

**Montana Water Center
Annual Technical Report
FY 2016**

Introduction

The Montana University System Water Center (MWC), located at Montana State University in Bozeman, was established by the Water Resources Research Act of 1964. In 2016, the Center's Director, Wyatt Cross, at Montana State University worked closely with the Assistant Director at Montana State University and the Associate Directors from Montana Tech of the University of Montana - Butte as well the University of Montana - Missoula, to coordinate statewide water research and information transfer activities. This is all in keeping with the Center's mission to investigate and resolve Montana's water problems by sponsoring research, fostering education of future water professionals and providing outreach to water professionals, water users and communities.

Research Program Introduction

The Montana University System Water Center (MWC), located at Montana State University in Bozeman, was established by the Water Resources Research Act of 1964. In 2015, the Center's Director, Wyatt Cross, at Montana State University worked closely with the Assistant Director at Montana State University and the Associate Directors from Montana Tech of the University of Montana - Butte as well the University of Montana - Missoula , to coordinate statewide water research and information transfer activities. This is all in keeping with the Center's mission to investigate and resolve Montana's water problems by sponsoring research, fostering education of future water professionals and providing outreach to water professionals, water users and communities.

Research Program Introduction The Montana Water Center funded three faculty seed grant projects and four graduate student fellowship projects in 2015 with USGS 104(b) research program funds. Each faculty research project is required to directly involve students in the field and/or with data analysis and presentations. Below is a brief statement of the researchers' and students' work.

Robert Payn of Montana State University received an award of \$14,961 to study “Understanding how beaver mimicry restoration influences natural water storage in Missouri River headwater streams.” A report from this project is presented later in this annual report.

Lindsey Albertson of Montana State University received an award of \$15,000 to study “Impacts of river flow and temperature on salmonfly productivity and terrestrial subsidy.” A report from this project is presented later in this annual report.

Alysia Cox of Montana Tech - University of Montana received an award of \$15,000 to study “Characterizing Microbial Activity as Related to Water Quality in the Clark Fork Headwaters: A Baseline Study.” A report from this project is presented later in this annual report.

Jordan Allen at Montana State University received a \$1,000 student fellowship to study “Impacts of glacial processes on nitrogen cycling in the Beartooth Mountains, Montana.” A report from this project is presented later in this annual report.

Keenan Brame at Montana State University received a \$1,000 student fellowship to study “Transportation, Sediment-Association, and the Future of Microbial Contaminants on the Little Bighorn River.” A report from this project is presented later in this annual report.

Rachel Powers at University of Montana received a \$1,000 student fellowship to study “Riparian Ecosystem Succession Following Fire Disturbance on the North Fork Flathead River, Montana.” A report from this project is presented later in this annual report.

Claire Qubain at Montana State University received a \$1,000 student fellowship to study “Snowpack controls on nitrogen availability and nitrogen uptake in a Rocky Mountain conifer forest.” A report from this project is presented later in this annual report.

Neerja Zambare at Montana State University received a \$1,000 student fellowship to study “Removal of selenium by co-precipitation with microbially induced calcite precipitation.” A report from this project is presented later in this annual report.

The Montana Water Center selected four faculty seed grant projects and five graduate student fellowship projects to fund in 2017 with USGS 104(b) research program funds administered by the Montana Water

Research Program Introduction

Center. The selected faculty grants are:

Jia Hu at Montana State University received a \$17,220 grant to study Rocky Mountain Juniper influences on Stream Flow Dynamics

Benjamin Colman of MT Tech received a \$17,213 grant to study Effects of floating treatment wetlands on the abundance and removal of dissolved and nanoparticulate contaminants in waste water lagoons.

W. Payton Gardner of MT Tech received a \$19,247 to study Exploring Hydrologic Connectivity Between Shallow and Deep Groundwater Flow Systems in Upland Catchments.

Laurie Yung of MT Tech received a \$23,334 to study Improving Climate Information to Enhance the Drought Preparedness of Montana Agricultural Producers.

The selected student fellowships are:

Emily Stoick at Montana State University received \$880 for Student Fellowship Project: Microbially induced metal precipitation and co precipitation in mine influenced water.

Charles Shama at Montana Tech \$670 Student Fellowship Project: Estimate Mountain Front Recharge in a Basin and Range Province in Southwest Montana.

Christine Brissette received \$900 at University of Montana to study Science to inform restoration: Effects of channel reconstruction on hydraulic exchange and baseflow generation.

Jonathon Byers at University of Montana received \$900 to study Remote Sensing of Snowpack in the Bitterroot Mountains of Montana Using Unmanned Aircraft Systems (UAS).

Caelan Simeone at University of Montana received \$900 to study Leaf Water Potential as an Improved Predictor of Drought Induced Conifer Stress.

Robin Welling \$346 at University of Montana received Student Fellowship Project: Influence of wood on sediment storage in a low order stream in the northern Rocky Mountains.

Understanding how beaver mimicry restoration influences natural water storage in Missouri River headwater streams

Basic Information

Title:	Understanding how beaver mimicry restoration influences natural water storage in Missouri River headwater streams
Project Number:	2016MT300B
Start Date:	3/1/2016
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Ecology, Groundwater
Descriptors:	None
Principal Investigators:	Robert A Payn

Publications

There are no publications.

**Understanding how beaver mimicry restoration influences natural water storage in
Missouri River headwater streams
An Interim Report for the Montana Water Center's Faculty Seed Grant Program**

Andrew L. Bobst and Robert A. Payn

30 April, 2017

Background

Beaver-mimicry restoration (BMR) seeks to simulate the effects of beaver activity on stream ecosystems, and has become a popular approach to aggrade incised streams and reconnect stream channels to riparian systems. Proponents of BMR suggest that it will improve stream and riparian habitat, improve water quality, reduce stream temperatures in the summer, increase water storage, and increase late-summer stream flows. The ecological benefits of BMR have been well documented, and research has shown that increased overland flow and reactivation of secondary channels are often effective at increasing groundwater recharge. However, the effects of BMR on seasonal dynamics of natural water storage in shallow aquifers have yet to be tested directly, and the specific hydrologic mechanisms that would promote higher and cooler late-summer flows due to aquifer storage remain poorly understood.

To increase groundwater discharge to the stream in the late-summer, an increase in recharge of the connected aquifer must occur during high flow conditions. Then, a meaningful fraction of water in that aquifer must be stored for long enough to discharge back to the stream late in the summer. Simple conservation of mass dictates that any increase in recharge must be offset by increased water leaving the aquifer over the long term; however, this steady-state perspective tells us nothing about when or where the discharge will occur. In addition, since recharge from and discharge to the stream are not the only components of the groundwater budget, other outputs of water, such as evapotranspiration, must be considered. The site-specific hydrogeologic setting will determine how BMR will affect the components of the dynamic groundwater budget.

Lower late-summer stream temperatures could be achieved in two ways. If there is increased late-summer groundwater discharge, the relatively cool groundwater would reduce surface water temperatures when mixed in the stream. Additionally, an increase in riparian vegetation (e.g. willow) due to raised water tables could shade the stream and reduce solar energy inputs. Alternatively, BMR could increase stream temperatures if the relatively slow-moving water in pools behind structures is not shaded.

In order to assess the effects of BMR, we are monitoring two restoration sites and developing models of groundwater flow and stream temperature. We have completed pre-installation monitoring at each site (BMR installation in fall of 2016), and continue to monitor treated,

untreated, and reference reaches at each site for post-installation data. Groundwater monitoring includes water table elevations and groundwater temperatures. Surface-water monitoring includes stage, discharge, and temperature (in-stream instruments and thermal sensing). Vegetation response is also being monitored through a combination of vegetation transects (monitored by collaborators at The Nature Conservancy, TNC) and remote sensing. Proof of concept theoretical models (MODFLOW) of dynamic changes in stream gains and losses from activating side channels have been completed. Heuristics from that effort are being used to develop theoretical models that operate at the same scale as our study sites and address a broader range of BMR goals and hydrologic contexts. Site specific models will ultimately be developed for the monitored sites for numerical experimentation testing the hypotheses regarding dynamic seasonal storage. Statistical models of stream temperature will be developed for the monitored sites based on pre-treatment conditions, and these models will be compared to post-treatment observations to understand the changes in stream temperature resulting from BMR.

This report briefly summarizes the activities funded by the first year of support from a Montana Water Center Faculty Seed grant awarded to PI Robert Payn in April of 2016. Graduate student Andrew Bobst had primary responsibility for coordinating or executing these activities, as well as compiling this report.

Activities from April 2016 to date

TNC used BMR strategies for stream restoration projects on Alkali Creek and Long Creek in 2016 (Figure 1). The restoration work was conducted in late-August on Long Creek, and in early-October on Alkali Creek.

Groundwater monitoring, surface-water monitoring, and remote sensing were conducted on Alkali Creek starting in August 2015, and on Long Creek starting in April 2016. Treated and untreated reaches were monitored.

At Alkali Creek (Figure 2) we monitored 59 piezometers, 5 surface-water sites, 10 stream temperature stations, and 3 groundwater recharge stations (1-dimensional vertical arrays of temperature and head measuring instruments collecting time series data). Remote sensing data (visible, near-IR and thermal) was collected at Alkali Creek in mid-August 2016.

At Long Creek (Figure 3) we monitored 42 piezometers and wells, 5 surface-water stations, 4 stream temperature stations, and 3 groundwater recharge stations. Remote sensing data was collected at Long Creek in mid-August 2016.

We have developed a series of preliminary theoretical models of changes in groundwater recharge and discharge resulting from BMR. These models are currently being refined and evaluated.

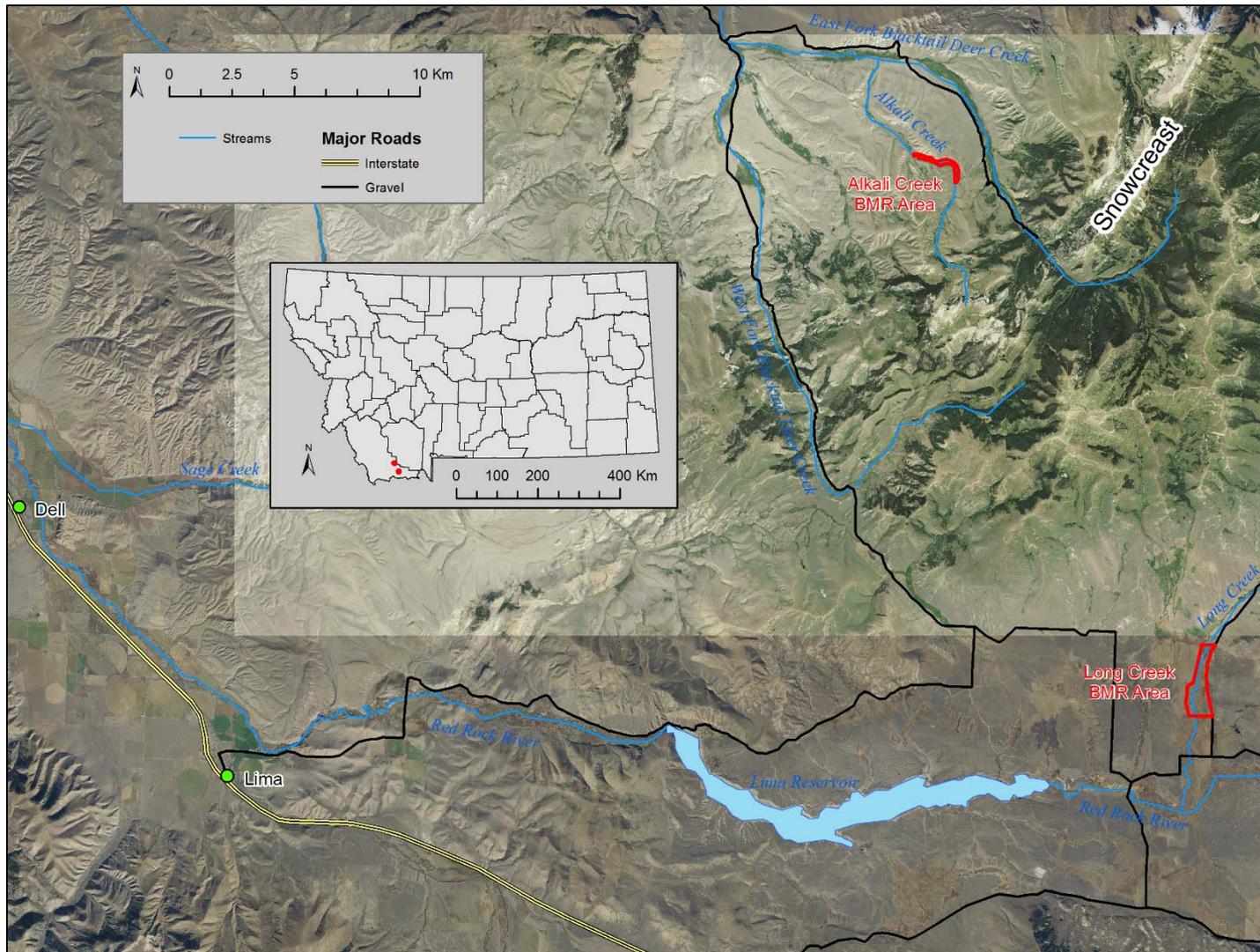


Figure 1. TNC installed BMR structures on Long Creek and Alkali Creek in the late summer and fall of 2016. These sites are located in Southwest Montana (USA), in the headwaters of the Missouri River Basin (Beaverhead and Jefferson River headwaters).

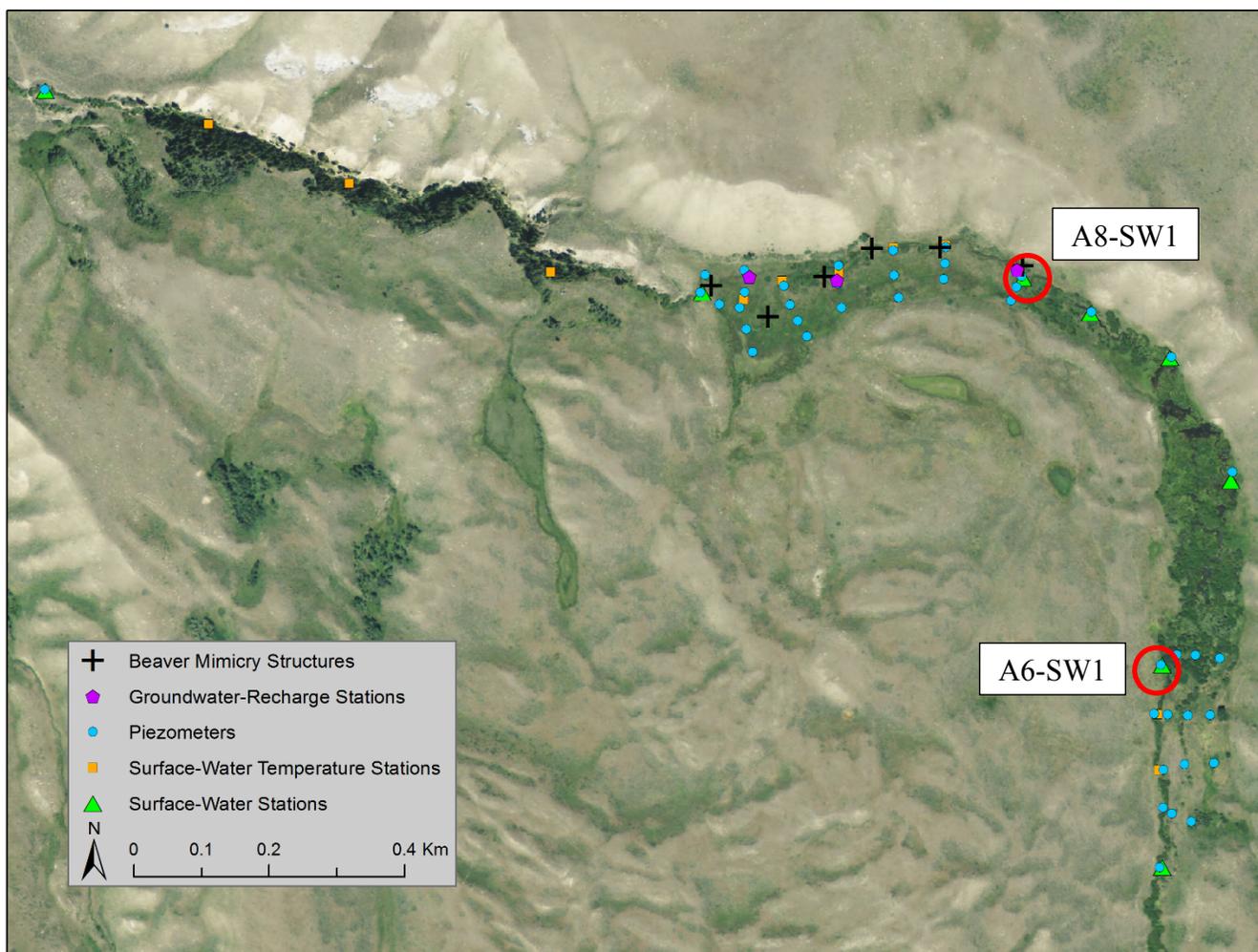


Figure 2. A total of 40 piezometers and 5 surface-water stations were installed at Alkali Creek in the late-summer of 2015. An additional 16 piezometers, 3 staff gauges, and 10 surface-water temperature sites were installed in the spring and early summer of 2016. TNC installed BMR structures on Alkali Creek mid-October 2016. Groundwater-recharge stations were installed in November 2016. Monitoring will occur twice per month from May to November through the fall of 2018.

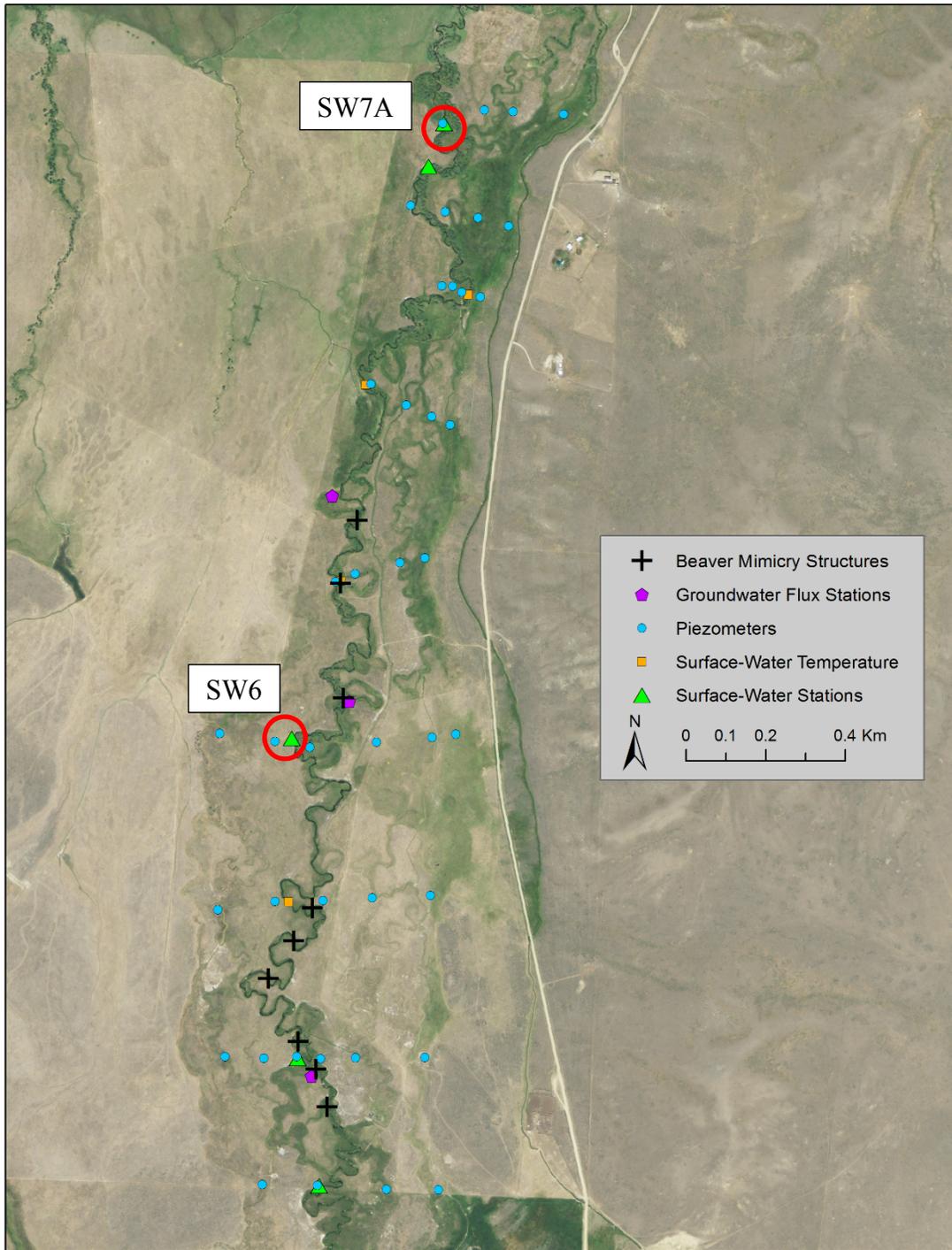


Figure 3. TNC has monitored 3 piezometers and 3 surface-water stations at the Long Creek site since 2012. An additional 39 piezometers, 2 surface-water monitoring stations, and 4 surface-water temperature stations were installed in the spring of 2016 (mostly in May). TNC installed BMR structures on Long Creek in late-August 2016. Groundwater-recharge stations were installed in November 2016. Monitoring will occur twice per month from April to November through the fall of 2018.

Preliminary observations

Though the majority of the data collected to date is from pre-installation conditions, we are able to make initial observations and comparisons that suggest the fundamental effects of BMR and inform future project decisions.

- 1) Groundwater levels near BMR structures rose rapidly as stream stage increased following installation (Figure 4). These increases indicate that either water flowed from the stream into the shallow aquifer, or groundwater that would otherwise flow into the stream was backed up in the aquifer. In some cases, a rapid response in the water table was apparent in wells more than 50 m from the structures.
- 2) As water passes through the beaver mediated reach on Alkali Creek, the water is warmed, and stream temperatures are buffered (Figures 2 and 5). At Long Creek the less extensive existing beaver ponds in the northern portion of the study area do not appear to have a strong influence on stream temperature (Figures 3 and 5).
- 3) Surface water flows and groundwater elevations peak in early June, indicating that the highest potential for recharge will be during May and early June.
- 4) Development of the theoretical groundwater models has shown that the areal extent of inundation created by a BMR structure during high flows strongly affects the amount of groundwater recharge that occurs. Also, the elevation of the groundwater table relative to the stream (gaining, losing, or disconnected losing streams) strongly affects the potential for water to return to the stream within the model domain. These models have also shown that evapotranspiration can be a significant portion of the water budget. In some modeled cases, BMR installation theoretically resulted in more water being consumed by evapotranspiration than water stored for later discharge to the stream.

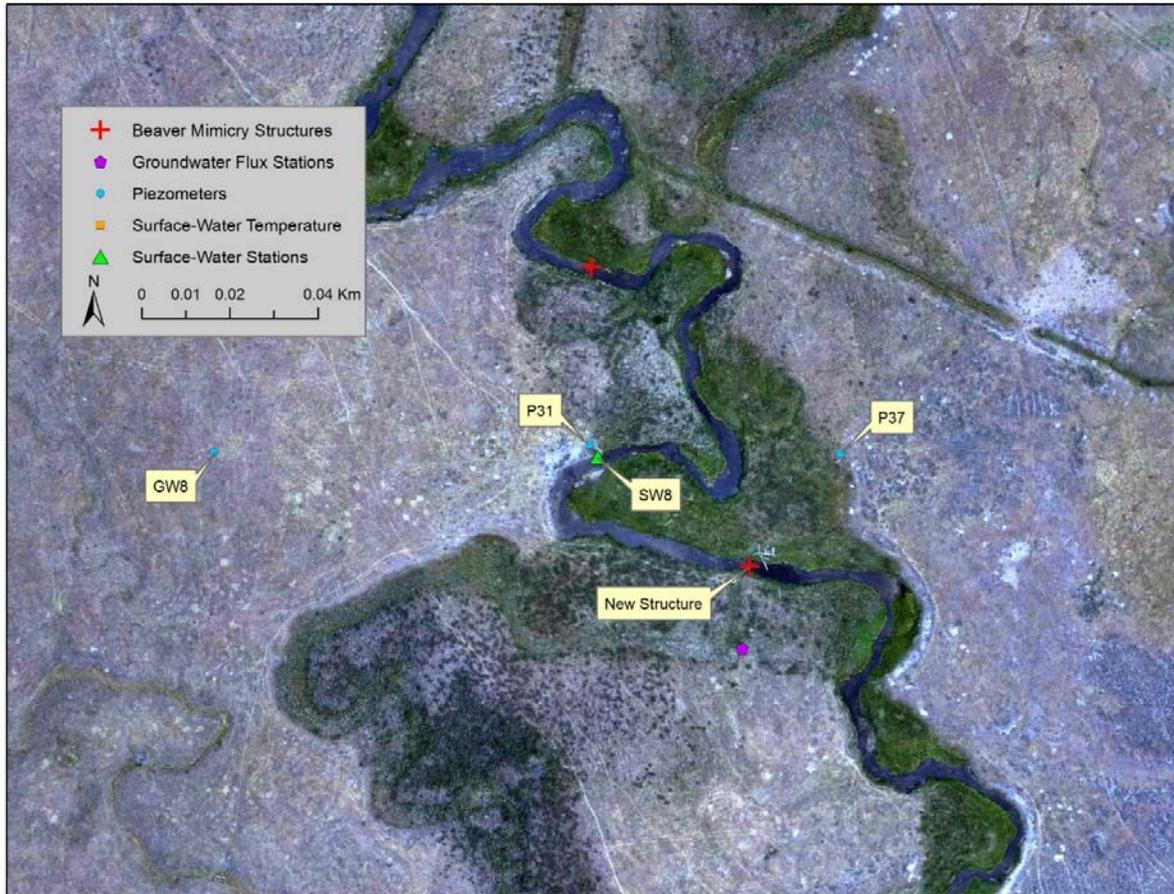


Figure 4. Surface water levels (SG8) and groundwater levels in wells and piezometers (GW8, P31, P37) near BMR structures rapidly responded to changes in stream stage after installation in September of 2016. In this example from Long Creek, GW8 is 78 m from the closest location on the stream and it demonstrates a nearly immediate increase in groundwater elevation following the installation of the BMR structure.

