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# Development Along Rattlesnake Creek: An Assessment of Stream Health, Channel Form, and Land Cover

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# DEVELOPMENT ALONG RATTLESNAKE CREEK:

# AN ASSESSMENT OF STREAM HEALTH, CHANNEL FORM, AND LAND COVER

By

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Using existing water quality data, historical aerial photographs, and recent orthoimagery, this research assessed how the environmental conditions of Rattlesnake Creek near Missoula, Montana have changed over nearly 90 years of human alteration of the Rattlesnake valley. To characterize stream health, the following indicators were investigated: fish genetic composition and species distribution, water temperature, streamflow, and nutrient levels. Five overlapping aerial photos from 1929 were georectified and compared to 2015 orthoimagery to assess changes in channel form (particularly channel straightening) and land cover across the Rattlesnake Creek valley bottom. Results indicate that trout species in Rattlesnake Creek have hybridized, in particular, rainbow trout, Yellowstone cutthroat trout, and native westslope cutthroat trout. Furthermore, upstream movement by native trout has been severely limited by the lower Rattlesnake Creek Dam, located 3.5 stream miles above the creek's confluence with the Clark Fork River. Average orthophosphate levels have decreased, while average nitrate levels have stayed roughly the same. Although stream discharge data are limited to a few years at various sites, recent data suggest an increase in annual peak discharge and a shift in peak discharge to earlier in the season compared to historical data. Stream temperatures were difficult to compare over time due to lack of data. The aerial photo analysis demonstrated small changes in channel form between 1929 and 2015 relative to the dramatic shift in land cover from grassland to developed during that time.

The lower Rattlesnake Creek Dam is planned to be removed, beginning in the summer of 2019. In addition to assessing changing conditions, this work also describes pre-removal baseline conditions, which may be used in the future to evaluate the effects of this dam removal. Although not all data acquired were suitable to describe long-term trends, they will likely still be of use if compared to future data, post-dam removal.

# CONTENTS

## TABLE OF FIGURES

## TABLE OF TABLES

# 1 INTRODUCTION

Rattlesnake Creek flows from the Rattlesnake Wilderness, through Missoula, Montana to the Clark Fork River. Long used by Native Americans, its lower basin was settled by Europeans in the 1800s in four distinct phases: logging, mining, homesteading, and integrating into the Missoula economy (Comer, 2005).

Around 1905, Montana Power Company constructed the lower Rattlesnake Creek Dam (hereinafter referred to as the Rattlesnake Creek Dam), located approximately 3.5 miles upstream of the confluence with the Clark Fork River. The dam was later modified with a concrete spillway structure in 1924. In 1979, Montana Power Company sold the dam and water rights to Mountain Water Company, which maintained the dam until 2017 (Memorandum of Agreement, 2017). The City of Missoula then acquired the facility, associated infrastructure, water rights, and the other Rattlesnake Wilderness dams in 2017. The City of Missoula partnered with Trout Unlimited and Montana Fish, Wildlife and Parks (Montana FWP) to remediate and restore the dam site. Trout Unlimited is the project manager of this dam removal (Memorandum of Agreement, 2017). Planned wetland restoration where the dam and reservoir currently sit is expected to make up for the water storage loss from removing the reservoir (Roberts personal communication, 5/2/2019). Construction is planned to begin the summer of 2019.

The purpose of this research is to assess how the environmental conditions of Rattlesnake Creek have changed over time while also documenting human-related land-cover change in the surrounding Rattlesnake valley. First, an investigation of past studies on the creek was performed, focusing on the following indicators of stream health: fish genetic composition and species distribution, water temperature, streamflow, and nutrient levels. These metrics were selected because they are parameters commonly used to evaluate stream health (Herman and

Nejadhashemi, 2015, Butryn et al., 2013, Poff and Zimmerman, 2010, Suplee et al., 2012) and because data on the creek were available. The presence (or absence) of historic data influences the usefulness of later monitoring, as pre-dam removal data could serve as a valuable baseline during and after the dam removal. Changes to channel form, particularly channel straightening, were analyzed by comparing historical aerial photos of Rattlesnake Creek to recent photos. This is of importance because straightening stream channels generally leads to a state of disequilibrium or instability, often causing stream entrenchment and corresponding changes in morphology (Rosgen, 1996). Finally, changes in land cover across the Rattlesnake Creek valley bottom were assessed using recent and historical aerial photos.

Through this research, several questions were addressed: 1) What general trends in the chosen parameters could be identified, if any, 2) What do comparisons of historical aerial images reveal about changes in channel form? Specifically, what changes can be seen in channel length and sinuosity, and 3) What major changes in land cover could be seen, specifically in the following land-cover types: Developed, Forest Cover, and Grassland/Herbaceous?

The current transition between pre-removal and post-removal "eras" is an ideal opportunity to assess pre-removal conditions. To best manage Rattlesnake Creek and surrounding habitat in the future, it is important that changing conditions surrounding Rattlesnake Creek are understood. Furthermore, analysis of the effects of any restoration project, dam removals included, is only possible if pre-removal conditions are documented. While not a comprehensive review of all available data on Rattlesnake Creek, this research summarizes trends in selected parameters while also tracking human-related alterations to the landscape, primarily through assessing land-cover change.

## 2 LOGIC OF STUDY DESIGN

### 2.1 Removal of Dams- Benefits and Concerns

Dam removal has become an increasingly important component of river restoration, often with the goal of re-establishing lateral and longitudinal connectivity and minimizing habitat fragmentation (Magilligan et al., 2016). There are many potential benefits associated with completing a dam removal project. By removing barriers, organisms are able to travel throughout the riverine system in search of optimal sediment sizes, water levels, food, and safety from predators (Bednarek, 2001). Furthermore, restoring an unregulated flow regime may result in increased biotic diversity as well as the reappearance of riffle/pool sequences, gravel, and cobble. An increased frequency in flooding events can help to reconnect riparian and aquatic habitats (Bednarek, 2001). Removing dams also eliminates temperature stratification and the accumulation of sand and silt which typically occur in reservoirs (Bednarek, 2001). Additionally, the costs associated with routine maintenance and meeting safety regulations offer additional incentive to remove dams (Vedachalam and Riha, 2014). Currently, there are an estimated 90,000 dams in the United States, and nearly 1,400 dams have already been removed (American Rivers, 2017).

While much hope has been placed in river restoration by dam removal, the physical and ecological responses to dam removals are often difficult to predict. The U.S. Geological Survey John Wesley Powell Center for Analysis and Synthesis dam removal working group identified seven of the most commonly raised management concerns associated with dam removals. These concerns include: the degree/rate of reservoir erosion, prolonged or excessive channel incision upstream of the reservoir pool, downstream sediment aggradation, elevated downstream turbidity, impacts of reservoir drawdown on local water infrastructure, non-native plant colonization of former reservoirs, and expansion of non-native fish (Tullos et al., 2016). Additionally, social factors such as the historical and cultural identity attached to dams, the willingness of dam ownership, and the ability of stakeholders to negotiate, all influence how and if the dam removal project continues (Magilligan et al., 2017). Due to the wide array of factors that affect this process, dam removals require scientific and technical expertise and an understanding of social factors.

The goals of the Rattlesnake Creek Dam removal project are ultimately to restore habitat for native fish and wildlife, improve water quality, reduce maintenance costs, and provide scenic open space and recreational opportunities for the Missoula community (River Design Group and Morrison Maierle, 2018). These goals align with the common benefits of dam removals described above. Furthermore, this project has the potential to improve recreational opportunities, as the dam site sits between the City of Missoula's Rattlesnake Greenway to the south and the Rattlesnake Recreation Area to the north (Memorandum of Agreement, 2017). This report will help to establish baseline conditions, primarily related to water quality and the status of native fish species. With continued monitoring, resource managers will be able to employ this research in assessing the attainment of these goals.

## 2.2 Stream Health Indicators

Stream health can be defined as the chemical, physical, and biological condition of a stream (Herman and Nejadhashemi, 2015). A variety of techniques have been used to evaluate stream health all around the world. To gain insight into the health of Rattlesnake Creek, existing data related to fish populations, water temperature, streamflow, and nutrient levels were compiled.

Many organisms can be used to evaluate the quality of stream health, such as algae, amphibians, diatoms, fish, macroinvertebrates, mammals, microorganisms, periphyton, phytoplankton, plants, reptiles, and zooplankton (Herman and Nejadhashemi, 2015). Fish were included in this assessment because of their ability to indicate stream health and due to the previous and ongoing investigations that have occurred on Rattlesnake Creek, primarily by Montana FWP. With only limited access to raw fisheries data on the Rattlesnake, inferences were drawn primarily based on one published report and communications with Ladd Knotek, a Montana FWP Fisheries Management Biologist.

Knotek et al. (2004) described several factors known to limit fish populations in Rattlesnake Creek. Most notably, the Rattlesnake Creek Dam acts as an upstream fish barrier, limiting access of native fish such as bull trout and westslope cutthroat trout to preferred spawning habitat. Additionally, the introductions of non-native fish such as brown, rainbow, and brook trout compete with, and in the case of rainbow and brook trout, hybridize with native westslope cutthroat and bull trout. Illegal harvest has also caused concern, as Rattlesnake Creek is readily accessible to the public from Missoula. Finally, Knotek et al. (2004) noted that, while difficult to measure, habitat degradation due to poorly regulated development has indirectly impacted the Rattlesnake Creek fishery.

Long-term stream temperature monitoring is an effective tool in detecting changes in fish distributions and in identifying the potential loss of suitable fish habitat (Butryn et al., 2013). Temperature has a substantial influence on the distribution of salmonids, particularly for bull trout (Selong et al., 2001) and westslope cutthroat trout (Bear et al., 2007). In addition, the logistical benefits of stream temperature monitoring are an important consideration. In comparison to conducting biological surveys, temperature data can be collected at a lower cost and higher frequency. Consequently, stream temperature is appealing as a preliminary metric for monitoring fish populations (Butryn et al., 2013). Stream temperature was selected as a parameter for this study because of its influence on native trout as well as availability of data on Rattlesnake Creek.

Streamflow is often considered a “master variable” that dictates many fundamental ecological attributes of riverine ecosystems (Poff and Zimmerman, 2010). Extreme events such as high flows and low flows exert selective pressure on populations to dictate the relative success of different species, and patterns of variation in sub-lethal flows can influence the relative success of different species (Poff and Zimmerman, 2010). Decreased streamflow also corresponds to elevated summer water temperatures (Nuhfer et al., 2017). When surface water or groundwater withdrawals reduce flows, water moves more slowly through a given reach. In turn, water temperature equilibrates to ambient air temperatures more rapidly, often resulting in increased warming rates for coldwater streams. As a result, downstream habitats that are marginally warm for trout may become unsuitable (Nuhfer et al., 2017).

Eutrophication is defined as “the process and condition which occurs when a body of water receives excess nutrients, thereby promoting excessive growth of plant biomass (i.e., algae)” (Wall, 2013). Eutrophication problems in the nearby Clark Fork River have prompted citizen complaints since the 1970s (Suplee et al., 2012). Concerns are primarily based on aesthetic qualities due to excessive algae and potential negative impacts on aquatic life caused by low dissolved oxygen levels (Suplee et al., 2012). In order to maintain algal biomass at levels the public finds acceptable for recreation, nutrient concentrations near the natural background are required (Suplee et al., 2012). For these reasons, nutrient levels were included in this study.

## 2.3 Aerial Photography

Aerial photography is routinely used to assess and map landscape change. Due to the level of spatial precision, aerial photographs are ideal for mapping small ecosystems and fine-scale landscape features, such as riparian areas. Aerial photographs also provide the longest available, temporally continuous, and spatially complete record of landscape change. In addition, the use of aerial photography often reduces costs involved in mapping, inventorying, and planning (Morgan et al., 2010).

The historical aerial photos used in this analysis were chosen for several reasons. First, the date at which they were taken provides the widest available temporal span in which to compare physical changes in channel form and land cover. While air photos are commonly available in the US beginning in the 1930s, a set of overlapping photos from 1929 with a scale of approximately 1:11,400 was available upon request through the University of Montana Mansfield Library Archives and Special Collections. The photos came from Missoula County, but no additional information about them is available at the Mansfield Library (Fritch, personal communication 12/4/2018).

These photos extend from Rattlesnake Creek's confluence with the Clark Fork River to approximately 200 yards below the Rattlesnake Creek Dam, located approximately 3.5 miles (~5.6 km) upstream of this confluence. Most of the changes in channel form are likely to have been made where the Rattlesnake valley has seen the most urban growth; however, the photos do not include the dam. There are also air photos of Rattlesnake Creek from 1937, but they are at much coarser resolution than the photos from 1929.

The Natural Resource Information System (NRIS) of the Montana State Library provided recent imagery National Agricultural Imagery Program (NAIP) photos from 2015, to which the historical photographs were georectified and later compared. Photos from 2017 were also available; however, they appear to have been photographed late in the day, and shadows from surrounding trees obscure visibility of the creek. Two 24 $km^2$ plots were downloaded (squares 1221 and 1421). The majority of the analysis area is found in square 1421, but the confluence of Rattlesnake Creek and the Clark Fork River is found in square 1221. The photos were in MrSID MG4 format with a ground resolution of one meter, and in Montana State Plane coordinates (Montana State Library Geographic Information Clearinghouse, 2018).

## 2.4 Channel Form

Stream and river channels are modified for many reasons: farming convenience, to aid navigation, to reduce flooding, and to flow adjacent to roads or railways. Consequently, many rivers have been channelized, with uniform bed morphology and little streamside vegetation (Maddock, 1999). Straightening stream channels ultimately leads to a state of instability and can cause stream entrenchment and corresponding changes to morphology (Rosgen, 1996). Physical habitat is a useful component of evaluating river health because it links the physical environment with instream biota (Maddock, 1999). While there are many more detailed analyses of physical habitat (e.g. channel cross- sections, longitudinal profiles, pebble counts, etc.), this study utilized only the broad-scale measurements of channel length and sinuosity because they are detectable using historical aerial photographs. Comparison of channel length and sinuosity between time periods was expected to illustrate channel straightening over time.

## 2.5 Land-Cover Change

Land cover is defined as “the natural and artificial compositions covering the earth’s surface at a certain location” (Avery and Berlin, 1992). The ability to identify and map land-cover change over time is an effective indicator of rural, urban, and industrial growth (Avery and Berlin, 1992).

Although riparian habitat was not delineated in this research, understanding the ecological role that it fills is of great importance when assessing the condition of Rattlesnake Creek. Riparian buffers are important elements in landscapes and are known to serve many ecological functions. They help to store nutrients and sediments, serve as wildlife corridors, filter non-point source pollution, reduce stream bank erosion, and regulate water temperature (Jones et al., 2010). The western United States retains as little as two percent of its original forested riparian habitat, often a consequence of the construction of dams, withdrawals of surface water and groundwater from floodplains for agriculture and human consumption, and unregulated livestock grazing (Jones et al., 2010). Well-developed stands of cottonwood (*Populus*) and willow (*Salix*) often typify healthy riparian ecosystems in the arid and semi-arid regions of the western United States. Furthermore, stands of seedlings, dependent on periodic flooding, are found in beds along stream margins (Jones et al., 2008).

As described in Section 2.4, various forms of development can greatly impact channel form. Additionally, urbanization and the corresponding increase in impervious surfaces often exert pressure on the hydrologic cycle (Shuster et al., 2005). Consequently, the capacity of a given landscape to infiltrate precipitation decreases. In turn, the water table is not able to recharge, and base flows decline (Shuster et al., 2005). These effects are of great importance and were considered when analyzing changing land cover in the study area.

The National Land Cover Database (NLCD) provides nationwide land cover and land-cover change data at Landsat Thematic Mapper’s 30 meter spatial resolution every five years (Homer et al., 2015). The Multi-Resolution Land Characteristics Consortium (MRLC) coordinates the production of the NLCD and is composed of 10 Federal Agencies. MRLC data are widely used and well-established (Wickham et al., 2014). While the relatively coarse resolution of the NLCD adequately illustrates regional change, it is not ideal for this study. Instead, NLCD land-cover criteria were used to guide manual digitization of both the 1929 historical photo mosaic and 2015 NAIP imagery. This is detailed in the Methods section.

Manual interpretation has been shown to be a high quality and reliable method for deriving land cover and land-cover change information (Loveland et al., 2002). While automated classification approaches can reduce the time required to derive land cover over large areas, the ability of manual interpretation to achieve higher local accuracy makes it an appropriate method for analyzing small areas (Loveland et al., 2002), such as that of the study area. Moreover, black and white photos contain only one band of data, meaning the spectral information available for automatic image classification approaches is limited in comparison to digital imagery produced by modern sensors, which capture reflectance from three or more spectral slices.

## 2.6 Study Area

Early settlement in the Rattlesnake drainage set the stage for urban development, including the construction of the Rattlesnake Creek Dam. Comer (2005) chronicled the early settlement of the Rattlesnake drainage in four distinct phases: logging, mining, homesteading, and integrating into the Missoula economy. In a deal orchestrated by Thomas Greenough, contract logging in the Rattlesnake drainage began in the early 1880s to provide railroad ties for the Northern Pacific Railroad. Thousands of railroad ties were floated down Rattlesnake Creek during the 1880s, as was remaining harvested timber that was deemed unsuitable for railroad ties. Much of the logging during this time took place in the Sawmill Gulch area (Comer, 2005). The late 1800s also saw a period of mining in the Rattlesnake drainage. Four mines were known to be in operation, although they are not believed to have been very profitable. Without the presence of igneous intrusions, precious metals were rarely discovered in the area. In general, mining in the area produced materials used for construction purposes (Comer, 2005).

In the early 1900s, the Rattlesnake drainage saw a rapid increase in homesteading, and with it, a variety of land uses. To facilitate agriculture in the valley areas, timber and stumps were removed, fences were built, livestock were brought in, and rocks were removed from fields and piled up or used to build walls. The Rattlesnake drainage was known to grow potatoes, hay, carrots, apples, plums, cherries, corn, and grain. Moonshine was likely produced in the area during the prohibition, especially in the upper drainage, where isolation and steep slopes were conducive for hiding operations. The Montana Silver Black Fox Company raised silver black foxes for their furs and was likely in operation below the Rattlesnake Creek Dam between 1925 and 1940. Additionally, several dairies likely existed in the drainage, while their locations are uncertain (Comer, 2005).

