Multi-Scaled Approaches for Protecting Montana's Watersheds and Water Resources

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MULTI-SCALED APPROACHES FOR PROTECTING MONTANA’S WATERSHEDS AND WATER RESOURCES

By

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Portfolio

presented in partial fulfillment of the requirements of the degree of

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Multi-Scaled Approaches for Protecting Montana’s Watersheds and Water Resources

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The central theme carried among my four portfolio pieces is: using scientific and governmental approaches to conserve watershed health. For the purposes of this portfolio, I define watershed health as a very general term that describes the state of water quantity and quality that is available for human and ecosystem needs in a watershed. I see each of my portfolio pieces focusing on a different scale and method (i.e., science or government, including different levels of government, local, state and federal) for conserving watershed health. My first portfolio piece reviews water quality degradation caused by pharmaceuticals and personal care products (PPCPs) and potential solutions at the municipal level, such as mycoremediation. The second portfolio component addresses water quantity through assessing city-wide water conservation programs. Ultimately, I made several recommendations to Missoula city officials. My third portfolio piece describes my experience working in the field and laboratory for the Montana Department of Environmental Quality. This component of my portfolio identifies one of the ways the State of Montana has approached protecting watershed health. My final portfolio piece reflects on my internship with American Rivers, where I investigated how to use Wild and Scenic Rivers designation to protect rivers from select mining activities.
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Portfolio Introduction

My intention for attending graduate school was to prepare myself for a career protecting watersheds and water resources in the West. My main goals when I applied to the Environmental Studies program were to explore my academic interests, cultivate desirable skills, and increase my professional experience. Ultimately, I hoped that in completing the Environmental Studies program I would develop a greater understanding of my career aspirations. Through my time in the Environmental Studies program, and in preparing this portfolio, I learned that there several approaches to effectively conserve watershed health. Thus, the title of my portfolio is “Multi-Scaled Approaches for Protecting Montana’s Watersheds and Water Resources.” The central theme carried among my four portfolio pieces is: using scientific and governmental approaches to conserve watershed health. For the purposes of this portfolio, I define watershed health as a very general term that describes the state of water quantity and quality that is available for human and ecosystem needs in a watershed.

I see each of my portfolio pieces focusing on a different scale and method (i.e., science or government, including different levels of government, local, state and federal) for conserving watershed health. My first portfolio piece reviews water quality degradation and potential solutions at the municipal level. The second portfolio component addresses water quantity through assessing city-wide water conservation programs. My third portfolio piece describes my experience working in the field and laboratory for a state agency. This component of my portfolio identifies one of the ways the State of Montana has approached protecting watershed health. My final portfolio piece reflects on my internship where I investigated how to use federal legislation to conserve watershed health.

The first component of my portfolio is a literature review titled “Mycoremediation of Pharmaceuticals in Wastewater Irrigated Soils.” This literature review combines a paper written in Vicki Watson’s Watershed Conservation Ecology, with additional research on mycoremediation in Vicki’s Pollution Ecology class. The first half of the paper evaluates the environmental fate of pharmaceuticals and personal care products (PPCPs) entering the environment from the Missoula Wastewater Treatment Plant (WWTP) effluent. I determined that recalcitrant PPCPs like carbamazepine, sulfamethoxazole, and trimethoprim pose a risk to current watershed health because they persist in water and soil, bioaccumulate in plants, and negatively impact soil communities. The second half of the review considers mycoremediation as a tool to remediate environmental contamination from wastewater effluent. The information discussed in this literature review will be increasingly valuable, as water resources become scarcer and the prevalence of wastewater irrigation increases.

My second portfolio piece is a briefing paper I wrote for the City of Missoula that discusses water conservation approaches for municipal water systems. This paper was initiated during an independent study supervised by Robin Saha. The paper is titled, “An Overview and Assessment of Water Conservation Approaches for Municipal Water Systems: Informing a Water Conservation Program for the City of Missoula.” The purpose of this briefing paper was to assess different components of municipal water conservation programs of select mid-sized cities in the West. This assessment informed recommendations to the City of Missoula for initiating an effective and energy efficient water conservation program for the drinking water system. The
report focused on three different water conservation approaches: rate structures, rebates, and education and outreach. I examined three different cities’ or districts’ water conservation programs including, Bozeman, Montana, Westminster, Colorado, and the Eastern Municipal Water District of California. I also discussed the relationship between energy and water, in addition to other justifications for water conservation.

My third portfolio component is a reflection piece detailing my summer job with the Montana Department of Environmental Quality (DEQ). During July and August of 2016, I led a field crew for the Montana Stream Reference Project. My primary duty as crew leader was being responsible for the logistics of traveling between sites. The focus of the Stream Reference Project is to identify and provide descriptions of the least impacted streams in each of Montana’s ecoregions. This information provides the foundation for developing water quality standards. Our field work consisted of physical, chemical, and biological sampling. I learned how to perform all the sampling procedures except for macroinvertebrate and periphyton collection and sediment metals. The sampling I focused on was algal biomass, phytoplankton, and plant identification for the riparian assessment. Following the completion of our field work, I analyzed the algal samples collected over the summer for the Reference Project, as well as Vicki Watson’s Clark Fork River research. This analysis was completed under the supervision of my graduate advisor, Vicki Watson. Through these job experiences, I learned one of the ways the State of Montana has approached protecting watershed health, as well as comprehensive stream sampling and algal biomass analysis procedures.

The final component of my portfolio summarizes my work with American Rivers as a research intern. My supervisor for this internship was Kascie Herron. The purpose of my internship was to research the application of Wild and Scenic Rivers designation, as it relates to protecting rivers from mining activities. This paper analyzed and synthesized my research into a document that can be easily read by laypeople. In this analysis, I described how mining activities have been regulated, litigated and/or stopped in Wild and Scenic rivers by using the St. Joe River in Idaho, Tuolumne River in California, North Fork of the Flathead River in Montana, and the Chetco River in Oregon as examples. Based on my research and analysis, I concluded that Wild and Scenic designation can be a valuable tool for protecting rivers from select mining activities. In other words, federal designation can be used to preserve water quality and conserve watershed health.

Through the development of this portfolio and my course of study at the University, I defined my desired career path. My professional goal is to work for a private company, nonprofit organization, or a government agency in the West, ideally Washington, as a water resource planner. It is possible that this goal may change, however my desire to protect watershed health and preserve water resources will remain consistent. In preparing my portfolio and completing the program requirements, I believe that I have achieved the goals I set out to accomplish when I began the Environmental Studies program.
Part One

Mycoremediation of Pharmaceuticals in Missoula’s Wastewater Irrigated Soils
Mycorremediation of Pharmaceuticals in Missoula’s Wastewater Irrigated Soils


Abstract

The purpose of this paper is to explore the need and potential of mycoremediation to degrade recalcitrant PPCPs in wastewater irrigated soils, specifically pollutants that persisted in wastewater effluent and resisted degradation in Missoula’s Wastewater Treatment Plant (WWTP) process. A comprehensive literature review of credible sources was conducted to identify fungi capable of degrading carbamazepine, sulfamethoxazole, and trimethoprim. The literature review demonstrated that carbamazepine, sulfamethoxazole and trimethoprim persist in surface and ground water, adsorb to soil, and bioaccumulate in plants. These, and other pharmaceuticals pose environmental health risks, while the human health concerns are low or unknown. Therefore, treatment methods for pharmaceutical pollution problems, like mycorremediation, should be explored. Research demonstrated that several species of white-rot fungi successfully degraded carbamazepine and sulfamethoxazole. However, many of the studies demonstrating carbamazepine and sulfamethoxazole degradation used environmentally unrealistic conditions. Evidence for degradation of trimethoprim could not be found. In order to further assess the potential of mycoremediation at the Missoula poplar plantation and Garden City Compost, it is necessary to fill in the knowledge gaps presented in this paper.

Introduction

Humans are exposed to thousands of synthetic chemicals every day, some of that exposure occurs by using personal care products and pharmaceuticals (PPCPs). Cosmetics, soaps, pain relievers, antibiotics and contraceptives are just a few examples of PPCPs. These compounds and their metabolites are flushed down the drain daily, eventually making their way to wastewater treatment plants (WWTPs). Unfortunately, traditional and advanced wastewater treatment processes do not completely breakdown all PPCPs that enter the system. Generally, treated effluents are discharged into surface water. Wastewater effluents have been identified as the main source of PPCPs and their metabolites in rivers, lakes, reservoirs, aquifers, and drinking water supplies (WHO Working Group 2011). Effluent pollutants also enter the environment through agricultural practices, like wastewater irrigation.

Agriculture accounts for roughly 80 percent of the United States’ water use (USDA ERS 2015). Due to climate change, even more water is required to produce the food necessary for sustaining a growing population. In a conscientious effort to conserve water resources, farmers around the world are using alternative sources of irrigation water. One example of agricultural water conservation is the use of grey water, or treated wastewater effluent for irrigation. In this practice, edible crops are watered with recycled, treated water from wastewater treatment facilities. In Israel, about half of the country’s agriculture is sustained by grey water irrigation (Pelley 2014). This practice has spread across the world to other arid and semi-arid areas like Africa, Asia, Mexico, California, and Arizona (Pelley 2014).
While it is essential for humans to conserve water, given the increasing threats of climate change, water scarcity, and a growing population, practices like wastewater irrigation pose several human and environmental health concerns. In the United States, there are no federal standards for PPCPs in drinking water, surface water, or groundwater. As a result, human health and environmental concerns have been raised regarding exposure to low levels of PPCPs. Much of the current research only addresses acute exposure and does not take into account chronic contact, or synergistic effects of chemicals (Carter et al. 2014; Pelly 2014; Barnes et al. 2002; Kummerer 2008; Fatta-Kassinos et al. 2011; Ahmed et al. 2015; Boxall et al. 2006). Numerous studies have considered the environmental fate of some PPCPs in soil, groundwater and surface water, and living organisms (Focazio et al. 2008; Kummerer 2001; Furlong et al. 2003; Shenker et al. 2011; Kinney et al. 2006).

Although treated effluent is not being used to irrigate edible crops in Missoula, Montana, similar environmental concerns have been raised regarding the WWTP’s use of treated effluent to irrigate its poplar plantation, especially the negative consequences to the soil-community. The Missoula poplar plantation is managed by the Hybrid Energy Group and was designed with the purpose of reducing nutrient loading to the Clark Fork River. The poplar plantation occupies 180 acres of land, with 160 planted acres. As of 2015, 84,000 hybrid poplar trees are growing on the site. It is estimated that during the irrigation season, the poplar plantation will use 137.7 million gallons of treated effluent. This represents 5 percent of the total annual effluent discharged from the Missoula WWTP (Platt pers. comm.). Once the trees reach maturity, this number will grow to 8 percent (Platt pers. comm.). The goal of the plantation is to protect the water quality of the Clark Fork River, it is also possible that the poplar trees might act as a sink for PPCPs.

The growing practice of wastewater irrigation has resulted in an influx of research studies devoted to mycoremediation of common wastewater pollutants (Marco-Urrea et al. 2009; Golan-Rozen et al. 2011; Eibes et al. 2011; GuoXia-li et al. 2014). Mycoremediation falls within the category of bioremediation; bioremediation is the practice of using biological organisms to decontaminate polluted landscapes. Mycoremediation uses fungi to remove pollutants from contaminated sites. Some varieties of fungi adsorb pollutants, while others fully or partially degrade the chemical compounds. Ideally, the goal of mycoremediation is to decompose the toxic compounds into harmless constituents like water, carbon dioxide, and nitrogen (Pointing 2001).

Fungi break down organic matter, releasing nutrients that can be used by plants. White-rot fungi are a physiological grouping of fungi, generally blasdiomycetes, that can break down lignin (Pointing 2001). White-rot refers to the appearance of wood after it has been broken down by fungus, since removal of lignin “bleaches” the wood (Pointing 2001). White-rot fungi can metabolize many different compounds because they have non-specific intracellular and extracellular enzymes.

Fungi, especially white-rot fungi, have been used to remediate large-scale oil spills, and degrade munitions waste, pesticides, organochlorines, polychlorinated biphenyls, polycyclic aromatic hydrocarbons (PAHs), synthetic dyes, and plastics (Pointing 2001).
The purpose of this paper is to identify which chemicals are of particular concern to Missoula and explore the need and potential of using mycoremediation to degrade these recalcitrant PPCPs in wastewater irrigated soils at the Missoula poplar plantation. This paper will be valuable for irrigators using wastewater irrigation on edible crops, as well as irrigators using this method on inedible crops. The target audience of this paper is irrigators employing wastewater irrigation, in addition to wastewater treatment staff using this method, such as those at Missoula WWTP. A copy of this paper will be presented to Missoula WWTP staff, Hybrid Energy Group’s operator of the poplar plantation, and Cliff Bradley at Montana Microbial Products.

**Approach**

To achieve the purpose of this paper, the following objectives are addressed:

1. Conduct a comprehensive, systematic review of credible sources on mycoremediation of pharmaceuticals found in wastewater irrigated soils.
2. Use above to answer these specific questions:
   a. Which PPCPs have been found in treated municipal effluent in the U.S. and in Missoula?
      i. Which PPCPs are chemically recalcitrant and resistant to degradation throughout the Missoula WWTP treatment processes?
   b. Which recalcitrant chemicals present in Missoula’s effluent are chemicals of concern, and do these chemicals pose a threat to human health and/or the environment?
      i. What is the environmental fate of these compounds in surface water, groundwater, soil and sediment?
      ii. Do these compounds bioaccumulate in plant tissue?
      iii. Are there human health concerns associated with exposure to low levels of these compounds?
      iv. Does the presence of low concentrations of these chemicals present any environmental risks?
   c. Can fungi degrade these chemicals and minimize this threat?
      i. Which type of fungi are used in mycoremediation?
      ii. What mechanisms do these fungi use in degradation?
      iii. Will the parent compounds be completely degraded? Or could degradation of the original compounds result in the production of another harmful substance?
      iv. What conditions are necessary for effective mycoremediation?
3. Analyze/synthesize above information to answer these more complex questions:
   a. What are the areas of scientific consensus?
   b. What are the areas of scientific controversy and what factors contribute to the controversy?
   c. What are the information gaps? What studies are needed to fill the gaps?
4. Based on the above conclusions, I recommend potential studies and the most effective methods of managing PPCPs of concern at the Missoula WWTP poplar plantation.
In order to address these objectives, a variety of databases and search engines were used to find credible sources. Peer-reviewed journal articles, scholarly books, and U.S. government documents and websites were used as sources. A variety of search statements were used. After identifying the chemicals of concern for the Missoula WWTP by answering questions 2 a and 2 b, search statements focused on mycoremediation of carbamazepine, sulfamethoxazole, and trimethoprim. An example of these search statements includes: “mycoremediation of carbamazepine.” Based on preliminary search results, it became clear that narrowing the focus of my research to white-rot fungi was necessary. Consideration of papers was not limited to those solely from the United States because wastewater irrigation is a common global practice. Preference was given to studies conducted in 2000 or later, over older research papers.

Results

PPCPs found in treated effluent in the United States and Missoula, Montana

In 2009, the U.S. Environmental Protection Agency (EPA) studied the occurrence of contaminants of emerging concern in wastewater. A large number of PPCPs were tested for at nine publicly owned treatment works (POTWs), 77 in total. Of those chemicals, 44 PPCPs were detected in at least one POTW’s influent, and 33 compounds were present in at least one POTW’s effluent (U.S. EPA 2009). In this study, carbamazepine, sulfamethoxazole and trimethoprim persisted in the POTW’s effluent. The EPA analysis identified carbamazepine in 100 percent of the POTW influent samples. Carbamazepine was detected in 80 percent of the POTW effluent samples. Sulfamethoxazole was present in 100 percent of the POTW influent samples and in 88 percent of the POTW’s effluent samples (U.S. EPA 2009). Trimethoprim was detected in 100 percent of the POTW influent samples, but was only present in 33 percent of effluent samples (U.S. EPA 2009). Though trimethoprim was only detected in 3 of the 9 POTWs tested, the concentration of trimethoprim in the effluent was similar to that of the influent (U.S. EPA 2009).

In 2010, the Missoula WWTP had its influent and effluent analyzed for 24 PPCPs. The compounds tested for included stimulants, depressants, herbicides, estrogens, analgesics, antibiotics, anti-seizure, and sunscreen, among others. Carbamazepine, sulfamethoxazole and trimethoprim were found to persist throughout the treatment processes and were present in Missoula’s effluent at concentrations similar to influent concentrations; in other words, they resisted degradation (Table 1). These results were provided by Starr Sullivan, the Missoula WWTP’s manager. Unfortunately, he could not access the methods, QA/QC results, or other information necessary to determine the accuracy and precision of the results. Therefore, I am assuming these results are accurate and precise.

Nine of the 24 compounds analyzed by Missoula WWTP were not tested for in the EPA study. The compounds exclusively tested for at the Missoula WWTP include: DEET, diazepam, diethylstilbestrol, 17-alpha-ethylestradiol, hydrocodone, meprobamate, oxybenzone, pentoxifyline, and methadone (Table 1; U.S. EPA 2009). Overall, the Missoula study only tested a fraction of the PPCPs found at other WWTPs. The reason for selecting these PPCPs was not shared by Starr Sullivan.
It is important to note that estrogens represent an area of concern for environmental health, especially aquatic life. Several estrogens were also detected at very low levels in Missoula WWTP’s influent. But in most instances, these hormones were not detected in Missoula WWTP’s effluent (Table 1). In addition, the hormones studied in the POTWs were detected in most influent samples, but were not detected in effluent (U.S. EPA 2009). Therefore, estrogens will not be discussed further in this literature review.

Carbamazepine, sulfamethoxazole and trimethoprim will be the only chemicals discussed in this literature review because they were found to persist throughout the treatment processes and were present in Missoula’s effluent at concentrations similar to influent concentrations. In addition, these chemicals were of concern in the U.S. EPA study.

In order to demonstrate the need for remediation efforts at the Missoula poplar plantation, it is necessary to discuss the environmental fate of these chemicals in surface water, groundwater, sediment and soil, as well as the bioaccumulation of these compounds by plants. Determining the human health and environmental risks of exposure to these chemicals is also important. The next sections are devoted to exploring the environmental fate and risk of exposure to carbamazepine, sulfamethoxazole, and trimethoprim.

Chemicals of Concern in Missoula, Montana

CARBAMAZEPINE

Carbamazepine is an anti-epileptic/anti-seizure prescription medication. This type of medication acts on the central nervous system by decreasing the overall neuronal activity in an organism. Carbamazepine specifically acts by blocking voltage-dependent sodium channels of neurons (Kummerer 2008). Carbamazepine has carbonyl and amino functional groups. These polar functional groups make carbamazepine moderately hydrophilic. Carbamazepine’s solubility is 17.7 mg/L in water, with an octanol-water partition coefficient of 2.3-2.5 (Rodarte-Morales et al. 2011).

Interestingly, most of carbamazepine is metabolized. Only 1 to 5 percent of carbamazepine is excreted (Ternes 1998; Jjemba 2006; Khetan and Collins 2007). However, carbamazepine was detected at levels well above the reporting limit (0.001 μg/L in water) in the Missoula WWTP influent; concentrations ranged from 0.3-0.54 μg/L (Table 1). The concentration of carbamazepine barely differed after WWTP treatment. Effluents contained between 0.46-0.52 μg/L of carbamazepine (Table 1). The presence of carbamazepine in WWTP influent despite being mostly metabolized is likely due to the high use of carbamazepine; patients prescribed the drug use it every day for a lifetime (Khetan and Collins 2007).

Environmental Fate of Carbamazepine in Surface Water and Groundwater

A 2001 U.S Geological Survey (USGS) study looking at a network of 25 groundwater and surface water sources of public drinking water supplies found that at least one of the 124 compounds studied was detected in 96 percent of the samples (Focazio et al. 2008). Roughly 74 compounds were present in the water samples; 43 compounds were detected in groundwater
sources, while 69 compounds were detected in surface water samples (Focazio et al. 2008). Carbamazepine was present in 21.6 percent of samples, sulfamethoxazole was found in 2.7 percent of samples, and trimethoprim was detected in 6.8 percent of samples (Focazio et al. 2008).

In 2003, the USGS performed a national groundwater reconnaissance and found that sulfamethoxazole was the most commonly detected (23 percent) human pharmaceutical at the 47 sites throughout the country (Kummerer 2008). The 2001 USGS national reconnaissance of untreated drinking water sources found that carbamazepine was the only human pharmaceutical analyzed that was among the 10 most frequently detected organic wastewater compounds (OWCs) (Focazio et al. 2008).

Photodegradation (decomposition of a compound by radiant energy) is a pathway that degrades PPCPs in surface water. Carbamazepine is fairly resistant to direct photolysis, a type of photodegradation that requires the absorption of light by the compound to transform it. Calisto et al. (2011) estimates that it would take between one and four weeks of unobscured sunlight to completely breakdown carbamazepine (9.5 mg/L in water).

Environmental Fate of Carbamazepine in Soil and Sediment

In 2002, USGS examined 30 streambed sediment and overlying water-column samples from 12 sites throughout the United States. In this study, 17 PPCPs were analyzed; 10 compounds were found in sediments, while 14 were detected in the overlying water samples. Carbamazepine was more evenly distributed between sediment and water samples than the other PPCPs studied (Furlong et al. 2003).

Shenker et al. (2011) demonstrated the relationship between organic matter and carbamazepine uptake by plants. In this study, cucumbers were grown in soil treated with carbamazepine. Concentrations of carbamazepine in the soil’s aqueous phase were greatest in sandy soil, with an organic content of 1.2 ± 0.06 percent (13.98 µg/L). Cucumbers grown in peat (32.6 ± 0.62 percent organic matter) had the lowest concentration of carbamazepine in the soil’s aqueous phase (0.57 µg/L). The concentration of carbamazepine in the soil’s aqueous phase is negatively correlated to organic matter in the soil (Shenker et al. 2011).

Kinney et al. (2006) studied three sites in Colorado; the organic content at each site from 0-30 cm was below one percent. Each study site was irrigated with reclaimed wastewater. The concentration of PPCPs in the wastewater was monitored and soil core samples were taken from the sites monthly. Carbamazepine, sulfamethoxazole and trimethoprim were detected in soils at one or more sample sites even before irrigation (Kinney et al. 2006). All three pharmaceuticals were present throughout the study at each study site. Concentrations of carbamazepine consistently increased in the soil over time with irrigation (Kinney et al. 2006). Carbamazepine accumulated to the greatest extent, and it also has the lowest water solubility of the three chemicals. In contrast, Carter et al. (2014) found no significant difference between concentrations of carbamazepine in soil (one percent organic content) at the beginning of the experiment and after 40 days of irrigation with prepared solvent. In other words, carbamazepine did not accumulate in the soil samples. These differences may be attributed to differences in
experimental conditions.

**Bioaccumulation of Carbamazepine by Plants**

Shenker et al. (2011) illustrated the relationship between organic matter and carbamazepine by studying how much carbamazepine cucumber plants bioaccumulated in different soil compositions. Cucumbers grown in sandy soil with the lowest organic content (1.2 ± 0.06 percent) bioaccumulated carbamazepine to the greatest extent (25.6 μg/kg fresh weight). The concentration of carbamazepine in the sandy soil’s aqueous phase was also the highest, at 13.98 μg/L. Cucumbers grown in peat (32.6 ± 0.62 percent organic matter) had the lowest concentration of carbamazepine in the fruit (6.4 μg/kg fresh weight) and the soil’s aqueous phase (0.57 μg/L). Shenker et al. (2011) demonstrated that there is a negative correlation between organic matter in soil and bioaccumulation of carbamazepine in plants. In other words, the lower the soil’s organic matter content, the greater the bioaccumulation of carbamazepine in cucumber plants. Interestingly, while more bioaccumulation occurred in sandy soil, the bioaccumulation factor was lower than in peat. The bioaccumulation factor was calculated in this study as the ratio between the concentration of carbamazepine in the plant (fresh weight) and its concentration in the soil (Shenker et al. 2011).