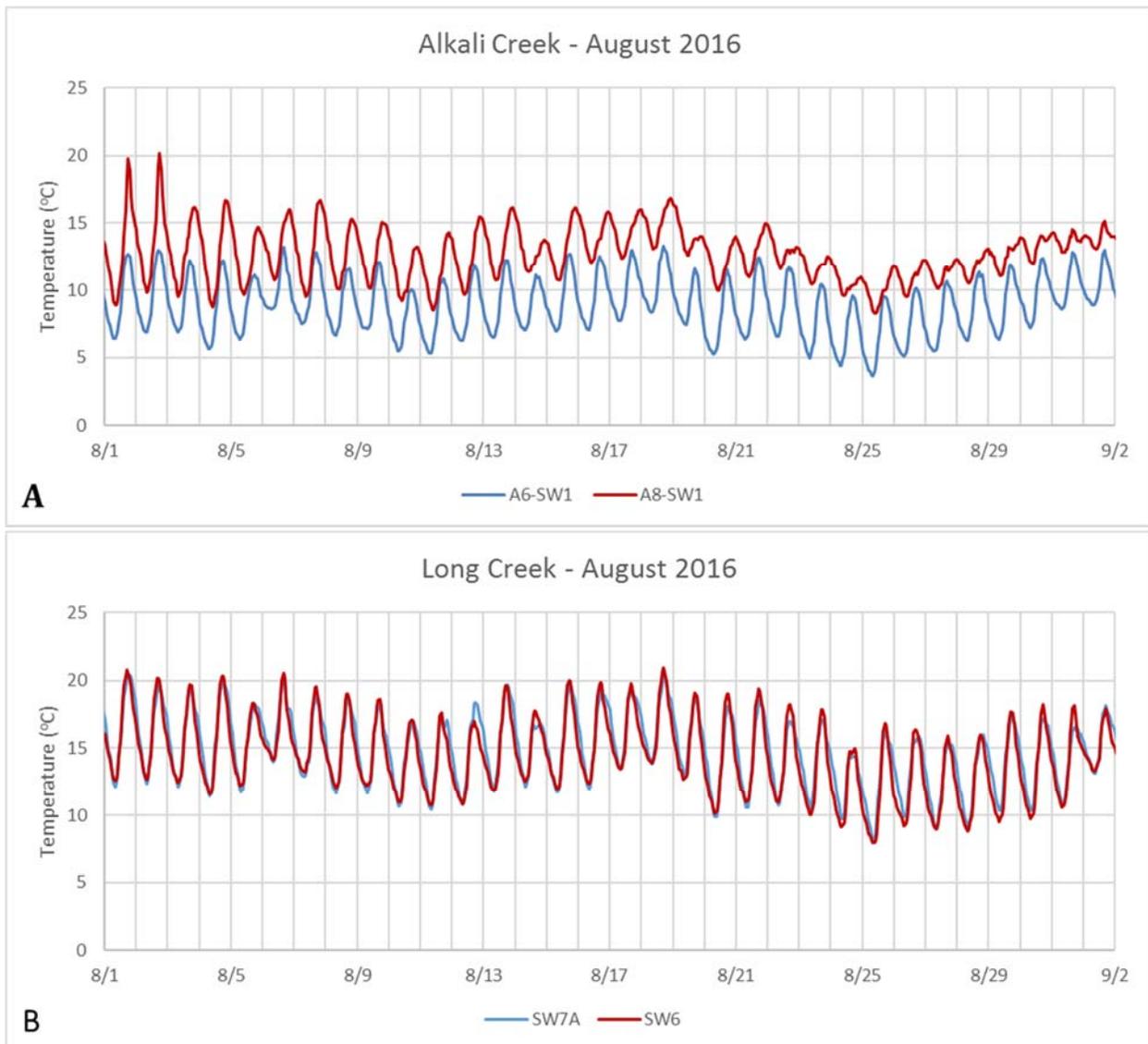


Figure 5. Late-summer stream temperatures increase and are buffered as water moves through the existing beaver complex on Alkali Creek (A); however stream temperature do not appear to be strongly influenced by the less extensive beaver ponds on Long Creek (B). Site locations are shown on Figures 2 and 3.

Planned activities through October 2017 (end of award)

We will monitor at Alkali Creek and Long Creek until roads become impassable. This will include continued monitoring of the existing sites, and collection of post-treatment remote sensing data in August.

The series of theoretical groundwater flow models will be completed and evaluated. This evaluation will include sensitivity analysis to understand which site characteristics are most important for increasing groundwater recharge, and for increasing August groundwater discharge to streams.

Statistical models of changes in stream temperature between monitoring stations will be developed using air temperature as the driver. These models will be developed using pre-BMR stream temperatures, and then they will be run during the post-BMR time period. Model results will be compared to observed stream temperatures to evaluate changes in stream temperature.

Progress toward project benefits

The data collected during this study is publicly available from MBMG's GWIC database at <http://mbmggwic.mtech.edu/sqlserver/v11/data/dataProject.asp?project=BMS&datatype=well&>

We anticipate developing at least three peer-reviewed publications from this work. The anticipated topics are:

1) Changes in dynamic groundwater recharge due to beaver-mimicry stream restoration

This publication would focus on the changes in groundwater recharge that would be anticipated from different types of beaver mimicry restoration in different hydrogeologic settings. Because increased groundwater recharge is the first step for attaining any of the other groundwater storage objectives of BMR, a firm understanding of the potential to change groundwater recharge is needed. Inundation models based on the detailed DEMs will be combined with the calculated recharge rates from the flux stations to estimate the amount of increased groundwater recharge. These measured rates will be further evaluated as they are incorporated into the site-specific groundwater flow models. Sensitivity analysis of the site-specific and theoretical groundwater flow models will aid in determining the site characteristics that most strongly control groundwater recharge. Installation of the flux measurement wells and initial model development completed this year represent progress toward this publication.

2) Changes in late-summer groundwater discharge to streams due to beaver-mimicry stream restoration

A typical goal of BMR is to increase late-summer stream flow using water storage in the shallow aquifer. This paper would assess the potential for recharged water to return to

streams at an appropriate place and time. The recharged water could be removed from the shallow aquifer by a variety of pathways (e.g. evapotranspiration or groundwater outflow), so it is necessary to understand the potential magnitude of these alternative pathways. To assess when, where, and how much of the recharged water returns to the stream we will use observed changes in stream flow, observed changes in groundwater gradients, changes in stream temperature patterns (thermal imaging), and groundwater flow modeling (including sensitivity analysis). The pre-installation data gathered at the study sites over the past year provide a critical contribution toward this publication.

3) *Effects of beaver mimicry stream restoration on late-summer stream temperatures at two sites in Southwest Montana*

BMR has been suggested to decrease late-summer stream temperatures due to increased groundwater inflow; however, this has not been clearly demonstrated, and monitoring of existing beaver ponds at Alkali Creek indicates that warming is occurring. The amount of warming or cooling due to BMR will likely depend on the degree to which the pools are shaded. This paper will focus on the empirical effects of BMR on stream temperature changes over the study reaches at Alkali Creek and Long Creek. The pre-treatment stream temperature monitoring that we have conducted over the last year, our planned post-treatment monitoring, and the statistical models of stream temperature changes will be the basis for this paper.

We also plan to develop guidance for selecting BMR sites that are most likely to meet project objectives. From our theoretical modeling it is clear that the amount of groundwater recharge will be strongly affected by the area inundated, and the duration of that inundation. It is also clear that the timing of increased groundwater outflow to the stream will be strongly affected by the relative elevations of the stream and the groundwater. In gaining streams the water will return relatively quickly, while in disconnected losing streams it may take many years for the water to return. We will use the planned sensitivity analysis of the theoretical and site-specific groundwater flow models to further explore the site characteristics that most strongly control the timing and magnitude of groundwater recharge and groundwater discharge to the stream.

Impacts of river flow and temperature on salmonfly productivity and terrestrial subsidy

Basic Information

Title:	Impacts of river flow and temperature on salmonfly productivity and terrestrial subsidy
Project Number:	2016MT301B
Start Date:	3/1/2016
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Ecology, Drought, Climatological Processes
Descriptors:	None
Principal Investigators:	Lindsey Albertson

Publications

There are no publications.

Impacts of river flow and temperature on salmonfly productivity and terrestrial subsidy

Overview: Funds for this award have been used to support PI Albertson and master's student Heidi Anderson. Additional funds provided by the undergraduate scholars program at MSU have helped Anderson work with two outstanding undergraduate research assistants (Niall Clancy; Cailey Philmon). We have made great progress in establishing monitoring methodology and a first year of data that tracked emergence of the iconic salmonfly *Pteronarcys californica*. Data have been included in two public talks given by PI Albertson (Idaho State, February 2017; Flathead Lake Biological Station, April 2017) and will be presented in a poster session by Anderson at the Society for Freshwater Science Annual Meeting in Raleigh, NC in June 2017. Anderson has also written a thesis proposal that has been disseminated to her thesis committee and describes her research project in full. This interim report stems from that thesis proposal.

Major data collection to date: In summer 2016, we collected preliminary field data to identify relative densities of *P. californica* larvae in the Madison and Gallatin Rivers. Qualitative sampling suggests that on the Madison River, *P. californica* are present in low densities above Hebgen Reservoir, abundant between Hebgen and Ennis Reservoirs, and are extremely rare below Ennis Reservoir. On the Gallatin, *P. californica* are extremely rare above Taylor's Fork, and common throughout the canyon, between Taylor's Fork and Spanish Creek. Densities decrease rapidly in the downstream direction after the river empties out onto the wide valley floor. In summer 2017, we will quantitatively map temperature, substrate type, and *P. californica* density along the Madison and Gallatin rivers to correlate these factors with *P. californica* density and distribution.

We will also measure the reproductive capacity of salmonflies across the natural variation of summer temperatures that they experience on these rivers to determine if temperature has a direct correlation with fecundity (quantified as size of egg mass and the number of eggs per female). Previous work has demonstrated that hatching success of *P. californica* eggs drops off significantly between 17.5°C and 20°C (Townsend et al., 2010). If *P. californica* fecundity is also diminished at similarly high water temperatures, this effect, together with reduced hatching success, could have serious implications for the currently robust salmonfly population just upstream of Ennis Reservoir, where water temperatures regularly exceed 20°C. These two factors could also represent one possible mechanism of the observed decline of the salmonfly population in the Lower Madison River. We have recently received a permit to collect salmonflies in Yellowstone National Park, which will allow us to expand our research sites in the Madison River.

Background: Increased temperature stress and fine sediment inputs are important mechanisms of ecological degradation in fluvial ecosystems (Jones et al., 2012; Poff et al., 2010), and are the two main hypothesized mechanisms for the decline of salmonflies in the Lower Madison River, Montana (Stagliano, 2010). Limited long-term datasets provide some evidence that conditions on the Lower Madison River have changed over the past forty years. Spring and summer water temperatures on the Lower Madison River have increased an average of 0.25 and 0.29° C per decade, respectively, since USGS monitoring began in 1977 (Figure 1). Similarly, days of extreme heat are increasing along the Lower Madison. In the last 4 years, water temperatures exceeded 20°C an average of 46 days/year, and the number of days over 20°C has increased a rate of ~6 days/decade at a long-term monitoring site below Madison Dam (Figure 2).

Consistent monitoring of substrate type is limited, but available data indicates that fine sediment and embeddedness is increasing on the Lower Madison River. Increased sedimentation is a widespread phenomenon in western Montanan rivers: in a 2015 survey of Montanan fishery biologists, fishing guides, and general fisherman, 100% of guides and fishery biologists and 50% of general fisherman reported an

increase of sediment and silt (Stagliano, 2010). On the Lower Madison River, two earlier reports (Fraley, 1978; Hauer, 1991) do not mention highly embedded substrate or vascular plants in their descriptions of the Lower Madison below Beartrap Canyon, both of which are now common on this section of the river.

Long-term datasets monitoring water temperature, substratum characteristics, and benthic macroinvertebrate population are uncommon. There is rising concern that salmonfly populations are in decline throughout the American West (e.g., Nehring et al., 2011; Stagliano, 2010), but in the absence of long-term data, quantifying the presence and/or extent of a population decline is difficult and often based on qualitative or anecdotal evidence. Our work in summer 2017 will establish baseline data regarding the status of *P. californica* on the Madison and Gallatin Rivers that can be used to document the future of these at-risk populations. Additionally, through a combination of field surveys and laboratory experiments, we will quantify how fine sediment and warm water temperatures affect *P. californica*, first by determining how these controls correlate with current *P. californica* distribution, and then by examining how these proposed mechanisms of decline affect individual salmonfly fitness.

Question 1 (Field Survey 2016/2017): How do salmonfly larval densities, longitudinal spatial distributions, fecundities, and body masses vary with differing temperature and fine sediment regimes along the Gallatin and Madison Rivers?

Hypothesis 1: We predict that the distribution of salmonflies along the Madison River will be strongly correlated with both summer temperatures and percent fine sediment, whereas substratum will be the more prevalent control on the relatively cool Gallatin River. This prediction is supported by previous studies in other rivers, which have demonstrated that *P. californica* have fairly low fine sediment and thermal tolerances (Huff et al., 2008; Bryce et al., 2011, Relyea et al., 2012). We also predict that body mass and fecundity will be lowest at sites with the most extreme (highest and lowest) temperature regime. This hypothesis is based on the concept of thermal optima, where macroinvertebrate performance increases as temperature increases until a threshold, after which performance drops off rapidly (Huey and Stevenson, 1979, Angilletta et al., 2002).

Density and distribution sampling: Larval density, water temperature, and substrate type will be sampled at ten sites along the Madison River and eight sites along the Gallatin River (Figures 3, 4). These sites span the length of the rivers' mainstems, so we will be able to determine variations in density along the full extent of their current range on these two rivers. The first goal of this portion of the project is to quantify the range and density of salmonflies along the Madison and Gallatin Rivers. It is imperative to formally study his seemingly obvious baseline knowledge in order to track salmonfly populations into the future. Additionally, our goals for this portion of the project are to determine the relative importance of temperature and percent fine sediment in limiting salmonfly abundance and range, and find how well salmonfly distribution in the Gallatin and Madison Rivers matches up with previously suggested thermal and fine sediment tolerances in other rivers (Huff et al., 2008, Bryce et al., 2010, Relyea et al., 2012).

A HOBO water temperature logger will be installed near the thalweg at each site. Larval densities will be collected monthly from May through September, using a modified surber sampler (area of 1 m²), with 4 individual samples taken and pooled per site (total area 4 m²). To quantitatively characterize substrate at each site, four samples will be randomly selected in a stratified design using quadrats. Each quadrat will consist of a 1 m² frame. We will take an underwater picture of each quadrat and use imageJ to quantitatively determine the percent fine sediment visible. Additionally, 10 rocks will be randomly selected from each quadrat and measured for embeddedness (Yes/No), length, width, and depth. Substrate characterization will take place twice, in late April and August, when flows are relatively low and the river is accessible.

Fecundity sampling: Adult females will be sampled at three sites on the Madison River (Ennis Inlet, Hebgen Outlet, and Yellowstone National Park) and two sites on the Gallatin River (Buffalo Horn and Spanish Creek), with selected sites representing the full range of temperature regimes along the two rivers

(14°C – 20°C mean July temperature). For each specimen, we will measure the number of eggs, ash free dry mass (AFDM) of egg mass, and AFDM of the adult salmonfly. The goal of this portion of the study is to determine if there is a difference in fecundity between sites with differing temperature regimes.

Emergence timing detection: In summer 2016, we examined how emergence moved in a wave from downstream to upstream along the Upper Madison River and Gallatin River, sex ratios during emergence, and the relationship between emergence timing and temperature. We will continue measurements of emergence timing in summer 2017 at a subset of sites, noting first emergence date and quantifying exuvia per m of shoreline at two sites on the Upper Madison River (Varney and Hebgen) and one site along the Gallatin River (Jack Smith). At each site, 50 m sample reaches will be established along uninterrupted stream banks adjacent to riffles (typical salmonfly larvae habitat). Immediately following emergence, exuvia will be collected at 10 randomly selected one meter sections of bank within each 50m reach. Sex of each exuvia will be recorded. The goal of this portion of the fieldwork is to establish long-term monitoring of salmonfly emergence for the Albertson Lab, and to further establish relationships between water temperature and emergence timing.

Biomass sampling: Fraley (1978) noted that in 1977, the average weight of adult salmonflies in the Lower Madison was ~13% less than those of the Upper Madison River. We will collect 100 salmonflies from the same two sites on the Upper Madison River (Varney and Ennis) and any salmonflies present at the same three sites that Fraley sampled on the Lower Madison River (Beartrap, Norris, and Cobblestone) where salmonflies are currently absent or undetectable to determine if adult salmonfly weight has changed since 1977.

Question 2 (Lab Experiment 2017): How do temperature and percent fine sediment affect salmonfly fitness (mortality, lipid content, growth rate, and food consumption)?

Hypothesis 2: We predict that mortality will be low in all treatments, but will be highest in treatments at the highest temperatures and percent fine sediment additions. We predict that lipid contents and food consumption will decrease in treatments with higher percent fine sediment. Previous work suggests that increased fine sediment may inhibit feeding processes in *P. californica*. Hornig and Brusven (1986) documented that mean daily ingestion rates were lower among individuals subjected to high levels of suspended sediments. Richardson and Gaufin (1971) noted that even in loose, boulder substrate, sand particles were present in 99.6% of *P. californica* gut samples examined. If sand is unavoidably digested, high fine sediment loads could have serious detrimental effects on *P. californica* ability to feed, and therefore inhibit ability to store lipids.

Conversely, we predict that lipid content, growth rate, and food consumption will increase with higher water temperatures until these response variables decline at the highest temperature treatment. This response would be in line with the well-established relative performance curve denoting thermal optima (Huey and Stevenson, 1979, Angilletta et al., 2002).

Motivation for Q2/H2 research: Increased temperature and sedimentation and are the two main hypothesized mechanisms for the decline of salmonflies in the Lower Madison River (Stagliano, 2010). We are designing two experiments to test how these proposed mechanisms of decline affect salmonfly fitness in a controlled laboratory setting. Our proposed proxies for fitness are mortality, growth rate, lipid content, and food consumption.

Mortality before reproduction and fecundity have a clear correlation with fitness – both response variables directly affect reproductive success. Because of salmonflies' long lifespan, we will address fecundity in the field experiments described above. In addition to these direct measures of fitness, it is important to understand how temperature and fine sediment affect young *P. californica* larvae. Salmonflies spend 3-4 years as aquatic larvae in the Madison and Gallatin Rivers (Gustafson, 1990). This

long larval period makes salmonflies particularly susceptible to chronic, sublethal effects, and it is therefore important to determine how salmonfly fitness is impacted by stressors during early larval stages. To determine the impact of increasing temperature and fine sediment on first-year larvae, we will measure growth rate, lipid content and food consumption of salmonfly larvae in the laboratory. Lipid concentration is a commonly used measure of fitness, and is strongly correlated with reproductive success in aquatic insects (Cargill et al., 1985, Koop et al., 2011). Food consumption and growth rate, are also important processes to maintain fitness.

Collection: *P. californica* larvae will be collected at three sites along the Gallatin River (45 30.570, -111 15.603), (45 17.741, -111 13.014), and (45 7.615, -111 13.897), and will be assimilated in tanks at ambient stream temperature before treatments begin to minimize shock. Larvae will be kept in the lab for 24 hours in tanks at water temperatures recorded at collection, then acclimated to the previously noted experimental temperatures at 1° C/30 minutes in order to avoid thermal shock. Tree leaves proximal to these sites will be collected from terrestrial vegetation and conditioned in the lab for one month prior to the experiment. Larvae will be free-fed with a set volume of pre-conditioned leaves from the source site. Lighting in the experimental room will be pre-programmed, the same for each treatment, and similar to the natural summer photoperiod: 14 hours light, 10 hours dark. Treatments will be randomly assigned to a tank. There will be 36 treatments, each replicated 3 times, for a total of 36 experimental units (Figure 5).

Experimental Design/Preparation: The experiment will be conducted at Bozeman's U.S. Fish and Wildlife Service Fish Technology Center (FTC) from May 1st through August 31st, 2017. Temperature will be manipulated between 12-24°C and substrate from approximately 0-15% fine sediment using fully factorial experiments in temperature-controlled tanks. Treatments for the experiment will include all combinations of four temperature levels (12, 16, 20, or 24°C,) and three levels of fine sediment (0, 7, and 15%), with three replicates of each treatment (Figure 5). These temperatures represent the range of summer water temperatures experienced by salmonflies on the Madison and Gallatin Rivers. Mean July (hottest month) water temperatures are 14°C, 16°C, and 20°C on the Gallatin River, Upper Madison, and Lower Madison River respectively.

In addition to matching field conditions, we have taken previous research regarding salmonfly thermal tolerances into account. We are interested in understanding the impact of chronic temperature stress, so all of our values lie under 27°C, the temperature where 50% of salmonflies die after 96 hours (TL_m^{96}) (Gaufin et al., 1975). Previous research indicates that there may be a fitness threshold between 19-20°C, and thus I designed the experiment to encompass this value. A field-based study estimated the thermal tolerance of salmonflies as an 18.6°C average of the daily maximum temperature for the warmest 7-day period of the year (Huff et al., 2008). Hatching success of *P. californica* also drops off significantly around this threshold, with a hatching success of 72.9% for *P. californica* eggs reared at 17.5°C compared to a 25.1% hatching success rate for eggs reared at 20°C (Townsend et al., 2010). Temperatures on the Lower Madison regularly exceed 20°C. In the last 4 years, water temperatures exceeded 20°C an average of 46 days/year, and the number of days over 20°C has increased a rate of 0.59 days/year at a long-term monitoring site below Ennis Reservoir.

The lower proposed fine sediment treatment levels are based on salmonfly preference (0% fine sediment) and previous estimates of *P. californica* sediment tolerances of 7% fine sediment (Huff et al., 2008) and 8.2% fine sediment and sand (Bryce et al., 2010). The upper proposed fine sediment treatment level is currently estimated to be 15%, but the actual value will be based on a field assessment of % fine sediment on the Lower Madison River in April 2017. In addition to varying levels of fine sediment, all tanks will have a gravel base and 4-5 large cobbles (76-304mm in diameter).

Lipid concentration/Growth Rate/Food consumption: The experiment we will run in summer 2017 will measure how first-year larval *P. californica* mortality, lipid content, growth rate, and food consumption is altered by differing water temperature and fine sediment regimes. Fraley (1978) noted that in 1977, the average weight of adult salmonflies in the Lower Madison was ~13% less than those of the

Upper Madison River. He attributed the lighter weights to lower fat reserves because of higher metabolic costs in the Lower Madison, but this hypothesis remains untested. The second experiment this summer is designed in part to test this hypothesis.

This experiment will run from approximately May 7th through August 27th. Each tank will contain six first-year *P. californica* larvae, for a total of 216 specimen (~16/m²), which is well within the natural density of *P. californica* in the Gallatin and Madison watersheds. Mortality date will be recorded when applicable. Body length will be measured weekly throughout the experiment to determine growth rate. We will be able to relate relationships between AFDM and body length using a model established in Spring 2017 (preliminary results – Figure 6). Volume of initial leaf mass will be estimated before the experiment by drying and weighing the same volume of leaf mass that will be placed in the tank, and final leaf mass will be determined by removing, drying, and weighing remaining leaf mass from the tank after the experiment, and subtracting this mass from the estimated initial leaf mass to determine total leaf loss throughout the experiment. Known amounts of additional leaf mass will be added into the tank as needed to ensure that food is not a limiting factor.

At the end of the experiment, half (three) of the individuals in each tank will be processed to determine body lipid content. Specimen will be frozen, dried at 55°F for three days—or until body mass has stabilized—and weighed. To extract lipids from dried bees, 10 ml of petroleum ether and one larve will be added to a capped immediately after specimen were removed from the oven. After 10 days, we will decant the ether and air-dry the vials containing salmonfly larvae for one hour under a laboratory hood. The vials will then be placed back into the oven until the masses again stabilize (~72 h), when a post-extraction body mass can be obtained. The post-extraction dry mass will be subtracted from the pre-extraction dry mass to estimate of the amount of lipid extracted. The result will then be divided by the pre-extraction dry mass to obtain an estimate of the proportion of dry mass comprised of lipids (P_L) for each salmonfly larvae (Lipid extraction methods are based on methodology in O’Neill et al., 2015).

The other three specimen in each tank will be analyzed for gut contents. Foregut contents, collected after the experiment is complete, will be dispersed in a few drops of water and drawn onto 0.45 µm membrane filters and placed on a slide. Each slide will be split into a grid, and objects at intersections will be classified as either organic or inorganic (sand/silt) material in order to determine % inorganic material in gut contents. Methodology based from Freilich et al. (1991).

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Figures

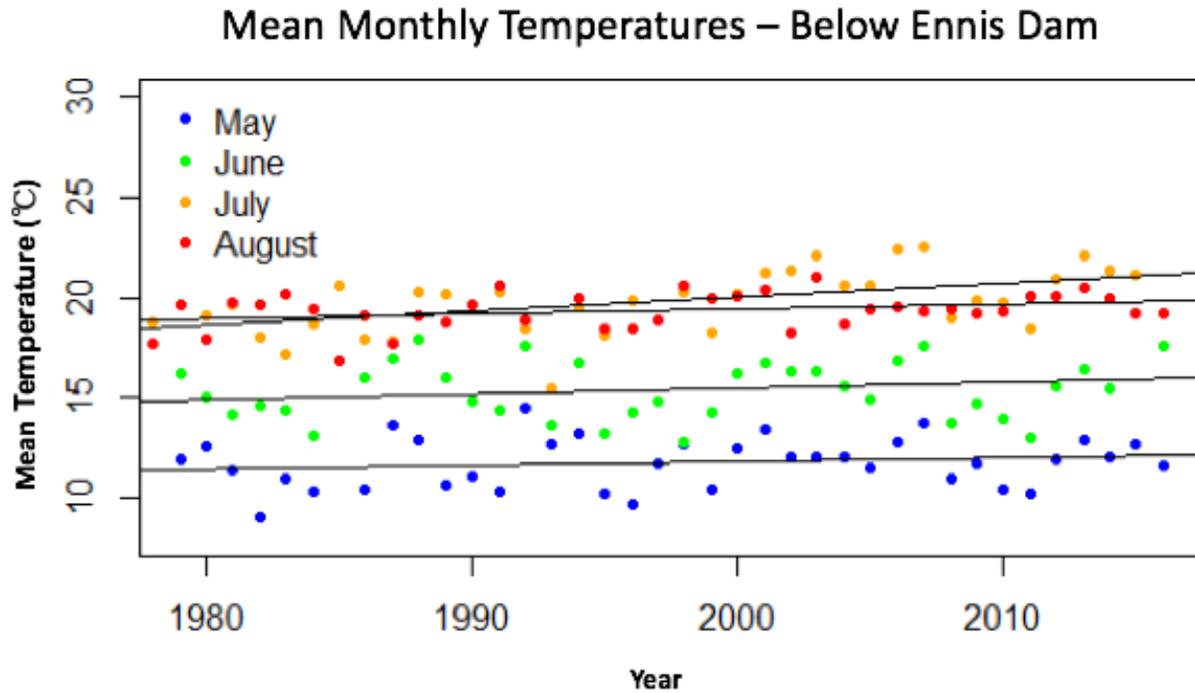


Figure 1. Mean monthly water temperatures, collected by the USGS, from 1977 to 2016 in the Madison River, downstream of Ennis Reservoir. Averages spring (March – May) and summer (June – August) temperatures are increasing at a rate of 0.25 and 0.29° C warming per decade, respectively. Warming is most prominent in July, which is warming at an average of 0.69° C per decade.

