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Baseline study of recovering headwater streams in the Sapphire Mountains, western Montana

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BASELINE STUDY OF RECOVERING HEADWATER STREAMS IN THE SAPPHIRE

MOUNTAINS, WESTERN MONTANA

By

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ABSTRACT

Many riparian areas in the western United States have been degraded by grazing and logging. In the year 2000, the Montana Department of Environmental Quality (DEQ) re-initiated an effort to identify and characterize reference streams, or least impacted streams in each region of the state. In Montana's Bitterroot Valley, most streams have been impacted by grazing, irrigation, and timber production. The Montana DEQ has not been able to identify reference streams in the Sapphire Mountains on the east side of this valley. MPG Ranch, located on the west-facing slopes of the Sapphire Mountains and purchased in 2009 by a conservation-minded landowner, has three previously unstudied streams, which are likely candidates for Montana DEQ reference streams. Hence, physical, chemical and biological data were collected at Davis, Woodchuck, and Tongue Creeks on MPG Ranch in the summer of 2015 to assess the potential of these streams to serve as reference streams and to establish a baseline for the ranch as managers of MPG work to restore ecosystems there. Key data collected includes levels of nutrients, benthic algal biomass, community composition of macroinvertebrates, temperature, pH, flow, slope, and other physical parameters of each stream. Results from this study suggest that Davis and Woodchuck Creek should be considered for further research as reference streams for the west-facing slopes of the Sapphire Mountains.

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INTRODUCTION

Need for Reference Streams in Montana's Sapphire Mountains

Many riparian areas in the western United States have been degraded by grazing and logging (Belsky, Matzke, Uselman 1999). While some areas are severely degraded, elsewhere degradation is more subtle and may not be immediately obvious to landowners. In the year 2000, the Montana Department of Environmental Quality (DEQ) re-initiated an effort to identify and characterize reference streams, or least impacted streams in each region of the state (Suplee and others 2005). These streams are important to Montana DEQ because often state narrative standards use "naturally occurring" water quality as a reference (Suplee and others 2005).

Reference streams are the least-impacted examples of streams in each ecoregion. The use of reference streams comes from the reference condition concept, which asserts that all groups of similar water bodies have least-disturbed examples that can be used as benchmarks for more impacted streams (Suplee and others 2005). A reference stream is chosen for having been subject to the least amount of human disturbance in comparison to all other similar streams in a region. Such streams provide our best estimate of what constitutes biological, physical, and chemical integrity for that respective set of streams, and reference streams are used to set restoration goals for impacted streams.

In Montana's Bitterroot Valley, most streams have been impacted by grazing, irrigation, and timber production. The Montana DEQ has not been able to identify reference streams in the Sapphire Mountains on the east side of this valley. Fortunately MPG Ranch is located on the west-facing slopes of the Sapphire Mountains, and since its purchase in 2009 by a conservation-minded landowner, the management of this land has changed from ranching, agriculture, and logging to environmental restoration and conservation.

MPG Ranch provides the best opportunity for stream ecology research in the west-facing slopes of the Sapphire Mountains. Because riparian areas are often the most productive and diverse parts of the Middle Rockies ecoregion, the condition of riparian ecosystems determines the health of wildlife communities, which are of great interest and importance at MPG Ranch (Gregory and others 1991; Woods 1999).

Because MPG Ranch encompasses most of the watershed of each of the streams on the ranch, watershed restoration and conservation efforts on the ranch have a good chance of success. A conservation easement has been in place since 2010 (Tollefson 2010). It is likely that in time these restoration efforts will result in a healthy reference stream that could be useful in guiding watershed and stream restoration projects throughout the Bitterroot River basin.

The purpose of the study described in this paper was to describe and assess the current state of MPG's streams using key parameters commonly used by the Montana Department of Environmental Quality (DEQ) to assess streams. Once established, this baseline will allow MPG Ranch to track its progress towards re-wilding this land.

STUDY APPROACH

In the summers of 2014 and 2015, I worked on the Montana DEQ Reference Stream Project which monitors streams that have previously been identified as Montana DEQ reference streams. Based on my experience working on this project, reference streams are often located on public land with some degree of protection. Occasionally, private land that is well managed may contain a least-impacted stream that can be used as a reference stream. MPG Ranch is one such example of conservation-focused management of private land, which may yield a reference stream. Within the Middle Rockies ecoregion, there are many Montana DEQ reference streams, including many in the Bitterroot Mountains on the west side of the Bitterroot Valley. But it would be valuable to have a reference stream on the west-facing slopes of the Sapphire Mountains (east side of the Bitterroot Valley), since, as stated earlier, DEQ currently has no reference streams on those slopes. Because the Sapphires' west slopes have undergone so much human disturbance, it would be useful to find a candidate reference stream there.

A reference stream is selected based on an in-depth examination of its watershed, including road density, land use and other factors beyond the scope of this study. The type of stream reach specific field data gathered for this baseline study, while useful to MPG Ranch and Montana DEQ, does not include all the watershed analyses used by the Montana DEQ to determine whether a stream at MPG could qualify for reference stream status (Suplee and others 2005). However this study will bring these streams to the attention of the DEQ and provide some evidence that, given the land use of the area, these streams may be the least impacted examples.

From June through September 2015, I performed a baseline study of three creeks at MPG Ranch using Montana DEQ reference stream data collection techniques (Montana DEQ 2012b) . This baseline will be useful for future management decisions on the ranch and to track the condition of each stream over time. Because logging and ranching activities have stopped in these areas, it is likely that each stream's condition will improve over time, and this baseline data will provide evidence for the ranch manager and owners to assess any changes in stream condition in coming years.

The Montana DEQ has identified a reference creek (Welcome Creek) on the east-facing slopes of the Sapphire Mountains. As this is the closest reference stream to the MPG streams, I gathered the same physical, chemical, and biological data to compare conditions in Welcome Creek to the MPG streams. The site I studied on Welcome Creek is upstream of the DEQ reference reach selected for Welcome Creek in order to better match the size and elevation of the MPG Ranch streams.

Research Design and Site Description

MPG Ranch Geography

MPG Ranch is located in the northern end of the west-facing slope of the Sapphire Mountain Range along the Bitterroot River near Florence, MT. It is part of the Middle Rockies ecoregion at the level III ecoregion scale (Woods 1999). Table S-1 has location information on the study reach including GPS points at the middle of the study reaches, the Township, Range and Section each creek is located in, the mid-reach elevation, and the geology and soil type at each study reach.

Figure S-1 is a map of land ownership around MPG Ranch. The MPG property was purchased by the Trust for Public Land and the Nature Conservancy and then sold to a private buyer with an attached conservation easement in 2009 (Tollefson 2010). To the north of the MPG property is Sapphire Ranch, formerly Maclay East Ranch, the majority of which is under a Rocky Mountain Elk Foundation conservation easement (Tollefson 2010).

Libby Maclay also owns land to the north of the South Fork easement, on a section of Davis Creek downstream from MPG Ranch and the study reach on Davis Creek. Montana State Trust land and Montana Legacy Project land surrounds most of the South Fork easement. U.S. Forest Service Land and Plum Creek Timber lands lie to the East of the South Fork section (Tollefson 2010). The Woodchuck Subdivision land, to the south of the conservation easement and the rest of MPG Ranch, is the only subdivision land nearby (Tollefson 2010).

Climate, Location, Geology, and Soil Type

The NOAA weather coop station closest to MPG Ranch is at Stevensville, Montana. According to this station's records spanning from 1911 to 2015, the highest average monthly temperature is 29.6°C, occurring in July, and the lowest average monthly temperature is -9.3°C, occurring in January (Western Regional Climate Center 2015). The average annual precipitation not falling as snow is 12.4 inches (Western Regional Climate Center 2015). The average annual snowfall (in inches of snow) is 23.7 inches, falling at about five to six inches per month in December, January, and February, with less in the other months (Western Regional Climate Center 2015).

Refer to Table S-1 for latitude and longitude; township, range, and section; elevation; geology; and soils of the study sites. It is notable that, all three MPG creeks and Welcome Creek drain from the Upper Belt Supergroup geologies, making them suitable for comparison. See Figure S-3 for a geologic map of Montana.

While it would be informative to this and future studies, more detailed information on the hydrology of the area including surface water and groundwater quantity is not currently available.

Past Land Use, Vegetation, Flow Regimes, Wildlife

There are three streams on MPG Ranch: Woodchuck Creek and Davis Creek (both are perennial streams in their headwaters), and Tongue Creek (an ephemeral stream). All the streams are intermittent below their headwaters. Except in times of very high flow, Davis Creek runs underneath the substrate before reaching its confluence with the Bitterroot River. Woodchuck Creek flows to the Bitterroot River during spring high flow periods (April and May) and during the rest of the year it dries up due to irrigation use and uptake by plants (Michael McTee of MPG Ranch, personal correspondence May 2016).

Most of the information I could gather on historical land use focuses on Davis Creek because of the easement on the South Fork of Davis Creek. I found less documentation regarding the land around Woodchuck and Tongue Creeks. Before the South Fork of Davis Creek easement was enacted in 2010, Tollefson, of Five Valleys Land Trust, compiled a document of background information on land use of the South Fork of Davis Creek (Tollefson 2010). This document provides the following relevant information about Davis Creek.

According to Tollefson, the Davis Creek area was logged by several logging companies starting in the late 1960s. The most recent intensive logging near Davis Creek was completed by Plum Creek Timber Company in 2006 and 2007. At that time, the riparian corridors along the South and Middle Forks of Davis Creek were left unlogged.

According to Tollefson, Bob and Jim Schroeder reported that cattle grazed the area lightly between 1970 and 2007. The Schroders reported the grazing occurred because some of their cattle would wander south from the Schroeder Ranch to the adjacent Davis Creek area (Tollefson 2010).

Montana Fish, Wildlife and Parks identified an isolated population of westslope cutthroat trout in the South Fork of Davis Creek, where the study reach is located. While connectivity for the fish is good within the South Fork of Davis Creek, fish cannot reach the Bitterroot River due to the three miles of dry channel downstream.

The study reach section of the South Fork of Davis Creek, is defined as riparian/wetland vegetation, surrounded by Douglas-fir dominated forest, surrounded by patches of ponderosa pine/Douglas-fir woodland, including ponderosa pine, grand fir, Engelmann spruce, subalpine fir, and western larch. Also, the tree trunk width often exceeds 20 inches diameter at breast height since the area was not extensively logged in the recent past. Deciduous trees in the riparian area here include quaking aspen, spring birch, and black cottonwood, interspersed with dense thickets of shrubs of Rocky Mountain maple, red-osier dogwood, gooseberry, raspberry, elderberry, speckled alder, and Douglas's hawthorn. Forbs here include western meadowrue, violet, stinging nettle, and cow parsnips (Tollefson 2010, and personal observations).

Wildlife is also plentiful in the Davis Creek area. The Welcome creek wolf pack has territory in easement property (Department of Environmental Quality 2006; MPG Ranch 2016; Tollefson 2010). Also observed on easement land are black bears, coyotes, elk, deer, and migratory birds (MPG Ranch 2016).

While riparian areas at Woodchuck and Tongue Creek have similar vegetation to Davis Creek, the riparian areas of these two smaller creeks are surrounded by dry grassland rather than shady conifer forest and hence are more exposed.

Woodchuck, located on the southernmost border of MPG Ranch, has a surface flow less than Davis Creek and more than Tongue Creek. This creek is deeply entrenched with sandy banks. Tongue Creek is an ephemeral stream that appears to flow only during snow melt and/or times of heavy precipitation. There are two artificial ponds directly upstream of the Tongue Creek study reach that were constructed to create amphibian habitat in the spring of 2015, shortly before the beginning of this study. Human traffic in the Tongue Creek area is restricted by ranch management. These restrictions are partly due to the high visitation of the area by elk.

Welcome Creek Site Description

The Welcome Creek area, part of Lolo National Forest in the headwaters of Rock Creek, was designated as a Wilderness area by the US Congress in 1978 (see Figure S-2 for a map of the area). The well-drained land type at Welcome Creek allows the accumulation of groundwater that recharges the streams (Berg 1977). Berg (1977) reported accumulations of talus along valley floors, which is consistent with my observations at the Welcome Creek study reach.

Berg (1977) reported that clear cuts were apparent in nearby Cinnamon Bear and Laveck Creek areas at the time of his study in the early 1970s, but he reported that the Welcome Creek area showed no evidence of recent logging. I found no record of logging along Welcome Creek since Berg's report. The vegetation along the Welcome Creek study reach was described as "Douglas-fir-pinegrass-shrub" habitat. Vegetation here includes Douglas-fir, redosier dogwood, and green alder in the riparian areas. Common forbs in the riparian include stinging nettle, black gooseberry, scouring rush and water horsetail.

Gold was discovered in the Welcome Creek area, and placer mining took place on upper Welcome Creek for a few years beginning in 1890 (Berg 1977). While it is likely that upstream placer mining released large quantities of sediment into the lower sections of Welcome Creek including the study reach, there is no visible evidence of those impacts today.

Berg (1977) wrote of a few lightning-caused fires along Welcome Creek, which is also consistent with my observations of the area. The fires near the study reach, were likely caused by lightning, and appear to have burned a few tall trees with the surrounding vegetation remaining relatively unaffected.

Stream Assessment Methods

Stream assessments were performed at similar elevations at each of the four study streams. In an attempt to access Welcome Creek closer to its headwaters, the assessments were performed at a slightly higher elevation than at the MPG streams and on a study reach upstream of the Montana DEQ reference stream reach.

HOBO and Maxim Integrated iButton temperature data loggers were installed to measure water and air temperatures at each stream from July 1 to September 15. A miniDOT dissolved oxygen (DO) logger was installed at Davis Creek to measure DO from July 21 to September 27. The later installation date for the DO logger was due to instrument availability.

Total discharge (stream flow) was measured at each stream from June 14 to 22. At Davis, Tongue, and Woodchuck, stream depth was too shallow to use a flow meter, so discharge was measured with the "Float Method" (Montana DEQ 2012b). At Welcome Creek, the "Flow Meter" method was used (Montana DEQ 2012b). Stream channel morphometry measurements were made in the late summer to early fall when stream flow is normally lowest. These measurements included average bankfull width, elevation at the middle of the study reach, average proportion of shading by vegetation, slope, width-to-depth ratio, entrenchment, and channel materials.

Water chemistry samples were collected once in the spring (June 14 to 17) and once in the late summer (August 24-26) at each stream, with the exception of Tongue Creek, which by that time was too dry to collect water chemistry samples. Water samples were collected and stored until analysis by technicians at the Missoula Wastewater Treatment Facility according to Montana DEQ protocol (Montana DEQ 2012b).

Macroinvertebrate and benthic algae samples were collected according to the DEQ method of fixed transect plots in which eleven transects were delineated in each study reach. Biological samples were taken at each transect, systematically alternating between left bank, center, and right bank (Montana DEQ 2012b). This systematic sampling method enabled the sampling of all potential habitats in the stream. The macroinvertebrate samples from each transect were composited into one sample for each study reach. In contrast, the benthic algae samples from each transect were analyzed separately and then later averaged together (Montana DEQ 2012b).

Macroinvertebrate samples were collected from June 14 to 22 to ensure that samples could be collected at each stream in the same few week period. This earlier collection date was chosen because I suspected that Tongue Creek might be dry later in the summer, which was the case.

Because diatoms were expected to be the dominant benthic algae present, algae samples were collected late in the summer from August 24 to 26 in order to allow maximum accumulation of the algae on stream substrates. Tongue Creek was dry by late August so benthic algae was not sampled in this creek. At Woodchuck Creek, accumulation of diatoms on substrate was too little to sample, so I estimated all samples would be below detection and thus did not collect benthic algae in this reach. Hence, benthic algae samples were collected for Davis and Welcome Creek only. All the biological and chemical samples were collected by August 26.

Natural Resource Conservation Service Riparian Assessment

I used the Natural Resource Conservation Service (NRCS) Riparian Assessment Method to rate the streams on characteristics such as channel stability, erosion, vegetation, presence of noxious weeds, and floodplain characteristics (Pick and others 2012). Under the NRCS method, a score of 100% indicates the stream conditions completely meet NRCS expectations of healthy stream condition. As various factors contributing to impairment are noted, points are subtracted from the total possible, hence the percentage score decreases.

For instance, a stream reach will lose points if up to 5% of the riparian area contains noxious weeds. More points are deducted for noxious weeds making up to 10% of the riparian, and zero points are awarded for that category if 10% or more of the riparian vegetation is made up of noxious weeds (Pick and others 2012).

Desirable woody plants are also weighted highly in the NRCS score. One category allocates points based on the number of desirable woody species that have "binding rootmass," meaning they have a root structure that will adequately support stream banks (Pick and others 2012). Full points are given for four or more such highly rated woody plants such as redosier dogwood or cottonwood. Another category allocates points based on the percent cover made up by these plants (Pick and others 2012). Full points for the percent cover category are given if 85% or more of the canopy cover is made up of the desirable woody plant species. Points are deducted as the percent cover of these plant species decreases.

Browsing by cattle and native ungulates is also a component of each reach's NRCS score. The purpose of this section is to determine whether browsing decreases the vigor of important woody species, preventing their adequate regeneration in the future (Pick and others 2012). No points are lost if up to 5% of the woody plant species in the riparian are visibly browsed. Some points are lost for visible browsing of 5-25% of woody species and even more are lost for greater proportions (Pick and others 2012). Finally, the presence of large woody debris, boulders and back channels are recorded in order to estimate how well the riparian area dissipates the energy of water in high flow or flood events.

Lab Analysis of Chemical and Biological Samples

Water chemistry samples were kept frozen on dry ice or in a freezer until analyzed in accordance with DEQ protocols (Montana DEQ 2012b). These samples were analyzed by lab technicians at the Missoula Wastewater Treatment Facility using EPA approved standard methods. These analyses determined the milligrams per liter of total persulfate nitrogen (a measure of total nitrogen), total phosphorus, soluble reactive phosphorus, ammonia, and nitrates and nitrites for each study stream. (See table A-1 for descriptions and citations of protocols used.)

Benthic algae chlorophyll *a* samples were kept on dry ice until stored in a freezer at -20°F. These samples were analyzed within 60 days of collection. At the UM Watershed Clinic, I analyzed the benthic algae samples from each study reach. Analysis of the algae samples determined the milligrams of chlorophyll *a* per square meter and grams of ash-free dry mass per square meter in each study stream. (See table A-1 for descriptions and citations of protocols used.)