Tomer Malchi and colleagues tracked 14 pharmaceuticals found in irrigation water used for edible crops in Israel, as cited in Pelley (2014). Scientists used the same water used by local farmers to address the issue of realistic compound concentrations. Caffeine, lamotrigine and carbamazepine were the only compounds detected in sweet potatoes and carrots; concentrations in the vegetables ranged from 0.013 ng/g to 4.130 ng/g. Malchi attributes his findings to these nonionic organic molecules being able to effectively cross the cell membranes, making them more likely to be taken up by plant roots (Pelley 2014).

Carbamazepine concentrates and accumulates to greatest extent in mature leaves compared to the stem and roots (Shenker et al. 2011; Carter et al. 2014). This suggests that carbamazepine may be transported in plants by water mass flow (Shenker et al. 2011). It has been hypothesized that in neutral chemicals, like carbamazepine, hydrophobicity is the most important chemical property associated with chemical uptake in plants from soil. Carbamazepine is moderately hydrophilic, allowing for easier translocation through the roots of the plant to the leaves. This accounts for the high concentration of carbamazepine (52 μg/g) in the mature leaves of the plants (Carter et al. 2014).

**SULFAMETHOXAZOLE AND TRIMETHOPRIM**

Sulfamethoxazole is part of the group of antibiotics called sulfonamides. Sulfamethoxazole is used to treat urinary tract infections and bronchitis, however, because of overuse and bacterial resistance sulfamethoxazole must be used in concert with trimethoprim (National Center for Biotechnology Information date unknown). Trimethoprim is an antibacterial agent that is typically used with various sulfonamide antibiotics. According to Just et al. (unpub), roughly 15 percent of sulfamethoxazole is fully excreted following ingestion. Other studies demonstrate similar values, stating that between 6 and 39 percent of sulfamethoxazole is fully excreted as the parent compound (Anderson et al. 2002; Jjemba 2006). However, Anderson et al. (2002) notes
that 55 to 75 percent of sulfamethoxazole is excreted as a metabolite. Between 30 and 69 percent of trimethoprim is fully excreted (Anderson et al. 2002; Jjemba 2006).

The water solubility of sulfamethoxazole is 610 mg/L (Rodarte-Morales et al. 2011). Sulfamethoxazole also has an octanol-water partition coefficient of 0.5-0.9 (Rodarte-Morales et al. 2011). Therefore, sulfamethoxazole has a greater affinity for water than does carbamazepine, because it is more hydrophilic. Sulfamethoxazole was recorded in Missoula’s influent at levels ranging from 1.6-2.4 µg/L (Table 1). Studies detected sulfamethoxazole in the treated effluent between 0.075-1.1 µg/L (Table 1). The reporting limit for sulfamethoxazole was 0.001 µg/L in water. Similar to carbamazepine, sulfamethoxazole was present in Missoula’s WWTP effluent at one of the greatest concentrations observed in the tested chemicals. Trimethoprim is fairly water soluble (400 mg/L), and is hydrophilic like sulfamethoxazole (0.64-1.115 octanol-water partition coefficient) (National Center for Biotechnology Information 2017). Like sulfamethoxazole, trimethoprim was detected in Missoula’s influent at a concentration of 1.0 µg/L (Table 1). Following treatment, the concentration of trimethoprim in the effluent ranged from 0.49-0.88 µg/L (Table 1).

Environmental Fate of Sulfamethoxazole and Trimethoprim in Surface Water and Groundwater

In a 1999-2000 national reconnaissance of streams throughout the United States, 95 PPCPs were analyzed; seven pharmaceuticals were detected in more than 10 percent of the samples. Sulfamethoxazole and trimethoprim were among these commonly detected compounds, the former was found in 19 percent of the sites, the latter in approximately 30 percent of the sites (Barnes et al. 2002).

Focazio et al. (2008) published a 2001 USGS study that analyzed groundwater and surface water sources for public drinking water supplies. Sulfamethoxazole was detected in 20 percent of the groundwater sites (Focazio et al. 2008).

According to the USGS, even though sulfamethoxazole readily degrades in streams, there is a risk of its continued persistence in groundwater because photodegradation cannot occur (USGS accessed 2015). Direct and indirect photolysis are different types of photodegradation. Direct photolysis does not significantly degrade trimethoprim, though indirect photolysis plays an important role in transforming the compound (Luo et al. 2012). Indirect photolysis is a result of the interaction between PPCPs and reactive oxygen species (ROS), created by dissolved organic matter (Luo et al. 2012).

Environmental Fate of Sulfamethoxazole and Trimethoprim in Soil and Sediment

Barnes et al. (2002) found that sulfamethoxazole was detected more frequently in water samples than sediment. This suggests that sulfamethoxazole has a higher affinity for water than sediment, compared to carbamazepine. With that said, Kummerer (2008) noted that quinolones, tetracyclines, and sulfonamides (e.g., sulfamethoxazole) are strongly sorbed (attached to soil particles) by organic matter and can accumulate in soils. However, the pharmacological effectiveness of the compounds after sorption to soil particles is unknown. Also, Kinney et al. (2006) demonstrated accumulation of sulfamethoxazole and trimethoprim in soil samples over
time, but less consistently than carbamazepine accumulation (Kinney et al. 2006). These studies suggest that all three compounds persist in soil, especially in high organic matter soils, due to strong sorption.

According to Kinney et al. (2006), a variety of factors will determine whether groundwater contamination following effluent irrigation is likely. These factors include, concentration of pharmaceuticals in irrigation water, soil and sorption characteristic, irrigation frequency, precipitation, ability of soil microfauna to degrade PPCPs, depth to water table, and physical properties of soil between 30 cm soil surface and the water table (Kinney et al. 2006). Carbamazepine is less mobile in soils with high organic content because it sorbs to the soil particles (Fatta-Kassinos et al. 2011). When organic matter is low, carbamazepine, sulfamethoxazole, and trimethoprim are found in high concentrations in the soil’s aqueous phase (Shenker et al. 2011).

Bioaccumulation of Sulfamethoxazole and Trimethoprim by Plants

Fewer studies have addressed the bioaccumulation of sulfamethoxazole and trimethoprim by plants, though Ahmed et al. (2015) found high levels of tetracyclines and sulfonamides in the nonedible parts of cucumber, cherry tomato, and lettuce. Boxall et al. (2006) grew lettuce and carrot plants in soil spiked with trimethoprim at environmentally relevant concentrations (1 mg/kg dry weight) until the plants reached maturity (103 days for lettuce and 152 days for carrots). This study found that trimethoprim does bioaccumulate in the lettuce leaves and carrots. However, the BCF for lettuce and carrots relative to the soil was less than one. Similarly, the BCF for lettuce and carrots relative to the soil’s aqueous phase was less than one (Boxall et al. 2006). Based on this finding, Boxall et al. (2006) determined that the threat of trimethoprim bioaccumulation in lettuce leaves and carrots due to chronic exposure is low.

Not all plants uptake PPCPs, or the same compound, in the same way. Influential factors include, root growth, rates of transpiration, size and shape of leaves, as well as the lipid content of the plant. Other factors are soil composition and the mixture of PPCPs present (Carter et al. 2014; Shenker et al. 2011).

Human Health and Environmental Risks Associated with Chemicals of Concern

Acute and Chronic Toxicity in Humans

Due to the presence of low concentrations of PPCPs in the environment, many concerns have been raised about the human risk of exposure to these commonly found compounds in wastewater used to irrigate edible crops. Much of the research only addresses acute exposure to singular compounds, rather than chronic exposure to multiple compounds at one time. It is important to note that these concerns are not applicable to the Missoula WWTP poplar plantation because it is unlikely humans will consume poplar leaves; however, this information will be valuable to irrigators employing wastewater irrigation for edible crops.

An example of this is the Acceptable Daily Intake (ADI) value of chemical compounds. The acceptable daily intake (ADI) value can be calculated to determine the amount of a PPCP that can be safely consumed without substantial human health risk. World Health Organization
WHO used three different principles for deriving ADIs of the compounds that were considered in their drinking water study (Table 2).

According to Carter et al. (2014), if edible crops were grown in soil contaminated with PPCPs (i.e., carbamazepine) at the levels used in their study (1 mg/kg in soil), then human consumption would not exceed the ADI. Ahmed et al. (2015) grew cucumbers, cherry tomatoes, and lettuce in soil that was irrigated with sulfamethoxazole to concentrations 5, 10, and 20 mg/kg of soil. This study found that sulfamethoxazole in the fruits was below the ADI (0-50 μg/kg body weight per day for sulfonamides) (Ahmed et al. 2015). As determined by the average adult consumption of plant material, and the potential daily intake of pharmaceuticals tested, Boxall et al. (2006) calculated the estimated daily exposure to trimethoprim. According to these calculations, exposure from consumption of plant materials contaminated with trimethoprim would account for approximately 10 percent of the ADI for trimethoprim. Based on the study by Shenker et al. (2011), daily consumption of 200 g of contaminated cucumbers would result in ingestion of 200 ng of carbamazepine daily. This level is much lower than the minimum therapeutic dose (70 mg/day per 70 kg), which is the lowest dosage of a compound that is therapeutically effective.

While PPCPs are often found in concentrations substantially lower than the ADI and minimum therapeutic dose, research has not been performed on the effect of long-term exposure to chemicals found at these low concentrations. Furthermore, in these studies, PPCPs were tested individually. Researchers did not account for the interaction between hundreds of chemicals humans are exposed to at one time, or over a lifetime.

In addition to the ADI, the European Food Safety Authority uses the Threshold of Toxicological Concern (TTC) to establish “safe levels” of chemicals in foods, for those that lack substantial data (Pelley 2014). It is unclear whether these “safe levels” are based on acute or chronic exposure. Based on the amount of chemicals found in the vegetables during an Israeli study, researchers determined that an adult would have to consume hundreds of kilograms of sweet potatoes or carrots to reach the TTC value for caffeine or carbamazepine (Pelley 2014).

Due to the low concentrations of PPCPs found in foods and drinking water, the short-term human risk of exposure is not high. However, there is a significant risk of allergic reactions among sensitive members of the population (Fatta-Kassinos et al. 2011).

**Acute and Chronic Toxicity in the Environment**

A primary concern when introducing PPCPs in the environment is that the drugs are still pharmacologically active and can act on non-human organisms. This concern is attributed to evolutionarily conserved receptors, biochemical pathways, and enzymes present in non-human organisms (Kummerer 2008). While the levels of PPCPs present in the environment are below the therapeutic dose for humans, other organisms may be more sensitive. In addition, it is possible that PPCPs may act in unknown and devastating ways once in the environment, even at low levels. If organisms like bacteria, algae, and zooplankton are harmed by PPCPs in the environment, there is the potential for severe damage to the natural equilibrium of the system (Kummerer 2008). Bacteria, algae, and zooplankton serve as the foundation of the food chain,
and if those organisms are harmed or reduced, organisms that are higher up in the food chain will also experience negative effects.

Much of the research investigating the environmental risks of PPCPs has been focused on acute toxicity. It has been found that carbamazepine is toxic to aquatic organisms at concentrations of 100 mg/L in solution (Kummerer 2008). Though, this concentration is higher than those generally observed in wastewater effluent.

Also, Thomulka and McGee (1993) studied the toxicity of five different antibiotics in relation to *Vibrio harveyi* using bioassays. One bioassay assessed acute toxicity, using luminescence as an endpoint, while the second looked at chronic toxicity, using reproduction as an endpoint. Nearly no negative effects were seen in the acute toxicity scenario, but a toxic effect from long-term exposure was demonstrated by most of the antibiotics (Thomulka and McGee 1993). In addition, De Liguoro et al. (2009) showed that the 48-hour EC$_{50}$ (effective concentration) of *Daphnia magna* immobilization for trimethoprim was 149 mg/L in artificial *Daphnia* medium. This concentration is much higher than what is observed in the environment. Available research suggests that PPCPs are unlikely to cause acute toxicity at levels observed in the environment at present. In the case of wastewater effluents, the concentrations of PPCPs are below acute toxicity levels (Kummerer 2008). The concentrations found in the aquatic environment are $10^3$-$10^7$ lower than the known LC$_{50}$ (lethal concentration) or EC$_{50}$ (effective concentration) values (Kummerer 2008).

Antibiotics can also negatively impact soil-dwelling organisms and communities. For instance, antibiotics can alter an organism’s ability to degrade organic matter in the soil (Kummerer 2008). In addition, Underwood et al. (2011) demonstrated that subtherapeutic levels of sulfamethoxazole cause negative health effects on native soil bacteria populations. When soil bacteria populations were treated with concentrations of 1 µg/L sulfamethoxazole in water, bacterial cell growth was delayed, denitrification was hindered, and the community composition changed (Underwood et al. 2011). Sediment composition plays a large role in the particular effect of a PPCP on the soil populations, because soil composition determines the extent of sorption (Kummerer 2008). However, antibiotics in soil can lose their antimicrobial activity because they are bound to sediment particles. Antibiotics can also form complexes with ions in the soil (Kummerer 2008). It should be noted that these findings are not accepted by all researchers (Kummerer 2008).

In addition, Ahmed et al. (2015) showed that tetracyclines and sulfonamide antibiotics at concentrations 5, 10, and 20 mg/kg of soil hindered plant growth in cucumber, cherry tomato, and lettuce seedlings. In contrast, Carter et al. (2014) found that plant growth was not significantly impaired by 1 mg/kg of carbamazepine in soil.

In a study investigating the effect of pharmaceuticals on arbuscular mycorrhizal fungi (AMF), Hills et al. (2008) showed that sulfamethoxazole and atorvastatin were more phytotoxic than doxycycline, carbamazepine, and 10 other veterinary and human pharmaceuticals. The EC$_{50}$ for sulfamethoxazole on hyphal growth and spore production is 45 µg/L in M-medium (Hills et al. 2008).
Antibiotic Resistance

The overuse and mismanagement of antibiotics in humans and animals has led to increased populations of antibiotic resistant bacteria. Antibiotic resistance is of particular concern because it reduces the effectiveness of antibiotics, which play a vital role in health care. Antibiotic resistance has been observed in bacteria present at WWTPs (Negreanu et al. 2012; Kummerer 2008). Czekalski et al. (2012) demonstrated that treated wastewater effluent contained greater proportions of multi-resistant bacteria than influent; bacteria exhibited resistance to sulfamethoxazole and trimethoprim. Therefore, antibiotic resistant genes enter the environment through discharge of effluent into surface water and when the effluent is land applied. For example, sulfonamides and trimethoprim resistant bacteria have been identified in some U.S. rivers (Khetan and Collins 2007).

Beginning in the 1980s, resistant bacteria were detected in drinking water (Kummerer 2008). Antibiotic resistant bacteria were also found on plants irrigated with contaminated water (Kummerer 2008). Negreanu et al. (2012) performed a study comparing antibiotic resistant bacteria and genes present in soils irrigated with freshwater and treated wastewater effluent. Four study plots were observed. One plot was irrigated for six years, two were irrigated for 12 years, and the fourth was irrigated for 15 years. This study found that the levels of resistant bacteria and resistant genes in soil irrigated with treated effluent was nearly identical to those soils irrigated with freshwater. These results indicate that land application of irrigated wastewater will not substantially add to antibiotic resistance in soil bacteria. Negreanu et al. (2012) suggests that bacteria present in wastewater are unable to compete with other bacteria or survive in the soil climate.

Degradation of Carbamazepine, Sulfamethoxazole and Trimethoprim

This literature review demonstrates that land application of wastewater effluent will likely cause some pharmaceuticals to accumulate in the soil at Missoula’s poplar plantation and the presence of pharmaceuticals in the environment, even at low levels, can negatively impact soil-dwelling organisms (Kinney et al. 2006; Fatta-Kassinos et al. 2011; Shenker et al. 2011; Kummerer 2008; Underwood et al. 2011). For these reasons, it is important to evaluate the effectiveness of PPCP mycoremediation at the Missoula poplar plantation. In addition, the uncertain human health risks associated with chronic exposure to low levels of pharmaceuticals provide incentive for researchers around the world to explore mycoremediation of wastewater irrigated soils for edible crops. The remainder of this section assesses the effectiveness of fungi at degrading carbamazepine, sulfamethoxazole and trimethoprim.

Marco-Urrea et al. (2009) assessed the effectiveness of four types of white-rot fungi (Trametes versicolor, Irpex lacteus, Ganoderma lucidum, Phanerochaete chrysosporium) at degrading 10 mg/L of carbamazepine, ibuprofen and clofibric acid in liquid media. This study found that all four varieties of white-rot fungi degraded ibuprofen. All but P. chrysosporium degraded ibuprofen completely. T. versicolor was the only fungus able to degrade clofibric acid. In addition, T. versicolor was the most effective fungi at breaking down carbamazepine, exhibiting 57 percent removal. The next best variety was G. lucidium, which removed 46 percent of carbamazepine. When T. versicolor was added in pellet form, the effectiveness of degradation
increased to 70 percent. Marco-Urrea et al. (2009) did not determine if these differences in effectiveness were statistically significant.

Golan-Rozen et al. (2011) found that of the three *Pleurotus ostreatus* fungi strains studied (F6, N001, PC9), PC9 metabolized the greatest amount of carbamazepine (99 percent) in liquid culture. Rodarte-Morales et al. (2011) reported similar results for carbamazepine degradation. Within the first week of the experiment, *Bjerkandera* sp. R1, *Bjerkandera adusta* and *P. chrysosporium* only degraded 33 percent of carbamazepine added. However, by the end of the two week testing period, carbamazepine was completely degraded in each of the fungal treatments (Rodarte-Morales et al. 2011).

Rodarte-Morales et al. (2011) also tested the effectiveness of the three species of fungi on sulfamethoxazole in sterile environment. After four days, *P. chrysosporium* degraded sulfamethoxazole to the greatest extent (32 percent) (Rodarte-Morales et al. 2011). At the study’s completion, sulfamethoxazole was fully metabolized by all three fungi (Rodarte-Morales et al. 2011).

Eibes et al. (2011) isolated versatile peroxidase (VP) from the white-rot fungi, *B. adusta*. This study also tested VPs degradation ability on several different pharmaceuticals (*in vitro*), including carbamazepine and sulfamethoxazole. Between 64 and 80 percent of sulfamethoxazole was degraded by VP over 7 hours, while no carbamazepine was removed.

A similar magnitude of sulfamethoxazole degradation was documented in GuoXia-li et al. (2014). At a concentration of 10 mg/L in liquid medium, *P. chrysosporium* metabolized 53 percent of sulfamethoxazole in 24 hours and 74 percent by the end of 10 days (GuoXia-li et al. 2014).

Rodríguez-Rodríguez et al. (2010) studied the effectiveness of using *T. versicolor* to degrade carbamazepine (approximate concentration of 0.067 mg/g dry solid) in bioslurry and solid-phase sludges. Rodríguez-Rodríguez et al. (2010) found that *T. versicolor* transformed 57 percent of carbamazepine in 24 hours in bioslurry cultures; a smaller amount of carbamazepine was degraded in the solid-phase sludge (48 percent) (Rodríguez-Rodríguez et al. 2010).

Rodriguez-Rodriguez et al. (2011) expanded upon the 2010 experiment by looking at the biodegradation of solid-phase sludge by *T. versicolor*. This treatment was performed on sterilized sludge, with environmentally relevant pollutant concentrations in test tubes. The initial concentration of carbamazepine in the raw sludge was 25.6 ng/g. This concentration was reduced by 43 percent to 9.1 ng/g after *T. versicolor* treatment after 42 days of inoculation.

In addition to removal of pharmaceuticals, Rodriguez-Rodriguez et al. (2011) assessed the toxicity of the treated sludge compared to the raw sludge. *Daphnia magna* 24–48 h acute immobilization test showed a reduction in toxicity units and increase in 24-hr and 48-hr EC50 for sludge treated with *T. versicolor*. Bioluminescence inhibition of *Vibrio fischeri* indicated that treated sludge no longer inhibited bioluminescence. The 24-hr EC50 for raw sludge was 0.005811 g/mL, after treatment the EC50 improved to complete non-toxicity. The final ecotoxicity experiment evaluated seed germination to test for phytotoxicity of raw and treated sludge.
Results demonstrate that treatment of sludge improved seed germination for lettuce (93 percent), pepper (72 percent), cucumber (44 percent) and tomato (95 percent).

Examples demonstrating the degradation of trimethoprim by white-rot fungi could not be found in this literature review.

**Mechanisms of Degradation**

White rot fungi are often used for mycoremediation because they contain extracellular, lignin-modifying enzymes. These enzymes include laccases and peroxidases (i.e., lignin peroxidase, manganese peroxidase, versatile peroxidase). Laccases use oxygen (O$_2$) as an electron acceptor, while peroxidases catalyze the reduction of peroxides (H$_2$O$_2$) (Bansal and Kanwar 2013). Manganese peroxidase is unique because it uses Mn$^{2+}$ as the electron donor. Versatile peroxidase can effectively act in the presence and absence of Mn$^{2+}$, hence the name versatile peroxidase. Through these processes, white-rot fungi are able to degrade lignin, oil and other compounds, by removing electrons from the molecule (Bradley pers. comm.). However, the lignin-modifying system is not the only mechanism fungi use to degrade pollutants.

White-rot fungi also employ the cytochrome P450 system, a group of intracellular enzymes, in degradation. The alternative enzymatic system was identified when fungi were found to degrade pollutants in the presence of nitrogen (Yadav and Reddy 1992). This suggests an additional metabolic pathway to the lignin-modifying system. The cytochrome P450 system induces hydroxilations, heteroatom oxygenation, dealklation, epoxidation of carbon-carbon double bonds, reduction, and dehalogenation (Bernhardt 2006).

Cytochrome P450 enzymes are also present in humans. This enzymatic system metabolizes medications and toxic substances present within the human body; cytochrome P450 enzymes represent 70 to 80 percent of the enzymes used in drug metabolism (Genetics Home Reference 2016). A single species of fungi can have over 100 cytochrome genes, while humans only express 57 cytochrome genes (Kelly and Kelly 2013). Scientists have identified about 150 cytochrome genes in *P. chrysosporium*, although only a few are associated with functions known to be useful. This is likely because research on cytochrome P450 enzymes in fungi is fairly limited, though the study has expanded (Kelly and Kelly 2013).

As noted previously, white-rot fungi can metabolize carbamazepine, either partially or fully. As a result, researchers have conducted many studies focused on determining the mechanisms responsible for fungal degradation of carbamazepine (Marco-Urrea et al. 2009; Golan-Rozen et al. 2011). The transformation of carbamazepine occurs by both intracellular enzymes and extracellular enzyme systems.

Marco-Urrea et al. (2009) tested *T. versicolor*'s ability to degrade ibuprofen, clofibric acid, and carbamazepine when cytochrome P450 enzymes were inhibited. Results show that degradation of carbamazepine and clofibric acid was depressed by more than half when the cytochrome P450 inhibitor was added to the media (Marco-Urrea et al. 2009). This suggests that although extracellular enzymes act on carbamazepine, intracellular enzymes (i.e., cytochrome P450 system) also play an important role in breaking down carbamazepine and clofibric acid. In
contrast, *T. versicolor* fully degraded ibuprofen, even when cytochrome P450 was inhibited (Marco-Urrea et al. 2009).

Eibes et al. (2011) also supports this conclusion. When testing VP’s effectiveness on carbamazepine, none of the compound was metabolized, indicating that cytochrome P450 is involved in the degradation of carbamazepine.

In the same experiment, up to 80 percent of sulfamethoxazole was metabolized by VP, hence extracellular enzymes are an important pathway in degradation of sulfamethoxazole (Eibes et al. 2011). A study conducted by GuoXia-li et al. (2014) also deduced that extracellular enzymes play a role in degrading sulfamethoxazole, specifically laccase.

Trimethoprim will not be discussed because the literature review did not produce any experiments where trimethoprim was tested.

**Toxicity of Metabolites Created**

It is important to understand the toxicity of degradation products created by mycoremediation. If the toxicity of metabolites exceeds the toxicity of parent compounds, then mycoremediation is not a feasible method for remediating pharmacological pollution. White-rot fungi do not act upon just carbamazepine, sulfamethoxazole and trimethoprim. It is possible that white-rot fungi will partially degrade compounds into metabolites that are more toxic than the parent compound. For example, this occurs when ibuprofen is degraded by white-rot fungi. Marco-Urrea et al. (2009) identified the formation of an ibuprofen metabolite, 1,2-hydroxyibuprofen, as a degradation product resulting from fungal metabolism. This metabolite is considered more toxic than ibuprofen itself. The remainder of this section only considers the metabolites created in the degradation of Missoula’s chemicals of concern, not other chemicals also present in the wastewater. But it is important to note the potential unintended consequences that may result from fungal metabolism.

