999). Because communities of macroinvertebrates are typically heterogeneous, there is a good chance that there will be some form of response when a stressor is introduced (Alba-Tercedor 2006).

Another advantage of using benthic macroinvertebrates as bioindicators is that there are numerous methods of analysis that can be utilized to determine stream or community health. The tolerance of invertebrate taxa under stressful conditions is used to measure the relative intensity and effect of stress in a system. Trained biologists can easily identify and qualify macroinvertebrates in terms of stress tolerance. The richness of the orders Ephemeroptera, Plecoptera, and Trichoptera are often the basis for common water quality assessment because these orders are considered sensitive, or non-tolerant to poor water quality (Alba-Tercedor 2006). This measurement is referred to as an Ephemeroptera-Plecoptera-Trichoptera (EPT) metric (Gore, Layzer, and Mead 2001). Additionally, sampling is simple and relatively cheap, and does not greatly affect other stream biota. Because each species has a different response or tolerance to pollution, the cumulative effects of a disturbance can be more fully understood. Records of water quality based on qualitative and quantitative presence of benthic macroinvertebrates are available for most states through water quality agencies. This allows for continuous understanding of a system's overall quality (Barbour et al. 1999).

Analyses of Invertebrate Populations

An assemblage of benthic macroinvertebrates can be analyzed using biological measurements, or bioassessment to qualify and quantify aspects of the invertebrates' "structure and function". Bioassessments are based in "characterizing reference conditions upon which comparisons can be made and identifying appropriate biological attributes with which to measure the condition". A "reference condition" is the ideal conditions for a biological community, where the environment is most natural and undisturbed in an area (Paul et al. 2005).

The Shannon-Weaver Diversity Index (SWDI) is a measure of diversity, and is rooted in the idea that more diversity is indicative of more stability of a population. It is commonly applied in biology to compare populations of undisturbed and disturbed areas (Goodman 1975).

This metric of population diversity accounts for the number of taxa present in a population as well as the proportions or evenness of the taxa within a sample. The formula for calculating average diversity is

$$H' = -\sum_{i=1}^{R} p_i \ln p_i$$

where H' is average diversity, and p_i is the number of individuals within a taxon divided by the total number of individuals in the sample. For each taxon, the proportion of individuals is multiplied by the natural logarithm of the proportion of individuals. Then, these values from every taxa are summed, and the inverse of this is the Shannon-Weaver diversity index value. This value falls on a scale from 0 to 5, with the maximum diversity of a given sample occurring at an SWDI value of 5, when all taxa are found to be equally abundant (Goodman 1975). A greater diversity within a population would be indicated by a relatively large number of taxa and mostly equal proportions in the sample (Pielou 1966). This index is not precise, however, and fails to account for the size of a sample (Goodman 1975).

Benthic macroinvertebrates play ecologically important roles within their ecosystem, but they are also useful organisms to human health, as they can serve as indicators of pollution in bodies of water. Numerous measurements have been derived over the years for using characterizations of invertebrate assemblages as gauges of water quality. Hilsenhoff derived a scale for specific invertebrate taxa tolerance to organic or nutrient pollution. This scale of tolerance values ranges from 0 to 10, with 0 being the most intolerant to pollution and 10 being the most tolerant to pollution. Generally, invertebrates with tolerance values from 0-2 are considered pollution intolerant, while those with values ranging from 8-10 are tolerant. Invertebrates that are more tolerant of pollution are able to survive in conditions with low dissolved oxygen (DO) concentrations, as increased organic matter and nutrients deplete DO

(Hilsenhoff 1987). The tolerance value of an invertebrate family is characterized in a family-level biotic index (FBI). An FBI value averages tolerance values for all families present in an invertebrate sample (Hilsenhoff 1988).

Other metrics used to characterize stream health seem relatively simple, but provide very useful information. Describing the health of a stream in terms of the presence of pollution-tolerant or pollution-intolerant invertebrates helps in understanding the livability of a stream, and therefore its pollution content. Pollution-intolerant taxa have an FBI value of 0-2, while pollution-tolerant taxa have an FBI value of 8-10. Using these criteria, the proportion of pollution-tolerant or intolerant taxa can be calculated by dividing the number of individuals within pollution-tolerant or intolerant taxon by the total number of individuals in a sample. Similarly, the number of EPT taxa within a sample can be compared to the number of Diptera taxa as a means for more crudely determining the relative amount of pollution within a stream ("Selecting Metrics" 2012).

Hydrologic and Geomorphological Changes Post-Fire

The effects of rainfall are greatly intensified in burned areas due to reduced cover by vegetation and the introduction of hydrophobic residues into the topmost layer of soil (Pettit and Naiman 2007). These factors substantially reduce the ability of water to infiltrate soil and cause it to act immediately as overland flow, capable of transporting sediments and objects of variable sizes (Meyer et al., 1992). Hydrological processes in a burned area are considered to be the most influential factor in the survivability of stream inhabitants (Arkle, Pilliod, and Strickler 2010). After a fire, the physical features of a stream can be affected, thereby influencing its ability to store sediment and organic matter and form suitable habitats for members of the ecosystem (Benda et al., 2003). Increased sediment is common in channels within recently burned areas, and suspended sediment has been measured to increase by roughly 500% in the first year after a fire (Ryan and Dwire, 2012). During precipitation events, charcoal, ash, and fine sediment combine with larger sediment. This mix of organic and inorganic materials of various sizes is transported as sheet or gully erosion dislodges the soil beneath it. This phenomenon increases the sediment concentration in these flows (Meyer et al., 1992, Pettit and Naiman 2007). Upon introduction into the stream, this debris flow will induce physical upheaval and move the sediment along the stream bed, depositing it further downstream. Within the stream, this intense addition of coarse sediment can also cause scouring, in which sediment is removed to the level of bedrock (Minshall 2003). The movement of this sediment contributes to the overall progression of the local physical landscape (Meyer et al., 1992).

Elevated amounts of woody debris are also characteristic of post-fire inputs to a stream (Pettit and Naiman 2007). Dead trees topple over in recently-eroded soils and are transported into streams via floods or landslides (Benda et al., 2003). Eventually, this material is typically flushed downstream by peak discharges caused by even more intense precipitation events. This acute, intense amplification in the amount of water traveling through a stream also contributes to the instability and destruction of the stream's banks (Arkle, Pilliod, and Strickler 2010).

Benthic Macroinvertebrate Responses to Fire

Research has been done into the responses of benthic macroinvertebrate communities in different time periods after fires of various intensities and durations. The size and gradient of a

Table 1. Summary of how recovery after a fire is characterized in terms of time after a fire occurs (Malison and Baxter 2010)

Response/Recovery Stage	Time Period
Immediate	Time of active burning-few days after
Short-term	Few days after burning-beginning of spring runoff
Midterm	Beginning of spring runoff of first year post-fire-more than 10 years after fire
Long-term	10s-100s of years after fire

stream, amounts of precipitation and runoff, riparian vegetation cover, regional lithology, and topography are all factors that have been found to influence the degree to which fires affect these communities. Overall, opportunistic, generalist species with ranges of habitat and diet preferences are the most capable of surviving after a fire. Strategists that can easily adapt to conditions following a disturbance become dominant (Minshall 2003).

Changes in macroinvertebrate communities after a fire are mostly attributed to instability of habitats. In the first few years after a fire disturbance, invertebrate communities in burned streams displayed new dynamics, and did not seem to become more similar to comparable unburned streams. Macroinvertebrate communities in unburned streams remained constant, except when affected by annual changes in discharge. Post-fire flooding affects factors that build or determine habitats, such as sediment loading, woody debris, riparian vegetation, and organic matter in streams. Burned streams have been found to have greater variability in food sources and stream bed substrate, which makes maintenance of a stable community composition unlikely (Arkle, Pilliod, and Strickler 2010).

Table 2. Criteria attributed to varying burn severities. Burn severity is determined through a consideration of the percentage of area burned severely, the percentage of area burned moderately, the percentage of area burned marginally or not burned, visual indicators based on the characteristics of ash, and runoff response after a fire. (Neary et al. 2011, Ice, Neary, and Adams 2004).

Burn Severity	% area burned severely	% area burned moderately	% area burned marginally or unburned	Visual indicator	Runoff Response
Low	< 2	<15	Remainder of area	Black ash	Little/no change
Moderate	<10	>15	Remainder of area	Gray ash	Moderate/high increase
High	>10	>80	Remainder of area	White or orange ash	High increase

The severity of a burn as it affects benthic macroinvertebrates has been heavily studied. It is believed that different burn severities affect food webs within streams to varying degrees (Malison and Baxter 2010). Higher severity burns correlate with lessened stability of invertebrate densities from year to year. Severely burned streams do not seem to return to pre-fire conditions, at least not within time periods that have been studied (Arkle, Pilliod, and Strickler 2010). Their effects are known to last at least five years, as indicated by the emergence of adult insects from streams (Minshall 2003). Typically, very severe burns stimulate invertebrate production and emergence, while low severity burns do not seem to affect these variables (Malison and Baxter 2010). Malison and Baxter (2010) theorize that severe fires create a "fire pulse"; a phenomenon in which stream productivity increases on several trophic levels, thereby increasing the amount of prey for aquatic and terrestrial predators (Malison and Baxter 2010).

Hydrologically, high-severity fires correspond with elevated amounts of fine sediment (Arkle, Pilliod, and Strickler 2010). The rate of sediment deposition also increases in severely burned areas, as hydraulic roughness is presumed to also intensify (Gore, Layzer, and Mead 2001). Macroinvertebrate communities fluctuate as a result of these phenomena via physical species removal, decreased primary productivity, or intolerance of fine sediment (Gore, Layzer, and Mead 2001, Arkle, Pilliod, and Strickler 2010). A decline in invertebrates classified as shredders indicates the loss and/or recovery of leaf detritus in streams, while the presence of scrapers signifies the presence of photosynthetic algae in a system, which may increase as riparian cover is removed and nutrients are added (Minshall 2003).

Similar Studies and Contention of Findings

Though studies have been done on streams experiencing under variable burn durations and intensities, contention still exists about the effects on invertebrate communities. Research done in YNP has found that community structure after a fire may resemble the pre-fire community after one to two years, however, variation can persist for up to a decade (Minshall 2003). Lotic systems may respond to fires for years after the disturbance, evidenced by continuous increased sediment loading almost 10 years after a fire in a stream in Wyoming (Ryan and Dwire 2012).

While macroinvertebrate communities may not recover to pre-fire compositions, it is apparent from their responses to fire that such disturbances are not catastrophic for their existence, and these ecosystems can be successful in their wake (Minshall 2003). The most telling component of this body of research lies in the findings of macroinvertebrate communities on a short-term scale. Responses in terms of taxa richness have been found to be both positive and negative in various studies, leaving the question of how invertebrate communities are affected in the months after a fire (Arkle, Pilliod, and Strickler 2010).

Studies comparing the benthic macroinvertebrate population compositions before and after wildfires have been done in Arizona and YNP. The invertebrates in these streams were differently affected in the six months following a fire. The Dude Fire of 1990 in Arizona burned 12,000 ha. Before the fire, the number of taxa in three different first order streams within the burn area was in the 20s, and there were roughly 7,000 individual invertebrates per square meter in the stream. A month after the fire, the number of taxa within the stream had decreased by about half and invertebrate density was found to be 73 individuals per square meter on average. This change in community composition was attributed to the occurrence of slurry flows and sediment input into the streams after precipitation events (Rinne 1997).

Wildfires burned substantial parts of YNP in 1988. Invertebrate communities were studied in several streams within the burned area, and in the six months after the fire, there were no significant changes in average taxa richness (Minshall et al. 1997). However, in other studies within this area, invertebrate richness, abundance, and diversity decreased in the same amount of time (Minshall et al. 1989). Possible explanations for these findings are sediment input and the relative inability of invertebrates to feed on burned organic matter (Minshall et al. 1997, Minshall et al. 1989).

Boulder Creek Watershed

The Boulder Creek Watershed covers 1150 km^2 in the Colorado Front Range. From its headwaters by the Continental Divide, the stream flows into Barker Reservoir and continues downstream of the reservoir via reservoir releases and Wastewater Treatment Plant discharge (See Figure 1). It is joined in the foothills west of Boulder, CO by North Boulder Creek. Tributaries, such as Fourmile Creek contribute flow to Boulder Creek, and because of the historical mining activity of the region, Fourmile Creek also transports some trace metals. Boulder Creek makes its way through the city of Boulder, and eventually converges with South Boulder Creek in the northeastern part of the city (Murphy et al. 2003).