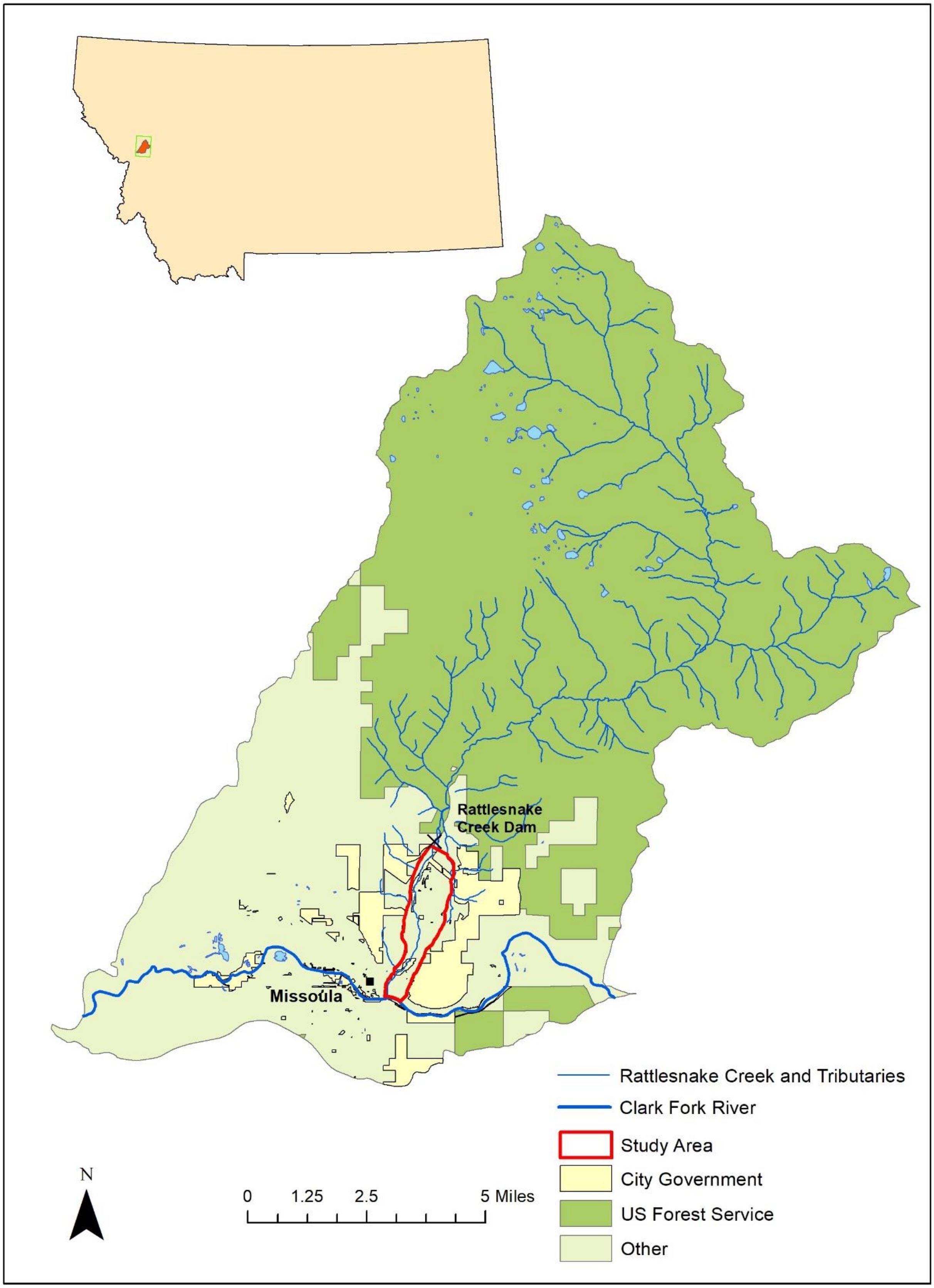
Starting around the time of World War I, people living in the lower Rattlesnake drainage began producing surplus crops and livestock to sell in Missoula. Others even commuted to Missoula daily for their jobs, where they worked in a variety of professions. People in the lower valley generally rented or owned small properties in comparison to those in the upper drainage (Comer, 2005).

Rattlesnake Creek, a third-order tributary to the Clark Fork River, originates in the Rattlesnake Wilderness and Recreation Area and extends approximately 23 miles to its mouth in the city of Missoula (Figure 1). The drainage encompasses approximately 81 square miles and is managed primarily by the U.S. Forest Service (Lolo National Forest). The lower five miles of the stream run primarily through private property in the outskirts of Missoula (Knotek et al., 2004).

For the purpose of analyzing stream health, this study did not limit compiled data to any particular reaches of Rattlesnake Creek. This allows for a more complete characterization of stream health.

In contrast, the analysis of aerial photos extended from the confluence of Rattlesnake Creek with the Clark Fork River to ~200 yards below the Rattlesnake Creek Dam, due to the coverage of the historical aerial photos. The valley bottom defined the “width” of the photo analysis, partially because there is less (and primarily systematic) geometric distortion on flat areas. Also, this boundary was a logical choice since the valley has seen the most development. The juncture between the eastern side of the valley and neighboring slopes is relatively distinct, offering an ideal boundary line which was digitized using a digital elevation model. The extent of the study area west of Rattlesnake Creek was limited to the valley bottom but was also restricted to the extent of the historical photos.

*Figure 1. Map of the study area location within the Rattlesnake Watershed (fifth-level USGS Hydrologic Unit Code).*



# 3 METHODS

## 3.1 Stream Health Indicators

A variety of sources were used to assess the health of Rattlesnake Creek. As stated in Section 2, parameters chosen to illustrate stream health include: fish populations, water temperature, streamflow, and nutrient levels. Table 1, below, describes sources that were compiled and used to assess stream health.

*Table 1. Data Sources*

| Health Indicator Assessed | Specific Parameter(s) | Years Monitored | Location | Author or Data Source |
|---|---|---|---|---|
| Fish | Species distribution and composition | 1999-2003 | Many locations | Knotek et al., 2004 |
| Stream Temperature | Max Daily Temp. | 2000-2005, 2011-2016 | Dam | Montana FWP unpublished data |
| | Max Daily Temp. | 2008-2010, 2012 | Mouth and Rattlesnake Trailhead | Clark Fork Coalition unpublished data |
| | Temp. (every 15 min.) | 2017-present | Greenough Park | Montana DNRC, 2019 |
| Discharge | Daily Mean Discharge | 1958-1967 | Mile 2 | USGS, 2018 |
| | Daily Mean Discharge | 2008-2010 | Mouth and Rattlesnake Trailhead | Clark Fork Coalition unpublished data |
| | Discharge (every 15 min.) | 2017-present | Greenough Park | Montana DNRC, 2019 |
| Nutrient levels | Ammonia, nitrate plus nitrite, orthophosphate, and total phosphorus | 2008 | Spring Gulch, Pineview, and Double Tree | Missoula County unpublished data |
| | Orthophosphate, nitrate | 1974, 1975 | Five locations | National Water Quality Monitoring Council, 2018 |

## 3.2 Photogrammetry

This section describes the processing that was performed to be able to reliably interpret the air photos used in this analysis. See Appendix A for a list of terms used in this section.

Orthophotos have been processed to remove most of the geometric distortions and relief displacements characterizing raw aerial photographs. Like maps, orthophotos are processed to have one scale across the image, and like photographs, they show the terrain in actual detail. Orthophotos allow true distances, angles, and areas to be measured as on a map (Lillesand et al., 2015). The 2015 NAIP ortho imagery was used as a base layer in this analysis as it meets the US Department of Agriculture’s Farm Services Agency (FSA) requirements for image resolution, horizontal accuracy, coverage area, and number of bands. Since 2009, all NAIP imagery acquisition contracts have specified that imagery is to match reference imagery within a ground surface distance of six meters (Montana State Library Geographic Information Clearinghouse, 2018).

Five overlapping aerial photos from 1929 were each georectified in ArcGIS, using the 2015 NAIP imagery as a base. This process involves three steps: matching ground control points (GCPs) from the scanned historical photo to the 2015 base layer, transforming GCP planar coordinates on the scanned image to the geographical projection and coordinate system of the base layer, and pixel resampling (Hughes et al., 2006). GCPs were selected on each historic photo and matched to the corresponding location in the 2015 orthorectified image. Specifically, eight to 10 GCPs in each aerial photo were selected across the valley bottom. Better accuracy may result by focusing GCPs near features of interest rather than across the entire aerial photo, as well as close to the center of a photo as possible (Hughes et al., 2006). Additionally, accuracy is increased if the points are on low relief, such as low gradient channels and their neighboring floodplain. Selecting GCPs on valley walls or other areas with high topographic complexity may unnecessarily skew the transformation (Hughes et al., 2006). The lack of substantial elevation changes in the Rattlesnake valley allowed for the use of georectification instead of orthorectification, which requires the use of a digital elevation model, to address relief displacements. As described above, GCPs were concentrated in the valley, where relief is minimal. Features clearly present in both photos, such as road intersections and buildings, were chosen as GCPs based on their potential to be accurately identified in both images and stable through time.

Second-order (quadratic) polynomial functions (Hughes et al., 2006) were used to transform the original image into one to compare to the orthorectified image. Polynomial transformations are named by the numerical value of the highest exponent used in the polynomial function. While georectification can adjust for different kinds of distortion (such as translation and scale changes in x and y, skew, and rotation), it cannot correct relief displacements because no elevation information is included (Rocchini et al., 2012).

A root mean square error (RMSE) was generated for each set of GCPs from the five historical aerial photos. A least-squares function fit between GCP coordinates on the scanned image and base layer during the transformation, was used to assign coordinates to the entire photo. After transformation, GCPs on the photo and base layer have slightly different coordinates, depending on the degree to which the overall transformation affects the area around each GCP. The total RMSE represents the difference in location between the GCPs on the transformed layer and base (Hughes et al., 2006). RMSE values of the five air photos used to create the photo mosaic, from upstream to downstream, are as follows: 1.80 m, 2.30 m, 2.18 m, 2.74 m, and 1.04 m.

Pixel resampling was performed after the second-order polynomial transformation. Since second-order and higher transformations can result in pixels of variable size across the image, a resampling step is necessary (Hughes et al., 2006). Cubic convolution is widely accepted as the best resampling method to use with air photos (Avery and Berlin, 1992); therefore, it was employed here.

After completing the image processing described above, all five aerial photos were joined to form a single raster mosaic, using an overlay ("First") operator, extending from the confluence of the Clark Fork River and Rattlesnake Creek to 200 yards downstream of the Rattlesnake Creek Dam.

### 3.3 Channel Form

The wetted channel centerline was digitized on the 1929 mosaic and the 2015 NAIP imagery using ArcGIS. To adequately distinguish the channel, digitization was performed at a scale of 1:4,000. The following characteristics were evaluated to consistently identify the channel and surrounding land cover, which is described in Section 3.4: shape, size, pattern, tone or color, texture, and site. Together, these elements aided in identifying the wetted channel, especially in locations with limited visibility. In addition, Gamma, Brightness, and Contrast values were adjusted using ArcGIS in order to improve visibility for digitization.

### 3.4 Land-Cover Change

This study analyzed changes to the following land-cover classes defined for the study area: Developed, Forest Cover, and Grassland/Herbaceous. This section details how National Land Cover Database (NLCD) classes were combined to form these three classes and the reasoning behind it.

Land-cover classification of historical (1929) and recent (2015) aerial photos was guided using NLCD 2011 criteria. Initial examination suggested that the study area appeared to be dominated primarily by the following classes: Woody Wetlands, Mixed Forest, Developed (Open, Low Density, Medium Density, High Density), Grassland/Herbaceous, and Pasture/Hay. These NLCD classes were combined into three land-cover classes: Developed, Forest Cover, and Grassland/Herbaceous. This was done for two reasons. First, the black and white 1929 photos only allow for a minimal degree of interpretation. While it would be ideal to distinguish certain classes, for example, Mixed Forest and Woody Wetland, the historical photos limited the analysis to primarily non-spectral differences. Second, the primary interest was major land development patterns and subtle changes would have added additional uncertainty. In summary, this analysis focused on comparing current and historical conditions, so the ability to distinguish the same categories at both time points was required.

All features were digitized at a scale of 1:3,000. The following alterations were made to the NLCD 2011 land cover classes:

- Evergreen Forest, Mixed Forest, and Woody Wetland were combined to form Forest Cover.
- All Developed classes (Open, Low Density, Medium Density, High Density) were combined to form one single Developed class.
- Grassland/Herbaceous, Pasture/Hay, and Cultivated Crops were combined to form a Grassland/Herbaceous class.

*Table 2. Land-cover classification criteria based on 2011 NLCD (USDA, 2014).*

| **Land-Cover Class** | **NLCD Land-Cover Class** | **Photo Interpretation Criteria** |
|---|---|---|
| Forest Cover | Evergreen Forest | Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage. |
| | Mixed Forest | Areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover. |
| | Woody Wetlands | Areas where forest or shrub land vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water. |
| Developed | Developed, Open Space | Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes. |
| | Developed, Low Intensity | Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20-49% of total cover. These areas most commonly include single-family housing units. |
| | Developed, Medium Intensity | Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-79% of the total cover. These areas most commonly include single-family housing units. |
| | Developed, High Intensity | Developed, High Intensity - Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80 to 100% of the total cover. |
| Grassland/ Herbaceous | Grassland/Herbaceous | Areas dominated by graminoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing. |
| | Pasture/Hay | Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation. |
| | Cultivated Crops | Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled. |

Forest cover in the study area is primarily found along Rattlesnake Creek. To avoid falsely assuming forest cover near the creek to be true riparian habitat that is periodically saturated, a broad Forest Cover class was created. The resolution and lack of color in the 1929 photo mosaic simply do not permit differentiation between riparian vegetation and plant species typically found in other parts of the watershed. Streamside vegetation, in general, provides shade to the channel and soil stability. Considering the great impact that the quantity of streamside vegetation has on aquatic ecosystem conditions, characterizing trends in the extent of the forested cover alongside Rattlesnake Creek is highly relevant.

### 3.5 Constraints

Several constraints limited what conclusions could be drawn from this analysis:

- While historical photos were georectified using all of the identifiable GCPs, distortion and displacement could not be perfectly corrected. Particularly in the two northernmost photos, there was a smaller degree of overlap. This means that portions of the photos farther away from the center were used in the mosaic and that, in turn, more displacement was present.
- The extent of the historical photos falls just short of the Rattlesnake Creek Dam. Although this constraint does not severely limit this analysis, it would be ideal to be able to see the dam structure and impoundment in order to further compare the historical site to its current state.
- Canopy cover limited visibility along the channel. Since Rattlesnake Creek is a relatively small stream, overhanging trees are able to nearly block the entire channel in certain locations. Especially in the 1929 mosaic, lack of direct visibility made digitization difficult at times. There is a strong possibility that side channels existed in 1929 that were

simply not visible through the canopy. The 2015 NAIP imagery, by comparison, provided better visibility of the channel, perhaps due to the colors aiding interpretation.

- The 2015 NAIP imagery, acquired from the Montana State Library, was used as the base layer in this analysis. This base layer is assumed to be "correct"; however, some degree of error is still present.
- Differentiating land-cover classes in the 1929 photo limited what classes could be used in the 2015 photos, assuming a comparison was desired. For example, riparian habitat and mixed forest in the 1929 photos could not be distinguished, so they were combined into one Forest Cover class and digitized in both photos.
- While established criteria were used to manually digitize, this process inherently introduces some degree of subjectivity.
- Lack of available data concerning indicators of stream health limited conclusions regarding how stream health has changed over time. Older data, in particular, were difficult to find and often not collected consistently.

## 4 RESULTS

### 4.1 Fish Populations

The majority of information compiled in this report concerning the status of native fish in Rattlesnake Creek came from Montana FWP. Unless otherwise stated, all information in Section 4.1 was acquired from the 2004 Montana FWP report: *Rattlesnake Creek Fisheries Assessment and Enhancement* (Knotek et al., 2004). Montana FWP has conducted numerous electrofishing sampling events, fish screen evaluations, and fish passage studies over the last 15 years (Knotek, personal communication 11/5/2018). Knotek et al. (2004) described the status of the Rattlesnake Creek fishery and examined studies dating back to 1960. Additional electrofishing data have been collected since the completion of this report in 2004, but fish species distribution and genetic composition have not changed dramatically since that time. The main exception is that brown trout are becoming somewhat more abundant in Rattlesnake Creek, and their distribution has gradually spread upstream, above the Rattlesnake Creek Dam. In addition, sculpin abundance has decreased (Knotek, personal communication 2/11/2019).

### *4.1.1 Genetic Composition*

Random *Oncorhynchus* genetic testing was conducted in 1985, 1986, and 2002 at several locations above the Rattlesnake Creek Dam. *Oncorhynchus* refers to rainbow trout, westslope cutthroat trout, Yellowstone cutthroat trout, and hybrids of these species. In all three instances, data collection was performed using backpack electrofishing surveys. Samples were then submitted to the University of Montana's Wild Trout and Salmon Genetics Laboratory. Table 3 shows the percentage of genetic markers indicating each species. It is important to note that pure rainbow trout have not been detected in Rattlesnake Creek in recent times, likely due to the fact that stocking was discontinued 50 years ago (Knotek, personal communication 4/11/2019). Therefore, it can be assumed that individuals with genetic markers characterizing rainbow trout have hybridized with westslope cutthroat trout and that the individuals sampled were a combination of pure westslope cutthroat trout and westslope cutthroat trout/rainbow trout hybrids. Genetic testing indicates that, although rainbow trout have not been stocked in the Rattlesnake for nearly 50 years, genetic markers indicating the species are still present.