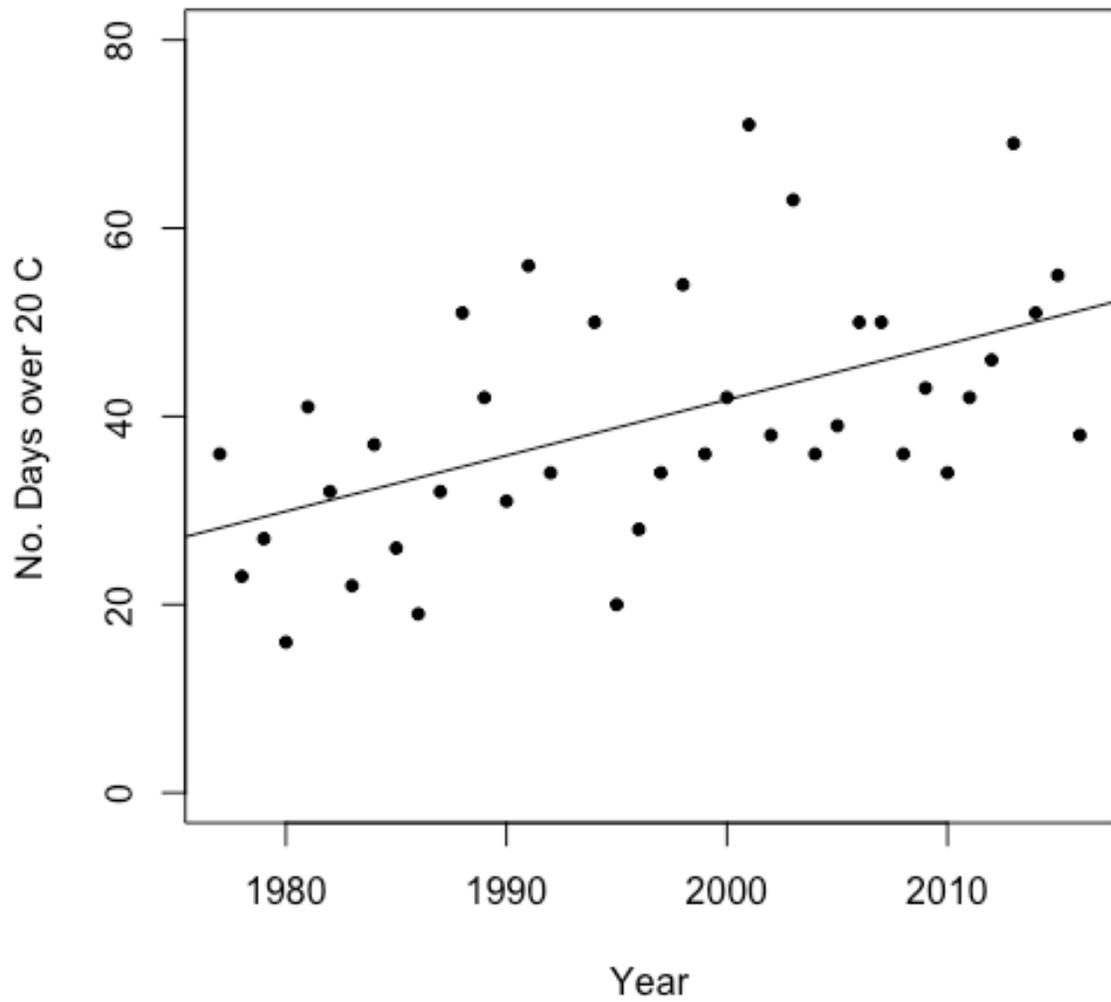


Figure 2. Number of days over 20 ° C per year between 1977 to 2016 at a site on the Lower Madison River, below Madison Dam. Data is collected by the USGS. The number of days that exceed 20 ° C is increasing at an average of 5.9 days per decade.

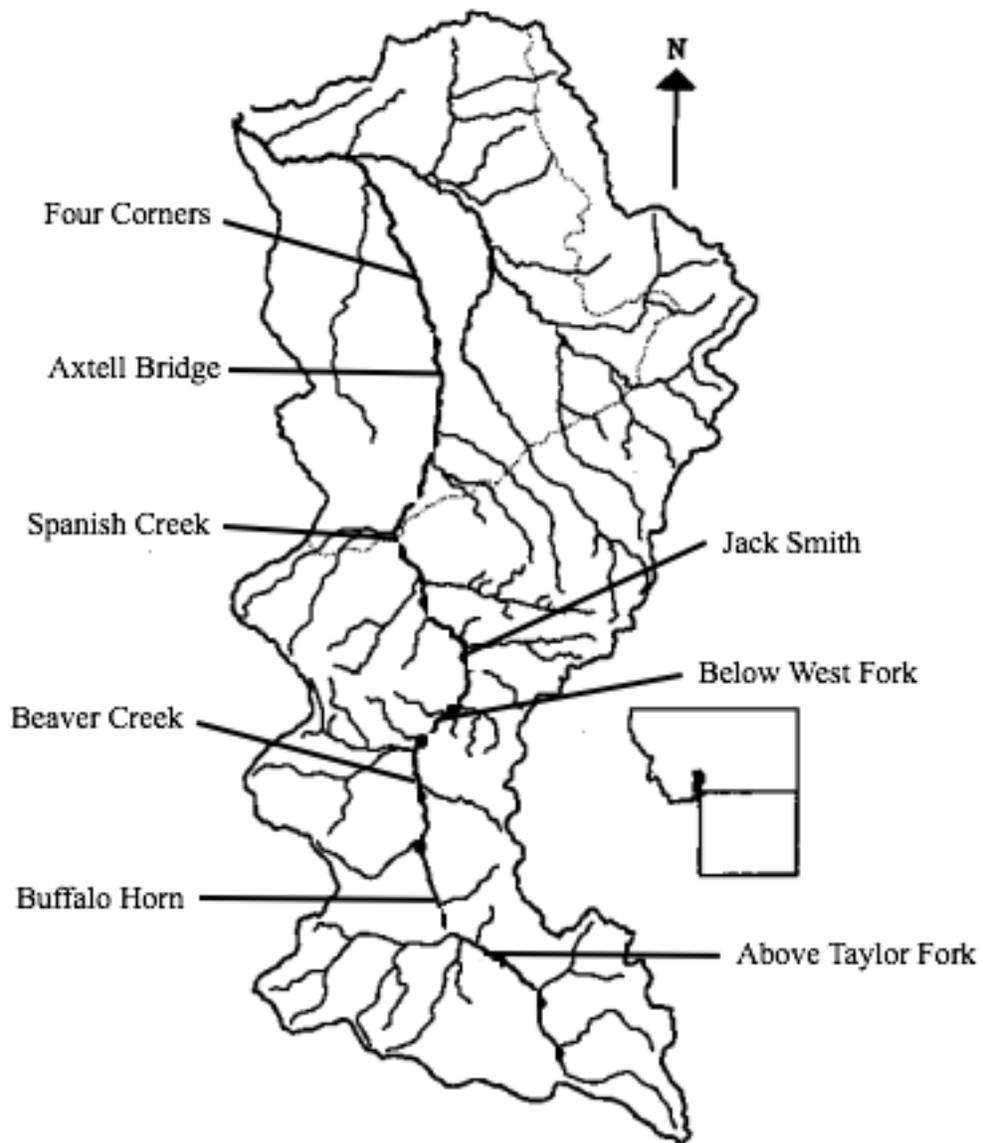


Figure 3. Study sites along the Gallatin River, Montana.

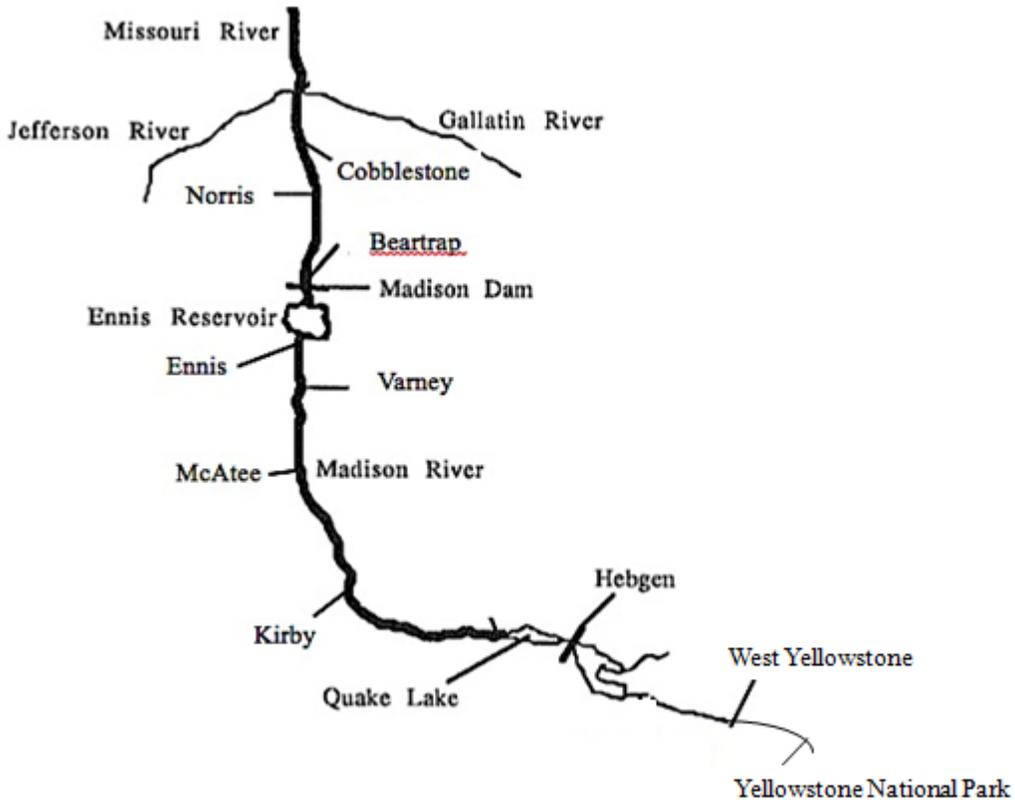


Figure 4. Study Sites along the Madison River, Montana.

12° C, no fine sediment	16° C, no fine sediment	20° C, no fine sediment	24° C, no fine sediment
12° C, 7% fines	16° C, 7% fines	20° C, 7% fines	24° C, 7% fines
12° C, 15% fines	16° C, 15% fines	20° C, 15% fines	24° C, 15% fines
12° C, no fine sediment	16° C, no fine sediment	20° C, no fine sediment	24° C, no fine sediment
12° C, 7% fines	16° C, 7% fines	20° C, 7% fines	24° C, 7% fines
12° C, 15% fines	16° C, 15% fines	20° C, 15% fines	24° C, 15% fines
12° C, no fine sediment	16° C, no fine sediment	20° C, no fine sediment	24° C, no fine sediment
12° C, 7% fines	16° C, 7% fines	20° C, 7% fines	24° C, 7% fines
12° C, 15% fines	16° C, 15% fines	20° C, 15% fines	24° C, 15% fines

Figure 5. Schematic of the 12 different proposed treatments, with three replicates of each.

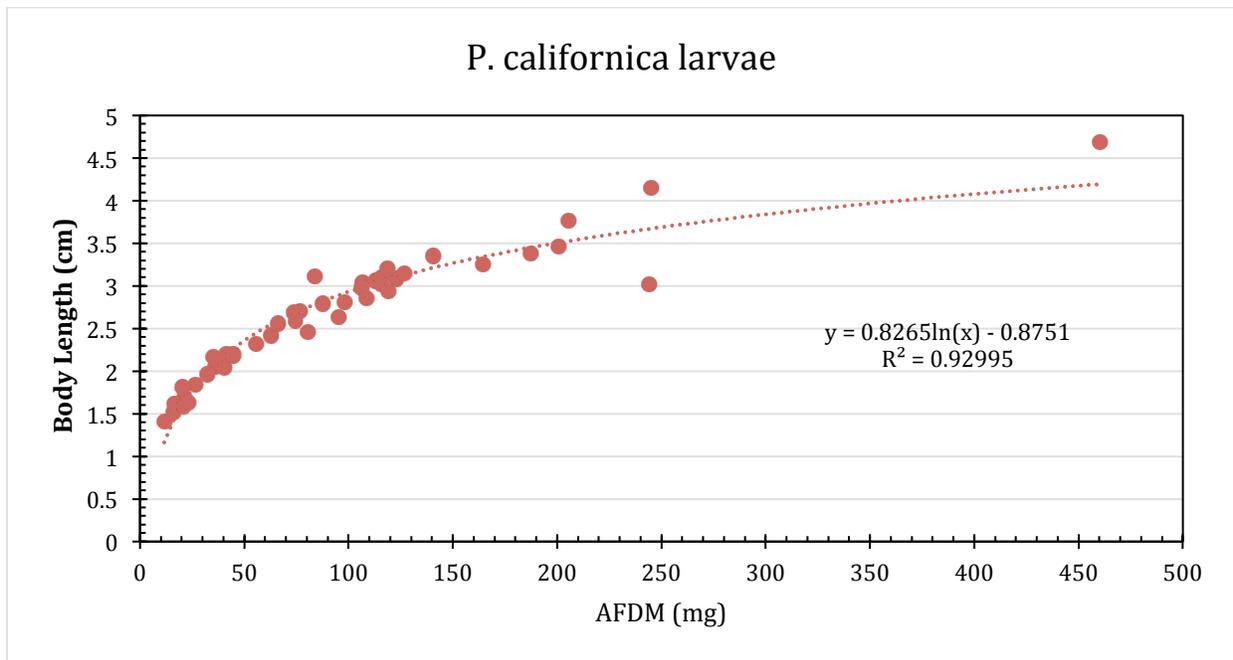


Figure 6. Relationship between AFDM and body length of *P. californica* larvae, collected collected just downstream of Jack Smith Bridge on the Gallatin River (45 17.741, -111 13.014).

Characterizing Microbial Activity as Related to Water Quality in the Clark Fork Headwaters: A Baseline Study

Basic Information

Title:	Characterizing Microbial Activity as Related to Water Quality in the Clark Fork Headwaters: A Baseline Study
Project Number:	2016MT302B
Start Date:	3/1/2016
End Date:	2/28/2018
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Ecology, Water Quality, Surface Water
Descriptors:	None
Principal Investigators:	Alysia Cox

Publications

There are no publications.

Characterizing Microbial Activity as Related to Water Quality in the Clark Fork Headwaters: A Baseline Study

Progress Report for the Montana Water Center

Dr. Alysia Cox

Laboratory Exploring Geobiochemical Engineering and Natural Dynamics (LEGEND)

Chemistry and Geochemistry Department

Montana Tech

Project Overview

This project aims to link microbial identity and activity with water quality data on the Upper Fork in order to provide both an indication of metal contamination from past mining on the overall health of the system and serving as a baseline for evaluating the effects of future climate change on microbial and chemical processes in this ecosystem. This research addresses the following basic questions: What is the baseline microbial community and activity in the headwaters of the Clark Fork and how do they relate to the water chemistry? What is the level of metal contamination reached in these headwaters and does the microbial community reflect that? How will microbial activity change with the climate (lower water flow, higher CO₂ available for photosynthesis)? The microbial community and activity is expected to correlate with the water chemistry and reflect the level of metal concentrations in these waters. These results will contribute to water quality and remediation solutions now and in the future.

Preliminary Results

Fourteen sites on Silver Bow and Blacktail Creeks, German Gulch, and the Upper Clark Fork were sampled every three months beginning in May 2016 (Figure 1). Preliminary data for this project were collected at five locations on Silver Bow and Blacktail Creeks in August 2015 and February 2016. At each site, time sensitive parameters were measured with a hydrolab (temperature, pH, conductivity, dissolved oxygen); field spectrophotometry was performed for dissolved silica, ferrous iron, and sulfide; water samples were collected and filtered for immediate analyses in the lab (hydrogen and oxygen isotopes in water, dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), major cations and anions, and trace elements), and biological samples, both sediment and planktonic biomass, were collected and frozen on dry ice for lab extraction and analyses.

We found that the headwaters of the Upper Clark Fork range in pH from 6.2 to 9.4 and in temperature from 0 to 20°C, with higher pH values and temperatures in August (Figure 2). This means that the water is outside the range of EPA aquatic life pH standards at some times and locations. The temperatures reached in August tend to be above the 15°C recommended for inland freshwater fish.

Zn concentrations vary from less than 10⁻⁷ to 10⁻⁵ molal in the Upper Clark Fork and Silver Bow and Blacktail Creeks (Figure 3). These concentrations are somewhat elevated for the pH values measured. A few sampling times and locations exceeded EPA aquatic life limits for dissolved zinc.

More connections will be made between the geochemistry of the Upper Clark Fork and the microbial life when already extracted DNA samples are sent for sequencing. The geochemical analyses are already performed. Analysis of DNA will reveal the metabolic potential of the system as well as provide a baseline for ecosystem health. Protein extractions to

be performed this summer will show microbial activity, allowing us to link metabolic activity with concurrent geochemistry.



Figure 1: 14 sampling locations on the Upper Clark Fork and Silver Bow and Blacktail Creeks (map done in DataBasin).

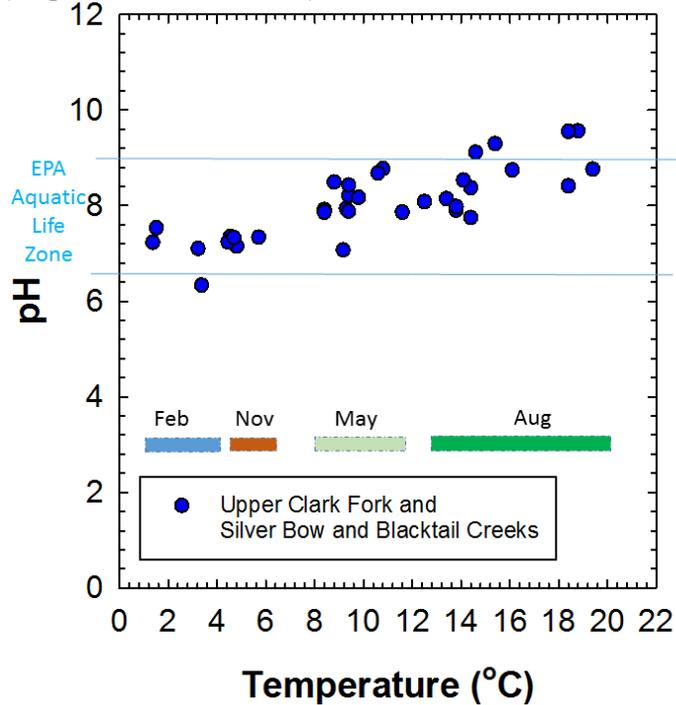
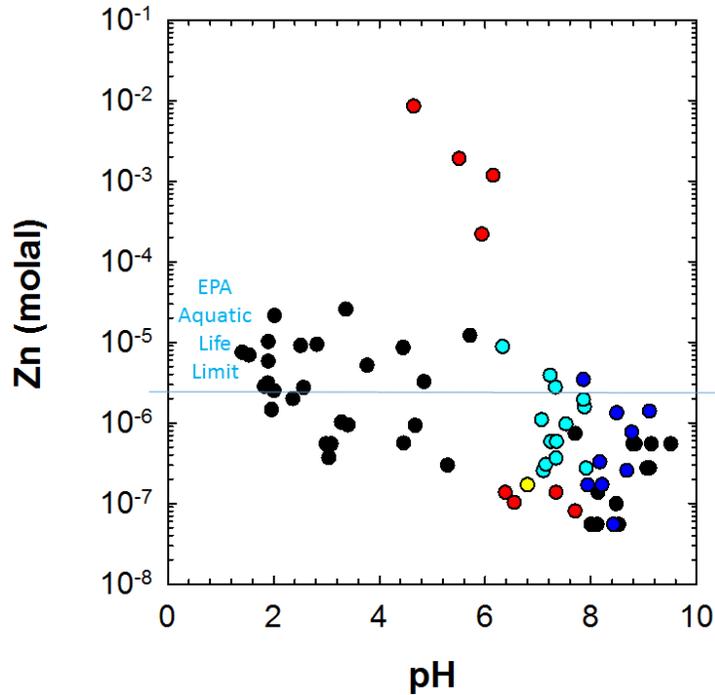


Figure 2: pH vs. Temperature on the Upper Clark Fork and Silver Bow and Blacktail Creeks.



- Yellowstone Hot Springs
- Whitetail Reservoir
- Butte Flooded Mines
- Upper Clark Fork River
- Upper Silver Bow and Blacktail Creeks

Figure 3: Zn vs. pH for a wide variety of sampling locations including the Upper Clark Fork and Silver Bow and Blacktail Creeks.

Ongoing Work

DNA extractions have been successfully performed on one set of the sediment samples, PCR for universal, Bacterial, Archaeal, and Eukaryotic 16S and 18S rRNA genes performed, and DNA preserved. Plans are underway to send pure DNA extracts off for metagenomic sequencing.

Protein extractions in LEGEND are starting on May 8th, the third phase of getting our lab fully operational. Analyses of these extracts will occur in-house this summer and will provide us with information about microbial activity.

This work is a part of Jordan Foster's undergraduate thesis. He has been interested in this project since his freshman year and will be starting his junior year this fall. We will be writing up geochemical and microbial results for publication in Frontiers.

Also, we plan to continue sampling every three months so we can observe how and why the system is changing over time. Samples will be preserved for later geochemical and biological analysis pending more funding.

Budget

This grant provided partial summer funding for three female scientists: one undergraduate (1.5 months), one graduate (1.5 months), and one assistant professor (0.5 months). It also provided field sampling supplies to help support 4 sampling expeditions, as well as lab supplies for LEGEND to be fully capable of environmental DNA extractions. In addition, funds were used to pay the Montana Bureau of Mines and Geology for major anions and trace elemental analyses.

Budget Match

The majority of the match was provided by my time. Joe Griffin, our consultant, also donated his time by helping us plan our sampling scheme and going out sampling with us.

Field Research Expeditions

Students involved (5 masters, 3 undergraduate): Jordan Foster, McKenzie Dillard, Renee Schmidt, Georgia Dahlquist, Shanna Law, Mallory Nelson, James Foltz, Cynthia Cree. Others involved: Joe Griffin, Cathy Cree.

February 2017, Upper Clark Fork/Silver Bow and Blacktail Creeks, (3 days), A Cox, field leader.

November 2016, Upper Clark Fork/Silver Bow and Blacktail Creeks, (2 days), A Cox, field leader.

August 2016, Upper Clark Fork/Silver Bow and Blacktail Creeks, (2 days), A Cox, field leader.

May 2016, Upper Clark Fork/Silver Bow and Blacktail Creeks, (3 days), A Cox, field leader.

Related Grant Activity

I submitted a grant to the Butte Area One Butte Natural Resource Defense Council (BNRC) entitled "Microbial Activity in Silver Bow and Blacktail Creeks" in the amount of \$77,225. This grant was recommended for funding by the BNRC on April 20th and goes to Helena for approval by the state and governor in a June 5th meeting.

I also used some of the data collected for this grant in an NSF CAREER proposal that was not funded in 2016. Reviews were positive and I will resubmit this July.

Undergraduate researcher Jordan Foster was supported the summer of 2016 on an Institute on Ecosystems Summer Fellowship for \$4,000. His work was directly related to this grant.

Publications

* indicates MS student MTEch author, ** indicates undergraduate MTEch author

Cox AD, Schmidt R*, Dahlquist GR*, Foster J**, Dillard M** 2016. Habitability from the surface to the deep. American Geophysical Union (AGU) Fall Meeting Abstract B51K-07.

Invited Talks

Cox A, Schmidt R*, Foster J**, Dahlquist G*. How healthy is our ecosystem? Check the microbes and geochemistry! Citizens Technical Environmental Committee (CTEC) Meeting, Butte, MT, April 13th, 2017.

Cox A. Microbial Activity in Silver Bow and Blacktail Creeks. Butte Area One Butte Natural Resource Defense Council Meeting, Butte, MT, April 5th, 2017.

Cox A. Environmental Dynamics in Geobiochemical Engineering: From Supervolcanoes to Silver Bow Creek. Montana Tech Public Lecture Series, Butte, MT, September 8th, 2016.

Cox A. Environmental Dynamics in Geobiochemical Engineering: From Supervolcanoes to Silver Bow Creek, NIH Bringing Research Into the Classroom (BRIC) Teacher Academy, Helena, MT, June 12th, 2016.

LEGEND Presentations

* indicates MS student MTech author, ** indicates undergraduate MTech author

Cox A, Schmidt R*, Dahlquist G*, Foster J**, Dillard M**, Law S*, Nelson M*, Cree C**, Foltz J*. Aquatic Habitats from Hot Springs to Silver Bow Creek. Montana Aquatic Research Colloquium Flathead Lake Biological Research Station, MT, Talk, April 8th, 2017.

Cox A, Foster J**, Schmidt R*, Dahlquist G*, Dillard M**. Defining Microbial Habitats in Mining Impacted Watersheds. Montana American Water Resources Association Conference, Fairmont Hot Springs, MT, Talk, October 14th, 2016.

Foster J**, Cox A. 2016. Stormwater in Silver Bow and Blacktail Creeks: Implications for the microbial community. Techxpo poster, April 3rd. Best Poster Department of Chemistry and Geochemistry.

Foster J**, Cox A, 2016. Stormwater in Silver Bow and Blacktail Creeks: Implications for the microbial community. Montana Academy of Sciences Meeting talk, April 9th. *Laurie Henneman Outstanding Student Presentation Award for Best Undergraduate Student Oral Presentation.

Student Fellowship: Impacts of glacial processes on nitrogen cycling in the Beartooth Mountains, Montana

Basic Information

Title:	Student Fellowship: Impacts of glacial processes on nitrogen cycling in the Beartooth Mountains, Montana
Project Number:	2016MT303B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Water Quality, Hydrogeochemistry, Climatological Processes
Descriptors:	None
Principal Investigators:	Jordan Allen

Publications

There are no publications.

Glacial influence on nitrogen cycling: Beartooth Mountains, MT

Background and context:

Nitrogen is one of the main limiting factors on primary production, and is particularly important in low-nutrient systems, as is the case in most alpine environments. Waters draining from glacial alpine catchments have inorganic nitrogen (N) concentrations, specifically nitrate, which are an order of magnitude higher than adjacent non-glaciated systems (Saros et al. 2010). Increased nitrate input to headwater lakes from the glaciated catchments increases phytoplankton and diatom populations and the elevated N concentrations persist downstream, impacting multiple downstream lakes (Slemmons and Saros 2015). However, the specific source of the elevated nitrate concentrations remains unknown. The goals of this project are to determine a) the magnitude of N concentration variation in adjacent glaciated and non-glaciated catchments in the Beartooth Mountains and b) the source(s) for this nitrate and the processes that control its supply.

Hypothesis:

Elevated nitrate in glaciated catchments derives its source from recently glaciated substrate. The finely comminuted bedrock provides increased fresh surface area to supply organic nitrogen and ammonia that is then converted microbially to nitrate, elevating nitrate levels in downstream waters.

Research Approach:

Study Area:

The Beartooth Mountains are located in a designated wilderness area in south central Montana, on the border of Wyoming, just northeast of Yellowstone National. Two different catchments are being compared in the Beartooth Mountains; one glacially fed (GF) catchment with an adjacent snow-fed (SF) catchment. The Jasper catchment (GF) will be compared to the Albino catchment (SF) in the eastern side of the Beartooth Mountains. The paired catchments provide an excellent natural laboratory to examine the effects of glacial processes because of their similarities in atmospheric input (rainfall/snowfall and precipitation source), elevation, and bedrock lithology.

Exploratory field work, 2015

The catchments were visited briefly in August 2015 and water and bedrock samples collected. The anion and cation concentrations of the water samples were determined via ion chromatography. The petrography of the rock samples were analyzed in thin sections and their chemical composition measured using X-ray fluorescence (XRF) techniques.

Winter, 2016

Snow was collected in April from a snowpit located in WY close to the Jasper/Albino paired catchments (this is the closest location that can be accessed by snowmobile, due to Wilderness designation for the MT lands) to determine the winter atmospheric input of N to these catchments. The water equivalence of the snowpack will be determined from density measurements and chemical species including nitrogen species will be analyzed via ion chromatography. Samples will also be taken for isotopic analysis $\delta^{18}\text{O-NO}_3$, $\Delta^{17}\text{O-NO}_3$ and $\delta^{15}\text{N-NO}_3$ of the snowpack (atmospheric) nitrate (Michalski et al., 2003; Christner et al., 2014; Louiseize et al., 2014; Wasiuta et al., 2015a & b).