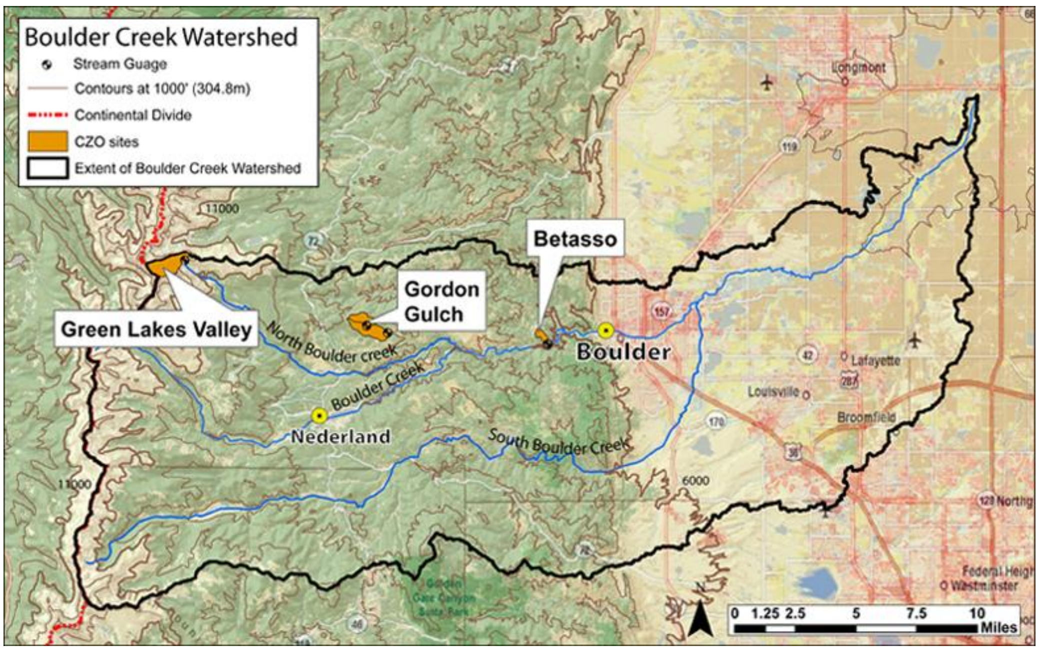
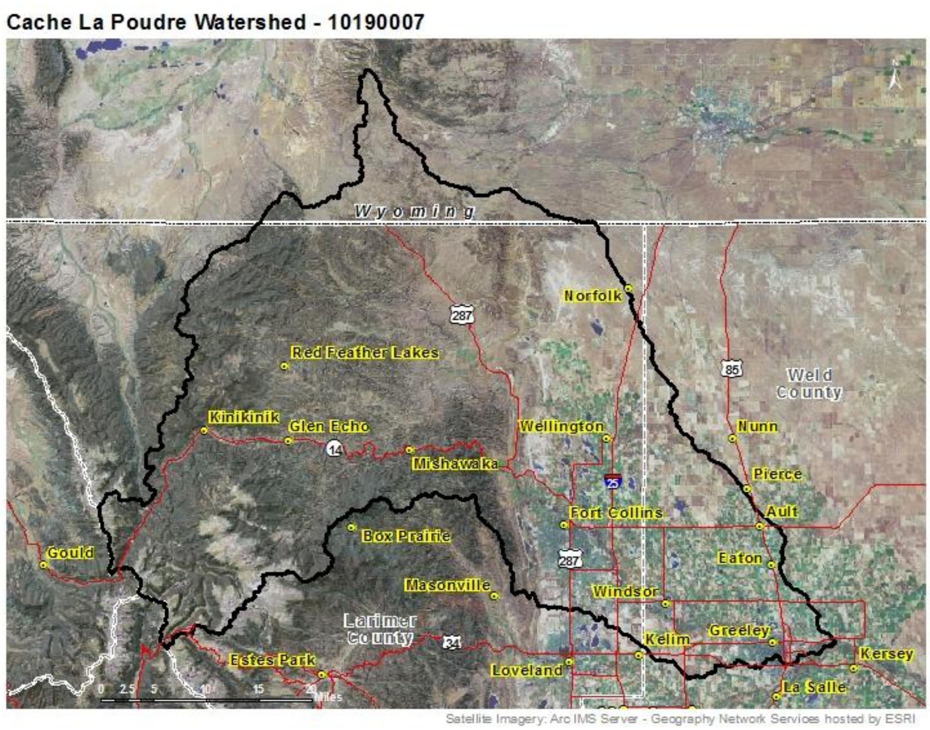


Figure 1. Map of the Boulder Creek watershed, delineated in black. North Boulder Creek feeds into Boulder Creek further up than South Boulder Creek. Image from http://czo.colorado.edu/pageImages/sites_

The reach of the stream that flows through the foothills along Highway 119 between Nederland and Boulder receives about 20 inches of precipitation each year on average (*St. Vrain Watershed* 2010). This area receives some input of pollution from cars and the highway, including automobile fluids, salts, and other debris (Murphy et al. 2003). Various plant species inhabit this area, such as native grasses, shrubs, ponderosa pines, and Douglas firs (*St. Vrain Watershed* 2010). The soil regime in this region is mesic, meaning that soil reaches a maximum annual temperature of 15°C and have an annual average temperature of roughly 8°C (*St. Vrain Watershed* 2010, Oram 2013). Soils here are also ustic, and therefore have limited moisture content but moisture is available when it is most needed for plant growth (*St. Vrain Watershed* 2010, "Ustic" 2013). The geology of this upper part of the basin is characteristically granitic, and has several deposits of metallic ores dispersed throughout (Murphy et al. 2003).

Cache la Poudre Watershed



:he la Poudre headwaters are located in Rocky Mountain National Park ("Cache la Poudre"). Image from http://www.co.nrcs.usda.gov/technical/WaterRes/CacheLaPoudre_WEB_DetailedMap.jpg.

The Cache la Poudre River, located just west of Fort Collins, Colorado, was selected as the burned stream (See Figure 2). The Cache la Poudre watershed encompasses 4568 km^2. Beginning in Rocky Mountain National Park, this river follows along Highway 14 and through northern Fort Collins, CO. Numerous smaller streams that start in Colorado and

Wyoming, such as Corral Creek, Little Beaver Creek, Sevenmile Creek, and Manhattan Creek, flow into the Cache la Poudre (Collins and Sprague 2013).

The transition area between the Great Plains and the mountains receives an average of 15 inches of precipitation each year. The landscape is composed of grasses, shrubs, and primarily coniferous trees such as ponderosa pines and Douglas firs. Soils in this region are mesic and ustic. The underlying geology of this stream section is predominately granitic and alluvial (*Cache la Poudre* 2009).

In the summer of 2012, 76% of the Cache la Poudre watershed burned in the High Park Fire (See Figure 3). It has been estimated that water repellent soil now dominates in 12,238 acres of the burn area, which has contributed to roughly a 55% reduction in soil infiltration of the area (*High Park Fire* 2012).

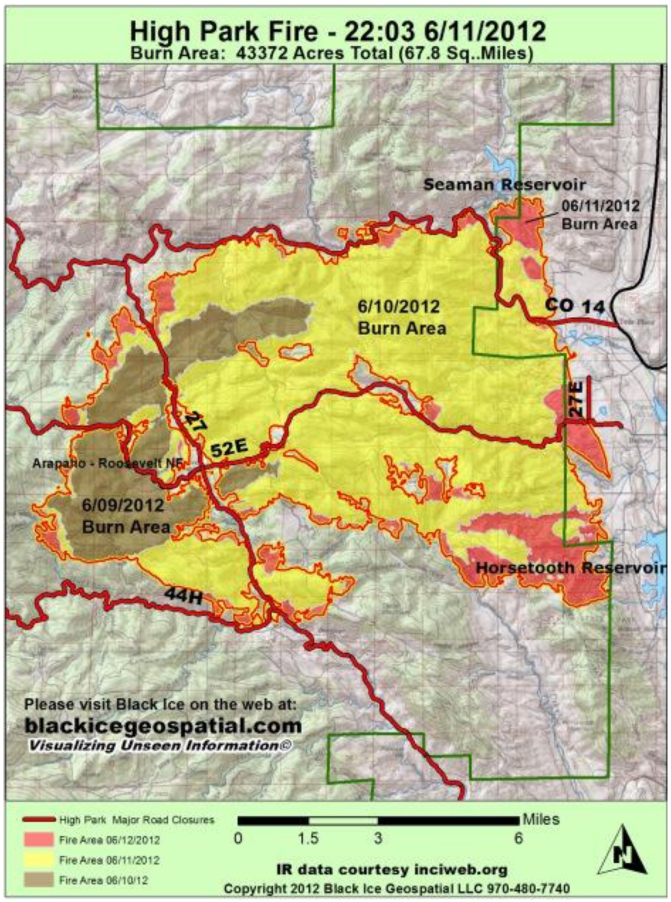


Figure 3. Map of the acreage burned in the High Park Fire. The Cache la Poudre River runs along CO-14 and many of its tributaries flow from the south, which was hugely affected by the fire.

Hayman Fire 2002

In the summer of 2002, the Hayman Fire burned more than 55,000 hectares along the Colorado Front Range. The fire burned primarily within the montane zone in areas vegetated mostly by ponderosa pine trees and Douglas firs. Soils in this region are derived from granitic formations. This burn area has been described as having a mixed fire regime. Mixed fire regimes include aspects of both frequent low-severity and infrequent high-severity fire regimes, such as high severity burning of the forest understory and canopy or short fire recurrence intervals. A study about the effects of thinning forests on sedimentation rates and input into streams was in progress in 2001, the year before the fire occurred. Because of this, information about sediment movement on hillsides and in streams under pre-fire conditions is available (Graham 2003).

In 2001, sediment fences were installed on hillsides to catch any sediment moving downhill. No sediment was collected in these fences between 2001 and early 2002, most likely because there was no active transportation mechanism. After the fire, severely-burned areas (See Table 2) experienced heightened levels of bare soil and ash trapped in these sediment fences. Water repellency in soils was measured up to 6cm deep in soils. Changes in aquatic systems within the burn area were also tracked, with each precipitation event after the fire contributing to erosion and sediment deposition. Total suspended solids (TSS) concentrations increased by a factor of almost 3000 (Graham 2003).

During the months until the first spring runoff event, invertebrates in affected streams were mostly found in areas where large substrates remained intact. Localized extinctions or complete losses of invertebrates also occurred, potentially due to extreme stream temperatures or harsh, uninhabitable stream chemistry. Invertebrate taxa which were capable of tolerating these conditions remained in some areas of burned streams. Overall, this study found that there was a reduction in invertebrate diversity and that sedimentation within stream channels was a contributing factor (Graham 2003).

METHODS

Site Selection & Criteria

A comparison between benthic macroinvertebrate taxa of an unburned stream and a burned stream with similar characteristics was designed to be able to evaluate the differences in invertebrate population composition and sediment size. Boulder Creek and the Cache la Poudre served as sample streams. These two systems are similar in their seasonal average discharge, lithology, surrounding vegetation, proximity to highways, elevation, and topography. Specific sampling sites were chosen based on their accessibility, visible flow pattern (pool vs. riffle), gradient, and riparian vegetation.

Discharge Measurement

Discharge estimation was the first measurement made at each site. With an assistant at an easily accessible point along the sample site, the width was measured by having one person hold the end of a tape measure at one bank, and the other person walking with the tape measure to the other bank. Width of the channel was measured at three different points along the stream in order to determine an average width. The depth of the stream was measured by holding the kicknet perpendicular to the water surface, net side-up, and touching the end of the handle to the bottom of the stream bed, marking the water level on the handle, and measuring the distance between the end of the handle and the water level. Depth was measured at five points across each width to account for variation in water depth. At these same five points, velocity was determined by first measuring a 10 ft. section in the stream at five different points across the stream, parallel to the direction of flow. One person would stand upstream, and drop an orange into the water at the beginning of the 10 foot section, and the person downstream would catch the orange and use a stopwatch to record the amount of time it took the orange to travel the 10-foot section. Discharge in a lotic system is calculated with the equation

$$Q = w \times z \times v$$

where Q is discharge, w is the width of the stream, z is water depth, and v is the velocity of the water at or near the surface.

Macroinvertebrate Collection and Identification

Macroinvertebrates were collected using kicknets with a frame measuring .09m^2 (0.3m x 0.3m). My assistant and I positioned ourselves adjacent to each other, with one person standing slightly further downstream. The kicknet was held against the bottom of the stream bed, and stayed stationary while sampling occurred. For five minutes, we used our feet to scrub off and dislodge rocks and organisms from the area directly upstream of our nets. After exactly five minutes of kicking substrate, the nets were lifted out of the water, and their contents were emptied into 16 oz. HDPE plastic containers. After transferring the net contents to the containers, the nets were held just below the water surface for 10 seconds in the same direction that the samples were taken to wash any remaining invertebrates into the bottom of the net. These lingering individuals were then transferred into the same plastic container as the rest of the sample. A different container was used to hold the contents of each net, so there were two samples per site, and two sites, giving a total of eight samples. The invertebrates were preserved within 2 hours of being collected, using denatured alcohol (95% ethanol, 5% methanol). This substance was added to the containers until all material in the container was submerged.

Macroinvertebrate sample sorting was done at the CIRES Center for Limnology lab, with one container at a time being examined. First, the sample was poured into a 50mL Nalgene bottle. The opening of the bottle was covered with fine mesh (>1mm openings) and a cap with its center cut out was screwed on to the bottle, thereby securing the mesh on the opening. The bottle containing the sample was then held upside down over the original sample container and squeezed to empty the liquid. This technique was especially helpful for the samples taken from the Poudre because of their high silt content. If/when the mesh became clogged, the cap and mesh would be taken off and inspected for invertebrates. If any were found, they would be picked out and transferred to the observation tray to be identified later. Remaining debris from the clogged mesh would be deposited back into the original sample container. The filtering process continued until all of the alcohol had been emptied from the 50mL Nalgene bottle.

Next, the sample was transferred into a 38cm x 8cm x 3cm white, opaque plastic tray, with 51 2.5cm x 2.5cm squares delineated on the bottom in pencil. In a diagram of the tray, the squares were numbered 1-51 (See Figure 4). The sample was evenly distributed throughout the tray by tilting and tapping the sides and moving detritus or invertebrates around with forceps as needed to approximately evenly distribute the material throughout the tray. Ethanol (90%) was added to the sample until there was a thin layer of ethanol covering the entire bottom of the tray. Examination was done underneath a dissecting microscope under 5x magnification. Upon initial inspection with the naked eye, if the sample appeared to contain more than 50 invertebrates, a subsampling method would be employed instead, enabling me to derive a representative sample of the population at a site without spending an excessive amount of time searching for and identifying macroinvertebrates.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
18																
35																

Figure 4. A graphical representation of the trays used during the examination and identification of the invertebrate samples. Each square corresponded to a number, with the squares increasing from left to right, then continuing in the next row down on the left side of the tray. This numbering system was implemented and used if a sample contained more than 50 invertebrates at first glance.

To subsample, I used a random number generator to generate 10 random integers, which would correspond to square numbers in the tray. Invertebrates were counted as “in” the square if roughly half of their body was within the boundary. If the sample did not appear to contain more than 50 invertebrates, every invertebrate in the sample was identified and collected. I examined each sample starting in the left upper corner (square 1), and moving down each row, then to the next column to the right. Invertebrates were identified and classified by their order and family using dichotomous keys provided in the First Edition of *An Illustrated Guide to the Mountain Stream Insects of Colorado* (Ward and Kondratieff 1992). A 25mL glass jar was filled with 90% ethanol to hold the invertebrates picked out of each sample. Once an invertebrate had been identified, it would be removed from the sample using microdissection forceps and placed into the 25mL jar.