*Table 3. Proportion of genetic markers characteristic of Oncorhynchus spp. upstream of Rattlesnake Creek Dam (Knotek et al., 2004).*

| **Location/Stream Mile** | **Date** | **Individuals tested** | **% WCT** | **% YCT** | **% RBT** |
|---|---|---|---|---|---|
| 13 | 10/4/1985 | 32 | 93.8 | 0.1 | 6.2 |
| 9 | 10/3/1986 | 30 | 77.8 | 0 | 22.2 |
| 4 | 7/31/2002 | 23 | 60.8 | 0 | 39.2 |

Note: WCT = Westslope cutthroat trout, YCT = Yellowstone cutthroat trout, RBT = rainbow trout.

### *4.1.2 Species Distribution*

Investigations on Rattlesnake Creek conducted between 1960 and 1991 had shown varied fish species compositions by reach. Native trout and sculpin occupied reaches upstream of the East Fork, although rainbow trout/westslope cutthroat trout hybridization had also occurred. Between the East Fork and the Rattlesnake Creek Dam, the proportion of brook and rainbow trout in the community increased in comparison to upper reaches. Below the Rattlesnake Creek Dam, native species were still present; however, introduced species such as brown and rainbow trout were abundant.

Montana FWP conducted additional surveys in 1999 and 2000 to characterize fish species composition and distribution (Table 4). All fish were captured by electrofishing, identified, and returned to the stream. Of the sites displayed, only Site 4 is located below the Rattlesnake Creek Dam. As with historical observations, sampling in 1999-2000 showed an abundance of brown trout, rainbow trout, and mountain whitefish below the dam. Bull trout, westslope cutthroat trout, and brook trout occupied habitat in upper reaches. As noted earlier, pure rainbow trout have not been found in Rattlesnake Creek for many years. Individuals identified as rainbow trout are likely hybrids with primarily rainbow trout morphological characteristics. Individuals identified as westslope cutthroat trout may also have genetic markers indicative of rainbow trout.

*Table 4. Electrofishing surveys in Rattlesnake Creek in 1999-2000 (Knotek et al., 2004).*

| **Section** | **Location** | **Date** | **Species** | **Individuals sampled** | **Trout Relative Abundance** |
|---|---|---|---|---|---|
| 1 | Upstream of Franklin Bridge | 9/23/1999 | Cutthroat | 12 | 55% |
| | | | Bull | 1 | 5% |
| | | | Brook | 9 | 40% |
| | | | Sculpin | Abundant | - |
| 2 | Upstream of Beescove Creek Mouth | 9/23/1999 | Cutthroat | 15 | 22% |
| | | | Bull | 18 | 26% |
| | | | Brook | 34 | 49% |
| | | | Bull x Brook | 2 | 3% |
| | | | Sculpin | Abundant | - |
| 3 | One mile upstream of Pilcher Creek Mouth | 9/23/1999 | Cutthroat | 18 | 29% |
| | | | Bull | 7 | 10% |
| | | | Brook | 36 | 58% |
| | | | Brown | 1 | 2% |
| | | | Sculpin | Abundant | - |
| 5 | Side Channel at Greenough Park | 7/25/2000 | Cutthroat | 5 | 8% |
| | | | Bull | 2 | 3% |
| | | | Brook | 5 | 8% |
| | | | Brown | 22 | 37% |
| | | | Rainbow | 26 | 43% |
| | | | Mountain Whitefish | Abundant | - |
| | | | Sculpin | Abundant | - |

*Note: Brown = brown trout, Cutthroat = cutthroat trout, Bull = bull trout, Brook = brook trout, Rainbow = rainbow trout, Bull x Brook = bull trout x brook trout cross. All identification based on physical appearance.*

### *4.1.3 Upstream Fish Passage at Rattlesnake Creek Dam*

Prior to the installation of a fish ladder at the Rattlesnake Creek Dam, adult bull trout and westslope cutthroat trout had been consistently documented at the base of the dam during their respective spawning migration periods. In April 2003, a permanent fish ladder was installed at the Rattlesnake Creek Dam, with the goal of enhancing fluvial westslope cutthroat trout and bull trout access to upstream spawning habitat.

The fish ladder performed reasonably well for the first five to seven years after installation, based on bull trout red counts, anecdotal fish observations in ladder, and the lack of observations of adult *Oncorhynchus* congregating below the dam. The ladder, however, appeared to promote superior passage for *Oncorhynchus* than for bull trout, with estimated passage efficiency greater than 90%, compared to an estimated passage efficiency of 40-60% for migrating bull trout (Knotek, personal communication 3/18/2019).

In recent years, the sluice gate at the base of dam has been open, with lower efficiency for *Oncorhynchus* and better assumed efficiency for bull trout. This discrepancy is possibly explained by the difference in spawning migration periods between *Oncorhynchus* and bull trout. Bull trout move on descending limb of hydrograph and can swim through the dam. *Oncorhynchus* generally move at peak flow, hence cannot swim through the dam, and often do not find ladder entrance effectively (Knotek, personal communication 3/18/2019).

#### *4.1.4 Assessment of Fish Losses in Irrigation Diversions*

Populations of many native fishes in the western United States have declined in part because of entrainment in irrigation ditches (Pierce et al., 2004). Six irrigation ditches are currently in operation on the lower five miles of Rattlesnake Creek: Quast Ditch, Williams Ditch, Cobban Ditch, Hollenbeck Ditch, Hamilton-Day Ditch, and Hughes-Fredline Ditch (Trout Unlimited, 2010).

Between 2001 and 2003, electrofishing was performed by Montana FWP to measure fish entrainment in Rattlesnake Creek diversions. Sampling was performed between August and September of each year when fish densities are highest in canals. Trout were abundant in all unscreened irrigation ditches (Table 5). The relative abundance of bull trout in the Cobban and Hamilton-Day diversions was very high relative to the creek. Knotek et al. (2004) suspected that bull trout entrainment was particularly high in the lower reaches of Rattlesnake Creek because of the lack of side channels that juveniles seek for protection and that irrigation diversions mimic these conditions. The effectiveness of the Quast and Williams fish screens could not be measured during sampling since pre-installation assessments were not performed (Knotek et al., 2004). After detecting high entrainment rates in 2001, the Cobban and Hamilton-Day fish screens saw mixed success in reducing entrainment in 2002 and 2003.

*Table 5. Fish sampling in irrigation diversion canals on Rattlesnake Creek, 2001-2003 (Knotek et al., 2004).*

| Diversion | Date Sampled | Section Length | Fish Species | Fish caught in diversion |
|---|---|---|---|---|
| Cobban | 8/22/2001 (B) | ~500 ft. | Bull | 53 |
| | | | Oncorhynchus Spp. | 25 |
| | | | Brown | 3 |
| | | | Brook | 16 |
| | 9/27/2002 (A) | ~250 ft. | Oncorhynchus Spp. | 2 |
| | | | Brown | 2 |
| | 8/19/2003 (A) | ~500 ft. | Oncorhynchus Spp. | 27 |
| Hamilton-Day | 6/25/2001 (B) | ~250 ft. | Bull | 3 |
| | | | Oncorhynchus Spp. | 11 |
| | | | Mountain Whitefish | 2 |
| | | | Brook | 5 |
| | 9/27/2002 (A) | ~350 ft. | Oncorhynchus Spp. | 22 |
| | | | Brown | 33 |
| | | | Brook | 6 |
| | 8/15/2003 (A) | ~500 ft. | Oncorhynchus Spp. | 22 |
| | | | Brown | 13 |
| | | | Brook | 2 |
| Quast | 6/23/2001 (A) | ~250 ft. | No Fish | 0 |
| | 10/10/2002 (A) | ~250 ft. | Oncorhynchus Spp. | 1 |
| | | | Brook | 20 |
| | 8/19/2003 (A) | ~500 ft. | No Fish | 0 |
| Williams | 6/23/2001 (A) | ~250 ft. | No Fish | 0 |
| | 10/10/2002 (A) | ~300 ft. | No Fish | 0 |
| | 8/19/2003 (A) | ~500 ft. | Oncorhynchus Spp. | 1 |
| | | | Brook | 2 |
| Hughes-Fredline | 9/27/2002 (U) | ~250 ft. | Oncorhynchus Spp. | 12 |
| | | | Brown | 45 |
| | | | Brook | 1 |
| | | | Mountain Whitefish | 5 |
| Hollenbeck | 8/12/2002 (U) | ~300 ft. | Oncorhynchus Spp. | 8 |
| | | | Brown | 15 |
| | | | Brook | 16 |

Note: Brown = brown trout, Bull = bull trout, Brook = brook trout. Oncorhynchus Spp. Refers to rainbow trout, westslope cutthroat trout, and hybrids of these species. (B) = Before Screening. (A) = After Screening. (U) = Unscreened.

In 2010, staff from Trout Unlimited, Montana Water Trust, and Clark Fork Coalition (CFC) surveyed the ditches to assess fish entrainment and screen maintenance (Trout Unlimited, 2010). They concluded that screens located at the Quast, Williams, and Cobban ditches were functioning properly and that no additional maintenance was required. The Hamilton-Day screen still allowed fish to pass into the canal and did not function as intended. The Hollenbeck ditch was not screened, but it led to a small pond and trapped few fish (Trout Unlimited, 2010). The Hughes-Fredline Ditch also had no fish screen but was known to entrain fish (Trout Unlimited, 2010). Since the 2010 survey, TU has replaced fish screens on the Hughes-Fredline Ditch (2015), Williams Ditch (2016), and Cobban Ditch (2018), but no additional assessments have been done (Roberts, personal communication 4/1/2019).

### 4.2 Stream Temperature

While recent water temperature data are available, limited historical water temperature data were found on Rattlesnake Creek. Montana FWP collected temperature data at the Rattlesnake Creek Dam from 2000 to 2005 and from 2011 to 2016 (Montana FWP unpublished data). Summer maximum daily temperatures at this site generally rose to approximately 16°C (~61°F) (Figure 2). The highest maximum daily temperature recorded was 20°C (~68°F), which occurred on 8/3/2000. Annual maximum daily temperatures generally peaked from late July to early August. Average maximum daily temperature (black line) was calculated from May through September to capture the season typically associated with highest water temperatures. The average is based on eight to 12 years of monitoring.

The Clark Fork Coalition collected temperature data at two locations on Rattlesnake Creek between 2008 and 2012. A TruTrack WT-HR data logger was used to measure water temperature every thirty minutes (Clark Fork Coalition unpublished data). Maximum daily temperatures were recorded at the mouth and above the Rattlesnake Creek Dam at the Rattlesnake trailhead (~mile 4) between 2008 and 2010 and then only at the mouth in 2012

(Figure 3, Figure 4). Summer maximum daily temperatures generally rose to approximately 18°C (~64°F) at the mouth and 17°C (~63°F) at the trailhead. The highest maximum daily temperatures recorded at the mouth and trailhead were 19.3°C (66.7°F) and 17.6°C (63.6°F), respectively. This occurred on 8/5/2010 at the mouth and 7/25/2009 at the trailhead. Annual maximum daily temperatures generally peaked from late July to early August. Average maximum daily temperature (black line) was calculated from July 9th through September and is based on three to four years of monitoring for the mouth and two to three years of monitoring for the trailhead. Lack of May and June data limited the extent to which temperatures could be averaged.

Montana DNRC began collecting continuous temperature data on Rattlesnake Creek at Greenough Park (~ mile one) in November 2017 (Figure 5) (Montana DNRC, 2019). Maximum daily stream temperatures recorded at this location range from -0.4°C (~32°F) to 17.1°C (62.8°F). With only one full season of monitoring, typical annual maximum temperatures cannot be characterized. Monitoring locations are included in Appendix B, Figure 17.

*Figure 2. Maximum Daily Temperature at Rattlesnake Creek Dam, 2000-2005 and 2011-2016(°C) (Montana FWP unpublished data).*

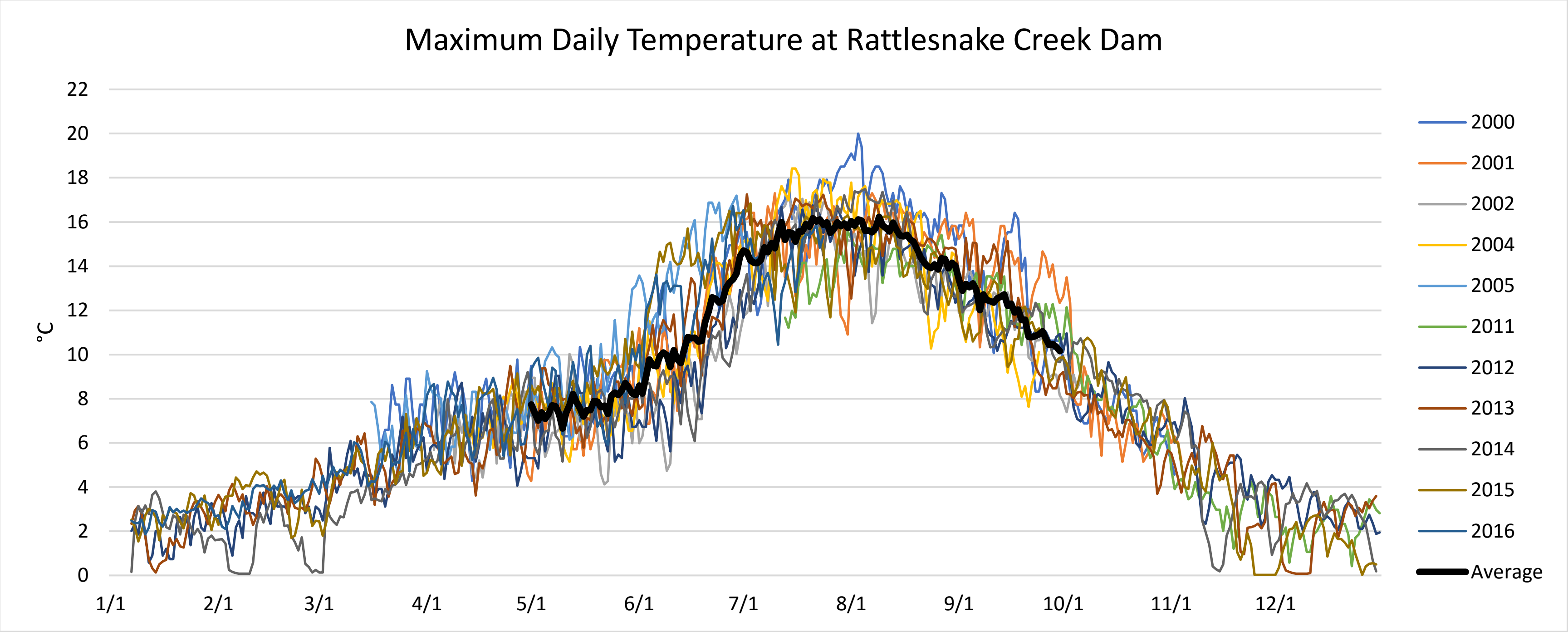


*Figure 3. Maximum Daily Temperatures at the Rattlesnake Creek Mouth, 2008-2010, 2012 (°C) (Clark Fork Coalition unpublished data).*

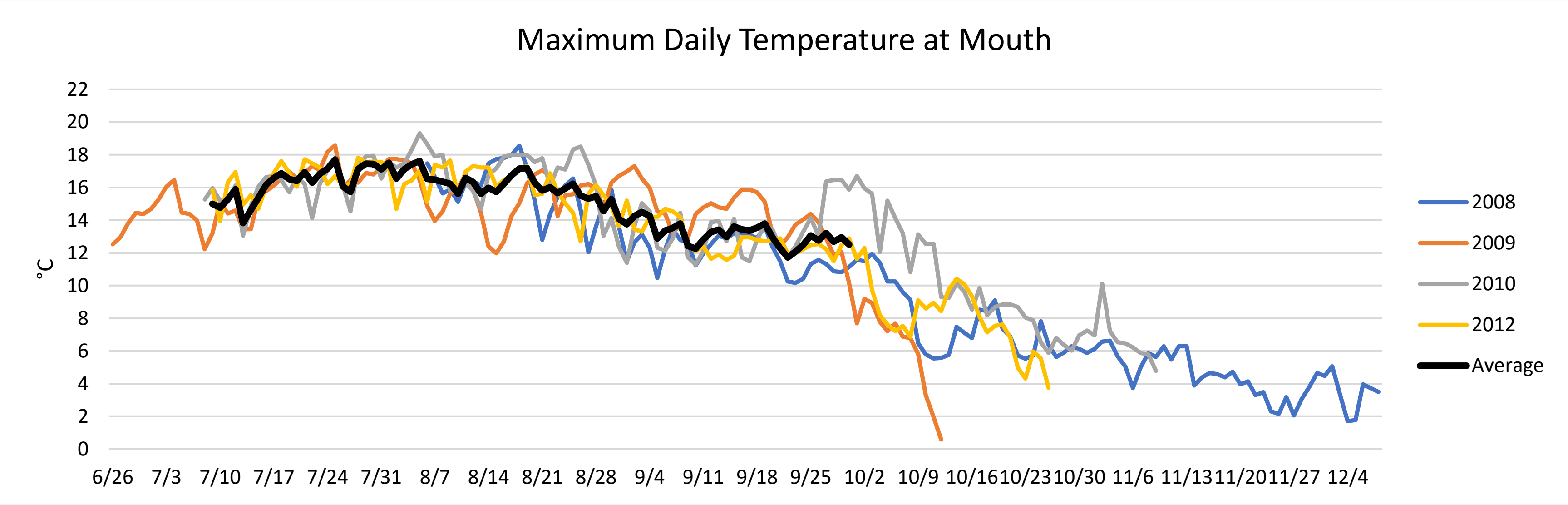


*Figure 4. Maximum Daily Temperatures at the Rattlesnake Creek Trailhead, 2008-2010 (°C) (Clark Fork Coalition unpublished data).*