Macroinvertebrate samples were preserved in 70% ethanol and analyzed by NABS certified taxonomists at Rhithron Associates, Inc. in the fall of 2015.

Data Analysis

Stream channel morphometry measurements were analyzed based on Rosgen's (1996) stream classification system.

Temperature data were analyzed to determine the weekly high, low and median temperatures. Additionally, water temperatures were compared to westslope cutthroat trout temperature preferences as defined by Bear et al (2007). Air temperatures recorded at each creek in the summer of 2015 were compared to summer 2015 air temperatures recorded at the nearest NOAA weather coop station and also to historical monthly averages recorded at this station (Western Regional Climate Center 2015).

Dissolved oxygen (DO) concentrations recorded in Davis Creek were compared to DEQ DO criteria (Montana DEQ 2012a).

Nutrient, benthic Chl-*a*, and AFDM concentrations from each stream were compared to Montana state numeric criteria for the Middle Rockies ecoregion (Suplee and Watson 2013).

Wease Bollman, North American Benthological Society certified taxonomist and Chief Biologist at Rhithron with over 20 years of experience in this field, analyzed the macroinvertebrate assemblage results using a multimetric index (the Montana Foothill Prairies and Valleys Index) which she developed (Bollman 1998). In addition, she wrote narrative summaries on the analysis of the macroinvertebrate assemblages collected at each stream (Bollman 2015).

RESULTS AND DISCUSSION

Physical stream characteristics: Morphometry, Flow, and Shading

Several physical characteristics were measured to establish baseline conditions as well as to determine the Rosgen classification for each stream. Dave Rosgen created a classification system which allows streams to be categorized based on channel morphology characteristics. Therefore, stream slope, width to depth ratio, entrenchment and channel bed materials were recorded for the purposes of estimating each study reach's Rosgen classification. In addition, I also measured stream elevation at mid study reach and average bankfull width (see Table P-1). Finally, I measured two more variable parameters: spring discharge and vegetation shading, measured on June 14 to 22 (see Table P-1).

Davis Creek

Physical characteristics measured at the Davis Creek study reach provided a mixed picture of Rosgen's classification for this creek (Rosgen 1996). The parameters measured at the Davis Creek study reach (see Table P-1) match the Rosgen definition of a C4 stream type, except that the slope is greater than the Rosgen definition of 2% or less (Rosgen 1996). Looking at slope only, this stream would be expected to be an A stream, but the Davis Creek study reach is neither entrenched nor high energy as Rosgen describes A streams to be (Rosgen 1996). At the top of the study reach, slope is between 1 and 2%, and in the bottom half of the study reach, slope is between 5 and 8%. Thus, the channel could be transitioning from one channel type to another in the study reach.

Woodchuck Creek

The parameters measured at the Woodchuck Creek study reach (see Table P-1) classify this study reach as a G4 reach, which is described as an entrenched gully with a low width to depth ratio occurring on a moderate gradient (Rosgen 1996). Qualitatively, this description fits the study reach.

Tongue Creek

The physical characteristics of the Tongue Creek study area do not allow it to be easily categorized according to Rosgen's stream classification scheme (see Table P-1). While the study reach has a relatively high slope (7.9%), it does not fit the other characteristics of an A stream type.

Welcome Creek

The Welcome Creek study reach was easily classified as a B3 channel type (see Table P-1) (Rosgen 1996).

Natural Resource Conservation Services Riparian Assessment Scores

Davis Creek

Davis Creek received an NRCS riparian assessment score of 97%. The main signs of degradation according to this assessment method were the abundance of noxious weeds and evidence of browsing of the riparian vegetation. Noxious weeds made up to 5% of the riparian area and included Canadian thistle, spotted knapweed, and leafy spurge. While these weeds are present in great numbers on the nearby road, there are far fewer noxious weeds in the riparian zone, but their presence is still of concern. Between 5 and 25% of second-year stems were visibly browsed. Given that the area is no longer grazed by cattle, deer and elk are the most likely browsers in this area.

Woodchuck Creek

Woodchuck Creek received an NRCS score of 88%. At the study reach, the stream is deeply incised, which prevents water from accessing the floodplain in a normal one-to-three year average cycle (Pick and others 2012). I estimated that only 75-85% of the canopy in the riparian area had a high stability rating as defined by the NRCS (Pick and others 2012). Similar to Davis Creek, the study reach at Woodchuck Creek had up to 10% noxious species including spotted knapweed and leafy spurge. Also, about 5 to 25% of the second year stems were browsed, probably by deer.

Tongue Creek

Tongue Creek received an NRCS score of 80%. The reach's score was negatively affected by the presence of noxious species including spotted knapweed, hounds tongue, and leafy spurge, which made up at least 10% of the riparian vegetation. Mature and seedling age classes were missing from some desirable woody plant species, such as quaking aspen, which only existed in the "pole" or intermediate age class (Pick and others 2012). These trees were only observed within the exclosures placed for them along the stream reach. Outside of these structures, browsing pressure by deer and elk is apparently too intense to allow vigorous growth of these and similar plants. Between 5 and 25% of second year stems were grazed, which also negatively affected the NRCS score at this reach.

Welcome Creek

Welcome Creek received an NRCS score of 100%. No invasive species were seen in the riparian area; the stream channel was obviously very stable thanks to the boulders and healthy riparian vegetation; and boulders and large woody debris were present to dissipate energy in periods of high flow. Unlike the riparian areas assessed at MPG Ranch, browsing by deer did not appear to be a significant pressure on riparian vegetation.

Stream and Air Temperatures in summer 2015

In order to assess stream temperature trends for the summer of 2015 at each of the four creeks, data loggers were placed at each of the stream reaches. One data logger at each study reach recorded stream temperature, and another recorded air temperature. Each data logger recorded the temperature every hour for the period of July 1 to September 15.

The weekly median air temperature for Davis Creek during the study period ranged from 17°C in the first week of July to 9.5°C in the first week of September (See Figure T-1a). The air temperature had an average weekly range of 18.6°C.

Davis Creek's water temperature for the recorded period had a weekly median between 13.3°C in the first week of July and 9.7°C in the second week of September (see Figure T-1b). Excluding a slight peak in the week of August 12, the general trend was a decrease in overall water temperature from July to September. The average weekly range was 5.5°C.

The median air temperature at Woodchuck Creek ranged from 17.2°C in the first week of July to 9.8°C in the first week of September (see Figure T-2a). The air temperature at Woodchuck Creek had an average weekly range of 24.3°C.

At Woodchuck Creek, the weekly median water temperature fell between 14.9°C in the first week of July and 10.7°C in the first week of September (see Figure T-2b). Woodchuck Creek's weekly changes in water temperature were more variable than those of the other creeks, with an average weekly range of 10.2°C. Less groundwater inputs could cause the stream temperature to be more variable than other streams.

The median weekly air temperature at Tongue Creek during the recording period ranged from 19.2°C in the first week of July to 9.4°C in the first week of September (see Figure T-3a). The average weekly range for the air temperature at Tongue Creek was 25.5°C.

Tongue Creek had a weekly median water temperature between 11.8°C in the first and last weeks of July to 10.0°C in the second week of September (see figure T-3b). The average weekly range was 2.8°C.

The weekly median air temperature at Welcome Creek during the recording period ranged from 18.3°C in the first week of July to 9.0°C in the first week of September (see Figure T-4a). The air temperature at Welcome Creek had an average weekly range of 18.5°C.

The weekly median water temperature at Welcome Creek ranged from 10.7°C in the first week of July to 9.1°C in the first week of September (see Figure T-4b). Welcome Creek's average weekly range in water temperature was 2.5°C.

At almost all study reaches, the peak air and water temperatures during the recording period occurred during the first week of July. There was a spike in air temperatures that occurred in the week of August 12, which, in the cases of Davis and Woodchuck Creek, overtook the first week of July for the highest recorded air temperature. The lowest air and water temperatures at all streams occurred in the first and second weeks of September.

Welcome Creek, as compared to MPG's creeks, had a lower average weekly range in water temperature, and a lower average weekly median water temperature. The average air temperature at Welcome Creek for the month of July was 16°C, and that for Davis was comparable at 15.2°C. However, the average water temperature at Welcome Creek in July was 10.5°C while that at Davis was 12.4°C. Thus, in hotter periods of time, Welcome Creek's water temperature was less affected (due likely to its greater total discharge) than the much smaller Davis Creek. Hence, Welcome Creek may not be the most appropriate stream to compare to the much smaller creeks at MPG in the case of water temperature.

Comparison to Historical Air Temperatures at Nearest NOAA station

In order to assess how closely the air temperatures observed at the creeks matched those at the closest NOAA station, , the study creeks' monthly high and low air temperatures for 2015 were compared to monthly high and low temperatures observed in the same time period in 2015 at the closest recording station in Stevensville, Montana. The 2015 temperature values from the MPG study reaches were also compared to Stevensville's historical temperatures (see Table T-1) (Western Regional Climate Center 2015).

While air temperatures at the study creeks were recorded for all of July and August, air temperatures were recorded for only the first two weeks of September at the four study creeks. Thus, comparisons of the study creek temperatures to historical averages for the month of September can only be made tentatively.

At Davis Creek, the low temperatures recorded in July and August were about 3°C lower than the Stevensville historical averages and 5.5°C lower than Stevensville 2015 values. For all three recorded months, Woodchuck Creek had low temperatures noticeably lower than the 2015 values or historical averages recorded in Stevensville. At Tongue Creek, the monthly high temperatures were noticeably higher than Stevensville historical and 2015 values. Similarly, the monthly low temperatures recorded at Tongue Creek were noticeably lower than the temperatures recorded at Stevensville historically and in 2015. Temperatures recorded at Welcome Creek closely matched Stevensville historical averages and were all slightly lower than 2015 values recorded in Stevensville.

The occurrence of more extreme high and low air temperatures at Woodchuck and Tongue Creeks could be due to the fact that these two sites are less vegetated than the other study sites, thus causing more dramatic daily temperature changes. This idea is supported by the higher average weekly air temperature ranges at Woodchuck and Tongue Creeks (24.3°C and 25.5°C, respectively), which exceed the weekly air temperature ranges at Davis and Welcome Creeks (18.6°C and 18.5°C respectively) by 5.7 to 7°C. Thus, there is the occurrence of more extreme temperatures as compared to the historical monthly values and 2015 values from Stevensville as well as the occurrence of greater weekly temperature changes at Tongue and Woodchuck Creeks, both of which are likely due to the particular elevation and vegetation at these study sites.

Stream temperatures vs Westslope Cutthroat Trout Thermal Requirement

The westslope cutthroat trout is listed as a species of concern by the U.S. Forest Service, U.S. Bureau of Land Management, and the Montana Natural Heritage Program (Montana Natural Heritage Program 2016). Hence the trout's temperature needs must be considered when evaluating stream temperatures. According to an environmental DNA study carried out on MPG Ranch, native westslope cutthroat trout have been determined to be present in the South Fork of Davis Creek, close to this study's research reach in Davis Creek (Carim and others 2015). Although Woodchuck Creek's small size and Tongue Creek's ephemeral nature make them both unlikely candidates for westslope cutthroat trout, it is useful to compare how each of these streams meets or fails to meet this species' thermal requirements.

In their 2007 study, Bear et al found that westslope cutthroat trout have the highest growth rate in the temperature range of 13 to 15°C. For each stream, I calculated the percentage of time the stream temperature fell into this ideal temperature range (see Table T-2). The study also found an "upper incipient lethal temperature" (UILT) at which 50% of fish die when contained for 60 days in water held at a given temperature (Bear, McMahon, Zale 2007). The study identified the UILT as 19.6°C. Thus, I also calculated the percentage of time each stream reached the UILT (See Table T-2).

The stream temperature at the Davis Creek, Tongue Creek and Welcome Creek study reaches never exceeded the UILT, and for 21%, 16% and 0% of the time, respectively, the stream temperature at the study reaches was within the peak growth temperature range.

The temperature in Woodchuck Creek exceeded the UILT threshold for 2% of the recording period. These exceedances of the UILT were short periods of two to three hours that occurred during the hottest part of the day throughout the recording period. Woodchuck Creek's temperature spent the most time in the peak growth temperature range, as 27% of the recording period logged within the 13-15°C range. Thus, while its total flow would probably not accommodate westslope cutthroat trout, its temperature, as recorded in the summer of 2015, made it a good fit for this species.

In general, MPG's streams are below the UILT and the peak growth temperature range for westslope cutthroat trout.

Dissolved Oxygen Levels in Davis Creek in summer 2015

A dissolved oxygen data logger was placed in Davis Creek from July 21 to September 27. Because of a malfunction by the logger, accurate data is only available for the periods of July 21 to July 30 and August 25 to September 27 (see Figure D-1 for raw data from logger). Adequate concentrations of dissolved oxygen are vital to aquatic life, and the Montana DEQ has set specific standards for dissolved oxygen based on requirements of early-stage aquatic life and other aquatic life (see table D-1)(Montana DEQ 2012a). The standards for early life stages are set to ensure sufficient DO concentrations for fish eggs, such as westslope cutthroat trout, in the stream spawning gravels.

The DO concentrations did not meet DEQ standards in a few cases. For the entire recording period (6 weeks), the 7-day mean ranged from 8.5 to 9.0 mg/L, failing to meet the early-stage aquatic life standard of 9.5 mg/L. Additionally, the 1-day minimum was 7.9 mg/L on three of the hottest days of the recording period, July 21, 22 and 25, and these minimum concentrations were just below the early-stage aquatic life standard of 8 mg/L. All other DO concentrations recorded were above DEQ standards for other aquatic life.

For the period when the dissolved oxygen logger malfunctioned, I used the lowest percent saturation recorded while the logger was still functioning properly (75.8%) and the highest temperature recorded by the temperature logger in that malfunction period (16 °C) to provide an estimate of the lowest DO concentration that would have occurred when the DO logger malfunctioned. This estimation is 7.6 mg/l DO, which is below the 1-day minimum Montana DEQ standard for early life stages of 8 mg/l (Montana DEQ 2012a).

The dissolved oxygen logger was placed at the top of the study reach in Davis Creek, which, as noted before, has a low slope, has bed materials dominated by silt, and is a low-energy section of the reach. These factors probably account for the failure of the dissolved oxygen concentrations in Davis Creek to meet DEQ standards in a few instances. This site was chosen to measure DO in the worst case scenario rather than being representative of most of the reach.

Stream Nutrients and Benthic Algae

Montana State Numeric Nutrient Criteria

The Montana Department of Environmental Quality developed numeric nutrient criteria in order to regulate nutrient pollution in wadeable streams (Suplee and others 2008). Phosphorus (P) and nitrogen (N) have been identified as the limiting nutrients of algal growth in most stream environments, so when N and P loading and levels increase, streams can be affected in several ways. Excess P and N can cause an increase in the growth of benthic filamentous algae, especially *Cladophora spp.*; an increase in daily fluctuations in dissolved oxygen (DO) and pH caused by phytoplankton productivity and community respiration; a change in macroinvertebrate communities, and fish kills caused by decreased DO (Suplee and others 2008).

Nutrient criteria have been developed for each of Montana's ecoregions. In the Middle Rockies ecoregion, the numeric nutrient criteria for total phosphorus (TP), total nitrogen (TN), Chlorophyll *a* (Chl-*a*) and Ash Free Dry Mass (AFDM) apply to the "growing season" or July 1 to September 30. This summer growing season is when nuisance algae such as *Cladophora spp.* most affect beneficial uses of streams such as recreational fishing (Suplee and others 2008). Because primary production by algae is linked to increases in P and N in streams, I sampled water chemistry and benthic algae in each of the creeks.

While TP and TN are the only forms of nutrients regulated in these streams, it is also useful to examine the proportion of soluble forms of P and N found in each sample. Soluble reactive phosphorus (SRP) is the part of the TP in the water sample that passes through a .45 μm filter, and this form is readily available to primary producers like algae. Thus, while

SRP is not regulated in Montana, if the concentration of SRP alone exceeds the Montana state TP criteria, that is a certainly a water quality concern.

Similarly, ammonia (NH_3) and nitrates and nitrites (abbreviated together as NOx), are the soluble forms of nitrogen and are more bioavailable to primary producers. Thus, if the concentration of NH_3 combined with the concentration of NOx exceeds the state TN criteria, this is also a concern to stream water quality. Ammonia can be toxic to animals at levels above the EPA criteria of 5.6 mg (in pH 8.0 freshwater at 0 to 14°C), (US EPA Office of Water 2013) which is three orders of magnitude greater than the levels observed in any of the study reaches.

Study Reach Nutrient Levels

At each stream, water quality samples were collected in the spring (June 14 to June 17) and in the late summer (August 24 to August 26) (see Table N-1). Tongue Creek was the only exception to this. I took samples at Tongue Creek only in the spring because by the end of August, the creek consisted of shallow pools, scattered between dry reaches, and there was not enough water to sample.

Phosphorus levels in study reaches in summer 2015

Montana state standards for wadeable streams in the Middle Rockies ecoregion state that, during the period of July 1 through September 30, total phosphorus (TP) concentrations should not exceed 30 μg/L (Montana DEQ 2014). Spring samples for the study creeks were taken before July 1, hence the state standards do not apply to this period. All the TP samples at all of the study creeks exceeded the state standard, and most of the SRP samples also exceeded the state standard (see Table N-1).

It is surprising that the reference stream, Welcome Creek, also exceeded water quality standards for nutrients; however the Welcome Creek study reach was not the same reach used by MT DEQ for the reference project.

Most of the P measured in the water samples was bioavailable since SRP made up between 50% to almost 100% of the TP measured in these samples (see Table N-1). Since the high level of TP cannot be attributed to spring runoff because most of the TP was in soluble (SRP) and not particulate form, it is possible that the groundwater in the study areas has high levels of P which contribute to P levels in the streams. For example, Carey (1991) observed high levels of P in Gold Creek of the upper Clark Fork River caused by groundwater inflows, and I speculate that groundwater could have a similar effect on the streams in this study.