Historical quantitative data about the phyla present within a stream were available electronically through the CDHPE. This information was downloaded from the EPA's Storage and Retrieval (STORET) data website, which houses water quality, biological, and physical data from various state and federal agencies, universities, and organizations throughout the country. Parameters were selected to yield results about macroinvertebrate taxa counts from 2000 to present in both Boulder Creek and the Cache la Poudre. The most recent available data for Boulder Creek and the Cache la Poudre was from October 2003 and November 2003, respectively ("STORET" 2012). The nets used by CDPHE are $0.5m^2$ and their protocol involves kicking sediment in the square meter upstream of the net. The effective area sampled by these nets is roughly 10 times greater than the effective area sampled by the nets used for sampling in November 2012. From this, it can be assumed that sample sizes in 2003 are 10 times greater than sample sizes in 2012, so the data between these two sampling times can be normalized by dividing the number of invertebrates in each taxon in 2003 by 10.

Macroinvertebrate populations were compared from 2003 to 2012 within each stream using a variety of metrics. The Shannon-Weaver index was calculated for each year at each site to assess overall population diversity. To understand how invertebrate populations responded to organic pollution, the Hilsenhoff tolerance values were applied then averaged for each site in 2003 and 2012. Using these tolerance values, the percentage of pollution tolerant and pollution intolerant invertebrates in a community can be determined. Additionally, the number of EPT taxa were counted for each site, as well as the number of Diptera taxa. This metric provided a basic understanding about the relative presence of pollution-tolerant or intolerant taxa.

Sediment Characterization

Sediments at each sampling site were measured in accordance with the Wolman pebble count method. A 10-foot section of stream was measured. Within the 10-foot section, I took slow, even steps in a zig-zag pattern across the section, moving downstream. Wherever my left big toe landed, I measured the sediment directly in front of it along three axes; its longest axis, an intermediate axis, and its shortest axes (referred to as *x*, *y*, and *z* in data tables). The sediments were categorized into size classes based on ranges in the length of their intermediate or *y* axis (See Figure 5). Thirty different sediments were measured at each site, and then these values were averaged to determine the average sediment size of the site.

Size Class	Size Range (mm)
Sand	<2
Very Fine Gravel	2-4
Fine Gravel	4-6
Fine Gravel	6-8
Medium Gravel	8-11
Medium Gravel	11-16
Coarse Gravel	16-22
Coarse Gravel	22-32
Very Coarse Gravel	32-45
Very Coarse Gravel	45-64
Small Cobble	64-90
Medium Cobble	90-128
Large Cobble	128-180
Very Large Cobble	180-256
Small Boulder	256-512
Medium Boulder	512-1024
Large Boulder	1024-2048
Very Large Boulder	2048-4096

Figure 5. Size range and size class designations for sediment collected and measured with the Wolman Pebble Count method.

Historical Discharge and Precipitation

Annual discharge patterns for both Boulder Creek and the Cache la Poudre were available in the form of hydrographs from the USGS. Monthly precipitation amounts could be accessed on the Colorado Climate Center website ("Colorado Data"). Information about discharge was available through the United States Geological Survey (USGS) website, in the form of hydrographs or numerical data ("Daily Streamflow" 2013).

RESULTS

Site Descriptions

Sampling at Boulder Creek was done on November 18, 2012, starting at 2:30 P.M. The first site sampled on Boulder Creek was located roughly 3 miles east of Nederland, CO on Highway 119 on the south side of the road. At this point, the stream is nestled at the base of a north-facing slope that is populated with ponderosa pine trees and grasses. There are a few deciduous bushes and trees on the north bank, which provided shade at this time of day. The highway is about 5 meters away from the nearest riverbank. At this point, there is no ice on any stretch of Boulder Creek from Nederland to Boulder. The water is clear, and leaves are visible along the stream bed. There are several riffles at this point in the stream, and the water is relatively fast-moving. There is little to no visible algae on the larger rocks in the water, and the banks are mostly sandy.

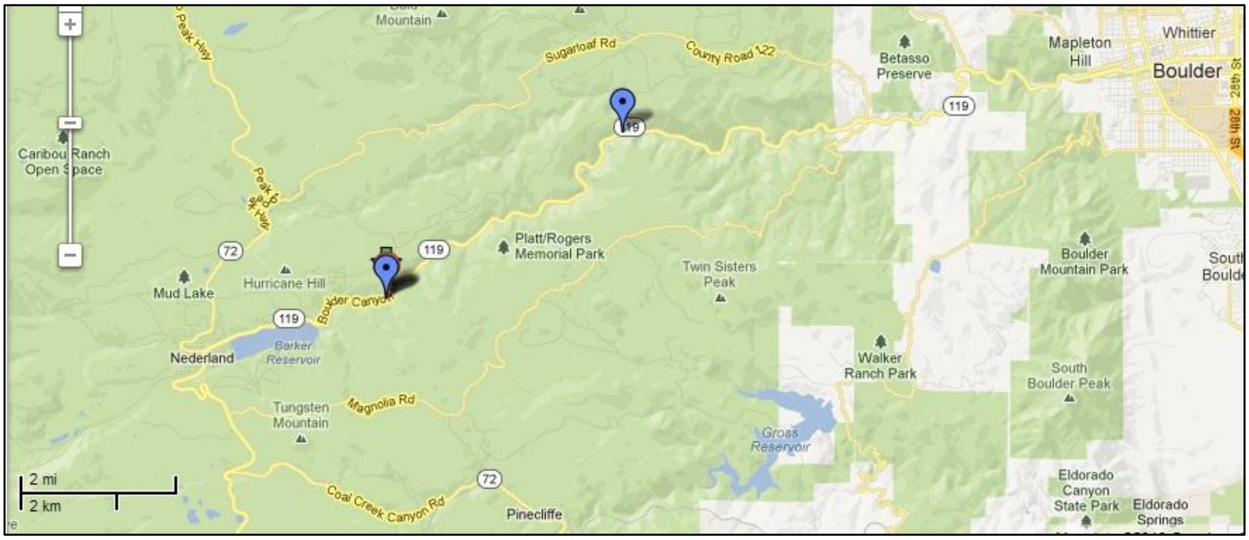


Figure 6. Location of Boulder Creek sample sites 1 and 2 along Highway 119 between Nederland and Boulder. Site 1 is on the left, closer to Nederland, and site 2 is on the right, closer to Boulder. (Google Maps 2013).

Site two on Boulder Creek is about 12 miles east of Nederland on Highway 119, also on the south side of the road (See Figure 6). We sampled here also on November 18, 2012, beginning just before 4:00 P.M. There are slightly more deciduous trees at this site than at the first Boulder Creek site, but also a comparable amount of coniferous trees, grasses, and riparian shrubs. Similar to the first site, this section of stream is in close proximity to the highway, and located at the bottom of a hillside, with mostly sandy banks. The rocks here also have little or no visible algae, and riffles are abundant.

Sampling of the Cache la Poudre was conducted on November 9, 2012. We began at site 1 at 4:30 P.M. Site 1 is located 13 miles west of Fort Collins along Highway 14/Poudre Canyon Highway (See Figure 7). The stream is roughly 100m away from a paved road and flows at the bottom of an unburned hillside. There are burned, standing trees at the top of this hillside, indicative of the close proximity of the burned area. Further down the hill, there are coniferous and deciduous trees as well as some grasses and small riparian bushes. Riffles are visible from the banks. The banks are sandy and blackened. The stream bed is also blackened, and it quickly became apparent that the entire stream bed was covered in a layer of silty black sediment.

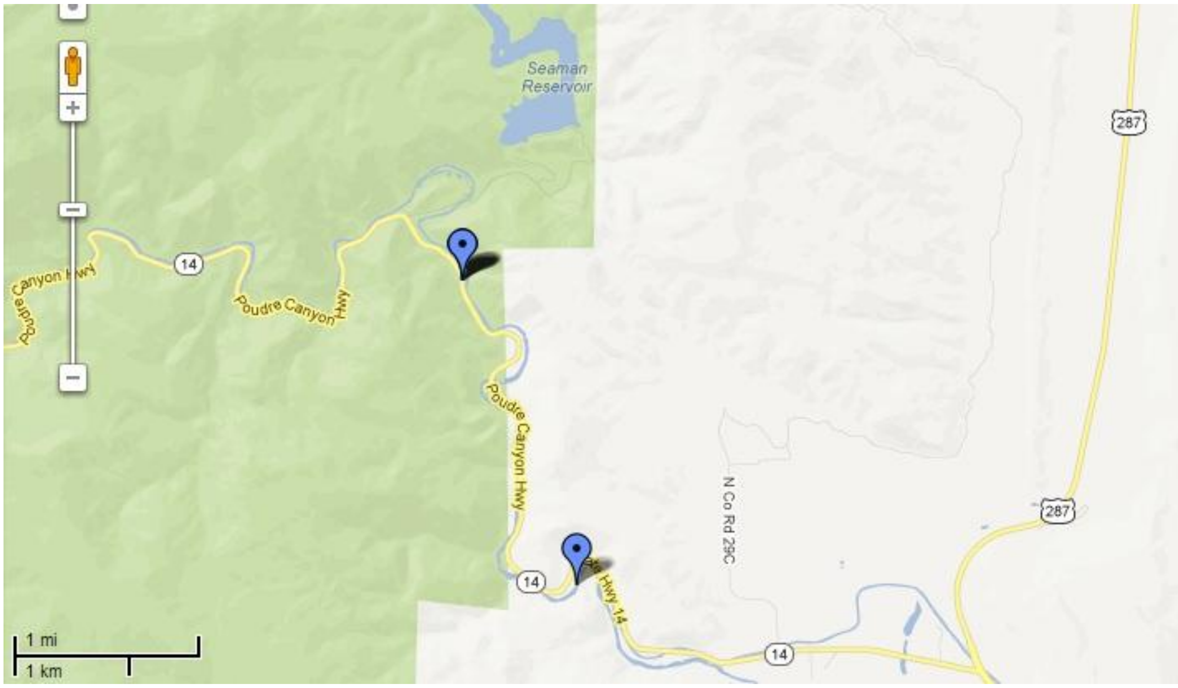


Figure 7. Map of the sampling sites for the Cache la Poudre River in relation to Seaman Reservoir and Highway 287. Site 1 is near the bottom of the map on the Poudre Canyon Highway. Site 2 is further north, also along Poudre Canyon Highway. (Google Maps 2013).

During the sampling at this site, we observed chunks of charcoal floating in the water. Charcoal was later found in the invertebrate sample from this site, ranging in size from about half a centimeter in diameter to roughly two centimeters in diameter.

Site 2 is located 15 miles west of Fort Collins on Highway 14, and is roughly 2.5 miles upstream from site 1. Sampling began here at 5:00 P.M. There are deciduous trees and a few coniferous trees near the banks, but bushes are the dominant form of vegetation here. Like the first sample site, the stream is between the highway and a hillside, but is only about 25m away from the road. No part of the burn area is visible from this location, but the banks are blackened just as the banks were at site 1. The same covering of silty black sediment coats the stream bed. Riffles are the dominant characteristic of water flow at this location.

Discharge

Between the two streams, average discharge was comparable, but the Cache la Poudre had a higher streamflow than Boulder Creek on the day it was sampled. The difference in sampling days is negligible because no precipitation fell over either watershed between these days. The discharge volume per second was slightly higher at the downstream site than discharge volume per second at the upstream site at both Boulder Creek and the Cache la Poudre.

Table 3. Averaged discharge of both sample sites in each stream on the day that sampling was done in terms of cfs and cms. The Cache la Poudre was visited on November 9, 2012 and Boulder Creek was sampled on November 18, 2012.

Sample Site Discharge Estimate November 2012	
Site	**Discharge (cms)**
Boulder Creek	1.20
Cache la Poudre	1.43

Sediment

The study conducted in the Hayman Burn Area fortunately had data about sediment size

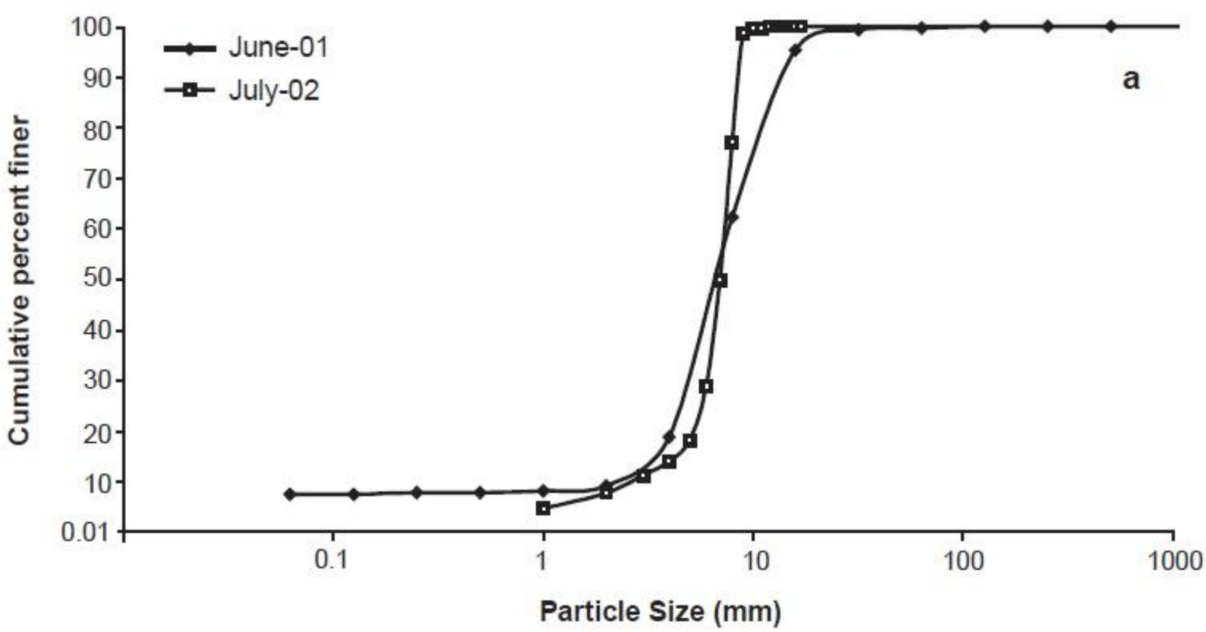


Figure 8. Sediment size distribution from Saloon Creek in terms of the percentage of individual particles that are finer than a given particle size. This graph is taken from the first part of Figure 24 in Part 6 of the Hayman Fire Case Study (Graham 2003).