Summer, 2016

Water samples were collected from the two catchments, measuring at multiple sites downstream from the glacier (Figure 1) at multiple time points during the summer meltseason. July, August,

September, and October concentrations of major anion and cation species were analyzed from both catchments. Samples for the isotopic analysis of nitrate will also be taken for comparison with those for snowpack input. Sediment and bedrock samples were collected for weathering experiments. Stream discharges were taken using both salt and float methods in an attempt to understand the order of magnitude of N flux through the system.

Fall, 2016

Laboratory weathering experiments were conducted using snow(melt) and ice-melt mixed with proglacial sediments to simulate natural weathering processes (Montross et al., 2013). One set of samples will be sterilized to evaluate abiotic processes only, the other set will contain the indigenous microbes, thus reflecting the sum of biotic and abiotic processes, with the biotic processes being obtained by difference (Montross et al., 2013). Geochemical and isotopic analyses of nitrate will be conducted for comparison with field samples.

Results

Field and lab work has shown agreement with previous studies that glacial catchments have approximately an order of magnitude higher nitrate (NO_3^-) than their non-glaciated counterparts. Initial results point to glacial and microbial processes driving these differences.

Analysis from a glacial stream in the Beartooth Wilderness from its headwaters at an alpine glacier to the first major lake were analyzed throughout the 2016 summer and fall (Figure 1). Ion chromatography of the waters in both glaciated and unglaciated catchments was used to show that nitrate levels were significantly higher in glaciated stream. Analysis of the highest waters in the glacial catchment showed that waters initially have very low nitrate concentrations immediately below the glacier, but that there is a significant amount of ammonium (NH_4^+) (see Figures 2-3). As the water moves downstream the concentration of ammonium decreases and the concentration of nitrate increases. There is also a higher concentration of nitrate as the season progresses from July to October. This increase in concentration is likely due to a decrease in runoff as snow and ice supply diminish through the melt season (Table 1). Flux of nitrate during the measured time period can be seen in Table 2.



Jasper and Albino Catchments (Imagery From August 2015)

 Proglacial area since 1952

source

 GF

 SF

Jordan Allen
05/10/2015
Montana GIS Clearinghouse
USGS NED
Contour interval: 20 meters

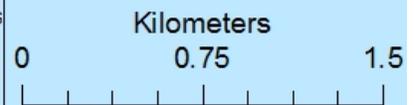
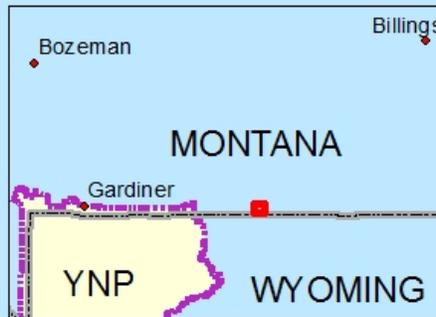


Figure 1 2016 summer-fall sites: Sites showing collection points in summer 2016. Source indicates a glacial (GF) or snow (SF) source upstream from the sample location. Sample locations are given in elevation.

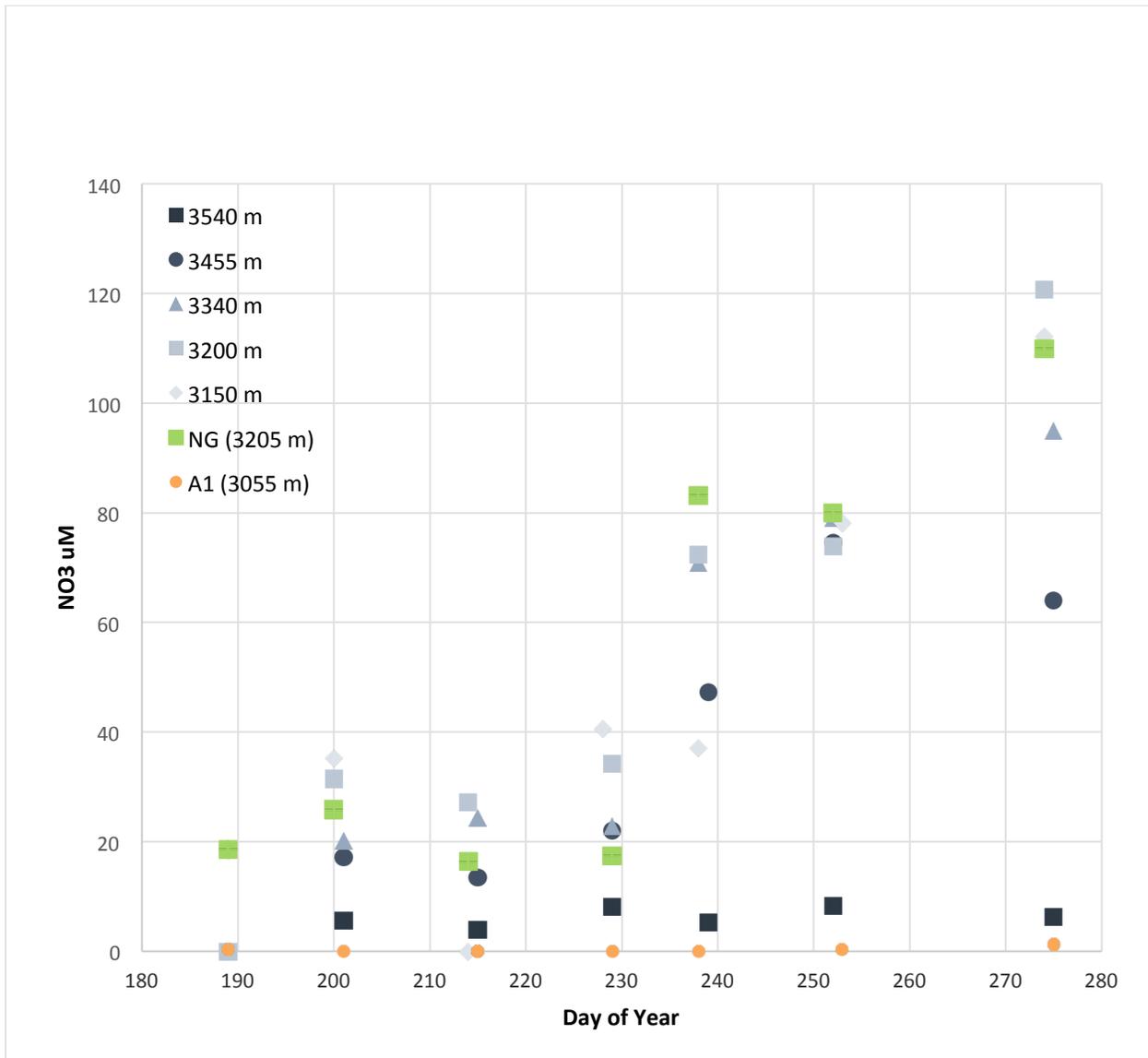


Figure 2 shows concentrations of nitrate at low elevation sites have up to several orders of magnitude higher nitrate concentrations in glaciated catchments when compared to catchments that are wholly unglaciated. These differences are amplified as the melt season progresses; glaciated sourced waters increase from ~20-40 ppm to 60-120 ppm as the melt season progresses, while the Albino (non-glaciated) waters remain low (<2 ppm). Non glacial sites are NG and A1 while glacial sites are denoted by elevation. The mirroring of the NG site with the glacial sites is suspected to be caused by glaciation in this small tributary stream's headwaters in the recent geologic past, but this research is still ongoing.

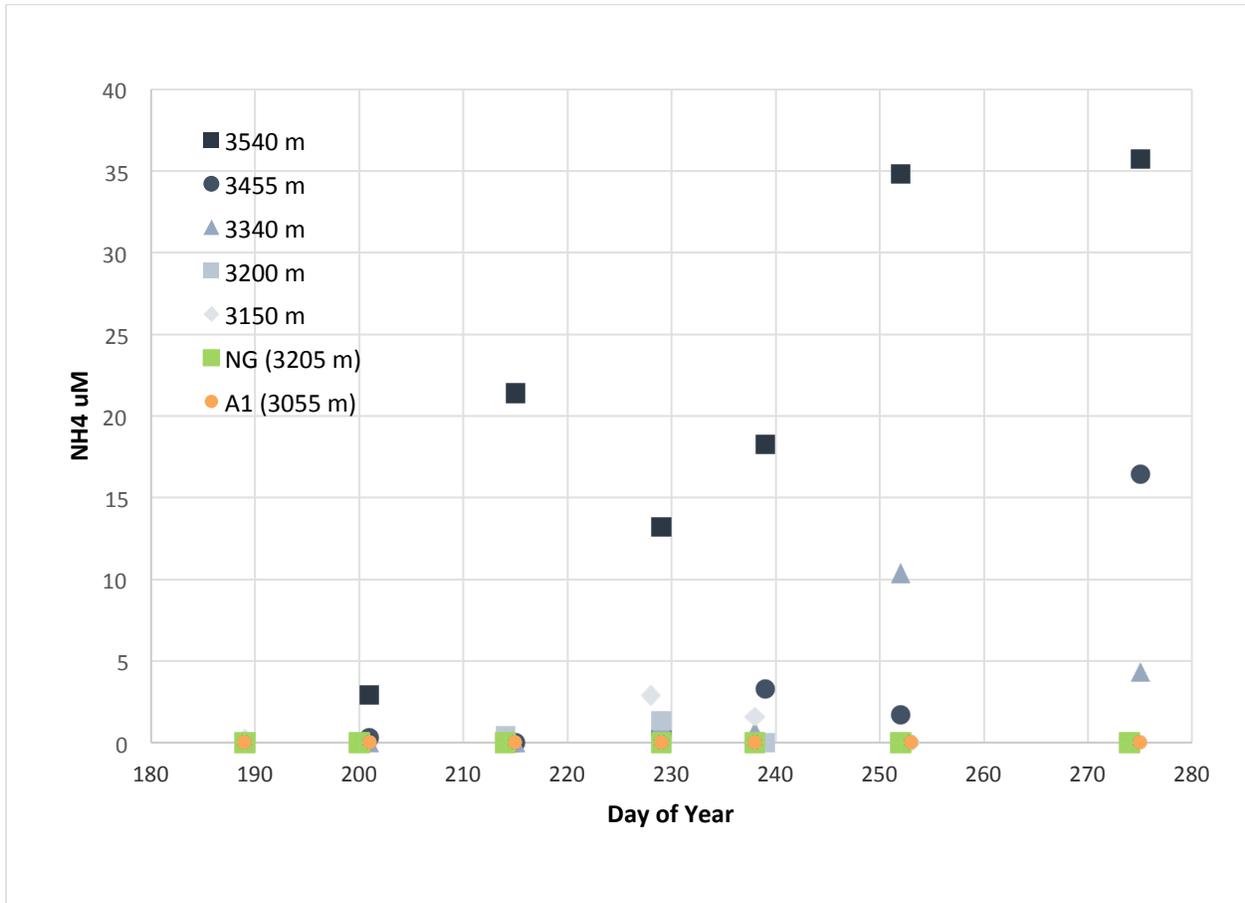


Figure 3 shows only trace quantities (<1 ppm) of ammonium in non-glacial waters (NG and A1). This is in contrast to the highest glacially sourced waters (all sites denoted by elevation); the highest two sites have significant amounts of ammonium (up to 35 ppm), but there is a dramatic decrease in ammonium concentrations below the highest two sites (never exceeding 10 ppm). Concentrations tend to increase as the melt season progresses, but the trend is less dramatic than with nitrate.

Table 1 showing measured discharge values of the glacial stream. Discharge measurements were taken between the two lowest sites (3150 and 3200) of the glacial catchment.

Day Number	Time of Day	Precip on Day (mm)	Avg Temp (deg C)	Float Q (m ³ /s)	Salt Q (m ³ /s)
189	15:15	3	8.3	0.153	NA
200	16:30	0	14.7	1.416	NA
214	15:45	5	11.6	1.196	NA
229	14:00	0	12.8	0.378	0.419
238	11:00	0	3.9	0.338	0.139
253	11:15	0	3.9	0.143	0.006
274	15:40	0	7.4	0.245	0.011

Table 2 showing the approximate flux of nitrate in the glacial stream during the measured time periods.

Micromolar nitrate flux/season (day 189-274) (float)	Micromolar flux/season (day 229-274) (salt)
1.26286E+11	13734897162

The progression of the increasing nitrate down-stream is most notable in the recently deglaciated area that lies below the retreating glacier. The proglacial area contains large amounts of recently ground fine grained sediments derived from the local bedrock. Glacial processes created this expanse of fine grained sediment by grinding and abrading the rock.

The local rock consists of many potassium rich minerals and contains ~3% potassium by weight (Figure 4 and Appendix 1). The potassium ion is similar in size and charge to the ammonium ion and ammonium can replace the potassium in certain conditions. The mineralogy of the rocks indicates that there have been metasomatic processes in the rocks history that would help facilitate this replacement process.

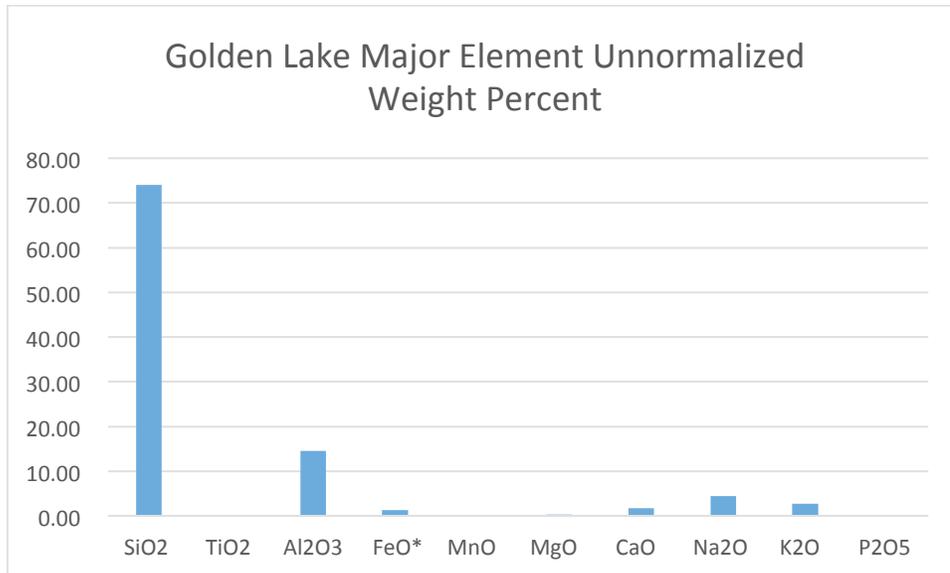


Figure 4 showing that representative bedrock is made of ~3% potassium, which ammonium often replaces

Microbial processes collectively known as nitrification can lead to the oxidation of ammonium to nitrate. It is plausible that this process is ongoing in the proglacial area due to the high abundance and availability of unoxidized ammonium present in the sediment.

Conclusion

Nitrate levels in the Beartooth Mountains are elevated in glacially derived waters when compared to precipitation derived waters in this alpine environment. Concentrations of nitrate increase throughout the melt season as stream levels decrease. Sediment derived from glacial processes provides a potential source for the nitrogen found in the waters. Microbial processes are a potential driver converting ammonium to nitrate in proglacial areas.

Ongoing research

Ongoing research hopes to analyze the RNA in the stream waters to identify potential nitrifiers and to identify isotopic signatures of the nitrogen to determine precise sources for the nitrate seen downstream of this alpine glacier.

Acknowledgments

I would like to thank the Montana Water Center, the Tobacco Root Geologic Society, the Montana Geologic Society, and Montana State University for their funding; this work would have not been possible without their support. I would also like to thank my field technicians Tim O'Brien, Adam Pate, Krystal Kiel, Paul Allen, Ian van Coller, and Drew Riemersma for all their help in the field. I would also like to acknowledge the input from my committee, other faculty, and fellow graduate students. It truly takes a village, thank you all.

Sincerely,

Jordan Allen

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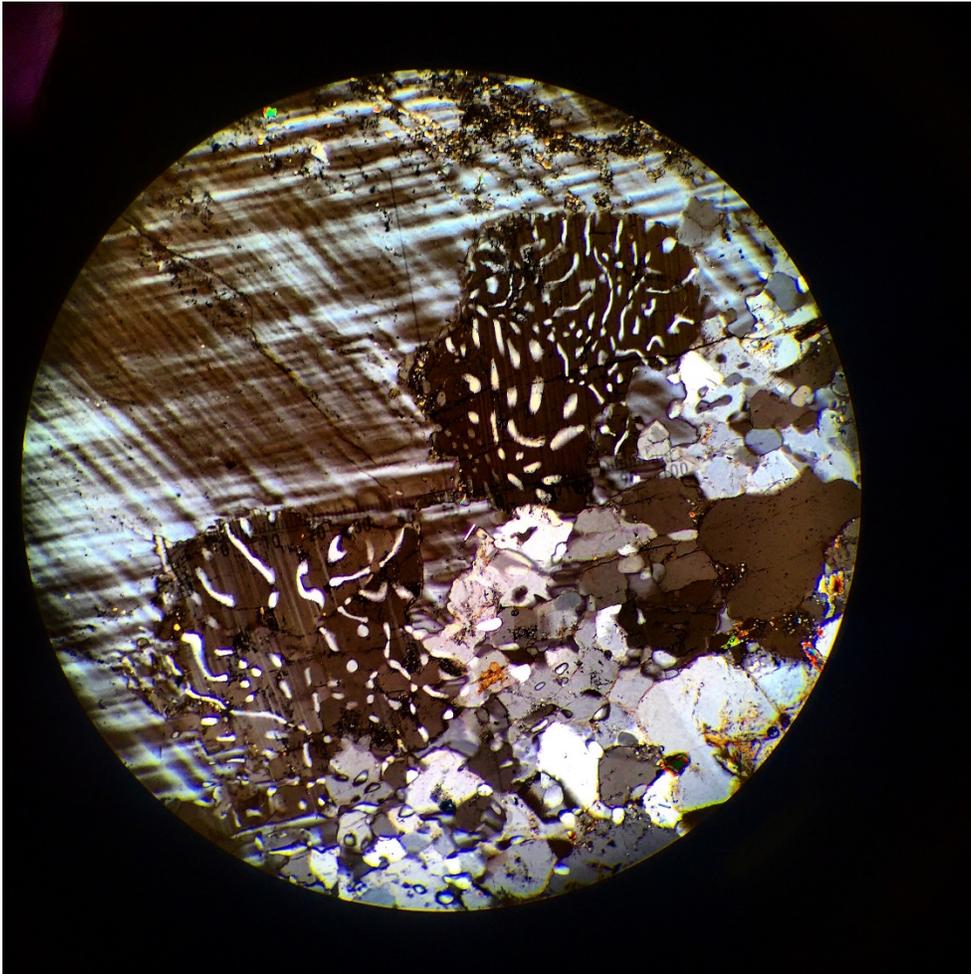
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Appendix 1

Sample 4

Location: Beartooth Mountains

Golden Lake



Main Stage Metamorphic Minerals

Quartz: 28%

Plagioclase: 10%

Microcline: 30%

Orthoclase: 27%

Biotite: 2%

Hornblende: 2%

Figure 5: FOV=4mm. This thin section shows large amounts of potassium bearing microcline. The Myrmekite is indicative of metasomatic processes that can facilitate ammonium replacing potassium in rocks

Accessory Minerals

Zircon: <1%

Muscovite: <1%

Clinopyroxene: <1%

Myrmekite:<1%

Opaque:<1%

Retrograde Minerals

Biotite alteration (oxides, radiation halos, others): 1%

Name: Hydrous Hornblende Biotite Quartz Feldspar Granular Gneiss

Megascopic Description:

Granular, un-oriented, pink-white-orange rock with large (1.5 cm) quartz, (1 cm) potassium feldspar, and (1 cm) plagioclase crystals. Much smaller (<0.1 cm) darker minerals (dark green-black) are seemingly randomly scattered and un-oriented; some of these can be identified as amphiboles with a hand lens.

Textural Description:

Quartz often exhibits mottled extinction. Quartz crystals range from .01-3.5mm in size.

Opagues are rare and never reach larger than .5 mm in length. Crystal habit is rare

Plagioclase is less common than the K-feldspars but can be large in size. Crystals range from .1-4mm

Microcline is present and in large quantities, typically .5-7 mm in size. The microcline exhibits typical tartan twinning. Because the grid twinning is an inversion texture, it shows that the original feldspar was once monoclinic.

([http://minerva.union.edu/hollochk/c_petrology/ig_minerals.htm#Potassium feldspars](http://minerva.union.edu/hollochk/c_petrology/ig_minerals.htm#Potassium%20feldspars))

Orthoclase seems to be present as well. The crystals range from .5-3mm in size; this makes sense if the slower cooling crystals became microcline with tartan twinning and were able to reach larger sizes due to their slower cooling.

Biotite is present and, along with hornblende, accounts for nearly all of the mafic minerals present in the rock. Crystals are un-oriented and reach up to .8 mm in length. Biotite appears to alter to

Hornblende is also present and is typically never larger than .7 mm.

Zircon is present as an accessory mineral in some biotites and is more easily seen by radiation halos in the biotites.

A few minor occurrences of muscovite were also seen but in very small quantities. The crystals never reached larger than .2 mm.

Clinopyroxene was seen in very small amounts and reached up to .1 mm in length.

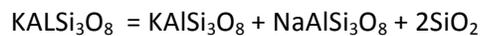
What appeared to be secondary oxides would also fill cracks in or around other crystals.

Myrmekite is also seen, with quartz growths never being larger than .05mm

Origin and History:

Slow cooling of orthoclase led to the development of microcline.

Myrmekite indicates metasomatic conditions of this rock.



H-T K-feldspar K-feldspar myrmekite

Student Fellowship: Transportation, Sediment-Association, and the Future of Microbial Contaminants on the Little Bighorn River

Basic Information

Title:	Student Fellowship: Transportation, Sediment-Association, and the Future of Microbial Contaminants on the Little Bighorn River
Project Number:	2016MT304B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	1
Research Category:	Biological Sciences
Focus Category:	Water Quality, Surface Water, Hydrology
Descriptors:	None
Principal Investigators:	Keenan Brame

Publications

There are no publications.

Keenan Brame 2016 Montana Water Center Student Fellowship Project Summary

ABSTRACT

Pathogen contamination is a common cause of pollution in rivers and streams in the United States, causing health concerns and illness, especially in children and the elderly. The Little Bighorn River, located on the Crow Reservation in southeastern Montana, has a history of microbial contamination but, despite awareness, members of the community use the river for recreation and in ceremonial practices. This study was conducted on June 30th, 2016 where 6 sites were sampled along the River, monitoring the indicator organisms: coliform and *Escherichia coli*. Microhabitats (planktonic, sediment-associated) within the water column were assessed for differences in indicator organism processing. Coliform and *E. coli* were detected at every site, with three sites having mean *E. coli* values greater than the recommended limit for recreation proposed by the EPA.

INTRODUCTION

Pathogen contamination is responsible for 30% of impairment of all assessed river and streams in the United States that have been assessed for ecological condition by the National Rivers and Streams Assessment (NRSA) ^[1]. Impairment is defined as a waterbody being too polluted to serve its primary purpose. Pathogen contamination poses a concern to human-water contact, places stress on water treatment plants, and can effect river-groundwater interface, affecting nearby well owners ^[2, 3, 4]. The Little Bighorn River, located on the Crow Reservation in south-central Montana, holds significant cultural importance to members of the community and is the source of municipal water for the largest town on the Reservation, Crow Agency, and an Indian Health Service hospital. The river serves as a recreation hot spot for many members of the community during the summer months and raw river water is used by Tribal members in ceremonial and traditional practices, despite awareness of water contamination ^[5]. Results of prior work have shown that microbial water contamination issues are of great concern during spring and summer months, when the river experiences the most recreational activity by community members ^[6, 7].

There is little known about how microorganisms attach to suspended sediment in water, their survival and transport when attached, and how projected changes in the climate will affect these microorganisms and waterborne disease. A spatial and temporal study was proposed for monitoring indicator organisms (coliform, *Escherichia coli*), their partitioning trends between sediment-association and planktonic microhabitats in the water column, and if these indicator organisms are present in locations that experience elevated levels of recreation. Indicator organisms are studied in aquatic environments as indicators of pathogen pollution. Often when coliform and *E. coli* are detected in inflated numbers there are other pathogens present, including those that pose a threat to human health. In this study, indicator organisms were quantified using Colilert and Quanti-Tray/2000 system (IDEXX Laboratories) which produces a most probable number (MPN) per 100mL of water sample.

This study was proposed to complete a sampling date during the receding limb of discharge, when peak-runoff flows are receding towards base flow. This sampling point complements one of many that will complete a three year field study on the Little Bighorn River and will be useful in comparing different stages of the dynamic river system. The primary questions for this study are if, for a given time, are there differences in numbers of coliform and *E. coli* between sites, and how does partitioning between planktonic and sediment-association differ between sites for coliform and *E. coli*.

METHODS

Site Descriptions

The Little Bighorn River flows north out of the Bighorn Mountains in Wyoming, through national forest and into Montana where the mountains transition into hills and plains. The most upstream site is located about 13 miles from the Montana/Wyoming border with the most downstream site located in Crow Agency, MT, about 45 miles away from the Montana/Wyoming border. 6 sites on the Little Bighorn River were selected in a previous proposal for sampling purposes and were used in this study to compare between other sampling dates. Sites were chosen based on public health impact (2 swim holes, municipal water treatment plant intake), spatial differences in swim holes (above each swim hole), and as a control (tributary). The following site locations and reference labels, which will be used throughout this report, are listed in the order sampled and from most upstream to most downstream sites on the River. (1) Spear Siding bridge above the Lodge Grass/Wyola swim hole (SS-ASH), 45.1808°N, -107.3888°W, (2) Spear Siding at the Lodge Grass/Wyola swim hole (SS-SH), 45.2102°N, -107.3807°W, (3) Lodge Grass Creek tributary (LGC), 45.0411°N, -107.6861°W, (4) Crow Agency water treatment plant intake (WTP), 45.5930°N, -107.4653°W, (5) above the Crow Fair swim hole (CA-ASH), 45.5977°N, -107.4533°W, and (6) at the Crow Fair swim hole (CA-SH), 45.6001°N, -107.4533°W.

The most upstream sites (SS-ASH, SS-SH, and LGC) are all free flowing, shallow (<3ft) and narrower than downstream sites with a gravel riverbed. WTP has standing water, the depth of which is unknown, due to a dam about 200 feet downstream from the intake that is used to flood an irrigation ditch. The most downstream sites (CA-ASH and CA-SH) are free flowing, but controlled by the irrigation ditch dam, which affects the discharge at these sites over the course of the summer, shallow (<3ft) and wider than upstream sites, with a gravel riverbed.

Field Sampling

On the 30th of June, 2016 samples were collected from the described sites over the course of 2 hours. This date was selected as discharge was declining from peak runoff towards summer base flow, a time point that has not been sampled over the course of the project. At each site, three 4 liter sterile bottles were filled with surface water in as quick of succession as possible from the middle of the Little Bighorn River, with the exception of WTP, which was taken from river bank. Each replicate was labeled and placed on ice immediately after sampling for return to MSU. Environmental data was collected using an EXO¹ Multiparameter Sonde (YSI Inc. / Xylem Inc.) to measure conductivity, specific conductance, pH, temperature, blue-green algae, chlorophyll, dissolved oxygen, and total dissolved solids (Table 1). Duplicate riverbed sediment samples were collected from each side of the river with sterile 50mL conical vials and stored on ice. A 100mL negative control of sterile deionized water was taken to the field, opened, and returned to MSU in the same cooler as water samples.