Nitrogen levels in study reaches in summer 2015

Montana state standards for these streams state that total nitrogen (TN) concentrations (in μg/L) should not exceed 300 μg/L. TN levels in samples from all the streams at MPG, in spring and fall, fell below the state TN standard of 300 μg/L. Spring TN levels in Tongue Creek (288 μg/L) were the closest to the state standard. However, much of this nitrogen was likely in particulate form because low levels of soluble inorganic nitrogen (nitrate + nitrite + ammonia, abbreviated as SIN) were found in the same sample (20 μg/L).

Similar to the MPG creeks, Welcome Creek spring and fall samples had TN concentrations below the state standard. Also, Welcome Creek had the lowest amount of seasonal fluctuation in nutrient levels from the spring to the fall.

All the study reaches appear to be N limited given the TN: TP and SIN: SRP ratios (see Table N-1).

pH levels in study reaches in summer 2015

The pH was also measured in conjunction with each nutrient sample (see Table N-1). The change in pH from about pH 8 in spring to about pH 6 in fall at Davis and Woodchuck Creeks is notable. A pH of about 8 was also measured at Tongue Creek in the spring. As these creeks drain from the Upper Missoula Group of the Belt Supergroup, the limey composition of these beds would probably raise the pH of the stream water to the pH 8 range (Furniss personal correspondence, April 2016). This geology could therefore explain the relatively high pH of the streams in spring.

It is possible that the drop to about pH 6 observed in the fall was caused by the percolation of rainfall affected by carbonic acid from the air. Furniss (personal correspondence, April 2016) notes anecdotally that rainfall in this area generally pH 5. Hence, the lower pH of rainfall could account for the lower pH recorded in the fall at Woodchuck and Davis Creeks.

Benthic Algae Levels Measured as Chlorophyll *a* and Ash Free Dry Mass

Benthic algae productivity and biomass levels may be limited by many different factors at different times and places in the same stream. Such factors may include nutrients, light, substrate, scour by flows, and grazing, among others.

Benthic algae are used as another indicator of stream water quality. Montana DEQ has set criteria for benthic algae levels also. The same time period for regulation (July 1 to September 30) applies to the recommended criteria for the two measures of benthic algae: Chl-*a* and AFDM (Suplee and others 2008). This period is considered the growing season for these algae and is thus when they are expected to affect beneficial uses as defined by the Montana Department of Environmental Quality (Suplee and others 2008).

In the end of August, benthic algae samples were collected at Davis Creek and Welcome Creek. Benthic algae samples were not collected at Tongue Creek due to the lack of water, and they were not collected at Woodchuck Creek due to the lack of visible algal material in the stream.

Benthic algae standards for the Middle Rockies eco-region are 125 mg Chl-a/m^2, and 35 g AFDM/m^2 (Suplee and Watson 2013). In western Montana's rivers, benthic algae communities are sometimes dominated by filamentous green algae and sometimes by diatoms. The latter normally reach their peak growth toward the end of the summer. Because diatoms dominate the MPG Ranch creeks, samples were collected late in summer from August 24 to 26. Both creeks sampled for benthic Chl-a showed Chl-a concentrations lower than the standards for this ecoregion (see table N-2).

The Davis Creek reach had a mean of 5 mg Chl-a/m^2, with a standard error of 2 mg Chl-a/m^2 and measurements ranging from 0 to 21mg/m^2. Samples from the Welcome Creek reach had mean Chl-a concentrations of 71 mg Chl-a/m^2 with a standard error of 32 mg Chl-a/m^2, with individual measurements ranging from 0 to 366 mg Chl-a/m^2.

Mean concentrations of ash-free dry weight for Davis Creek fell below standards while those for Welcome Creek exceeded criteria. Davis Creek had an average of 21 g AFDM/m^2 with a standard error of 11 g AFDM/m^2 and measurements ranged from below detection to 82 g AFDM/m^2. Welcome Creek had an average concentration of 44 g AFDM/m^2 with a standard error of 16 g AFDM/m^2, and concentrations ranged from below detection to 182 g AFDM/m^2.

The Welcome Creek study reach exhibited higher levels of soluble N in late summer. Hence, perhaps the difference in algae growth in the two streams is due to greater N limitation in Davis Creek. Overall, the level of algae in Davis Creek is not a concern for water quality parameters affected by high levels of algae.

Macroinvertebrate Assemblages as Indicators of Stream Condition

From June 14 through June 22, macroinvertebrate samples were collected at each of the four study reaches. The analysis of these samples by Rhithron Associates, Incorporated (Bollman 2015) produced a two-part analysis: the Montana Valley and Foothill Prairies (MVFP) Index results and the narrative summary results. In the first section, Bollman, of Rhithron Associates, uses a quantitative multimetric index developed for the ecoregions of western Montana to determine the percent impairment of each stream compared to expected conditions for a foothills stream in western Montana (Bollman 1998). The second section provides a narrative (qualitative) summary of stream conditions expected given the macroinvertebrate assemblage observed in the sample. A summary paper of these results and a metric summary of each macroinvertebrate assemblage (both provided by Rhithron Associates) are included as Appendix A and Appendix B, respectively, to this document.

Quantitative Indices

The MVFP multimetric index is composed of six indicators of stream condition, based on western Montana's valley and foothill prairie ecoregions (Bollman 1998). The index was developed based on data from 124 "more-or-less randomly selected" streams throughout the ecoregions of western Montana (Bollman 2016, personal communication).

Both least impaired and impaired streams were used. During the early 2000's, the MVFP was used by the DEQ as an assessment tool; currently, the DEQ uses a predictive model for its assessments (Bollman 2016, personal communication). While it is no longer used by the DEQ, the MVFP remains a useful index for western Montana streams.

To calculate MVFP scores, six indicators are incorporated into the final score for each sample, which is represented as a percentage of the maximum possible score (Bollman 2015). This multimetric index takes into account the following factors: Ephemeroptera (mayfly) taxa richness, Plecoptera (stonefly) taxa richness, Trichoptera (caddisfly) taxa richness, number of sensitive taxa (sensitive to factors of disturbance including high water temperatures, nutrient or organic pollution, toxic pollution, sediment deposition, unstable substrate and other factors), percent filter feeders, and percent tolerant taxa (tolerant to disturbance factors listed above) (Bollman 2015). This index is particularly relevant to my study because, Bollman, selected the specific factors in the index because they were especially sensitive to grazing impacts in Western Montana.

Davis Creek received a MVFP Index score of 83% of the total possible index points, which indicates a "slightly impaired" condition (Bollman 2015). Of all the creeks sampled from MPG Ranch, Woodchuck Creek received the highest MVFP Index score, 94%, indicating a "non-impaired" condition (Bollman 2015). Tongue Creek received a MVFP Index score of 50%, which represents a "moderately impaired" condition (Bollman 2015). The reference stream, Welcome Creek received the highest MVFP Index score of all the samples, 100%, which indicates a "non-impaired" condition (Bollman 2015).

Qualitative Interpretation Report

The next section of Bollman's 2015 report on the macroinvertebrate samples gives a narrative summary for each stream based on various index scores and the presence or absence of functional groups or indicative taxa such as mayflies.

Davis Creek

The macroinvertebrate sample collected at Davis Creek provides mixed indications of the overall water quality of the study reach (see Table M-1). The relatively low abundance of turbellarian flatworm *Polycelis sp.* indicates that groundwater input is not an important factor to streamflow (Bollman 2015).The lower than expected number of mayfly taxa (based on montane streams in western Montana ecoregions) and the relatively high biotic index score (4.59) suggests slightly degraded water quality (Bollman 2015). The "biotic index," as it is referred to in this report and used in Bollman's 2015 analysis, is a modified Hilsenhoff Biotic Index (HBI). The biotic index can be used as an indicator of water quality parameters such as pH, conductivity, water temperature, the presence of filamentous algae, and sediment deposition (Bollman 1998, as cited in Bollman 2015). Hence, the biotic index is a measure of pollution and disturbance tolerance since as these disturbance-tolerant taxa increase, so does the biotic index score.

The hemoglobin-bearing midge *Polypedilum sp.* was common in this sample, which indicates areas of hypoxic (low oxygen) substrate in the stream reach at Davis Creek (Bollman 2015). The presence of midge *Microspectra sp.* in the sample suggests the presence of filamentous algae and thus nutrient rich streamflow (Bollman 2015). While filamentous algae were not observed in the study reach, the other conclusions drawn from these samples match my observations. At the top of the study reach, there were pools with a low slope of no more than 2% and a buildup of fine sediment. These areas are likely where the midge *Polypedilum sp.* was collected and where the potentially hypoxic conditions occurred.

In contrast to these signs of slight degradation, seven disturbance sensitive taxa were also found in the sample, implying excellent water quality (Bollman 2015). The high taxa richness (51 taxa) in the sample as a whole indicated diverse and intact instream habitats, while the presence of 11 caddisfly taxa and 21 clinger taxa indicated that sediment deposition does not obstruct colonization of stony substrates by these organisms (Bollman 2015). In slight contrast to this, the Fine Sediment Biotic Index (FSBI) score of 4.38 implies a moderate tolerance of sediment deposition in the assemblage of macroinvertebrates in the study reach (Bollman 2015). The presence of six stonefly taxa indicates natural channel morphology, stable stream banks, and functional riparian zones (Bollman 2015). Additionally, the presence of semivoltine taxa (organisms with long life cycles) indicates stable habitats and perennial instream flows (Bollman 2015). All expected functional components were present in the sample assemblage (Bollman 2015).

The above interpretations of good water quality match my observations of the downstream section of the study reach. Here, stream slope was recorded as between 5 to 12%, and there was visibly less sediment deposition in this downstream section compared to the upstream section of the reach. Sand, pebbles and some cobbles not covered by fine sediment were visible, and water appeared to move more quickly than it did in the upstream section of the reach. The downstream section of the Davis Creek study reach is probably where the majority of the stoneflies, mayflies, caddisflies, and sensitive taxa were collected, as the conditions there match the habitat requirements for these taxa. The upstream sections of the reach probably provided the species that are tolerant of sediment deposition and hypoxic substrate. In future collections of macroinvertebrates, it may be informative to keep samples from the two different sections of the Davis Creek study reach separate.

The thermal preference of the Davis Creek sample assemblage was estimated to be 13°C (Bollman 2015). This is only slightly higher than the recorded July average of 12.4°C and the overall recorded average (11.7°C) (see Table M-2). However, the recorded weekly high water temperatures at the study reach commonly ranged from 14 to 16°C.

The relatively low abundance of the turbellarian flatworm *Polycelis sp.* is thought to indicate the possibility of a variety of different water quality conditions within the study reach (Bollman 2015). Since the turbellarian flatworm is often present in areas where groundwater contributes to surface water flow ("gaining" stream reaches), the lower relative abundance of the flatworm in Davis Creek than in Welcome or Woodchuck Creeks indicates that groundwater influences surface flow less in the Davis Creek study reach than in Welcome or Woodchuck Creeks (Bollman 2015). Therefore, Bollman (2015) argues that this suggests that the study reach is composed of relict communities living near groundwater seeps and more disturbance tolerant communities living in areas of nutrient enrichment.

Woodchuck Creek

The relatively high number of mayfly taxa and the relatively low biotic index score suggest excellent water quality in Woodchuck Creek's study reach (see table M-1) (Bollman 2015). The presence and relative abundance of the turbellarian flatworm *Polycelis sp.*

suggests groundwater inputs are important factors in stream flow (Bollman 2015). This conflicts with the recorded higher fluctuations in water temperature, as groundwater would usually be expected to cause surface water temperatures to be more stable (Power and others 1999).

The presence of four stonefly taxa suggests unaltered stream channel morphology, intact riparian vegetation, and stable streambanks (Bollman 2015). The four semivoltine taxa identified indicate that the stream has perennial flow with no toxic inputs (Bollman 2015). These interpretations align with my observations of the Woodchuck Creek study reach.

While the presence of seven caddisfly taxa and 18 clinger taxa indicates stony substrates that are not greatly affected by sediment deposition, the FSBI score of 3.95 implies a moderately sediment tolerant assemblage of macroinvertebrates (Bollman 2015). The number of filterers in the sample suggests some suspended fine organic particulate material. However, the abundance of fingernail clams in the filterer category may contradict this assumption, as these clams live within the sediment and filter water completely within the sediment rather than filtering particles in the water column (Bollman 2015). Given that I did not observe as much fine sediment at the Woodchuck study reach as at the other MPG creeks, the reinterpretation of the FSBI based on the abundance of fingernail clams supports my observations.

The presence of five sensitive cold stenotherm taxa (those which can only live in cold water temperatures) suggests cold water stream conditions and no nutrient enrichment, and the thermal preference estimated for this assemblage was 13°C (see Table M-2) (Bollman 2015). This estimation is slightly lower than 14.2°C the recorded average temperature for the hottest month, July, but it is very close to the overall recorded average temperature of 13.2°C. In contrast, the weekly high water temperatures recorded at Woodchuck Creek ranged from 23 to 15°C.

Although the assemblage of macroinvertebrates sampled at Woodchuck Creek generally indicates good water quality, there was a low number of sample specimens (434 total specimens), which could be related to low water quality, poor habitat, sampling limitations, or oligotrophic conditions (Bollman 2015). According to my observations while sampling this reach, and the observations made by Bollman (2015) based on the sample assemblage, none of these factors seems to explain the paucity of individuals in the sample. I suspect that the very low flow in Woodchuck Creek, which occurs despite all other positive stream conditions, could explain the small number of sample specimens. Another explanation is a discrepancy in sampling technique; perhaps I did not expend the same amount of effort while collecting the macroinvertebrate sample at Woodchuck Creek as I did at the other study reaches.

Tongue Creek

The low mayfly richness (3 taxa, 4.7% of sample) and high biotic index score (5.44) suggest that water quality in Tongue Creek is impaired (see table M-1). In total, only one individual from one sensitive taxon (caddisfly, *Allomyia sp.*) was present in the sample (Bollman 2015).

The low richness of caddisflies (four taxa) and clingers (seven taxa) indicates the limitation of stony substrate colonization likely due to sediment deposition (Bollman 2015). This is supported by the FSBI score of 3.37 which indicates moderate sediment tolerance. The low stonefly richness (two individuals from one taxon) indicates an altered channel morphology, unstable streambanks, or disrupted riparian zone function (Bollman 2015).

There was also a lack of scrapers in the sample (Bollman 2015). The lack of scrapers in the sample indicated the absence of algal films (Bollman 2015). This is likely due to two factors. First, the thick depositions of fine sediment on the little rocky substrate present would inhibit algal growth. Second, while there was little shade in the stream reach, which would usually result in greater algal film growth, because the creek dries up by late summer the algae has insufficient time to grow, thus limiting availability of algae for the scrapers that depend on it.

Biting midges and gnats (Ceratopogonid flies) were found to be abundant in this sample, which often indicates cattle grazing nearby (Bollman 2015). While no cattle grazing occurs presently in the vicinity of the Tongue Creek study reach, elk are a common presence, and there was evidence of regular crossing of the creek by elk or other large mammals upstream of the study reach.

No cold stenotherms (organisms which can only tolerate relatively cold stream temperatures) were found in the sample, and the thermal preference of the assemblage was estimated as 16°C (see Table M-2) (Bollman 2015). This estimated temperature is high compared to the overall average recorded water temperature of 11.5°C in Tongue Creek. The weekly high water temperature at Tongue Creek ranched from 11.4 to 15.6°C.

Another uncommon facet of Tongue Creek's study reach was the unusual abundance of nematodes, which made up 41.3% of the sampled assemblage (Bollman 2015). The prevalence of nematodes makes the invertebrate assemblage difficult to interpret because nematode tolerances have not been fully determined (Bollman 2015). Nematodes, however, are associated with intermittent channels, which are accompanied by factors such as sediment deposition, nutrient enrichment and reach-scale habitat disruption (Bollman 2015). Thus, while the presence of nematodes cannot yet be used to predict other factors about this stream, it does correctly predict that Tongue Creek is ephemeral.

Tongue Creek's macroinvertebrate assemblage suggests impaired water quality, which agrees with nutrient levels that exceed state standards, and fine sediment dominating the substrate.

Welcome Creek

The high mayfly richness (12 taxa) and low biotic index score (2.33) for the sample assemblage from Welcome Creek indicates excellent water quality (see Table M-1) (Bollman 2015). The turbellarian flatworm made up 5.8% of the sample, indicating that groundwater contributes moderately to surface streamflow in the sampled reach (Bollman 2015).

The high richness of caddisflies (11 taxa) and clingers (32 taxa) indicates that stony substrate colonization is not inhibited by sediment deposition (Bollman 2015). The relative richness of stonefly taxa (7 taxa) indicates intact habitat features such as unaltered channel morphology, stable streambanks, and functional riparian zones (Bollman 2015). The abundance of scrapers suggests the presence of algal films and a lack of shading (Bollman 2015). This interpretation matches with my observations since the shading was estimated to be 45% at Welcome Creek. The taxa richness of the overall sample suggests diverse and intact stream habitats (Bollman 2015). These interpretations all align with my observations of the study reach at Welcome Creek. While Tongue Creek also had a low amount of shade, the water dried up too quickly to allow algae growth.

Cold stenotherms made up 15.7% of the sample, and the thermal preference of the sample was estimated to be 11°C, the lowest estimate of all the samples (see Table M-2) (Bollman 2015). The average temperature recorded in the Welcome Creek study reach was 10.5°C and the weekly high temperature ranged from 10.3 to 12.4°C, exceeding the estimated thermal preference of the macroinvertebrate assemblage.

As Welcome Creek is a DEQ reference stream located in a wilderness area, I would expect the macroinvertebrate sample to indicate excellent water quality despite exceeding algae criteria. Thus, the MVFP index score and narrative summary results are not surprising. Further, I would expect Welcome Creek to have water quality superior to that of any of the creeks at MPG Ranch because its surrounding watershed has been protected in a wilderness area since 1978, while logging at MPG Ranch ended only in 2007 (Tollefson 2010).

Table M-2 shows the estimated thermal preferences based on the macroinvertebrate assemblages collected at each study reach, recorded monthly high temperatures, recorded monthly average temperatures, and the overall average temperature recorded at each study reach. In the months of July and August the high temperatures recorded at Davis and Woodchuck Creeks exceed the estimated thermal preferences of the respective macroinvertebrate assemblages. These peak monthly temperatures represent a period of stress during the day on the macroinvertebrates in Davis and Woodchuck Creeks.