distribution before the fire. Data provided in Graham 2003 shows the distribution of particle sizes in Saloon Creek and Brush Creek in terms of the cumulative percentage of particles or individual sediments that are finer than a given particle or sediment size. The data from Saloon Creek shows that in June 2001, before the fire occurred, about 75% of the sediments measured in the stream were smaller than 10mm, with roughly 25% of the sampled sediments being larger than 10mm. In July 2002, after the Hayman Fire, roughly 95% of sediments were found to be smaller than 10mm, with a minimal proportion of the sediments were larger than 10mm (Graham

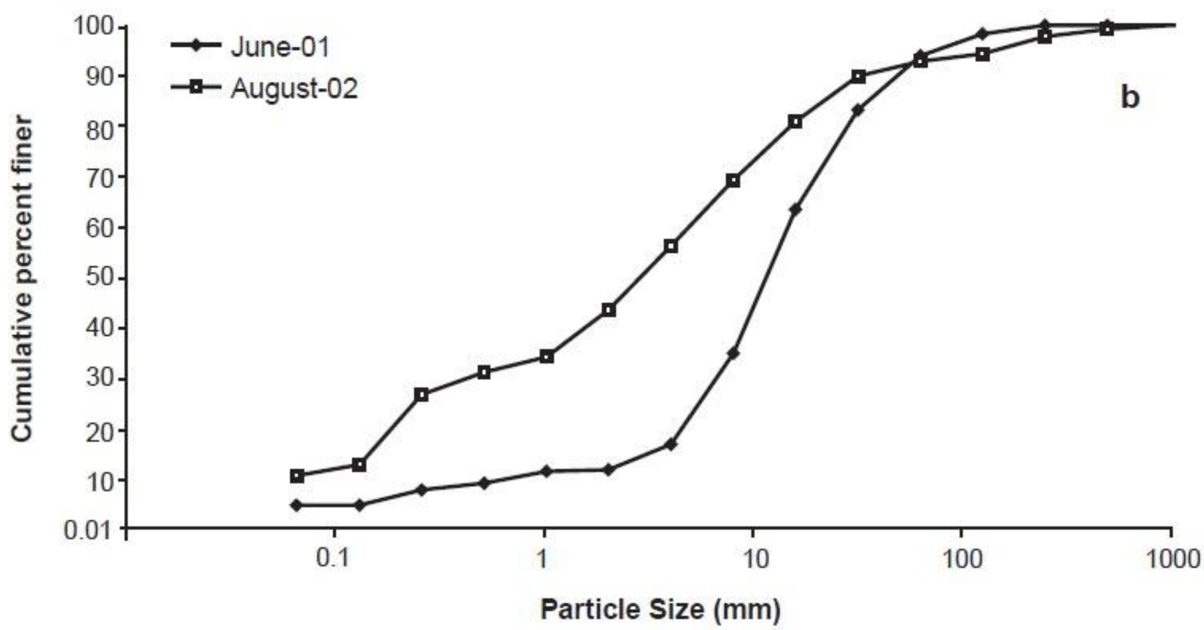


Figure 9. Distribution of sediment sizes in Brush Creek in terms of cumulative percent of finer particles. This graph is taken from the second part of Figure 24 in Part 6 of the Hayman Fire Case Study (Graham 2003).

2003) (See Figure 8).

Particle size distribution in Brush Creek was measured in June 2001, before the fire, and August 2002, after the fire. Pre-fire particles in Brush Creek were more evenly distributed than pre-fire particles in Saloon Creek. Almost 50% of the measured sediments were less than 10mm in size, and approximately 10% of the particles were larger than 100mm. The distribution of sediment sizes after the fire was also more even in Brush Creek than Saloon Creek. A larger proportion of sediment was finer than 10mm after the fire than before the fire, with about 75% of the sediments being measured as smaller than 10mm in diameter. There was also a larger proportion of sediment that was coarser than 100mm after the fire compared to before the fire (Graham 2003) (See Figure 9).

Similar graphs were constructed from the sediment measurements made in Boulder Creek and the Cache la Poudre in November 2012. Boulder Creek, as a reference or unburned stream, has slightly similar sediment distribution patterns to Saloon Creek and Brush Creek in the year before the Hayman Fire. Almost 25% of the measured particles in Boulder Creek were finer than 100mm. Most of the sediment was finer than 300mm (See Figure 10).

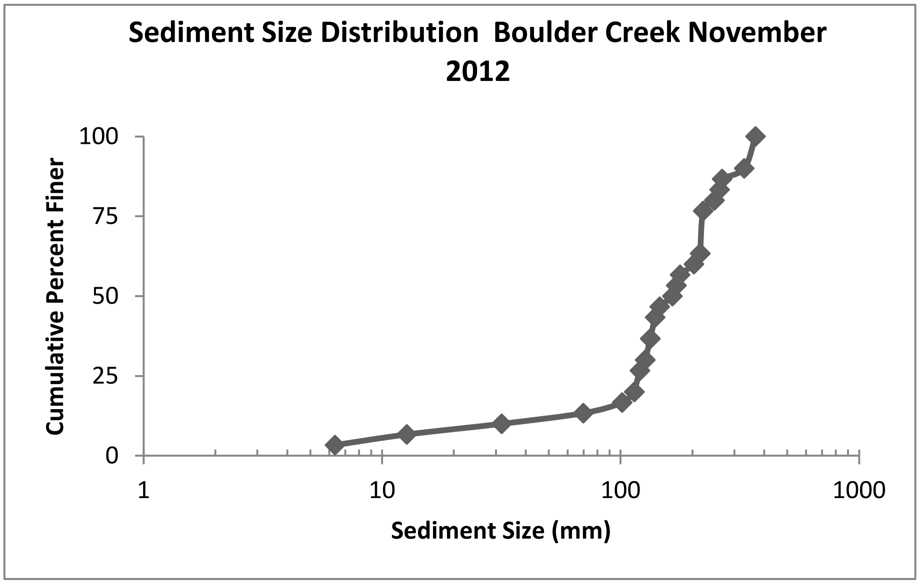


Figure 10 shows the sediment size distribution from Boulder Creek in terms of the percentage of individual particles that are finer than a given particle size.

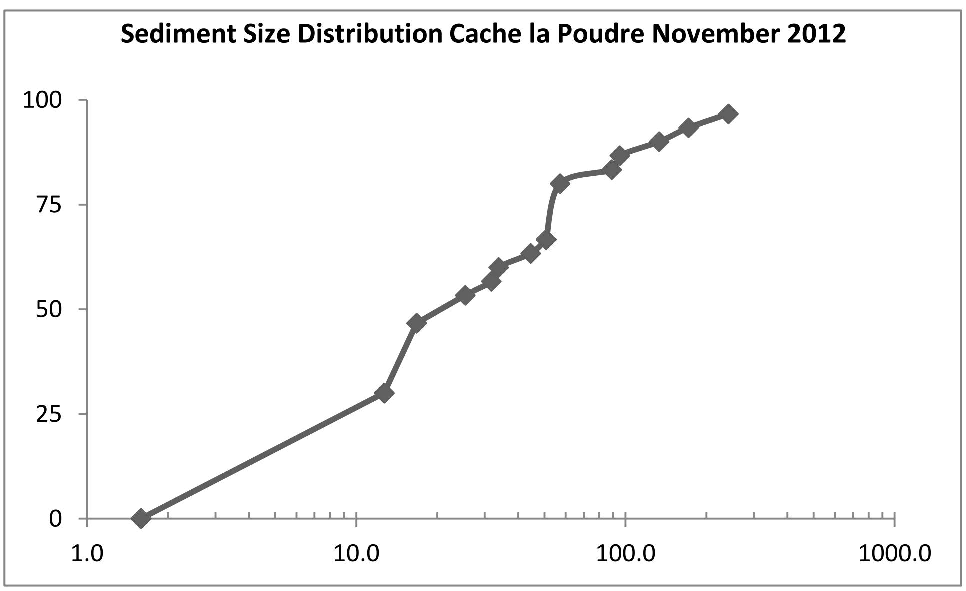


Figure 11. Distribution of sediment sizes in the Cache la Poudre in terms of the cumulative percent of sediments finer than a given particle size.

The sediment

size distribution in the Cache la Poudre post-fire shows that approximately 25% of the measured sediments were finer than 10mm. About 25% of the particles were larger than 100mm in diameter. This suggests that there was a more even distribution of sediment sizes after a fire (See Figure 11).

Sediment size distribution data was also analyzed using the criteria of the Wolman Pebble Count method, thus classifying the sediments in one of six categories based on the length

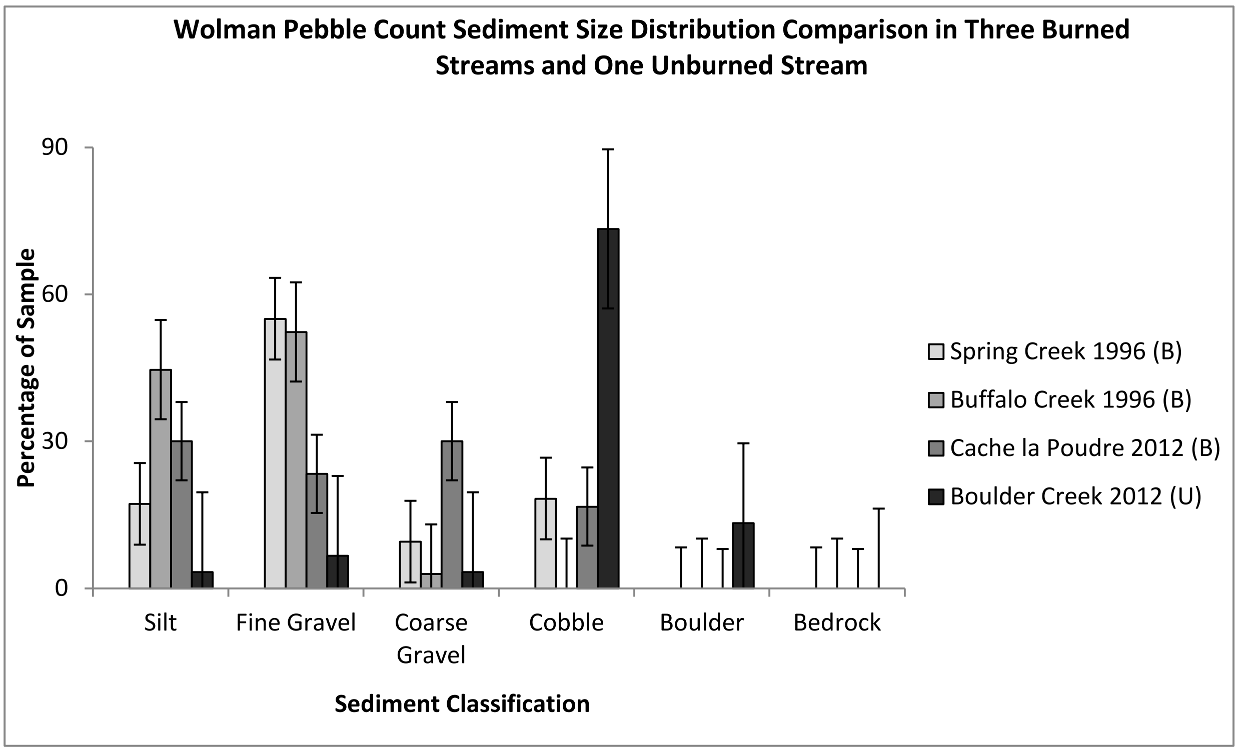


Figure 12. Data compilation of sediment size distribution data from three burned streams (Spring Creek, Buffalo Creek, and the Cache la Poudre), and one unburned stream (Boulder Creek). Burned streams are graphed in shades of red, while the unburned stream is graphed in green. Sediments were classified based on the Wolman Pebble Count criteria outlined in Figure 6.

of the particle's intermediate axis. Generally, burned streams contained more silt, fine gravel, and coarse gravel than unburned streams. Unburned streams had a higher proportion of cobble than burned streams, and also included more boulders than burned streams. Sediments that would be classified as bedrock were not found in samples taken in burned or unburned streams (See Figure 12).

Macroinvertebrate Counts

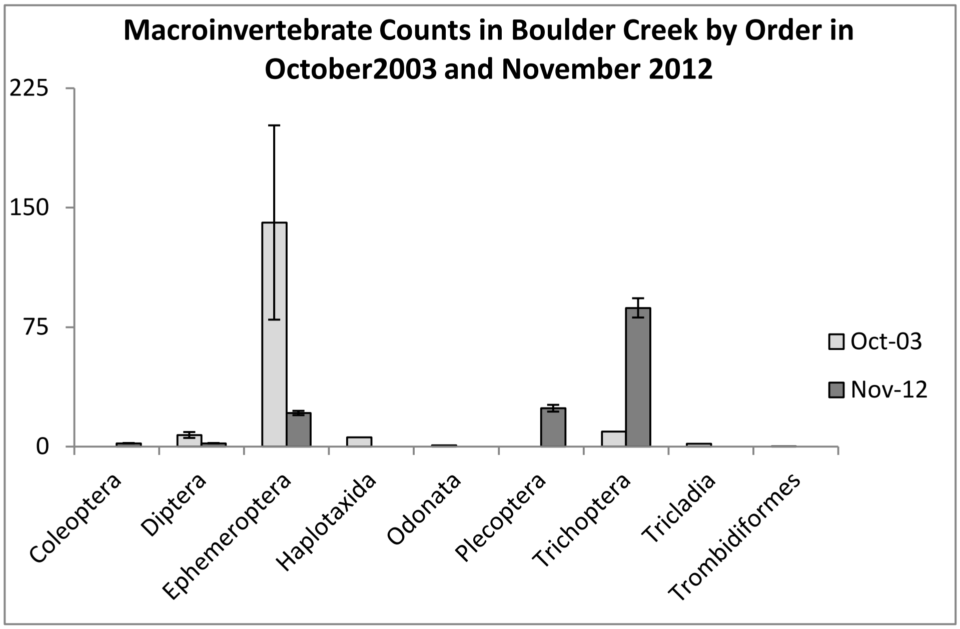


Figure 13. Number of invertebrates collected from Boulder Creek from each order during sampling in October 2003 and November 2012. Variation in sampling technique and net size was accounted for by normalizing the data.