Golan-Rozen et al. (2011) compared degradation efficiency when high levels of carbamazepine (10 mg/L in media) were present, and environmentally relevant levels (4.6 nM in media). When *P. ostreatus* PC9 degrades carbamazepine, several metabolites are formed. These include 10,11-epoxycarbamazepine, 10,11-dihydroxycarbamazepine, and 2- or 3-hydroxycarbamazepine (Golan-Rozen et al. 2011). At unnaturally high concentrations, nearly all carbamazepine was transformed into 10,11-epoxycarbamazepine, which continued to accumulate throughout the experiment. This metabolite exhibits similar properties to carbamazepine, most notably its pharmacological activity (Golan-Rozen et al. 2011; Faingold and Fromm 1992).

At environmentally realistic concentrations carbamazepine converted almost completely into 10,11-epoxycarbamazepine, however, 10,11-epoxycarbamazepine did not accumulate. After 14 days of incubation, the concentration of 10,11-epoxycarbamazepine decreased to 0.1 nM (Golan-Rozen et al. 2011).

Versatile peroxidase, extracted from *Bjerkandera adusta*, was added to 25 mg/L of sulfamethoxazole in acetone. In this experiment, 3-amino-5-methylisoxazole (AMI) was
identified as a degradation product (Eibes et al. 2011). Information regarding the toxicity and pharmacological activeness of this metabolite was not found. Other compounds produced during degradation of sulfamethoxazole were oxalic acid, acetic acid, and nitrate, nitrite, and sulfate ions (Eibes et al. 2011).

The toxicity of trimethoprim’s metabolites was not discussed because the literature review did not uncover any studies involving trimethoprim.

**Limiting Factors and Environmental Requirements in Mycoremediation**

Kulshreshtha et al. (2014) emphasizes the importance of performing a feasibility study prior to beginning any mycoremediation process. It is necessary to determine the prime environmental conditions for fungal growth, and whether fungi can successfully remediate a particular site. Researchers should focus on contaminant distribution, reactivity, and biodegradability of the chemical contaminants. Soil characteristics, available oxygen, and presence of inhibitory constituents are also important (Kulshreshtha et al. 2014).

Since the ecological role of white-rot fungi is to degrade plant materials, so that nutrients (carbon and nitrogen) become bioavailable, the metabolism of pharmaceutical pollutants is triggered by an environment limited by carbon and nitrogen. Marco-Urrea and Reddy (2012) explain that fungi do not use the pharmaceuticals, or environmental pollutants as an energy source, but rather the other available sources of carbon and sugar in the environment. Therefore, when attempting to perform mycoremediation, it is important to have enough carbon and nitrogen in the environment so that the fungal mechanisms are induced. In situations where fungi are limited by available carbon and nitrogen, soils must be amended with additional carbon and nitrogen in the form of corn cobs, wheat or alfalfa straw, wood chips, bark and peat (Baldrian 2008). These sources of nutrients can also be pre-inoculated with fungi (Baldrian 2008).

Another factor influencing the establishment and growth of fungi is the presence of other microorganisms. Fungi grown in non-sterile environments tend to require more energy resources because the fungi have to compete and interact with other microorganisms, which requires additional energy output (Baldrian 2008). White-rot fungi in the genus of *Pleurotus* and *Phanerochaete*, as well as *Trametes versicolor* fungi are considered “strong competitors” (Baldrian 2008).

Temperature is another significant component in effective mycoremediation. Soares et al. (2005) compared the performance of different species of white-rot fungi (*P. chrysosporium*, *P. ostreatus*, *T. versicolor* and *Bjerkandera* sp. BOL13) when degrading nonylphenol, an endocrine-disruptor. Nonylphenol was present in the experiment at a concentration of 100 mg/L. *T. versicolor* and *Bjerkandera* sp. BOL13 removed 97 mg/L and 99 mg/L of nonylphenol in 25 days (Soares et al. 2005). This degree of degradation occurred at 22°C. *T. versicolor* and *Bjerkandera* sp. BOL13 continued to substantially degrade nonylphenol at lower temperatures. Once the temperature reached 4°C, fungi were unable to degrade any nonylphenol (Soares et al. 2005). Although this research does not involve carbamazepine, sulfamethoxazole or trimethoprim, white-rot fungi have nonspecific enzymes that enable degradation of several pharmaceuticals. From these results, it can be inferred that temperature plays a critical role in degradation of the compounds considered in this literature review. Baldrian (2008) explains that
temperature influences the activity of enzymes responsible for pollutant degradation; as the temperature of the environment increases (up to a maximum temperature), the activity and production of enzymes also increases.

**Discussion**

Studies have demonstrated that carbamazepine, sulfamethoxazole, and trimethoprim persist in surface and groundwater (Barnes et al. 2002; Focazio et al. 2008; Kummerer 2001), accumulate and adsorb to soil (Shenker et al. 2011; Kinney et al. 2006; Fatta-Kassinos et al. 2011), and can bioaccumulate in plants (Shenker et al. 2011; Carter et al. 2014; Ahmed et al. 2015; Pelley 2014; Boxall et al. 2006).

A small, pilot poplar plantation for wastewater irrigation was established near the Missoula WWTP. The soil composition at the pilot poplar plantation is loamy sand, with only one percent organic matter (Carey 2010). By referencing Shenker et al. (2011), one can reason that the soil conditions at the small, pilot poplar plantation promote high concentrations of carbamazepine in the soil’s aqueous phase, and potentially greater bioaccumulation in poplar tree leaves. However, the soil composition at the large poplar plantation that was later established near the WWTP, may differ from the pilot plantation. Also, bioaccumulation studies were not performed on woody plant species. Therefore, this assumption must be tested in the field to evaluate its accuracy.

Bioaccumulation of carbamazepine, sulfamethoxazole and trimethoprim in plants is a concern for edible crops. This literature review demonstrates that the acute risk of exceeding the ADI or TTC for these compounds, by consuming foods irrigated with wastewater, is low (Shenker et al. 2011; Carter et al. 2014; Boxall et al. 2006; Pelley 2014). However, the human risk from chronic exposure to low levels of pharmaceuticals has not been studied.

Presence of sub-therapeutic levels of carbamazepine, sulfamethoxazole and trimethoprim pose a risk to microbial communities (Kummerer 2008; Underwood et al. 2011; Fatta-Kassinos et al. 2011), aquatic organisms (Kummerer 2008; Thomulka and McGee 1993), and threatens to introduce antibiotic resistant bacteria into the environment (Negreanu et al. 2012; Kummerer 2008; Czekalski et al. 2012; Khetan and Collins 2007).

Irrigating the Missoula poplar plantation with treated effluent will not add any more of the compounds to the environment than if effluents were solely discharged into the Clark Fork River. Actually, wastewater irrigation may remove some of the PPCPs from the environment by bioaccumulation in the poplar trees. The fate of PPCPs bioaccumulated in poplar trees is unknown. For instance, PPCPs may degrade in poplar trees, or PPCPs may reenter the soil after poplar leaves fall and decompose. But, mycoremediation does provide an opportunity to reduce the amount of these, and potentially other PPCPs, from contaminating soils and harming the soil community.

Based on this review, the two species used the most in testing the effectiveness of mycoremediation were *T. versicolor* and *P. chrysosporium*. Studies and literature reviews have demonstrated that white-rot fungi, *T. versicolor* can degrade environmental pollutants (Pointing
Numerous studies demonstrated the ability of white-rot fungi to metabolize sulfamethoxazole (Eibes et al. 2011; Rodarte-Moraes et al. 2011; Guo Xia-li et al. 2014) and carbamazepine (Marco-Urrea et al. 2009; Eibes et al. 2011; Golan-Rozen et al. 2011; Rodarte-Moraes et al. 2011). However, no analyses were found that addressed degradation of trimethoprim by fungi.

The three studies that identified some transformation of sulfamethoxazole all reported different amounts of degradation. Rodarte-Moraes et al. (2011) described complete metabolism of sulfamethoxazole by Bjerkandera sp. R1, B. adusta and P. chrysosporium. Media contained approximately 1 mg/L of pollutant, and the plates were incubated for two weeks. Eibes et al. (2011) also used B. adusta, though not all the sulfamethoxazole was degraded in this experiment. In this study, the culture was spiked with 25 mg/L sulfamethoxazole, and degradation by the isolated VP was measured for 7 hours. Nearly three-quarters of sulfamethoxazole (10 mg/L initial concentration) was transformed by P. chrysosporium over 10 days in Guo Xia-li et al. (2014). Each experiment was performed in vitro, in a sterilized environment, however results varied. Rodarte-Moraes et al. (2011) observed complete degradation. The most successful experiment used an environmentally realistic concentration of sulfamethoxazole and was conducted for the longest amount of time.

In the Rodarte-Moraes et al. (2011) and Golan-Rozen et al. (2011) studies, carbamazepine was completely degraded. These experiments had the longest incubation times and most environmentally similar carbamazepine concentrations. Marco-Urrea et al. (2009) observed transformation of over half of carbamazepine, while Eibes et al. (2011) reported no degradation. The differences in results likely relates to the disparities in experimental design.

The literature demonstrated the potential for mycoremediation to create toxic degradation products. Golan-Rozen et al. (2011) identified the metabolites produced by degradation of carbamazepine, primarily 10,11-epoxycarbamazepine, a pharmacologically similar compound to carbamazepine (Golan-Rozen et al. 2011; Faingold and Fromm 1992). However, the results occurred under high pharmaceutical concentrations (10 mg/L). When the experiment was conducted with a smaller, environmentally realistic concentration 10,11-epoxycarbamazepine was formed, but eventually degraded into an inactive compound (10,11 trans-diol). Sulfamethoxazole also transforms into a metabolite when degraded by fungi; Eibes et al. (2011) identified 3-amino-5-methylisoxazole (AMI) as a degradation product. The toxicity of 3-amino-5-methylisoxazole (AMI) was not determined. Although toxic metabolites were formed by fungal degradation of pharmaceuticals, this occurred at concentrations not found in the environment. Therefore, I would assert that this is not a serious risk for carbamazepine contamination; though the toxicity of other pharmaceutical metabolites must be determined to assess overall toxicity.

While this literature review demonstrates consistent degradation of carbamazepine, sulfamethoxazole and many other pharmaceuticals, the majority of experiments were performed in vitro (Marco-Urrea et al. 2009; Eibes et al. 2011; Rodarte-Moraes et al. 2011; Golan-Rozen et al. 2011; Rodriguez-Rodriguez et al. 2011). Many studies used concentrations of pharmaceuticals that were magnitudes greater than those present in wastewater effluents (Marco-
Urrea et al. 2009; Golan-Rozen et al.). It is important to study concentrations of chemicals of concern like those found in the environment, because lower concentrations may allow for greater transformation of the compounds (Golan-Rozen et al. 2011). The use of environmentally relevant concentrations, or samples from real wastewater, would provide a better appraisal of mycoremediation’s effectiveness at degrading pharmaceuticals.

Another aspect of actual environmental conditions that is necessary when evaluating the successfulness of mycoremediation is the presence of other microorganisms. Baldrian (2008) identified the presence of other microorganisms as a limiting factor in the colonization of fungi in an environment, this poses a problem because most experiments demonstrating degradation of pharmaceuticals were performed in sterile environments. Therefore, it is important to conduct experiments in the most environmentally representative conditions possible, including the use of realistic pollutant concentrations and presence of other microorganisms. With that said, the most valuable studies will be those that are performed in the field.

Conclusions and Recommendations

The WHO recognizes carbamazepine, sulfamethoxazole, and trimethoprim as “core” pharmaceuticals. The WHO considers medications on the “core list” to meet the minimum needs of a basic health care system (WHO 2015). Pharmaceuticals on this list are the most effective, safe, and cost-effective. Therefore, it can be surmised that these medications will continue to be used regularly in the United States and be present in WWTP effluent.

This literature review has demonstrated that carbamazepine, sulfamethoxazole, and trimethoprim persist in the environment and can cause some environmental problems. Although, studies have also shown that the acute human health concerns are low. With that being said, the potential problems caused by chronic exposure are unstudied. Mycoremediation can potentially provide a viable solution for these problems caused by pharmaceutical pollution, as long as research fills in the gaps of current studies. Also, other chemicals, particularly those present in the Missoula WWTP effluent, should be reviewed and the feasibility of mycoremediation for those chemicals should be assessed.

Though the focus of this paper is on mycoremediation of wastewater irrigated soils, the Missoula WWTP recently purchased Garden City Compost, formally EKO Compost. The Garden City Compost facility comports biosolids from the Missoula WWTP into a product that is then sold to consumers in bulk form to be potentially used on edible crops. Because of this, I would recommend that the Missoula WWTP operators first focus feasibility, viability and safety studies at Garden City Compost rather than the poplar plantation.

It is challenging to assess the overall possibility and potential effectiveness of white-rot fungi mycoremediation at the Missoula poplar plantation and Garden City Compost because this literature review addressed just three of the most recalcitrant and resistant pharmaceuticals present in Missoula’s wastewater effluent. Also, many of the studies that demonstrated degradation of carbamazepine and sulfamethoxazole used environmentally unrealistic conditions. Additionally, trimethoprim lacked research on degradation by fungi, and the toxicity of metabolites created in the degradation process. Despite these gaps in information and
knowledge, I believe mycoremediation has potential to minimize the number of pharmaceuticals entering the environment via the Missoula poplar plantation and Garden City Compost, as well as lessening the environmental risks associated with their presence. I conclude that it is necessary to address the knowledge gaps identified in this paper, to sufficiently assess the potential of mycoremediation at the Missoula poplar plantation and at Garden City Compost.

Tables

Table 1. Missoula WWTP study (Sullivan pers. comm.).

<table>
<thead>
<tr>
<th>STP Samples ng/L (ppt)</th>
<th>Use</th>
<th>Reporting Limit* (ng/L)</th>
<th>Influent Monday</th>
<th>Influent Tuesday</th>
<th>Influent Wednesday</th>
<th>Effluent</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Androstenedione</td>
<td>Androgen</td>
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<td>100</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Atrazine</td>
<td>Herbicide</td>
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<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
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<tr>
<td>Bisphenol A</td>
<td>Industrial Chemical/Mimics Estrogen</td>
<td>10</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>170</td>
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<tr>
<td>Caffeine</td>
<td>Stimulant</td>
<td>5</td>
<td>55,000</td>
<td>42,000</td>
<td>30,000</td>
<td>nd</td>
<td>110</td>
</tr>
<tr>
<td>Carbamazepine</td>
<td>Anti-seizure</td>
<td>1</td>
<td>540</td>
<td>480</td>
<td>300</td>
<td>520</td>
<td>460</td>
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<td>DEET</td>
<td>Insect Repellent</td>
<td>5</td>
<td>3,200</td>
<td>2,500</td>
<td>4,000</td>
<td>nd</td>
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</tr>
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<td>Diazepam</td>
<td>Muscle Relaxer</td>
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<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
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<td>Diethylstilbestrol</td>
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<td>nd</td>
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<td>nd</td>
</tr>
<tr>
<td>17-beta-estradiol</td>
<td>Estrogen</td>
<td>2</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>detected</td>
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<tr>
<td>Estriol</td>
<td>Estrogen</td>
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<td>250</td>
<td>nd</td>
<td>nd</td>
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<tr>
<td>Estrone</td>
<td>Estrogen</td>
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<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>18</td>
</tr>
<tr>
<td>17-alpha-ethynylestradiol</td>
<td>Synthetic Ovulation Inhibitor</td>
<td>2</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
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<td>nd</td>
</tr>
<tr>
<td>Fluoxetine</td>
<td>Antidepressant</td>
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<td>nd</td>
<td>nd</td>
<td>nd</td>
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<td>nd</td>
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<td>Oxybenzone</td>
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<tr>
<td>Progesterone</td>
<td>Ovulation Inhibitor/Estrogen</td>
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<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Sulfamethoxazole</td>
<td>Antibiotic</td>
<td>1</td>
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<td>1,600</td>
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<td>1,100</td>
<td>75</td>
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<tr>
<td>Testosterone</td>
<td>Androgen</td>
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<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
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<tr>
<td>Trimethoprim</td>
<td>Antibiotic</td>
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<td>nd</td>
<td>1,000</td>
<td>1,400</td>
<td>490</td>
<td>880</td>
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<tr>
<td>17-alpha-estradiol</td>
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<td>1</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
</tr>
<tr>
<td>Pentoxifyline</td>
<td>Improve Blood Flow</td>
<td>1</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>1.9</td>
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<tr>
<td>Methadone</td>
<td>Opiate</td>
<td>5</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
<td>nd</td>
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<tr>
<td>Acetaminophen</td>
<td>Analgesic</td>
<td>10</td>
<td>160,000</td>
<td>50,000</td>
<td>8,800</td>
<td>nd</td>
<td>nd</td>
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</tbody>
</table>

*The reporting limit is the minimum concentration of a compound that can be reported within
certain parameters of precision and accuracy of laboratory conditions.

Table 2. Principles for deriving ADIs for compounds considered in this study (WHO Working Group 2011).

<table>
<thead>
<tr>
<th>Category of analytes</th>
<th>Derivation of ADIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compounds that are not carcinogenic</td>
<td>Dividing the highest dose at which an effect was not observed (NOAEL) or the lowest dose at which an effect was observed (LOAEL) in animal or human toxicity studies by uncertainty factors to account for extrapolation to potentially sensitive populations</td>
</tr>
<tr>
<td>Compounds with positive evidence of carcinogenicity in high-dose animal studies and data on tumour incidence per dose level</td>
<td>A linear extrapolation model was used to predict the tumorigenic response at low dose level</td>
</tr>
<tr>
<td>Carcinogenic compounds with reported evidence in animal studies, but no available tumour incidence data</td>
<td>A safe dose corresponding to a cancer risk of one in a million was estimated</td>
</tr>
</tbody>
</table>
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Part Two

An Overview and Assessment of Water Conservation Approaches for Municipal Water Systems

Water System Acquisition Update
AN OVERVIEW AND ASSESSMENT OF WATER CONSERVATION APPROACHES FOR MUNICIPAL WATER SYSTEMS

Informing a Water Conservation Program for the City of Missoula

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Environmental Studies Program
The University of Montana
June 2017
Acknowledgments

I would like to express my very sincere appreciation to Professor Robin Saha, my faculty advisor for this project, for his valuable and constructive guidance throughout the entire course of this project. His encouragement, generosity with his time, and wealth of knowledge were instrumental factors in the completion of this paper. Professor Saha went far beyond the requirements of an advisor and for that I cannot express my gratitude enough.

I wish to thank the Missoula City Council Public Works Committee for allowing me to present my research at a Public Works meeting on May 25, 2016. Your openness, thoughtful questions, and ideas are greatly appreciated. I am especially grateful of Bryan von Lossberg for providing the valuable opportunity to share my work with such an influential audience. I would also like to thank Bryan for donating his time and thoughts that aided in the improvement of this paper.

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Finally, I would like to extend my thanks to Lain Leoniak and Stu Feinglas for generously sharing their knowledge and passion for water conservation programs, in addition to answering my numerous questions over the past few months.
**Executive Summary**

The City of Missoula has worked to purchase Mountain Water Company and its drinking water system from a series of private owners. The purchase of the water system was finalized in 2017, as a result, the city will also acquire the carbon footprint associated with servicing and running the water system. Therefore, the acquisition of the drinking water system adds another potential barrier to Missoula’s goal for achieving carbon neutrality by 2025, as stated in Missoula’s Climate Action Plan (CCAP).

The purpose of this briefing paper is to assess different components of municipal water conservation programs of select mid-sized cities in the West. This assessment will inform recommendations to the City of Missoula for initiating an effective and energy efficient water conservation program for Missoula’s drinking water system.

Implementing a water conservation program is important for the City of Missoula because it will:

- Help Missoula meet the goals of CCAP and mitigate the threat of climate change
- Reduce costs for the municipality, wastewater treatment plant (WWTP), and drinking water customers
- Lessen non-point source pollution from stormwater and irrigation runoff
- Support Missoula’s identity as a good steward of the environment

A 2010 Montana Public Service Commission study found that 40 percent of the water pumped from the Missoula Aquifer does not reach Mountain Water’s customers’ taps because of leaks in the water system. Therefore, reducing leaks in the water system infrastructure is a conservation measure, but that objective does not fall within the scope of this paper. The water system infrastructure needs repair, but the value of stand-alone water conservation projects must be recognized. It is important to incorporate other water conservation measures while the system is undergoing improvement and afterwards.

I began this project by conducting initial interviews with the purpose of determining the type of information that would be useful to city decision makers. Local community members including a city council member, city employee, and a couple of Climate Smart Missoula staff were interviewed.

To achieve the purpose of this briefing paper, I first analyzed various sources of information on water conservation to determine common and effective water conservation approaches employed by municipalities. Based on this research, I next identified the three main water conservation approaches used in water conservation programs. These include: A) water rate structures, B) rebates, and C) community education and outreach. I also examined case examples of each approach by using jurisdictions that are comparable to Missoula. These included Bozeman, Montana, Westminster, Colorado, and the Eastern Municipal Water District, near Los Angeles, California.

I noted the justification for such programs, assessed their effectiveness (i.e., water savings) and the administrative requirements of each approach. My analysis allowed me to make reasonable
recommendations to city officials to create a cost-effective and energy efficient water conservation program that benefits customers, the municipal utility, and the environment.

**Water Rates that Encourage Conservation: Increasing Block Rate Water Structures**

Since saving money influences customer behavior, well-designed water rate structures are a highly effective way to encourage water conservation. Increasing block rate water structures offer the greatest degree of water conservation for rate schemes. This pricing scheme is designed such that the cost per unit of water increases incrementally, in blocks, when certain consumption levels are reached. Increasing block rate structures reward efficient water users and provide disincentives for greater water use. Increasing block rate water structures are valuable because they convey the “true cost of water.” Increasing block rates also acknowledge that access to a basic amount of water at an affordable cost is a human right.

*Figure 0-1.* Illustration of A) decreasing block rates, B) uniform rates, C) seasonal water rates, and D) increasing block rates.

![Figure 0-1](image)

Note: This figure was modified from “Water Rate Structures in Colorado: How Colorado Cities Compare in Using this Important Water Use Efficiency Tool” (Western Resources Advocates et al., 2004).

The two most commonly used rate structures that encourage water conservation are increasing block rates and increasing block rate water budgets. The increasing block rate structure in Westminster, Colorado, and block rate water budget of Eastern Municipal Water District were studied in this paper. After evaluating water demand and use patterns over the past 30 years, Westminster found that since 1980, per capita water demand decreased by 21 percent. The water rate structure and other conservation programs saved its customers 80 percent in tap fees and 91 percent in rates, compared to what the cost would have been without any conservation measures.
Similar to increasing block rates, some utilities design water budgets so that the cost per unit of water increases in blocks as certain consumption levels are achieved. However, in water budget rate structures the blocks, also called budgets, are individually set for each customer. Water budgets are based on specific factors distinctive to each customer such as, lot size, housing structure size, irrigable landscape area, number of bathrooms, and household members.

A study of Eastern Municipal Water District (EMWD) determined that after three years into water budget implementation, the EMWD’s water demand decreased by 20.1 percent. Another substantial finding is that customers within the water budget framework tended to retain their water conservation habits even if the price of water decreased. Under this water budget scheme, the average price per unit of water customers paid rose by only 4 percent. If the water utility wanted to achieve the same level of water use reduction within the flat-rate water structure, the cost of water would have to rise by 48 percent. In other words, obtaining significant decreases in water use with limited increases in average price per unit water is better achieved with water budgets.