Overall, the macroinvertebrate sample analysis seems reasonable based on my observations. With a few exceptions, the interpretations made by Bollman (2015) closely match my qualitative observations of each stream reach. Thus, the macroinvertebrate samples provide a richer understanding of the condition of each of MPG Ranch's creeks.

CONCLUSIONS

The study reaches at MPG showed unimpaired to moderately impaired conditions. For instance, the macroinvertebrate assemblages at Davis and Woodchuck study reaches scored close to reference conditions while Tongue Creek's assemblage indicated moderately impaired conditions.

Temperatures recorded at all streams were within an acceptable range for macroinvertebrates and fish such as the westslope cutthroat trout. Water temperatures in Davis and Tongue Creeks were generally colder than the Upper Incipient Lethal Temperature threshold or the ideal range for westslope cutthroat trout. Most remarkably Woodchuck's stream temperature spent the most time in the ideal range yet was the only stream to (briefly) exceed the UILT temperature.

Since surface flow is very low for all streams at MPG, water temperature in these creeks is more easily affected by changes in air temperature than in a stream like Welcome Creek with much greater surface flow. This could have implications for stream biota in the future, especially macroinvertebrates, which are sensitive to these temperature changes.

Groundwater is also an important factor affecting stream temperature. Woodchuck and Davis Creeks' macroinvertebrate assemblages showed an influence from groundwater, but Tongue Creek's assemblage showed no groundwater influence. However, some data from the study creeks seemed counterintuitive. The notable groundwater influence suggested by Woodchuck Creek's macroinvertebrate assemblage seemed to contradict its very variable stream temperature. What is causing this discrepancy is unclear currently.

High phosphorus levels, in the form of TP and SRP, are a topic of potential concern. All the streams had TP and SRP concentrations that exceeded or were close to Montana state standards in both the spring and fall, but I speculate that high TP and SRP levels in the study streams could be due to groundwater influences.

There are a few factors affecting all the ranch streams that should be taken into account in future management decisions. For example, invasive plants and browsing pressure by native ungulates affect all three streams. These issues are not new; they are both previously noted in the conservation easement document (Tollefson 2010) and in my conversations with ranch manager Philip Ramsey, who confirmed that these are management concerns of the ranch. However, the effect of ungulate browsing and invasive plant species should be noted as an important issues for the ranch's streams and uplands.

Browsing is especially notable at the Tongue Creek study reach. This is probably partly due to the common passage of elk through the area. The ranch management has noted the prevalence of elk here and qualifies the area as sensitive because of the prevalence of elk. Given that its condition has been identified as "impaired" by DEQ criteria and according to macroinvertebrate analysis, this baseline study further supports limiting human activity in that area.

I also recommend further study of the area to better understand the hydrology of the streams and MPG Ranch in general. A weather station could provide useful data to enable this further understanding. Additionally, soil surveys could provide information on how soil composition affects these streams.

Most surprising was the unexpectedly good stream condition found in the Woodchuck reach, especially based on the macroinvertebrate samples. This good condition should be taken into account in future management decisions affecting Woodchuck Creek.

Davis Creek was expected to show the best stream condition. However, the fact that DO concentrations fell below state standards means that DO could be a concern in the upstream section of Davis during hot summers. This could have adverse effects on fish and macroinvertebrate populations there. However, this problem is likely confined to the silty, pooling sections of the upstream part of the study reach, where the DO logger was placed in the summer. Low DO should be less of a concern in the faster-moving downstream sections of the reach.

At Davis Creek, the convergence of elevated TP and SRP, DO levels slightly below state standards during hot days and macroinvertebrate assemblages that suggest nutrient enrichment and hypoxia should all be noted by ranch managers.

The great difference in total discharge, temperature, precipitation, and general climatic conditions at Welcome Creek makes it less useful as a reference stream for comparison to the MPG streams. This illustrates the need for a Montana DEQ reference stream on the west-facing slopes of the Sapphire range. Thus, given the land use and generally good conditions at Davis Creek and Woodchuck Creek, these study reaches could have potential as Montana DEQ reference stream reaches.

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TABLES AND FIGURES

Tables

Table S-1: Site characteristics of study stream reaches: location, elevation, geology, soil types (Montana Bureau of Mines and Geology 2014; Montana State Library 2016; Stoeser and others 2005; Vuke and others 2007)

	Davis Cr	**Woodchuck Cr**	**Tongue Cr**	**Welcome Cr**
Latitude (mid-reach)	46.73199	46.67637	46.69313	46.563333
Longitude (mid-reach)	-113.99228	-113.98693	-114.01011	-113.719444
Section, Township, Range	S9 T11N R19W	S28 T11N R19W	S20 T11N R19W	S3 T9N R17 W
Elevation (m)	1184	1162	1155	1289
Geology	Upper Missoula Group	Piegan Group of Wallace Formation	Upper Missoula Group	Georgetown Limestone of Upper Missoula Group
Soils	Winkler gravelly loam, and Winkler very gravelly sandy loam, 30 to 60 percent slopes	Big arm gravelly loam, 30 to 60 percent slopes	Bigarm gravelly loam, 30 to 60 percent slopes	Kawuneeche family, stream bottoms

Table A-1: Analytical methods used to quantify nutrients and algal biomass

Constituent	**Method**	**Method Limit of Detection**	**Reference**
Total Phosphorus	"B" is the persulfate digestion; "F" is the automated ascorbic acid reduction	2 µg/l	SM 4500-P(B)-F-99 (Rice and others 2012)
Total Nitrogen	Persulfate digestion followed by nitrate analysis	50 µg N/l	SM 4500-N C-97 (Rice and others 2012)
Soluble Reactive Phosphorus	Automated ascorbic acid reduction	2 µg/l	SM 4500-P F-99 (Rice and others 2012)
Ammonia	Automated phenate	10 µg/l	SM 4500-NH3 G-97 (Rice and others 2012)
Nitrate-Nitrite	Automated cadmium reduction	2 µg/l	SM 4500 NO3 (F) (Rice and others 2012)
Algal ash-free dry mass	Loss on ignition at 500°C	0.8 g/m^2	10200 I (Greenberg and others 1992)
Algal chlorophyll *a*	Spectrophotometric with acidification to correct for pheophytin	1 mg Chl*a*/m^2	(Sartory and Grobbelaar 1984)
Macroinvertebrate Analysis	Taxonomic identification of aquatic macroinvertebrates	n/a	(MT Department of Environmental Quality 2006)

Table P-1: Study stream reach physical morphometry measurements

	Davis Cr.	Woodchuck Cr.	Tongue Cr.	Welcome Cr.
Spring Discharge (m^3/s)	0.03	0.008	0.002	0.3
Spring discharge recorded on:	6/15/15	6/14/15	6/17/15	6/16/15
Average Bankfull Width (m)	1.7	1.5	1.7	5.7
Average Veg. Cover (%)	92	82	44	45
Stream Slope (%)	5.7	3.8	7.9	4.7
Width to Depth Ratio	12.1	10.5	7.3	24
Entrenchment	slightly entrenched, > 2.2	entrenched, 1.0 - 1.4	slightly entrenched, > 2.2	moderately entrenched, 1.4 to 2.2
Channel Material	various: fine sediment, gravel and sand	cobbles and sand with fine sediment	fine sediment with sand and gravel	boulders and cobbles with sand
Rosgen Classification	C4, except for slope	G4	unclear	B3
NRCS Scores (%)	97	88	80	100

Table T-1: Recorded maximum and minimum monthly air temperatures in summer 2015 for the MPG study reaches and the historical average monthly maximum and minimum temperatures recorded at Stevensville recording station (in °C) (Western Regional Climate Center 2015).

	Davis Cr.	Woodchuck Cr.	Tongue Cr.	Welcome Cr.	Stevensville 2015	Stevensville Historical Average
July Max.	27.6	31.7	37.3	29.5	29.0	29.6
July Min.	5.5	4.2	4.7	6.5	11.0	8.6
Aug. Max.	28.5	31.9	35.9	28	29.0	28.7
Aug. Min.	3.6	1.3	2.8	6	9.0	7.4
Sept. Max.	22.8	27.9	27.8	20.5	23.4	22.5
Sept. Min.	2.2	0.8	1.1	3.5	5.3	3.5

Table T-2: Percent of time water temperature at each study reach was within the ideal temperature range for westslope cutthroat trout and percent of time water temperature exceeds UILT for westslope cutthroat trout (Bear, McMahon, and Zale 2007).

	Davis Cr.	Woodchuck Cr.	Tongue Cr.	Welcome Cr.
Percent of Time in Ideal Temperature Range (13-15°C)	21	27	16	0
Percent of Time above UILT (19.6°C)	0	2	0	0

Table D-1: Dissolved oxygen concentrations (mg/l) recorded at the top of Davis Creek Study reach from July 21 to July 30 and August 25 to September 27. Gap in recording time due to instrument malfunction. 30-day mean averaged from August 25 to September 27 period. Montana DEQ dissolved oxygen standards for early life stages and other life stages (Montana DEQ 2012a).

	Davis Creek	**Standard to Support Early Life Stages**	**Standard to Support Other Life Stages**
30-day Mean	8.8	--	6.5
7-day Mean	8.5 - 9.0*	9.5	--
7-day Mean Minimum	8.1 - 8.7*	--	5
1-day Minimum	7.9**	8	4

* DO concentrations ranged between the above listed values for the 6 weeks recorded.

** The one-day minimum DO concentration violated the early life stages standard (7.9 mg/L) for 3 days out of 44 recorded days.

Table N-1: Water chemistry nutrients quantified for each sampled stream, in µg/L. Montana state standards, applicable July 1-September 30 (Montana DEQ 2014).

	Davis Cr.		**Woodchuck Cr.**		**Tongue Cr.**		**Welcome Cr.**		**State Standards**
Nutrient (µg/L)	*Spring 15-June*	*Fall 24-Aug*	*Spring 14-Jun*	*Fall 25-Aug*	*Spring 17-Jun*	*Fall (No flow)*	*Spring 16-Jun*	*Fall 26-Aug*	*July 1 to Sept 30*
TP	44	47	36	49	102	--	32	32	30
SRP	35	33	19	32	86	--	32	29	N/A
TPN	188	133	243	139	288	--	191	121	300
$NO_x + NH_3$	48	21	54	10	20	--	55	52	N/A
TN:TP Ratio	4.3	2.8	6.8	2.8	2.8	--	6	3.8	N/A
SIN: SRP Ratio	1.4	1.1	2.8	.3	.2	--	1.7	1.8	N/A
pH	8.2	6.4	8.2	6.6	8.3	--	8.3	8.2	N/A

Table N-2: Chlorophyll *a* and Ash Free Dry Mass levels from Davis Creek and Welcome Creek benthic algae samples, August 2015. Montana state standards, applicable July 1-September 30 (Montana DEQ 2014).

	Davis Creek		**Welcome Creek**		**State Standards: Middle Rockies Ecoregion**
	Mean	Standard Error	Mean	Standard Error	
Chl-*a* (mg/m^2)	5	2	71	32	125
AFDM(g/m^2)	21	11	44	16	35

Table M-1: Taken from Bollman 2015. Montana Valleys and Foothill Prairies Metric values, scores, and impairment classifications for the study streams, collected June 14-22, 2015 (Bollman 2015).

Sites	Davis Cr.	Woodchuck Cr.	Tongue Cr.	Welcome Cr.
METRIC VALUES				
Ephemeroptera richness	4	8	3	12
Plecoptera richness	6	4	1	7
Trichoptera richness	11	7	4	11
Sensitive taxa richness	7	5	1	13
Percent tolerant	8.9%	9.0%	11.4%	3.2%
Percent filter-feeders	7.2%	2.8%	1.8%	<1%
METRIC SCORES				
Ephemeroptera richness	2	3	1	3
Plecoptera richness	3	3	1	3
Trichoptera richness	3	3	2	3
Sensitive taxa richness	3	3	1	3
Percent tolerant	2	2	1	3
Percent filter-feeders	2	3	3	3
SITE SCORES	15	17	9	18
Percent of Maximum	83%	94%	50%	100%
Impairment Classification	Slightly impaired	Non-impaired	Moderately Impaired	Non-impaired

Table M-2: Estimated thermal preferences of macroinvertebrate assemblages as compared to monthly and overall average temperatures (in °C) recorded at each study reach (Bollman 2015).

	Davis Cr.	**Woodchuck Cr.**	**Tongue Cr.**	**Welcome Cr.**
Thermal preference	13	13	16	11
July average	12	14	12	10
July high	16	23	16	12
August average	12	13	12	10
August high	16	21	15	12
September average	10	11	10	9
September high	13	16	12	11
Overall Average	12	13	12	10