Laboratory

Samples were returned same day to MSU where more ice was added to each cooler and stored in a 4°C cold room for storage until processing. Each replicate sample was shaken by turning the containers over at least 4 times quickly then separated into 3 different sterile containers for processing different components of the study (planktonic, total, microbial community). Planktonic samples were processed first, starting with the first location sampled (SS-ASH) and finishing with the last location sampled (CA-

ASH). Two replicates were processed at the same time. 2, 250mL centrifuge tubes were filled from one replicate to allow for adequate volume for total suspended solids (TSS) and indicator organism processing. Once 6, 250mL centrifuge tubes were filled and balanced, they were placed in a Sorvall GSA rotor in a Sorvall RC-5B Refrigerated Superspeed Centrifuge (Du Pont Instruments) and centrifuged at 2700rpm (1146xg) for 10 minutes at 4°C [8,9]. After centrifugation, 50mL of water was transferred from each centrifuge tube to sterile bottles for mixing with IDEXX Colilert substrate packs. 50mL of sterile deionized water was mixed with the sample water for dilution to ensure the IDEXX Quanti-Tray/2000 did not blow out, allowing for all coliform counts to be represented. Duplicates from each replicate were taken, leading to 6 MPNs per site, and 36 MPNs per date for planktonic coliform and *E. coli* counts. Colilert substrate was added to each replicate, shaken, transferred to a Quanti-Tray/2000, sealed and placed in a 35°C incubator without shaking for 24 hours. The remaining 100mL of water in the centrifuge tubes was transferred to 250mL glass bottles for storage in the 4°C cold room until TSS processing.

Total indicator organism processing followed a similar protocol as planktonic. Each total replicate was shaken then 25mL was transferred to sterile bottles for indicator organism processing. Duplicates were again taken for each replicate, leading to 6 MPNs per site and 36 MPNs per date for total coliform and *E. coli*. 75mL of sterile deionized water was added to each replicate, Colilert substrate packs were added to each replicate, shaken, transferred to Quanti-Tray/2000, sealed and placed in a 35°C incubator without shaking for 24 hours. Once all raw water samples were incubated, the negative control sample followed the same protocol for coliform and *E. coli* detection. The original 3 replicate samples for the site were placed in the cold room until TSS processing.

Total suspended solids were processed following Standard Method 2540D [10]. in duplicate for each treatment per working sample, producing 36 TSS values per treatment, per day.

The third working sample for each replicate was processed in the same manner as the planktonic indicator organism numbers for microbial community collection. Samples were centrifuged following the same protocol as above. 125mL from each duplicate passed through one 0.22µm filter, totaling 250mL of planktonic water sample per replicate. The remaining water was discarded and each centrifuge bottle with remaining sediment-associated pellet had sterile water added to it, shaken, briefly vortexed, and the water-sediment mixture was passed through a 0.22 µm filter, totaling 500mL of sediment-associated water per replicate. Filters were stored in -80°C freezer until DNA extraction (not performed for this report).

Riverbed sediment samples were allowed to settle. Water was decanted off the top of the sediment, sediment was homogenized and duplicate aliquots were taken and placed in sterile 1.5mL conical vials and frozen at -80°C until DNA extraction (not performed for this report).

RESULTS

MPN Results

Every Quanti-Tray/2000 was positive for coliform and *E. coli*, except for the negative control sample. WTP, CA-ASH and CA-SH sites produced total *E. coli* MPN means higher than the recommended recreational limit of 126 colony forming units (CFU) per 100mL of water sample [11] (Figure 1). ANOVA results showed that there is no significant difference between total *E. coli* MPN means in SS-ASH, SS-SH, LGC and WTP, but are significantly different from CA-ASH and CA-SH, which are not significantly

different from each other. CA-ASH and CA-SH planktonic *E. coli* MPN means were also elevated above the recreational limit (Figure 2). Upstream sites SS-ASH and SS-SH produced planktonic *E. coli* mean MPNs less than that of the recommended limit, along with LGC. Planktonic *E. coli* MPN means follow the same ANOVA site clustering as total *E. coli* results.

Total coliform MPN trends showed similar results to that of *E. coli* except for LGC, which had the largest average MPN total of all sites (Figure 3). SS-ASH and SS-SH total coliform MPN mean values are not significantly different and are significantly different from all other sites. WTP total coliform MPN means are significantly different from all other sites. LGC, CA-ASH and CA-SH total coliform means are not significantly different from one another, but are significantly different from other sites. Planktonic coliform MPN averages follow similar trends to that of total coliform results, but show less difference between sites (Figure 4). SS-ASH planktonic coliform MPN mean is not significantly different from that of SS-SH and is significantly different from all other sites. SS-SH mean planktonic coliform MPN is not significantly different from WTP, but is from LGC, CA-ASH, and CA-SH. The LGC mean planktonic coliform MPN is not significantly different from CA-ASH and CA-SH, but is for all other sites. The WTP mean planktonic coliform MPN is not significantly different from CA-SH, but is from LGC, CA-ASH and SS-ASH. The CA-ASH mean planktonic coliform MPN follows the same trend as LGC. The CA-SH mean planktonic coliform MPN is not significantly different from LGC, CA-ASH and WTP, and is significantly different from SS-ASH and SS-SH.

Indicator Organism Partitioning and Trends

Total and planktonic coliform and *E. coli* counts were plotted against each other (Figures 5 and 6). Coliform produced an r^2 value of 0.61 and *E. coli* produced an r^2 value of 0.85.

Partitioning was calculated by dividing the planktonic MPN count for coliform or *E. coli* by the total MPN count coliform or *E. coli* for each site giving the proportion of planktonic cells compared to that of the total (Figures 7 and 8). ANOVA results for *E. coli* partitioning trends show that the mean SS-SH *E. coli* planktonic proportion is significantly different from CA-ASH and CA-SH, which are not significantly different from each other, and not significantly different from SS-ASH, LGC and WTP. Mean planktonic proportion of *E. coli* MPNs for sites SS-ASH, LGC and WTP are not significantly different from any other site. Mean planktonic proportions of coliform MPNs for sites SS-ASH and SS-SH are not significantly different from each other, and are significantly different from all other sites, which are not significantly different from each other.

Total Suspended Solids and Indicator Organism Relation

Mean TSS values were under 20mg/L for all sites except LGC which had a mean value of 58.31mg/L (Figure 9). ANOVA results show that the mean TSS values for SS-ASH and SS-SH are not significantly different and differ from all other sites. Mean TSS values for all other sites are significantly different from each other.

Comparing total coliform and *E. coli* MPNs has proven to have a positive relationship in prior sampling dates. This report provided an opposite view, that showed a very weak relationship between total coliform and TSS ($r^2 = 0.35$) and no relationship between total *E. coli* and TSS ($r^2 = 0.05$) (Figures 10 and 11).

DISCUSSION

An important observational study point was completed for the purposes of monitoring indicator organisms during discharge recession from peak to base flow on the Little Bighorn River. This study provided an important river setting to a three-year study that will provide information on indicator organism trends on a commonly used river on the Crow Reservation. Data collected during this study period will be compared between other sampling points to provide information to the local community on water quality and possible health impacts of recreating in the River.

Results of indicator organism processing showed that *E. coli* and coliform was present at every site sampled and that of *E. coli* was elevated beyond the recommended limit for recreation in the two sites in Crow Agency. These results had an immediate impact in that while sampling, there were young children swimming in the swim hole (CA-SH) below where sampling was conducted. These results were able to be relayed to the Steering Health Committee in Crow Agency after samples were processed and data analyzed.

Partitioning trends of potentially harmful organisms in water systems is of current interest and is important to understand what times of the year and river conditions that organisms are partitioning between planktonic and sediment-associated habitats because it is hypothesized that those associated with sediments can survive and remain viable longer in a freshwater system. Partitioning trends change throughout the year and this sampling date will provide information to how changing river dynamics might play into this.

In previous sampling dates, TSS and cell counts have been positively correlated, but this study showed that this is not always the case. Understanding what drives microbial pollution on the River is important to human health on the Reservation and is currently under more investigation. Molecular work being developed now for use when DNA samples are extracted will provide more information regarding the sources of pollution and how the total microbial community differs between microhabitats within the water column.

TABLES

Site	Temp (°C)	pH	Cond (µS/cm)	Specific Cond (µS/cm)	Chl-a (µg/L)	Chl-a (RFU)	BGA-PC (µg/L)	BGA-PC (RFU)	DO (% sat)	DO (mg/L)	TDS (mg/L)
SS-ASH	20.506	8.42	353	386	0.53	0.12	0.08	0.04	95.7	8.61	230
SS-SH	21.068	8.44	359	388	1.23	0.24	1.89	1.14	93.7	8.34	233
LGC	23.054	8.41	458	475	3.16	0.82	3.26	0.74	88.7	7.59	298
WTP	24.341	8.45	476	482	1.85	0.50	0.16	0.12	85.8	7.17	309
CA-ASH	25.134	8.49	484	482	1.48	0.40	0.15	0.11	98.7	8.14	313
CA-SH	25.124	8.49	485	484	1.47	0.38	0.15	0.11	98.9	8.15	315

Table 1. Environmental data collected at each site using continuous measurements on EXO¹ Multiparameter Sonde. Data are collected using a laptop and measurements are taken after pH and temperature are shown as constant.

FIGURES

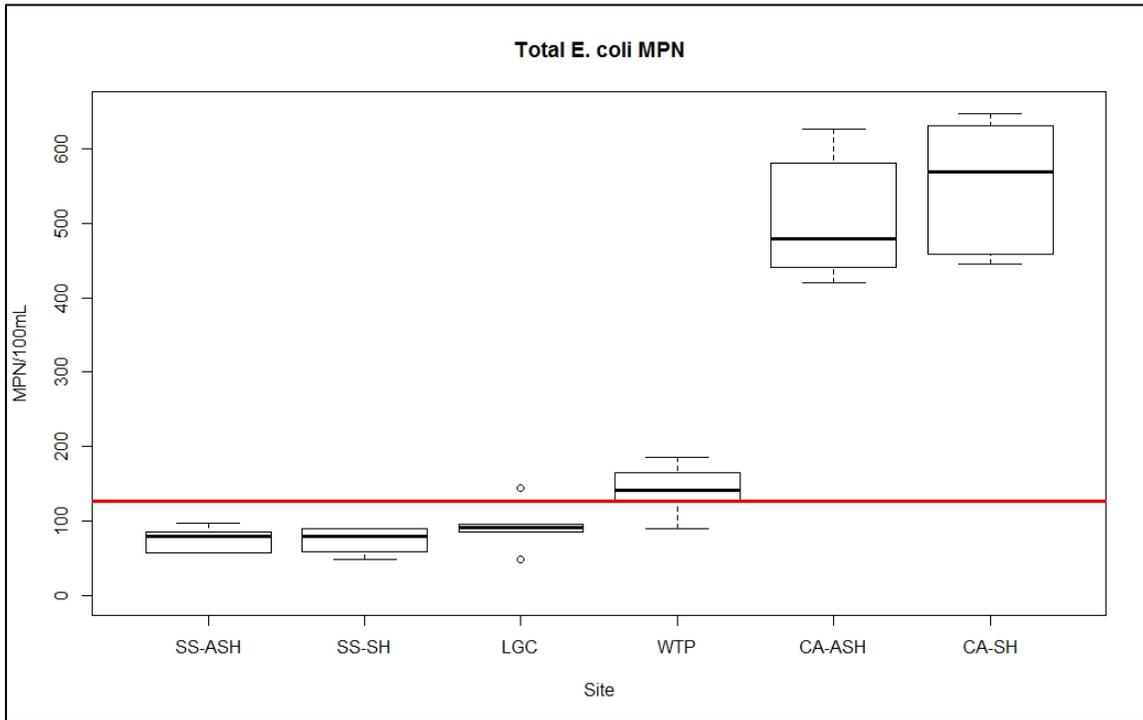


Figure 1: Boxplot of total *E. coli* MPNs. Horizontal line represents 126CFU/100mL recommended recreational limit for *E. coli*. Sites are in order upstream to downstream from left to right on the x-axis.

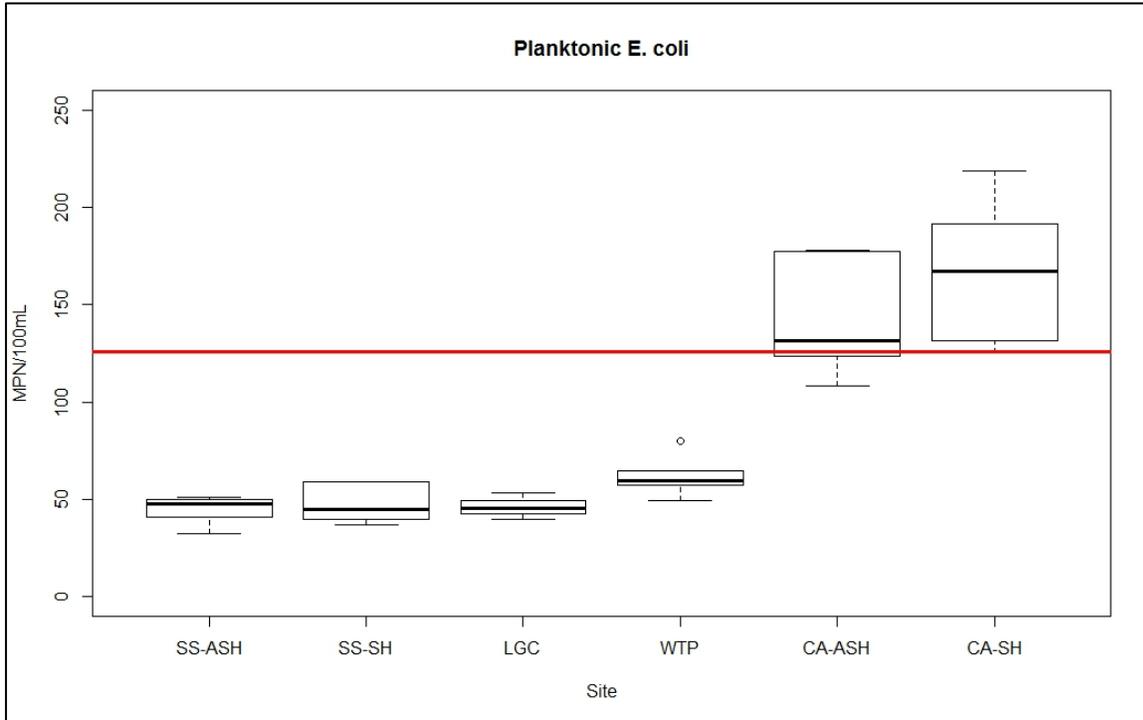


Figure 2. Boxplot of planktonic *E. coli* MPNs.

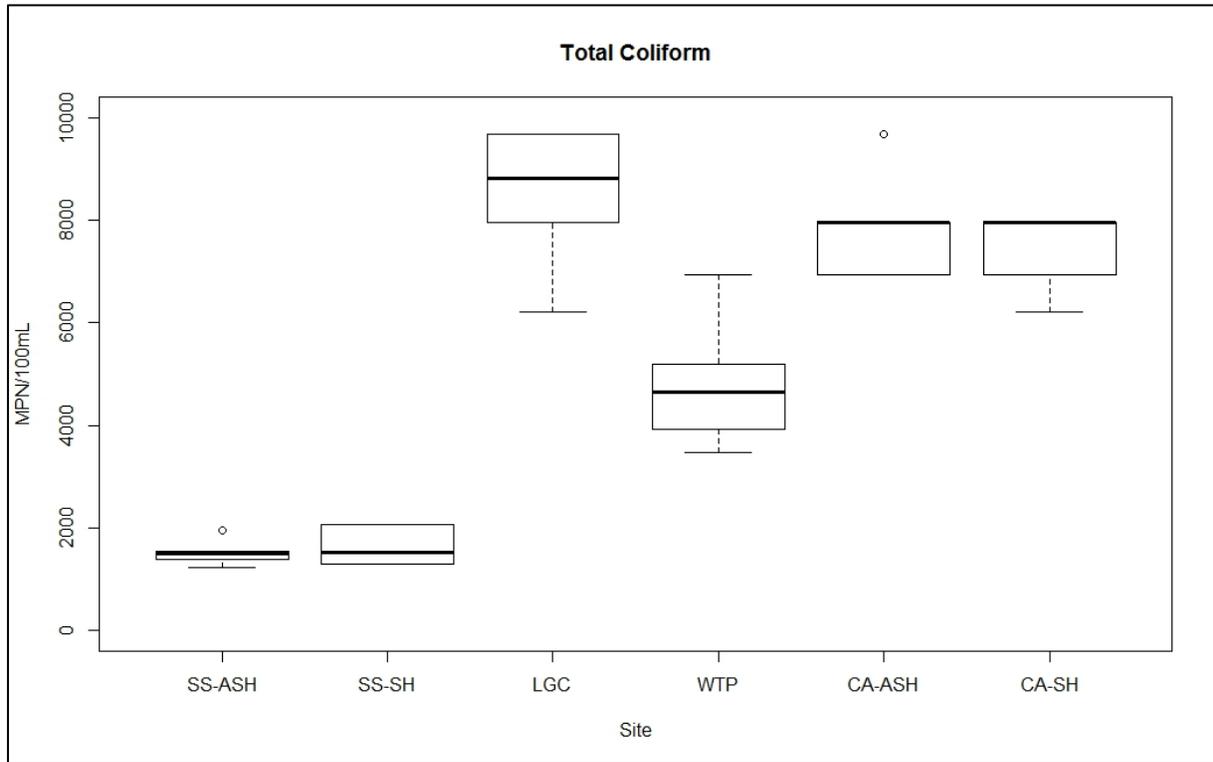


Figure 3: Boxplot of total coliform MPNs.

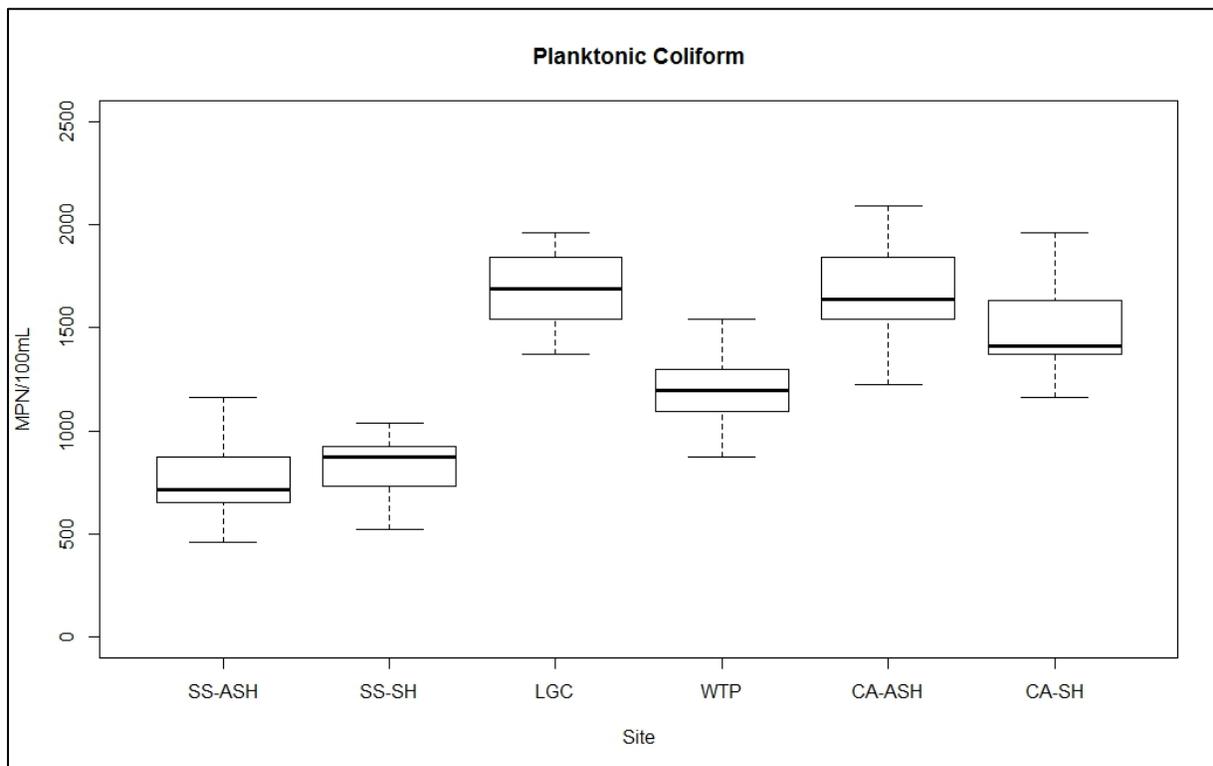


Figure 4: Boxplot of planktonic coliform MPNs.

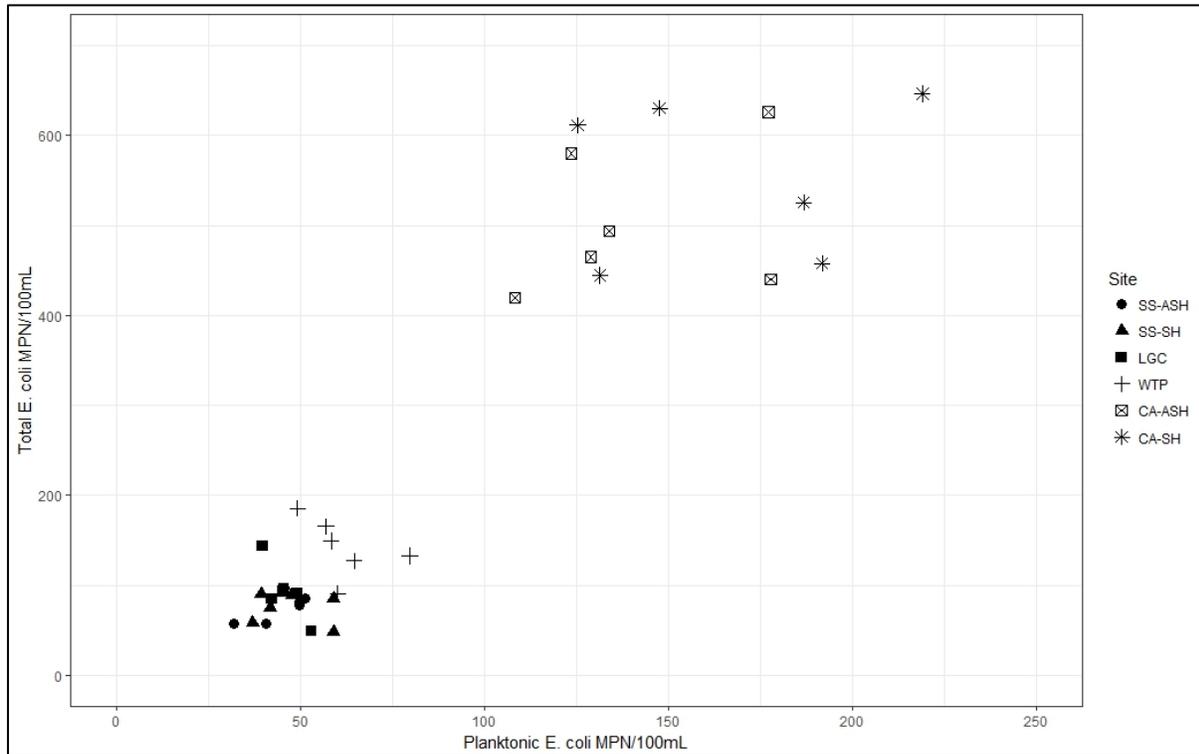


Figure 5: Total *E. coli* MPNs vs. planktonic *E. coli* MPNs.

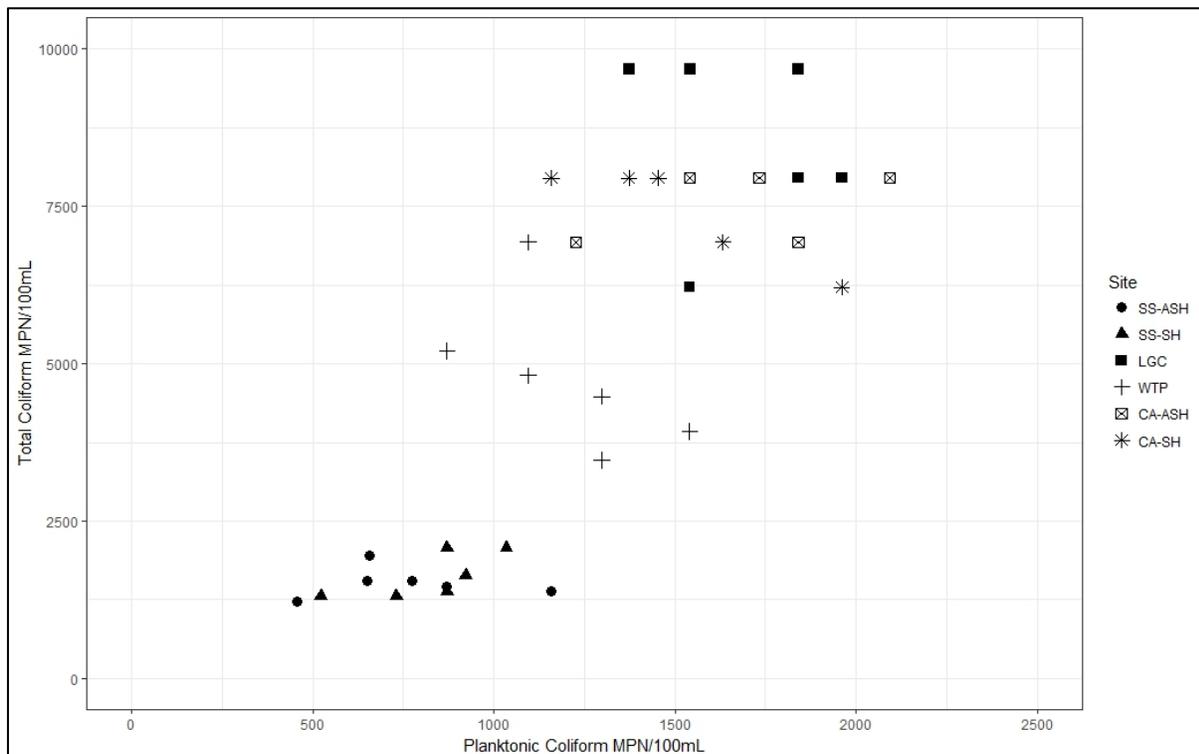


Figure 6: Total coliform MPNs vs. planktonic coliform MPNs.