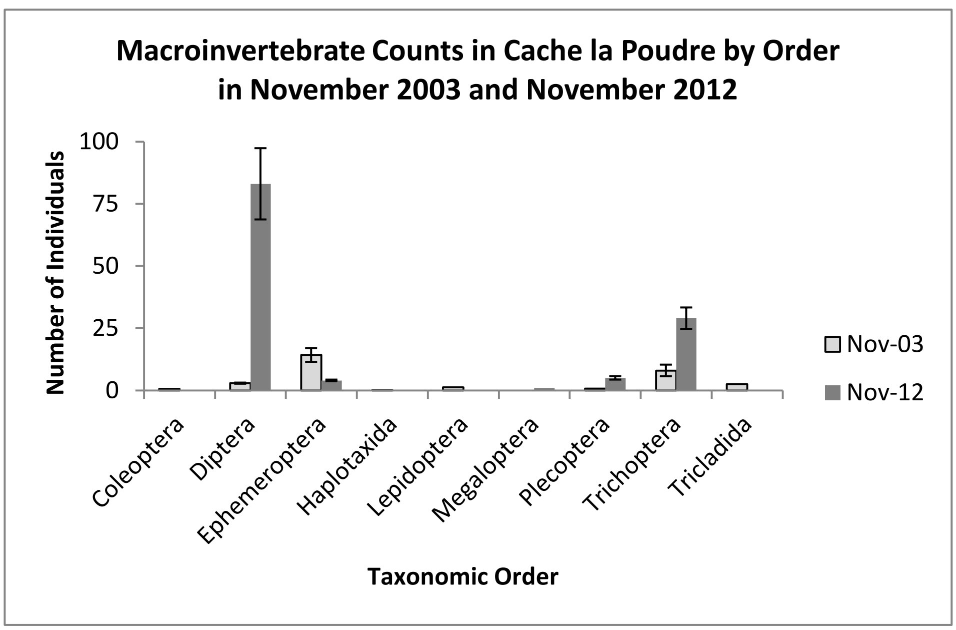


Figure 14. Number of invertebrates of each order in the Cache la Poudre during sampling in November 2003 and November 2012. Variation in sampling technique and net size was accounted for by normalizing the data.

The macroinvertebrate sampling of Boulder Creek, done by the Rivers of Colorado Water Watch Network in October of 2003, yielded the largest invertebrate sample of this entire study with a total of 1657 identified individuals. Seven orders were found in this stream, with the majority of invertebrates belonging to the order Ephemeroptera

(See Figure 13).

In the sampling done in November 2012 in Boulder Creek, invertebrates from five different orders were present in the stream on the day samples were collected. Notably, the orders Trichoptera, Ephemeroptera, and Plecoptera were well represented, which suggests that the environment was livable for some of the more sensitive taxa. Though there were a number of representatives from Ephemeroptera, Plecoptera, and Trichoptera, there were more individuals of the order Diptera than these three taxa combined (See Figure 13). This is typically a sign that water quality may be degraded, as less sensitive taxa outnumber more sensitive taxa.

According to the data from November 2003 in the Cache la Poudre, eight distinct orders of invertebrates were living in the stream at the time. The sampling, done by the Rivers of Colorado Water Watch Network, yielded just over 300 individuals (See Figure 14). This

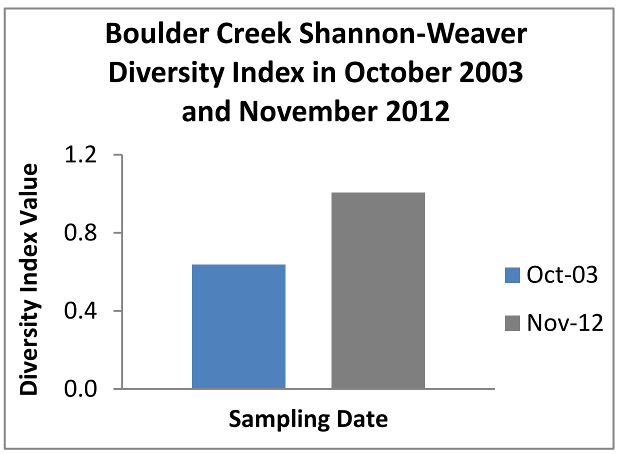


Figure 15. Shannon-Weaver Diversity Index value for Boulder Creek in October 2003 and November 2012.

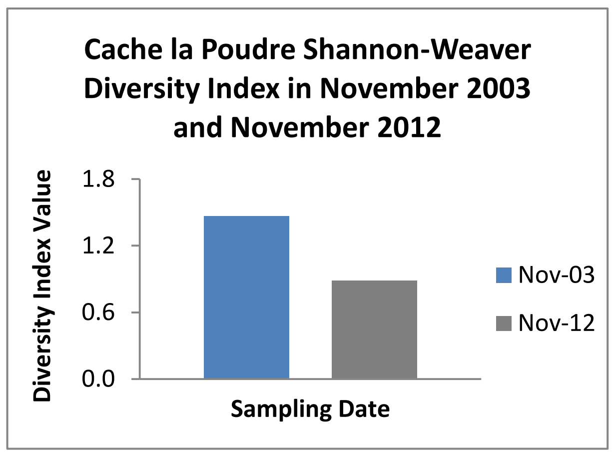


Figure 16. Shannon-Weaver Diversity Index value for the Cache la Poudre in November 2003 and November 2012.

relatively high number of different orders and families within the sample generally indicates a good amount of diversity within the population.

The earlier sample only contained five orders of benthic macroinvertebrates. Individual invertebrates from the order Diptera outnumbered individuals from the remaining orders

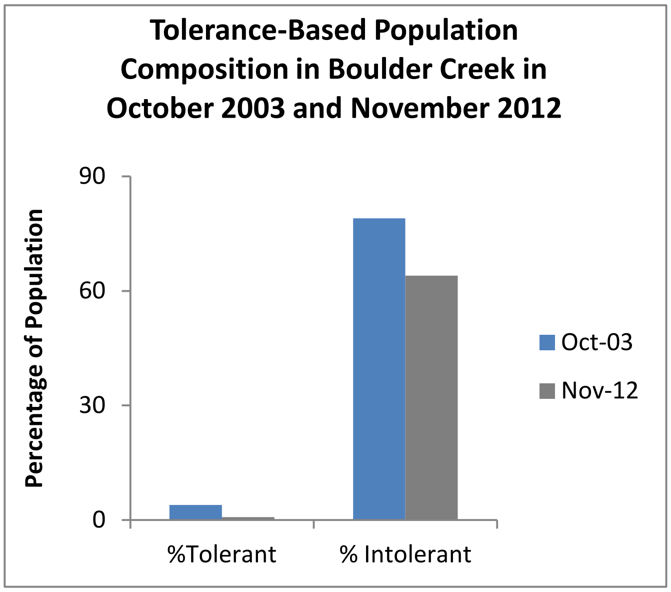


Figure 17. Composition of the invertebrate community of Boulder Creek in October 2003 and November 2012 in terms of taxa tolerance to pollution.

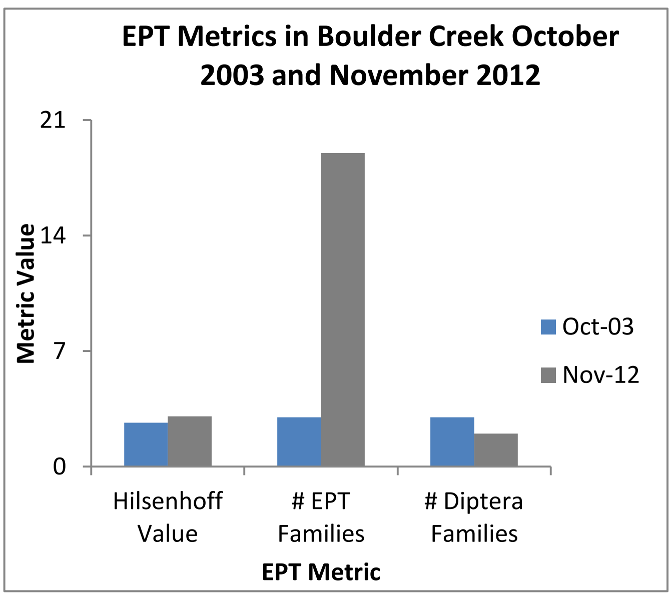


Figure 18. Calculated EPT metric values for benthic macroinvertebrates in Boulder Creek in October 2003 and November 2012.

combined See Figure 14). This majority of pollution-tolerant individuals makes it very likely that some degree of pollution is occurring in the Cache la Poudre.

The SWDI value for Boulder Creek in 2003 (0.6368) was lower than the SWDI value for Boulder Creek in 2012 (1.005) (See Figure 15). This indicates that there was a general increase in the diversity of macroinvertebrates in Boulder Creek between 2003 and 2012, but the lower SWDI values mean that the taxa in the sample are relatively unevenly distributed. In the Cache la Poudre, SWDI values generally decrease between November 2003 (1.467) and November 2012 (0.8859) (See Figure 16). These relatively low SWDI values are similar to those in Boulder Creek during this time period, meaning that there is a low degree of evenness of invertebrate taxa in these streams.

Boulder Creek's invertebrate community contained a low percentage of tolerant families in 2003 (3.92%), and this decreased further in November 2012 (0.74%) (See Figure 17). The

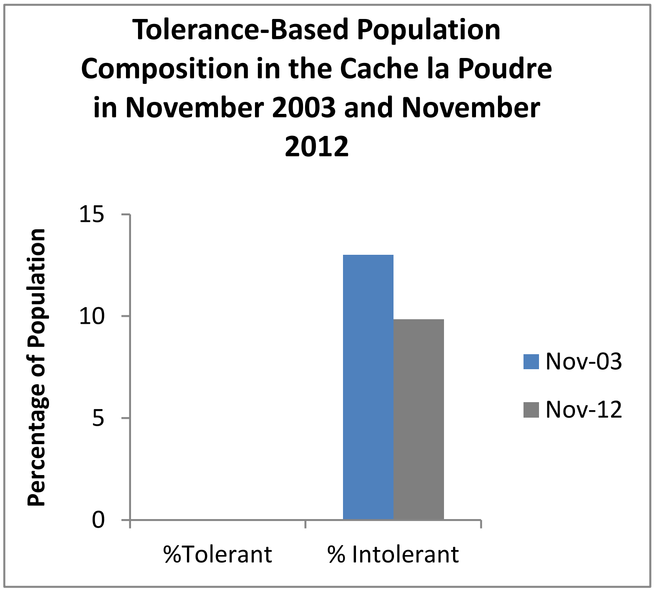


Figure 19. Composition of the invertebrate community based on tolerance to pollution in the Cache la Poudre in November 2003 and November 2012.

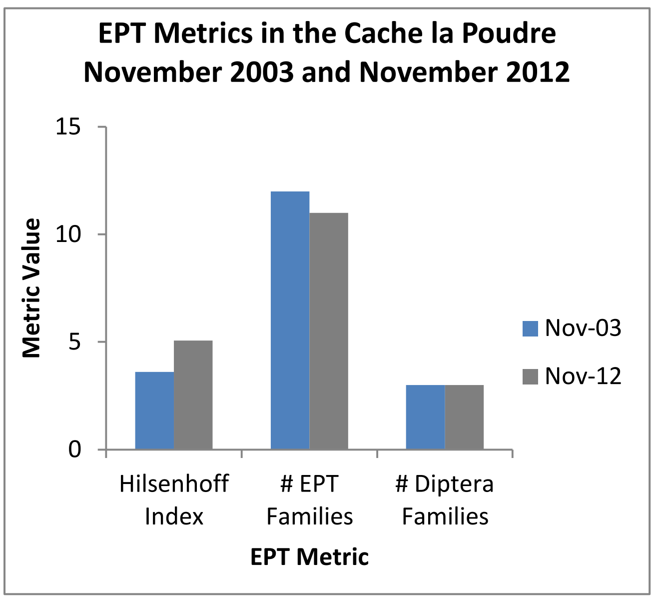


Figure 20. Calculated values of EPT metrics for invertebrates in the Cache la Poudre in November 2003 and November 2012.

proportion of pollution intolerant families in Boulder Creek in 2003 (79.03%) also decreased in 2012 (63.97%) (See Figure 17). These changes in percentages of community pollution conflict because there is no clear trend in increasing tolerance or intolerance in invertebrate taxa. The FBI, calculated using Hilsenhoff tolerance values, increases slightly from 2003 to 2012 (2.7 to 3.1), indicating a minor increase in the overall tolerance of invertebrates in Boulder Creek (See Figure 18). Despite this, the number of EPT families increases considerably during this same time period from 3 families to 19 families (See Figure 18). The number of Diptera families decreases between 2003 and 2012 from 3 to 2 (See Figure 18).

According to Hilsenhoff tolerance values, the invertebrate communities of the Cache la Poudre in 2003 and 2012 do not contain any pollution-tolerant families. However, the percentage of pollution-intolerant taxa in 2003 (13%) decreases by late 2012 (9.84%) (See Figure 19). This trend suggests that more sensitive, pollution-intolerant taxa became less common in the Cache la Poudre over time. The

FBI in the Cache la Poudre increased between 2003 and 2012 (3.6 to 5.1) (See Graph 14). Though the number of EPT families was slightly less in 2012 (11) than in 2003 (12), the number of Diptera families remained the same between the two years (3 families) (See Figure 20).