Currently, Mountain Water’s metered customers pay a uniform water rate. Even as the volume of water used increases, the unit price of water remains constant. Unmetered customers are charged a flat monthly fee regardless of water usage, since the volume of water used is not measured. The proposed Missoula Water Division rate schedule sets a starting rate based on meter size, and the price per 100 cubic feet of water is $2.00. Compared to increasing block rate water schemes, this proposed rate structure does not provide a strong water conservation incentive since the per unit cost of water does not increase as water use increases.

Water budgets are associated with greater administration and implementation costs than increasing block rate structures because of the complexity of determining individual water budgets for each household. Due to the strong incentive to conserve water, notable water savings experienced by other municipal utilities, and the lower administrative cost, I concluded that implementing an increasing block rate structure would be the most desirable for Missoula.

**Rebates for Water Conserving Appliances and Fixtures**

Rebates are one of the more common water conservation strategies. Thousands of cities across the United States offer rebates (i.e., partial refunds) to customers when they purchase water efficient fixtures and appliances. Typically, rebates are offered for residential indoor appliances like high-efficiency toilets, washing machines, and showerheads. Indoor water use, especially in the bathroom, offers one of the greatest opportunities for water conservation.

The City of Bozeman in Montana administers several rebate programs that have demonstrated marked success at reducing water use. By investing less than $70,000 in rebates between 2014 and 2015, the City of Bozeman experienced $1.1 million in water savings. The Water Conservation Division’s calculations assume that for every acre-foot of water saved from the rebate programs, $5,500 was saved. Cost savings were determined by considering the true cost of water in Bozeman. These cost savings are experienced by both the city and water customers; water savings resulted from avoiding the cost associated with expanding the water supply system.
A rebate program for residential households that is focused primarily on bathroom water appliances and fixtures has great potential in Missoula. In 1992, the Energy Policy Act required all homes built since 1994 to have low-flow toilets, showerheads, and faucets. Based on the 2014 Census, 68 percent of single and multi-family residences in Missoula were built prior to 1990. Therefore, more than two-thirds of the residences in Missoula could potentially participate in rebate programs. Rebate programs are desirable because they tend to be less controversial than mandatory conservation measures and they can be designed to direct money into local businesses.

**Education and Outreach to Change Behavior**

Education and outreach programs are an essential component of water conservation programs. Successful water conservation education and outreach programs explain to the public why water conservation is important (i.e., the benefits of water conservation and the potential dangers of not conserving water), as well as the mechanism for meeting conservation goals. Water savings can be maximized if the water users with the greatest water usage are identified, and educational information and outreach projects are primarily directed at this group. Utilities should convey the information in a variety of formats, several times a year.

There are numerous approaches to sharing water conservation information and engaging with the community. Typical tactics range from incorporating water conservation information on water bills, to participating at and holding local events. Notable education and outreach programs in Westminster, Colorado include its: Water Festival, Water Awareness Week, free irrigation audits, Garden in a Box program, free xeriscaping seminars, and tabling at public events. The City of Bozeman designed several education and outreach campaigns, aspects of these campaigns are its: Educator Guide, Water Conservation Division website, presentations discussing Bozeman’s water source and ways to conserve water, free leak detection kits, and “bill stuffers.”

Mountain Water currently works with and supports local environmental education nonprofits like the Watershed Education Network, Clark Fork Coalition and SpectrUM’s Groundwater Academy. This collaboration is an important aspect of the current water system. These organizations, among many others may also express interest in partnering with the city in designing water conservation education materials and projects.

**Conclusions and Recommendations**

After my research on different water conservation approaches, I concluded that an increasing block rate structure should be an important element of a water conservation program for the city-operated drinking water system. Examples from other jurisdictions demonstrate the effectiveness of this type of rate structure at incentivizing water conservation. Increasing block rates have an added advantage: they are not costly or complex to administer. As a first step, however, it is necessary to critically review the current structure Mountain Water has in place, and identify the areas that should remain unchanged and the aspects that should be modified.
My research also showed that rebate programs and education and outreach program are important components of effective water conservation programs. The benefits of such programs far-exceed their cost. Moreover, my research demonstrated that rebate and education programs are among the most common water conservation strategies adopted by municipal water utilities in communities similar to Missoula.

Based on these conclusions and additional findings in the body of my paper, I recommend that the City of Missoula develop a strong water conservation program from the outset. Specifically, I recommend that the city:

1. Calculate the current carbon footprint of the water system, assess the current water demand, and establish water conservation goals based on carbon footprint reduction goals.
2. Critically review the current rate structure Mountain Water has in place, and identify the areas that should remain unchanged and the aspects that should be modified.
3. Transition all unmetered customers to meters.
4. Create a comprehensive water conservation program that includes the three P’s (pricing, programs, persuasion).
   a. Pricing: Increasing block rate structure
   b. Programs: Rebate programs focused first on residential bathroom appliances and fixtures
   c. Persuasion: Partner with local environmental education nonprofits to create extensive education and outreach programs
5. Incorporate the water conservation program into the Public Works Department.
6. Acquire the Alliance for Water Efficiency Conservation Tracking Tool (version 2.0).
7. Join the American Water Works Association (AWWA) and Association of Metropolitan Water Agencies (AMWA) to gain access to their resources.
8. Establish 10-year goals for the water conservation program that include evaluation metrics.
9. Periodically (at least every 5 years) review and revise the water conservation program with public input.

In conclusion, I believe the City of Missoula currently sets a very commendable example of environmental stewardship. Water is arguably the most valuable resource on this planet. If Missoula can save water, it should. In the process, Missoula will lead by example and reinforce the importance of environmental stewardship, minimize non-point source pollution, reduce energy use and associated carbon dioxide emissions, help meet its climate action goals, save money and support the local economy. Of course, it will take time, expertise, and capital, but with the breadth of water conservation resources available, it is possible to design a water conservation program that best suits Missoula and serves the public good.
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1. INTRODUCTION

Rising sea levels, more frequent forest fires, desertification, changes in precipitation patterns, and overall increases in global climate temperature are only a few of the observed and anticipated consequences of climate change. Numerous natural resources will be negatively impacted by global climate change—water is among those resources. More than two-thirds of Earth is covered with water. However, only 2.5 percent is freshwater, and less than half of that amount is available for human use.1 The Intergovernmental Panel on Climate Change (IPCC) states that, “observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems.”2 Residents of Missoula, Montana are fortunate to have access to a rapidly recharging aquifer.

National, state, and city governments around the world are becoming increasingly aware that action needs to be taken immediately to curb greenhouse gas emissions and other factors contributing to global climate change. Adopted in 2009, Missoula’s Conservation and Climate Action Plan (CCAP) showcases the city’s acknowledgement of climate change and the positive role it can play in climate mitigation. The CCAP put forth a plan for achieving carbon neutrality by 2025. The City of Missoula explains that the CCAP “serves as the road map to maintain progress in the city’s commitment to reducing energy and fuel consumption, reducing greenhouse gas emissions, practicing fiscal responsibility, and being good stewards of natural resources, environment, economy, quality of life and community.”3

The City of Missoula has worked to purchase Mountain Water Company and its drinking water system from a series of private owners. The purchase of the water system was finalized in 2017. The city’s desire to own the water system was grounded in the belief that “a privately owned monopoly utility cannot operate in the best interests of the public” and that “a community’s water system is a public asset that is best owned and operated by the public, through municipal government.”4 5 As Mayor Engen stated in his testimony to the Montana Public Service Commission, “the City of Missoula is the only major municipality in Montana that does not own its water system.”6

6 Ibid.
With the acquisition of the drinking water system, the city will also acquire the carbon footprint associated with servicing and running the water system. Therefore, owning and operating the drinking water system adds another potential barrier to Missoula’s goal for achieving carbon neutrality by 2025, as stated in Missoula’s Climate Action Plan (CCAP). At this point, the exact carbon footprint of the drinking water system is unknown. When asked if the City of Missoula would have a greater interest in water conservation measures than a private company, the Mayor responded, “yes, because there is no profit motive, a public water utility is predisposed to a greater interest in water-conservation measures, including metered water and water-efficient fixtures and landscaping.”

Many publically-owned water utilities promote some type of a water conservation program. These water conservation programs typically consist of one or more of the following components: 1) water rate structures geared toward encouraging water conservation; 2) rebates for energy and water efficient appliances and fixtures; and 3) community education and outreach efforts. Programs differ between jurisdictions, due to the particular needs of each municipality’s water users and the characteristics of the local water supply. The justification for implementing water conservation programs varies from preserving dwindling resources, preventing costly expansion of water supplies, minimizing maintenance and operation costs of infrastructure, reducing energy consumption and associated emissions, and being good stewards of the environment, to simply saving money for the municipality and its customers.

Missoula is an environmentally and conservation-minded city with a civically engaged and informed community. Based on my conversations with city employees, city council members, and active individuals in the non-governmental sector, I believe that Missoula should implement a water conservation program. A water conservation program will increase resilience to the persistent threat of climate change, uphold the goals of Missoula’s CCAP, and protect the world’s most valuable resource.

The purpose of this briefing paper is to assess different components of municipal water conservation programs of select mid-sized jurisdictions in the West. This assessment will inform recommendations to the City of Missoula for initiating an effective and energy efficient water conservation program for Missoula’s drinking water system.

A 2010 Montana Public Service Commission study found that 40 percent of the water pumped from the Missoula Aquifer does not reach Mountain Water’s customers’ taps because of leaks in the water system. If the City of Missoula were to replace the aging water mains, the cost would be over $128 million. Therefore, reducing leaks in the water system infrastructure is a conservation measure, but that objective does not fall within the scope of this paper.

In Local Climate Action Planning, Boswell and others (2012) explain that “combining incentives and education with strategies such as the provision of new infrastructure bolsters long-term

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7 “Pre Filed Testimony of John Engen, City of Missoula Mayor,” Department of Public Service Regulation Before the Public Service Commission of the State of Montana (PSC).
9 Ibid.
[emission reduction strategy] effectiveness.”\textsuperscript{10} Therefore, all the approaches discussed in this paper would be in addition to fixing the infrastructure. The water system infrastructure needs repair, but the value of stand-alone water conservation projects must be recognized. Completion of the water pipe maintenance will not occur immediately and the 2025 date for Missoula’s carbon neutrality goal is quickly approaching. For this reason, it is important to implement other water conservation measures while the system is undergoing improvement.

2. METHODS

I began this project by conducting initial interviews with the purpose of determining the type of information that would be useful to city decision makers. Local community members including a city council member, city employee, and a couple of Climate Smart Missoula staff and committee members were interviewed.

To achieve the purpose of this briefing paper, I first analyzed various sources of information on water conservation, in order to determine common and effective water conservation approaches employed by municipalities. For this stage of research, my primary sources included publications and web-based resources from the Alliance for Water Efficiency (AWE), American Water Works Association (AWWA), and Association of Metropolitan Water Agencies (AMWA).

Based on this initial research, I next identified the three main water conservation approaches used in water conservation programs. These include: A) water rate structures, B) rebates and, C) community education and outreach.

I chose to omit infrastructure fixes and landscape ordinances from my analysis. The justification for excluding infrastructure improvement from my analysis is stated in the introduction. Landscape ordinances were not researched in-depth because this approach imposes a mandatory rule on homeowners. I do not believe this sort of water conservation approach would be welcomed by the community, nor is such a strong regulation necessary for the City of Missoula.

After identifying the main water conservation approaches used by municipalities, I sought out and found case examples of each approach used by jurisdictions comparable to Missoula. For the case examples, I used reports from AWE, AWWA, the Water Research Foundation (WRF), and articles published in scholarly journals. I also conducted interviews of water conservation program managers and reviewed utility reports and websites. To be included in this paper, the city had to be a Rocky Mountain city similar in population and economic characteristics to Missoula. In one instance, an example could not be found for water budgets that adhered to these criteria. Therefore, a water budget for the Eastern Municipal Water District in Southern California was studied.

Section 3.A. of this paper (Water Rates), describes the four different water rate structures considered (i.e., decreasing block rate, uniform, seasonal rate, increasing block rate). In this section, I identify the most effective rate structures for promoting water conservation. My research focuses on two types of increasing block rate structures: increasing block rate structures

and water budgets. I review Westminster, Colorado’s pricing scheme as an example of an increasing block rate structure. The water budget for Eastern Municipal Water District in Southern California represents an example for that type of water rate pricing. Important aspects of this section include: background information, a description of how each municipality established the pricing blocks, effectiveness, as well as financing and administration of the pricing structure for each example.

Section 3.B. (Rebates) explains what rebates are, their purpose, and the justification for rebate programs. In addition, I discuss the opportunity for rebate programs in Missoula. I use Bozeman, Montana’s extensive rebate program as an example for this water conservation approach. In addition to providing background information on Bozeman’s water conservation program, I offer a description of each individual rebate program, including its financing and administration. Finally, I provide an assessment of the effectiveness of the rebate programs.

Section 3.C. (Education and Outreach) identifies the characteristics and goals of typical education and outreach water conservation programs. I cover common methods for sharing information and educating the public. I conclude this section with a description of education and outreach programs from Westminster, Colorado and Bozeman, Montana.

Next, I used the information developed in Section 3, which is summarized in Table 2-1 below, to identify the trends in water conservation programs, consider the justification for such programs, assess the effectiveness (i.e., water savings), as well as the administration requirements of each approach. These findings are presented in Section 4. (Discussion).

Section 5 (The Importance of Water Conservation for Missoula) explains how and why climate action goals provide an additional justification for a water conservation program in Missoula. Recognizing Missoula’s commitment to carbon neutrality, this section describes the relationship between energy and water. Including ways that water conservation has been incorporated into climate action plans in other cities can serve as an example for Missoula.

Based on my research and analysis, I end this paper (Section 6. Conclusions and Recommendations) with brief conclusions and several recommendations for the City of Missoula that I believe will best assist in the creation of an effective and energy efficient water conservation program for the city. These recommendations were based on my analysis (i.e., water savings, cost of administration, etc.), personal experience living in Missoula, and knowledge of the Missoula community values.
Table 2-1. Summary of the research discussed in Section 3 for water rates, rebates, and education and outreach programs.

<table>
<thead>
<tr>
<th>Water approach</th>
<th>Purpose</th>
<th>Distinguishing characteristics</th>
<th>Municipal systems that use the approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increasing Block Rate</td>
<td>o Creates a financial incentive for water conservation.</td>
<td>• Series of increasing blocks representing set volumes of water consumption.</td>
<td>Westminster, CO.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Higher-volume water use = Higher cost per unit water.</td>
<td></td>
</tr>
<tr>
<td>Water Budget</td>
<td>o Creates a financial incentive for water conservation.</td>
<td>• Series of increasing blocks representing set volumes of water consumption.</td>
<td>Eastern Municipal Water District, CA.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Blocks are customized based on specific housing unit, site, and household attributes.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Higher-volume water use = Higher cost per unit water.</td>
<td></td>
</tr>
<tr>
<td>Rebates</td>
<td>o Offers a means for achieving water reduction.</td>
<td>• Partial refunds to customers that purchase accredited water efficient appliances and fixtures</td>
<td>Bozeman, MT.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(indoor and outdoor).</td>
<td></td>
</tr>
<tr>
<td>Education &amp; Outreach</td>
<td>o Identifies water conservation incentives offered by the city.</td>
<td>• Variety of informational programs including:</td>
<td>Bozeman, MT; Westminster, CO.</td>
</tr>
<tr>
<td></td>
<td>o Encourages water conservation by instilling water efficiency habits into customers.</td>
<td>- Water conservation information on water bills</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Provides feedback to city regarding water conservation program.</td>
<td>- Information bill stuffers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>o Fosters sense of place among community and supports partnerships with local organizations.</td>
<td>- Conservation tips</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- Conservation website</td>
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<tr>
<td></td>
<td></td>
<td>- Teacher guides</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Speakers at schools</td>
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<td>- Xeriscaping seminars</td>
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<tr>
<td></td>
<td></td>
<td>- Tabling at community events</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Sprinkler system audits/assessments</td>
<td></td>
</tr>
</tbody>
</table>
3. WATER CONSERVATION APPROACHES

A. Water Rate Structures

What is a water rate structure?

Western Resources Advocates and others (2004) identify four types of water rate structures related to metered water systems:11 1) decreasing block rates, 2) uniform rates, 3) seasonal rates, and 4) increasing block rates. As described below (also see Figure 3-1), these rate structures vary in their potential to encourage water conservation.

In a decreasing block rate structure, as the consumer uses more water, the price per unit of water decreases. This rate scheme does not promote water conservation (Figure 3-1. A.).

Uniform rates remain constant regardless of the volume of water consumed, that is, the price per unit of water does not change with greater water use (Figure 3-1. B.). This structure does not strongly encourage consumers to conserve water.

Setting seasonal rates represents one method for incentivizing water efficiency, particularly in the hot summer months (Figure 3-1. C.). Summer water rates will be higher than winter water rates, because water is in greater demand in the summertime for outdoor watering. With a seasonal rate structure, a substantial summertime incentive to conserve water exists, however, no strong motivation to use water efficiently in the winter months is present.

Increasing block rate structures vary, but at its core, as the volume of water used increases, the cost per unit of water also rises incrementally (Figure 3-1. D.). This type of rate structure recognizes that access to clean drinking water is a human right by providing potable water at an affordable cost for basic needs. If designed effectively, increasing block rate structures will reward efficient water users and provide disincentives for greater water use. It is important to note that economists have long supported pricing as “an efficient and effective means to address water scarcity.”12

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11 If customers are not metered, they are charged a flat-fee per month, since water usage is not measured. This is the case for some Mountain Water Company customers.
http://www.saws.org/who_we_are/community/RAC/Docs/Eleventh_Mtg_Arch_1.pdf.
Which rate structure is best at promoting water conservation?

Of the four rate structures described in this paper, an increasing block rate water scheme offers the greatest financial incentive for water conservation.

According to Western Water Advocates and others (2004), for a water rate structure to effectively promote water conservation, the structure “must communicate the true cost of water.”

13 To determine the actual value of water, cities should consider three characteristics: 1) how much it costs the utility to operate and maintain the system, 2) the cost of losing the environmental benefits of water, and 3) the cost of purchasing additional water supplies to meet future demands.

14 In addition to this definition, the social and environmental costs of increased carbon emissions must also be included as part of the true cost of water.

Assuming full water rights were obtained as part of the purchase of the water system, and that the Missoula Aquifer continues to recharge quickly and does not become contaminated, there is a low likelihood Missoula will need to acquire new water supplies. With that being said, the cost of repairing the water system infrastructure is substantial. In addition, the risk of degradation to our riverine ecosystem, and loss of valuable recreation and tourism, could present serious concerns if there are prolonged drought or climatic changes resulting in long-term drying trends. The Clark Fork Coalition notes that, “changes in streamflow, higher-than-average temperatures,

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14 Ibid.
and shifts in snowpack and precipitation have the potential to make human and natural systems much more vulnerable across Western Montana.” For these reasons, I believe the City of Missoula should consider water rate structures that accurately value the “true cost of water.”

Any type of increasing block rate pricing structure compels customers to diminish their water use in order to save money. Increasing block rates and increasing block rate water budgets, which will be referred to as water budgets, comprise the two most common rate structures that aim to promote water conservation. To assess the effectiveness of the two rate structures at encouraging water conservation, and determine which scheme is more feasible for Missoula, the following subsections detail a case example of each rate structure. Topics discussed include the design of each rate structure, water savings achieved, and financing and administration.

### i. Increasing Block Rate Structures

At its most basic level, an increasing block rate structure is characterized by incremental increases in the cost per unit of water as the consumer uses more water. According to Alliance for Water Efficiency, “the most important aspect of conservation rates is designing the rate structure so a large portion (two-thirds or more) of the charges are based on the quantity of water the customer consumes.” Typically, successful increasing block rate structures operate with three to four tiers (see Figure 3-1, D.). The first tier represents efficient water usage for a standard household at the minimum fair price that covers basic operating, maintenance, system improvement and debt servicing costs. Increasing tiers correspond to higher water consumption, and therefore higher prices per unit of water. The Alliance for Water Efficiency states that typically, each increasing tier is priced at 50 percent or greater than the previous tier. In general, when designing increasing block rate structures, over half of residential customers will exceed the first tier upon initial implementation. One third of the customers will reside in the third tier, and 10 percent will be within the highest tier.

A comparative study of water use efficiency in the Southwestern United States demonstrated an inverse relationship between increasing block rates and per capita water use. Cities with strong increasing block rate structures demonstrate the lowest per capita water use. If designed correctly, an increasing block rate will encourage efficient water use, reward consumers who practice water conservation with lower water prices, and equitably price essential water needs to ensure the greatest possible affordability for basic necessities. Increasing block rates acknowledge that access to a basic amount of water at an affordable cost is a human right. In addition, a properly structured rate scheme will offer consistent revenues. The sources studied in

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17 Ibid.
19 Ibid.
this paper identify increasing block rate structures as the most effective conservation rate
structure.

Customer pricing insensitivity creates a challenge when designing increasing block rate schemes. Customer pricing insensitivity can occur because higher-income water users tend to be more willing to pay more, and thus, higher-income water users’ behavior may not be as influenced by price signals. Water utilities must ensure that the block increases will have a significant effect on high-income customers that use a large volume of water, but will not discriminate against lower-income customers. “Aggressive increasing block rate structures” demonstrate one method of protecting against this sort of inequity. In this scenario, the utility charges customers considerably higher costs for high-volume uses (e.g., extensive outdoor irrigation), and utilities make low-volume water uses (e.g., water for drinking, cooking, cleaning and efficient irrigation) much more affordable.\(^{20}\)

**Example of an Increasing Block Rate Structure: Westminster, Colorado**

Westminster, Colorado is a northwest suburb of Denver with a population of 106,000 in 2010. Surface water running into Standley Lake supplies the city’s drinking water. But the city predicts that at maximum buildout, most of Westminster’s water (87 percent) will come from the South Platte River Basin. Colorado’s Statewide Water Supply Initiative (SWSI) identifies the South Platte River Basin as “water short.”\(^{21}\) Therefore in 1976, the City of Westminster, Colorado decided to implement a water conservation program that focused on a new increasing block rate structure. In addition, the city instituted a Municipal Building Code that requires efficient plumbing fixtures in all new development.\(^{22}\) Westminster states the maintenance of reliable water sources, even during severe drought, as the purpose of the city-wide water conservation measures.

On average, Westminster’s residential sector consumes the most water at 63 percent.\(^{23}\) For this reason, Westminster focuses much of its water conservation efforts on residential use. In 2010, Westminster water customers began to question the purpose of water conservation because their water rates increased despite decreasing their water consumption (Table 3-1). To address this concern, Westminster studied what water rates and tap fees would be if per customer water demand stayed constant with 1980 demands. The city examined marginal costs associated with expanding the water system by removing water conservation measures from their calculations.\(^{24}\)


\(^{22}\) Ibid, 31.

\(^{23}\) Ibid, 14.

The marginal cost of water service is “the cost or savings incurred in providing more or less water service.”

The city concluded that water conservation reduced per capita water use by 21 percent since 1980 (Figure 3-2). If these reductions had not occurred, Westminster would have been forced to add 7,295 acre-feet to the water supply to meet the water demand. Furthermore, adding more water would have cost the city almost $218.9 million. Therefore, the city determined that implementing water conservation measures, like its increasing block rate structure, rebate programs, and plumbing codes saved water customers 80 percent in tap fees and 91 percent in rates.

Figure 3-2. Average per capita water demand in the City of Westminster from 1980-2010.

Note: This figure was obtained from “Conservation Limits Rate Increases for a Colorado Utility: Demand Reductions Over 30 Years Have Dramatically Reduced Capital Costs” (Feinglas et al., 2013).

27 Ibid.
28 A tap fee is defined as the cost of connecting a home to the water system.

<table>
<thead>
<tr>
<th>Residential Water (Gallons)</th>
<th>2004(^{30}) (Price per 1,000 gallons)</th>
<th>2012(^{31}) (Price per 1,000 gallons)</th>
<th>2016(^{32}) (Price per 1,000 gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 4,000</td>
<td>$1.95</td>
<td>$2.38</td>
<td>$2.76</td>
</tr>
<tr>
<td>5,000 – 20,000</td>
<td>$2.95</td>
<td>$3.93</td>
<td>$4.57</td>
</tr>
<tr>
<td>21,000+</td>
<td>$4.25</td>
<td>$5.82</td>
<td>$6.80</td>
</tr>
</tbody>
</table>

Note: All prices are for residents inside the Westminster city limits. The sources for these unit prices indicated the residential water gallon range. It is unclear how water usage that falls within the gaps is addressed.