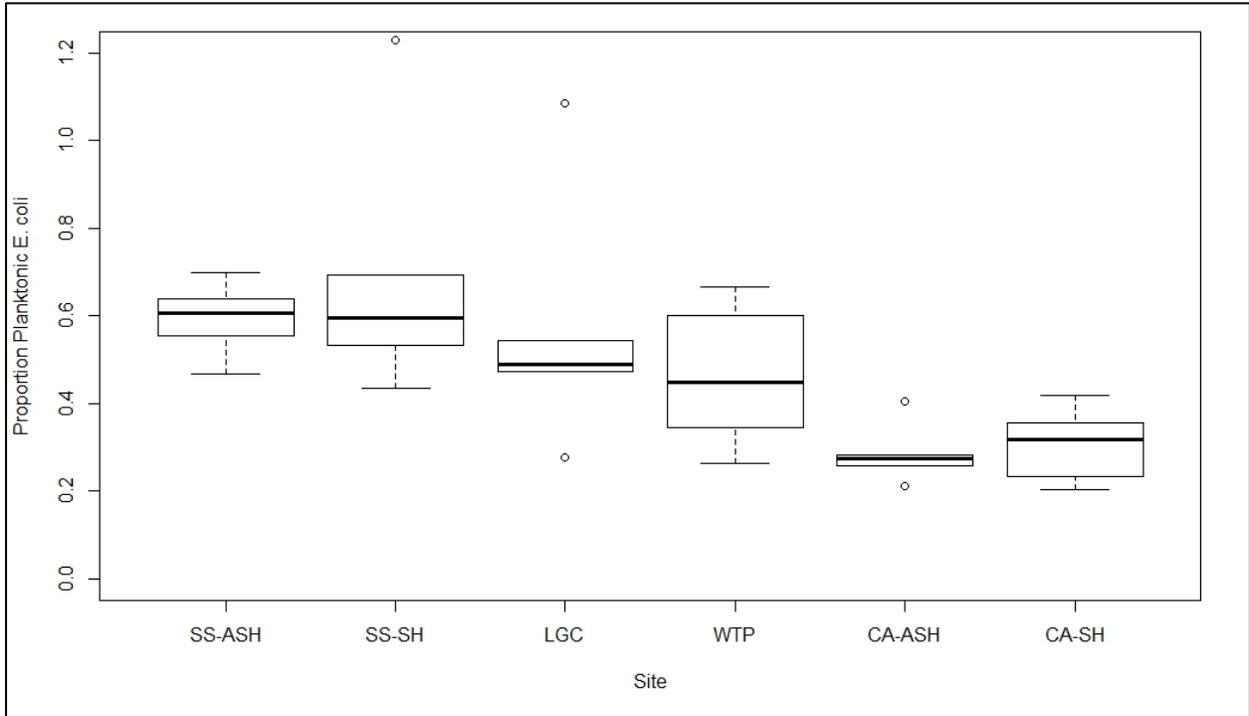


Figure 7: Proportion planktonic *E. coli*.

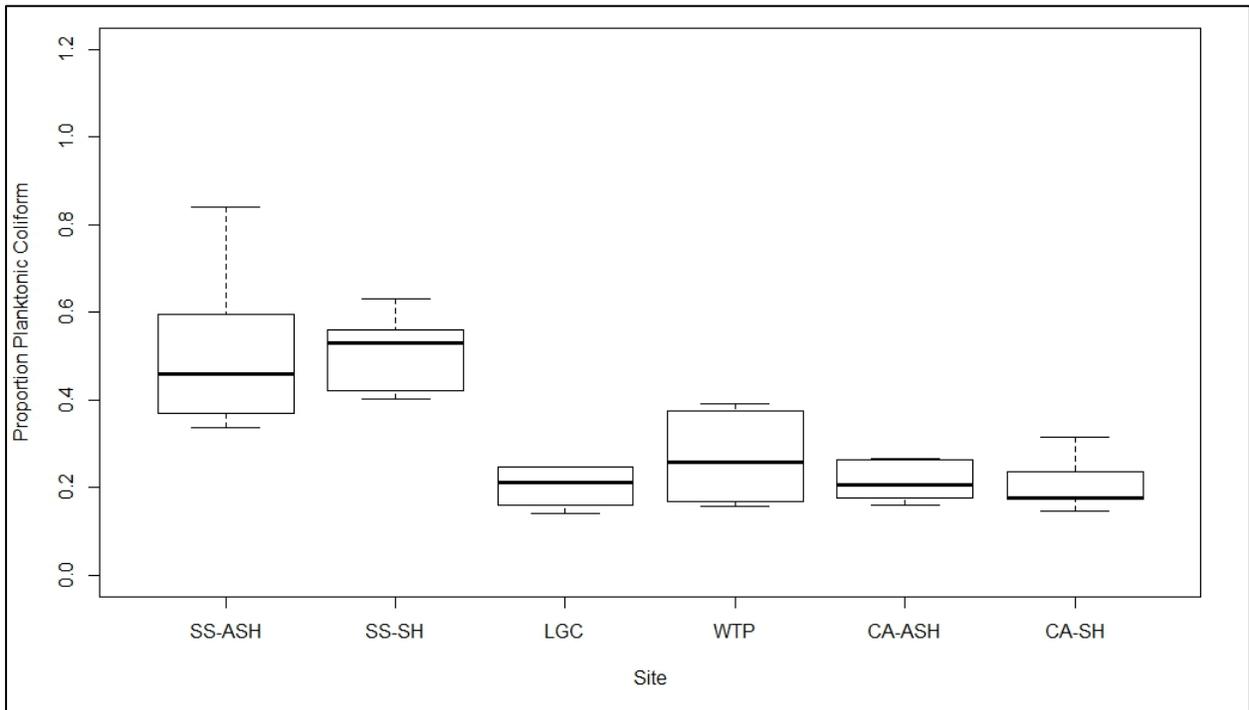


Figure 8. Proportion planktonic coliform.

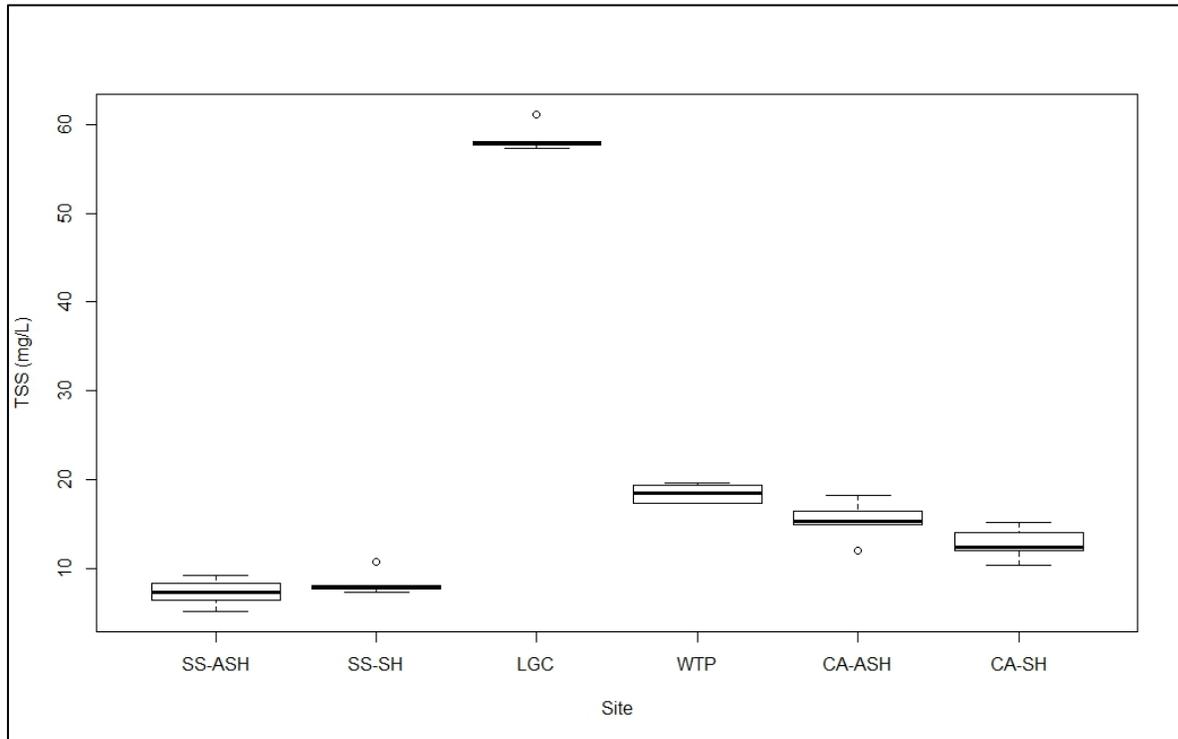


Figure 9. Boxplot TSS.

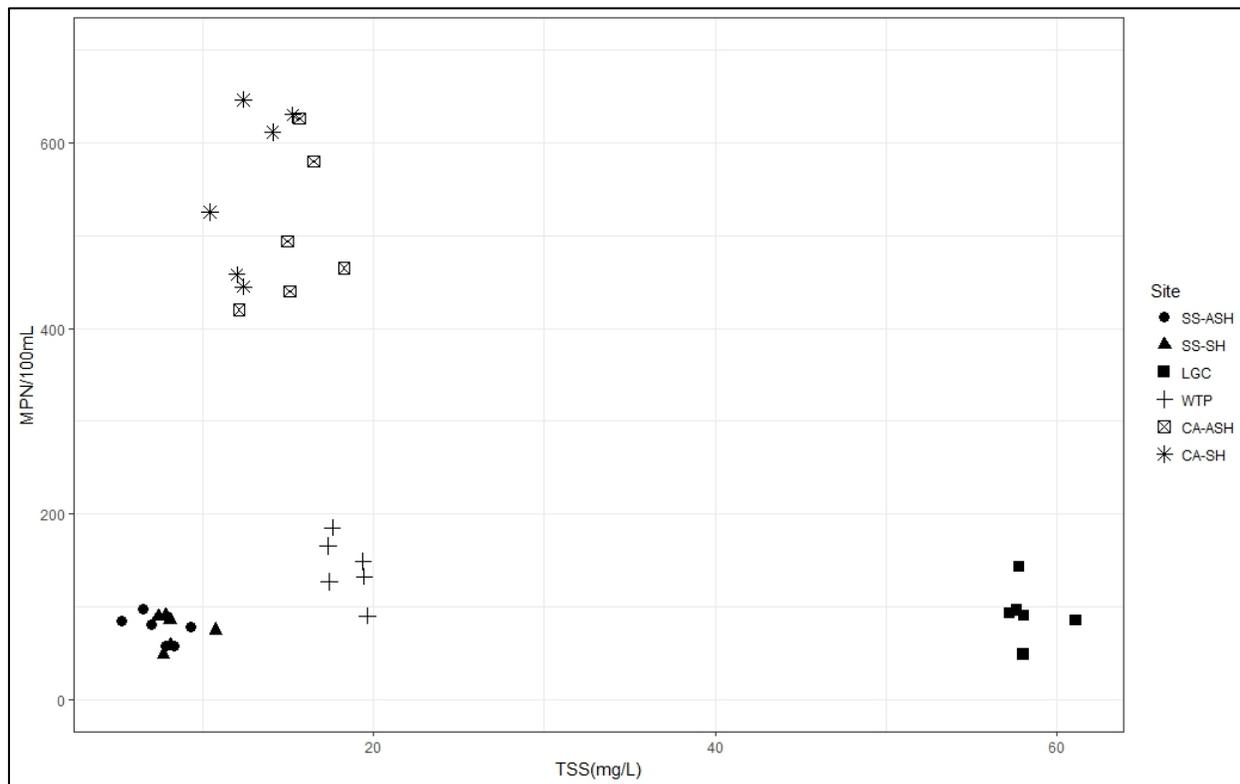


Figure 10. E. coli v TSS

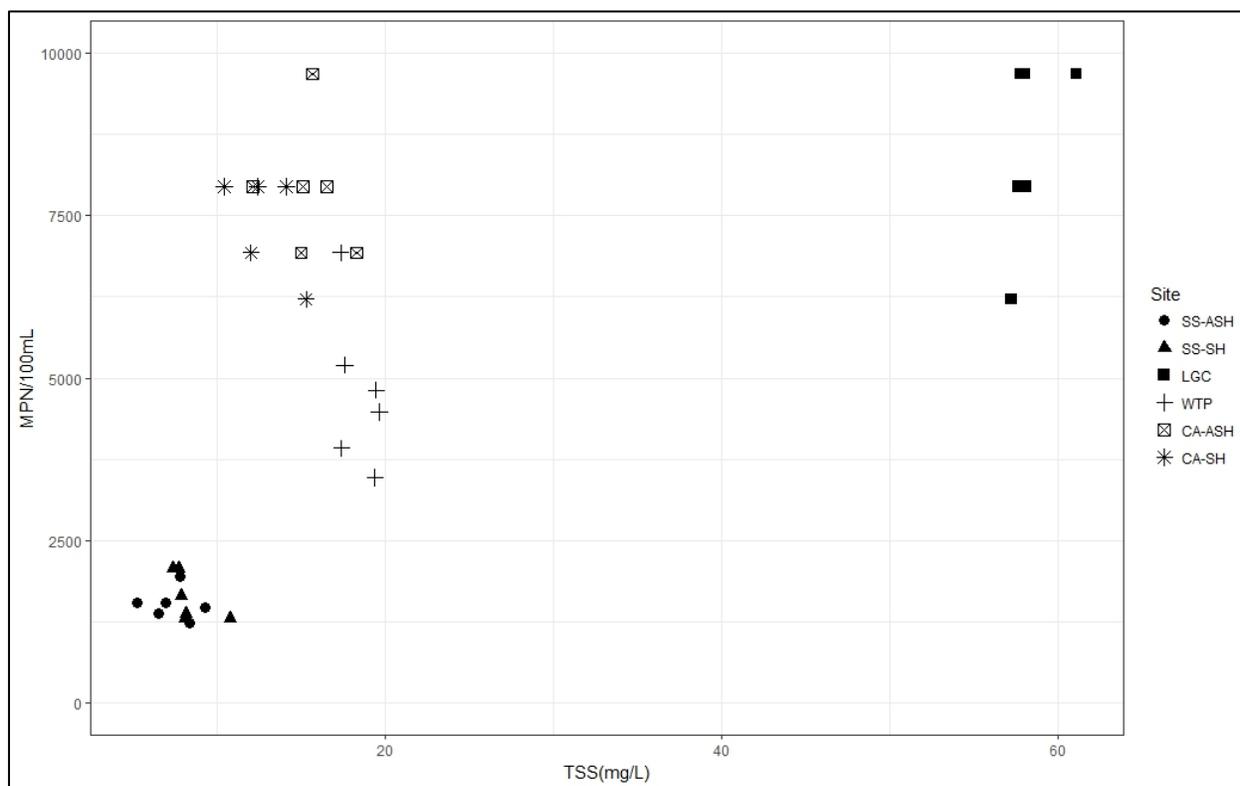


Figure 11. Coliform vs. TSS

ACKNOWLEDGEMENTS

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Student Fellowship: Riparian Ecosystem Succession Following Fire Disturbance on the North Fork Flathead River, Montana

Basic Information

Title:	Student Fellowship: Riparian Ecosystem Succession Following Fire Disturbance on the North Fork Flathead River, Montana
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Publications

There are no publications.

Montana Water Center Fellowship-Final Report

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Introduction

In North America, the occurrence of natural fire disturbance on ecosystems has recently been accepted to have beneficial effects on long-term forest ecosystem health. In fact, restoration and conservation practices have incorporated fire as a management tool. This restoration practice must be tailored to an ecosystem's unique mechanisms and post-fire disturbance behavior as it is known (Christensen, 2014). In contrast to upland forests ecosystems, the study of fire disturbance changes, or succession, is poorly understood in riparian ecosystems. Currently, studies typically take place immediately following fire (short-term: <1 yr) or relatively soon thereafter (mid-term: 1-10 yr). There is a lack of knowledge about how riparian ecosystems respond in the long-term (>10-300 yr) (Tuckett and Koetsier, 2016). Because of current limitations of knowledge, and the inevitability that fire management will continue in forest ecosystems, broadly based research on riparian fire disturbance regimes is required to design strategies for sustainable streamside management.

Riparian ecosystems are considered to be among the most diverse and dynamic habitats. These areas offer key habitat components to an array of species and can serve as refuge for wildlife (Naiman and Decamps, 1997). In addition, riparian areas are considered buffer strips that provide numerous ecological functions to their nearby stream systems. Riparian tree canopies contribute to the reduction of stream temperatures, which is needed for cold-water aquatic species. Woody debris from riparian areas add structure to in-stream habitats as well as allochthonous organic matter as a food source (Tuckett and Koetsier, 2016). The roots from riparian plants contribute to bank stability by upholding soil structure (Johnson, 2004). They serve as buffers for nutrients as well as stabilizing the banks. These functions that riparian areas provide have the potential to be greatly

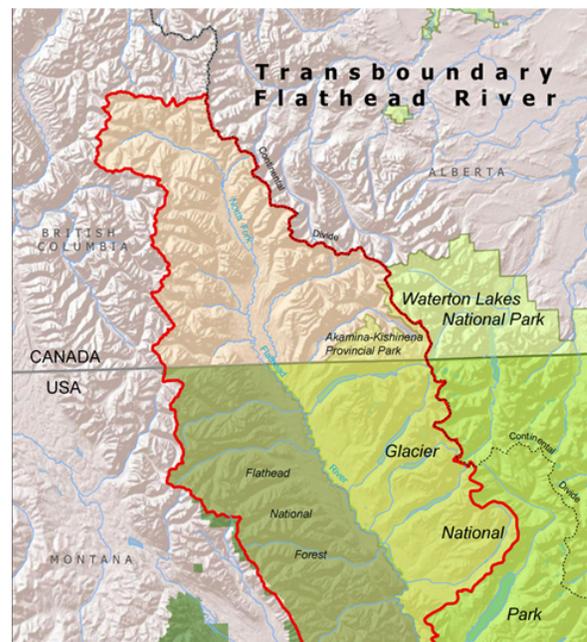
influenced by fire. Fire changes plant community composition and abundance. Considering this, the regeneration of riparian vegetation can dictate the duration and magnitude of fire disturbance on these ecosystems (Minshall, 2003).

It is important that there is rapid riparian regeneration post-fire to ensure that vital ecological functions are provided to adjacent streams. The term “resiliency” as applied to ecosystems, is defined as “the amount of disturbance that an ecosystem could withstand without changing self-organized processes and structures” (Holling, 1973). This study seeks to gain an understanding of how fire disturbance affects riparian ecosystems in terms of ecosystem resiliency.

Riparian areas are typically subjected to many forms of disturbances, such as fluvial, wind, avalanche, drought, insect outbreaks and plant disease (Halovsky, 2008). Riparian plant species possess adaptations to fluvial disturbances that assist survival and reestablishment, thus contributing to the rapid recovery of many streamside habitats. For example, sprouting enables the survival of vegetation on site. Exposure to wind and water, post-disturbance, aids to recolonization (Dwire and Kauffman, 2003). The high soil moisture level and water tables can also contribute to quicker recovery in riparian areas. The inherent network structure of riparian areas includes linkages between channels and floodplains (lateral), between upstream and downstream (longitudinal), and between channel and river bed (vertical). These linkages contribute largely to the resilience of riparian ecosystems following disturbances (Richardson et al., 2007).

Study Area

The North Fork of the Flathead River in northwestern Montana near the Canada-US border provides the North American hydrographic apex



with headwater streams flowing to the Pacific Ocean, Hudson Bay and Gulf of Mexico. The area contains Glacier National Park and Flathead National Forest with Stillwater and Coal Creek state forests to the west (Figure 1). Watersheds included in these protected areas are considered relatively untouched (Rood et al., 2005). Developments along the North Fork are concentrated in the Polebridge community and Apgar at the southern end of Lake McDonald in Glacier National Park (Bunnell and Zimmerman).

This region has experienced several large-scale wildfires in the past decades, altering the fluvial geomorphology of the North Fork and its tributaries, as well as the surrounding landscape. The Red Bench Fire burned 38,000 acres of National Park, National Forest, and private land near Polebridge, MT in September 1988. In early September, 2001, the Moose Fire burned from the Flathead National Forest over the North Fork river into Glacier National Park, burning a total of 71,000 acres. Historically, fire has been relatively infrequent along most areas of the North Fork. The fire regime, determined from stands dominated by lodgepole pine, is measured to be over 100-year intervals. There have been recent exceptions. Stand replacing fires burned in 1967 and 1988 (Red Bench Fire) are considered to be resultant of prolonged drought conditions.

River Habitat Assessment

In determining riparian ecosystem health, standardized assessment protocols have proven to be valuable tools to effectively measure the current health and functional condition, as well as serve as a guide for future restoration and monitoring programs (Stacey et al., 2006). In Montana, as in much of the U.S., our streams are currently only monitored for water quality by the Department of Environmental Quality (DEQ). There is not a standardized stream assessment plan that monitors the health of the larger riparian ecosystem on a regular basis. Montana Fish, Wildlife and Parks

(FWP) and the Bureau of Land Management (BLM) have riparian, or wetland assessment surveys that have been implemented as part of restoration projects, but these are intensive and may be prove to be too expensive as a monitoring tool.

In Germany and other countries strongly influenced by humans, many rivers have been constrained to flow unnaturally, partly in canals that often lack natural vegetation and wildlife. As a response, in 1996 the German government introduced improvements to the Federal Water Act (Wasserhaushaltsgesetz, WHG) which focused on restoring near-natural habitat conditions for surface waters. In 1999, the first national river habitat assessment program was introduced. With the addition of Austria, France and the United Kingdom, in 2004, it was decided that all EU members must complete a national GIS-based inventory of surface water bodies and an assessment of their ecological and chemical status. Currently, water pollution prevention and river management planning include monitoring of both river habitat and water quality based on the first assessment of the ecological status of the river (Kamp, et al., 2007).

In the absence of a nationwide, or statewide total river assessment and monitoring program, this study aims to carry out and analyze a river ecosystem assessment developed in the United States for western river systems. In this study, the disturbance will not be human-caused but following severe fires, which is so prevalent in the American west.

A riparian habitat assessment and monitoring method is needed to gain important knowledge on the current state of these essential ecosystems and the future responses to a changing disturbance regime.

Methodology

To understand the fire and riparian ecosystem interface, I will study pre-fire to post-fire conditions to observe possible changes in vegetation and stream geomorphology.

The purpose of this study is to assess the midterm impacts of fire disturbance on the North Fork Flathead River riparian ecosystem. To address the questions of riparian ecosystem behavior, the follow objectives will be pursued:

Riparian Ecosystem Field Assessment:

With the EU's approach of stream health assessment and monitoring in mind, I will implement an established Rapid Stream-Riparian Assessment (RSRA) developed by Stacey et al. (2006) for riparian ecosystems in the Southwest United States. According to the developers, "It is particularly appropriate for small to medium sized streams and rivers in the American Southwest, but with slight modification it also should be applicable to reaches in other temperate regions and geomorphic settings."

This particular RSRA relies on a quantitative evaluation of indicator variables in five ecological categories including; vegetation composition and structure, terrestrial wildlife habitat, aquatic and fish habitat, water quality and fluvial geomorphology. Within each of these categories, the RSRA evaluates several variables that reflect the overall function of the system. Each variable, or indicator, is rated on a scale ranging from "1" (highly impacted and non-functional) to "5" (healthy and completely functional system). After all surveys are completed, a mean score for each set of indicators is calculated, and then used to calculate a mean score for all five categories. A full explanation of categories, indicators and scoring methods is found in the RSRA guide (Stevens et al., 2005, see Appendix for score sheet). There will be three study areas representing three phases of riparian habitat:

- 28 years post-fire: Red Bench Fire
- 15 years post-fire: Moose Fire

- Unburned: An area that has not experienced fire for 50+ years and will be used as a reference.

Each study area consists of:

- 1 km reach where data are collected
- Two different but adjacent 200 m sample transects within the 1 km where specific quantitative data are collected: an in-stream transect and a riparian zone transect. The riparian zone transect is placed on the first terrace within a meter or so of the bankfull mark. Data are collected either once every 2 meters along the 200 meters (100 sample points, like algae or vegetation cover) or along the entire 200 meters (e.g., woody debris or amount of unstable banks).
- A second 200 m riparian zone sample transect for floodplains wider than 100 m

Following is a summary of the categories, their indicators and the methods and tools used to calculate a score:

Data to be collected in 1 km reach:

Category: Water Quality

Indicator: *Channel Shading and Solar Exposure*

Three random but representative points are selected along the entire 1 km study reach that are not visible from each other. The amount of shading over the water surface that would occur at mid-day are visually estimated, as well as the percent of stream shading within view both upstream and downstream of each observation point. The amounts are averaged. The time of day when this assessment is made is recorded (closest to mid-day is best).

Category: Hydrogeomorphology

Indicator: *Floodplain Connection and Inundation*

The possibility that the stream will be able to escape its bank and flow over the floodplain during typical high flow events can be measured by the ratio of the height between the channel bottom and the historic terrace and the distance between the channel bottom and its first bank. To calculate the historic floodplain to current bankfull ratio, three random but representative points are chosen along the entire 1 km study reach. A laser level is used to measure the distance between the bottom of the channel and current bankfull level. The distance or height of the beginning or closest part of the historic floodplain to the channel bottom is measured. Next, the historic floodplain depth is divided by current bankfull depth. The average of the three ratios is taken to calculate the final score for this indicator. The final score indicates the level of connectivity between the stream and its floodplain; a high ratio (and low indicator score) demonstrates less potential for overbank flooding.

Indicator: *Hydraulic Habitat Diversity*

The number of distinctive hydraulic channel features that would offer unique habitats in the overall 1 km reach is counted. Features include; riffles, scour pools, cobble or boulder debris fans, flowing side channels, backwaters, sand-floored runs, or other features that can provide different habitats for fish and other aquatic organisms.

Indicator: *Riparian Area Soil Integrity*

The amount of soil disturbance in the riparian zone is estimated, including both erosion from human activities (e.g., roads, trails) as well as damage from livestock and native ungulates.

Indicator: *Beaver Activity*

The extent of recent beaver activity within the last year, as indicated by tracks, drags, digging marks, cut stems, burrows, dams, and caches is determined. For example, if beavers are no longer present but were historically, then score this indicator as 1.

Category: Fish/Aquatic Habitat

Indicator: *Cobble Embeddedness*

To determine embeddedness, three riffle areas along the reach are randomly selected. Within each area, the assessor stands in the middle of the channel and randomly picks up from the bottom six rocks that are 3-8 inches in diameter and notes the degree to which each rock was embedded within the substrate. For example, if the sediment line separates the rock halfway between top and bottom, the rating is 50% embedded. The average of the average of the rocks measured at each of the three sites is taken to determine the final score.

Category: Riparian Vegetation

Indicator: *Native Shrub and Tree Demography and Recruitment*

The distribution of age classes (seedlings, saplings or immature, mature, and snags) of the dominant riparian native species is determined during the 1 km reach walk-through. The assessor comments on unexpected demographic conditions, such as the absence of particular age classes of expected dominant species, such as willows and cottonwoods.

Indicators: *Non-native Herbaceous and Woody Plant Species Cover*

The percentage of cover provided by non-native shrub, tree, and herbaceous plant species is visually estimated. The cover by a plant is represented by the ground area that would be shaded by that plant if the sun were directly overhead.

Category: Terrestrial Wildlife Habitat

Indicator: *Shrub, Mid and Upper Canopy Patch Density and Connectivity*

The frequency and connectedness of patches of all classes should be estimated during the overall study reach walkthrough. Include both native and non-native species for these scores.

Indicator: *Fluvial Habitat Diversity*

The different types of riparian landforms that can provide unique habitats for wildlife are recorded. These include wet meadows, ox-bows, marshes, cut banks, sand bars, islands in the channel, etc.

Data to be collected in the 200 m in-stream transect:

Category: Water Quality

Indicator: *Algal Growth*

Walking in the channel about 1m from the water's edge, using the ocular tube, every 2 meters the presence or absence of filamentous algae is recorded. The total percent cover of filamentous algae is calculated by dividing number of positive hits by the total number of data collection points along the transect.