Figures

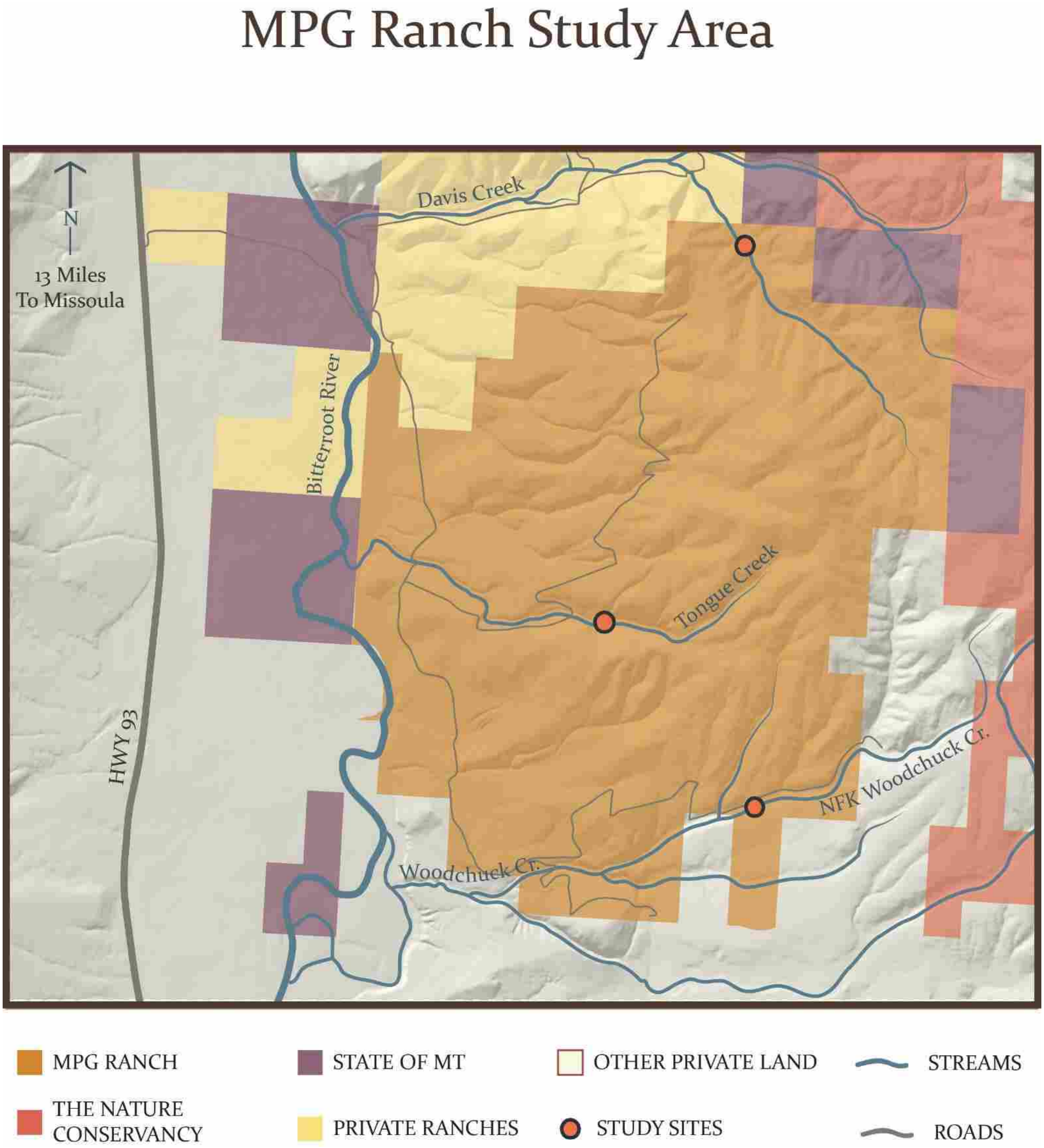


Figure S-1: Map of MPG Ranch Study Area, created by Aaron Kamoske

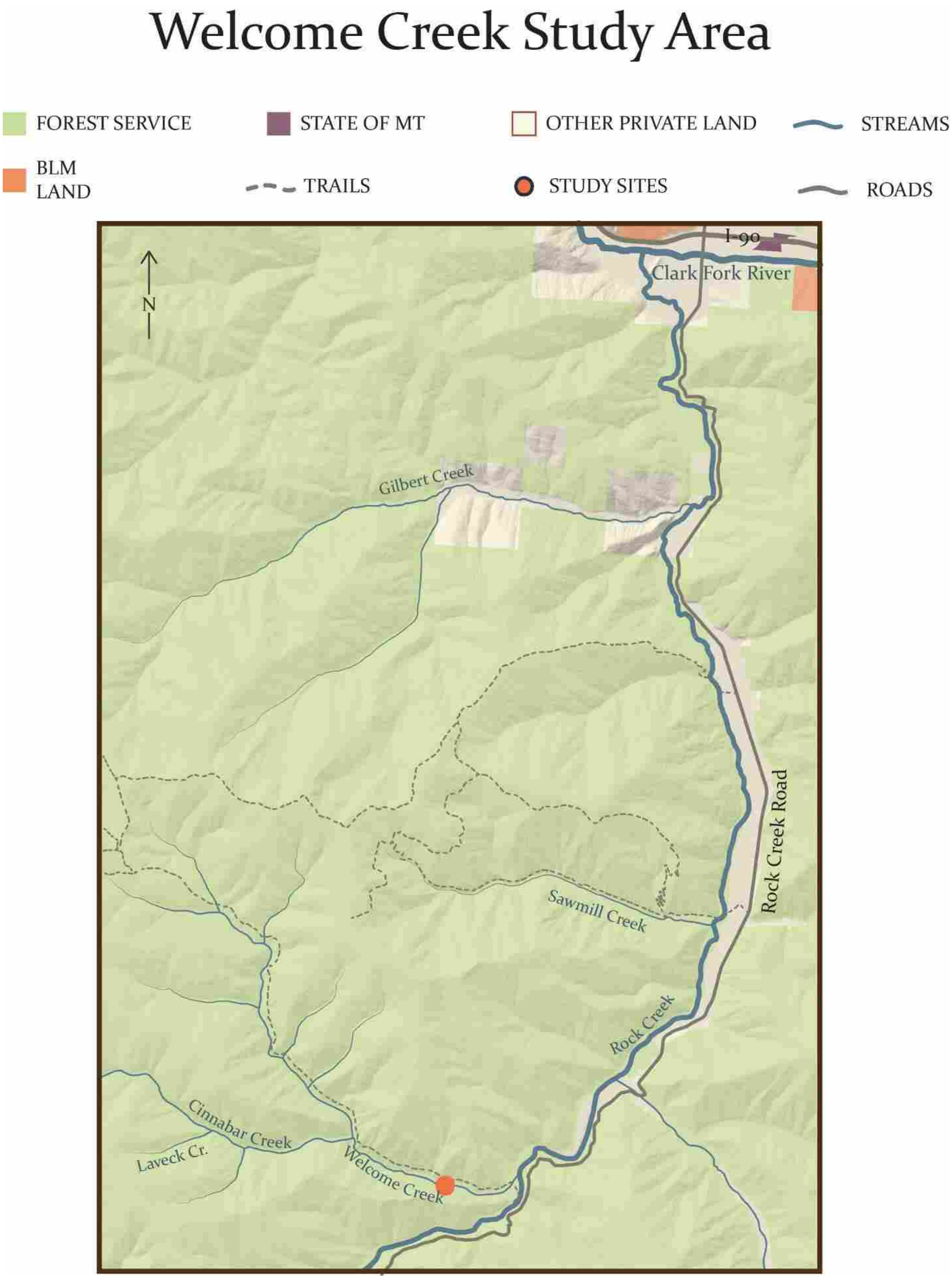
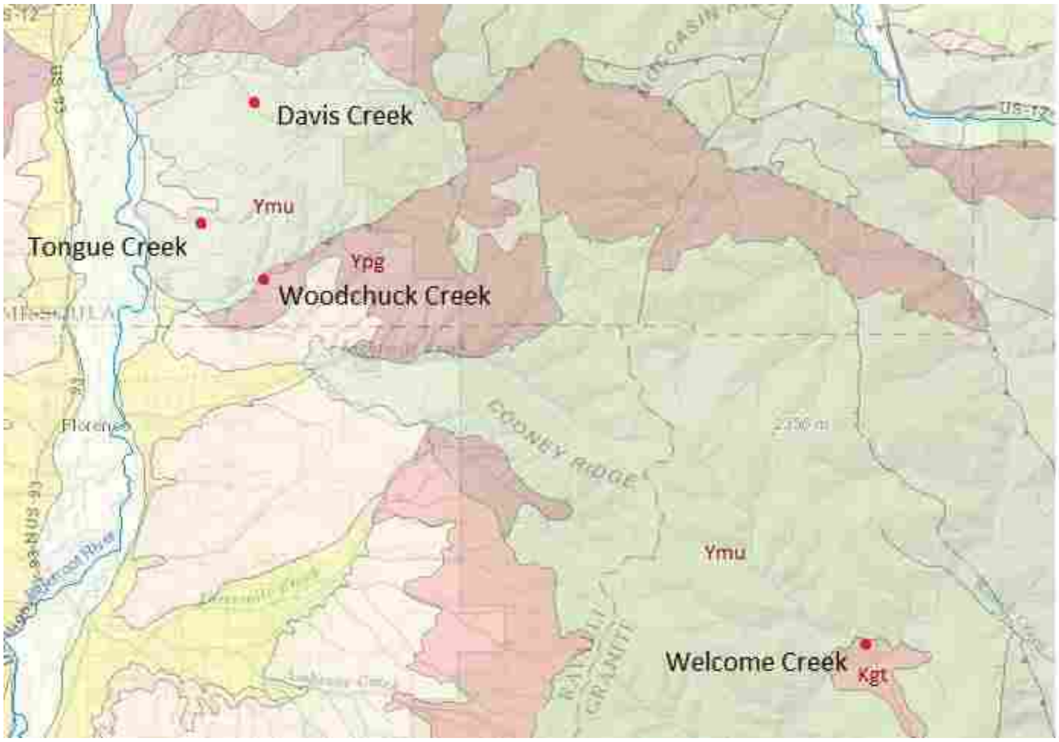


Figure S-2: Map of Welcome Creek study area, created by Aaron Kamoske

Geology of study area



Ymu: Upper Missoula Group
Ypg: Piegan Group of Wallace Formation
Kgt: Georgetown Limestone of Upper Missoula Group

Figure S-3: Geologic map of study area (Montana Bureau of Mines and Geology 2014).

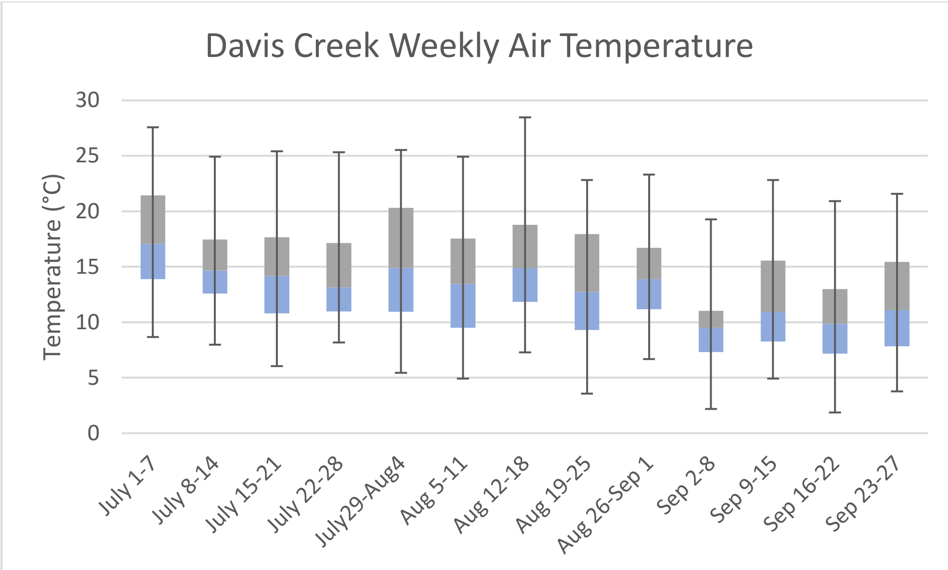


Figure T-1a: Davis Creek weekly air temperature boxplots

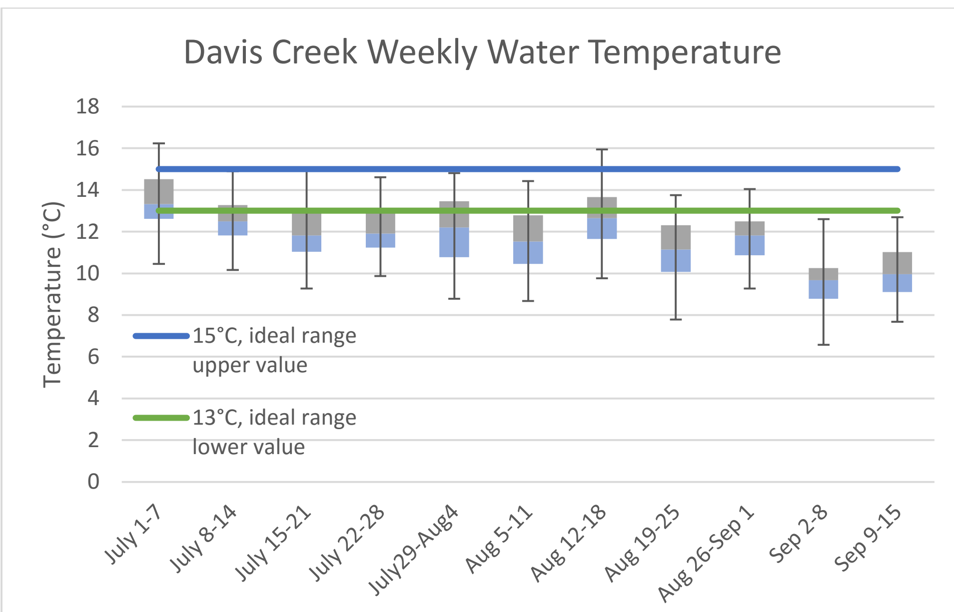


Figure T-1b: Davis Creek weekly water temperature boxplots. Upper Incipient Lethal Temperature for westslope cutthroat trout (19.6°C) is completely above stream temperature range, hence is not shown here.

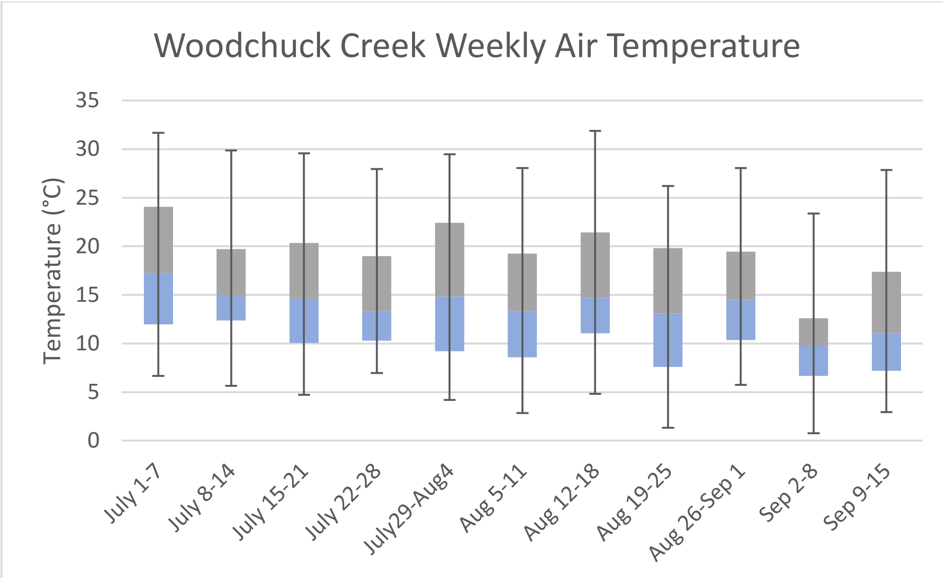


Figure T-2a: Woodchuck Creek weekly air temperature boxplots

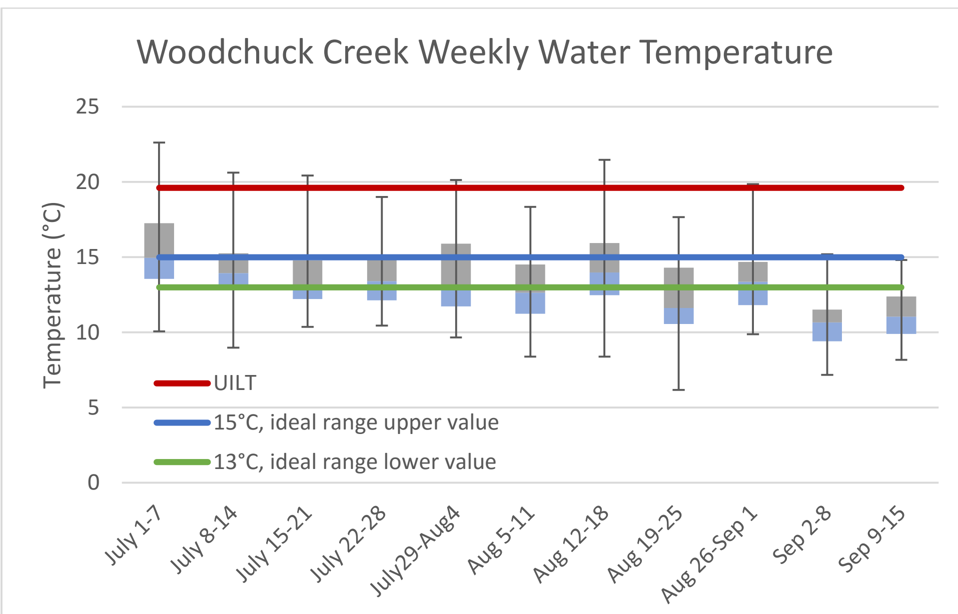


Figure T-2b: Woodchuck Creek weekly water temperature boxplots. UILT is Upper Incipient Lethal Temperature for westslope cutthroat trout (19.6°C).

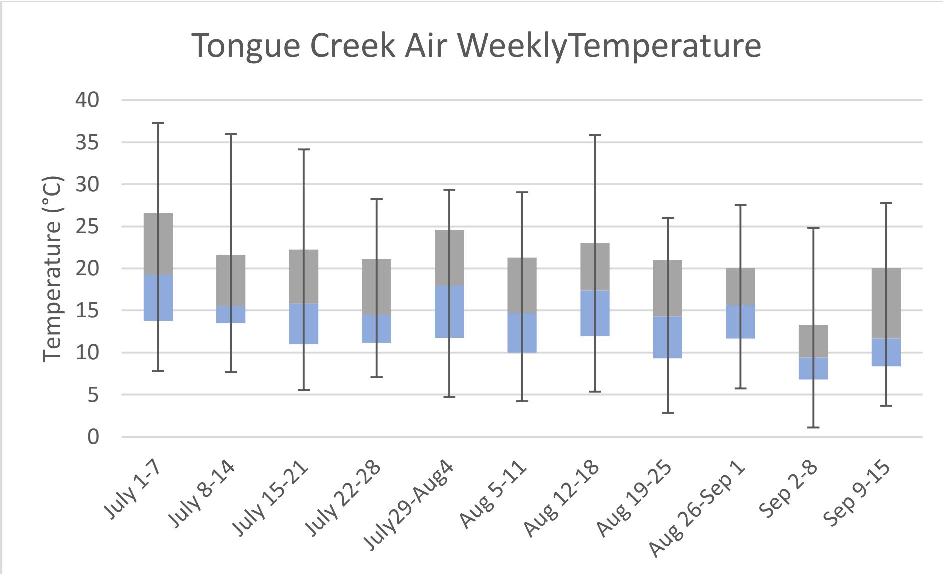


Figure T-3a: Tongue Creek weekly air temperature boxplots

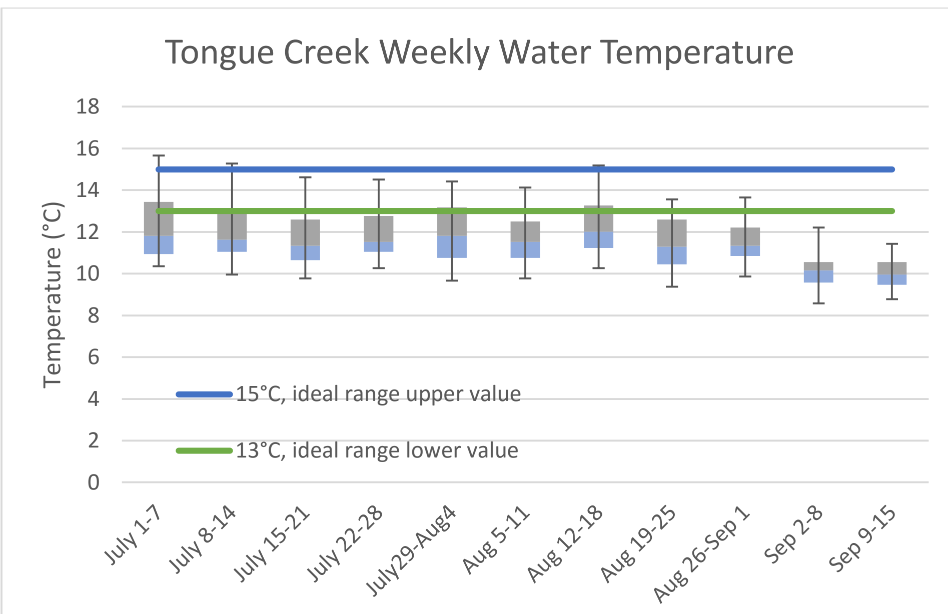


Figure T-3b: Tongue Creek weekly water temperature boxplots. Upper Incipient Lethal Temperature for westslope cutthroat trout (19.6°C) is completely above stream temperature range, hence is not shown here.

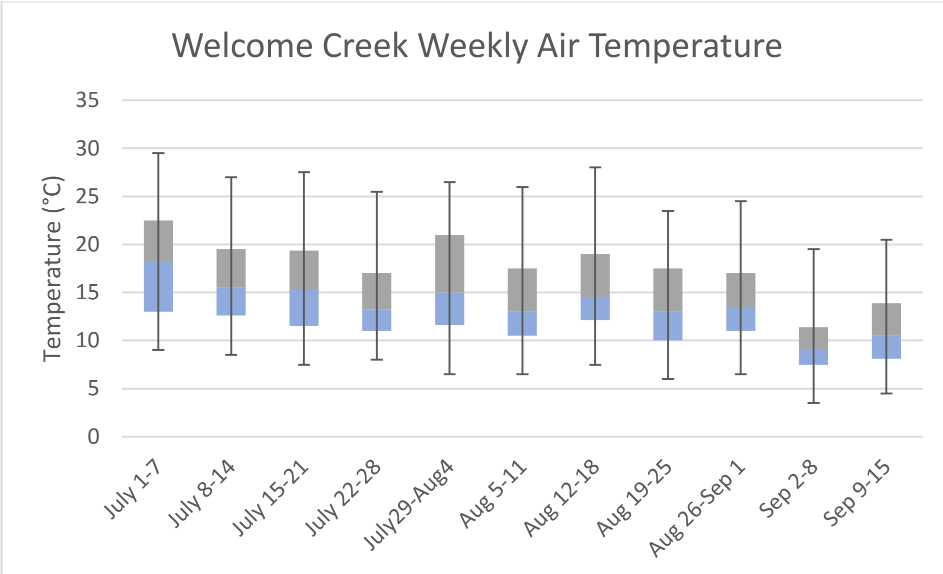


Figure T-4a: Welcome Creek weekly air temperature boxplots

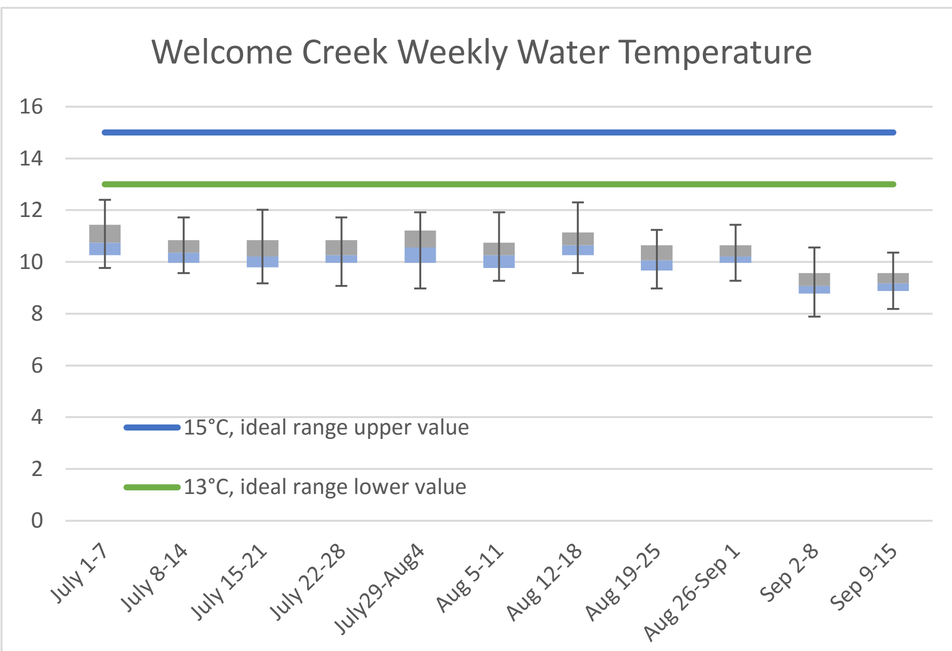


Figure T-4b: Welcome Creek weekly water temperature boxplots. Upper Incipient Lethal Temperature for westslope cutthroat trout (19.6°C) is completely above stream temperature range, hence is not shown here.