The evident increase in Westminster’s pricing blocks can be attributed to inflation and population growth placing a greater strain on water supplies. This type of block pricing provides moderate water conservation price incentives to average water users.\(^{33}\) Westminster determined the pricing blocks by taking into account the “true cost of water” for the city, customer pricing insensitivity, and water conservation goals.

Differences exist between the main motivation for water conservation in Westminster and Missoula. With that said, the City of Westminster presents an impressive example of how water conservation—especially pricing—can benefit customers, the water utility, and the environment.

**Financing and Administration of Increasing Block Rate Structures**

Westminster’s water conservation program is administered by the Utilities Operations Division, which is part of the Public Works and Utilities Department. The Utilities Operations Division is responsible for operating and maintaining the city’s water and wastewater systems.\(^{34}\) The overall budget for the Utilities Operations Division amounts to $14,934,194 for 2016. In the 2016 budget, the city allocated 81.50 full-time equivalency (FTE) staff members to the Utilities Operations Division, this number went up from 78.50 FTE in 2013.\(^{35}\) Stuart Feinglas acts as the Water Resources Analyst for Westminster, as well as the city’s Water Conservation Coordinator.

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\(^{33}\) Western Resources Advocates et al. Water Rate Structures in Colorado: How Colorado Cities Compare in Using this Important Water Use Efficiency Tool, 12.


\(^{35}\) City of Westminster Adopted Budget 2015-2016: Public Works and Utilities (Westminster: City of Westminster), 159.
Primarily responsible for administering the water conservation program, Feinglas states that the city allots only 0.25 to 0.5 FTE of a staff position to the water conservation plan. The responsibility of running a lot of Westminster’s conservation programs lies with contractors. Feinglas explained that “since conservation is built into the city’s DNA there are so many positions that make conservation as a part of their regular job (Building Division, Utility Operations, Finance, Community Development) that I cannot truly estimate the time they spend on it.”

Feinglas did not offer a cost estimate for administering the increasing block rate structure in Westminster. However, he did explain that the cost of implementing and administering an increasing block rate water structure is dependent on a variety of factors including but not limited to, whether or not all customers are metered, the difference between the current billing system and future billing demands, and public relations campaigns.

Regarding public relations, Feinglas explained that the initiatives consisted of mailers, meetings and phone calls to the public. These efforts informed the public of the impacts they should expect when switching to the increasing block rate structure. The cost associated with administering an increasing block rate structure is more of a startup fee, a water conservation plan may include implementing a new rate structure, but the cost and responsibility of the rate structure would lie with the utility running the water system (at least in the case of Westminster).

The annual budget for Westminster’s water conservation plan has been around $70,000 for the past few years. Westminster devotes much of the budget to the city’s numerous educational programs (see Section 3.C. Education and Outreach). The city used to offer a toilet and washing machine rebate programs, but the city found that many customers would install efficient appliances even without the rebates.

ii. Water Budgets

Water budgets are a type of increasing block rate structure, but are individualized rather than employing the same rate structure for each water customer. Each municipal utility determines which factors to consider, but generally, household occupancy and outdoor landscape influence water consumption to the greatest extent. Additional factors that influence water use include lot and house size, number of bathrooms and climate conditions. For example, Figure 3-3

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36 Stuart Feinglas, email to author, April 28, 2016.
37 Ibid.
38 Ibid.
39 Ibid.
40 Ibid.
41 Ibid.
42 Ibid.
43 “Conservation Oriented Rate Structures,” Alliance for Water Efficiency.
demonstrates the difference in water budget allocation as household size, lot size, and seasons change.

In general, large households have larger water budgets than smaller households because each additional occupant uses a baseline amount of water. Figure 3-3 demonstrates this aspect of water budgets. If we consider the first tier in Figure 3-3, and compare the water budget for a 5-person household to the water budget for a 3-person household in any season, the larger household is charged $1.48 per 100 cubic feet up until approximately 1,100-1,600 cubic feet of water is used, while the smaller household is charged $1.48 per 100 cubic feet up until approximately 800-1,300 cubic feet of water is used. Also, lot size impacts outdoor irrigable area. For example, as lot size increases, water budgets also increase (see Figure 3-3). The size of water budgets is especially dependent on the season. The water budget for a 5-person household in the summer is significantly larger than for that same household in the winter, due to warmer temperatures, higher rates of evapotranspiration, and increased water demand (see Figure 3-3). In some circumstances, each household could have its own, unique water budget (see Figure 3-3). Customers must self-report if their household status changes, like household occupancy.45

*Figure 3-3. Water budget for a 5-person household (hh) and a 3-person household (hh).*

Water budgets are designed to include lower rates for water consumption at levels needed for basic life functions such as drinking, cooking, bathing and cleaning.46 Proponents of water

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46 Baerenklau et al., 2013, 2-3.
budgets argue that customers view water budgets more favorably than other variations because of its equitable, individualized block design. A problematic aspect of water budgets relates to the implications of lot size on water allocation. For example, a household on a large lot will be allocated more water than a household on a small lot, therefore the household with the larger lot size can use more water before entering the next, higher-costing tier (see Figure 3-3). As a result, water budgets encourage the development of larger housing structures and lot sizes, which ultimately results in increased energy and water usage.

*Example of a Water Budget: Eastern Municipal Water District, California*

Eastern Municipal Water District (EMWD) is located in Southern California, southeast of Los Angeles. EMWD comprises seven cities: Hemet, Menifee, Moreno Valley, Murrieta, Perris, San Jacinto and Temecula.47 The governance structure of EMWD, as well as its size and climate is different than other locations considered in this paper. It nevertheless offers a helpful look at how water budgets can be designed. In 1950, EMWD was organized as a Municipal Water District. The public elects EMWD’s Board of Directors and the District operates under California law.48 Baerenklau and others (2013) analyzed the impact of a revenue-neutral increasing block-rate water budget rate structure on residential water demand in the Eastern Municipal Water District of Southern California. The analysis considers more than 13,000 single-family households from 2003 to 2012.

*Table 3-2* shows the calculations used by EMWD to establish the water budget blocks, or tiers. The various water budget tiers represent what EMWD consider “efficient,” “excessive” and “wasteful” water use. Block 1 corresponds to indoor water use, this block of the water budget is a function of household size (HHS), per-person allowance (PPA), drought factor (DF), and indoor variance (IV). Block 2 is the cumulative indoor and outdoor water use. It is a function of evapotranspiration (ET), conservation factor (CF), irrigated area (IA), outdoor variance (OV), and drought factor (DF) (*Table 3-2*). Individual household water budgets encompass the cumulative amount of indoor and outdoor water use. Block 2 represents “efficient” water use. The water utility

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49 HHS is reported to EMWD by each household.

50 PPA is 60 gallons per day which is set by EMWD.

51 Depending on the environmental conditions DF is set less than or equal to 1.

52 IV is based on unusual indoor circumstances (i.e., medical need or in-home daycare). This value is negotiated between EMWD and the reporting households.

53 ET is determined by real-time measurements for a reference crop. These measurements are translated to represent 50 designated microclimate zones within EMWD.

54 CF is a conversion factor that changes the reference crop ET to turfgrass ET.

55 Households self-report IA to EMWD.

56 OV is based on unusual outdoor circumstances (i.e., maintenance of large animals or turfgrass establishment). This value is negotiated between EMWD and the reporting households.
deems any consumption exceeding Block 2 as “excessive” or “wasteful” (Block 3 and 4 Table 3-2).

If customers’ water use falls into Block 3 and 4, the water utility charges those users more accordingly. The designated amount for “efficient” water use can vary from month-to-month because of the factors used to design the budget (i.e., evapotranspiration and other weather conditions).

Table 3-2. Equations used to calculate blocks for increasing block rate water budget in EMWD.57

<table>
<thead>
<tr>
<th>BLOCK</th>
<th>TYPE OF WATER USE</th>
<th>EQUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Indoor water use</td>
<td>( w_1 = (\text{HHS} \times \text{PPA}) \times DF + IV )</td>
</tr>
<tr>
<td>2</td>
<td>Outdoor water use (efficient)</td>
<td>( w_2 = w_1 + (\text{ET} \times \text{CF} \times \text{IA} \times \text{OV}) \times DF )</td>
</tr>
<tr>
<td>3</td>
<td>Excessive water use</td>
<td>( w_3 = 1.5 \times w_2 )</td>
</tr>
<tr>
<td>4</td>
<td>Wasteful water use</td>
<td>( w_4 = \text{water use in excess of } w_3 )</td>
</tr>
</tbody>
</table>

The study concluded that revenue-neutral increasing block rate water budgets can significantly influence water demand. After three years into program implementation, the water demand decreased by 20.1 percent.58 According to this study, customers within the water budget framework tended to retain their water conservation habits even if the price of water decreased.59 This study illustrates that although the impact on water demand is not immediate, water budgets can substantially influence water consumption and conservation. Under this block rate scheme the average price per unit of water rose by only 4 percent.60 If the water utility wanted to achieve the same level of reduction within the uniform rate water structure, the cost per unit of water would have to rise by 48 percent before customers felt the financial pressure to conserve water.61

**Financing and Administration of Water Budgets**

While water budget rate structures aim to maximize water efficiency potential, they are challenging to implement. Theoretically, every customer may have a unique water budget. In addition, administering a water budget rate structure will require a substantial billing system to handle the thousands of accounts. Due to the complexity of determining water budgets and individualized nature of the water structure, utilities incur higher administrative costs when implementing water budgets.

EMWD did not provide an amount for how much water budget implementation and administration cost. However, a variety of factors influence the cost of implementing and administering an increasing block rate water structure, including but not limited to, whether all customers are metered, and the difference between the current billing system and future billing demands. One study found that implementation costs such as updating the billing system and

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57 Baerenklau et al., 2013, 5.
58 Baerenklau et al., 2013, 10.
59 Ibid.
60 Ibid.
61 Ibid.
determining water budget allowances for three different water districts varied from $365,000 to $1.5 million.62

B. Rebates

What are rebates?

Rebates encompass one of the more common water conservation strategies. Thousands of cities across the United States offer rebates (i.e., partial refunds) to customers when they purchase water efficient fixtures and appliances. Rebates administered by cities encourage people to purchase water efficient products when they otherwise may not. Typically, cities offer rebates for residential indoor appliances like high-efficiency toilets, washing machines and showerheads. Indoor water use, especially in the bathroom, represents the greatest opportunity for water conservation. Some cities also provide rebates for outdoor technology like sprinkler systems.

Typically, cities provide rebates for specific types of appliances that have been certified by an authoritative body. The main certification programs are ENERGY STAR®, WaterSense and Consortium for Energy Efficiency (CEE). ENERGY STAR® remains the most recognizable efficiency certification. Established by the United States Environmental Protection Agency (EPA) in 1992, ENERGY STAR® primarily focuses on energy efficiency, though they do certify products that conserve water like clothes washers and dishwashers.63

The EPA began a program, WaterSense, specifically devoted to water conservation. As a result, many rebate programs require that rebates go towards WaterSense labeled products. In order to be certified by WaterSense, appliances must “be at least 20 percent more efficient without sacrificing performance.”64 To be certified, a product should meet specific criteria for efficiency and performance designated by the EPA; accredited, independent, third-party certifying bodies determine whether or not products meet the EPA standards.

CEE was developed as a collaborative effort between energy efficiency administrators from the U.S. and Canada. The group works towards increased development and availability of energy efficient products and services.65 In 2011, CEE enacted the CEE Super Efficient Home Appliances Initiative. One aspect of the initiative determined energy efficiency standards that went beyond those of ENERGY STAR®. For example, one of the programs describes the characteristics required for clothes washers that meet Federal Standards, ENERGY STAR® requirements, and CEE’s Tier 1, Tier 2, and Tier 3 classification.66 Tier 1 standards are

equivalent to those of ENERGY STAR’s®, but exceed Federal Standards. The most efficient clothes washers, in terms of water and energy, fall within Tier 3. Based on my research, rebate programs usually require installation of WaterSense and/or CEE certified appliances.

Why create a program with rebates?

Based on its 2016 study of 1,000 single-family homes in Pennsylvania, the Water Research Foundation found that 63 percent of the households did not meet the study’s efficiency criteria for toilets, and only 54 percent met the criteria for clothes washers. The majority of the homes met the standards for shower fixtures, with only 20 percent not meeting the efficiency criteria. According to the Water Research Foundation, if 100 percent of the households installed high-efficiency toilets, washing machines and showerheads, the per capita water use would drop by 35 percent.

Single and multi-family residences represent an area with substantial water conservation potential, especially in Missoula. In 1992, the Energy Policy Act required all homes built since 1994 to have low-flow toilets, showerheads and faucets. Based on the 2014 Census, 67.9 percent of single and multi-family residences in Missoula were built prior to 1990. Therefore, more than two-thirds of the housing residences in Missoula could potentially participate in a rebate program. It is likely that a rebate program could result in significant reductions in water consumption for Missoula. As discussed below, the City of Bozeman achieved substantial reductions in per capita water use since implementing its rebate programs.

Example of Rebate Programs: Bozeman, Montana

Due to the City of Bozeman’s growing population and shrinking water supply, the city created a Water Conservation Plan in 2002. As of 2010, Bozeman’s water use decreased by 30 percent from 1989 levels, despite significant population growth. However, Bozeman still needed to decrease their water consumption to meet future water supply needs. On February 6, 2012, the City of Bozeman authorized a taskforce to develop an Integrated Water Resources Plan (IWRP) that could feasibly address the water supply needs for the next 30-50 years. The taskforce completed the IWRP in 2014. A significant portion of the IWRP pertains to water conservation programs.

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Of the solutions identified by the IWRP taskforce to meet the water supply gap, water conservation presented the largest area of potential savings (10,100 acre-feet overall). In 2014, the city hired a Water Conservation Specialist to design a water conservation program. In the first year of implementation, Bozeman’s water conservation program focused on a voluntary rebate program for single and multi-family residences. This program concentrated on replacement of indoor water appliances and fixtures with the greatest water use (i.e., toilets, washing machines and showerheads). The program offers rebates to approved applicants in the form of a check. The indoor rebated products available are summarized in Table 3-3.

Table 3-3. Bozeman’s residential indoor rebate program.

<table>
<thead>
<tr>
<th>Indoor Products</th>
<th>Rebated Amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td>WaterSense high-efficiency toilets (connected to an existing system)</td>
<td>$125 (If original toilet was installed prior to December 31, 1996); $50 after (December 31, 1996). Maximum of $250.</td>
</tr>
<tr>
<td>New, CEE Tier 1, 2, or 3 washing machines (purchased from local retailers)</td>
<td>$150</td>
</tr>
<tr>
<td>New, CEE Tier 1, 2, or 3 washing machines (purchased from local retailers)- new construction</td>
<td>$100 (at each address)</td>
</tr>
<tr>
<td>WaterSense high-efficiency showerheads (with maximum flow rates of 1.75 gpm)</td>
<td>$20. Maximum of 2.</td>
</tr>
<tr>
<td>WaterSense high-efficiency showerheads (with maximum flow rates of 1.75 gpm) – new construction</td>
<td>$10. Every qualified new showerhead.</td>
</tr>
<tr>
<td>WaterSense high-efficiency urinal fixtures and valves (no more than 0.125 gallons per flush (gpf))</td>
<td>$200 maximum.</td>
</tr>
<tr>
<td>WaterSense high-efficiency urinal fixtures and valves (no more than 0.125 gallons per flush (gpf)) – new construction</td>
<td>$100 per urinal fixture and valve.</td>
</tr>
</tbody>
</table>

To ensure that customers receiving a rebate installed the fixture or appliance, Bozeman put in place several verification terms. The specific terms for each program can be found on each

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72 Lain Leonaik, email to author, May 26, 2016.
program’s website (toilet73; washing machine74; showerhead75; urinal76). I will use the terms for the toilet rebate program as an example.

The first clause states that, “the City reserves the right to do an on-site inspection to verify installation of the toilet(s) rebated through this program. Access to the rebated toilet(s) must be provided at the time of inspection”.77 If the appliance installation cannot be confirmed at the time of inspection, the user must reimburse the city for the rebate received. The second section requires proof of installation with the rebate application, and if proof is not included, then the application will not be reviewed. Proof of installation can either be an invoice from a certified plumber or photo documentation of the installed toilet. The final term reserves the city’s right to schedule an appointment for an inspection. The first and final clauses address the concern of applicants providing fraudulent proof of installation. The Water Conservation Division requires proof of installation for all appliance rebates.

The Water Conservation Division determined that a rebate program for outdoor water use was a secondary priority for Bozeman. The water conservation program’s outdoor water use goals for 2015-2016 centered around residential use, specifically through a sprinkler system rebate program. Sprinkler rebates are offered for retrofitting an existing sprinkler system or new construction.

Prior to applying for a sprinkler rebate, the interested applicant must complete a pre-application sprinkler check-up. The check-up should be completed by an approved provider. If the applicant chooses to perform a self-guided check-up, the Water Conservation Division staff must verify the check-up by completing a site inspection. After the check-up has been verified, the customer can apply for a sprinkler rebate. The application must include a diagram, photographs or a project description identifying the sprinkler system improvements, as well as an invoice from an approved provider and an itemized receipt. Similar to Bozeman’s indoor rebate programs, the Water Conservation Division lists necessary terms that hold consumers accountable after receiving a rebate. More specific limitations and instructions can be found on Bozeman’s Sprinkler Rebate Program webpage.78 Table 3-4 identifies the various outdoor rebates offered to Bozeman’s water customers.79

According to the City of Bozeman’s annual report, between 2014 and 2015 Bozeman invested over $67,000 in toilet, washing machine and irrigation system rebates—the rebates amounted to approximately 202 acre-foot water savings. In 2014, 144 high-efficiency toilets were installed,
and in 2015 that number rose to 206. In the same time frame, the rebate program resulted in the installation of 156 high-efficiency clothes washers. After launching sprinkler rebates in May of 2015, 11 irrigation systems were modified. By investing less than $70,000 in rebates, the City of Bozeman experienced $1.1 million in water savings.\(^8\) The Water Conservation Division assumed that for every acre-foot of water saved from the rebate programs, $5,500 was saved.\(^9\) Cost savings were determined by considering the true cost of providing potable water in Bozeman. Both the city and water customers experience these savings; water savings resulted from avoiding the cost associated with expanding the water supply system.

Table 3-4. Bozeman’s residential outdoor sprinkler rebate program.

<table>
<thead>
<tr>
<th>Sprinkler System Products</th>
<th>Rebated Amounts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualifying WaterSense® Smart Controller (retrofit to an existing system)</td>
<td>$250.00 or 50% of retail price (whichever is less) (1 per property)</td>
</tr>
<tr>
<td>Qualifying WaterSense® Smart Controller (new construction)</td>
<td>$50.00</td>
</tr>
<tr>
<td>MSMT Nozzles (retrofit to an existing system that replaces pop up spray heads)</td>
<td>$5.00 per nozzle or 50% of the retail price of each nozzle (whichever is less) Minimum of 5</td>
</tr>
<tr>
<td>MSMT Nozzles (new construction)</td>
<td>$1.00 per nozzle Minimum of 5</td>
</tr>
<tr>
<td>Rain Sensor (retrofit to an existing system)</td>
<td>$50.00 per sensor or 50% of retail price (whichever is less) (1 per property)</td>
</tr>
<tr>
<td>Rain Sensor (new construction)</td>
<td>$10.00 per sensor (1 per property)</td>
</tr>
</tbody>
</table>

Note: This table was obtained from the City of Bozeman Water Conservation website.

Figure 3-4 illustrates Bozeman’s water use before and after implementation of the water conservation rebate programs that began in 2014. Water consumption increased from 2014 levels, though this is likely due to the increase in population and 760 meters added to the system (Figure 3-4). Furthermore, in two years Bozeman’s gallons per capita daily (gpcd) decreased by

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\(^9\) Lain Leonaik, email to author, May 26, 2016.
7.4 percent from 122 gpcd in 2013 to 113 gpcd in 2015. These reductions occurred despite “increases in population and metered connections, and drier than average years.”

Figure 3-4. Comparison of water use and overall population in Bozeman, Montana from 2000 to 2015.

Note: This figure is from the City of Bozeman Water Conservation, “2014-2015 City of Bozeman Water Conservation Update: Annual Report to the City Commission.”

Administration and Financing of Rebate Programs:

In the 2014 fiscal year, Bozeman budgeted $50,000 for implementing the water conservation program, including a consumer education program and rebate programs. By 2015, this amount more than doubled, to $106,050. The recommended budget for the 2016 fiscal year requests $356,276 for the water conservation program. The budget increased because of rebate program expansions, more services were offered, and a Water Conservation Technician was hired. The Water Conservation Division, which administers the water conservation program, is part of the Public Works/Services Department. Two full-time staff members run the Program: a Conservation Program Manager/Specialist, Lain Leoniak, and a Water Conservation Technician.

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83 Ibid, 3.
C. Education and Outreach

Public education and outreach programs play an important role in water conservation programs. Education and outreach programs have several objectives. One objective of such programs is to identify water conservation opportunities offered by the city. A second objective is to encourage water conservation by instilling water conservation behaviors into customers. Also, educational and outreach programs provide feedback to the city regarding the water conservation program. These types of programs aim to foster a sense of place among community and support partnerships with local environmental organizations. The boundary between what constitutes an education program versus an outreach program is blurry. According to Water Outreach Education, part of the University of Wisconsin Extension school, “‘education’ refers to efforts involving the formal education system and ‘outreach’ to efforts intended to excite wider public interest.”87 For the purposes of this paper, I make no distinction between education and outreach.

Mountain Water already uses education and outreach programs. These efforts include informing customers of water conservation tips on their website, as well as sponsoring local environmental organizations that conduct water education and outreach, including the Clark Fork Coalition, Watershed Education Network and the SpectrUM’s Groundwater Academy.88 In addition, Mountain Water has proudly supported several community projects (e.g., Rattlesnake Creek fish ladder, Rattlesnake Bridge Project, Missoula’s Water-Wise Garden, Trout Friendly Lawn Program).89

Education and outreach programs vary from city to city. If a city has a water conservation program, there is almost a guarantee it will have a community education component. Successful water conservation education and outreach programs explain to the public why water conservation is important (i.e., the benefits of water conservation and the potential dangers of not conserving water), as well as the mechanism for meeting conservation goals.90

Identifying water users with the greatest water usage, and focusing the majority of educational outreach on this group will maximize water savings.91 Utilities should convey the information in a variety of formats, and do so repeatedly. Specialists recommend that utilities use a shared theme across all of the educational products; this can include a logo, motto, and/or spokesperson.92 The Alliance for Water Efficiency explains that “a person must hear a message

92 Alliance for Water Efficiency. “Public and Consumer Education Programs.”
more than three times, on three separate occasions before the message is retained in long term memory.”

Guidance documents recommend directing educational programs not just to residents and schools, but also towards water system employees. Educating employees will save water and in funds allocated towards operation and production.

Typical approaches for sharing water conservation information:

- **Water bills**
  - Comparing resident’s water use to neighbors with similar characteristics
  - Providing water system/water rate updates
  - Including conservation tips
- **Utility/Water Conservation Program website**
  - Offering conservation tips
  - Providing links to water conservation programs
  - Advertising water conservation events
  - Scheduling speakers (for schools and organizations)
  - Providing water conservation resources (WaterSense, WaterWise, AWE, AWWA, school curricula, etc.)
- **Local events**
  - Tabling
  - Xeriscaping seminars
  - Water conservation classes and tours
  - Water conservation contests between schools or neighborhoods
- **Outreach and resources for local schools**
  - Education packets (curricula) for teachers and students
  - School visits
  - Special talks and presentations
- **Newsletters (online and mailings)**
- **Other mailings**
  - Television, radio, newspaper and social media ads, PSA, and announcements
- **Partnerships and sponsorships of environmental education nonprofits**

If a water conservation education program is implemented exclusively, the purpose is to encourage the immediate adoption of specific conservation behaviors. These programs are typically a response to an urgent need to conserve water due to drought or other causes of water shortages. In some cases, utilities experienced 20 percent declines in water use after reaching out to the public for water reductions. Reductions in water use result from behavioral changes such as water customers taking shorter showers, irrigating less frequently, and making other conscious efforts to conserve water. The Alliance for Water Efficiency claims that these behavioral changes made to address temporary water shortages often end within a year despite continued education.