Category: Hydrogeomorphology

Indicator: *Vertical Bank Stability*

The length of the channel bank where there are actively-eroding, near-vertical cut banks is estimated on each side of the 200m in-stream transect, and divided by 400 m to arrive at the percent cut banks.

Category: Fish/Aquatic Habitat

Indicator: *Riffle-Pool Systems- Number and Distribution*

The number of pools and riffles is recorded. For the purpose of this indicator, riffles need to have a cobble bottom.

Indicator: *Underbank Cover*

Underbank cover is the amount of bank that has at least 15 centimeters (6 inch) horizontal distance from the edge of the bank underwater into the undercut. The total amount of underbank cover along each bank of the 200 m in-stream transect is estimated and divided by 400 m to arrive at the percent undercover bank.

Indicator: *Large Woody Debris*

The number of large woody debris pieces observed within the 200 m in-stream transects is recorded. This is wood that is not rooted and at least partially in the water or located in the active stream channel and that is at least 15cm in diameter and 1m in length.

Indicator: *Overbank Cover and Terrestrial Invertebrate Habitat.*

The distance along both banks of the 200 m in-stream transect where there is vegetation (including grass, shrubs and trees) hanging over the channel is estimated. The total distance of overbank cover on each side of the 200 m in-stream transect is divided by 400 m to arrive at the percent overbank cover.

Data to be collected in the 200 m riparian zone transect:

Category: Riparian Vegetation

Indicator: *Riparian Zone Plant Community Structure and Cover*

The presence or absence of vegetation cover observed in each of the four structural layers (ground, shrub, middle canopy, and upper canopy) is recorded for the riparian transect. Using an ocular cross-hair tube, the assessor walks along the transect and every 2 meters looks directly up and down through the tube, and records the presence or absence of plant material (dead or alive) intersecting the vertical sight line of the cross-hairs in each structural layer. The line-of-sight through the ocular tube is meant to determine whether a ray of light originating directly overhead will strike any vegetation as it passes through each layer. To determine the percent cover for that layer, use the number of "hits" through the ocular tube for cover in each layer (out of what should be about 100 samples along the 200m transect). The percent cover for the four layers is averaged to achieve an overall score.

Indicator: *Mammalian Herbivory (Grazing) on Ground Cover, Shrubs and Small Trees*

When recording the number of positive and negative cover hits for each structural layer on the riparian zone transect with the ocular tube, evidence of mammalian herbivore impacts is recorded. The number of "hits" is used to estimate percent ground cover, shrubs, and small trees that has been grazed by herbivores.

Results

The reader should refer to the Rapid Stream Riparian Assessment Guide for a detailed description of how the data were collected in order to interpret the meaning of the assessment scores (Appendix A).

Unburned (Control):

Individual Area Scores:

Water Quality Mean Score: 3.5

Algal Growth: 5

Channel Shading: 2

Hydrogeomorphology Mean Score: 3.5

Floodplain Connection: 1

Vertical Bank Stability: 5

Hydraulic Habitat Diversity: 4
Riparian Area Soil Integrity: 5
Beaver Activity: 3

Fish/Aquatic Habitat Mean Score: 4.6

Riffle-Pool Distribution: 3
Underbank Cover: 5
Cobble Embeddedness: 5
Large Woody Debris: 5
Overbank Cover: 5

Riparian Vegetation Mean Score: 4.1

Lower Riparian Zone Plant Cover: 4
Upper Riparian Zone Plant Cover: 4
Shrub Demography and Recruitment: 5
Tree Demography and Recruitment: 5
Non-native Herbaceous Plant Species: 5
Non-native Woody Plant Species: 5
Mammalian Herbivory on Ground Cover: 3
Mammalian Herbivory on Shrubs and Small Trees: 2

Terrestrial Wildlife Habitat Mean Score: 4.5

Shrub Patch Density: 5
Mid-canopy Patch Density: 4
Upper Canopy Patch Density: 4
Fluvial Habitat Diversity: 5

Overall Score: 4.1

Red Bench (1988):

Individual Area Scores:

Water Quality Mean Score: 3.5

Algal Growth: 5
Channel Shading: 2

Hydrogeomorphology Mean Score: 3.4

Floodplain Connection: 1
Vertical Bank Stability: 4
Hydraulic Habitat Diversity: 5

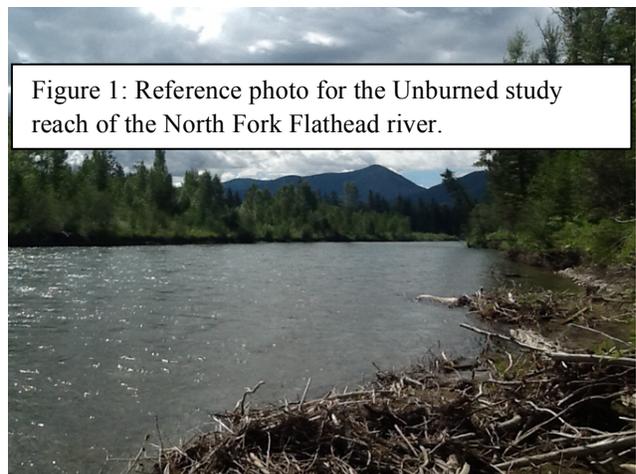


Figure 1: Reference photo for the Unburned study reach of the North Fork Flathead river.

Riparian Area Soil Integrity: 3

Beaver Activity: 4

Fish/Aquatic Habitat Mean Score: 3.4

Riffle-Pool Distribution: 2

Underbank Cover: 3

Cobble Embeddedness: 5

Large Woody Debris: 5

Overbank Cover: 2

Riparian Vegetation Mean Score: 3.9

Lower Riparian Zone Plant Cover: 3

Upper Riparian Zone Plant Cover: 3

Shrub Demography and Recruitment: 4

Tree Demography and Recruitment: 4

Non-native Herbaceous Plant Species: 5

Non-native Woody Plant Species: 4

Mammalian Herbivory on Ground Cover: 5

Mammalian Herbivory on Shrubs and Small Trees: 2

Terrestrial Wildlife Habitat Mean Score: 3.5

Shrub Patch Density: 4

Mid-canopy Patch Density: 3

Upper Canopy Patch Density: 2

Fluvial Habitat Diversity: 5

Overall Score: 3.53

Moose Fire (2001):

Individual Area Scores:

Water Quality Mean Score: 2.5

Algal Growth: 4

Channel Shading: 1

Hydrogeomorphology Mean Score: 2.2

Floodplain Connection: 2

Vertical Bank Stability: 2

Hydraulic Habitat Diversity: 3



Figure 2: Reference photo for the Red Bench Fire study reach of the North Fork Flathead river.

Riparian Area Soil Integrity: 3

Beaver Activity: 1

Fish/Aquatic Habitat Mean Score: 3.2

Riffle-Pool Distribution: 2

Underbank Cover: 2

Cobble Embeddedness: 5

Large Woody Debris: 5

Overbank Cover: 2

Riparian Vegetation Mean Score: 3.8

Lower Riparian Zone Plant Cover: 3

Upper Riparian Zone Plant Cover: 3

Shrub Demography and Recruitment: 4

Tree Demography and Recruitment: 3

Non-native Herbaceous Plant Species: 5

Non-native Woody Plant Species: 5

Mammalian Herbivory on Ground Cover: 5

Mammalian Herbivory on Shrubs and Small Trees: 2

Terrestrial Wildlife Habitat Mean Score: 2.8

Shrub Patch Density: 5

Mid-canopy Patch Density: 2

Upper Canopy Patch Density: 1

Fluvial Habitat Diversity: 3

Overall Score: 2.9

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Figure 3: Reference photo of Moose Fire study reach on the North Fork Flathead river.



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Appendix A

Rapid Stream-Riparian Assessment Score Sheet revised April 2010

Reach _____ Stream _____ Watershed _____

Survey Date _____ Time _____ Background information available? (yes/no) _____

Observers _____ Email _____

Contact Info: Address _____ Phone _____

Reach (UTM) Upstream _____ E _____ N _____ Elevation _____

Photo identification _____ (Preferred datum - NAD 83)

NAD _____ Downstream _____ E _____ N _____ Elevation _____

Photo Identification: _____

Stream Transect Start _____ E _____ N Upstream or Down?

(optional) Stream Transect Photo Id: _____ USGS Quad Map Name: _____

Scores: WQ _____ HG _____ F/AH _____ RV _____ TWH _____ Overall Rating _____ Condition _____

Previous Ratings: DATE _____ Overall Rating _____ Current Trend _____

Individual Previous Scores WQ _____ HG _____ F/AH _____ RV _____ TWH _____

Score (1-5 or N/A)	Indicator Number	Indicator	Scoring Definitions and Directions Scores of 5 indicate that the indicator is close to the potential of the geologically and biologically similar reference reach, and/or what would be expected to be found in a healthy ecosystem. Scores of 1 indicate riparian or stream components that are not functioning properly. Use N/A if the indicator is not relevant or appropriate for this particular reach.	Notes on measurement methods
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WATER QUALITY

Score: % =	1	Algal Growth	1 = >50% of stream bottom covered by filamentous algae 2 = 26-50% of bottom covered by filamentous algae 3 = 11-25% of bottom covered by filamentous algae 4 = 1-10% of bottom covered by filamentous algae 5 = no filamentous algae on stream bottom	Walking upstream, use ocular tube to score 1m from bank every 2m in 200m in-stream transect. Do not count single cell algae on the surface of rocks.
Score: % =	2	Channel Shading, Solar Exposure	1 = stream channel completely unshaded (0%) 2 = slight shading (1-15%) 3 = moderate shading (16-30%) 4 = substantial shading (31-60%) 5 = Channel mostly shaded (>60%)	Look up and down stream in three different representative points in the overall stream reach. Average the three points.

Water quality mean score:	Notes:
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HYDROGEOMORPHOLOGY (STREAM FORM)

Score:	3	Floodplain Connection and Inundation	<p>1 = >1.7 bankfull / depth ratio average of 3 locations 2 = >1.5 - 1.7 bankfull / depth ratio 3 = >1.4 - 1.5 bankfull / depth ratio 4 = >1.3 - 1.4 bankfull / depth ratio 5 = 1.0 - 1.3 bankfull / depth ratio</p>	Use field worksheet and measure ratios at three representative locations in the overall stream reach. Calculate the average of three ratios and score using Figure 3.
avg=				
	4	Vertical Bank Stability	<p>1 = >90% of channel banks are vertically unstable (use the average of both banks) 2 = 61 - 90% of banks are unstable 3 = 31 - 60% of banks are unstable 4 = 5 - 30% of banks are unstable 5 = <5% of banks are unstable</p>	Estimate along both banks of 200m in-stream transect. Do not include rock or cliff faces in calculating total length of unstable banks (use "N/A").
%=				
	5	Hydraulic Habitat Diversity	<p>1 = no diversity (variability) of stream form features 2 = low diversity, 2 habitat types present, 3 = moderate diversity, 3 types present, 4 = moderately high diversity, 4 types present, 5 = high diversity, 5 or more present.</p>	Check in overall walk through. Examples include runs, pools, cobble or boulder debris fans, running side channels, backwaters, sand-floored runs, etc.
	6	Riparian Area Soil Integrity	<p>1 = >25% of riparian soil surface disturbed 2 = 16 - 25% disturbed 3 = 6 - 15% disturbed 4 = 1 - 5% disturbed 5 = <1% disturbed</p>	Check in overall walk through. Look for unnatural surface disturbances in the riparian zone from such things as vehicles, foot travel, and ungulate activity.
%=				
	7	Beaver Activity	<p>1 = beavers not now present but were historically 2 = no beaver dams, a few signs of activity but none within the last year 3 = activity in past year but no dams 4 = beaver dams on some of the stream 5 = beaver activity and dams control stream</p>	Check in overall walk through. Beaver sign includes tracks, drags, digging marks, cut stems, burrows, dams, and caches active within past season.
Hydrogeomorphology mean score:		Notes:		

FISH/AQUATIC HABITAT

Qualifier: If the stream is no longer perennial, but used to be a fishery, the mean score entered for this section is a "1." (It is no longer functioning as fish/aquatic habitat.)

	8	Riffle-Pool Distribution	1 = no riffle-pool habitat in stream transect 2 = one to several riffle-pool systems 3 = limited to moderate riffle-pool distribution in reach 4 = moderate to abundant riffle-pool distribution 5 = riffle-pools abundant (>50% of transect has pools connected by riffles)	Check along 200m in-stream transect. Look for geomorphic consistency (e.g. high gradient streams will have more pools than low gradient streams).
%=	9	Underbank Cover	1 = no underbank cover in 200m stream transect 2 = <10% transect has underbank cover 3 = 10 - 25% of transect has underbank cover 4 = 26 - 50% of transect has underbank cover 5 = >50% of transect has underbank cover	Check along both banks of 200m in-stream transect. Undercut must be at least 15cm (6 in) into the streambank. Average the measures on both banks to score.
%=	10	Cobble Embeddedness	1 = average of >50% of rock volume is imbedded in fine silt. (avg. of three sites) 2 = 41 - 50% of rock imbedded 3 = 26 - 40% of rock imbedded 4 = 20 - 25% of rock imbedded 5 = <20% of rock imbedded	Determine the percent embeddedness of a random sample of 6 rocks 3-8" in diameter from riffles in each of three different random points along the overall stream reach.
	11	Aquatic Macroinvertebrate Diversity	1 = no aquatic (benthic) macroinvertebrates found 2 = 1 macroinvertebrate order present 3 = 2 macroinvertebrate orders present 4 = 3 macroinvertebrate orders present 5 = 4 or more orders present	Examine 6 rocks 15cm (6") or larger at the same sites used for Indicator 10. Use Appendix 1 or other guide to identify macroinvertebrate orders.
	12	Large Woody Debris	1 = no large woody debris (LWD) in transect 2 = <3 LWD pieces in transect 3 = 3 - 5 LWD pieces in transect 4 = 6 - 10 LWD pieces in transect 5 = >10 LWD pieces in transect	Count woody debris pieces larger than 15cm (6") in diameter and 1m (3 ft) long or longer in the channel in the 200m in-stream transect
%=	13	Overbank Cover and Terrestrial Invertebrate Habitat	1 = no grass, shrubs, or trees overhang water 2 = <10% of banks have grass, shrubs, or trees that overhang the water 3 = 10 - 25% of banks have overhanging veg. 4 = 26 - 50% of banks have overhanging veg. 5 = >50% of banks have overhanging veg.	Check along both banks of 200m in-stream transect. Look for geomorphic consistency. Do not include rocks or cliff faces (use "N/A"). Average both banks when scoring.
Fish/Aquatic Habitat mean score:		Notes:		

RIPARIAN VEGETATION

G= _____%
 S= _____%
 MC= _____%
 UC= _____%

Score: avg= %	14	Riparian Zone Plant Community Structure and Cover	1 = <5% average plant cover in riparian zone 2 = 5 - 25% average plant cover 3 = 26 - 50% average plant cover 4 = 51 - 80% average plant cover 5 = >80% average plant cover	Use the field worksheet and ocular tube to determine the cover for the ground, shrub, midcanopy and upper canopy layers along 200m transect in the riparian zone. Look for geomorphic consistency.
Score:	15	Shrub Demography and Recruitment	1 = no native shrubs present in study reach 2 = one age class present 3 = two classes present, one class with seedlings or saplings 4 = three age classes present 5 = all age classes present	Determine during the overall walk through the number of age classes (seedlings, saplings, mature, standing dead) for the dominant (most cover) native shrub species.
	16	Tree Demography and Recruitment	1 = no native trees present in study reach 2 = one age class present 3 = two classes present, one class with seedlings or saplings 4 = three age classes present 5 = all age classes present	Determine during the overall walk through the number of age classes (seedlings, saplings, mature, standing dead) for the dominant (most cover) deciduous native tree species.
	17	Non-native Herbaceous Plant Species	1 = >50% of herbaceous plant cover are not native species 2 = 26 - 50% herbaceous not native 3 = 11 - 25% herbaceous not native 4 = 5 - 10% herbaceous not native 5 = <5% of herbaceous cover not native	Estimate on the overall walk through.
	18	Non-native Woody Plant Species	1 = >50% of woody plant cover are not native species 2 = 26 - 50% of woody cover not native 3 = 11 - 25% of woody cover not native 4 = 5 - 10% of woody cover not native 5 = <5% of woody cover not native	Estimate on the overall walk through.
%=	19	Mammalian Herbivory (Grazing) Impacts on Ground Cover	1 = >50% of plants impacted by grazing 2 = 26 - 50% of plants impacted 3 = 11 - 25% of plants impacted 4 = 5 - 10% of plants impacted 5 = <5% of plants impacted	Use the field worksheet and ocular tube to determine the number of "hits" showing herbivory on the ground covering plants (grasses and forbs) on the 200m riparian zone transect.

RIPARIAN VEGETATION, CONTINUED

20	Mammalian Herbivory (Browsing) Impacts on Shrubs and Small Trees	<p>1 = >50% of plants (shrubs and trees) impacted 2 = 26 - 50% of plants impacted 3 = 11 - 25% of plants impacted 4 = 5 - 10% of plants impacted 5 = <5% of plants impacted</p>	<p>Estimate the percentage of shrubs and small trees that have branch tips that have been clipped or eaten by large mammals.</p>
----	---	---	--

%=

Riparian Vegetation, mean score:	Notes:
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TERRESTRIAL WILDLIFE HABITAT

21	Shrub Patch Density	<p>1 = no shrub patches in stream reach 2 = few, isolated small shrub patches 3 = more patches but still isolated 4 = few large open areas between large patches 5 = almost continuous dense shrub cover</p>	<p>In overall walk through, examine patches and clusters of shrubs (<4m tall) and openings between those clusters. Look for geomorphic consistency.</p>
22	Mid-Canopy Patch Density	<p>1 = no mid-canopy shrub or tree patches in reach 2 = few isolated small patches in mid canopy 3 = more patches but still isolated 4 = few large open areas between large patches 5 = almost continuous dense mid-canopy cover</p>	<p>In overall walkthrough, examine clusters of mid-canopy large shrubs and trees (4-10m tall) and openings between those clusters. Look for geomorphic consistency.</p>
23	Upper Canopy Patch Density	<p>1 = no upper-canopy trees present in reach 2 = few isolated small patches in upper canopy 3 = more patches but still isolated 4 = few large open areas between large patches 5 = almost continuous dense upper-canopy cover</p>	<p>In overall walk through, examine clusters of upper canopy trees (>10m tall) and openings between those clusters. Look for geomorphic consistency.</p>
24	Fluvial Habitat Diversity	<p>1 = no other fluvial habitat besides the stream channel 2 = one other type of fluvial habitat present 3 = two other types present 4 = three other types present 5 = four or more other types present</p>	<p>Examine during overall walk through. Fluvial habitat types include flood-plain ponds, oxbows, sand bars, wet meadows, beaver ponds, and stable cutbanks.</p>

Terrestrial Wildlife Habitat, mean score:	Notes:
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Rapid Stream Riparian Assessment Field Worksheet

revised March 30, 2010

Stream reach identification: _____ Date: _____

Whole Study Reach

Begin by recording the GPS locations of the ends of the study reach on the Score Sheet, and take reference photos at both ends of the study stream reach. Data for the following indicators are gathered on the whole reach walk through:

Indicator 5 (Hydraulic Habitat diversity), **Indicator 6** (Riparian Area Soil Integrity) **Indicator 7** (Beaver, Signs of activity), **Indicator 15** (Native Shrub Demography), **Indicator 16** (Native Tree Demography), **Indicator 17** (Non-Native Herbaceous species), **Indicator 18** (Non-Native Woody Plant Species), **Indicator 21** (Shrub Patch Density), **Indicator 22** (Mid-Canopy Patch Density), **Indicator 23** (Upper Canopy Patch Density), and **Indicator 24** (Fluvial Habitat Diversity).

Indicator 5: Hydraulic Habitat Diversity (number of different in stream below-water features).

Check each type of hydraulic (stream) features providing important aquatic habitats.

- D edge water
- D lateral pool
- D high velocity or gradient riffle (high velocity run)
- D low velocity or gradient riffle (low velocity run)
- D scour pool
- D cobble/boulder debris fans
- D active, flowing side channels
- D backwaters
- D sand-floored runs
- D other (type _____)

Total number of different feature types: _____

Indicator 6: Riparian Area Soil Integrity.

Notes _____ Percent soil area disturbed _____

Indicator 7: Beaver Activity.

Signs of beaver activity include tracks, drags, digging marks, cut stems, burrows, dams, and caches.

Signs observed _____

Indicator 15: Native Shrub Demography and recruitment.

Circle age classes present: seedling, immature, mature, old dead clumps.

Dominant native species: _____ Other notes: _____

Indicator 16: Native Tree Demography and Recruitment.

Circle age classes present: seedling, immature, mature, snags.

Dominant native species _____

Notes _____

Indicator 17: Non-Native Herbaceous Plant Species Cover.

Grasses and forbs, as percentage of total grass and forb cover.

Percent of non-native herbaceous plants _____

Notes _____

Indicator 18: Non-Native Woody Plant Cover.

Shrubs and trees, as percentage of total shrub and tree cover.

Percent of non-native woody plant cover _____

Notes _____

Indicator 21: Shrub Patch Density.

Notes _____

Indicator 22: Mid-canopy Patch Density.

Notes _____

Indicator 23: Upper Canopy Patch Density.

Notes _____

Score sheet notes for Indicators 21, 22, 23

	1	no patches in stream reach
	2	few, isolated shrub patches
3		more patches but still isolated from each other
4		few large open areas between large patches
5		almost continuous dense cover for the layer

Indicator 24: Fluvial Habitat Diversity.

Check each type of geophysical feature within the riparian zone that provides a unique habitat for plants and animals:

- D flood-plain ponds
- D oxbows
- D large and isolated sand or gravel bars
- D wet meadows
- D marsh
- D stable cutbanks
- D beaver pond
- D others (name _____)

Total number of fluvial habitat types _____

Three Representative Reach Sites

Data for the following indicators are collected at three different and representative sites along the study reach. The locations used for each indicator may be the same or different as appropriate, and they do not need to be located in the 200m transect.

Indicator 2: Channel Shading and Solar Exposure.

Percent of stream surface shaded at mid-day.

Time observed _____ (if not mid-day, estimate what shading at noon would be like)

Observation Site 1: Percent stream shaded _____ %
 (Optional) UTM E _____ N _____

Observation Site 2: Percent stream shaded _____ %
 (Optional) UTM E _____ N _____

Observation site 3: Percent stream shaded _____ %
 (Optional) UTM E _____ N _____

Average of three observation sites
 _____ %

Indicator 3: Floodplain Connection and Inundation.

Data are taken at three representative sites.

Site 1: Current bankfull depth (AB) _____

Historic floodplain height (AC) _____

Floodplain/bankfull ratio _____

Ratio = (AC)/(AB)

(Optional) UTM E _____ N _____

(Optional) Photo ID _____ Direction _____

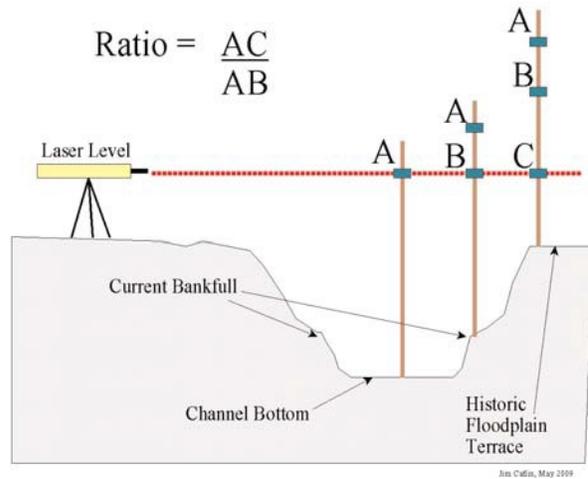
Site 2: Current bankfull depth (AB) _____

Historic floodplain height (AC) _____

Floodplain/bankfull ratio =(AC)/(AB) _____

(Optional) UTM E _____ N _____

(Optional) Photo ID _____ Direction _____



(continued on next page)

Indicator 3 (Continued)

Site 3: Current bankfull depth (AB) _____ Historic floodplain height (AC) _____

Floodplain/bankfull ratio $= (AB)/(AC)$ _____

(Optional) UTM E _____ N _____

(Optional) Photo ID _____ Direction _____

Indicator 3, average of the three ratios for three sites _____

Three Representative Instream Riffle Sites

Collect the data for Indicators 10 and 11 at the same representative stream riffle locations (these sites may be different than those used for the other indicators. Make sure that these sites represent typical riffles in your reach.)

Indicator 10: Cobble Embeddedness (three representative riffles, examine six samples 3-8" in diameter per site).

Riffle site 1: Rock embedded _____ Average _____

(Optional) UTM E. _____ N _____

Riffle site 2: Rock embedded _____ Average _____

(Optional) UTM E. _____ N _____

Riffle site 3: Rock embedded _____ Average _____

(Optional) UTM E. _____ N _____

Overall average of averages of embeddedness: _____

Indicator 11: Aquatic Invertebrates

Examine at least six rocks at least six inches in diameter at each of the sites used to measure embeddedness. Use the key in Appendix 1 for identification. List the invertebrate orders found below and record which are most common or rare. Note the presence of crawfish, but for this protocol, do not include them in the final tally of the total number of orders found in the samples to determine the final score.

In-stream 200 meter transect

Data for the following assessment indicators are collected on this transect:

Indicator 1 (Algal Growth), **Indicator 4** (Vertical Bank Stability), **Indicator 8** (Riffle-Pool Distribution), **Indicator 9** (Underbank Cover), **Indicator 12** (Large Woody Debris), and **Indicator 13** (Overbank Cover and Terrestrial Invertebrate Habitat).

Location: UTM E _____ N _____
(Optional Photo) Identification _____ Photo direction _____

Indicator 1: Algal Growth.

Beginning from the downstream end of the transect, record the presence of filamentous algae taken every 2 meters looking straight down with the ocular tube one meter into the stream from the bank. If the stream is less than 2 m wide, walk up the center of the channel.

Yes _____

No _____

Percent of total stops on transect that are "hits" for algae _____

Indicator 4: Vertical Stability of Stream Banks.

Meters of unstable bank (include both sides) _____

Meters of stable bank (include both sides) _____

Total _____ Percent of transect _____

Indicator 8: Riffle-Pool Distribution.

Number of riffle-pool units in transect _____

Approximate amount of total transect with riffle/pool habitat _____

Indicator 9: Underbank Cover.

Meters of underbank cover (include both sides) _____

Meters lacking underbank cover (include both sides) _____

Total _____ Percent of transect _____

Indicator 12: Large Woody Debris.

6 inches or more in diameter and three feet or longer with some portion submerged in water.

Pieces of large woody debris _____ Total _____

Indicator 13: Overbank Cover and Terrestrial Invertebrate Habitat.

Do not include rocks or cliff faces.

Meters of vegetation hanging over bank (include both sides) _____

Meters lacking hanging vegetation (include both sides) _____

Total _____ Percent of stream transect _____

Riparian Zone 200 meter transect

Data for the following indicators are collected on this transect:

Indicator 14 (Riparian Zone Plant Community Structure),

Indicator 19 (Mammalian [wild and domestic livestock] Grazing of Ground Cover), and

Indicator 20 (Mammal Browse of Shrubs).

Indicator 14: Riparian Zone Plant Community Structure.

Every 2m observe directly up and down for groundcover, shrub, middle and upper canopy layers.