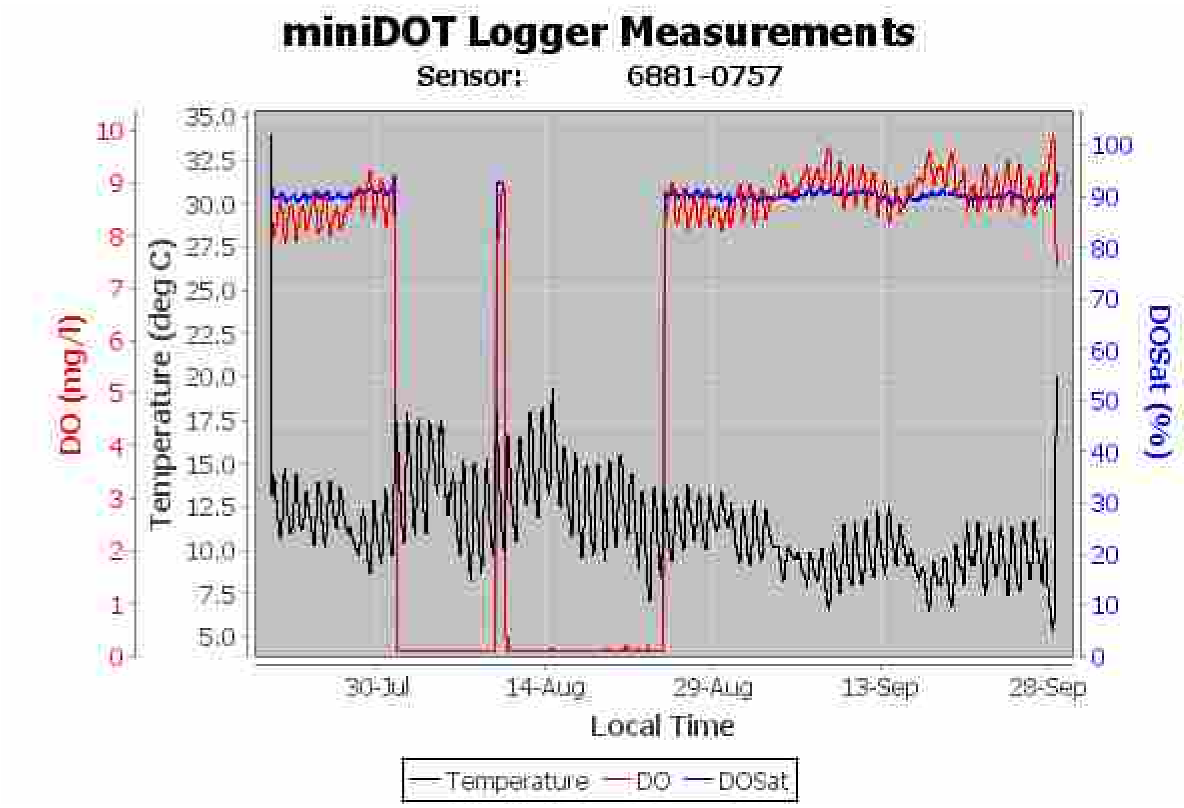


Figure D-1: Raw data from miniDOT Dissolved Oxygen logger, showing apparent instrument malfunction. Data collected from July 21 to September 28, 2016.

GLOSSARY OF TERMS

AFDW - Ash free dry weight. An estimate of biomass obtained by drying at 105°C, weighing, then burning for one hour at 500°C, weighing again, and taking the difference in the weights (Suplee and others 2008).

Aquatic macroinvertebrates – organisms that live in water bodies, lack spinal columns and are visible to the naked eye, are used as indicators of water quality and perform key roles in aquatic ecosystems (Suplee and others 2008).

Benthic – found on or within the stream bottom or substrate

Chlorophyll *a* (Chl-*a*) – the green pigment found in plants, used to quantify the amount of living algae in a sample

Cold stenotherms – organisms which can only tolerate relatively cold stream temperatures

Ecoregion – regions mapped based on their relative perceived homogeneity in combinations of factors such as land use, land surface form, natural vegetation, soils, and geology (Montana DEQ 2014).

Metric score – (assigned according to the Montana Valleys and Foothill Prairies Multimetric index) based on the number of taxa that fall into a particular category of macroinvertebrates, a metric score of 3, 2, 1, or 0 is assigned to that category by the MVFP Multimetric Index (Bollman, 2015)

Metric value – (assigned according to Montana Valleys and Foothill Prairies Multimetric index) the number of taxa within a particular category of macroinvertebrates (e.g., "Ephemeroptera" or "sensitive") recorded in the macroinvertebrate assemblage (Bollman, 2015)

Reference stream – streams for a given region that represent the least disturbed condition as compared to its counterparts in the same region; reference streams are used in Montana to derive meaning from narrative water quality standards (Suplee and others 2005).

Total nitrogen – (TN) the sum of all nitrate, nitrite, ammonia, and organic nitrogen, as N, in a water sample that has not been filtered (Montana DEQ 2014). Persulfate digestion was used to determine TN in this study.

Total phosphorus – (TP) the sum of orthophosphates, polyphosphates, and organically bound phosphates, as P, in a water sample that has not been filtered (Montana DEQ 2014).

UILT – Upper Incipient Lethal Temperature. 19.6°C; stream temperature not to be exceeded to avoid stress of westslope cutthroat trout (Bear et al 2007).

Wadeable stream – a stream, whether perennial or intermittent in which the channel can be safely waded by a person during baseflow conditions (Montana DEQ 2014).

APPENDIX A: Rhithron Associates Report of Macroinvertebrate Assemblages

ASSESSING AND INTERPRETING AQUATIC INVERTEBRATE ASSEMBLAGES

ON STREAMS OF THE MPG RANCH,

RAVALLI COUNTY, MONTANA

Report to

Morgan Vinyard and Dr. Vicki Watson
The University of Montana: Environmental Studies Program

Prepared by

Wease Bollman

Rhithron Associates, Inc.
Missoula, Montana

INTRODUCTION

Analysts at Rhithron Associates, Inc. provided sample processing and taxonomic analysis for 4 benthic samples collected by Morgan Vinyard at 3 sites on the MPG Ranch in the Bitterroot Valley of Western Montana and 1 site on Welcome Creek. The Welcome Creek site was intended to serve as a reference condition for the MPG Ranch sites. Samples were analyzed using methods consistent with the current protocols recommended by the Montana Department of Environmental Quality (MDEQ 2006).
Data deliverables included taxonomic identifications and counts for each sample, and a suite of calculated metrics based on the composition of each sample. A technical summary accompanying the data delivery described sample analysis methods, quality assurance/quality control (QA/QC) systems, and QA/QC results. The technical summary also included taxa lists and metric summaries based on the sample analysis.

This report includes a biological assessment of the invertebrate data based on a multimetric index, and a series of narrative interpretations of the taxonomic and functional composition of the samples. The multimetric index used here is the MVFP index (Bollman 1998), which was developed specifically for the ecoregions of Western Montana. MDEQ currently uses a predictive model for biological assessments, but limited access to predictor variables makes the model impossible to calculate at present.

THE MVFP BIOASSESSMENT INDEX

Multimetric indices result in a single numeric score, which integrates the values of several individual indicators (metrics) of biologic health. The six metrics constituting the bioassessment index used for MVFP sites in this study were selected because, both individually and as an integrated metric battery, they are robust at distinguishing impaired sites from relatively unimpaired sites (Bollman 1998). They have been demonstrated to be more variable with anthropogenic disturbance than with natural environmental gradients. Each of the six metrics developed and tested for western Montana ecoregions is described below.

1. Ephemeroptera (mayfly) taxa richness. The number of mayfly taxa declines as water quality diminishes. Impairments to water quality which have been demonstrated to adversely affect the ability of mayflies to flourish include elevated water temperatures, heavy metal contamination, increased turbidity, low or high pH, elevated specific conductance and toxic chemicals. Few mayfly species are able to tolerate certain disturbances to instream habitat, such as excessive sediment deposition.

2. Plecoptera (stonefly) taxa richness. Stoneflies are particularly susceptible to impairments that affect a stream on a reach-level scale, such as loss of riparian canopy, streambank instability, channelization, and alteration of morphological features such as pool frequency and function, riffle development and sinuosity. Just as all benthic organisms, they are also susceptible to smaller scale habitat loss, such as by sediment deposition, loss of interstitial spaces between substrate particles, or unstable substrate.

3. Trichoptera (caddisfly) taxa richness. Caddisfly taxa richness has been shown to decline when sediment deposition affects habitat. In addition, the presence of certain case-building caddisflies can indicate good retention of woody debris and lack of scouring flow conditions.

4. Number of sensitive taxa. Sensitive taxa are generally the first to disappear as anthropogenic disturbances increase. Sensitive taxa include organisms sensitive to a wide range of disturbances, including warmer water temperatures, organic or nutrient pollution, toxic pollution, sediment deposition, substrate instability and others.
5. Percent filter feeders. Filter-feeding organisms are a diverse group; they capture small particles of organic matter, or organically enriched sediment material, from the water column by means of a variety of adaptations, such as silken nets or hairy appendages. In forested montane streams, filterers are expected to occur in insignificant numbers. Their abundance increases when canopy cover is lost, water temperatures increase, and filamentous algae becomes abundant.
6. Percent tolerant taxa. Tolerant taxa are ubiquitous in stream sites, but when disturbance increases, their abundance increases proportionately. The list of taxa used here includes organisms tolerant of a wide range of disturbances, including warmer water temperatures, organic or nutrient pollution, toxic pollution, sediment deposition, substrate instability and others.

Scoring criteria for each of the six metrics are presented in Table 1. Metrics differ in their possible value ranges as well as in the direction the values move as biological conditions change. For example, Ephemeroptera richness values may range from zero to ten taxa or higher. Larger values generally indicate favorable biotic conditions. On the other hand, the percent filterers metric may range from 0% to 100%; in this case, larger values are negative indicators of biotic health. To facilitate scoring, therefore, metric values were transformed into a single scale. The range of each metric has been divided into four parts and assigned a point score between zero and three. A score of three indicates a metric value similar to one characteristic of a non-impaired condition. A score of zero indicates strong deviation from non-impaired condition and suggests severe degradation of biotic health. Scores for each metric were summed to give an overall score, the total bioassessment score, for each site in each sampling event. These scores were expressed as the percent of the maximum possible score, which is 18 for the MVFP metric battery. Scores were translated into impairment classifications according to criteria outlined in Table 2.

Table 1. *Metrics and scoring criteria for bioassessment of streams of the Montana Valley and Foothill Prairies ecoregion (Bollman 1998).*

	Score			
Metric	**3**	**2**	**1**	**0**
Ephemeroptera taxa richness	> 5	5 - 4	3 – 2	< 2
Plecoptera taxa richness	> 3	3 - 2	1	0
Trichoptera taxa richness	> 4	4 - 3	2	< 2
Sensitive taxa richness	> 3	3 - 2	1	0
Percent filterers	0 – 5	5.01 - 10	10.01 – 25	> 25
Percent tolerant taxa	0 – 5	5.01 - 10	10.01 – 35	> 35

Table 2. *Criteria for the assignment of impairment classifications.*

Percent of maximum score	**Impairment classification**
>83	non-impaired

78 – 55	slightly impaired
50 – 21	moderately impaired
<17	severely impaired

INTERPRETATION METHODS

Metric and taxonomic signals for water quality, thermal condition, sediment deposition and habitat indicators were investigated and are described in narrative interpretations. These interpretations of the taxonomic and functional composition of invertebrate assemblages are based on demonstrated associations between assemblage components and habitat and water quality variables gleaned from the published literature, the writer's own research (especially Bollman 1998) and professional judgment, and those of other expert sources (e.g. Wisseman 1996). Often, canonical procedures are used for stressor identification; however, the substantial data required for such procedures (e.g., surveys of habitat, historical and current data related to water quality, land use, point and non-point source influences, soils, hydrology, geology) were not readily available for this study. Instead, attributes of invertebrate taxa that are well-substantiated in diverse literature, published and unpublished research, and that are generally accepted by regional aquatic ecologists, are combined into descriptions of probable water quality and instream and reach-scale habitat conditions. The approach to this analysis uses some assemblage attributes that are interpreted as evidence of water quality and other attributes that are interpreted as evidence of habitat integrity. To arrive at impairment hypotheses, attributes are considered individually, so information is maximized by not relying on a single cumulative score, which may mask stress on the biota. Such an approach also minimizes the possibility of using inappropriate assessment strategies when the biota at a site is atypical of "characteristic" sites in a region.

Mayfly taxa richness, the Hilsenhoff Biotic Index (HBI) value (Hilsenhoff 1987), the richness and abundance of hemoglobin-bearing taxa and the richness of sensitive taxa are used as indicators of water quality. Mayfly taxa richness has been demonstrated to be significantly correlated with chemical measures of dissolved oxygen, pH, and conductivity (e.g. Bollman 1998, Fore et al. 1996, Wisseman 1996). The HBI has a long history of use and validation (Cairns and Pratt 1993, Smith and Tran 2010, Johnson and Ringler 2014). The index uses the relative abundance of taxa and the tolerance values associated with them to calculate a score representative of the tolerance of a benthic invertebrate assemblage. Higher HBI scores indicate more tolerant assemblages. In one study, a modified HBI was demonstrated to be significantly associated with conductivity, pH, water temperature, sediment deposition, and the presence of filamentous algae (Bollman 1998). This modification is referred to as the "biotic index" in this report. Nutrient enrichment in Montana streams often results in large crops of filamentous algae (Watson 1988). Thus in these samples, when macroinvertebrates associated or dependent on filamentous algae (e.g. LeSage and Harrison 1980, Anderson 1976) are abundant, the presence of filamentous algae and nutrient enrichment are also suspected. In addition, low oxygen concentrations are often a result of nutrient enrichment in situations where enrichment has encouraged excessive plant growth; nocturnal respiration by these plants creates hypoxic conditions. Hemoglobin-bearing taxa are very tolerant of environments with low oxygen concentrations, because the hemoglobin in their circulating fluids enables them to carry more oxygen than organisms without it. Finally, sensitive taxa exhibit intolerance to a wide range of stressors (e.g. Wisseman 1996, Hellawell 1986, Barbour et al. 1999), including nutrient enrichment, acidification, thermal stress, sediment deposition, habitat disruption, and other causes of degraded ecosystem health. These taxa are expected to be present in predictable numbers in well-functioning streams.

The absence of invertebrate groups known to be sensitive to metals, and the Metals Tolerance Index (MTI, McGuire 1998) are used to indicate possible metals contamination. Metals sensitivity for some invertebrate groups, especially the heptageniid mayflies, is well-known (e.g. Kiffney and Clements 1994, Clements 1999, Clements 2004, Montz et al. 2010, Iwasaki et al. 2013). In the present approach, the absence of these groups in environs where they are typically expected to occur is considered a signal of possible metals contamination, especially when these signals are combined with a measure of overall assemblage tolerance of metals. The MTI ranks taxa according to their sensitivity to metals. Weighting taxa by their abundance in a sample, assemblage tolerance is estimated by averaging the tolerance of all sampled individuals. Higher values for the MTI indicate invertebrate assemblages with greater tolerance to metals contamination.

Thermal characteristics of the sampled sites are predicted by benthic invertebrate assemblages. The richness and abundance of cold stenotherm taxa (Clark 1997, Stamp et al. 2010), which require low water temperatures, and the calculation of the predicted temperature preference of the macroinvertebrate assemblage (Brandt 2001) are used to indicate the thermal characteristics of sites. Hemoglobin-bearing invertebrate taxa are also indicators of warm water temperatures (Walshe 1947), because dissolved oxygen is directly associated with water temperature (colder water can hold more dissolved oxygen); oxygen concentrations can also vary with the degree of nutrient enrichment. Increased temperatures and high nutrient concentrations can, alone or in concert, create conditions favorable to hypoxic sediments, habitats preferred by hemoglobin-bearers.

The condition of instream and streamside habitats is also estimated by characteristics of invertebrate assemblages. Stress from sediment is evaluated by caddisfly richness and by “clinger” richness (Kleindl 1995, Bollman 1998, Karr and Chu 1999, Wagenhoff et al. 2012, Leitner et al. 2015). The Fine Sediment Biotic Index (FSBI) (Relyea et al. 2001) is also used because it shows promise when applied to the montane and foothills regions. Similar to the HBI, tolerance values are assigned to taxa based on the substrate particle sizes with which the taxa are most frequently associated. Scores are determined by weighting these tolerance values by the relative abundance of taxa in a sample. Higher values of the FSBI indicate assemblages with greater fine sediment sensitivity. However, it appears that FSBI values may be influenced by the presence of other deposited material, such as large organic material, including leaves and woody debris.