Precipitation and Discharge

Currently, there is no available data about monthly precipitation amounts over these watersheds in particular. Because both Boulder and Fort Collins are located east of the corresponding watershed and the jet stream moves from west to east, it can be assumed that most precipitation that fell over the municipality also fell over the watershed. In 2003, Boulder received more precipitation than Fort Collins. Both cities received relatively low amounts of precipitation in July and the highest amount of precipitation in August (See Figure 21).

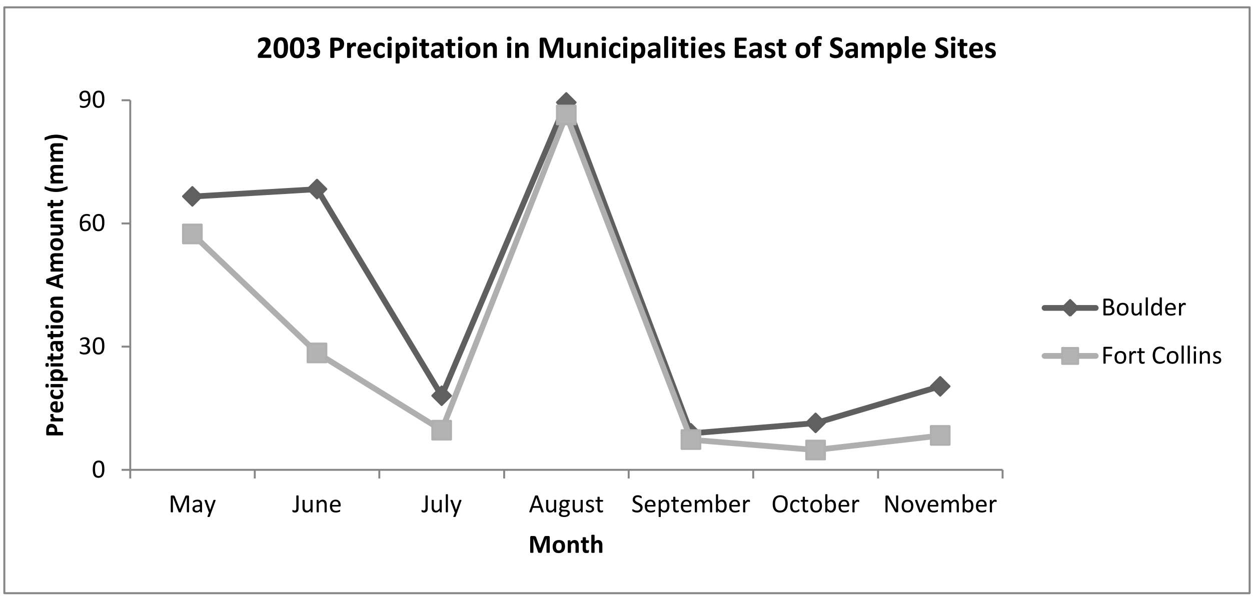


Figure 21. Amount of precipitation received from May to November in 2003 in municipalities east of sample sites. This graph was constructed using data from the Colorado Climate Center ("Colorado Data" 2010).

Summer precipitation patterns in 2012 were almost opposite of 2003 patterns. The red star on the Fort Collins curve marks the date on which the High Park Fire was 100% contained (*High Park Fire* 2012). Both Boulder and Fort Collins received relatively low amounts of precipitation in June and August, but substantially higher amounts of precipitation in July (See

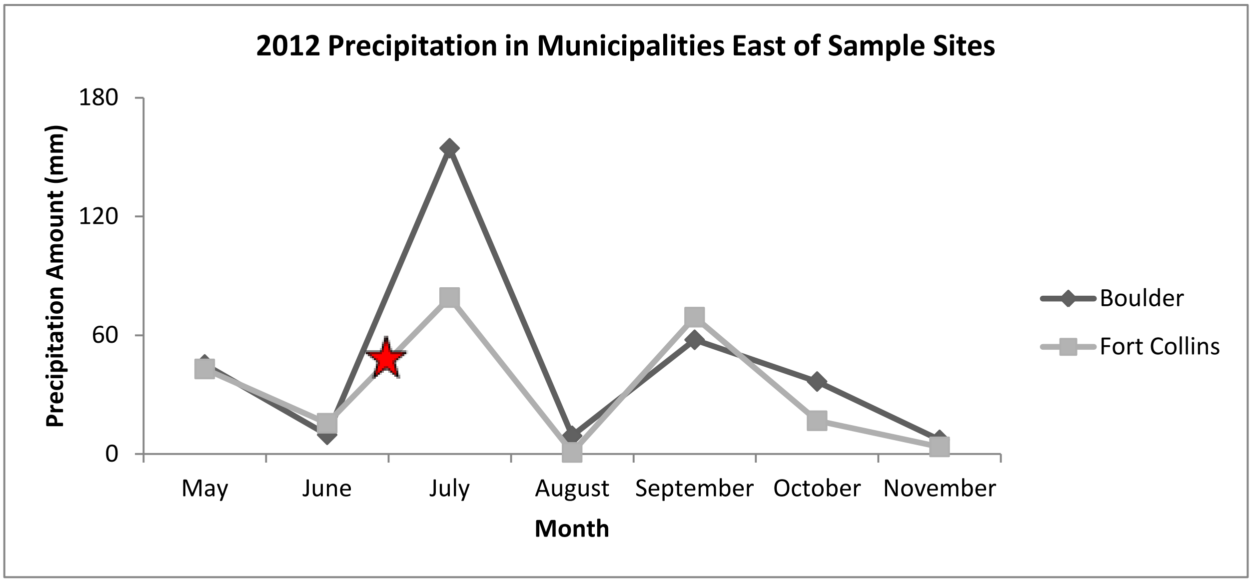


Figure 22. Amount of precipitation received each month from May to November in 2012 in municipalities east of sample sites. This graph was constructed using data from the Colorado Climate Center ("Colorado Data" 2010).

Figure 22). There was also noticeable heightened precipitation in September in 2012 compared to 2003 (See Figures 21 and 22).

A hydrograph of the Cache la Poudre over a one-year period between January 2012 and January 2013 shows changes in streamflow (See Figure 23). The red star on the hydrograph at the end of June marks the date on which the High Park Fire was completely contained (*High Park Fire* 2012). In April 2012, there is an abrupt increase in stream discharge. This most likely marks the beginning of water input from snowmelt. Subsequent spikes in discharge can be attributed to episodic precipitation events. Any precipitation events occurring after the fire was

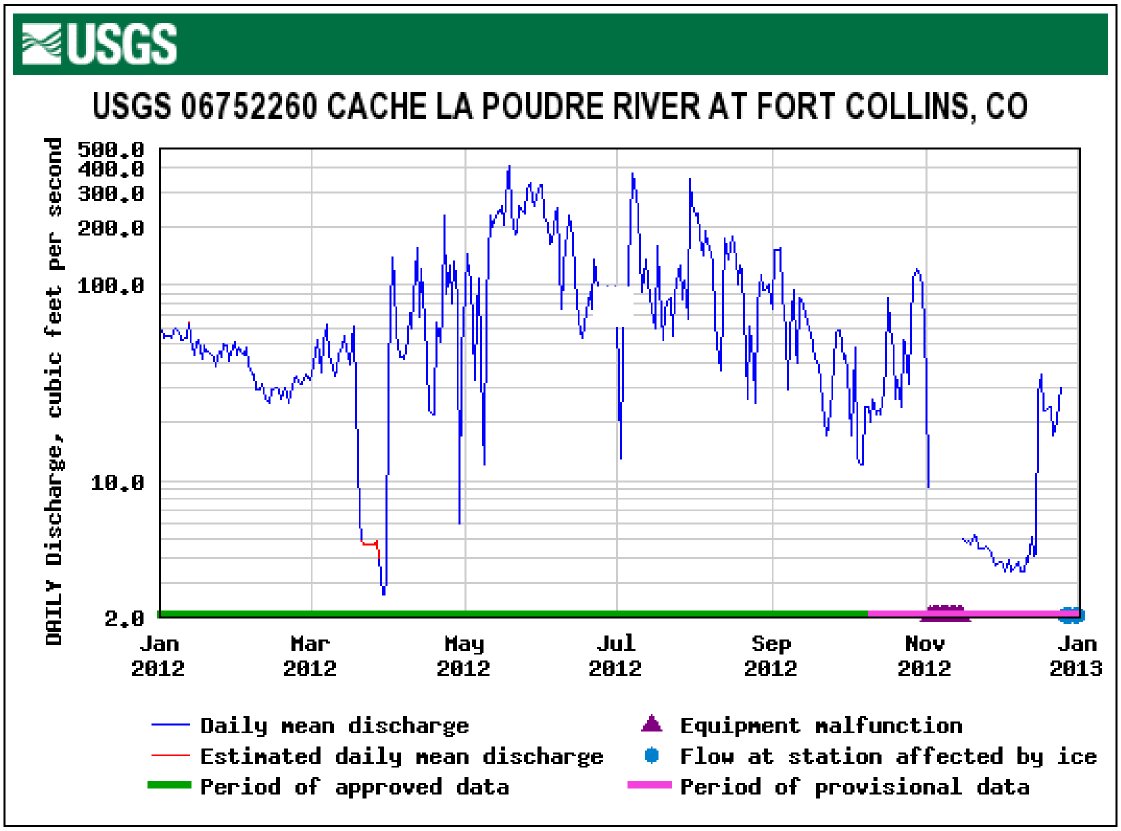


Figure 23. Hydrograph from the USGS at the Fort Collins gauging station along the Cache la Poudre. This hydrograph displays the discharge in the Cache la Poudre from January 2012 to January 2013.

contained can be assumed to have contributed to some form of hillslope erosion and sediment input into the Cache la Poudre.

DISCUSSION

This study investigated how short-term changes in stream sediment following a fire affect the composition of benthic invertebrate communities by comparing conditions in a reach of Boulder creek to a reach of the Cache la Poudre affected by the High Park Fire of 2012. It also considered what changes in invertebrate community composition might suggest about a stream's health. Contention persists between the findings of similar studies that addressed invertebrate communities' response to wildfires and stream sedimentation in the months before spring runoff, but this study contributes to that body of knowledge and helps guide further research. The original hypothesis was that the average size of stream sediment will decrease within the first six months after a fire because of the input of fine sediment from hillside erosion adjacent to a burned stream. This will cause invertebrate communities to become less diverse because of the sediment's impact on food sources, and this loss of diversity will serve as an indication that overall stream health has also decreased.

Identifying the approximate dates and magnitudes of episodic precipitation events after the High Park Fire was important in establishing that sediment input from hillside erosion occurred in the High Park burn area. In 2003 and 2012, precipitation patterns at Boulder and Fort Collins were similar. In these two years, a relatively high amount of precipitation would fall during a summer month, with relatively low amounts of precipitation falling in the months before and after (See Figures 21 and 22). From the data provided in Graham (2003), it can be assumed that the most erosion and sediment input into streams occurred during months with the highest amount of precipitation. The most precipitation fell in Fort Collins and in the Cache la Poudre in July 2012, which was the month right after the fire was 100% contained. A comparable amount of precipitation also fell in September, so it is likely that most erosion happened in July and September of 2012 (See Figure 22). Examination of the hydrograph of the Cache la Poudre in 2012 shows that the highest post-fire discharge peaks occur in July, August, and September (See Figure 23). By combining precipitation records with stream flow data, it can be inferred that the most substantial erosion and sedimentation events took place in July and September.

Understanding changes in the distribution of stream sediment sizes helped in understanding how pollution and changes to the physical environment might have played a role in changes in invertebrate communities. In the Hayman Fire case study, there was a 20% increase in the fineness of sediments that were less than 10mm in diameter after a fire (Graham 2003) (See Figures 8 and 9). After the High Park Fire, the Cache la Poudre contained roughly 25% of sediment that was less than 10mm (See Figure 11). Applying the trend in findings from the Hayman Fire, it can be assumed that prior to the fire, around 5% of the surface bed sediment was finer than 10mm. Comparing sediment classifications between unburned and burned streams shows that burned streams contain more silt, fine gravel, and coarse gravel than unburned streams, which have much higher cobble and boulder content (See Figure 12). Substantially higher proportions of sediment were measured as finer than 10mm in the data from the Hayman Fire than the data from the High Park Fire (See Figures 8,9, and 11). This can be explained by a difference in sediment sampling methods between the two studies. Sediments were collected via sediment fences in the Hayman Fire study, and they were collected randomly in a reach of a stream using the Wolman Pebble Count method in the High Park Fire study. Samples from the Hayman Fire study contained considerably more individual particles than samples from the High Park Fire, thereby making them more representative of the distribution of sediment sizes in a given stream (Graham 2003).

The encompassing trend from both the Hayman Fire and the High Park Fire is that streams contained higher proportions of finer sediment after a fire than before a fire. This is consistent with the hypothesis, and can account for some of the pollution and trophic changes in streams after fires occur within the watershed. Pollution-tolerant taxa, specifically Diptera, contain species classified as shredders, collectors, scrapers, and predators. Knowing that the overall size of stream sediment decreases after fires, it is possible that substrate is not large enough to support periphyton, and finer substrate tends to coat and impede scrapers' and collectors' food sources ("Aquatic Insect-Substratum" 1984). The input of burned organic matter into a stream after a fire would also detract from food availability for shredders. These impacts on macroinvertebrate food sources could decrease the number of invertebrates that serve as prey for predacious invertebrates as well.

Calculating the diversity of benthic invertebrate communities with SWDI values allowed comparisons to be made between invertebrate communities before and after a substantial fire. Based on SWDI values, diversity in Boulder Creek in 2003 was lower than the diversity of Boulder Creek in 2012 (See Figure 15). This could be explained by invertebrate communities becoming more established over this time period, resulting in a greater amount of richness and evenness in invertebrate taxa. The trend in diversity in the Cache la Poudre between 2003 and 2012 is opposite of that seen in Boulder Creek, as invertebrate diversity decreased from 2003 to 2012 (See Figure 16). A reduction in diversity indicates that fewer taxa were present in 2012 than in 2003. This change could have also been accompanied by less taxa evenness, with large differences in the number of individuals within each taxon. Decreased invertebrate diversity in the Cache la Poudre after a fire and increased diversity in an unburned stream over the same time period supports the hypothesis that invertebrate communities become less diverse after a fire.