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93 Alliance for Water Efficiency. “Public and Consumer Education Programs.”
94 Ibid.
95 Ibid.
efforts until the next water shortage.\textsuperscript{96} For this reason, the Alliance for Water Efficiency recommends that education and outreach campaigns should not be used as the sole water conservation strategy.\textsuperscript{97}

While the Alliance for Water Efficiency asserts that education and outreach programs are not effective at influencing lifelong water conservation behaviors, these programs do enhance the effectiveness of other water conservation efforts, especially rebate programs. For this reason, cities like Westminster and Bozeman incorporate extensive water conservation education programs into their water conservation program.

\textit{Examples of Education and Outreach Programs}

Many education and outreach programs exist nationwide, but I decided to use the programs from two of the examples I identified above. Education and outreach programs make up a major part of Westminster’s and Bozeman’s water conservation programs, and a large portion of their water conservation program budgets go towards these efforts.

\textbf{Westminster, Colorado:}

Educational events and programs comprise a substantial amount of Westminster’s conservation program. The Water Festival\textsuperscript{98} and Water Awareness Week account for Westminster’s biggest education programs. The annual Water Festival delivers an educational experience for fourth and fifth grade students, parents, and teachers in the cities of Westminster, Thornton and Northglenn. Since 2004, the Water Festival engaged over 11,000 students. Local professionals teach students about water conservation, the history of Colorado water law, water chemistry, the water cycle, local water systems, aquatic wildlife and ecology.\textsuperscript{99} The purpose of the Water Festival is to engage students hands-on in the discussion of local and global water issues. Funded by the cities of Westminster, Thornton and Northglenn, the Festival is organized by the Water Festival Committee. City employees from each of the three cities make up the Water Festival Committee. During Water Awareness Week, Westminster holds water awareness presentations at local elementary schools, in addition to exhibiting water awareness displays at malls and public facilities. At the same time, water festivals are also held at local schools.\textsuperscript{100}

Other notable educational programs are free irrigation audits\textsuperscript{101}, the Garden in a Box program (Center for Resource Conservation)\textsuperscript{102}, free xeriscaping seminars (Department of Parks, Recreation and Libraries) and tabling at public events.

\textsuperscript{96} Alliance for Water Efficiency. “Public and Consumer Education Programs.”
\textsuperscript{97} Ibid.
\textsuperscript{98} Heather Waters. “You are invited to register for the 2013 Water Festival,” accessed May 14, 2016, \url{http://events.r20.constantcontact.com/register/event?llr=kwud54gab&oeidk=a07e6d77076b903cd}.
\textsuperscript{99} Ibid.
\textsuperscript{100} Draft: City of Westminster Water Conservation Plan, (City of Westminster and Aquacraft, 2012), 6.
\textsuperscript{101} Westminster Free Irrigation Audits: \url{https://conservationcenter.org/slow-the-flow-2/outdoor-sprinkler-consultation/}
\textsuperscript{102} Westminster Garden in a Box Program: \url{https://conservationcenter.org/gardens/}
Money from the water conservation program budget goes towards administering these programs and purchasing materials and supplies, mostly for promotional giveaways out at events.\(^{103}\) Although Westminster is not able to reliably associate these programs with measurable water savings, the city strongly believes in the importance of water conservation education programs, especially those focused on youth.

**Bozeman, Montana:**\(^{104}\)

Bozeman’s education and outreach programs focus attention on students, teachers, as well as the general public. One of the initial education and outreach programs developed an Educator Guide, specifically made for Bozeman educators. The Water Conservation Division partnered with the Stormwater Division and Project WET to design the Educator Guide. This pilot education project included interactive science activities for five local teachers; activities aimed to teach teachers and students about Bozeman’s watershed and the dramatic influence individual actions can have on the health of the watershed. The program’s goal was to “present complex concepts specifically related to Bozeman’s watersheds, water conservation and stormwater, to educators via lessons plans that are relevant, accessible and create positive experiences for young learners.”\(^{105}\) The pilot project received so much praise that the Water Conservation Division decided to expand the program to two more schools in 2016.

Bozeman also runs a Public Information Campaign that includes the Water Conservation Division’s website.\(^{106}\) The Public Information Campaign presented discussions of Bozeman’s water source and ways to conserve water for several organizations including the Greater Gallatin Watershed Council, Montana State University Fall Water School, Idaho-Montana Parks and Recreation Fall Conference, the League of Women Voters, MSU Sustainability Series, Bozeman Public Library Wonderlust Series Friday Forum, Bozeman homeowner’s associations and neighborhood councils. The Water Conservation Division also published pieces about its water conservation program in the AWWA Journal, Montana Quarterly, Bozeman Chronicle, and Bozeman Magazine. The Public Information Campaign successfully garnered media coverage to improve public awareness regarding where Bozeman’s water comes from, why water conservation is necessary, and how to access resources for conserving water.

The Water Conservation Division designed a very extensive website. Some of the website’s highlights include discussion regarding the value of water, ways Bozeman can benefit from water conservation, a link to the IWRP, resources for the rebate programs, a home use water calculator, and additional water conservation information. A second phase of website development in May 2015 added an explanation about how to calculate outdoor water use, sprinkler system audit instructions, additional rebate and incentive program information, and a list of Bozeman specific “water smart” plants.

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\(^{103}\) Stuart Feinglas, email to author, April 28, 2016.


\(^{106}\) [http://www.bozeman.net/government/water-conservation](http://www.bozeman.net/government/water-conservation)
Bozeman also conducted an Indoor Residential Water Usage Public Education Campaign. The strategies used in this campaign range from bill stuffers informing all customers about the rebates offered, to free leak detection kits, aerators and shower timers.

The Outdoor Residential Water Usage Public Education Campaign represents the final facet of Bozeman’s education and outreach program. In this campaign, tips for outdoor water conservation were included in local print advertisements and online news platforms during the 2015 irrigation season. These advertisements also informed customers of the new rebate programs for outdoor water use. Other strategies included advertising the Conservation Division’s website, offering a class and exam for Landscape Irrigation Auditors Certification, sprinkler system assessments/audits for 20 residents, and locating a Water Bottle Fill Station at heavily trafficked community events (e.g., Bogert Farmer’s Market and Music on Main) to encourage reusable water bottle use and appreciation for Bozeman’s tap water. Bozeman also worked with local experts to develop several plant lists that identify drought tolerant and water smart plants.

4. DISCUSSION

Based on my research, most municipal water conservation programs are made up of multiple components. Some programs focus on water rates and public education, while others incorporate rebates and education. Certain programs may have all three approaches. As one water conservation guidance document states, “individually, each component of a water conservation program can get results, but the most reliable results are obtained by the integration of all components.”\(^\text{107}\) Regardless of the program’s approach to achieving water conservation goals, public education and outreach always remain a core aspect.

Advocates for water budgets argue that water budgets offer the greatest opportunity for water conservation; the potential for water reductions was illustrated in EMWD. But by allocating more water to larger households and lot sizes during water short months, water budgets contradict the good intention of conserving water. Another point used to justify implementing water budgets is that water budgets ensure equity among water users because of the individualized nature of each water budget. However, I would argue that this equity is at a superficial level. Critics of water budgets argue that, “if home lot sizes are assumed to rise with personal income, water budget rates will exacerbate rate regressivity to the advantage of the social elite.”\(^\text{108}\) As Beecher (2012) says, “access to water for human sustenance should be assured in an affluent society, but a green lawn can hardly be considered a human right or necessity, at least not among moderate ideologies.”\(^\text{109}\)

In addition, increasing block rate structures are easier and less expensive to implement than water budgets. Both water rate structures require a robust billing system, especially water budgets. Olmstead and Stavins’ research suggests that water rates that encourage water

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\(^\text{107}\) Water Conservation Education Programs: EPD Guidance Document, (Georgia Environmental Protection Division Watershed Protection Branch, 2007), 3.
\(^\text{108}\) Beecher (2012), E70.
\(^\text{109}\) Ibid, E78.
conservation like water budgets and increasing block rate structures are “more cost effective than implementing non-price demand management programs.”\textsuperscript{110} Rebate programs are an example of non-price demand management programs.

However, transitioning all unmetered customers to metered systems is a prerequisite for any sort of increasing block rate scheme. Making this transition will likely raise issues with some customers, but undergoing this change is necessary if Missoula wants to treat all customers equally. Hypothetically, if an unmetered customer with a flat-rate uses more water than the average water user, then metered customers will be subsidizing them. However, there is no way to determine if flat-rate customers use more than the average amount of water because of the nature of being unmetered. Furthermore, it will be impossible to accurately assess the actual water savings of any water conservation effort if some systems are not metered.

Due to the many issues associated with water budgets, increasing block water rates present a less problematic rate structure that encourages water conservation. This assumes that the water rate is designed to optimize water efficiency and minimize consumer pricing insensitivity.

Quesnel and others (2016) analyzed energy efficiency rebate programs and applied the findings to water rebate programs. The study found that although a portion of consumers are intrinsically motivated to install energy efficient appliances because it is the “right thing to do,” saving money remained the greatest factor influencing consumers to purchase energy efficient appliances. Therefore, depending on the characteristics of a city, rebate programs are very likely to provide an opportunity for substantial water savings because of the financial incentive (i.e., saving money) they offer customers.

Water rate structures that encourage water conservation and rebates programs provide similar financial incentives and work well together. The water rate structure catalyzes the customer to conserve water, while rebates offer a means to conserve water so that consumers can experience water and subsequent bill savings. The rebate itself also saves the customer money because the cost of the appliance or fixture is reduced.

Rebate programs are relatively easy to administer and manage, as are education and outreach programs. Unfortunately, it is challenging, if not impossible to measure the effectiveness of education and outreach programs at encouraging water conservation. For this reason, when cities calculate the water savings attributed to a particular water conservation approach, they often say that education and outreach does not have any water savings. This is likely inaccurate. Therefore, cities typically account for the impact of community education and outreach programs on water conservation by stating that it helps to maximize potential water savings.

Every city and utility I examined in my research, regardless of whether they have a water conservation program or not, has some sort of education and community outreach component. At

the most basic and minimum level, many utilities offer conservation tips on their website, or a link to accredited water efficient appliances (e.g., WaterSense).

The book *Local Climate Action Planning* identifies greenhouse gas emissions reductions strategies. The authors (Boswell and others) explain that although changes in pricing can alter citizen behavior, effectiveness of the measure will significantly improve when paired with outreach.\(^{111}\) Though the authors are not directly speaking to water conservation planning, I believe the point still holds true for water conservation programs.

Based on a study performed by DeOreo and others (2016), the average indoor water use in single-family residences is 138 gallons per household per day (gphd).\(^{112}\) Missoula is fortunate to be in an area with a plentiful water supply. The next section discusses why water conservation is necessary for an area that is not currently experiencing depletion of its water source.

### 5. THE IMPORTANCE OF WATER CONSERVATION FOR MISSOULA

Mountain Water Company described Missoula’s aquifer as a “seemingly endless source of clean, fresh water.”\(^{113}\) So why does Missoula need to conserve water? Aren’t water conservation programs just another cost on top of acquiring the water system? Considering the observed and expected impacts of climate change and growing global population, conserving water is morally responsible. In addition, water conservation offers several benefits to the City of Missoula and its citizens.

Reduced water demand will minimize the cost of infrastructure maintenance, operation, and expansion.\(^{114}\) This benefit of water conservation is likely of special importance to the city. With the aging, inefficient water system infrastructure in place, the city will have to pay substantially to renovate the system. By decreasing the amount of water being pumped to customers, there will be less wear and tear on pipes and pumps. Conserving water will extend the lifetime of the current infrastructure and help defer maintenance and repairs.

In addition, incorporating water conservation into the water utility will reduce non-point source pollution from stormwater and irrigation runoff.\(^{115}\) Many property owners apply fertilizers, pesticides or other chemicals to their landscape; when it rains substantially or the landscape is over-watered, those chemicals are washed into storm drains and water bodies.

Xeriscaping is one of many different water conservation strategies. Native plants are well-adapted to the current climate and environment and tend to require less water, additional

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\(^{112}\) DeOreo et al. (Water Research Foundation, April 2016), 11.


\(^{115}\) Ibid, 4.
nutrients, and protection from pests. Additionally, if grass lawns are watered less, the amount of fertilizers and pesticides washed into sensitive aquatic systems will decrease.

One of the most substantial arguments for a water conservation program relates to Missoula’s CCAP. Water conservation will help Missoula meet its climate action goals by reducing energy consumption and associated greenhouse gas emissions. In addition, a water conservation program will directly benefit Missoula residents, since water and energy are closely linked. Conserving water will reduce the community carbon footprint because as water use decreases, the energy needed to pump and treat drinking water and sewage also decreases.

A. The Relationship Between Water and Energy

Purchasing Mountain Water Company offers considerable benefits for the citizens of Missoula, although it does present an added challenge when it comes to achieving the goal of carbon neutrality by 2025. Owning and operating the drinking water system means adding its carbon footprint to the city’s carbon footprint; this was not originally incorporated into the city’s various emissions inventories in recent years. Water is heavy. One gallon of water weighs 8.34 pounds. As a result, water requires significant amounts of energy even before customers use water. The River Network estimates that at least 290 million metric tons of the nation’s carbon footprint goes to moving, treating and heating water. Hence, water conservation will reduce the carbon footprint of Missoula’s water utility, wastewater treatment plant, and community.

Griffiths-Sattenspiel and Wilson state that, “investments in water conservation, efficiency, reuse and LID [low impact development] are among the largest and most cost-effective energy and carbon reduction strategies available.” According to Griffiths-Sattenspiel and Wilson, the largest municipal energy cost goes towards supplying and treating water and wastewater. They identify “end use” water conservation, or water conservation at the tap, as the area for the greatest potential water and energy savings. The energy required for supplying and treating water varies between cities because it is based on a variety of factors. If customers consume less water, it follows that less water needs to be treated and pumped to customers, resulting in a reduction of the water utility’s and municipal government’s carbon footprint.

Water conservation practices will also directly benefit water users and reduce the community carbon footprint. For example, by upgrading water using appliances and fixtures in every household in the United States, hot water use would diminish by roughly 20 percent. Based on River Network estimates, this reduction in hot water will save 41 million megawatt-hours (MWh) of electricity, 240 billion cubic feet of natural gas, and approximately 38.3 million metric tons of carbon dioxide emissions. Due to the direct relationship between water and energy, saving water also saves households on their energy bill, in addition to shrinking the community carbon footprint.

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118 Ibid, 36.
119 Ibid, 27.
120 Ibid.
carbon footprint. Furthermore, if water customers reduce the amount of water consumed, less water will enter the wastewater treatment plant.

“Missoula’s Greenhouse Gas Emissions Inventory and Analysis, 2003-2008” identified wastewater as Missoula’s most energy intensive sector of municipal operations.121 Large amounts of energy are required to pump and treat wastewater so that it is safe to discharge into the Clark Fork River. That inventory indicated that approximately 55 percent of the City of Missoula’s carbon emissions from municipal operations are associated with the WWTP and municipal buildings.122 Customer water conservation will lower the carbon footprint of the Missoula WWTP because less water will be pumped to the WWTP, treated, and then pumped to the river or poplar plantation. By reducing the amount of water that is pumped and treated, the energy required to power the process is also decreased. By extension, water conservation will help lower the city’s carbon footprint and help the city achieve its greenhouse gas emission reduction goals.

B. Water Conservation and Climate Action Plans

Because of the clear relationship between water use and energy, many cities incorporate water conservation strategies into their climate action plans. Bozeman, Montana represents one example. In 2008, the City of Bozeman adopted a Municipal Climate Action Plan (MCAP). In creating the MCAP, the Bozeman Climate Protection Task Force stated 40 recommendations, all of which were adopted by the City Commission. Recommendation WWR-5 asks that the MCAP set water conservation goals, and then measure, monitor, verify and act on these goals. A description of the WWR-5 is included below:

Declare water conservation a Commission goal and request quarterly reports from the City engineer on water usage per capita. With the aid of the City Engineering department, set firm goals for water usage, beginning with City facilities and grounds (e.g., parks). The Task Force recognizes that in our dry western climate, water quality and quantity have a huge influence on development, lifestyle, and quality of life. The Task Force recommends that the City Commission support such water conservation programs such as low water use landscaping and incentives for high volume toilet replacement.123

This recommendation is also closely linked to Planning, Building and Energy recommendation to manage energy usage.

The Bozeman community also created the Community Climate Action Plan in 2011. The Community CAP lists water conservation as one of the main emission reduction strategies. The Community CAP highlights Bozeman’s 2008 Toilet Rebate Program as a successful water

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conservation approach.\textsuperscript{124} Water and wastewater represents 27 percent of the total municipal emissions for the City of Bozeman, the second greatest contributing sector of carbon dioxide emissions.\textsuperscript{125} In both the Municipal and Community CAPs, the documents identify water conservation as an essential emission reduction strategy.

In July 2015, Climate Smart Missoula and the City of Missoula came together to create the Missoula Community Climate Smart Action Plan v1.0. This plan was designed to “enhance the work that the City of Missoula and other entities, groups, and businesses are already doing” towards creating a community resilient to climate change.\textsuperscript{126} Strategies to address water conservation include developing education and assistance programs with property managers, renters, and neighborhood associations, as well as community education programs.

In addition to the Missoula Community Climate Smart Action Plan v1.0, Missoula’s CCAP incorporates water conservation into the plan, though it is only on a small scale. One of MCAP’s strategies is installing water wise and efficient bathroom fixtures in city-owned buildings and facilities during 2016. This effort will save the city 1.2 metric tons of carbon dioxide emissions, and net over $44,000 in savings.\textsuperscript{127} If additional water conservation goals were incorporated into the CCAP, and Missoula’s work expanded to the residential sector, the water and energy savings realized would be even greater. Furthermore, these efforts would help reduce the community-wide carbon footprint.

6. CONCLUSIONS AND RECOMMENDATIONS

Numerous factors drive water demand, such as, climate, weather patterns, type of water source, population growth, development patterns, the local economy, household finances, and more intangible characteristics of the community. For these reasons, one cannot reliably predict the effectiveness of water conservation approaches based on other cities’ results, though it is helpful to look at ways other cities have approached water conservation and their experience and outcomes.

After considering the extensive research and different water conservation approaches, I concluded that an increasing block rate structure should be an important element of a water conservation program for the City of Missoula. Examples from other cities demonstrate the effectiveness of such a rate structure at encouraging water conservation. Increasing block rates have an added advantage: they are not costly or complex to administer. As a first step, however, however,

\textsuperscript{127} Chase Jones and Andrew Valainis. Conservation & Climate Action Plan (City of Missoula Montana), 37.
it is necessary to critically review the current structure Mountain Water has in place, and identify the areas that should remain unchanged and the aspects that should be modified.

My research also showed that rebate programs and education and outreach program are important components of effective water conservation programs. The benefits of such programs far-exceed their cost. Moreover, my research demonstrated that rebate and education programs are among the most common water conservation strategies adopted by municipal water utilities in communities similar to Missoula.

Based on these conclusions and additional findings in the body of my paper, I recommend that the City of Missoula develop a strong water conservation program from the outset. Specifically, I offer the following recommendations to the city.

First, when determining which approaches are best suited for the City of Missoula, it is necessary to calculate the current carbon footprint of the water system, assess the current water demand, and establish water conservation goals based on carbon footprint reduction goals. The city should incorporate these water conservation goals and strategies into Missoula’s CCAP. Including water conservation and strategies into the CCAP will best enable Missoula to achieve their goal of carbon neutrality by 2025.

Second, the city should critically review the current rate structure Mountain Water has in place, and identify the areas that should remain unchanged and the aspects that should be modified. This information, along with identifying the city’s carbon footprint reduction and water conservation goals, can be used to choose the strategies that best suit the city’s ultimate endpoint.

Third, the city should transition all unmetered customers to meters. Metering every customer’s water use will ensure that all customers are treated equitably, water conservation goals can be measured, and efficient water practices are encouraged. As stated by Mountain Water, “conservation rises dramatically in metered homes and offers many people the opportunity to decrease their water bills.”

Fourth, the City of Missoula should establish a comprehensive water conservation program that includes an increasing block rate structure, rebate programs, and education and outreach. My research clearly shows that the three water conservation approaches I studied are connected. “Building Better Rates for an Uncertain World” by the Alliance of Water Efficiency discusses the three P’s: pricing, programs and persuasion. Pricing gives water customers an incentive to conserve water, acting as the catalyst for water conservation. Programs like rebates provide customers with a means to achieve that goal. Persuasion, also known as community education and outreach, encourages water consumers to save water and teaches them how to conserve water and money.

I would urge the city to consider an increasing block rate structure. Numerous studies support the finding that increasing block rate structures are the most effective water conservation strategy.

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This rate structure is not as complex to implement as water budgets, nor is it as costly to administer. Not to mention, customers with larger lot sizes are not favored in this pricing scheme. In comparison to water budgets, an increasing block rate structure is less of a jump from the current rate schedule proposed.

Desirable for a variety of reasons, rebate programs produce a significant degree of end use water and energy savings. In addition, since such programs are voluntary, they are generally not as controversial as mandatory measures. Also, rebates programs can be designed to direct money into the local economy.

Regardless of the approach or approaches that the City of Missoula decides on, it is imperative that education and outreach be a part of the program. Missoula has a strong base of nonprofit organizations, many of which dedicate their time to environmental education. The City of Missoula should continue Mountain Water’s collaboration with local environmental education organizations. Additionally, if those organizations are interested in a partnership with the city in formulating education and outreach programs, the city should capitalize on this valuable resource and opportunity.

Education and outreach programs provide important mechanisms for conversing with the community. These programs will allow Missoula to learn about the community’s values, their likes and dislikes, as well as gain community support, and ensure that the water conservation program chosen is right for Missoula and can be successful.

Fifth, the city’s water conservation program should be part of the Public Works Department. This recommendation was offered as advice from one water conservation manager I spoke with. If the water conservation program is placed under the Sustainability or Climate Action Plan umbrella, it will flounder for funding and be unsuccessful. Both Bozeman’s Water Conservation Program and Westminster’s were part of the Public Works Department for their cities.

Sixth, the City of Missoula should acquire the Alliance for Water Efficiency Conservation Tracking Tool (version 2.0) because it will allow the city to strategically and reasonably consider all water conservation options. With this tool, a city can develop a hypothetical portfolio that includes various conservation measures. Although the outputs are based on some assumptions, the tool is valuable for planning purposes because it provides water savings and implementation cost estimates. The City of Bozeman utilized this resource for determining the conservation program that was best suited for their city.

Seventh, the City of Missoula should join the American Water Works Association (AWWA) and Association of Metropolitan Water Agencies (AMWA) to gain access to their resources. The majority of my information came from or connected to these two associations. However, I was not able to access some of the AWWA and AMWA resources because I am not a member or because they require purchase. It is safe to assume that these resources will help Missoula in the

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131 Lain Leonaik, phone call, March 9, 2016.
process of assuming management of the water system and formulating a water conservation program.

Eighth, the city should establish 10-year goals for the water conservation program that include evaluation metrics. Bozeman found that, “the most successful programs appear to be based on establishment of goals for a 10-year timeframe, with a 5-year review of progress towards goal achievement.”

Therefore, my final recommendation is that the city periodically, at least every 5 years, review and revise the water conservation program with public input. Other critical components that influence the success of a water conservation program are performing pilot study programs and hiring a Conservation Program Coordinator.

As stated in Missoula’s CCAP, “the City of Missoula believes that it is uniquely positioned to act as a leader and catalyst for positive action in the community through conservation and climate action planning.” What makes a city a leader? I think great leaders are constantly thinking ahead and planning for the future. Great leaders do what is needed even before it is necessary.