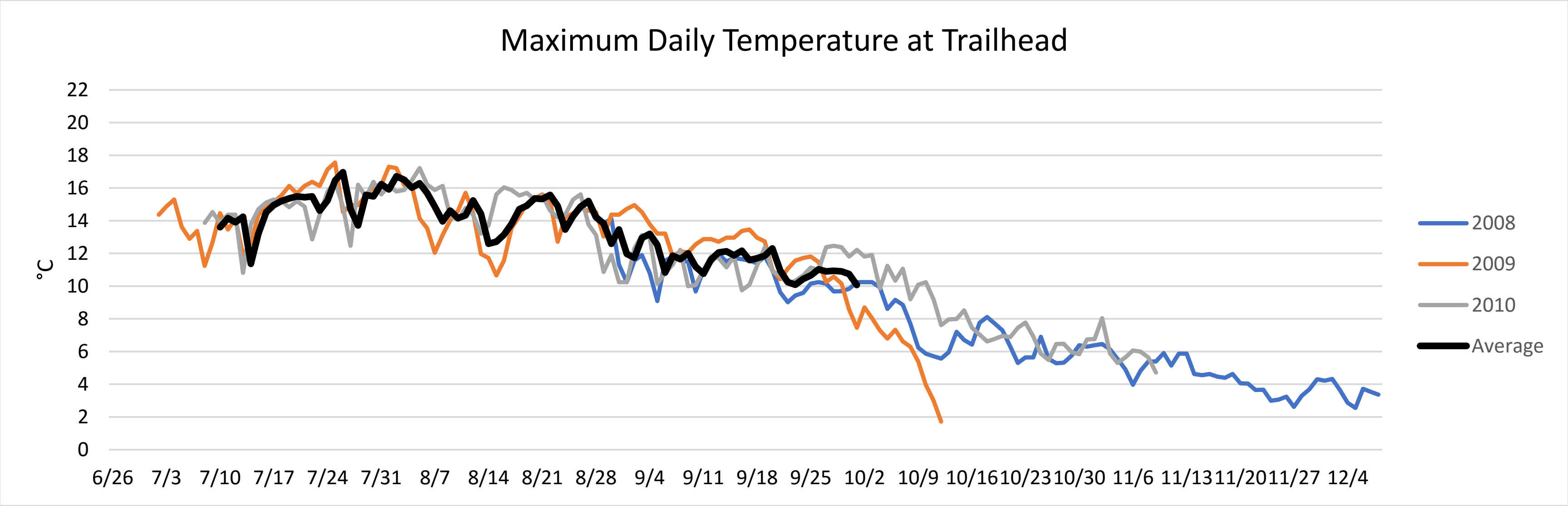
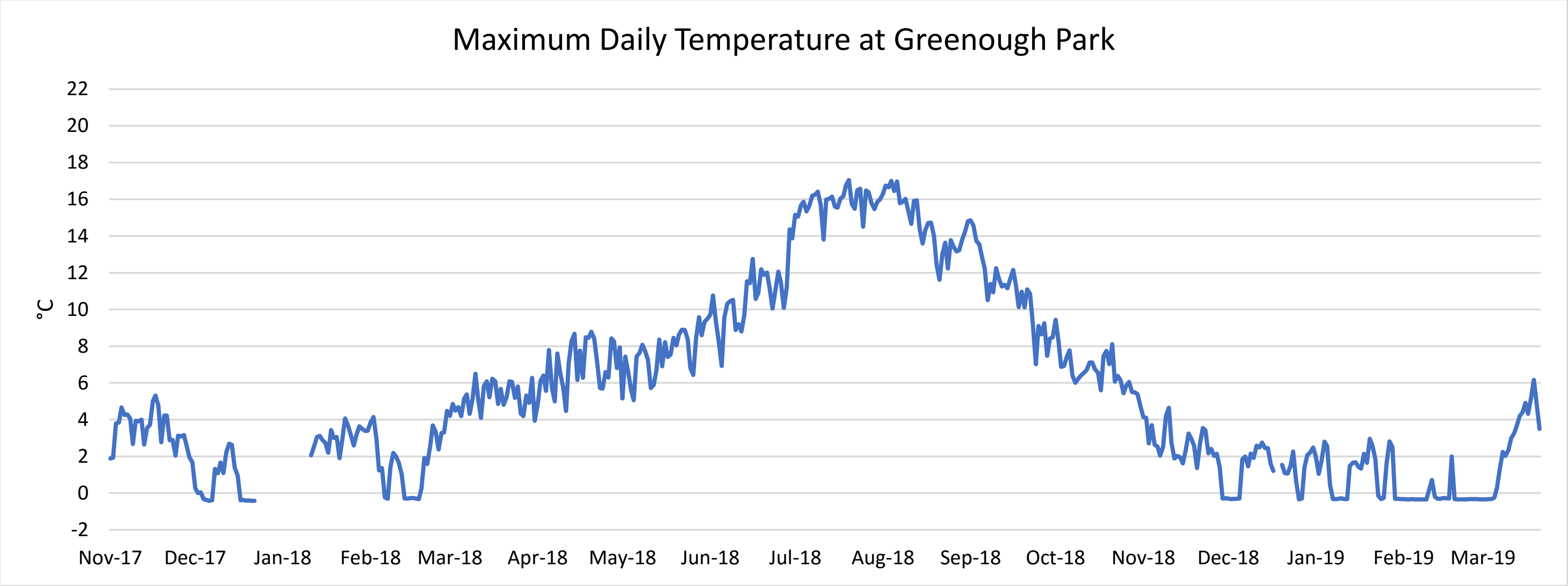


*Figure 5. Maximum Daily Temperatures at Greenough Park, 2017- current (°C) (Montana DNRC, 2019).*



Temperatures known to indicate suitable thermal habitat for long-term persistence of native trout were compared to recent data. Maximum daily temperatures between 13-15°C and 10.9-15.4°C are ideal for the optimum growth of westslope cutthroat trout and bull trout, respectively (Bear et al., 2007 and Selong et al., 2001). Table 6 shows the number of days with recorded temperatures exceeding 15°C (the upper limit of native trout optimum growth temperatures) at various sites sampled on Rattlesnake Creek. The number of days per year exceeding optimum growth temperatures ranged from zero to 60, although monitoring duration was highly variable between years.

*Table 6. Days with Maximum Daily Temperatures exceeding 15°C at sites sampled on Rattlesnake Creek.*

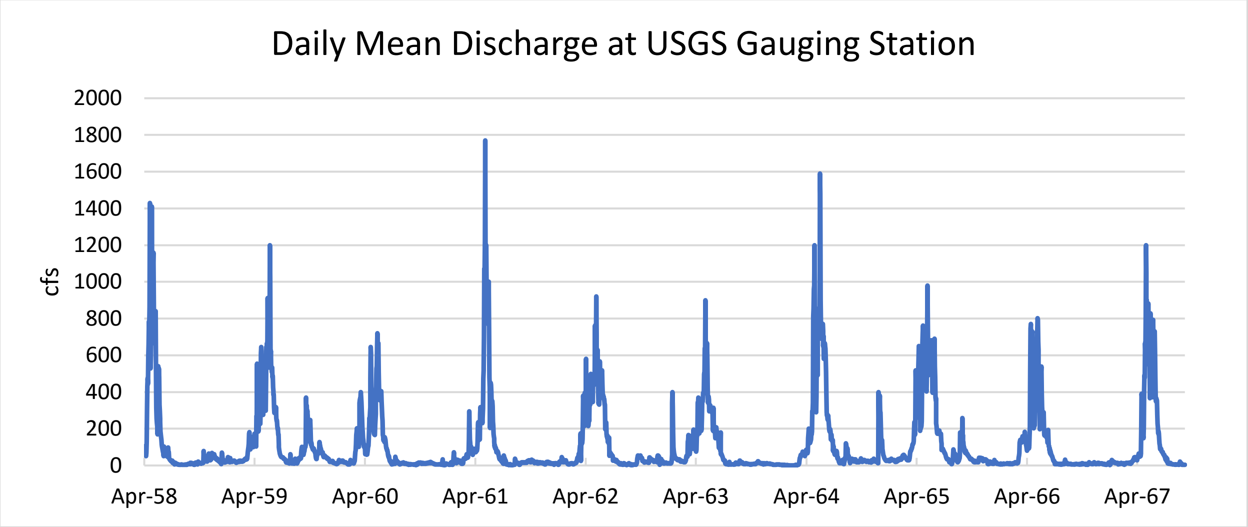
| Monitoring Location | Years Monitored | Duration Monitored | Number of Days with Maximum Daily Temperature >15°C |
|---|---|---|---|
| Mouth (Mile 0) | 2008 | Aug 6th-Dec 8th | 19 |
| | 2009 | June 26th-Oct 12th | 52 |
| | 2010 | July 8th-Nov 9th | 56 |
| | 2012 | July 9th-Oct 26th | 47 |
| Greenough Park (Mile 1) | 2017 | Nov 7th-Dec 28th | 0 |
| | 2018 | Jan 17th-Dec 31st | 41 |
| | 2019 | Jan 1st-March 27th | 0 |
| Dam (Mile 3.5) | 2000 | March 16th-Nov 2nd | 60 |
| | 2001 | April 29th-Nov 4th | 48 |
| | 2002 | April 3rd-Oct 6th | 26 |
| | 2003 | April 15th-Aug 21st | 42 |
| | 2004 | April 14th-Sept 24th | 43 |
| | 2005 | April 6th-July 22nd | 14 |
| | 2011 | July 13th-Dec 31st | 4 |
| | 2012 | Jan 1st-Dec 31st | 34 |
| | 2013 | Jan 1st-Dec 30th | 54 |
| | 2014 | Jan 1st-Dec 30th | 38 |
| | 2015 | Jan 1st-Dec 30th | 33 |
| | 2016 | Jan 1st-July 24th | 14 |
| Trailhead (Mile 4) | 2008 | Aug 29th-Dec 8th | 0 |
| | 2009 | July 2nd-Oct 12th | 22 |
| | 2010 | July 8th-Nov 9th | 27 |

Note: Due to the duration of annual monitoring, all days with temperatures exceeding 15°C may not have been recorded.

## 4.3 Stream Discharge

Daily mean discharge data were collected on Rattlesnake Creek at a USGS station, located approximately one-third of a mile upstream of the confluence with the Clark Fork River, between 1958 and 1967 (Figure 6). Flows recorded at this location ranged from 0.3 to 1770 cfs (cubic feet per second). Annual runoff generally peaked in early June. During this period, October base flows typically ranged from 23 to 59 cfs.

*Figure 6. Daily Mean Discharge taken at USGS Station 12341000 on Rattlesnake Creek 1958-1967 (USGS, 2018).*



The Clark Fork Coalition collected daily mean discharge data at the Rattlesnake Creek mouth from 2008 through 2010 and in 2012 (Figure 7). At the Rattlesnake Trailhead (~mile four), discharge was measured from 2008 through 2010 (Figure 8). A TruTrack WT-HR data logger was used to measure water height every thirty minutes (Clark Fork Coalition unpublished data). During this period, October base flows typically ranged from 22 to 29 cfs at the mouth and 30 to 32 cfs at the Rattlesnake Trailhead. Although annual peak discharge was not recorded, 2012 appears to have seen considerably higher discharge than 2008, 2009, or 2010 at the mouth.

*Figure 7. Daily Mean Discharge at the Rattlesnake Creek Mouth, 2008-2010, 2012 (cfs) (Clark Fork Coalition unpublished data).*

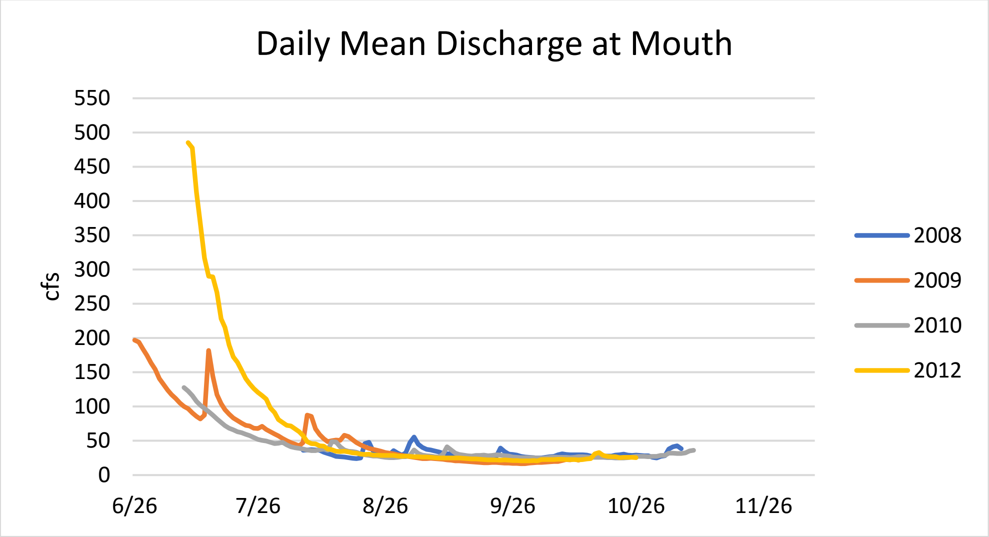
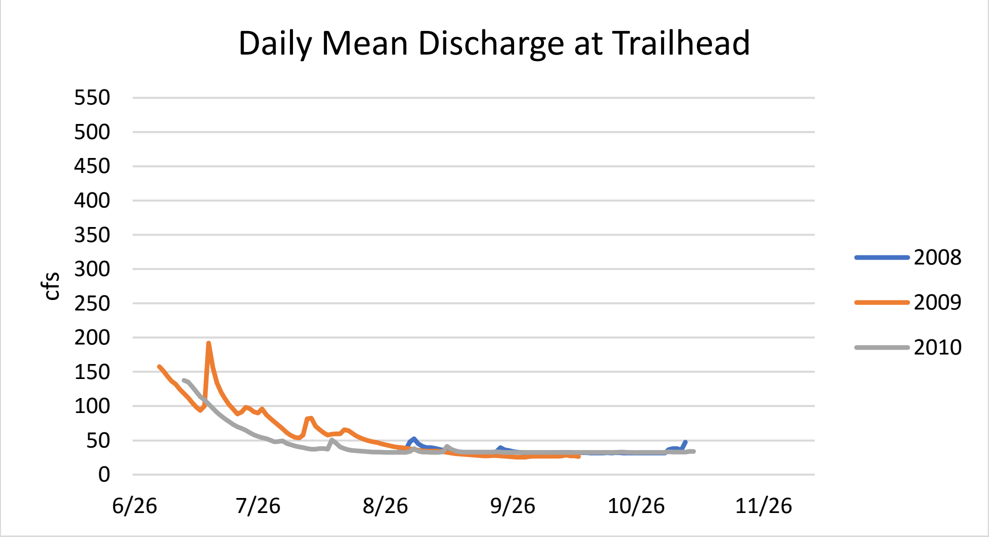
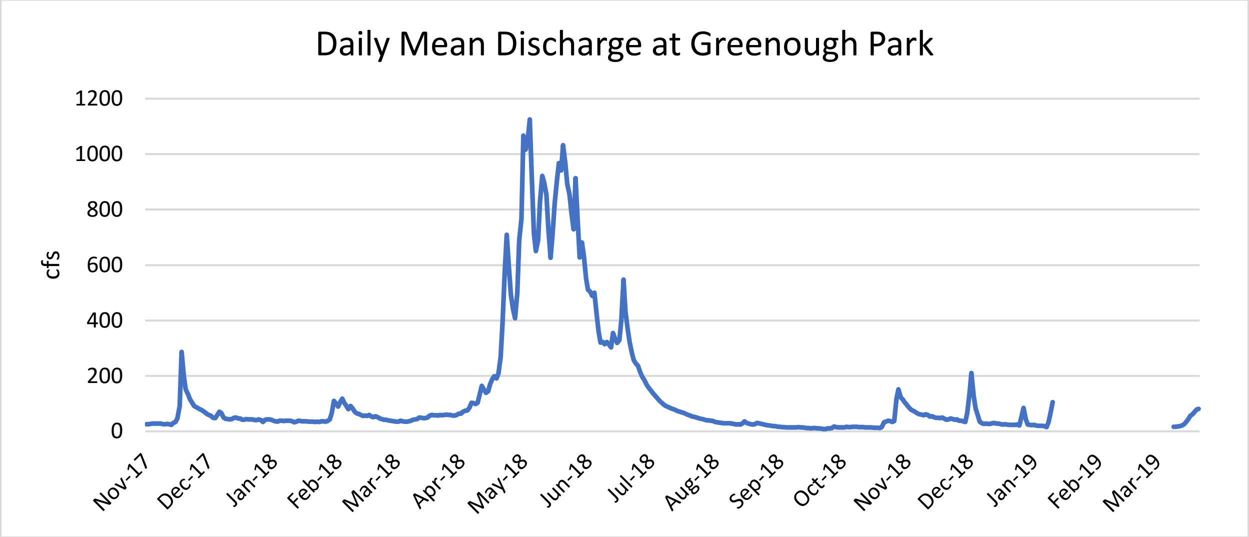


*Figure 8. Daily Mean Discharge at the Rattlesnake Creek Trailhead, 2008-2010 (cfs) (Clark Fork Coalition unpublished data).*



Montana DNRC began collecting continuous discharge data on Rattlesnake Creek at Greenough Park (~mile 1) in November 2017 (Figure 9). Flows recorded at this location range from 8.3 to 1,125.2 cfs. With only one full season of monitoring, typical annual runoff and base flows cannot be estimated. Discharge monitoring sites are included in Appendix B, Figure 17.