Changes in stream health were also measured with invertebrates. In Boulder Creek, the percentage of pollution-tolerant taxa decreased from 2003 to 2012 (See Figure 17). This could mean that a shift in the proportion of pollution-tolerant to pollution-intolerant invertebrates occurred over time. Another explanation is that the number of pollution-tolerant individuals in the community decreased because of a lack of availability of exploitable food sources. The percent of pollution-intolerant invertebrate taxa also decreased between 2003 and 2012 (See Figure 17). Because tolerant and intolerant taxa are defined by values on the ends of the Hilsenhoff tolerance value spectrum, the decrease in both pollution-tolerant and pollution-tolerant taxa could be a result of the increased presence of moderately tolerant or intolerant taxa in the stream.

Three EPT metrics were used to evaluate invertebrate communities in Boulder Creek and the Cache la Poudre. In Boulder Creek, the Hilsenhoff-derived FBI value increased from 2003 to 2012, indicating a slight shift in the community towards more pollution-tolerant taxa (See Figure 18). This trend is not very consistent with changes in the calculated percentage of pollution-tolerant taxa in Boulder Creek over the same time period. The number of EPT families noticeably increased from 2003 to 2012, suggesting that the stream became relatively healthier over time, and more capable of supporting more sensitive invertebrates than it was previously (See Figure 18). The small decrease in the number of Diptera families in Boulder Creek over this time period shows that there were slightly fewer insensitive taxa (See Figure 18). However, the presence of Diptera in a stream should not always serve as a negative indication of stream health because invertebrate diversity increases as a result.

Observed trends in benthic macroinvertebrate communities in Boulder Creek from 2003 to 2012 suggest that numbers of moderately tolerant or intolerant invertebrates have increased in this stream. The increased amount of EPT taxa in the stream and decreased Diptera taxa are aspects of the EPT metrics that do not directly contradict one another, so it can be inferred that Boulder Creek is relatively healthy despite its increased FBI value. The hypothesis is partially supported by the finding that an unburned reference stream is relatively healthy.

Invertebrate communities in the Cache la Poudre consistently contained no tolerant taxa in 2003 and 2012 (See Figure 19). A lack of habitat or food sources for pollution-tolerant invertebrates cannot be ruled out, but it is also possible that the absence of these taxa indicates low pollution levels. The proportion of pollution-intolerant taxa decreased from 2003 to 2012, making it possible that pollution increased and intolerant invertebrates could not survive, or changes in habitat features and food sources killed these invertebrates or forced them to migrate to different reaches of the stream (See Figure 19).

In terms of EPT metrics, there was an increase in pollution-tolerant taxa according to a slight increase in the FBI values between 2003 and 2012 (See Figure 20). Because this increase in tolerant taxa is not reflected in the change in percentage of tolerant taxa, it is likely that invertebrates with moderately “tolerant” Hilsenhoff tolerance values (5-7) became more common in this reach. The number of EPT families decreased minimally from 2003 to 2012, potentially because of small increases in pollution during this time (See Figure 20). The number of Diptera families was constant between these two years, which may indicate persistent levels of pollution during this timeframe.

Decreased amounts of pollution-intolerant taxa coupled with an increased stream FBI value and fewer EPT families from 2003 to 2012 suggests with some confidence that stream health did decrease through 2012. These three factors complement one another, and the constant percentage of tolerant taxa and Diptera families can be explained by other possible influences that were not measured in this study. A reduction in stream health in a burned stream is consistent with the hypothesized outcome.

Previous studies by Rinne and Minshall in Arizona and YNP, respectively, found different responses of invertebrate communities in the six months after fires. While taxa richness was found to be virtually unchanged in YNP, the density and diversity of invertebrates decreased drastically in Arizona (Rinne 1997, Minshall et al. 1997). These two studies are representative of the divergence of findings regarding invertebrate communities shortly after large-scale fire disturbances. This study conducted on an unburned and a burned stream in the Colorado Front Range determined that invertebrate diversity decreases in the six months after a fire, and therefore supports similar findings from other studies. It is important to consider differences between the streams in these other studies, as different invertebrate community responses could be shaped by factors other than sediment input, such as changes in water chemistry.

Despite the ability to draw conclusions from this study, several imperfections in data collection and analysis require that the findings of this study be interpreted with some skepticism. Precipitation measurements made by the Colorado Climate Center were only available by city, not by the area of a watershed. Precipitation amounts recorded over entire watersheds would have been more accurate than amounts recorded over cities, so it is possible that the precipitation amounts listed for each month (See Figures 21 and 22) are somewhat exaggerated. Stream discharge data was also not available for the reach of Boulder Creek where invertebrate samples were taken because the gauging site is only operated from April to October. Annual discharge patterns between Boulder Creek and the Cache la Poudre are also different because Boulder Creek receives controlled releases of water from Barker Reservoir, and the Cache la Poudre does not receive substantial stream flow from artificial water bodies.

Comparisons of sediment size distributions between pre-fire and post-fire conditions were not easily made due to the lack of recently published data about sediment size distribution in Boulder Creek or the Cache la Poudre before the High Park Fire. Though findings from studies conducted before and after the Hayman Fire could be extrapolated and applied to these streams, differences in how sediments were sampled and measured may contribute to some differences in recorded sediment sizes. This makes it difficult to accurately compare pre- and post-fire sediment size distributions.

Additionally, the most recent comprehensive data from CDPHE about invertebrate communities in Boulder Creek and the Cache la Poudre are almost a decade old. This lack of intermediate invertebrate counts makes attributing changes in a community over a period of time complicated. Any disturbances that occurred since 2003 were not reflected in recorded changes in invertebrate communities, so the presence of invertebrates in 2012 cannot be directly attributed to the High Park Fire of 2012. It is possible that other factors such as beetle kill or decreases in stream flow were partially responsible for alterations to invertebrate communities between 2003 and 2012.

In general, this study highlights the need for more research to be conducted in a variety of areas. The current lack of consensus about the short-term effect of fires and sediment input on macroinvertebrate communities is somewhat helped by this study and its contributions to this body of knowledge. However, more studies on this scenario in the Colorado Front Range must be conducted in order to be able to fully understand what can be expected in the aftermath of a fire. Gathering invertebrate and sediment size data on a more regular basis would improve the quality of these studies in the future, and would help in understanding how invertebrate communities and sedimentation fluctuates from year to year. Monitoring benthic macroinvertebrates in streams is essential to ensuring that both aquatic ecosystems and water resources are healthy.

APPENDIX

Macroinvertebrate Counts

Boulder Creek Oct. 2003 Summary			
Subject Taxon	**Family**	**Order**	**Result Value**
Dicrotendipes	Chironomidae	Diptera	**4**
Phaenopsectra	Chironomidae	Diptera	**16**
Polypedilum	Chironomidae	Diptera	**8**
Cladotanytarsus	Chironomidae	Diptera	**2**
Micropsectra	Chironomidae	Diptera	**10**
Rheotanytarsus	Chironomidae	Diptera	**2**
Cricotopus	Chironomidae	Diptera	**10**
Nanocladius	Chironomidae	Diptera	**4**
Rheocricotopus	Chironomidae	Diptera	**2**
Simulium	Simuliidae	Diptera	**12**
Ceratopogonidae	Ceratopogonidae	Diptera	**2**
Fallceon quilleri	Baetidae	Ephemeroptera	**94**
Baetis insignificans	Baetidae	Ephemeroptera	**0**
Tricorythodes minutus	Leptohyphidae	Ephemeroptera	**1312**
Tubificidae	Naididae	Haplotaxida	**58**
Argia	Coenagrionidae	Odonata	**7**
Hydroptila	Hydroptilidae	Trichoptera	**94**
Dugesia	Dugesiidae	Tricladida	**18**
Sperchon	Sperchonidae	Trombidiformes	**2**
		SAMPLE SIZE	**1657**

Boulder Creek Oct. 2003					
Order	**Family Totals**	**Count**	**Tolerance Value**	**(#*tol)/total**	**FBI**
Diptera	Chironomidae	6	6	0.2096	**2.6620**
	Simuliidae	1	6	0.0434	
	Ceratopogonidae	0	6	0.0072	
Ephemeroptera	Baetidae	9	4	0.2265	
	Leptohyphidae	131	2	1.5807	
Haplotaxida	Naididae	6	8	0.2795	
Odonata	Coenagrionidae	1	9	0.0380	

Trichoptera	Hydroptilidae	9	4	0.2265
Tricladida	Dugesiidae	2	4	0.0434
Trombidiformes	Sperchonidae	0	6	0.0072
		166		

# EPT Taxa	3	**% Tolerant**	5.66
# Diptera Taxa	3	**% Intolerant**	79.04

Boulder Creek Site 1 Nov. 2012 Summary		
Ephemeroptera	Isonychiidae	2
	Polymitarcyidae	1
	Ephemeridae	1
	Ephemerellidae	9
	Caenidae	1
Trichoptera	Rhyacophilidae	1
	Polycentropodidae	18
	Hydroptilidae	3
	Lepidostomatidae	3
	Hydropsychidae	5
	Leptoceridae	1
	Psychomyiidae	39
Plecoptera	Taeniopterygidae	10
	Perlodidae	2
	Perlidae	4
	Pteronarcyidae	1
	SAMPLE SIZE	**101**

Boulder Creek Site 2 Nov. 2012 Summary

Order	**Family**	**Abundance**
Trichoptera	Hydroptilidae	4
	Psychomyiidae	4
	Polycentropodidae	8
	Hydropsychidae	1
Ephemeroptera	Ephemerellidae	2
	Oligoneuriidae	2
	Caenidae	2
	Baetidae	1
Plecoptera	Capniidae	4
	Taeniopterygidae	3
Diptera	Syrphidae	1
	Muscidae	1

Coleoptera	Hydrophilidae	1
	Amphizoidae	1
	SAMPLE SIZE	**35**

Boulder Creek Nov. 2012 Summary		
Trichoptera	Hydropsychidae	6
	Hydroptilidae	7
	Lepidostomatidae	3
	Leptoceridae	1
	Polycentropodidae	26
	Psychomyiidae	43
	Rhyacophilidae	1
Ephemeroptera	Baetidae	1
	Caenidae	3
	Ephemerellidae	11
	Ephemeridae	1
	Isonychiidae	2
	Oligoneuriidae	2
	Polymitarcyidae	1
Plecoptera	Capniidae	4
	Perlidae	4
	Perlodidae	2
	Pteronarcyidae	1
	Taeniopterygidae	13
Diptera	Syrphidae	1
	Muscidae	1
Coleoptera	Hydrophilidae	1
	Amphizoidae	1
	TOTAL SAMPLE SIZE	**136**

Boulder Creek Nov. 2012					
Order	**Family**	**Count**	**Tolerance Value**	**(#*tol)/total**	**FBI**
Trichoptera	Hydropsychidae	6	4	0.1765	**3.0515**
	Hydroptilidae	7	4	0.2059	
	Lepidostomatidae	3	1	0.0221	
	Leptoceridae	1	4	0.0294	
	Polycentropodidae	26	6	1.1471	
	Psychomyiidae	43	2	0.6324	
	Rhyacophilidae	1	0	0.0000	
Ephemeroptera	Baetidae	1	4	0.0294	

	Caenidae	3	7	0.1544
	Ephemerellidae	11	1	0.0809
	Ephemeridae	1	4	0.0294
	Isonychiidae	2	2	0.0294
	Oligoneuriidae	2	2	0.0294
	Polymitarcyidae	1	2	0.0147
Plecoptera	Capniidae	4	1	0.0294
	Perlidae	4	1	0.0294
	Perlodidae	2	2	0.0294
	Pteronarcyidae	1	0	0.0000
	Taeniopterygidae	13	2	0.1912
Diptera	Syrphidae	1	10	0.0735
	Muscidae	1	6	0.0441
Coleoptera	Hydrophilidae	1	5	0.0368
	Amphizoidae	1	5	0.0368
	Organism Dens.	136		

#EPT Taxa	19	**% Tolerant**	0.74
# Diptera Taxa	2	**% Intolerant**	63.97

Cache la Poudre Nov. 2003 Summary

Characteristic Name	Family	Order	Result Value
Microcylloepus pusillus	Elmidae	Coleoptera	**3**
Zaitzevia parvulus	Elmidae	Coleoptera	**1**
Optioservus	Elmidae	Coleoptera	**2**
Hexatoma	Tipulidae	Diptera	**12**
Simulium	Simuliidae	Diptera	**5**
Eukiefferiella	Chironomidae	Diptera	**2**
Cricotopus	Chironomidae	Diptera	**3**
Rheotanytarsus	Chironomidae	Diptera	**1**
Cardiocladius	Chironomidae	Diptera	**1**
Diamesa	Chironomidae	Diptera	**5**
Fallceon quilleri	Baetidae	Ephemeroptera	**2**
Acentrella insignificans	Baetidae	Ephemeroptera	**3**
Tricorythodes minutus	Leptohyphidae	Ephemeroptera	**11**
Paraleptophlebia	Leptophlebiidae	Ephemeroptera	**3**
Ephemerella	Ephemerellidae	Ephemeroptera	**25**
Epeorus	Heptageniidae	Ephemeroptera	**4**
Baetis tricaudatus	Baetidae	Ephemeroptera	**94**
Tubificidae	Naididae	Haplotaxida	**1**
Petrophila	Crambidae	Lepidoptera	**12**
Perlodidae	Perlodidae	Plecoptera	**4**

Claassenia sabulosa	Perlidae	Plecoptera	**4**
Cheumatopsyche	Hydropsychidae	Trichoptera	**3**
Brachycentrus occidentalis	Crachycentridae	Trichoptera	**1**
Oecetis	Leptoceridae	Trichoptera	**14**
Lepidostoma	Lepidostomatidae	Trichoptera	**3**
Hydropsyche	Hydropsychidae	Trichoptera	**58**
Chimarra utahensis	Philoptamidae	Trichoptera	**1**
Dugesia	Dugesiidae	Tricladida	**26**
		SAMPLE SIZE	**304**