I believe the City of Missoula currently sets a very commendable example of environmental stewardship. Water is arguably the most valuable resource on this planet. If Missoula can save water, it should. In the process, Missoula will lead by example and reinforce the importance of environmental stewardship, minimize non-point source pollution, reduce energy use and associated carbon dioxide emissions, help meet its climate action goals, save money and support the local economy. Of course, it will take time, expertise and capital, but with the breadth of water conservation resources available, it is possible to design a water conservation program that best suits Missoula and serves the public good.

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134 Ibid.
135 Chase Jones and Andrew Valainis. Conservation & Climate Action Plan (City of Missoula Montana), 5.
7. WATER CONSERVATION RESOURCES

AWE: Alliance for Water Efficiency [http://www.allianceforwaterefficiency.org](http://www.allianceforwaterefficiency.org)
- AWE is a nonprofit advocating for water efficient products and programs. A few of AWE’s goals include 1) providing complete information on water-efficient products, practices and programs, 2) training water conservation professionals, and 3) educating water users. This organization offers many valuable resources like access to Annual Reports, Strategic Planning documents, and a resource library.

AWE Home Water Use Calculator [http://www.home-water-works.org](http://www.home-water-works.org)
- Created by AWE, this tool estimates a household's water use and compares it to other homes, in addition to provided suggestions for where to begin home water conservation measures.

- This free tool provided by AWE models the effects of different water rate structures. This product is unlike other modeling programs because it accounts for customer consumption variability, demand response, drought pricing, probability management, and fiscal sustainability.

- AWWA is the “largest nonprofit, scientific and educational association dedicated to managing and treating water.” This website provides innumerable resources related to managing water resources, including but not limited to water conservation, water loss control, and source water protection. Members gain greater access to and discounts for these valuable resources.

- This publication is a utility management standard that describes the integral aspects of establishing, executing, and assessing a successful water conservation program.

City of Bozeman Comprehensive Water Rate Study: April 2007. HDR. [https://www.bozeman.net/Smarty/files/a6/a67c26e4-00a9-44ae-ae69-0773071f96c9.pdf](https://www.bozeman.net/Smarty/files/a6/a67c26e4-00a9-44ae-ae69-0773071f96c9.pdf)
- This document was prepared by HDR Engineering for the City of Bozeman. The purpose was to conduct a complete water rate study that achieved the goal of developing a financial plan and water rates that would meet the city’s needs.

- This document was published in 2014 and outlines the Water Awareness and Conservation Survey conducted by BBC Research and Consulting for the City of
Bozeman. This survey may be useful in determining the proper water conservation program/approach for Missoula.

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Water System Acquisition Update

The City of Missoula has battled with the Carlyle Group to obtain ownership of Mountain Water Company since 2013. At the time of writing “An Overview and Assessment of Water Conservation Approaches for Municipal Water Systems” a District Court Judge, Karen Townsend had ruled that the city’s plan was “more necessary than its current use as a private, for-profit enterprise” (O’Brien 2015). However, the Carlyle Group appealed the District Court’s decision to the Montana Supreme Court. Therefore, the future of the eminent domain case was uncertain. My briefing report offered information regarding water conservation programs in the chance that the City of Missoula would obtain ownership of the water utility. In August of 2016, the city won the eminent domain case in a 5-2 ruling by the Montana Supreme Court (Erikson 2016). During this time, the Carlyle Group sold Mountain Water Company to Liberty Utilities.

The struggle for ownership of Mountain Water Company is finally ending, as the Missoula City Council approved a series of bonds for the purchase of the water utility in early 2017 (Bragg 2017). The City of Missoula will pay Mountain Water Co. $83.7 million and several million more in attorney fees and other costs, amounting to $96.4 million (Szpaller 2017). A comprehensive agreement will be placed before City Council by May 20th, 2017, with the objective of fully transferring ownership to the city by May 31st, 2017 (Szpaller 2017). However, due to lack of consensus regarding final paperwork, a final meeting with the city and Liberty Utilities was postponed (Chaney 2017). According to an article in the Missoulian, “the delayed deal determines exactly how Liberty hands over the utility, its scheduled maintenance projects and operations to municipal control” (Chaney 2017). Despite meeting setbacks, Mayor Engen expects that the city will be operating the water system by mid-June (Chaney 2017). Once ownership is transferred to the city, Mountain Water Company will be renamed Missoula Water (Szpaller 2017).

References


Part Three

A Summer in the Mountains: A Reflection on My Time Working for the Montana DEQ
A Summer in the Mountains: A Reflection on My Time Working for the Montana DEQ

From July through August of 2016, I worked for the Montana Department of Environment Quality (DEQ) on their Montana Stream Reference Project. The Stream Reference Project was initiated in the early 1990s by Rosie Sada and Michael Suplee of the Montana DEQ. The purpose of the project was to provide “reference” data (i.e., physical, chemical, and biological data) for streams in each of Montana’s ecoregions that have experienced as little human impact as possible. Montana has seven unique ecoregions: Northern Rockies, Idaho Batholith, Canadian Rockies, Middle Rockies, Transitional, Northwest Glaciated Plains, and the Northwest Great Plains. My field season was spent in the Canadian Rockies and the Transitional ecoregions.

As of 2016, the DEQ identified 184 sites throughout Montana (Sada and Suplee 2016). These sites were selected based on several criteria such as: watershed road density, percent land use for agriculture, logging density, logging and grazing impacts, active or abandoned mines, and point source pollution (Sada and Suplee 2016). Upon visiting each site, Stream Reference Project crews provided an evaluation that categorized each site as either Tier 1 or Tier 2. The DEQ defined Tier 1 sites as “essentially pristine, virtually unaltered from original state” (Sada and Suplee 2016). Tier 2 sites are those sites which are “minimally impacted” by human activity (Sada and Suplee 2016). When we were taught how to evaluate streams as Tier 1 or Tier 2, Michael and Rosie did not have us consider climate change as a human impact.

I worked as the crew leader on a team of three Environmental Studies graduate students for the Stream Reference Project. Before heading out to the field for training, we spent time in Helena at the DEQ Headquarters preparing for the field and becoming acquainted with the purpose and goals of the Stream Reference Project. During this time in Helena we used
coordinates to mark the location of each site on a map, contacted private property owners to ask permission to sample on their land, and prepared the sampling equipment. Rosie and Michael joined our crew in the field for roughly two weeks of training. Over training we learned all the sampling procedures, other than a handful of exceptions.

Following training, we traveled to approximately 20 more sites to complete stream sampling. Normally, it would take two days to complete a site. A typical first day in the field began by driving and or hiking in to each site. After reaching the site, we would perform a visual assessment of the water clarity and move onto water chemistry sampling. The water chemistry analytes collected for included nutrients, metals, temperature, turbidity, and conductivity, in addition to a few others. During water chemistry sampling, I collected water samples for phytoplankton analysis. This involved pumping between 250-2,000 mL of stream water through a filtration system that collected phytoplankton on a fiberglass filter. Once these initial samples were collected, we determined the length of the sampling reach by measuring the average wetted width of the stream and multiplying that number by 40. The reach was divided into 11 equal transects labeled A through K (A was the furthest upstream transect). If the length of the reach was greater than 500 meters, sampling procedures for several parameters were altered to accommodate the length of the reach.

After the 11 transects were marked, I began sampling for algal biomass at each transect while the other crew members sampled for sediment metals, periphyton, macroinvertebrates, in addition to, completing a visual aquatic survey at each transect. Sampling for algal biomass was a very time-consuming procedure that required high attention to detail and concentration. The most prominent substrate at the sampling location would determine the method for collection. If the main substrate was mud, a core sample was taken. At the transects that were comprised
mostly of macrophytes, I would use a hoop to collect aquatic plant samples. If the stream bed was primarily gravel or rocks, I used a template to designate an area where I scraped and scrubbed off algae. The algae collected from the rocks was filtered onto a fiberglass filter. This was the most commonly used sampling method for algal biomass across all sites. Normally, completion of these tasks marked the end of the first day at a site. The next day was spent collecting physical data to determine geomorphological classification (i.e., bankfull, slope, pebble count, and floodprone area), in addition to measuring streamflow. My tasks on the second day were identifying plants along the length of the reach and performing a riparian assessment. However, I would also assist my crew with other tasks that needed to be completed before the day ended.

After the field season ended, I analyzed the algae samples collected over the summer for the Stream Reference Project and Vicki Watson’s Clark Fork River research. This analysis was performed under the supervision of my graduate advisor, Vicki Watson. Laboratory analysis quantified the areal biomass of attached algae by using chlorophyll a analysis (Sartory 1982; Sartory and Grobbelaar 1984) and ash free dry weight analysis (American Public Health Association 1981). The information obtained from this analysis was input into Excel to calculate the amount of chlorophyll from a particular stream or river reach. The physical, chemical, and biological data collected over the past decades for the Stream Reference Project has been used to guide the development of water quality standards (Sada and Suplee 2016). I would also argue that this data collected could be used to inform restoration projects.

Both the Stream Reference Project field work and chlorophyll analysis opportunities were presented to me by Vicki Watson. From these opportunities, I gained experiences that bring diversity to my resume and will further my career goals. Prior to working for the DEQ I had
never performed field work, so all the field sampling methods I learned over the summer were new to me. In addition, while I had worked in an environmental chemistry lab after college, I had little experience using instruments. These job opportunities provided many skills necessary for working in the watershed and water resource management field.

Though the skills I acquired from these jobs are important, I grew the most from the challenges I overcame. For example, when we prepared to go out to the field we would bring primary equipment and at least one backup. Equipment is your lifeline in the field and without functioning sampling equipment you cannot perform your job. However, sometimes both your primary and secondary equipment breaks. This is what happened to the handheld pump I used for both the phytoplankton and chlorophyll sampling. I overcame this obstacle by applying my resourcefulness; I installed the functioning part from one pump into the working part of the other, to create a single working pump. Also, my primary duty as crew leader was being responsible for the logistics of traveling between sites. While this appears to be straightforward, organizing travel and sleeping arrangements can become challenging when the schedule changes frequently. This experience taught me how to be flexible and adjust to a constantly changing schedule. But organization was also critical to successfully altering travel arrangements, while staying within the travel budget. Resourcefulness, adaptability, and organization are three characteristics that will prove useful in any career.

Overall, working on the Stream Reference Project, in both capacities, was a significant experience that will advance my career prospects after leaving the Environmental Studies program. From these positions, I made connections in the watershed management field, gained and fostered skills that will benefit my career endeavors, and harnessed my current skills and
knowledge that ensured my success. If other students are given the same job opportunities, I would strongly recommend that they act upon them.
Works Cited


Part Four

Digging Deeper: A Reflection on an Internship with American Rivers

Application of Wild and Scenic Rivers Designation: Does designation protect rivers from mining activities?
Digging Deeper: A Reflection on an Internship with American Rivers

Beginning in the fall semester of 2016, I interned with American Rivers under the supervision of Kascie Herron and Robin Saha; I completed my internship the following semester. The purpose of my internship with American Rivers was to research the application of Wild and Scenic Rivers designation, as it relates to protecting rivers from mining activities. I was tasked with writing a paper that analyzed and synthesized my research into a document that could be easily read by laypeople. In this analysis, I described how mining activities have been regulated, litigated and/or stopped in Wild and Scenic rivers using specific examples.

The first section of my paper introduces the reader to the Wild and Scenic Rivers Act. The information presented in this section includes the purpose of the Wild and Scenic Rivers Act, definitions important to understanding the legislation, background information on the Montanans for Healthy Rivers Wild and Scenic Rivers Proposal, and a brief history of mining in the United States and its consequences. The second main section describes the application of Wild and Scenic designation and how the Wild and Scenic Rivers Act addresses mining. A substantial component of this section is the examples I use to illustrate how Wild and Scenic designation protects rivers from mining activities. I categorized the examples based on how designated rivers were protected from mining. After looking at four river examples, I found that the St. Joe River in Idaho and the Tuolumne River in California used mining restrictions, while the North Fork of the Flathead River in Montana and the Chetco River in Oregon were protected by using mineral withdrawal. The next major section discusses how Montanans for Healthy Rivers can ensure that designated rivers are protected, at some level, from mining. I conclude that Wild and Scenic designation can be a useful tool for protecting rivers from select mining activities.
Working on this paper for American Rivers was my first introduction to the Wild Scenic Rivers Act. Prior to this internship, I was not aware of the Act’s existence, let alone that it could be used as a tool to conserve watershed health. Although my knowledge of the topic coming into the internship was nonexistent, I understood the Act and its designation implications because of the skills I established during my time at the University of Montana. For instance, in the spring of 2015 I took Len Broberg’s Environmental Law for Non-Lawyers course. This class served as an introduction to the legal and legislative world. I used the skills from this class, like reading and understanding litigation and federal legislation, in researching and completing my paper for American Rivers. Without this background, I think I would have found the entire internship process especially challenging.

This internship was important to my overall graduate experience because my I have had limited practice working on policy issues, and it gave me the opportunity to explore this part of watershed management. From this internship, I expanded my knowledge specifically about the Wild and Scenic Rivers Act, but also on how to conserve watershed health using national approaches (i.e., federal designation). Even though I have experience writing research papers, I found this internship particularly transformative because of its focus on policy. My new understanding of Wild and Scenic Rivers designation influenced my perception of how I might want to address watershed protection in my career. Rather than limiting my job searches to science specific jobs, I will also consider jobs at nonprofit organizations that address policy issues, like American Rivers. Through researching how Wild and Scenic designation can protect rivers from mining activities, I witnessed the important role nonprofit organizations play in ensuring watershed protection. That is not to say I was unaware of the influence nonprofits have on environmental issues, I just did not think policy-focused work was meant for me. After
completing this internship, I realized I found a new academic interest in the Wild and Scenic Rivers Act.

By explaining how the Wild and Scenic Rivers Act addresses mining, and providing specific examples, I believe this paper will be a very useful resource for people working on Wild and Scenic River issues. I appreciate that the information I found through this process will fill in several information gaps that needed to be addressed. As described in my paper, “the need for this paper arose from increased visibility of the Montana-based effort to seek new Wild and Scenic River designations in Montana. In addition to, more public interest regarding specific applications of the Act.” I found it rewarding that my paper spoke to a specific community need and has the potential to influence watershed protection efforts in the future. I believe a unique characteristic of the Environmental Studies Graduate program at the University of Montana is its emphasis on solving real-world problems that directly impact Montanans. My internship with American Rivers serves as a great example of this focus.

The difficulties I experienced during this internship primarily related to finding information on specific topics. For instance, I found it very challenging to identify examples of how Wild and Scenic designation has been used to protect rivers from mining activities. In addition, locating river management plans and Environmental Impact Statements for designated rivers proved to be nearly impossible. The least enjoyable aspect of this experience was no longer being able to access certain governmental agency websites, like the Bureau of Land Management during April. In order to overcome these challenges, I relied upon my resourcefulness and the resources I have access to at the University of Montana. For example, I contacted professors and research librarians at the University for suggestions on certain topics.
By using my network of individuals and their expertise, I dealt with the difficulties I experienced in a timely manner. This aspect of my internship exemplified the importance of networking.

Although a research paper detailing the application of Wild and Scenic designation was the most useful product for American Rivers, I wish I could have been more engaged with the organization itself. Also, I think I would have grown more from this experience if I was forced to go outside of my comfort zone and work with stakeholders, or create a product that was entirely different than something I have created before. If I could change the internship, I would have broken the internship into two parts. The first part being the research paper and the second, a project using the information from the paper to create a different product (e.g., a presentation for stakeholders, or a booklet that identifies the main takeaways from my research paper). In order to make this possible, I would have needed to plan my schedule differently so there was more time to focus on the research paper in the fall, with the hope of working with American Rivers in the spring semester on a different project.

My goal coming into graduate school was to gain experiences that expand my knowledge and skillset to better prepare me for a professional career working in watershed management. This internship furthered my career goals by adding another tool to my “toolbox” for protecting watersheds and water resources. Using federal Wild and Scenic designation to retain the integrity of rivers threatened by mining, approaches watershed management from a national level. This experience also broadened my perception of the type of career I might be interested in after graduate school. Another important way this internship furthered my career goals is by giving me the opportunity to create connections with professionals working to protect watershed health.

American Rivers is a national nonprofit organization that can offer many opportunities to students, including professional connections. Kascie was very flexible and willing to work with
me on a project that I was excited about completing. I would recommend that other students pursue internships with American Rivers, especially those that work with Kascie Herron. Ultimately, this was a valuable experience, both academically and professionally. Through this internship, I was really able to dive into the application of Wild and Scenic designation, but I also learned to not limit myself to topics within my comfort zone.
APPLICATION OF THE WILD AND SCENIC RIVERS ACT

Does designation protect rivers from mining activities?

Lexie Yoder, American Rivers
May 19, 2017
Photo credit: Tim Palmer
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Background

Politicians have recognized the importance of protecting our nation’s water, air, and wilderness areas for decades. Several historic environmental legislative acts were approved by Congress during the 1960s. Often the Clean Air and Clean Water Acts, National Environmental Protection Act, and Wilderness Act are associated with this significant period in environmental history. In addition to the familiar legislation, the lesser known Wild and Scenic Rivers Act was enacted during this time.

Almost two-thirds of the nation’s dams were built before 1969; during the height of dam development the nation started to observe the negative impact dams had on the environment. Increased awareness about river modification implications led President Lyndon B. Johnson to sign the Wild and Scenic Rivers Act in 1968. The purpose of the Wild and Scenic Rivers Act is to uphold the national policy that:

“certain selected rivers of the Nation which, with their immediate environments, possess outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values, shall be preserved in free-flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations” (16 U.S.C. 28.).

The passage of this monumental legislation created a National Wild and Scenic River System that comprises segments of 208 rivers in 40 states, including Puerto Rico (National Wild and Scenic Rivers System, A National System 2017). The Act classifies river segments as either “wild,” “scenic,” or “recreational.” Wild rivers are “those rivers or sections of rivers that are free of impoundments and generally inaccessible except by trail, with watersheds or shorelines essentially primitive and waters unpolluted” (16 U.S.C. 28.). The Act describes these rivers as a representation of “vestiges of primitive America.” Scenic rivers and segments are also free of impoundments, but shorelines or watersheds are accessible by roads in some places. Recreational river areas are “those rivers or sections of rivers that are readily accessible by road or railroad, that may have some development along their shorelines, and that may have undergone some impoundment or diversion in the past” (16 U.S.C. 28.).

Eight rivers were first designated upon the approval of the legislation and 27 rivers were identified for study. The original Wild and Scenic Rivers include Clearwater, Eleven Point, Feather, Rio Grande, Rogue, St. Croix, Salmon (Idaho), and Wolf (16 U.S.C. 28.). After studying the outstandingly remarkable values (ORVs), sections of Montana’s Flathead and Missouri Rivers were designated in 1976. ORVs are defined in the Wild and Scenic Rivers Act as special values that make a river worthy of special protection (e.g., scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values). According to the Army Corps of Engineers National Inventory of Dams, over 76,361 dams have been completed in the United States since before 1900 (“NID” 2016). These dams have impacted 600,000 miles of rivers in the United States (National Wild and Scenic Rivers System, A National System 2017). Compared to the 17 percent of rivers impacted by damming and river modification, only one-
quarter of one percent of rivers are protected by the Wild and Scenic Rivers Act (National Wild and Scenic Rivers System, A National System 2017).

Montanans for Healthy Rivers: Wild and Scenic Rivers Proposal

Montanans for Healthy Rivers is a coalition of Montanans working to preserve the water quality and free-flowing nature of rivers in western Montana (“About Us” 2012-2013). After four years of communicating with various stakeholders, the partnership drafted a Citizen’s Proposal to designate more Wild and Scenic Rivers in Montana. American Rivers represents one of the many groups in this coalition fighting to protect current Wild and Scenic Rivers, as well as propose more rivers for designation. Since the designation of the North, Middle and South Forks of the Flathead River and 150 miles of the Missouri River in 1976, no additional rivers or segments in Montana have been approved for designation.

The intention of the Citizen’s Proposal is to designate 54 river segments in western Montana, amounting to almost 700 miles. The proposed rivers fall within eight different watersheds (e.g., Clark Fork, Middle Fork Flathead, North Fork Flathead, South Fork Flathead, Swan Watershed, Upper Missouri, Missouri Headwaters) (Montanans for Healthy Rivers Draft Citizen Proposal for New Wild and Scenic Rivers 2017).

The purpose of this paper is to analyze past and present applications of Wild and Scenic designation specifically related to protecting rivers from mining activities. The Wild and Scenic Rivers Act is a relatively unfamiliar piece of legislation for most Americans, and knowledge regarding how designation impacts specific activities is even less. The need for this paper arose from increased visibility of the Montana-based effort to seek new Wild and Scenic River designations in Montana. In addition to more public interest regarding specific applications of the Act. For instance, the regulation of mining activities under the Wild and Scenic Rivers Act stimulated many questions. This paper will describe how mining activities have been regulated, litigated and/or stopped in Wild and Scenic Rivers using specific examples.

Mining in the United States and its Consequences

During the late 1840s, the California Gold Rush began. Thousands of prospectors flocked to the newly acquired State of California in the search for gold. Gold rush miners and prospectors adopted local prospecting customs that predated California’s introduction into the United States (Bakken 2008). The practice of prospecting on public land spread throughout the West and was adopted by state legislators, despite contradicting federal mining laws. The Mining Law of 1872 was an effort to reconcile state and federal legislation (Bakken 2008).

The Mining Law of 1872 states that “all valuable mineral deposits in lands belonging to the United States, both surveyed and unsurveyed, are hereby declared to be free and open to exploration and purchase, and the lands in which they are found to occupation and purchase, by citizens of the United States and those who have declared their intention to become such” (30 U.S.C. §22-54). The Mining Law of 1872 has remained relatively unchanged since its creation. For example, patenting a mining claim in 2017 costs five dollars per acre, the same price it cost in 1872 (30 U.S.C. §22-54). The antiquated Mining Law of 1872 has been interpreted to give
mining precedence over all other land uses, resulting in a history of intense mineral exploration and environmental degradation.

The EPA documented that 40 percent of the headwaters in the West have been contaminated due to mining activities (EPA 2000). For instance, the five most hazardous Superfund sites in the State of Montana are a result of mining pollution, including the Upper Clark Fork Complex, one of the largest Superfund sites in the United States (“Superfund” 2016; McQuillan 2015). Unfortunately, many of the nation’s Wild and Scenic Rivers are also threatened by mining impacts.

The Hardrock Mining Reform and Reclamation Act of 2015 was introduced to the House and Senate. Though the bill is no longer active because a new Congress was sworn in January of 2017, the bill represents an attempt at reforming outdated mining legislation. If passed, the Act would have prevented patents from being issued for any application filed after September 30, 1994. In addition, the Act would have rolled back subsidies enjoyed by the mining industry for centuries. Mining operations that produce locatable minerals (more than $100,000 gross income) would have been subject to a four to eight percent royalty. The bill would have permanently withdrawn specific designated areas, like wilderness study areas and Wild and Scenic River study areas1, from locating mining claims. Additionally, the Act would have allowed state, local, or tribal governments to petition the Secretary of Interior for mineral withdrawal with the purpose of protecting “specific values” (H.R. 963).

Application of the Wild and Scenic Rivers Act

As stated previously, the purpose of the Wild and Scenic Rivers Act is to protect rivers that possess outstandingly remarkable values and are in a free-flowing condition, so that the rivers may be enjoyed for generations to come. Protection of Wild and Scenic Rivers occur through the joint effort of land owners, conservationists, river recreationists, and government agencies and regulations. Management jurisdiction depends on whether river segments are located on federal, state, or private land. Most rivers designated recently and under consideration in the Draft Citizen’s Proposal in Montana flow through public land. Therefore, these rivers are administered by the corresponding land management agency (i.e., National Forest Service, National Park Service, Bureau of Land Management, U.S. Fish and Wildlife Service) (National Wild and Scenic Rivers System, Wild & Scenic Rivers Information 2017). Designated rivers should be managed as to protect and enhance the values that caused the river to be designated (National Wild and Scenic Rivers System, Wild & Scenic Rivers Information 2017). Consequently, the Act prohibits federal assistance for the construction of dams, or other activities that will negatively impact the free-flowing quality of the river, water quality, or other ORVs.