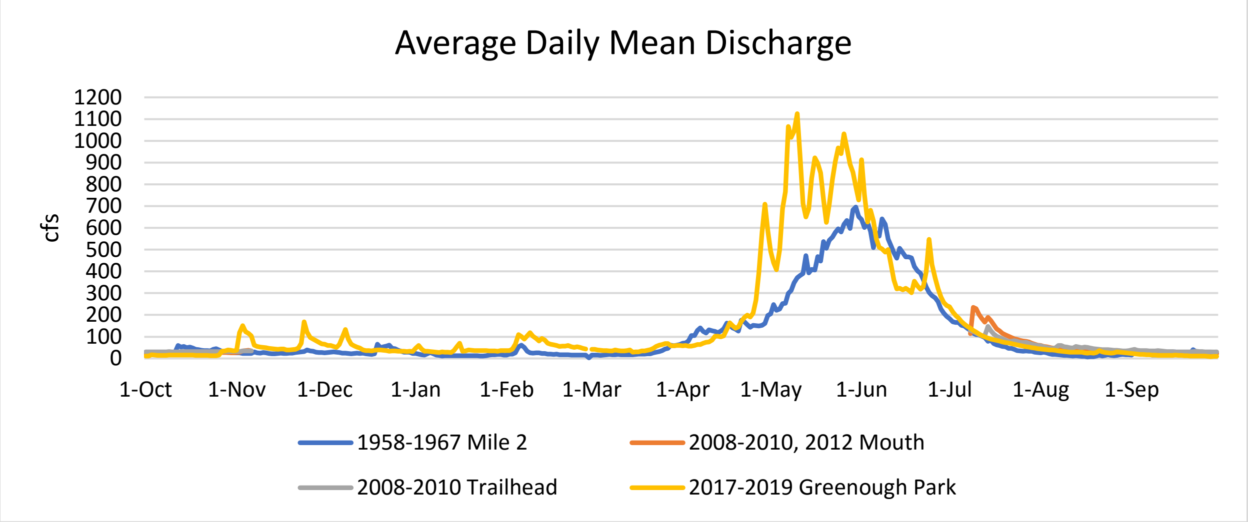
*Figure 9. Daily Mean Discharge taken at DNRC Hydrology Station at Greenough Park, 2017- current (Montana DNRC, 2019).*



Many consecutive years of historical data exist for stream discharge. Figure 10 shows the average daily mean streamflow at the different sites sampled at their respective times. Values were calculated based on a nine to ten-year mean for the 1958-1967 USGS data, a two to four-year mean for 2008-2012 CFC data, and a one to two-year mean for 2017-2019 Montana DNRC data. Mean values were calculated year-round for 1958-1967 and 2017-2019 measurements and between July 8th and November 6th for 2008-2012 measurements.

The ability to compare the timing and duration of annual peak runoff is limited due to lack and duration of recent sampling. The DNRC gauge has only been in operation for one full season, so mean values may not characterize typical streamflow, especially considering the unusually high runoff during the spring of 2018. What recent data are available show a more intense peak runoff, shifted approximately two weeks earlier in the year. Additionally, several small peaks in November and December were recorded at the DNRC station. CFC monitoring was performed for consecutive years; however, it did not begin each year until after the annual peak runoff. It is important to note that, while the peak 2018 discharge exceeded the 1959-1967 average daily mean discharge, five out of ten years of USGS monitoring (1958, 1959, 1961, 1964, and 1967) still recorded a higher peak than 2018. Hence, continued stream discharge monitoring is necessary to establish accurate trends.

*Figure 10. Average Daily Mean Discharge at four locations on Rattlesnake Creek over multiple years (USGS, 2019, CFC unpublished data, USGS, 2018).*



To compare base flows over time, daily mean discharge data for the month of October were averaged. Table 7 shows the October average daily mean discharge at each of the monitoring sites, years monitored, and the number of days used to calculate each average. Measurements taken from 1958-1966 at the USGS station are highest, at 35.3 cfs, followed by 2008-2010 at Rattlesnake Trailhead (31.3 cfs), 2008-2010 and 2012 at the mouth (25.6 cfs), and 2018 at Greenough Park (17.9 cfs). Measurements taken between 1958 and 1966 show a high degree of variation, compared to the other data. The most effective comparisons can be made between monitoring locations that are in close proximity to each other (i.e. at the mouth, mile 0.3, and mile one).

*Table 7. Average Daily Mean Discharge for the Month of October at four locations on Rattlesnake Creek over multiple years.*

| Location | Years Monitored | Days Monitored | October Mean Discharge (cfs) | Standard Deviation |
|---|---|---|---|---|
| Mile 0.3 | 1958-1966 | 279 | 35 | 55 |
| Mouth (Mile 0) | 2008, 2009, 2010, and 2012 | 100 | 25.6 | 3.03 |
| Trailhead (Mile 4) | 2008, 2009, 2010 | 74 | 31.3 | 1.93 |
| Greenough Park (Mile 1) | 2018 | 31 | 17.9 | 8.08 |

## 4.4 Nutrients

Existing instream nutrient data were used to evaluate changing conditions in Rattlesnake Creek. Missoula County collected orthophosphate, total phosphorus, ammonia, total kjeldahl nitrogen, and nitrate plus nitrite measurements in 2008 at three locations. The Montana Department of Environmental Quality (Montana DEQ) collected various orthophosphate, nitrate, and a small amount of nitrate plus nitrite measurements in 1974 and 1975 at five locations on Rattlesnake Creek. See Appendix B, Figure 18 for a map of nutrient sampling locations. Orthophosphate levels (mg/l) were compared between 2008 and 1974-1975. Historic nitrate and nitrate plus nitrite measurements were compared to 2008 nitrate plus nitrite data. This comparison was made due to the fact that in oxygenated environments, nitrite is usually negligible. The combined concentration of nitrate and nitrite is commonly referred to as “nitrate” because of the very low levels of nitrite that are typically found in comparison to nitrate (Wall, 2013). Neither data source provided a detection limit. Here, it is assumed to be the value that is halfway between zero and the lowest reported value

### *4.4.1 Phosphorus*

Orthophosphate is a soluble form of phosphorus, meaning it is readily available to algae and aquatic plants (Minnesota Pollution Control Agency, 2007). Orthophosphate measurements were collected by Montana DEQ from 1974 to 1975 at five locations on Rattlesnake Creek: Lolo Street (~mile 1.5), Mountain View Drive (~mile two), Creekwood Road (~mile 2.6), downstream of the Rattlesnake Creek Dam (~mile three), and near Rattlesnake Trailhead (~mile four) (Table 8). Orthophosphate levels ranged from below detection (at all locations) to 0.49 mg/l, recorded at Lolo Street.

*Table 8. Orthophosphate levels (mg/l) on Rattlesnake Creek from 1974-1975 (National Water Quality Monitoring Council, 2018).*

| | At Lolo St. | At Mountain View Drive | At Creekwood Road | Downstream from Dam | Rattlesnake Trailhead |
|---|---|---|---|---|---|
| 7/26/1974 | BD | BD | BD | BD | BD |
| 7/29/1974 | BD | 0.01 | - | 0.03 | - |
| 8/5/1974 | 0.02 | 0.24 | BD | 0.02 | BD |
| 8/26/1974 | BD | 0.04 | BD | BD | BD |
| 9/4/1974 | 0.01 | - | BD | 0.01 | 0.03 |
| 9/10/1974 | 0.05 | 0.04 | BD | BD | BD |
| 10/29/1974 | 0.49 | 0.09 | - | - | - |
| 3/18/1975 | 0.01 | 0.1 | - | - | - |
| 3/19/1975 | - | - | - | 0.01 | - |
| **Mean** | **0.07** | **0.08** | **0.005** | **0.01** | **0.01** |

Note: BD = Below Detection. Detection limit assumed to be approx. 0.005.

Orthophosphate measurements were collected by Missoula County in 2008 at three locations on Rattlesnake Creek: the mouth, Pineview Drive (~mile 1.9), and the Rattlesnake Trailhead (~mile 4) (Table 9). Orthophosphate levels ranged from below detection (at Pineview Drive) to 0.078 mg/l, recorded at Mountain View Drive, which is listed as a suspect value. Excluding suspect values, the largest 2008 orthophosphate value is 0.012, which was recorded at the mouth and Pineview Drive.

*Table 9. Orthophosphate levels (mg/l) on Rattlesnake Creek in 2008 (Missoula County unpublished data).*

| | Mouth | Pineview | Trailhead | Blank |
|---|---|---|---|---|
| 3/17/2008 | 0.012 | 0.005 | 0.078* | 0 |
| 4/18/2008 | 0.006 | 0.012 | 0.007 | 0.001 |
| 5/15/2008 | 0.005 | 0.006 | 0.005 | 0.001 |
| 6/12/2008 | 0.008 | BD | 0.008 | 0.001 |
| 7/18/2008 | 0.009 | 0.009 | 0.009 | 0 |
| 8/15/2008 | 0.011 | 0.01 | 0.01 | 0.001 |
| 9/16/2008 | 0.011 | 0.011 | 0.011 | 0.001 |
| 10/16/2008 | 0.005 | 0.004 | 0.005 | 0.001 |
| 11/14/2008 | 0.005 | 0.005 | 0.005 | 0.001 |
| **Mean** | **0.008** | **0.007** | **0.008** | |

Note: BD = Below Detection. Detection limit assumed to be approx. 0.002.
*Suspect value. Not included in Mean.

Mean Rattlesnake Creek orthophosphate levels appear to have decreased between the mid-1970s and 2008. The mean of all recorded orthophosphate levels between 1974 and 1975 is 0.04 mg/l. The mean of all recorded levels in 2008 is 0.008 mg/l, excluding the suspect value. The mean orthophosphate concentration recorded between 1974 and 1975 is based on 32 total samples collected at five sites in the months of March, July, August, September, and October. The 2008 mean is based on 27 total samples collected at three sites each month between May and November. Sampling locations are not identical between 1974-1975 and 2008; however, the uppermost sampling location of both data sets is the same (Rattlesnake Trailhead). In addition, the 2008 Pineview Drive site is less than one-half of a mile upstream of the 1974-1975 Lolo Street site. While it would be ideal to compare samples collected at the same locations, available data still suggest that 2008 orthophosphate levels are lower than 1974-1975 levels.

### *4.4.2 Nitrogen*

Ammonia, nitrate, and nitrite are inorganic forms of nitrogen. Of these, nitrate is typically the dominant form of nitrogen in waterbodies with elevated nitrogen, and it is highly soluble. Total kjeldahl nitrogen is the combination of organic nitrogen and ammonia plus ammonium.

Total nitrogen is commonly estimated by adding total kjeldahl nitrogen, nitrate, and nitrite (Wall, 2013). Nitrate measurements were collected by Montana DEQ from 1974 to 1975 at the same five locations on Rattlesnake Creek at which orthophosphate monitoring was performed (Table 10). Nitrate levels ranged from below detection (at all locations) to 0.12 mg/l, recorded at Mountain View Drive.

*Table 10. Nitrate levels (mg/l) on Rattlesnake Creek, 1974-1975 (National Water Quality Monitoring Council, 2018).*

| | At Lolo St. | At Mountain View Drive | At Creekwood Road | Downstream from Dam | Rattlesnake Trailhead |
|---|---|---|---|---|---|
| 7/26/1974 | BD | BD | 0.04 | BD | BD |
| 7/29/1974 | BD | BD | - | BD | - |
| 8/5/1974 | 0.09 | BD | BD | BD | BD |
| 8/26/1974 | 0.02 | 0.02 | BD | BD | BD |
| 9/4/1974 | BD | - | BD | BD | BD |
| 9/10/1974 | 0.02 | BD | BD | BD | BD |
| 10/29/1974 | 0.03 | 0.02 | - | - | - |
| 3/18/1975 | 0.03* | 0.12* | - | - | - |
| 3/19/1975 | - | - | - | 0.02* | - |
| **Mean** | **0.03** | **0.03** | **0.02** | **0.01** | **0.01** |

Note: BD = Below Detection. Detection limit assumed to be approx. 0.01.
*Nitrate plus Nitrite measurement

Nitrate plus nitrite measurements were collected by Missoula County in 2008 on Rattlesnake Creek at the mouth, Pineview Drive, and the Rattlesnake Trailhead (Table 11). Nitrate plus nitrite levels ranged from 0.002 mg/l (at Pineview Drive) to 0.046 mg/l, recorded at the mouth.

*Table 11. Nitrate plus Nitrite levels (mg/l) on Rattlesnake Creek in 2008 (Missoula County unpublished data).*

| | Mouth | Pineview | Trailhead | BLANK |
|---|---|---|---|---|
| 3/17/2008 | 0.011 | 0.008 | 0.011 | 0 |
| 4/18/2008 | 0.007 | 0.008 | 0.007 | 0 |
| 5/15/2008 | 0.007 | 0.006 | 0.005 | 0 |
| 6/12/2008 | 0.012 | 0.036 | 0.014 | 0 |
| 7/18/2008 | 0.015 | 0.005 | 0.003 | 0.001 |
| 8/15/2008 | 0.046 | 0.005 | 0.004 | 0.001 |
| 9/16/2008 | 0.041* | 0.005* | 0.004* | -2.662* |
| 10/16/2008 | 0.009 | 0.002 | 0.003 | 0.001 |
| 11/14/2008 | 0.014 | 0.016 | 0.012 | 0.001 |
| **Mean** | **0.02** | **0.01** | **0.007** | |

*Suspect value. Not included in Mean.

Mean Rattlesnake Creek nitrate levels have remained reasonably consistent between the mid-1970s and 2008. The mean of all recorded nitrate levels between 1974 and 1975 is 0.02 mg/l. The mean of all recorded nitrate levels in 2008 is 0.01 mg/l, excluding suspect values. The mean nitrate concentration recorded between 1974 and 1975 is based on 32 total samples collected at five sites in the months of March, July, August, September, and October. The 2008 mean is based on 24 total samples collected at three sites each month between March and November. As with phosphorus, nitrogen sampling locations are not identical between 1974-1975 and 2008; however, samples were collected below the Rattlesnake Trailhead at stream mile four for both time periods. While it would be ideal to compare samples collected at the same locations, available data still suggest little change in nitrate levels.

### *4.4.3 Total Phosphorus and Total Nitrogen*

Montana DEQ now uses total nitrogen and total phosphorus as the basis for their nutrient criteria (Montana DEQ, 2014). The Middle Rockies Ecoregion numeric nutrient standard is 300 µg/l (0.3 mg/l) for total nitrogen and 30 µg/l (0.03 mg/l) for total phosphorus (Montana DEQ, 2014). These criteria apply July 1st to September 30th. Measurements used to calculate these parameters were collected in 2008, meaning they can be compared to Montana DEQ's numeric nutrient criteria. Data from 1974-1975 cannot be compared to Montana DEQ criteria because they do not include necessary parameters used to calculate total nitrogen or total phosphorus. Total nitrogen can be derived by taking the sum of total kjeldahl nitrogen (organic nitrogen, ammonia, and ammonium) and nitrate plus nitrite. Total nitrogen (Table 12) and total phosphorus (Table 13) measurements from 2008 are shown below. Highlighted rows indicate samples that were collected between July 1st and September 30th and hence can be compared to Montana DEQ numeric nutrient criteria.

*Table 12. Total Nitrogen levels (mg/l) on Rattlesnake Creek in 2008 (Missoula County unpublished data).*

| | Mouth | Pineview | Trailhead |
|---|---|---|---|
| 3/17/2008 | 0.122 | 0.124 | 0.162 |
| 4/18/2008 | 0.220 | 0.138 | 0.090 |
| 5/15/2008 | 0.176 | 0.237 | 0.151 |
| 6/12/2008 | 0.163 | 0.204 | 0.307 |
| 7/18/2008 | 0.081 | 0.097 | 0.104 |
| 8/15/2008 | 0.126* | 0.117* | 0.036* |
| 9/16/2008 | - | - | - |
| 10/16/2008 | 0.050 | 0.042 | 0.039 |
| 11/14/2008 | 0.158 | 0.156 | 0.150 |
| **Mean** | **0.137** | **0.139** | **0.130** |

*Calculation based on suspect value.

Note: Total Nitrogen was not calculated on 9/16/2008 because total kjeldahl nitrogen was not measured.

No total nitrogen values between the applicable dates exceeded the 0.3 mg/l standard; however, three of the six values are suspect. No total phosphorus values between the applicable dates exceeded the 0.03 mg/l standard.

*Table 13. Total Phosphorus levels (mg/l) on Rattlesnake Creek in 2008 (Missoula County unpublished data).*

| | Mouth | Pineview | Trailhead | BLANK |
|---|---|---|---|---|
| 3/17/2008 | 0.004 | 0.007 | 0.005 | 0.002 |
| 4/18/2008 | 0.007 | 0.008 | 0.007 | 0 |
| 5/15/2008 | 0.012 | 0.03 | 0.009 | 0 |
| 6/12/2008 | 0.008 | 0.008 | 0.008 | 0.004* |
| 7/18/2008 | 0.007 | 0.01 | 0.007 | 0.001 |
| 8/15/2008 | 0.006 | 0.006 | 0.005 | 0.001 |
| 9/16/2008 | 0.004 | 0.005 | 0.006 | - |
| 10/16/2008 | 0.007 | 0.005 | 0.005 | 0.004* |
| 11/14/2008 | 0.012 | 0.013 | 0.012 | 0.002 |
| **Average** | **0.007** | **0.01** | **0.007** | |

*Suspect value

The ratio of nitrogen to phosphorus in water and in algae (called the Redfield ratio) has been used an indicator of which of the two nutrients most limits algal growth. A ratio between 6 & 10 suggests co-limitation while higher ratios suggest phosphorus limitation and lower ratios suggest nitrogen limitation (Suplee and Watson, 2013). To discourage nitrogen-fixing blue-green algae, Suplee and Watson (2013) recommended a total nitrogen: total phosphorus ratio of 10:1 for the Middle Rockies ecoregion, hence Montana DEQ's nutrient criteria of 300 µg/l (0.3 mg/l) for total nitrogen and 30 µg/l (0.03 mg/l) for total phosphorus.

The nutrient standards apply only to the summer (between July 1st and September 30th), and there are only six pairs of nitrogen & phosphorus samples in 2008; the mean ratio of these six pairs equals 14:1. This suggests phosphorus limitation. After removing suspect values from consideration (8/15/2008), the mean nitrogen: phosphorus ratio equals 12:1, again suggesting phosphorus limitation. This ratio is based on three samples, all collected on 7/18/2008. In contrast, the ratio of soluble nitrogen to soluble phosphorus (nitrate: orthophosphate), suggests strong nitrogen limitation (mean ratio of 1.3:1). These conflicting results may ultimately suggest that the system is co-limited by nitrogen and phosphorus.