Functional characteristics of the macroinvertebrate assemblages may also reveal the condition of instream and streamside habitats. Alterations from predicted patterns of the functional characteristics may be interpreted as evidence of water quality or habitat disruption. Predicted patterns are based on the morphology and behaviors associated with feeding, and are interpreted in terms of the River Continuum Concept (Vannote et al. 1980) in the narratives. For example, the abundance of stonefly predators is likely to be related to the diversity of invertebrate prey species, and thus the complexity of instream habitats. Sites with fewer than expected stonefly species are likely to have reduced habitat complexity. Also, the absence of long-lived species (those that take 2 years to mature in the stream) is likely related to catastrophes like periodic scour, thermal stress or toxic pollutants that could interrupt long life cycles. In addition, shredders and the microbes they depend on are sensitive to modifications of the riparian zone vegetation (Plafkin et al. 1989).

RESULTS

Bioassessment scores and impairment classifications

When the MVFP index is applied to the taxonomic data, 2 sites achieve “non-impaired” classifications. These sites are the reference site on Welcome Creek (100% of maximum score), and the Woodchuck site on the MPG Ranch (94.4%). The Davis site on the Ranch is rated as “slightly impaired” (83.3%) and the Tongue site is rated “moderately impaired” (50.0%). Figure 1 summarizes and compares MVFP bioassessment scores for these sites. Table 3 gives metric values, scores, and impairment classifications based on the MVFP index.

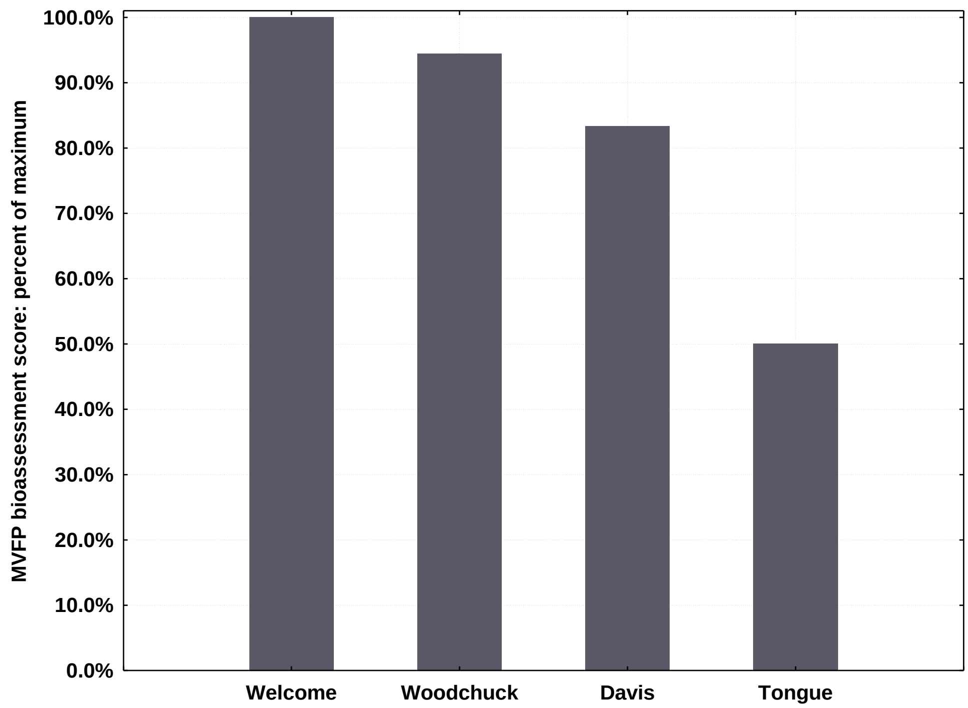


Figure 1. *MVFP (Bollman 1998) bioassessment scores for the Welcome Creek reference site and 3 stream sites on the MPG Ranch. June 14-22, 2015.*

Table 3. *MVFP (Bollman 1998*) **metric values, scores, and impairment classifications** for the *Welcome Creek reference site and 3 stream sites on the MPG Ranch. June 14-22, 2015.*

SITES	Welcome	Woodchuck	Davis	Tongue
METRIC VALUES				
Ephemeroptera richness	12	8	4	3
Plecoptera richness	7	4	6	1
Trichoptera richness	11	7	11	4
Sensitive taxa richness	13	5	7	1
Percent tolerant	3.2%	9.0%	8.9%	11.4%
Percent filter-feeders	<1%	2.8%	7.2%	1.8%
METRIC SCORES				
Ephemeroptera richness	3	3	2	1
Plecoptera richness	3	3	3	1
Trichoptera richness	3	3	3	2
Sensitive taxa richness	3	3	3	1

Percent tolerant	3	2	2	1
Percent filter-feeders	3	3	2	3
SITE SCORES	18	17	15	9
Percent of Maximum	**100.0%**	**94.4%**	**83.3%**	**50.0%**
Impairment Classification	**Non-impaired**	**Non-impaired**	**Slightly impaired**	**Moderately impaired**

Ecological interpretation of aquatic invertebrate assemblages

- **Welcome**

High mayfly taxa richness (12) and a low biotic index value (2.33) strongly suggest that water quality was excellent in this reach. There is no evidence for nutrient and/or organic enrichment or metals contamination. At least 13 sensitive taxa were supported at the sampled site; these included baetid mayflies in the *Baetis bicaudatus* complex, ephemerellids *Drunella doddsii* and *Caudatella hystrix*, and stoneflies *Zapada columbiana* and *Visoka cataractae*. The turbellarian flatworm *Polycelis* sp. accounted for 5.8% of the sampled assemblage, suggesting that groundwater influences surface flow here. The thermal preference of the invertebrate assemblage was calculated at 11.1°C. Cold stenotherm taxa accounted for 15.7% of sampled animals.

Caddisflies (11 taxa) and "clingers" (32 taxa) were well-represented, suggesting that fine sediments did not appreciably limit colonization of stony substrates. The FSBI value (5.14) was the highest value calculated for sites in this study, indicating a moderately sediment-sensitive assemblage. Overall taxa richness (59) suggested diverse and intact instream habitats. High stonefly taxa richness (7) may be related to reach-scale habitat features: functional riparian zones, stable streambanks, and natural channel morphology may be indicated. At least 3 semivoltine taxa apparently persist at this site. Because of their long life cycles, their presence suggests that catastrophic dewatering, thermal stress, or toxic pollutants were not influential. All expected functional components were represented in the sample. Scrapers (especially the heptageniid mayflies *Cinygmula* sp. and *Epeorus* spp.) were abundant, implying well-developed algal films and perhaps a lack of riparian shading.

- **Woodchuck**

The sample collected at this site was relatively depauperate: only 434 specimens were sorted from the entire collection. Low abundance may be related to poor habitat or water quality, neither of which seems likely in this case. Sampling effort and characteristics of the stream or substrate that influence sampling may also account for low abundance, as can extremely oligotrophic conditions or very low water temperatures. In spite of the limited number of organisms, richness metrics generally performed as expected for a montane or foothills stream. The Woodchuck site supported at least 8 mayfly taxa, including the sensitive heptageniid *Cinygma* sp. The biotic index value (2.72) was within expectations for a montane site with excellent water quality. Five sensitive cold stenotherm taxa were counted in the sample, implying cold water temperatures and little influence from nutrient and/or organic enrichment. There was no evidence of metals contamination. The thermal preference of the invertebrate assemblage was estimated at 13.1°C. Abundant turbellarians (*Polycelis* sp.) suggest that groundwater inputs augmented surface flow in the reach.

Seven caddisfly taxa and 18 "clinger" taxa were counted: it seems likely that stony substrates were not appreciably contaminated with deposited fine sediment. The FSBI value (3.95), however, indicated a moderately sediment-tolerant assemblage. Overall taxa richness (41) suggests diverse and intact instream habitats. Stonefly taxa richness (4) was within expectations for a montane site. Richness in this group may be related to intact riparian vegetation, stable streambanks, and unaltered channel morphology. The abundance of the chloroperlid *Sweltsa* sp., which accounted for nearly 15% of the sampled assemblage, was notable. Four semivoltine taxa were present in the sample: surface flow in the reach apparently persisted year-round, and toxic inputs or thermal extremes can be ruled out. All expected functional groups were present. Filterers were somewhat more abundant than expected for a montane or foothills stream, which could suggest that suspended fine organic particulate material was prevalent. However, the filterer group includes the fingernail clams (Sphaeriidae) which were abundant in the sample: these animals probably do not filter suspended particles from the water column, but are more likely to feed interstitially, completely within the sediment. Predators, especially *Sweltsa* sp., were also notably abundant.

- **Davis**

Although metrics associated with water quality suggest impairment, there are contrary signals from components of the invertebrate assemblage sampled at the Davis site. Mayfly taxa richness (4) was somewhat lower than expected, and the biotic index value (4.59) was somewhat higher than expected. These findings suggest slightly degraded water quality. The hemoglobin-bearing midge *Polypedilum* sp. was common, suggesting areas of hypoxic substrates. Low oxygen conditions may result from nutrient enrichment, which contributes to excessive algal growth. The presence of filamentous algae is suggested by the abundance of the midge *Micropsectra* sp., which is often associated with such flora. On the other hand, the site supported at least 7 sensitive taxa, including the nemourid stonefly *Visoka cataractae*, and caddisflies in the *Rhyacophila atrata* complex as well as the uenoid *Neothremma* sp. These taxa imply excellent water quality. The moderately-elevated biotic index value calculated for the assemblage may be partly due to the high tolerance value (7) assigned to the chironomid *Monodiamesa* sp., which was the most abundant taxon in the sample. In fact, chironomids dominated the taxonomic composition of the assemblage. *Monodiamesa* sp. is generally reported from oligotrophic-to-mesotrophic conditions, and may not be as tolerant as suggested by the tolerance value assignment. (Its association with sandy substrates in much of the published literature suggests that sand was a common component of the benthic substrates at this site.) Another noteworthy feature of the invertebrate assemblage collected at the Davis site is the lower relative abundance (6.2%) of the turbellarian *Polycelis* sp., compared to the 2 "non-impaired" sites at Welcome and Woodchuck. *Polycelis* sp. is often associated with groundwater seepages into surface flow, and is a characteristic taxon in "gaining" stream reaches. The relatively low abundance at this site not only suggests that groundwater may have been less influential here, but also that significantly different instream water quality conditions may have existed in close proximity. Areas around groundwater seeps may have supported a "relict" community of more sensitive organisms, while slightly nutrient-enriched flow supported algal growth and a more tolerant assemblage, dominated by relatively tolerant midges (e.g. *Micropsectra* sp., *Zavrelimyia* sp., *Polypedilum* sp., etc.) and fingernail clams (Sphaeriidae). The thermal preference of the invertebrate assemblage was calculated at 12.7°C.

Fine sediment deposition apparently did not appreciably influence colonization of stony substrates, since no fewer than 11 caddisfly taxa and 21 “clinger” taxa were reported in the data. The FSBI value (4.38) indicated a moderately sediment-sensitive assemblage. High overall taxa richness (51) suggests that instream habitats were intact and diverse. At least 6 stonefly taxa were supported here: stable streambanks, natural channel morphology, and functional riparian zones may be implied. Semivoltine taxa were well-represented: stable habitats and water quality apparently supported long life cycles at this site. All expected functional components were present.

- **Tongue**

Mayflies were neither abundant (4.7%) nor diverse (3 taxa) at the Tongue site, and the biotic index value (5.44) was much higher than expected for a montane or foothills stream. These findings suggest that water quality was impaired here. The single sensitive taxon collected at the site, the caddisfly *Allomyia* sp., was represented by a single individual. The invertebrate fauna was strongly dominated by free-living or free-living stages of nematodes, which accounted for 41.3% of sampled animals. Nematode species are known to have wide-ranging tolerances to water-quality perturbations, but low taxonomic resolution and the scarcity of studies make it impossible to relate nematode abundance to water quality parameters. However, some studies have demonstrated increased abundance of the group in irrigation return (Grimm 1978), runoff water flowing overland or in temporary channels (Cadet et al. 2003, Villenave et al. 2003), intermittently flowing channels (Smith et al. 2001), or in streams in which there has been disturbance to riparian vegetation and exposure of bare soils (Smith et al. 2001). Sediment deposition, nutrient enrichment, and reach-scale and instream habitat disruption may accompany these types of stressors. The larvae of ceratopogonid flies (biting midges, or gnats) were exceptionally abundant in the sample, suggesting that cattle grazing may have been a dominant land use in the vicinity of the sampled site. There was no evidence that groundwater influenced surface flow at this site. The thermal preference of the invertebrate assemblage was estimated at 16.0°C.

Low caddisfly richness (4) and low “clinger” richness (7) suggest that sediment deposition limited colonization of stony substrates. The FSBI value (3.37) was the lowest value calculated for sites in this study, indicating that the assemblage was moderately tolerant of sediment. Overall taxa richness (39) was somewhat lower than expected, suggesting monotonous or disrupted instream habitats. A single stonefly taxon (*Malenka* sp.) was collected, and it was represented by only 2 individuals. Low richness in this group may be related to unstable streambanks, altered channel morphology, or disrupted riparian zone function. It seems likely that surface flow persisted in the reach year-round. Although 5 semivoltine taxa were counted, 2 of these are pioneering taxa, and aggressive colonizers. Three relatively sedentary semivoltine taxa were present. The nematodes collected from the Tongue site likely include several functional groups, so an analysis of the functional composition of the sampled assemblage is difficult. However, the scarcity of scrapers can be noted: they may have been excluded by the obliteration of stony substrates by deposited sediment or perhaps by other factors.

Ordination of invertebrate assemblages

An ordination of the invertebrate data is presented in Figure 2. Principal Components Analysis (PCA: McCune and Grace 2002) was used to explore the similarity of the faunal data among the sites. This multivariate technique produces a plot in which assemblages that are more similar in taxonomic composition are plotted closer together, while dissimilar assemblages are plotted farther apart.

The distribution of sites along Axis 1 elucidates the uniqueness of the reference site on Welcome Creek. The characteristics of the invertebrate assemblage sampled there seem to indicate a high-gradient stream with excellent water quality and intact reach-scale and instream habitats. It seems reasonable to interpret Axis 1 scores as related to gradient, water temperature, and instream and reach-scale habitat quality. The distribution of sites along Axis 2 is more difficult to interpret, but may be related to substrate characteristics. While the Welcome and Woodchuck sites supported assemblages that suggested diverse, stony substrates, the Davis site may have had substrates with a relatively large sand component. The Tongue site supported an assemblage suggestive of substrates with a large component of fine sediment deposits.

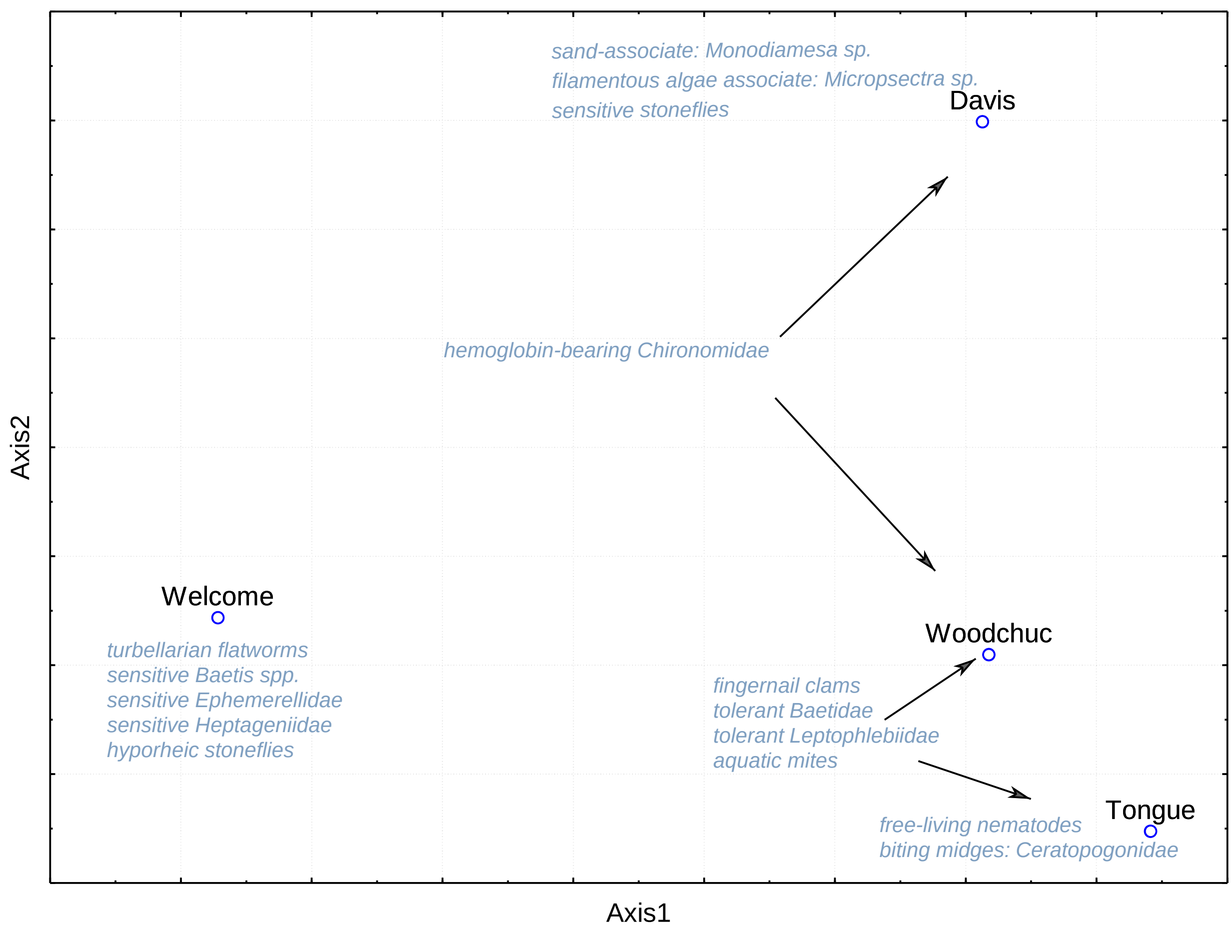


Figure 2. *Ordination (Principal Components Analysis) of invertebrate assemblages at the Welcome Creek reference site and 3 sites on the MPG Ranch, June 14-22, 2015. The spread on Axis 1 accounts for 40.1% of the variance in assemblage composition. Axis 2 accounts for a further 31.2% of variance.*

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APPENDIX B: Macroinvertebrate Assemblage Metric Data

Macroinvertebrate Metric Data from Rhithron Associates, collected June 14-22, 2015.