Designation of rivers does not impact existing water rights, nor does it hinder development, private property rights, recreation opportunities, or agriculture (National Wild and Scenic Rivers System, Wild & Scenic Rivers Information 2017). Wild and Scenic designation explicitly

1 According to Section 2(a)(ii) of the Wild and Scenic Rivers Act, a governor can request that a river be designated, if certain conditions are met. Wild and Scenic River study areas are those requested rivers that are undergoing study to determine if the certain conditions are met.
protects rivers from activities that will harm free-flowing condition, however, the extent of protection for water quality and ORVs is less clear. The following sections will consider the extent to which Wild and Scenic designation protects rivers from mining activities by reviewing various applications of Wild and Scenic legislation and relevant case studies.

**Mining Addressed in the Wild and Scenic Rivers Act**

Section 9 of the Wild and Scenic Rivers Act explains that the Act will not affect mining laws, other than three exceptions. The first exception follows, that all prospecting, mining operations, and all other activities on mining claims within the designated river segments that have not been “perfected” are subject to regulations set forth by the Secretary of the Interior, or the Secretary of Agriculture for United States Forest Service (USFS) lands.

Mining activities on National Forest land are regulated by the Forest Service in accordance with 36 C.F.R. 228 Part A ("Mining Claims” 2011). Based on the regulations, if an operation “is causing or will likely cause significant disturbance of surface resources” then a proposed plan of operations must be submitted (36 C.F.R. 228.4(a)).

BLM regulations reiterate that wild designated river segments are withdrawn from mineral entry, but:

> “Existing valid claims or leases within the river boundary remain in effect, and activities may be allowed, subject to regulations that minimize surface disturbance, water sedimentation, pollution, and visual impairment. Reasonable access to mining claims and mineral leases will be permitted. Subject to valid existing rights, mining claimants may only obtain title to the mineral deposits and such rights to the surface and surface resources as are reasonably required for prospecting or mining” (BLM 2012).

The regulations stated above also apply to river segments classified as scenic and recreational, though the river segments are not withdrawn from mineral entry (BLM 2012).

The extent of valid existing rights of any mining claim within Wild and Scenic designated river segments is further described in Section 9 a (ii) of the Act. This section explains that mining claim rights only apply to “the use of the surface and the surface resources as are reasonably required to carrying on prospecting or mining operations” (Section 9 a (ii)). The interpretation of this section of the legislation was litigated in *Dinning v. Babbit* (E.D. CA 2000).

In 1933, John Lighthill located a placer claim along the Scott River, a tributary of the Klamath River in California. In 1988, the Lighthill Estate applied for a patent with the BLM. The patent was approved by the BLM, however, the Scott River was designated scenic and recreational in 1981, so the BLM issued limited rights to the surface resources in congruence with Section 9 a (ii) of the Wild and Scenic Rivers Act. The Lighthill Estate disagreed with the government’s interpretation of the legislation, arguing that “subject to valid existing rights” required the BLM to issue a patent that included full surface rights. In *Dinning v. Babbit*, the U.S. District Court for
the Eastern District of California upheld the BLM’s decision. Though the Estate held a valid claim prior to the Scott River’s designation, since the Lighthill Estate applied for a patent after the Scott River was designated, the patent could not issue full surface rights to the claim (Interagency Wild and Scenic Rivers Coordinating Council 2002).

The Wild and Scenic Rivers Act’s third exception to mining laws withdraws Federal lands, within one-quarter of a mile from the bank of segments classified as wild, from appropriation and operation under mining laws. This section explains that no new mining claims can be approved, however, existing valid claims or leases are allowed. Mining activities must adhere to regulations that emphasize minimizing mining impacts like, water disturbance, water sedimentation, pollution, and visual impairment (Marsh 2017).

**Case Studies: Protecting Wild and Scenic Rivers Using Mining Restrictions**

**St. Joe River, Idaho**

In 1975, a Draft Environmental Impact Statement (EIS) was completed for the St. Joe River Wild and Scenic River Study Area. The St. Joe River was recommended for Wild and Scenic designation because of its fisheries, recreation access, scenic qualities, wildlife, and water quality (National Wild and Scenic Rivers System, St. Joe River 2017). The preferred alternative proposed designating the river segment within the Idaho Panhandle National Forests as a Wild and Scenic River and relying on state action to protect the lower portion of the St. Joe. This Draft EIS considered the various impacts designating the St. Joe River would have on the environment and socioeconomics. One of the factors evaluated was mining in the St. Joe basin, and whether mineral development was suitable and compatible with Wild and Scenic values.

During 1971 and 1972, the U.S. Bureau of Mines surveyed the St. Joe River Valley and determined the St. Joe basin has a rich mining potential like the Coeur d’Alene mining area. Veins of copper, lead, silver and gold were discovered close to the St. Joe River. In addition, sand and gravel bars were identified as an economically fruitful resource (Idaho Panhandle National Forests 1975). The Draft EIS determined that mining land use was incompatible with Wild and Scenic River values in three of the four landscapes (e.g., floodplains, riverbreaks and steep mountainsides, valley benches and terraces). The Draft EIS concluded that “dredge mining in the upriver reaches would not be allowed; it would have adverse effects on water quality, cutthroat populations, and spectacular backcountry river scenery” (Idaho Panhandle National Forests 1975).

On November 10, 1978, the St. Joe River in Idaho was added to the National Wild and Scenic River System; a total of 66.3 miles of the river were designated, 26.6 miles are categorized as wild and the remaining 39.7 miles are recreational. The river is managed by the Idaho Panhandle National Forests (Forest Service, St. Joe Wild & Scenic River Development and Management Plan 2017). One goal of the St. Joe River Management Plan is to “permit mineral development, under regulations issued by the Secretary of Agriculture, where it would not detract from river values” (Forest Service, St. Joe Wild & Scenic River Development and Management Plan 2017). The Forest Service aims to reduce the environmental harm caused by mining activities by
working with miners on minimizing their impact (Forest Service, St. Joe Wild & Scenic River Development and Management Plan 2017).

There are no patented mining claims along the Wild and Scenic corridor, though there are numerous unpatented claims. The St. Joe River Management Plan explains that another important management goal is determining the “validity of existing claims, and the property values associated with these claims” (Forest Service, St. Joe Wild & Scenic River Development and Management Plan 2017). Following the Draft EIS completed in 1975, the enabling legislation designating the St. Joe River banned dredge and placer mining along the main stem and tributary corridors. Though, the removal of sand and gravel above the high-water mark for road maintenance and construction is permitted (16 U.S.C. 28).

The Idaho State board of Land Commissioners placed similar mining restrictions on mining along National Wild and Scenic Rivers within Idaho. Idaho Code Section 47-1323 prohibits “dredge mining or use of any other type of mining equipment including plans, rockers, hand tools, hand operated sluices and other similar equipment” on Wild and Scenic Rivers, including the St. Joe River and its tributaries (Idaho Department of Water Resources 2017).

Tuolumne River, CA

The Tuolumne River begins in the Sierra Nevada Mountains and flows through Yosemite National Park. The river is sourced by the Dana Fork and the Lyell Fork, which eventually converge in the Tuolumne Meadows. Sixty-two miles of the Tuolumne River were added to the National Wild and Scenic River System in 1984 (National Wild and Scenic Rivers System, Tuolumne River 2017). The BLM, USFS (Stanislaus National Forest), and NPS (Yosemite National Park) manage the Tuolumne River with the intention of protecting and enhancing the river’s numerous ORVs (e.g., scenic, recreational, geologic, fisheries, wildlife, cultural, historic and biology) (National Wild and Scenic Rivers System, Tuolumne River 2017).

The California Gold Rush brought prospectors to the Tuolumne Meadows in 1852. Following the discovery of silver at Tioga Hill in 1860, mining activities increased (Trexler 1961, 1980). Keith et al. (2008) describes the impact of Wild and Scenic designation saying that “designation of the Tuolumne River placed restrictions on these recreational mining activities, basically making the activities no longer possible.” Select lands, including the segments designated wild, were withdrawn from new mineral entry. However, the Tuolumne Wild and Scenic River Management Plan does not appear to place extraordinary restrictions on mining activities. The Management Plan states that mining activities on lands open to mineral entry must follow the restrictions 36 C.F.R. 228 Subpart A, described on page 5, and Forest Service Manual (FSM) Chapter 2810 (Stanislaus National Forest 1988).

The FSM Chapter 2810 states that “all prospecting, mining operations, and all other activities on mining claims which are not perfected before inclusion of a river in the Wild and Scenic River System are subject to such regulations as the Secretary of Agriculture may prescribe to effectuate the purposes of the Wild and Scenic Rivers Act” (FSM 2816.3). Also, perfected mining claims only give the right to the surface resources as are “reasonably required to carrying on prospecting
or mining operations” (FSM 2816.3). The language in the agency restrictions aims to prevent water quality degradation caused by mining activities.

**Case Studies: Protecting Wild and Scenic Rivers Using Mineral Withdrawal**

**North Fork of the Flathead River, Montana**

The North Fork of the Flathead River is renowned for its wild beauty, nearly pristine water quality, access to outdoor recreation, and diversity of wildlife, including the greatest density of grizzly bears in Interior North America (Bosse 2015). Beginning in the Canadian Rockies, the North Fork makes its way along the western portion of Glacier National Park, until it empties into Flathead Lake 153 miles later (Bosse 2015). The North Fork of the Flathead River was added to the National River System in 1976, along with the Middle and South Forks of the Flathead River.

Coal, oil, gas, and gold deposits are present in the Flathead Watershed (Bosse 2015). Proposals to mine and drill on these valid claims initiated the inclusion of the North Fork of the Flathead River on American Rivers’ Most Endangered Rivers list in 2009 (Bosse 2015). Protection of the North Fork of the Flathead River is a transnational issue. In 2010, Montana and British Columbia signed an agreement titled the 2010 Memorandum of Understanding (MOU); this arrangement would help to conserve the integrity of the North Fork of the Flathead River and Flathead Watershed (Office of the Premier 2011).

In the deal, Canada agreed to permanently withdraw the Flathead Watershed from mineral development if the United States did the same (North Fork 2017). As part of the international agreement, The Nature Conservancy of Canada and The Nature Conservancy in the United States provided $9.4 million that went towards mining and energy companies in Canada with valid claims, so the companies would forfeit their right to act on existing claims (Office of the Premier 2011). In addition to the forfeited claims, 200,000 acres of claims were voluntarily relinquished in the United States (Bosse 2015).

In following through with the 2010 international deal, President Obama signed into law the National Defense Authorization Act at the end of 2014, which contained the North Fork Watershed Protection Act (Scott 2014). The legislation permanently bans future mining and drilling in 430,000 acres in the United States portion of the North Fork of the Flathead River (Bosse 2015). The North Fork Watershed Protection Act represents a “win” for Wild and Scenic Rivers against detrimental mining actions.

**Chetco River, Oregon**

Located in southwestern Oregon, within the Rogue River-Siskiyou National Forest and Kalmiopsis Wilderness, the Chetco River is known for its water quality and healthy steelhead and Chinook salmon runs. In 1988, portions of the Chetco River were designated Wild and Scenic. Nearly 45 miles of the Chetco River are classified wild, scenic or recreational; over half of the river segments are considered wild, eight river miles are classified as scenic, and 11 are recreational. The USFS manages the Chetco River; a management plan for the Wild and Scenic...
designated portions of the Chetco River was not created until 1993 (National Wild and Scenic Rivers System, Chetco River 2017; Siskiyou National Forest 1993).

In 1993, the USFS finalized an Environmental Assessment for their sixth Forest Plan amendment. As part of the amendment, the Chetco River Management Plan was incorporated into the Siskiyou Forest Plan. This Forest Plan amendment presents the chosen alternatives to be implemented for wild, scenic, and recreational river segments. Implications to mineral entry will be discussed below.

According to the River Management Plan for the Chetco Wild and Scenic River (1993), accessible minerals, mainly placer gold exist within the lands along the Chetco River corridor. These known mineral deposits occur within the Kalmiopsis Wilderness Area. The wilderness area includes wild river segments, as a result of both the Wilderness Act and wild classification, this section of the river is closed to new mineral entry. As of 1993, 66 mining claims are within the Chetco wild river segment. This is, the mining claims were established prior to Wild and Scenic designation. Following the guidance of the River Management Plan for the Chetco Wild and Scenic River (1993), mining operations must establish that the claim has valid existing rights before receiving approval for their Plan of Operation. One mining operation inside the wild river segment boundaries has obtained approval for their Plan of Operation, and a second existing claim filed for a patent. Scenic and recreational river segments of the Chetco River contain 31, primarily inactive, mining claims (Siskiyou National Forest 1993).

The USFS determined that Alternative II for the wild segments will be implemented; wild river segments were withdrawn from mineral entry. For scenic river segments, Alternative II will be applied, but with a modification to mineral withdrawal recommendation. The USFS changed the language to maintain scenic river segments open to mineral entry. Alternative VII, chosen for recreational river segments will also maintain mineral access (Siskiyou National Forest 1993). The USFS justified maintaining mineral entry by stating:

“it would be impractical to recommend mineral withdrawal on an area that has low mineral potential and low probability of existing claims being developed into mining operations. Recommending mineral withdrawal of an area to the BLM implies a high level of need and carries a burden of documentation that warrants recommending only those areas with a high probability for claims or development. In this case, the need does not exist” (Siskiyou National Forest 1993).

Despite the “low probability” for development mineral claims, in 2010, suction dredge gold mining proposals stretched along nearly half of the Chetco River. Suction dredge mining disrupts the riverbed, drastically increasing turbidity; this type of mining is especially detrimental to salmon and aquatic organisms because the dredging activity clogs fish gills and coats the bottom of riverbeds in a film of sediment (Oregon Chapter American Fisheries Society 2013). The Chetco River was incorporated into the National Wild and Scenic Rivers System because of its salmon and steelhead runs. Due to the imminent mining threat, American Rivers included the Chetco River on their list for the nation’s most endangered rivers (“Wild and Scenic Chetco River” 2016). The risk of gold mining along the Chetco River initiated several efforts to permanently close mining outside of the Kalmiopsis Wilderness.
The USFS, members of Congress, and environmental groups pushed forward legislation requiring temporary and permanent mineral withdrawal along the Wild and Scenic Chetco River. In 2010, President Obama approved a preliminary mining withdrawal from areas outside of the Kalmiopsis Wilderness for two years (“Fact Sheet” Oregon 2016). Congressional representatives from Oregon introduced an amendment to Congress on March 15, 2013. The amendment titled, Chetco River Protection Act of 2013, added a section that withdrew the Chetco River segment designated from “(i) entry, appropriation, or disposal under the public land laws; (ii) location, entry, and patent under the mining laws; and (iii) disposition under all laws pertaining to mineral and geothermal leasing or mineral materials” (H.R. 1215). The bill failed to be enacted. However, as of July 26, 2013, 5,610 acres of National Forest land along the Chetco River will be temporarily withdrawn from mining for five years (Targeted News Service 2013).

To permanently protect the Chetco River from mining operations, Oregon Senator Ron Wyden introduced two Acts to the Senate in 2015. The Southwest Oregon Watershed and Salmon Protection Act was introduced to the Senate on February 3, 2015. The proposed Act permanently withdraws federal land in Curry and Josephine Counties from mining and geothermal leasing. In addition, the Act will amend river segment designations along the Chetco River to increase the amount of wild river segments. If passed, this amendment permanently protects the Wild and Scenic Chetco River from mineral and geothermal leasing (S.346).

In addition to the Southwest Oregon Watershed and Salmon Protection Act, Wyden introduced the Oregon Wildlands Act to Congress on July 25, 2015. Aptly named, the Oregon Wildlands Act sets out to increase the Wild Rogue Wilderness, classify more river segments as wild rivers, and amend segment designations for the Chetco River to permanently withdraw mining claims from sensitive areas (S.1699). Despite volunteer efforts and political support, neither bill has moved forward for review.

**Discussion**

Research shows that adding rivers to the National Rivers System does not inherently protect the classified river from all mining activities. However, mining restrictions can be written into enabling legislation that protects designated rivers from certain mining activities, as demonstrated with the St. Joe River in Idaho. The evidence provided in the Draft EIS played a key role in the establishing those mining restrictions. By identifying the suitability of mining in certain landscapes along the St. Joe, as well as mining’s compatibility with Wild and Scenic values, a case was made for restricting certain types of mining in and along the St. Joe River.

Without including these additional mining restrictions, wild rivers enjoy more protection than scenic or recreational river segments because wild river areas are automatically withdrawn from establishment of new mining claims and mining operations. Though, valid existing mining claims can be patented and perfected. Scenic and recreational river segments are not automatically withdrawn from establishment of new mining claims or mining operations and are managed under the rules established by the Mining Law of 1872, and the administering agency rules. Due to the greater cost associated with stricter water quality restrictions, it is possible mining activities will decrease in scenic and recreational river segments, like in the case of the Tuolumne River in California (Stanislaus National Forest 1988; Keith et al. 2008).
To effectively protect Wild and Scenic Rivers from mining activities, Congress must implement permanent mineral withdrawal. Both the North Fork of the Flathead in Montana and Oregon’s Chetco River represent examples of successful mineral withdrawal in Wild and Scenic River corridors. These efforts required years of persistence, and strong volunteer and Congressional voices supporting mineral withdrawal. Looking to these examples should prove useful when trying to permanently withdraw all segments of Wild and Scenic Rivers from new mining claims.

The Hardrock Mining Reform and Reclamation Act of 2015 is crucial to the future protection of the environment, especially Wild and Scenic Rivers. Hopefully, there are efforts to reintroduce this bill into the new Congressional session. If enacted, the Hardrock Mining Reform and Reclamation Act of 2015 will initiate unprecedented mining law reform by requiring mining operations to pay their fair share to taxpayers. This Act would balance mining with other valuable uses, like recreation and conservation. In addition, the Act will protect special places from environmental degradation caused by mining activities by requiring agencies to review whether Wild and Scenic study areas, roadless areas, Wilderness study areas, and other places deserve protection from mining (Earthworks 2015). Also, the Act will give state, local, and tribal governments the opportunity to protect special areas with mineral withdrawal by petitioning the Secretary of the Interior.

**Conclusion**

The purpose of this paper was to analyze past and present applications of Wild and Scenic designation specifically related to protecting rivers from mining activities. The research and case examples suggest Wild and Scenic can be a useful tool for protecting river segments from select mining activities. If Montanans for Healthy Rivers wishes to protect the proposed river segments in their Draft Citizen’s Proposal, it is important to use Study Area EIS’s as an opportunity to fully and accurately document the sensitivity of areas to mining activities. Wild and Scenic designation, particularly wild classification, also provides a justification for mineral withdrawal. For sensitive areas, a combination of mining restrictions and mineral withdrawal, or wild classification, would provide the most protection from mining activities. Designating rivers as Wild and Scenic should not be used as fail-safe approach to protect rivers from all mining activity, though it does offer an opportunity to add an additional layer or two of protection to the rivers.
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*Montanans for Healthy Rivers Draft Citizen Proposal for New Wild and Scenic Rivers.*


U.S. Forest Service Mining Regulations 36 C.F.R. 228.4(a).


**Mining Definitions**

**Citizen:** “A person or company that has legal citizenship in the United States” (“Mining Claims” 2011).

**Locatable materials:** “Metallic minerals (gold, silver, lead, copper, zinc, nickel, etc.) and nonmetallic minerals (fluorspar, mica, certain limestones and gypsum, tantalum, heavy minerals in placer form, and gemstones” (“Mining Claims” 2011).

**Mining claim:** “Selected parcel of Federal land, valuable for a specific mineral deposit or deposits, for which you have asserted a right of possession under the General Mining Law. Your right is restricted to the development and extraction of a mineral deposit” (“Mining Claims” 2011).  
  
  **Lode claim:** “Cover classic veins or lodes having well-defined boundaries and also include other rock in-place bearing valuable mineral deposits” (“Mining Claims” 2011).  
  
  **Placer claim:** “Cover all those deposits not subject to lode claims” (“Mining Claims” 2011).  

**Patented:** “A patented mining claim or millsite is one for which the Federal Government has conveyed title to you, making it private land. You may mine and remove minerals from a mining
claim without a mineral patent. A mineral patent gives you exclusive title to the locatable minerals, and in most cases, also grants you title to the surface” (“Mining Claims” 2011).

- Since 1994, a moratorium on accepting new mineral patent applications has been renewed annually (“Mining Claims” 2011).

**Perfected:** “when the location of a mining claim is perfected under the law, it has the effect of a grant by the United States of the right of present and exclusive possession. The claim is property in the fullest sense of that term; and may be sold, transferred, mortgaged, and inherited without infringing any right or title of the United States” (*Wilbur, Secretary of the Interior v. United States ex rel. Krushnic* (1930)).
Portfolio Conclusion

When I applied to the Environmental Studies program at the University of Montana, I set out to prepare myself for a career in the watershed management field. I aimed to enhance my current skills, and gain new skills and knowledge that would further my professional goals. In the process of completing this program, I determined that finding a career working to protect watersheds and water resources was my ultimate professional objective.

My professional goal is to work for a private company, nonprofit organization, or a government agency in the West, ideally in Washington, as a water resource planner. Each of my portfolio pieces has assisted in the discovery of this ambition, but also provided skills and knowledge necessary to achieve my career goal.

My first portfolio piece allowed me to explore scientific literature and apply that knowledge to real-world problems. Water scarcity is one of the current and expected consequences of climate change; therefore, this literature review serves an increasingly important purpose now and will in the future. In writing this literature review, I gained a greater understanding about the consequences of wastewater irrigation, as well as methods to protect watersheds from potential contamination from pharmaceutical and personal care products. This portfolio piece shows that I can comprehend scientific literature, determine the limitations of scientific papers, summarize scientific results, and convey this information in a coherent manner. Many environmental planning positions desire applicants with a scientific background and expertise, because they possess advanced technical writing skills.

The report written for the City of Missoula gave me the opportunity to actively engage with my local community and produce a useful document that can influence positive change. This was my first experience performing interviews, writing a policy report, presenting to City Council, and being interviewed by a local journalist. I now feel confident in my ability to complete similar tasks in a professional capacity. This briefing report also explored a topic I had little prior experience with. Therefore, I believe this report demonstrates my ability to efficiently research a topic, summarize and assess key components of a topic, and effectively display my knowledge orally and in writing. Not to mention, I established several professional contacts that will be useful as I enter the professional world. All these skills are essential in the planning profession.

In working with the Montana DEQ, I witnessed how state agencies operate, learned what intense work and time is devoted to a singular project, and gained insight into what type of research is required to develop and interpret standards. This opportunity was immensely valuable for my growth as a future professional and as a citizen. During this experience, I learned scientific sampling and analytical laboratory procedures that will increase the diversity of my resume. In addition, I honed my leadership, teamwork, organization, resourcefulness, and adaptability skills. Personally, I overcame many fears and improved my self-confidence during this experience. I believe this opportunity will greatly increase my desirability to future employers because it demonstrates that I am able to succeed in different work environments (i.e., field, laboratory, and office).

Working as a research intern for American Rivers fills a void in my resume. This research paper
is an important aspect of my portfolio because it proves my competency at reading and interpreting case law and federal legislation. These skills are incredibly valuable in the environmental and planning fields. This portfolio piece also shows that I can explain complex and confusing information to non-experts, which is critical to technical writing.

During my time in the Environmental Studies program, I established valuable personal and professional contacts that played a significant role in the positive experience I have had at the University of Montana. Based on the classes I have taken, the direction of my portfolio, and the skills I have acquired during graduate school, I believe that I am qualified for water resource planning positions. Now, I am looking forward a career dedicated to protecting watersheds and water resources.

\[\text{i} \quad \text{I was featured in the } \text{Missoulian} \text{ article, “UM report makes recommendations for water conservation program” by Keila Szpaller. The article is provided at the following link:} \]
\begin{quote}
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\[\text{ii} \quad \text{I was featured in the University of Montana, 2017 } \text{Vision} \text{ magazine. The spotlight can be found on page 23 of Vision at the following PDF link:} \]
\begin{quote}
http://www.umt.edu/urelations/pubs/Vision%20magazine/Vision%202017/Vision%202017.pdf
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