## 4.5 Channel Form

The wetted channel centerline was manually digitized in the 1929 mosaic and in the 2015 NAIP imagery at a scale of 1:4,000 (Figure 11). The valley length (the distance from the top extent of the photo mosaic to the confluence with the Clark Fork River) of 6,094 m was used to calculate sinuosity.

Sinuosity calculated for 1929 is equal to 1.15. Sinuosity calculated for 2015 is equal to 1.13 (Table 14). In general, the 1929 and 2015 channels have many of the same characteristics (Figure 11). While the creek shows a high degree of straightening throughout the entire study area, it is most obvious in the lowest one-half mile and the uppermost mile. There appears to be one braided section in the 2015 channel, between approximately stream miles 2.5 and 3.0. It is important to note that visibility of the channel in densely forested reaches of the 1929 channel was somewhat obscured, meaning that small side channels may exist that could not be digitized.

*Table 14. Rattlesnake Creek Channel Length and Sinuosity from 1929 to 2015.*

| Photo Year | Channel Length (m) | Sinuosity |
|---|---|---|
| 1929 | 6,093.66 | 1.15 |
| 2015 | 5,973.97 | 1.13 |

*Figure 11. Rattlesnake Creek (green) digitized from 1929 aerial photo mosaic (left) and Rattlesnake Creek (orange) digitized from 2015 NAIP imagery (right).*

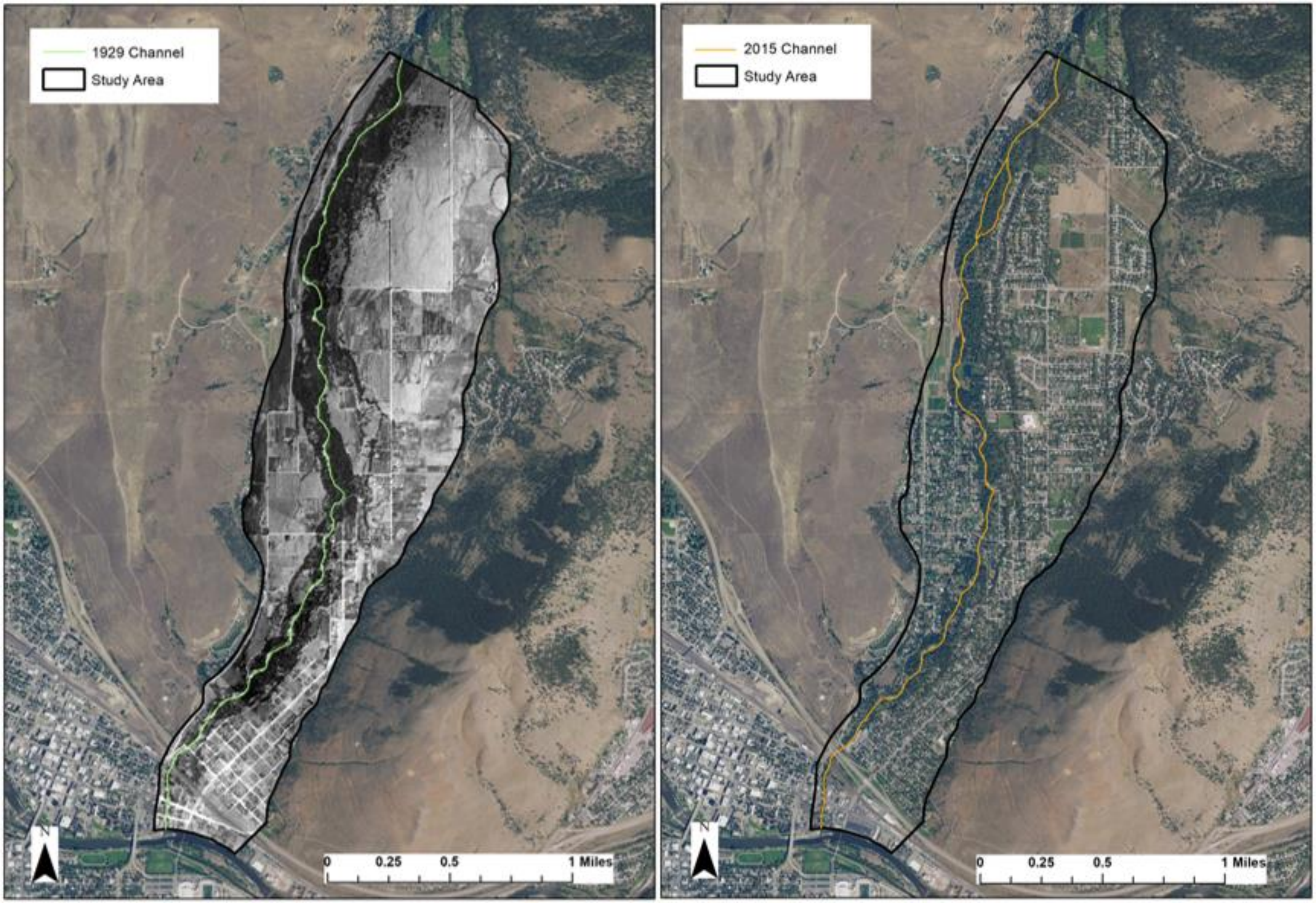


*Figure 12. Rattlesnake Creek in 1929 (green) and 2015 (orange) shown within 1929 mosaic, on top of 2015 imagery.*

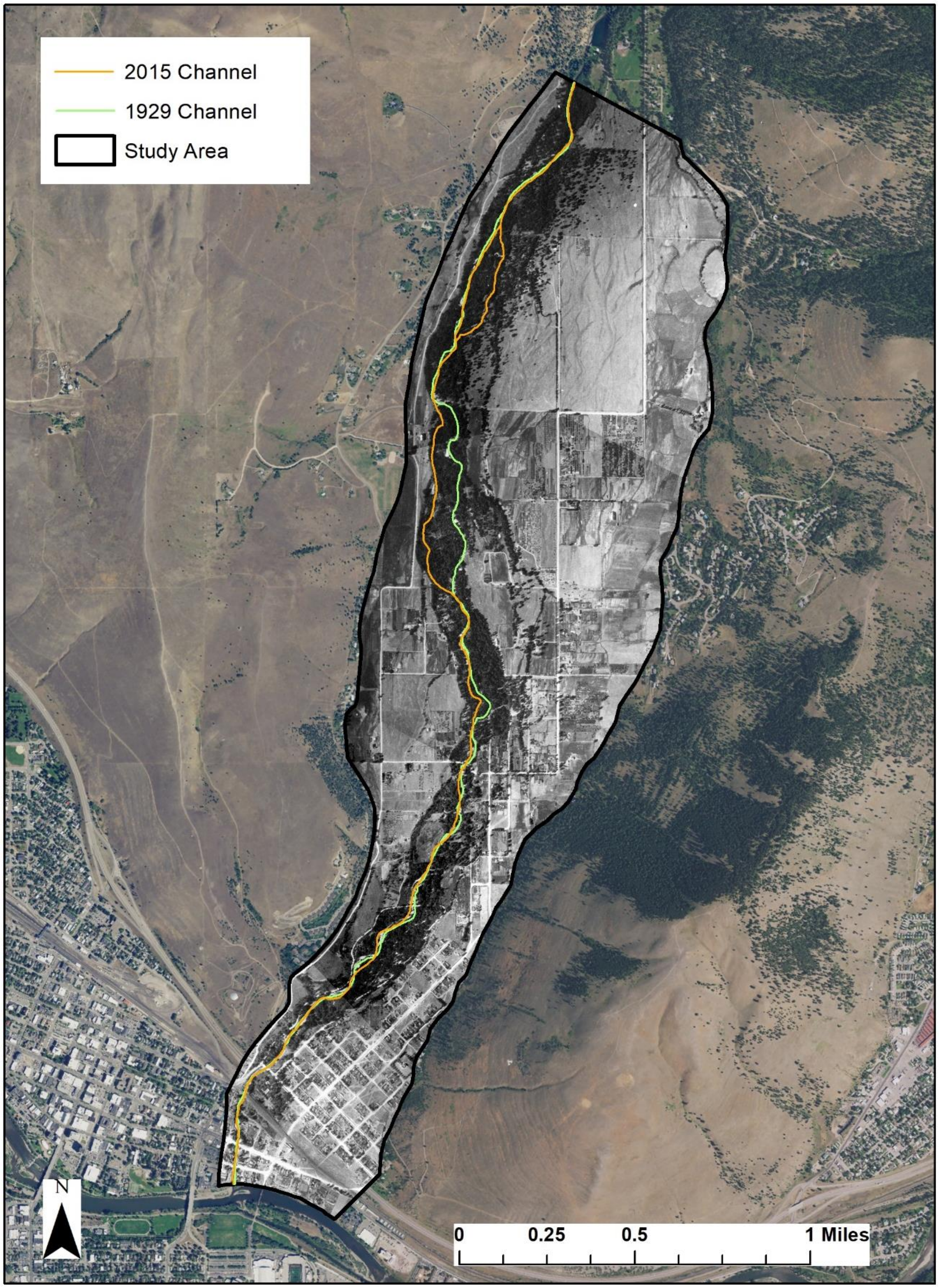


Figure 12 shows the digitized channels from both 1929 and 2015 together on top of the 1929 mosaic. Overall, there was a very slight decrease in channel length and corresponding decrease in sinuosity from 1929 to 2015, indicating a small degree of channel straightening over this period. While this comparison shows minimal change in sinuosity, results of channel digitization suggest that lateral channel movement took place, primarily along the middle to upper reaches of the study area between river miles 2.0 and 3.0. The lower mile of Rattlesnake Creek indicates very little change in channel form over this period.

## 4.6 Land Cover

Land-cover classification of historical (1929) and recent (2015) aerial photos was guided using NLCD 2011 criteria. See Section 3.4 for a detailed description of how land cover classes are defined.

### *4.6.1 Land Cover in 1929*

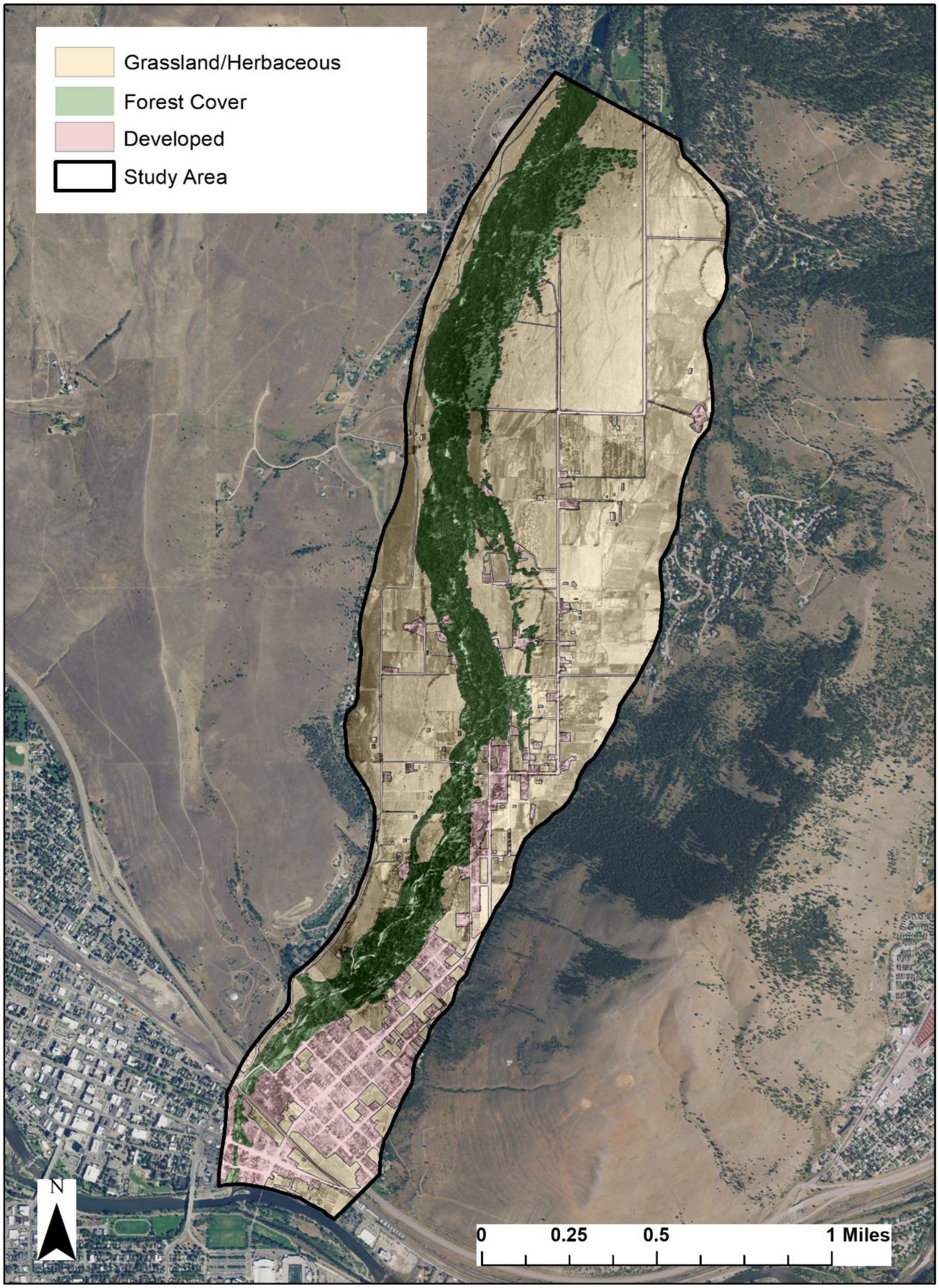
The digitized land-cover classes are shown, semi-transparent in Figure 13 so that the underlying features in the 1929 mosaic are visible. Development along the first mile of the Rattlesnake drainage appears to have been primarily residential. Roads were well-established, and many homes were built at high densities. Some homes were adjacent to open lots. There appears to be some agriculture adjacent to the Clark Fork River, at the southern end of the study area. At approximately mile one, the degree of development decreased considerably, and land cover shifted to grassland/herbaceous. The west side of Rattlesnake Creek had very little development.

There appears to be a variety of farming and agriculture in the valley, especially between miles 1.0 and 2.5. While it is difficult to distinguish the type of agricultural practices, patterns and textures visible in these photos clearly indicate agriculture accompanied by a few structures, likely houses or barns. Main roads were in place at this time. North Van Buren Street/Rattlesnake Drive extended through the entire study area. West Greenough Drive and Duncan Drive up to Mountain View Drive were in place on the west side of the creek. Cross streets such as Lolo Street, Dickinson Street, Mountain View Drive, Lincoln Hills Drive, and Tamarack Street are all visible.

Beyond ~mile 2.5, there are less indicators of crops and more open pasture. Visible in the pasture east of Rattlesnake Creek at ~mile 2.5- 3.0 are former meander markings across much of the valley. The uppermost mile of the study area also shows the presence of irrigation ditches. Williams Ditch ran along the eastern edge of the valley, parts of which are visible in the 1929 photo mosaic.

Forest in the study area was almost exclusively found along Rattlesnake Creek. The width of the forested corridor generally increased upstream. At its widest (in the upper mile of the study area), this corridor was approximately 535 yards (489 meters) wide (NLCD classifies Forest as areas with trees dominated greater than 20% of total vegetation cover). At its most narrow point (the bottom quarter mile of the study area) the forested corridor was approximately 16 yards (15 meters). Forest species composition cannot be determined from the 1929 photo mosaic.