Cache la Poudre EPT Metrics Nov-03

Order	Family	Count	Tolerance Value	(#*tol.)/total	FBI
Coleoptera	Elmidae	1	4	0.0800	**3.603333**
Diptera	Tipulidae	1	3	0.1200	
	Simuliidae	1	6	0.1000	
	Chironomidae	1	6	0.2400	
Ephemeroptera	Baetidae	10	4	1.3200	
	Leptohyphidae	1	4	0.1467	
	Leptophlebiidae	0	2	0.0200	
	Ephemerellidae	3	1	0.0833	
	Heptageniidae	0	4	0.0533	
Haplotaxida	Naididae	0	8	0.0267	
Lepidoptera	Crambidae	1	5	0.2000	
Plecoptera	Perlodidae	0	2	0.0267	
	Perlidae	0	1	0.0133	
Trichoptera	Hydropsychidae	6	3	0.6100	
	Crachycentridae	0	3	0.0100	
	Leptoceridae	1	4	0.1867	
	Lepidostomatidae	0	1	0.0100	
	Philoptamidae	0	3	0.0100	
Tricladida	Dugesiidae	3	4	0.3467	
	Organism Dens.	30			
% Tolerant	0		**# EPT Taxa**	12	
% Intolerant	13		**# Diptera Taxa**	3	

Cache la Poudre Site 1 Nov. 2012 Summary		
Trichoptera	Hydroptilidae	1
	Hydropsychidae	1
Diptera	Ceratopogonidae	27
	Empididae	2
	SAMPLE SIZE	**31**

Cache la Poudre Site 2 Nov. 2012 Summary		
Diptera	Empididae	48
	Muscidae	1
	Ceratopogonidae	5
Trichoptera	Psychomyiidae	3
	Hydropsychidae	22
	Philopotamidae	1
	Uenoidae	1
Ephemeroptera	Ephemerellidae	2
	Oligoneuriidae	1
	Isonychiidae	1
Plecoptera	Nemouridae	1
	Taeniopterygidae	1
	Capniidae	3
Megaloptera	Corydalidae	1
	SAMPLE SIZE	**91**

Cache la Poudre Nov. 2012 Summary		
Diptera	Ceratopogonidae	32
	Empididae	50
	Muscidae	1
Ephemeroptera	Ephemerellidae	2
	Isonychiidae	1
	Oligoneuridae	1
Megaloptera	Corydalidae	1
Plecoptera	Capniidae	3
	Nemouridae	1

	Taeniopterygidae	1
Trichoptera	Hydropsychidae	23
	Hydroptilidae	1
	Philopotamidae	1
	Psychomyiidae	3
	Uenoidae	1
	TOTAL SAMPLE	**122**

Cache la Poudre Nov-12					
Order	**Family**	**Count**	**Tolerance Value**	**(#*tol.)/total**	**FBI**
Diptera	Ceratopogonidae	32	6	1.5738	**5.0738**
	Empididae	50	6	2.4590	
	Muscidae	1	6	0.0492	
Ephemeroptera	Ephemerellidae	2	1	0.0164	
	Isonychiidae	1	2	0.0164	
	Oligoneuridae	1	2	0.0164	
Megaloptera	Corydalidae	1	0	0.0000	
Plecoptera	Capniidae	3	1	0.0246	
	Nemouridae	1	2	0.0164	
	Taeniopterygidae	1	2	0.0164	
Trichoptera	Hydropsychidae	23	4	0.7541	
	Hydroptilidae	1	4	0.0328	
	Philopotamidae	1	3	0.0246	
	Psychomyiidae	3	2	0.0492	
	Uenoidae	1	3	0.0246	
	Organism Dens.	122			

% Tolerant	0	**# EPT Taxa**	11
% Intolerant	0	**# Diptera Taxa**	3

Sediment Measurements

Table 1. Rainfall regimes in the western United States

Rainfall regimes are a combination of seasonal rainfall type and rainfall intensity condition. The observed ratio of summer to winter precipitation is for the data presented in the current paper

Seasonal type	Characteristics	Seasonal ratio: summer rainfall : winter rainfall		Rainfall intensity condition	2-year, 30-min rainfall intensity $I_{30}^{2\ year}$ (mm h^{-1})	
		Lower	Upper		Lower	Upper
ARIZONA	Winter and summer wet	0.3	1.1	EXTREME	>52	100
	Spring dry			HIGH	>36	52
	Fall (autumn) moist			MEDIUM	>20	36
PACIFIC	Winter maximum	0.02	0.3	HIGH	>36	52
	Summer minimum			MEDIUM	>20	36
				LOW	>15	20
SUB-PACIFIC	Winter wet	0.1	0.7	LOW	>10	20
	Spring moist					
	Summer and fall dry					
PLAINS	Winter minimum	0.6	2.0	EXTREME	>52	100
	Summer maximum			HIGH	>36	52
				MEDIUM	>19	36

Moody and Martin 2009

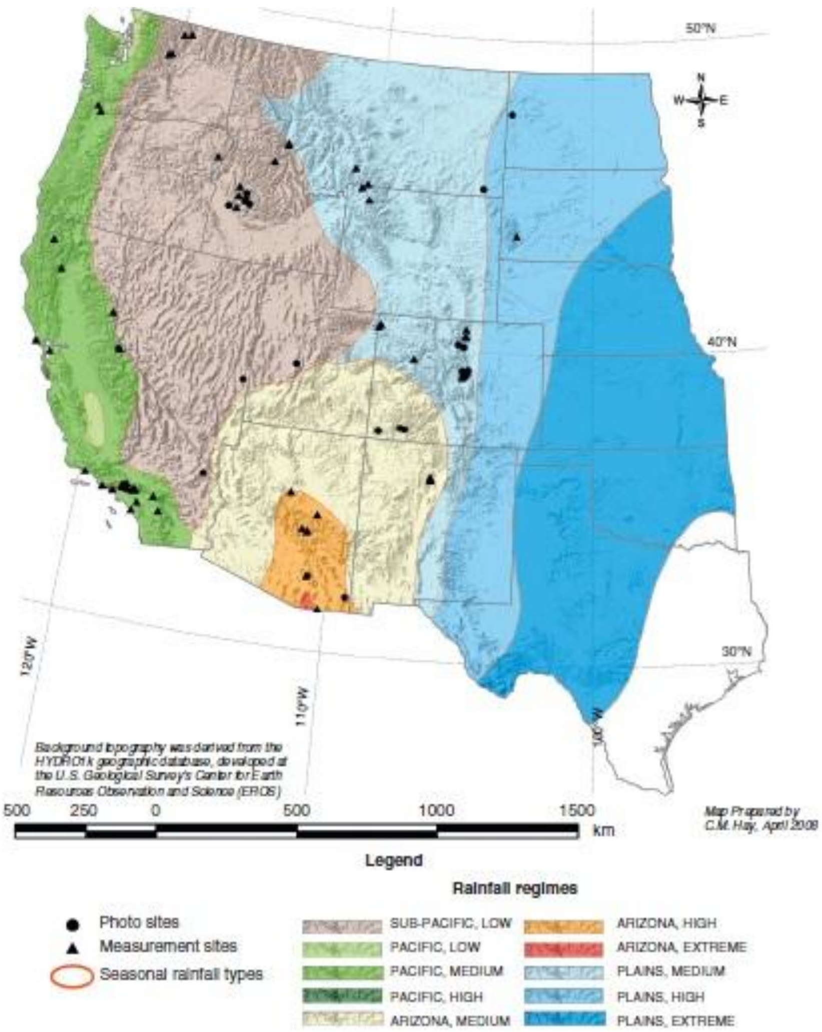


Fig. 1. Rainfall regimes in the western United States are a combination of rainfall types (ARIZONA, PACIFIC, SUB-PACIFIC, and PLAINS) and the degree (LOW, MEDIUM, HIGH, and EXTREME) of the 2-year 30-min rainfall intensity, $I_{30}^{2\,year}$. The boundaries of the rainfall types are slightly modified from those originally delineated by Kincer (1919) to conform to the isopluvial maps for the 2-year 30-min rainfall intensity, $I_{30}^{2\,year}$, published by Hershfield (1961). The locations of sites with measurements of sediment yield after wildfire published in the literature are shown as solid triangles, and sites with photographic evidence are shown as solid circles. The boundaries for the PACIFIC-HIGH are small. One is located on the coast south of San Francisco and the second is near Los Angeles but partially hidden by several solid triangles. The source of the hillshaded base map is the HYDRO1k database, US Geological Survey, Center for Earth Resources Observation and Science (EROS).

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Boulder Creek
November 2012

Sediment	y (in)	y (cm)	y (mm)
1	9.75	24.765	247.65
2	5.5	13.97	139.7
3	6.75	17.145	171.45
4	9.75	24.765	247.65
5	13	33.02	330.2
6	4.5	11.43	114.3
7	2.75	6.985	69.85
8	8.5	21.59	215.9

9	5.25	13.335	133.35
10	8.5	21.59	215.9
11	4	10.16	101.6
12	10.25	26.035	260.35
13	6.75	17.145	171.45
14	5.75	14.605	146.05
15	8	20.32	203.2
16	8.75	22.225	222.25
17	4.5	11.43	114.3
18	4.75	12.065	120.65
19	5	12.7	127
20	1.25	3.175	31.75
21	6.5	16.51	165.1
22	8.5	21.59	215.9
23	7	17.78	177.8
24	14.5	36.83	368.3
25	0.0625	0.15875	1.5875
26	10.5	26.67	266.7
27	5.25	13.335	133.35
28	0.25	0.635	6.35
29	0.5	1.27	12.7
30	5	12.7	127

Cache la Poudre November 2012			
Sediment	**y (in)**	**y (cm)**	**y (mm)**
1	4	10.16	101.6
2	7.75	19.685	196.85
3	5	12.7	127
4	0.0625	0.15875	1.5875
5	3.5	8.89	88.9
6	6	15.24	152.4
7	8.75	22.225	222.25
8	3.25	8.255	82.55
9	4	10.16	101.6
10	8.5	21.59	215.9
11	5	12.7	127
12	4	10.16	101.6
13	3.75	9.525	95.25
14	4.5	11.43	114.3
15	0.0625	0.15875	1.5875
16	3.5	8.89	88.9
17	3	7.62	76.2
18	8.5	21.59	215.9
19	3.5	8.89	88.9

20	4	10.16	101.6
21	6.75	17.145	171.45
22	5	12.7	127
23	6	15.24	152.4
24	3.25	8.255	82.55
25	5	12.7	127
26	0.0625	0.15875	1.5875
27	9.5	24.13	241.3
28	0.0625	0.15875	1.5875
29	6	15.24	152.4
30	5.25	13.335	133.35

Precipitation and Discharge

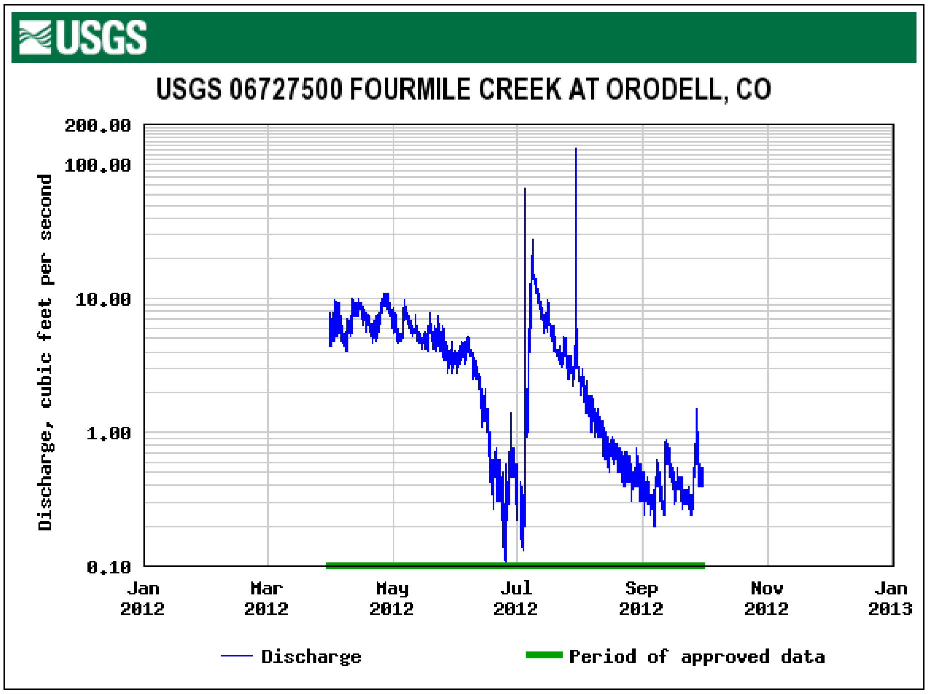
2003 Monthly Precipitation Amounts							
	May	**June**	**July**	**August**	**September**	**October**	**November**
Boulder	66.5	68.3	18.0	89.4	8.9	11.4	20.3
Fort Collins	57.4	28.4	9.7	86.4	7.4	4.8	8.4

2012 Monthly Precipitation Amounts							
	May	**June**	**July**	**August**	**September**	**October**	**November**
Boulder	45.2	9.7	154.4	9.1	57.7	36.6	7.1
Fort Collins	42.9	15.5	79.0	0.8	69.1	16.8	3.6

	2003 Max. Precip. Events			
	Boulder		**Fort Collins**	
	Date	**Amount (mm)**	**Date**	**Amount (mm)**
1	30-Aug	45.2	30-Aug	63.2
2	10-May	35.3	10-May	41.4
3	18-Aug	33.5	29-Aug	16.5

	2012 Max. Precip. Events			
	Boulder		**Fort Collins**	
	Date	**Amount (mm)**	**Date**	**Amount (mm)**
1	10-Jul	50.3	26-Sep	48.8

2	12-Sep	35.3	7-Jul	23.6
3	7-Jul	24.1	6-Jul	19.3
3 (tie)	8-Jul	24.1		



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