Sample ID	Sample Station Name	Group	Metric	Value
UM15MV001	Woodchuck	Air	Air Breather Percent	4.38%
UM15MV001	Woodchuck	Air	Air Breather Richness	2
UM15MV001	Woodchuck	Biotic Index	Hilsenhoff Biotic Index	2.72
UM15MV001	Woodchuck	Biotic Index	Intolerant Percent	55.30%
UM15MV001	Woodchuck	Biotic Index	Supertolerant Percent	9.22%
UM15MV001	Woodchuck	Cold	Cold Stenotherm Percent	5.07%
UM15MV001	Woodchuck	Cold	Cold Stenotherm Richness	5
UM15MV001	Woodchuck	Composition	All Non-Insect Abundance	107
UM15MV001	Woodchuck	Composition	All Non-Insect Percent	24.65%
UM15MV001	Woodchuck	Composition	All Non-Insect Richness	7
UM15MV001	Woodchuck	Composition	E Richness	8
UM15MV001	Woodchuck	Composition	EPT Percent	50.92%
UM15MV001	Woodchuck	Composition	EPT Richness	19
UM15MV001	Woodchuck	Composition	Other Non-Insect Percent	23.27%
UM15MV001	Woodchuck	Composition	P Richness	4
UM15MV001	Woodchuck	Composition	T Richness	7
UM15MV001	Woodchuck	Composition	Taxa Richness	41
UM15MV001	Woodchuck	CTQs	CTQa	72.10
UM15MV001	Woodchuck	Diversity	Evenness	0.05
UM15MV001	Woodchuck	Diversity	Margalef D	6.67
UM15MV001	Woodchuck	Diversity	Shannon H (log2)	4.34
UM15MV001	Woodchuck	Diversity	Shannon H (loge)	3.01
UM15MV001	Woodchuck	Diversity	Simpson D	0.07
UM15MV001	Woodchuck	Dominance	Dominant Taxa (10) Percent	68.89%
UM15MV001	Woodchuck	Dominance	Dominant Taxa (2) Percent	23.96%

UM15MV001	Woodchuck	Dominance	Dominant Taxa (3) Percent	32.95%
UM15MV001	Woodchuck	Dominance	Dominant Taxon Percent	14.75%
UM15MV001	Woodchuck	Family	Baetidae/Ephemeroptera	0.13
UM15MV001	Woodchuck	Family	Hydropsychidae/Trichoptera	0.00
UM15MV001	Woodchuck	Function	Collector Percent	37.79%
UM15MV001	Woodchuck	Function	Filterer Percent	8.99%
UM15MV001	Woodchuck	Function	Filterer Richness	1
UM15MV001	Woodchuck	Function	Predator Percent	35.25%
UM15MV001	Woodchuck	Function	Predator Richness	11
UM15MV001	Woodchuck	Function	Scraper/Filterer	1.00
UM15MV001	Woodchuck	Function	Scraper/Scraper+Filterer	0.50
UM15MV001	Woodchuck	Function	Scraper+Shredder Percent	17.05%
UM15MV001	Woodchuck	Habit	Burrower Percent	1.15%
UM15MV001	Woodchuck	Habit	Burrower Richness	2
UM15MV001	Woodchuck	Habit	Clinger Percent	47.47%
UM15MV001	Woodchuck	Habit	Clinger Richness	18
UM15MV001	Woodchuck	Habit	Swimmer Percent	11.06%
UM15MV001	Woodchuck	Habit	Swimmer Richness	2
UM15MV001	Woodchuck	Hemoglobin	Hemoglobin Bearer Percent	0.23%
UM15MV001	Woodchuck	Hemoglobin	Hemoglobin Bearer Richness	1
UM15MV001	Woodchuck	Metals	Metals Tolerance Index	2.58
UM15MV001	Woodchuck	Pollution	Pollution Sensitive Richness	5
UM15MV001	Woodchuck	Pollution	Pollution Tolerant Percent	2.77%
UM15MV001	Woodchuck	Sediment	Sediment Sensitive Percent	0.00%
UM15MV001	Woodchuck	Sediment	Sediment Sensitive Richness	0
UM15MV001	Woodchuck	Sediment	Sediment Tolerant Percent	0.69%
UM15MV001	Woodchuck	Sediment	Sediment Tolerant Richness	1
UM15MV001	Woodchuck	Subclass	Oligochaeta+Hirudinea Percent	1.38%
UM15MV001	Woodchuck	Voltinism	Multivoltine Percent	21.43%
UM15MV001	Woodchuck	Voltinism	Semivoltine Richness	4

UM15MV001	Woodchuck	Voltinism	Univoltine Richness	20
UM15MV002	Welcome	Air	Air Breather Percent	1.20%
UM15MV002	Welcome	Air	Air Breather Richness	1
UM15MV002	Welcome	Biotic Index	Hilsenhoff Biotic Index	2.33
UM15MV002	Welcome	Biotic Index	Intolerant Percent	57.97%
UM15MV002	Welcome	Biotic Index	Supertolerant Percent	1.59%
UM15MV002	Welcome	Cold	Cold Stenotherm Percent	15.74%
UM15MV002	Welcome	Cold	Cold Stenotherm Richness	11
UM15MV002	Welcome	Composition	All Non-Insect Abundance	71
UM15MV002	Welcome	Composition	All Non-Insect Percent	14.14%
UM15MV002	Welcome	Composition	All Non-Insect Richness	6
UM15MV002	Welcome	Composition	E Richness	12
UM15MV002	Welcome	Composition	EPT Percent	60.16%
UM15MV002	Welcome	Composition	EPT Richness	30
UM15MV002	Welcome	Composition	Other Non-Insect Percent	7.57%
UM15MV002	Welcome	Composition	P Richness	7
UM15MV002	Welcome	Composition	T Richness	11
UM15MV002	Welcome	Composition	Taxa Richness	59
UM15MV002	Welcome	CTQs	CTQa	65.33
UM15MV002	Welcome	Diversity	Evenness	0.04
UM15MV002	Welcome	Diversity	Margalef D	9.59
UM15MV002	Welcome	Diversity	Shannon H (log2)	4.83
UM15MV002	Welcome	Diversity	Shannon H (loge)	3.35
UM15MV002	Welcome	Diversity	Simpson D	0.05
UM15MV002	Welcome	Dominance	Dominant Taxa (10) Percent	59.16%
UM15MV002	Welcome	Dominance	Dominant Taxa (2) Percent	20.52%
UM15MV002	Welcome	Dominance	Dominant Taxa (3) Percent	26.89%
UM15MV002	Welcome	Dominance	Dominant Taxon Percent	12.75%
UM15MV002	Welcome	Family	Baetidae/Ephemeroptera	0.29
UM15MV002	Welcome	Family	Hydropsychidae/Trichoptera	0.10

UM15MV002	Welcome	Function	Collector Percent	53.39%
UM15MV002	Welcome	Function	Filterer Percent	3.19%
UM15MV002	Welcome	Function	Filterer Richness	3
UM15MV002	Welcome	Function	Predator Percent	7.57%
UM15MV002	Welcome	Function	Predator Richness	11
UM15MV002	Welcome	Function	Scraper/Filterer	7.00
UM15MV002	Welcome	Function	Scraper/Scraper+Filterer	0.88
UM15MV002	Welcome	Function	Scraper+Shredder Percent	32.67%
UM15MV002	Welcome	Habit	Burrower Percent	0.80%
UM15MV002	Welcome	Habit	Burrower Richness	1
UM15MV002	Welcome	Habit	Clinger Percent	57.17%
UM15MV002	Welcome	Habit	Clinger Richness	32
UM15MV002	Welcome	Habit	Swimmer Percent	1.00%
UM15MV002	Welcome	Habit	Swimmer Richness	1
UM15MV002	Welcome	Hemoglobin	Hemoglobin Bearer Percent	0.00%
UM15MV002	Welcome	Hemoglobin	Hemoglobin Bearer Richness	0
UM15MV002	Welcome	Metals	Metals Tolerance Index	1.82
UM15MV002	Welcome	Pollution	Pollution Sensitive Richness	13
UM15MV002	Welcome	Pollution	Pollution Tolerant Percent	0.20%
UM15MV002	Welcome	Sediment	Sediment Sensitive Percent	1.00%
UM15MV002	Welcome	Sediment	Sediment Sensitive Richness	1
UM15MV002	Welcome	Sediment	Sediment Tolerant Percent	1.20%
UM15MV002	Welcome	Sediment	Sediment Tolerant Richness	1
UM15MV002	Welcome	Subclass	Oligochaeta+Hirudinea Percent	6.57%
UM15MV002	Welcome	Voltinism	Multivoltine Percent	29.68%
UM15MV002	Welcome	Voltinism	Semivoltine Richness	3
UM15MV002	Welcome	Voltinism	Univoltine Richness	30
UM15MV003	Tongue	Air	Air Breather Percent	4.70%
UM15MV003	Tongue	Air	Air Breather Richness	7
UM15MV003	Tongue	Biotic Index	Hilsenhoff Biotic Index	5.44

UM15MV003	Tongue	Biotic Index	Intolerant Percent	4.11%
UM15MV003	Tongue	Biotic Index	Supertolerant Percent	13.50%
UM15MV003	Tongue	Cold	Cold Stenotherm Percent	0.78%
UM15MV003	Tongue	Cold	Cold Stenotherm Richness	1
UM15MV003	Tongue	Composition	All Non-Insect Abundance	316
UM15MV003	Tongue	Composition	All Non-Insect Percent	61.84%
UM15MV003	Tongue	Composition	All Non-Insect Richness	6
UM15MV003	Tongue	Composition	E Richness	3
UM15MV003	Tongue	Composition	EPT Percent	7.05%
UM15MV003	Tongue	Composition	EPT Richness	8
UM15MV003	Tongue	Composition	Other Non-Insect Percent	59.10%
UM15MV003	Tongue	Composition	P Richness	1
UM15MV003	Tongue	Composition	T Richness	4
UM15MV003	Tongue	Composition	Taxa Richness	39
UM15MV003	Tongue	CTQs	CTQa	90.36
UM15MV003	Tongue	Diversity	Evenness	0.07
UM15MV003	Tongue	Diversity	Margalef D	6.09
UM15MV003	Tongue	Diversity	Shannon H (log2)	3.16
UM15MV003	Tongue	Diversity	Shannon H (loge)	2.19
UM15MV003	Tongue	Diversity	Simpson D	0.22
UM15MV003	Tongue	Dominance	Dominant Taxa (10) Percent	88.45%
UM15MV003	Tongue	Dominance	Dominant Taxa (2) Percent	57.73%
UM15MV003	Tongue	Dominance	Dominant Taxa (3) Percent	68.69%
UM15MV003	Tongue	Dominance	Dominant Taxon Percent	41.29%
UM15MV003	Tongue	Family	Baetidae/Ephemeroptera	0.63
UM15MV003	Tongue	Family	Hydropsychidae/Trichoptera	0.00
UM15MV003	Tongue	Function	Collector Percent	25.05%
UM15MV003	Tongue	Function	Filterer Percent	11.35%
UM15MV003	Tongue	Function	Filterer Richness	3
UM15MV003	Tongue	Function	Predator Percent	30.53%

UM15MV003	Tongue	Function	Predator Richness	8
UM15MV003	Tongue	Function	Scraper/Filterer	0.02
UM15MV003	Tongue	Function	Scraper/Scraper+Filterer	0.02
UM15MV003	Tongue	Function	Scraper+Shredder Percent	2.74%
UM15MV003	Tongue	Habit	Burrower Percent	4.70%
UM15MV003	Tongue	Habit	Burrower Richness	8
UM15MV003	Tongue	Habit	Clinger Percent	7.44%
UM15MV003	Tongue	Habit	Clinger Richness	7
UM15MV003	Tongue	Habit	Swimmer Percent	4.50%
UM15MV003	Tongue	Habit	Swimmer Richness	2
UM15MV003	Tongue	Hemoglobin	Hemoglobin Bearer Percent	0.59%
UM15MV003	Tongue	Hemoglobin	Hemoglobin Bearer Richness	2
UM15MV003	Tongue	Metals	Metals Tolerance Index	4.24
UM15MV003	Tongue	Pollution	Pollution Sensitive Richness	1
UM15MV003	Tongue	Pollution	Pollution Tolerant Percent	1.76%
UM15MV003	Tongue	Sediment	Sediment Sensitive Percent	0.00%
UM15MV003	Tongue	Sediment	Sediment Sensitive Richness	0
UM15MV003	Tongue	Sediment	Sediment Tolerant Percent	1.76%
UM15MV003	Tongue	Sediment	Sediment Tolerant Richness	3
UM15MV003	Tongue	Subclass	Oligochaeta+Hirudinea Percent	2.74%
UM15MV003	Tongue	Voltinism	Multivoltine Percent	13.70%
UM15MV003	Tongue	Voltinism	Semivoltine Richness	5
UM15MV003	Tongue	Voltinism	Univoltine Richness	13
UM15MV004	Davis	Air	Air Breather Percent	1.89%
UM15MV004	Davis	Air	Air Breather Richness	3
UM15MV004	Davis	Biotic Index	Hilsenhoff Biotic Index	4.58
UM15MV004	Davis	Biotic Index	Intolerant Percent	22.50%
UM15MV004	Davis	Biotic Index	Supertolerant Percent	17.39%
UM15MV004	Davis	Cold	Cold Stenotherm Percent	5.10%
UM15MV004	Davis	Cold	Cold Stenotherm Richness	6

UM15MV004	Davis	Composition	All Non-Insect Abundance	83
UM15MV004	Davis	Composition	All Non-Insect Percent	15.69%
UM15MV004	Davis	Composition	All Non-Insect Richness	7
UM15MV004	Davis	Composition	E Richness	4
UM15MV004	Davis	Composition	EPT Percent	24.39%
UM15MV004	Davis	Composition	EPT Richness	21
UM15MV004	Davis	Composition	Other Non-Insect Percent	13.80%
UM15MV004	Davis	Composition	P Richness	6
UM15MV004	Davis	Composition	T Richness	11
UM15MV004	Davis	Composition	Taxa Richness	51
UM15MV004	Davis	CTQs	CTQa	71.97
UM15MV004	Davis	Diversity	Evenness	0.04
UM15MV004	Davis	Diversity	Margalef D	7.98
UM15MV004	Davis	Diversity	Shannon H (log2)	4.64
UM15MV004	Davis	Diversity	Shannon H (loge)	3.22
UM15MV004	Davis	Diversity	Simpson D	0.06
UM15MV004	Davis	Dominance	Dominant Taxa (10) Percent	66.16%
UM15MV004	Davis	Dominance	Dominant Taxa (2) Percent	25.90%
UM15MV004	Davis	Dominance	Dominant Taxa (3) Percent	33.46%
UM15MV004	Davis	Dominance	Dominant Taxon Percent	15.31%
UM15MV004	Davis	Family	Baetidae/Ephemeroptera	0.38
UM15MV004	Davis	Family	Hydropsychidae/Trichoptera	0.00
UM15MV004	Davis	Function	Collector Percent	49.53%
UM15MV004	Davis	Function	Filterer Percent	8.88%
UM15MV004	Davis	Function	Filterer Richness	3
UM15MV004	Davis	Function	Predator Percent	22.68%
UM15MV004	Davis	Function	Predator Richness	13
UM15MV004	Davis	Function	Scraper/Filterer	0.77
UM15MV004	Davis	Function	Scraper/Scraper+Filterer	0.43
UM15MV004	Davis	Function	Scraper+Shredder Percent	24.20%

UM15MV004	Davis	Habit	Burrower Percent	5.48%
UM15MV004	Davis	Habit	Burrower Richness	2
UM15MV004	Davis	Habit	Clinger Percent	25.14%
UM15MV004	Davis	Habit	Clinger Richness	21
UM15MV004	Davis	Habit	Swimmer Percent	1.89%
UM15MV004	Davis	Habit	Swimmer Richness	2
UM15MV004	Davis	Hemoglobin	Hemoglobin Bearer Percent	6.24%
UM15MV004	Davis	Hemoglobin	Hemoglobin Bearer Richness	1
UM15MV004	Davis	Metals	Metals Tolerance Index	3.13
UM15MV004	Davis	Pollution	Pollution Sensitive Richness	7
UM15MV004	Davis	Pollution	Pollution Tolerant Percent	7.18%
UM15MV004	Davis	Sediment	Sediment Sensitive Percent	0.38%
UM15MV004	Davis	Sediment	Sediment Sensitive Richness	1
UM15MV004	Davis	Sediment	Sediment Tolerant Percent	1.89%
UM15MV004	Davis	Sediment	Sediment Tolerant Richness	2
UM15MV004	Davis	Subclass	Oligochaeta+Hirudinea Percent	1.89%
UM15MV004	Davis	Voltinism	Multivoltine Percent	56.33%
UM15MV004	Davis	Voltinism	Semivoltine Richness	4
UM15MV004	Davis	Voltinism	Univoltine Richness	24

APPENDIX C: Soil Mapping Units

Soil mapping units found within one mile of study sites:

Davis Creek watershed:

- Most soils are gravelly loams (Bigarm, Winker and Repp gravelly loams);
- plus some Argixerolls-Haploxerolls complex

Woodchuck Creek watershed within one mile of study site:

- Most soils are gravelly loams (Bigarm, Winker and Repp gravelly loams);
- plus some Meagher-Perma complex,
- and Argixerolls-Haploxerolls complex

Tongue Creek watershed:

- Bigarm and Winker gravelly loam soils;
- greater area of Argixerolls-Haploxerolls complex than other sites.

Welcome Creek watershed

- Described as mostly stony outcrops (Mitten, Tevis and Broadmoor families)

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