*Figure 13.Map of land-cover classes in 1929.*



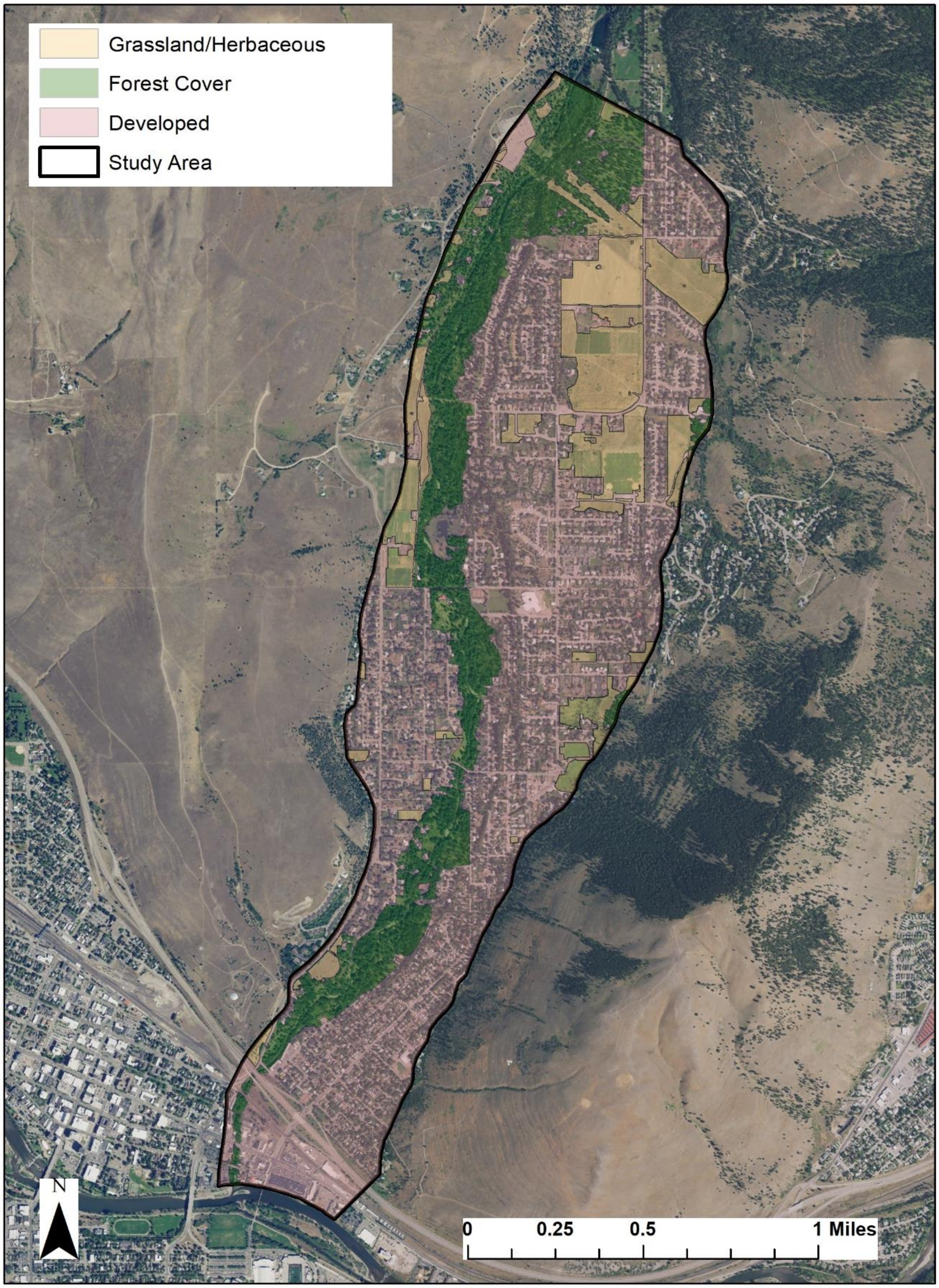
### *4.6.2 Land Cover in 2015*

In 2015, development appears to be primarily residential neighborhoods (Figure 14). The majority of the lower half of the study area is developed, often high-density. Residential development periodically extends to the thick forest near the channel for the entire study area. For instance, at ~ mile 2.25, there is a pond and surrounding lawn extending to within feet of the channel. There are several parks in the study area, including Greenough Park, Gregory Park, Tom Green Park, and Pineview Park. Greenough Park and Tom Green Park were classified as Forest, while Gregory Park and Pineview Park were classified as Developed. Power lines extend across Rattlesnake Creek near the northern boundary of the study area to a North Western Energy substation located on the edge of the study area boundary.

Within the study area, large spaces of Grassland/Herbaceous that remain in 2015 appear to be mainly pastures, along with some cultivated cropland. A vineyard occupies eight acres of herbaceous/grassland at ~mile 2.5-3.0, with a 17-acre plot of cropland just to its north. The University of Montana Program in Ecological Agriculture and Society (PEAS) Farm is located about halfway up the study area on the west side of Rattlesnake Creek.

The majority of Forest in the study area is found along Rattlesnake Creek. The width of the forested corridor varies along the stream, with development abutting the channel. At its widest (in the upper mile of the study area), this corridor is approximately 637 yards (582 meters) wide, though much of this cover is likely elevated several yards above the channel. At its most narrow point, the forested corridor is approximately 18 yards (16 meters). Forested areas appear to be primarily Evergreen forest or Mixed forest. The 2015 NAIP imagery was taken when the leaves were still on the deciduous trees. In contrast, the 2017 NAIP imagery was taken later in the year, after leaves had fallen, aiding in identifying coniferous trees. This later imagery was not used for other parts of this analysis due to the presence of long shadows that obstructed the view of other important features, primarily the channel.

*Figure 14. Map of land-cover classes in 2015.*



Overall, profound land-cover change occurred between 1929 and 2015 (Table 15, Figure 15, and Figure 16). The percentage of Grassland/Herbaceous dropped by 47%, while Developed increased by 51%. In comparison, change in the total extent of Forest was relatively small, a decrease of three percent.

While small patches of Grassland/Herbaceous were replaced with development in the lower valley, the most dramatic change in land cover occurred in the upper two-thirds of the study area, where large areas of Grassland/Herbaceous were replaced by development. This trend was observed on both sides of Rattlesnake Creek, although the east side of the valley has more area due to the location of the channel. Development along both sides of the creek, primarily residential, expanded into what was previously forested cover, substantially narrowing the Forest Cover class flanking Rattlesnake Creek; however, an increase in Forest Cover was visible at the north end of the study area, just downstream of the Rattlesnake Creek Dam.

*Table 15. Spatial change within study area, including Grassland/Herbaceous, Forest Cover, and Developed from 1929 to 2015.*

| | **Land-Cover Type** | | | | | |
|---|---|---|---|---|---|---|
| | **Grassland/Herbaceous** | | **Forest Cover** | | **Developed** | |
| | **acres** | **%** | **acres** | **%** | **acres** | **%** |
| **1929** | 823.2 | 62% | 306.2 | 23% | 188.5 | 14% |
| **2015** | 194.8 | 15% | 269.8 | 20% | 852.4 | 65% |

*Figure 15. Percentage of land-cover types within the study area, 1929 and 2015.*

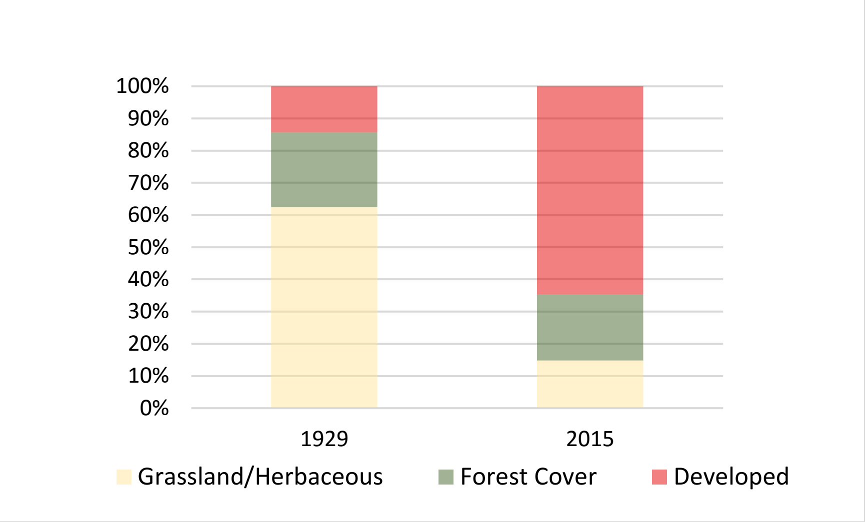
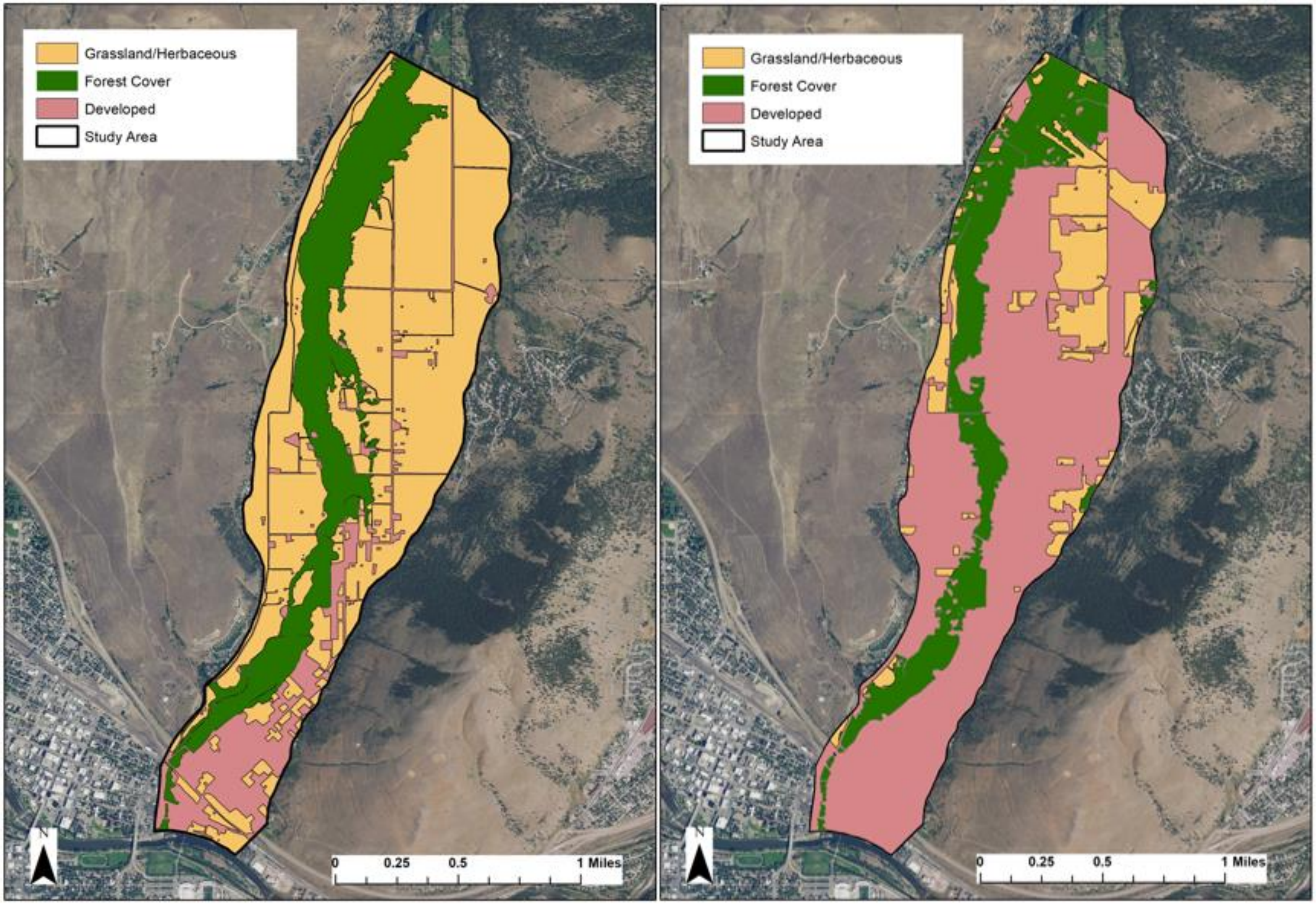


*Figure 16. Rattlesnake Creek land cover, 1929 (left) and 2015 (right).*



# 5 DISCUSSION

The use of aerial photography in combination with indicators of stream health offers the opportunity to better understand the changes that Rattlesnake Creek and the surrounding valley have experienced over the past 90 years. Somewhat remarkably, photos of the Rattlesnake valley are available from the 1920s, when the use of planes to capture photos was still a relatively new practice. Here, the following questions can be addressed: 1) What general trends in the chosen stream health parameters, if any, could be identified, 2) What do comparisons of historical aerial images reveal about changes in channel form? Specifically, what changes can be seen in comparing channel length and sinuosity, and 3) What major changes in land cover could be seen?

The following sections describe how findings can be integrated to address the research questions above.

## 5.1 Trends in Stream Health Parameters

Overall, trends in fish populations are difficult to characterize. Raw data are limited, and trends are entirely based upon reports published by Montana FWP and personal communication with their Fisheries Biologist. Furthermore, results dating back to before the 1960s either do not exist or are unavailable. From the perspective of fish species composition and distribution, the two most obvious changes in Rattlesnake Creek that can be established are: 1) the onset of hybridization of westslope cutthroat, rainbow, and Yellowstone cutthroat trout and 2) the restriction of upstream passage due to the construction of the Rattlesnake Creek Dam in 1905.

Several of the high elevation lakes in the Rattlesnake Wilderness Area are probable sources of hybridization since they support self-sustaining populations of rainbow and

Yellowstone cutthroat trout that were stocked in the early and mid-l900s. Public groups and individuals were encouraged by state and federal agencies to “seed” new waters during this time (Knotek et al., 2013). Rattlesnake Creek differs from the general trend observed in other tributaries to the Clark Fork River where introduced trout species occupy lower gradient, warmer reaches, while bull and westslope cutthroat trout occupy the colder headwaters. This is likely due to the presence of self-sustaining, high-elevation lakes in the Rattlesnake basin (Knotek et al., 2004).

While the installation of the fish ladder near the Rattlesnake Creek Dam yielded reasonable success, its ability to promote the passage of both westslope cutthroat and bull trout was not entirely successful. The difference in spawning migration periods between westslope cutthroat and bull trout generally caused the operation of the dam to favor passage of one species or the other. Without data indicating native fish passage prior to the installation of the Rattlesnake Creek Dam, a true assessment of how native fish originally migrated up Rattlesnake Creek cannot be made.

Recent temperature data on Rattlesnake Creek are available; however, the lack of historical monitoring prior to 2000 means that little can be determined regarding long-term stream temperature trends. Even recent data collected do not always span the entire peak stream temperature season. With the recent installation of the DNRC gauging station at mile one, consistent stream temperature monitoring will be available going forward. Seeing as how shading around the channel was generally maintained, it is unlikely that any changes in temperature would be due to increased exposure to sunlight. Climate change, an increase in impervious surfaces within the valley, and periodic dewatering could all potentially contribute to an increase in stream temperature. Additional years of monitoring are required to be able to draw such conclusions.

While the lack of historical monitoring prevents establishing long-term trends, recent temperature data can be compared to known optimum trout growth temperatures to indicate the upper range of suitable thermal habitat for long-term trout persistence (Bear et al., 2007). Maximum daily temperatures between 13-15°C and 10.9-15.4°C are ideal for the optimum growth of westslope cutthroat trout and bull trout, respectively (Bear et al., 2007 and Selong et al., 2001). Although examining the number of days of water temperatures exceeding limits conducive for optimum growth does not necessarily indicate fish mortality, it does clearly indicate when conditions are not suitable for long-term persistence. Above these temperature ranges, growth rate, feed consumption, and feed efficiency are all potentially impacted (Selong et al., 2001). Furthermore, the occurrence of daily maximum temperatures exceeding 15°C indicates the survival advantage of species with a wider tolerance range (i.e. brown trout and rainbow trout) over native westslope cutthroat and bull trout.

Although not definitive, 2018 data suggest an increase in annual peak discharge and a shift in peak discharge to earlier in the season compared to 1958-1967 data (Figure 10). This is consistent with common impacts of urbanization and the predicted impacts of climate change. As described in Section 2.5, an increase in impervious surfaces often accelerates the movement of water through the system by reducing infiltration. Consequently, groundwater does not fully recharge, and late summer base flows may decrease. Available data indicate that mean daily mean discharge in the month of October have decreased between 1958-1966 and recent monitoring (Table 7), suggesting that late-season base flows have indeed decreased. Due to the inconsistency in recent monitoring, it is important to continue monitoring stream discharge and to observe if the trends suggested here continue. Based on the rate of urbanization in the area and the predictions of climate change, higher peak runoff and lower base flows are expected in future.

Available instream nutrient data suggest that mean orthophosphate levels have decreased, while mean nitrate levels have remained approximately the same between the mid-1970s and 2008. This decrease in orthophosphates could be due to a number of factors. It is possible that improved infrastructure may have contributed to this trend. While Rattlesnake Creek has no wastewater treatment facilities, sewer and septic systems can have a profound influence on nutrient levels. There have been a number of phases of sewer main extensions, but the first and largest began in the early 2000s (Ross, personal communication 5/14/2019). Gravity sewer mains in the Rattlesnake valley now extend roughly 3.1 river miles above the confluence with the Clark Fork River. Additionally, phosphorus found in pasture and cropland runoff may have decreased since the mid-1970s. This could be caused by changes in agricultural practices or simply from a reduction in cropland. Although no aerial photos from the 1970s were available for this study, overall trends between 1929 and 2015 indicate a major decrease in the grassland/herbaceous land-cover class, primarily due to increasing development. Furthermore, inspection of 1964 and 1987 air photos suggests a decrease in agriculture since the mid-1970s, primarily between river miles 1.5 and 2.5.

Results also indicate that neither total nitrogen nor total phosphorus levels from 2008 exceeded Montana DEQ criteria for the Middle Rockies ecoregion. It is important to note that the purpose of water quality criteria and standards is to specify the level of a pollutant that will protect beneficial uses. This is the level to which degraded streams need to be restored (Suplee and Watson, 2013). Furthermore, 2008 total nitrogen: phosphorus ratios suggest phosphorus limitation while soluble nitrogen: phosphorus ratios suggest nitrogen limitation. This likely suggests that algae growth is co-limited by nitrogen and phosphorus.

## 5.2 Changes in Channel Form

The small degree of change in channel form between 1929 and 2015, combined with the low sinuosity values (1.15 and 1.13, respectively) indicate relatively little about development that has occurred over this time period. Instead, they suggest that modification of the stream may have occurred prior to historical aerial photographs. A low-gradient slope, such as that of the valley constituting the study area in this project, would typically lead to a meandering channel with a sinuosity of at least 1.2. Sinuosity values of 1.13 or 1.15 are generally indicative of steep, cascading step/pool streams (Rosgen, 1996). Furthermore, a considerable amount of development along the first mile of Rattlesnake Creek was already in place at the time of the historical photos, seemingly confining this section of the channel by 1929. As a result, the amount of lateral channel movement in the first mile above the confluence with the Clark Fork River appears to be negligible.

## 5.3 Changes in Land Cover

Overall, land cover in the study area saw a dramatic shift between 1929 and 2015, from largely Grassland/Herbaceous to Developed. The proportion of Forest Cover remained roughly the same, in part, because Forest lost throughout the lower three miles of the study area was nearly equal to additional Forest expansion in the uppermost one-half mile.

As described in Section 2, riparian buffers help to store nutrients and sediments, serve as wildlife corridors, filter non-point source pollution, reduce stream bank erosion, and regulate water temperature (Jones et al., 2010). While the Forest classified in this study does not necessarily represent true riparian habitat, it helps to signify the extent of urban encroachment along the stream. Photos from both time points, but particularly 2015, indicate that due to urban encroachment, Rattlesnake Creek has a very minimal floodplain in which to move laterally without encroaching on developed areas. However, little could be determined concerning species composition of streamside vegetation in 1929 due to the quality of the photo. This vegetation would still shade the channel and potentially help to stabilize the soil, but photos do not indicate if species characteristic of healthy western floodplains, such as willow and cottonwood, were present. A 2017 NAIP image taken later in the year shows colors suggestive of deciduous trees, perhaps cottonwoods.

Additionally, the high degree of urbanization that was documented in the study area and the corresponding increase in impervious surfaces likely indicate increasing pressure on the hydrologic cycle. Consequently, the lower 3.5 miles of the Rattlesnake drainage may be less able to infiltrate precipitation, compared to 1929. Typically, this may lead to a decline in late season base flows, which is what October average daily mean discharge measurements suggest in this study.

# 6 CONCLUSIONS AND FUTURE MONITORING RECOMMENDATIONS

Five air photos from 1929 were georectified and digitized in order to evaluate changing land cover and channel form over time within the Rattlesnake valley, between approximately the Rattlesnake Creek Dam and the confluence with the Clark Fork River. NAIP imagery from 2015 represented recent conditions, to which 1929 conditions were compared. Fish species composition, stream temperature, stream discharge, and stream nutrient levels served as indicators of stream health. In an effort to characterize stream health over this time period, data were acquired from a variety of sources (i.e. Montana FWP, USGS, Clark Fork Coalition, Montana DNRC, and Missoula County) and analyzed. Data did not extend back to 1929 but were still included here. Overall, several trends were established or suggested:

- Rainbow trout, Yellowstone cutthroat trout, and native westslope cutthroat trout have hybridized, and the remaining effects are documented in genetic testing. Non-native trout, such as brown and rainbow trout dominate reaches below the dam.
- Upstream movement by native trout has been severely limited by the Rattlesnake Creek Dam. Even with the fish ladder installed below the dam in 2003, westslope cutthroat and bull trout struggle to migrate upstream in search of spawning habitat.
- Stream temperatures were difficult to compare over time due to lack of data prior to 2000 and inconsistency in monitoring location and frequency.
- Although recent stream discharge data are insufficient to be definitive, 2018 data suggest an increase in annual peak discharge and a shift in peak discharge to earlier in the season compared to 1958-1967 data. This is consistent with the predicted impacts of climate change and common impacts of increased impervious surfaces.
- Average orthophosphate levels have decreased from the mid-1970s. Average nitrate levels have stayed roughly the same.
- Rattlesnake Creek has exhibited lateral channel movement between stream miles two and three but little elsewhere in the study area. At both time points, the channel appears to be straightened compared to what would be expected of a stream running through a low gradient slope. This suggests that the channel was modified prior to 1929.
- An increase in development and decrease in grassland/herbaceous is the most obvious change in land cover within the study area. This corresponds to an increase in impervious surfaces, likely indicating increasing pressure on the hydrologic cycle. Continued encroachment of development into the remaining floodplain also will further restrict lateral channel movement.

While some available data on Rattlesnake Creek were not suitable for establishing long-term trends, due to the lack of either recent or historic data, it is still valuable to understand how, when, and where data were collected in the past. This knowledge will help land managers to more effectively monitor the state of Rattlesnake Creek during and after the dam removal. The presence of pre-dam removal data will make post-removal data more useful, by providing baseline conditions. Only about 10% of all stream improvement projects implemented in the United States are evaluated, and most studies that are performed are short-term, meaning for less than five years (Pierce et al., 2013). As a result, many land managers cannot assess the effectiveness of a given action. For this reason, it is important that the parameters described here continue to be monitored during and after the dam removal. The limitations of this study in establishing trends in stream temperature and discharge demonstrate how valuable past data are in evaluating trends.

Currently, Montana FWP has five long-term electrofishing monitoring sites from mile 0.5 to ~mile 14.0 on Rattlesnake Creek, two of which were established in 2018 (Knotek, personal communication 11/5/2018). Undoubtedly, fish species distribution is of great importance in future monitoring, for both native and non-native species. Will non-native brown and rainbow trout continue to dominate the lower reaches of Rattlesnake Creek? Will native westslope cutthroat and bull trout have better access to upstream spawning habitat? Montana FWP appears well-prepared to answer these questions and will also continue to monitor temperatures at the dam site, along with numerous other sites that will be added in summer 2019 (Knotek, personal communication 4/1/2019). Stream temperature and discharge will continue to be recorded at the recently installed DNRC gauging station in Greenough Park. This was installed in November 2017, meaning at least two annual high runoff periods should be recorded prior to major alterations at the dam site. The fact that historical discharge data (~mile 0.3) and the recently installed DNRC station (~mile 1.0) are relatively close to one another will allow for meaningful comparisons. CFC does not have any formal plans at this time to monitor Rattlesnake Creek (Whiteley, personal communication 4/2/2019).

Missoula County recorded 2008 nutrient measurements on Rattlesnake Creek, and they have plans to track and update trends in nutrient levels in Rattlesnake Creek (Ross, personal communication 4/1/2019). It is recommended that total nitrogen and total phosphorus be monitored in the future. These parameters are more closely correlated to benthic algal levels than soluble nutrient forms are (Suplee and Watson, 2013). However, nitrate and orthophosphate monitoring is still encouraged, as these are the forms of nutrients that directly support algal growth.

The parameters included here indicate baseline stream health. This does not minimize the importance of other monitoring. Sediment composition, groundwater levels, and macroinvertebrate communities could all potentially be valuable indicators of Rattlesnake Creek's response to the upcoming dam removal. The deposition of sediment downstream of the removal site can alter aquatic and riparian habitat (Tullos et al., 2016). Tullos et al. (2016) recommended measuring bed relief, or "the difference in elevation along a cross section between the bottom of the pool and the top of the bar", in order to assess habitat variability and homogenization. While there are minimal historical sediment data available, the assessment of sediment transport and turbidity during and after the removal is recommended.

Dam removals also have the potential to cause the lowering of a water table that had been elevated because of the dam (Tullos et al., 2016). Studying site specific surface geology, well records, and projected dam-removal hydraulics, in addition to developing groundwater models will all contribute to an understanding of groundwater response to a given dam removal (Tullos et al., 2016). While the restoration of wetlands at the dam site is expected to replace any storage lost from removing the dam (Roberts, personal communication 5/2/2019), groundwater monitoring is still recommended. Reduced macroinvertebrate community density is another commonly observed effect of dam removal (Renöfält et al., 2013). Hydraulic conditions, discharge, water temperature, and water quality are all factors that impact macroinvertebrates and are known to be altered by dam removals (Renöfält et al., 2013). For this reason, assessing macroinvertebrates prior to and after this project is recommended.

Other ongoing and planned monitoring is set to take place on Rattlesnake Creek. Dr. Andrew Wilcox, University of Montana Dept. of Geosciences, has done bi-annual sediment transport and hydrologic modeling in the lower Rattlesnake with his graduate-level fluvial geomorphology course. This monitoring will likely continue after the dam is removed.

The Watershed Education Network (WEN) Stream Team is a citizen science group that engages Missoula community members, University of Montana students, and high school students in water monitoring on local streams. Beginning this year, the WEN Stream Team plans to focus its efforts on monitoring Rattlesnake Creek. WEN is working with Trout Unlimited to develop a monitoring strategy (Wise, personal communication 3/19/2019). Among other parameters, WEN will likely perform pebble counts and potentially macroinvertebrate collection.

Additional analyses could be performed to further document land-cover and channel change within the study area. Due to time constraints, the air photo analysis of this study was limited to 1929 and 2015. Air photos from intermediate years (including 1937, 1964, and 1987) are available and could yield more information about the timing of events between 1929 and 2015 affecting land cover. Additionally, evaluating changes in road density and/or total number of structures in the study area may provide additional information and could be performed relatively quickly. Concerning channel form, recently acquired LiDAR (Light Detection and Ranging) data could be utilized to gain insight on channel migration zones and floodplain connectivity. LiDAR was flown near the dam site in 2016, meaning additional flights done during and after the dam removal could characterize changing topography.

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## APPENDIX A: IMAGE PROCESSING DEFINITIONS

Air photo mosaic- An assemblage of two or more overlapping aerial photographs that form a composite view of the total area covered by the individual photographs (Avery and Berlin, 1992).

Cubic convolution resampling- A way to calculate the output cell value by calculating the weighted average of the closes 16 input cells based on distance (Weng, 2012).

Georectification- The process that assigns horizontal map (x, y) coordinates to an image. It includes matching of ground-control points (GCPs) on the scanned photo image and base layer, transforming of the GCP coordinates on the scanned image from a generic raster set to a geographical projection and coordinate system, and pixel resampling (Hughes et al., 2006).

Ground Control Point (GCP)- A specific location on a map whose geographic coordinates are known (Weng, 2012).

Image Displacement- The shifting of ground objects from their correct positions because all objects are positioned as though they were being viewed from the same point. Relief is the most significant source of image displacement (Avery and Berlin, 1992).

Orthoimage- The digital version of an orthophotograph. It can be produced from a stereoscopic pair of scanned aerial photographs or from a stereopair of satellite images (Weng, 2012).

Orthophotograph- The reproduction of an aerial photograph with all tilts and relief displacements removed and a constant scale over the whole photograph. All features are located in their correct horizontal positions, as though they were being viewed from directly overhead (Weng, 2012).

Photogrammetry- The science of obtaining reliable measurements by means of photography (Weng, 2012).

Relief- The difference in the relative elevations of ground objects (Weng, 2012).

Orthorectification- The process involving the spatial manipulation of a digitized or digital photograph into an orthophoto, by adding vertical map (x, y, and z) coordinates to accurately represent distances, angles, and areas (Morgan et al., 2010).

Pixel Resampling- The process of extrapolating data values to a new grid. It is the step in rectifying an image that calculates pixel values for the rectified grid from the original data grid (Weng, 2012).

Root Mean Square Error- a metric based on the Pythagorean Theorem that represents the difference in location between the GCPs of the transformed layer and the base layer (Hughes et al, 2006).

Scale- the relationship between the distance on a map or image and the actual distance on the Earth’s surface (Weng, 2012).

Transformation- The use of linear and nonlinear functions to change the coordinates of the distorted image into new coordinates in alignment with their true ground positions (Weng, 2012).

## APPENDIX B: MONITORING LOCATIONS

*Figure 17. Stream Discharge and Temperature Monitoring Locations.*

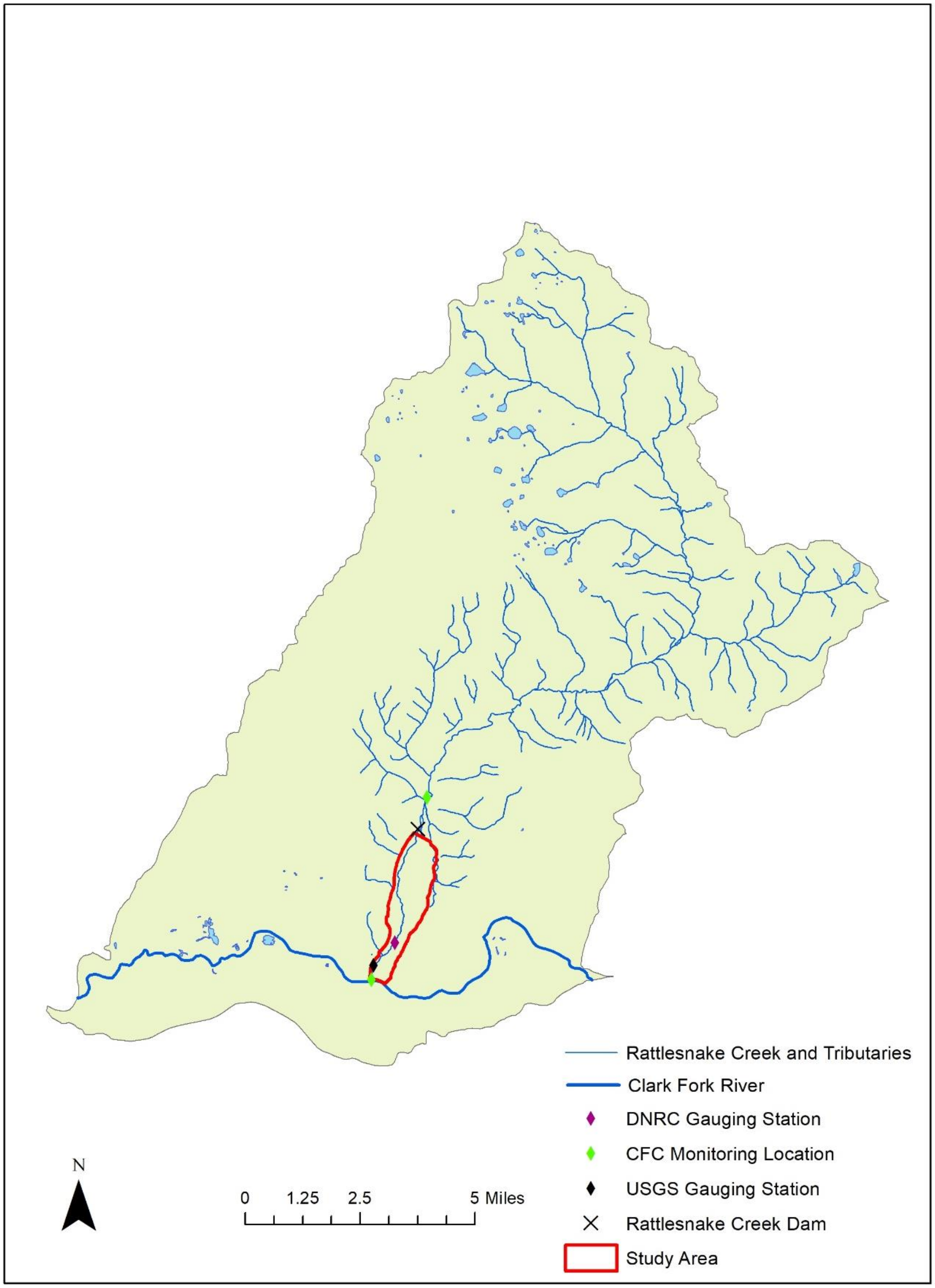
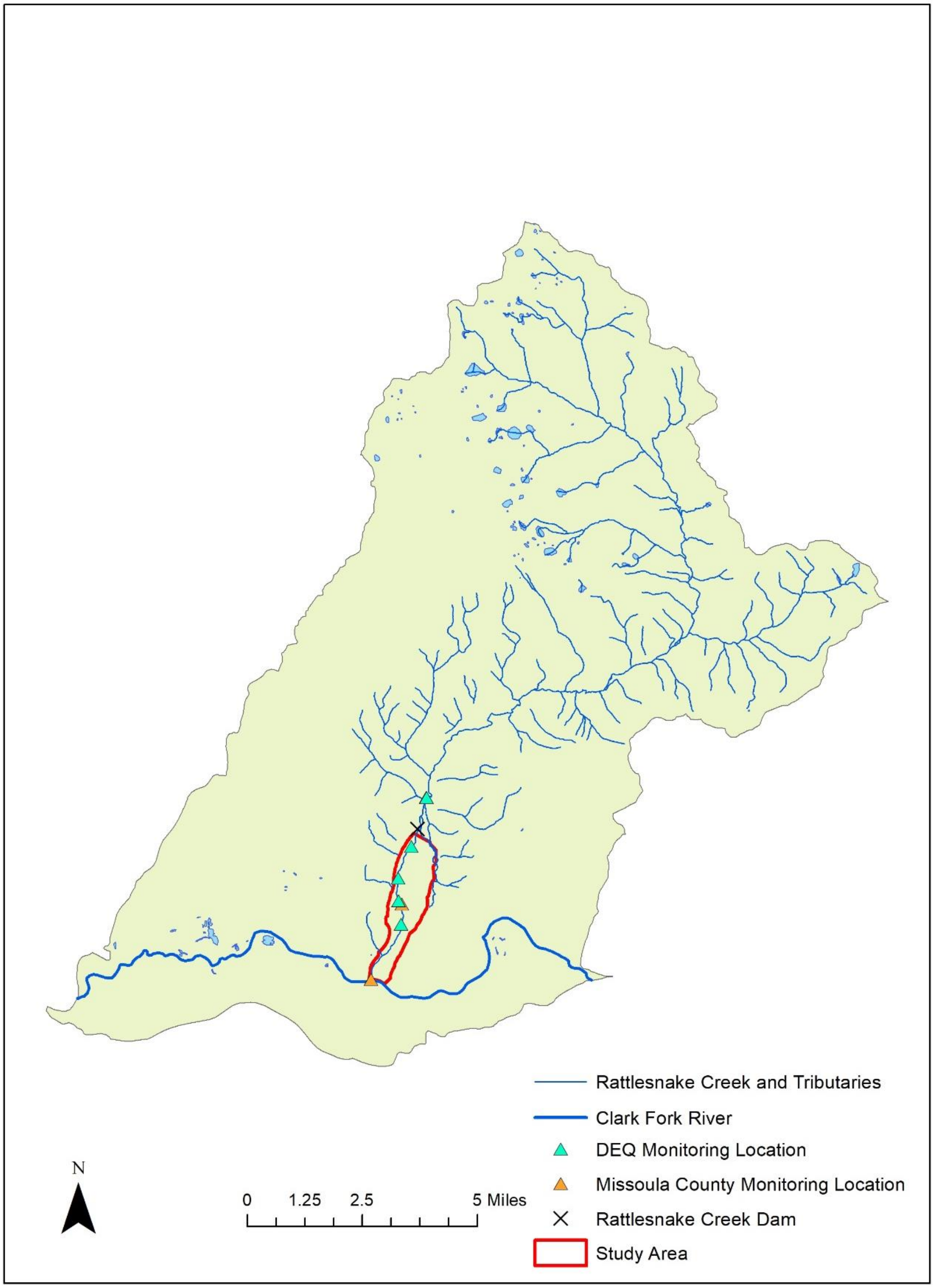


*Figure 18. Stream Nutrient Monitoring Locations.*



Note: Uppermost site (near Rattlesnake trailhead) was monitored by both Montana DEQ and Missoula County.