Ground layer count (0-1 meter above ground):

Yes _____

No _____

NA _____

Total ground layer positive hits _____ Percentage positive hits _____

Shrub layer count (1-4 meters above ground):

Yes _____

No _____

NA _____

Total shrub count positive hits _____ Percentage positive hits _____

Middle layer canopy (4-10 meters above ground):

Yes _____

No _____

NA _____

Total middle canopy positive hits _____ Percentage positive hits _____

Upper canopy layer (more than 10 meters above ground):

Yes _____

No _____

NA _____

Total upper canopy positive hits _____ Percentage positive hits _____

Average percent cover in upper riparian zone (all four layers) _____

Indicator 19: Ungulate Grazing in Riparian Zone, Groundcover grazed.

Count grass and forb cover that show signs of grazing when performing observations for Indicator 14, Plant Community Structure and Cover.

No _____

Yes _____

NA _____

Total positive hits _____ Percentage positive hits _____

Indicator 20: Mammalian Browsing of Shrubs and Small Trees in Riparian Zone.

Percent of trees and shrubs showing clipped branches in the Riparian Zone:

Browsed _____ Not browsed _____

Total not browsed _____ Total browsed _____

Percentage of woody plants browsed _____

[NOTE: OPTIONAL SECOND RIPARIAN ZONE TRANSECT IN CASE OF VERY WIDE (>100m) FLOODPLAIN. Indicator 14b: Riparian Zone Plant Community Structure.

Every 2m observe directly up and down for groundcover, shrub, middle and upper canopy layers.

Ground layer count (0-1 meter above ground) :

Yes _____ No _____ NA _____

Total ground layer positive hits _____ Percentage positive hits _____

Shrub layer count (1-4 meters above ground):

Yes _____ No _____ NA _____

Total shrub count positive hits _____ Percentage positive hits _____

Middle layer canopy (4-10 meters above ground):

Yes _____ No _____ NA _____

Total middle canopy positive hits _____ Percentage positive hits _____

Upper canopy layer (more than 10 meters above ground):

Yes _____ No _____ NA _____

Total upper canopy positive hits _____ Percentage positive hits _____

Average percent cover in upper riparian zone (all four layers) _____

Student Fellowship: Snowpack controls on nitrogen availability and nitrogen uptake in a Rocky Mountain conifer forest

Basic Information

Title:	Student Fellowship: Snowpack controls on nitrogen availability and nitrogen uptake in a Rocky Mountain conifer forest
Project Number:	2016MT306B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Solute Transport, Nutrients, Ecology
Descriptors:	None
Principal Investigators:	Claire Qubain

Publications

There are no publications.

Snowpack and soil moisture controls on nitrogen availability in a Rocky Mountain conifer forest

The goal of this project was to explore how snowpack and soil moisture control nitrogen dynamics in a temperate conifer forest. I was successful in demonstrating the first objective presented in my proposal. My objective and hypotheses were proposed as follows. **Objective** Evaluate topographic controls on seasonal nitrogen (N) availability through influences on snowpack and soil moisture. **H1** N availability is higher under deeper snowpack. **H2** Soils located in hollows with higher soil moisture have higher N availability than those on hillslopes with lower soil moisture.

In general, ammonium (NH_4^+) and nitrate (NO_3^-) were highest at low elevation sites at the beginning of the season and in the fall (Fig. 1 and 2). We attribute these patterns to higher levels of soil moisture from snowmelt in the spring and rain wet-up in the fall. At the high elevation sites, the highest peak appeared in the middle of the growing season. This is likely because green alder, a N-fixing tree, is present only at the high elevation sites and adds plant available N to the soil throughout the season.

To address snowpack controls on soil nitrogen availability, I focused my effort on our high elevation, south facing site during the 2016 season. I found that neither peak snow depth (Fig. 3) or peak snow water equivalent (SWE) (Fig. 4) were important factors in determining NH_4^+ concentrations in the soil throughout the growing season (p-value = 0.8 and 0.5 for peak snow depth and peak SWE, respectively). NO_3^- was also not controlled by snow depth or SWE (p-value = 0.9 and 0.8, respectively).

After sampling snow at each of our four sites in spring 2017, I will attempt to answer the same question “Is soil N availability higher during the growing season if peak SWE is greater in the preceding winter?” To begin to address this question, I sampled peak snow depth (Fig. 5) and peak SWE (Fig. 6) in February 2017. Strong evidence of a mean difference in snow depth of 14.6 cm exists between high and low elevation sites (p-value < 0.00001 and a 95% confidence interval of 18.5 to 10.6 cm). Further, strong evidence of a 6.8 cm difference in snow depth between hollow and hillslope positions exists across all sites (p-value = 0.002 with a 95% confidence interval of 11.1 to 2.6 cm). The sites’ aspects did not prove to be an important factor in determining snow depth. Further, there was no evidence for a difference in SWE between low and high elevation sites or between snowpacks at different topographic positions (hollows or hillslopes) (p-value = 0.4 and 0.5 for elevational and topographic differences, respectively). Evidence for a 3.03 Kg/m^2 difference in SWE between north or south facing drainages was inconclusive (p-value = 0.08 with a 95% confidence interval of 0.4 to 6.5). After analyzing soil samples collected in February and April for NH_4^+ and NO_3^- concentrations, will be able to determine with better confidence if moisture from snow melt influences N availability in soil.

To address my hypothesis that soil N availability would be higher in hollows with higher soil moisture rather than on hillslopes with drier soils, I measured the soil moisture content in the same soils analyzed for NH_4^+ and NO_3^- (Fig. 7). The soils were collected from the first 15 cm of the soil profile. During both the 2015 and the 2016 growing seasons, strong evidence for changes in N availability according to variability in percent soil moisture exists. In 2016, an increase of 11.0 $\text{mg NH}_4^+/\text{Kg}$ soil occurred for an increase of 1% moisture (p-value < .00002 with a 95% confidence interval of 9.3 to 12.7 $\text{mg NH}_4^+/\text{Kg}$ soil). In the same season, an increase of 1.56 $\text{mg NO}_3^-/\text{Kg}$ Soil occurred for every increase of 1% soil moisture (p-value < 0.00006 and a 95% confidence interval of 1.0 to 2.1 $\text{mg NO}_3^-/\text{Kg}$ soil). No evidence suggested that NH_4^+ or NO_3^- changed due to differences in elevation during this season, however that was not the case for our findings during the 2015 growing season. Refining my current models to include time series analyses may change the findings presented.

Overall, soil moisture is an important control of N availability throughout the season at Lubrecht Experimental Forest. With further statistical analysis and sampling, I may be able to detect a link between snowpack and soil N availability.

When does vegetation use plant-available N?

In my original proposal, I included that I would carry out a study to test when conifers were using N available in the soil. While I sampled uptake rates of 8 Douglas Fir trees three times across the 2016 growing season, I ran into a few issues that made the data unusable. First, NH_4^+ off-gases at a pH of 7 and above, and I mixed my test solutions at that pH. The NH_4^+ uptake rate I measured was in fact an NH_4^+ volatilization rate. Further, many of the samples showed an increase in NO_3^- instead of the expected decrease. I attribute this to having soil fall into the solution during the 90 minute test period or to placing a dirty root into solution. To improve my observations, I followed the same procedure explained in my proposal but tested saplings in the greenhouse using buffered solutions. Data from this experiment is in the process of being analyzed.

Figures

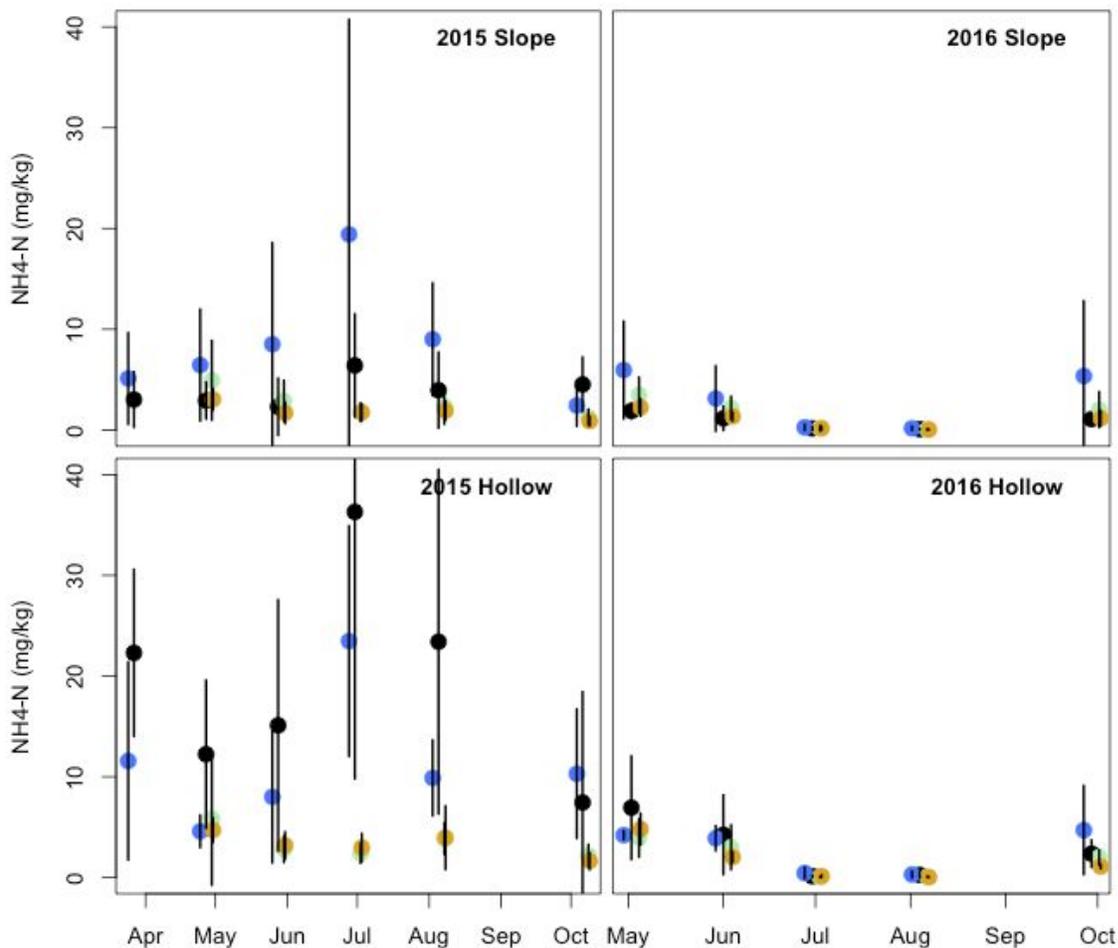


Fig 1. Seasonal patterns of NH_4^+ are shown at each of the four sites sampled, where blue represents the high

elevation, south facing site, black is the high elevation, north facing site, yellow is the low elevation, south facing site, and green is the low elevation, north facing site. Error bars display the standard deviation.

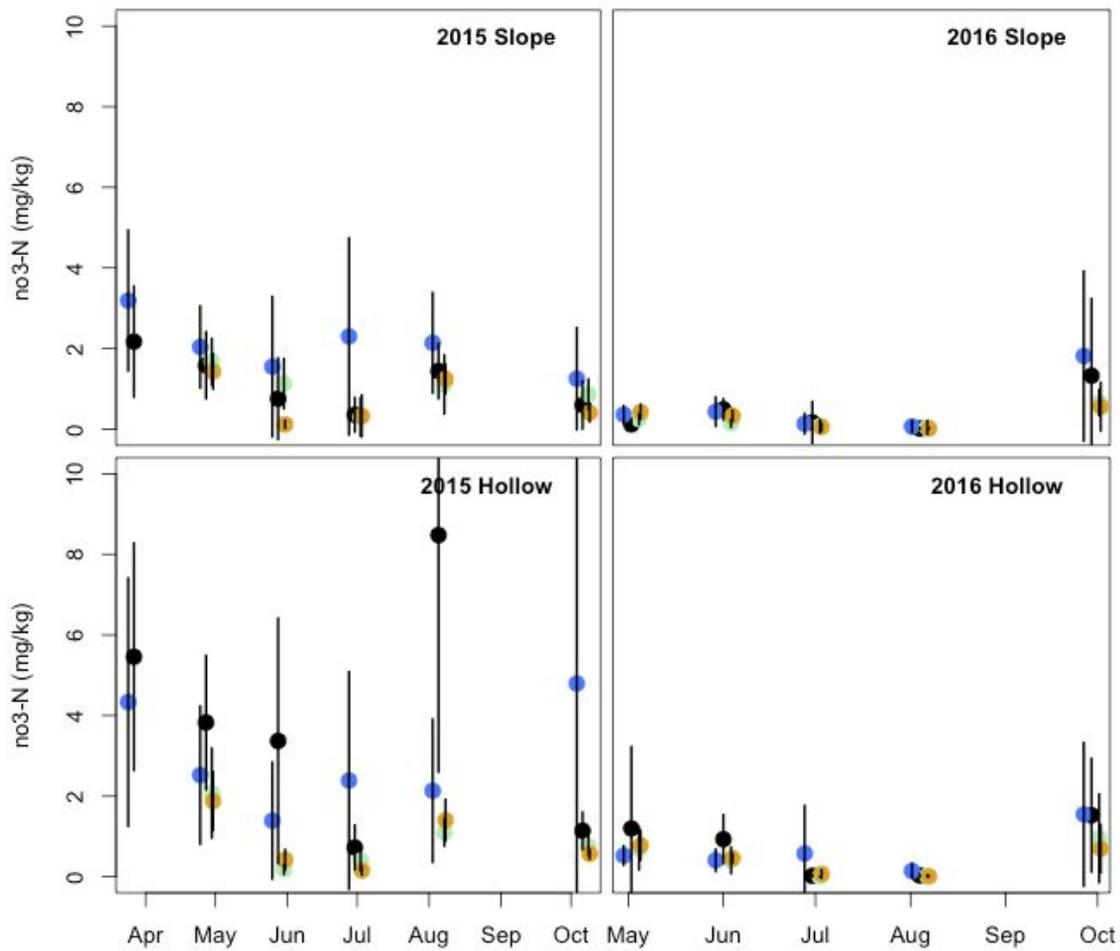


Fig 2. Seasonal patterns of NO_3^- are shown at each of the four sites sampled, where blue represents the high elevation, south facing site, black is the high elevation, north facing site, yellow is the low elevation, south facing site, and green is the low elevation, north facing site. Error bars display the standard deviation.

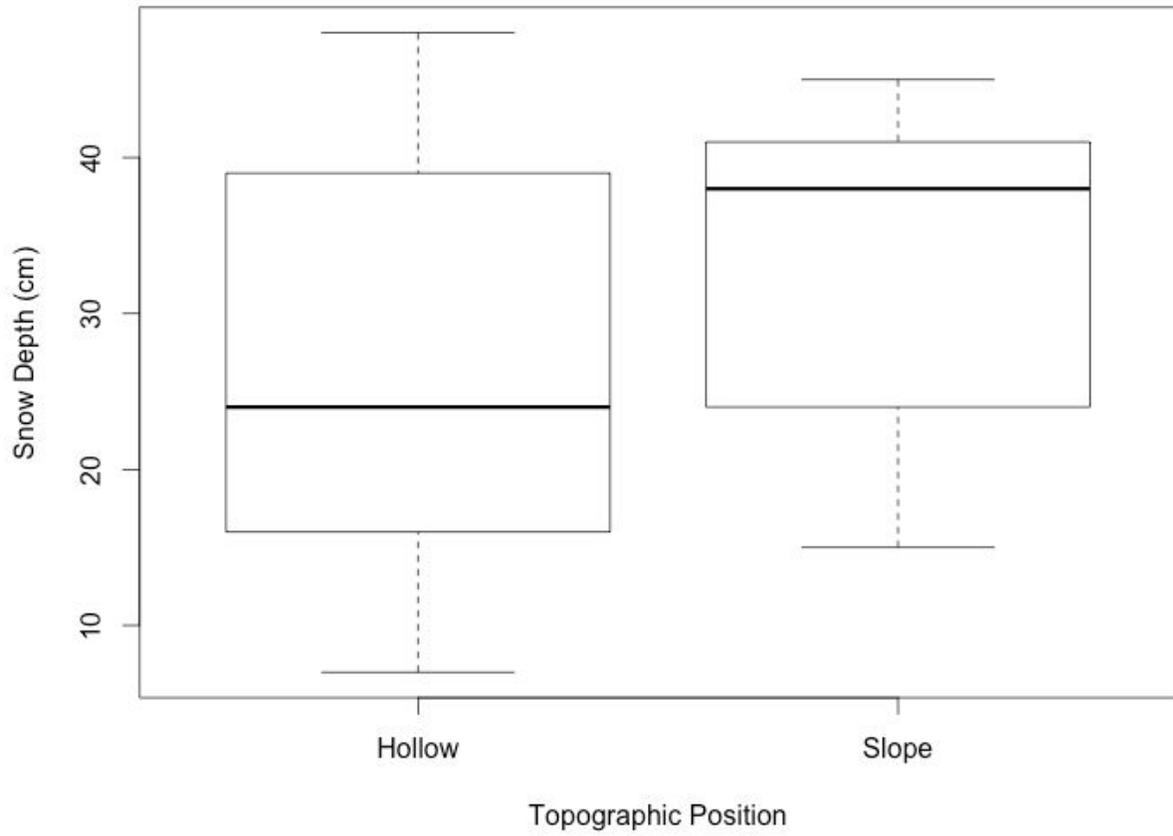


Fig. 3 – Peak snow depth sampled on 3/15/16 from the high elevation, south facing site

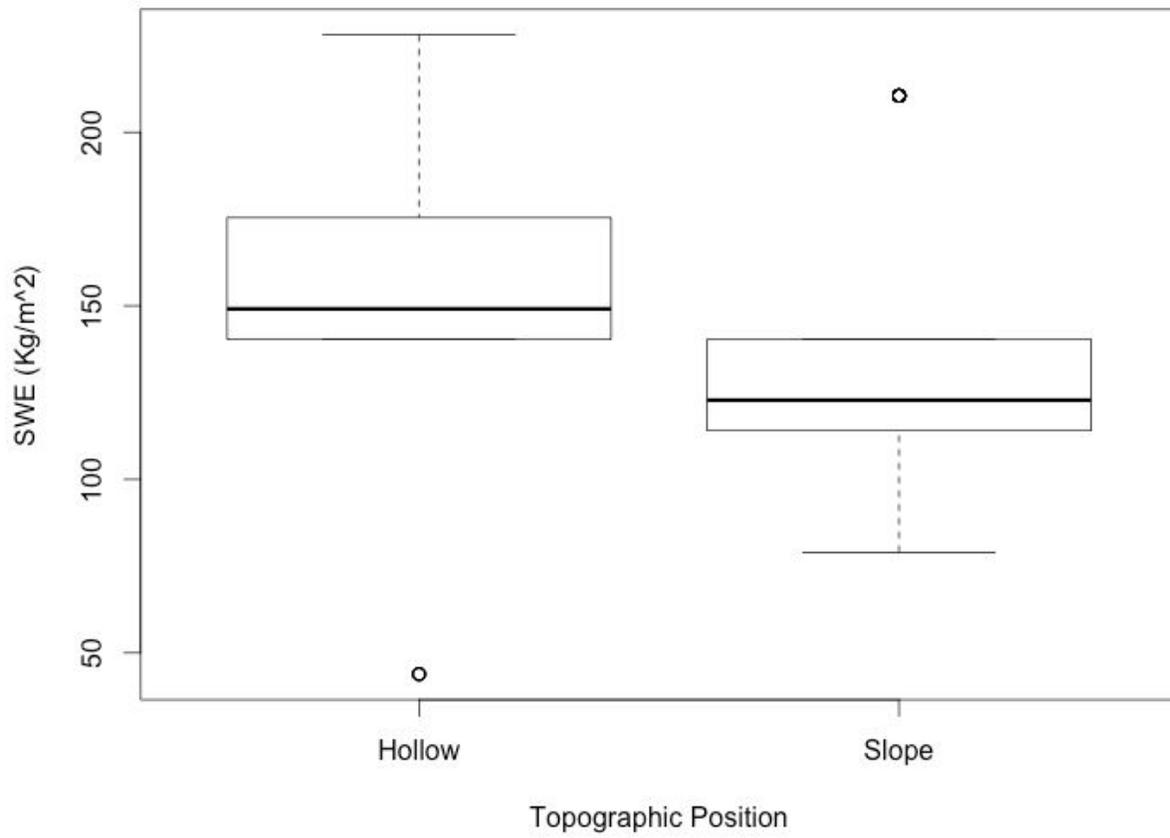


Fig. 4 – Peak SWE sampled on 3/15/16 from the high elevation, south facing site

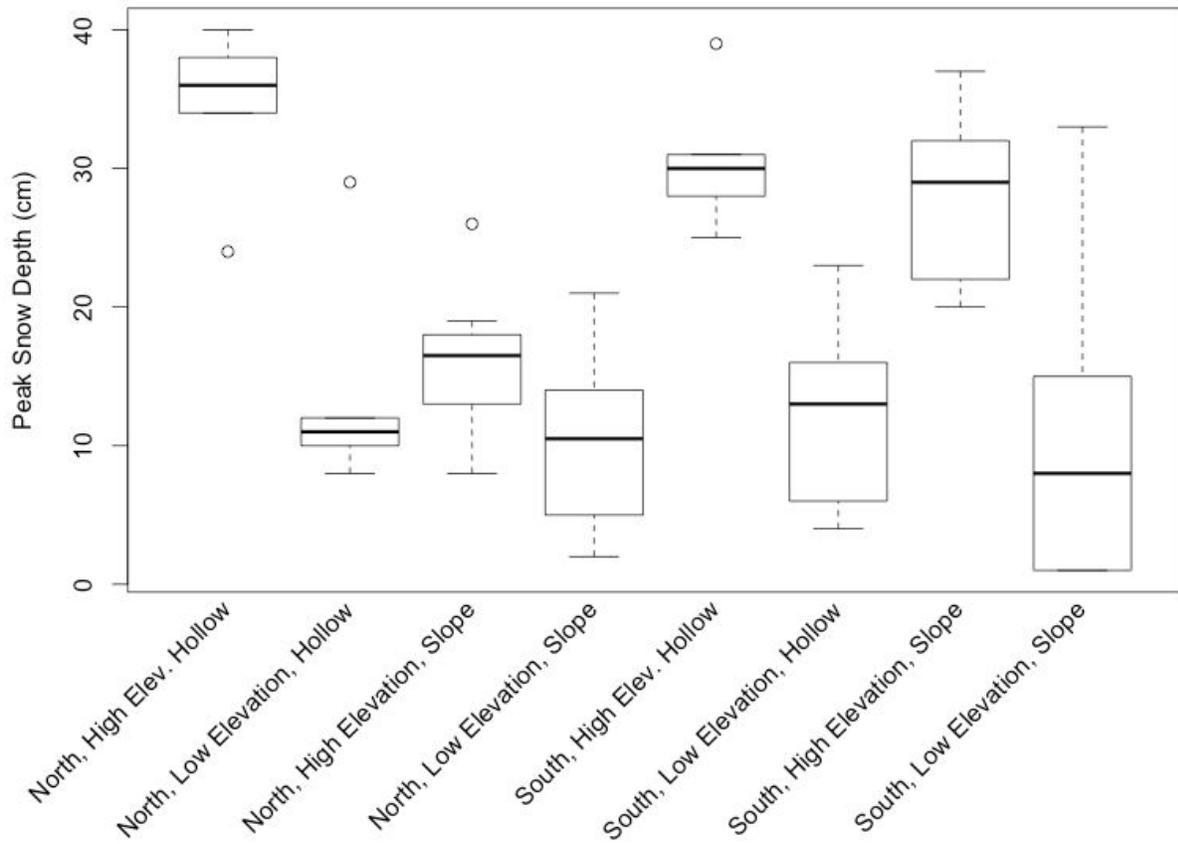


Fig. 5 – Peak snow depth sampled on 2/24/17 (high elevation sites) and 2/27/17 (low elevation sites)

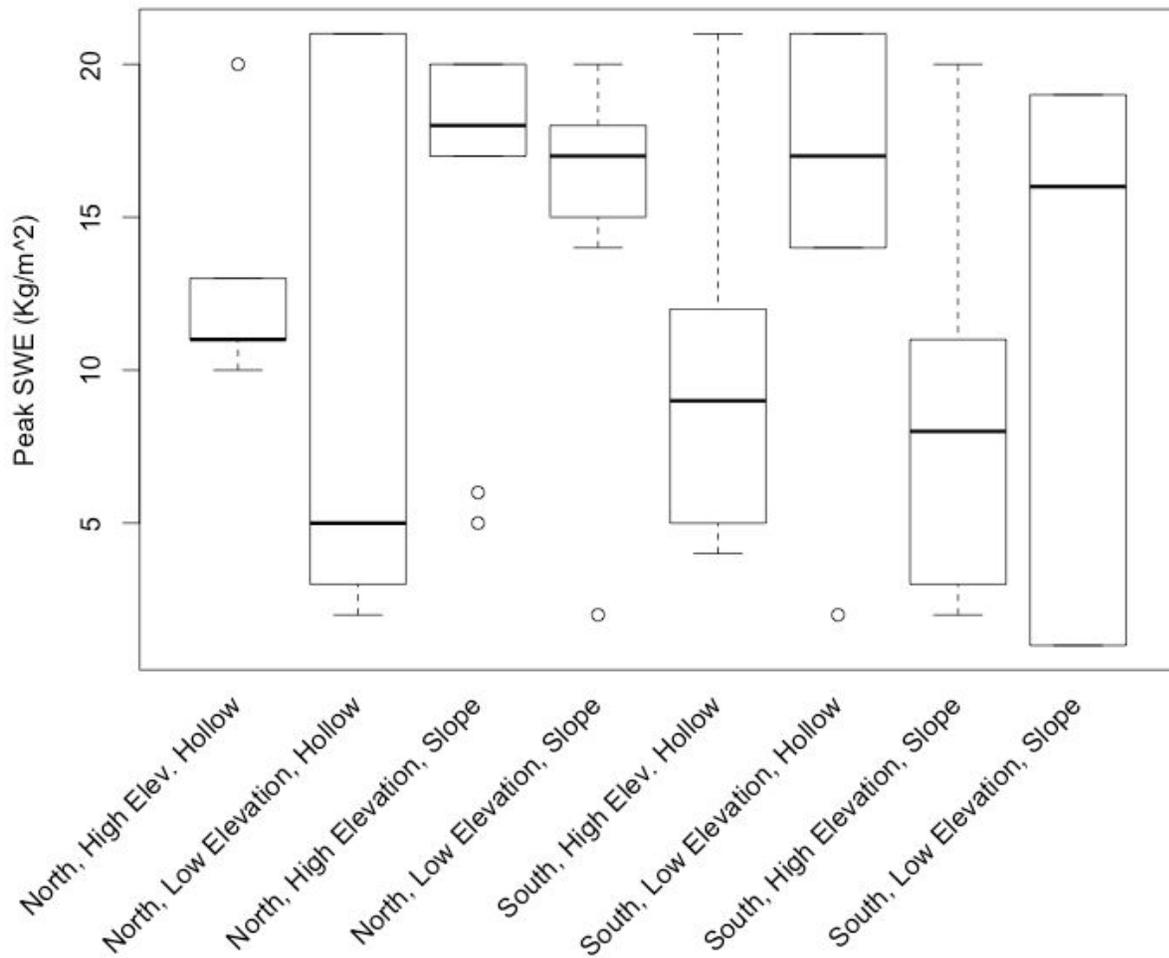


Fig. 6 – Peak SWE sampled on 2/24/17 (high elevation sites) and 2/27/17 (low elevation sites)

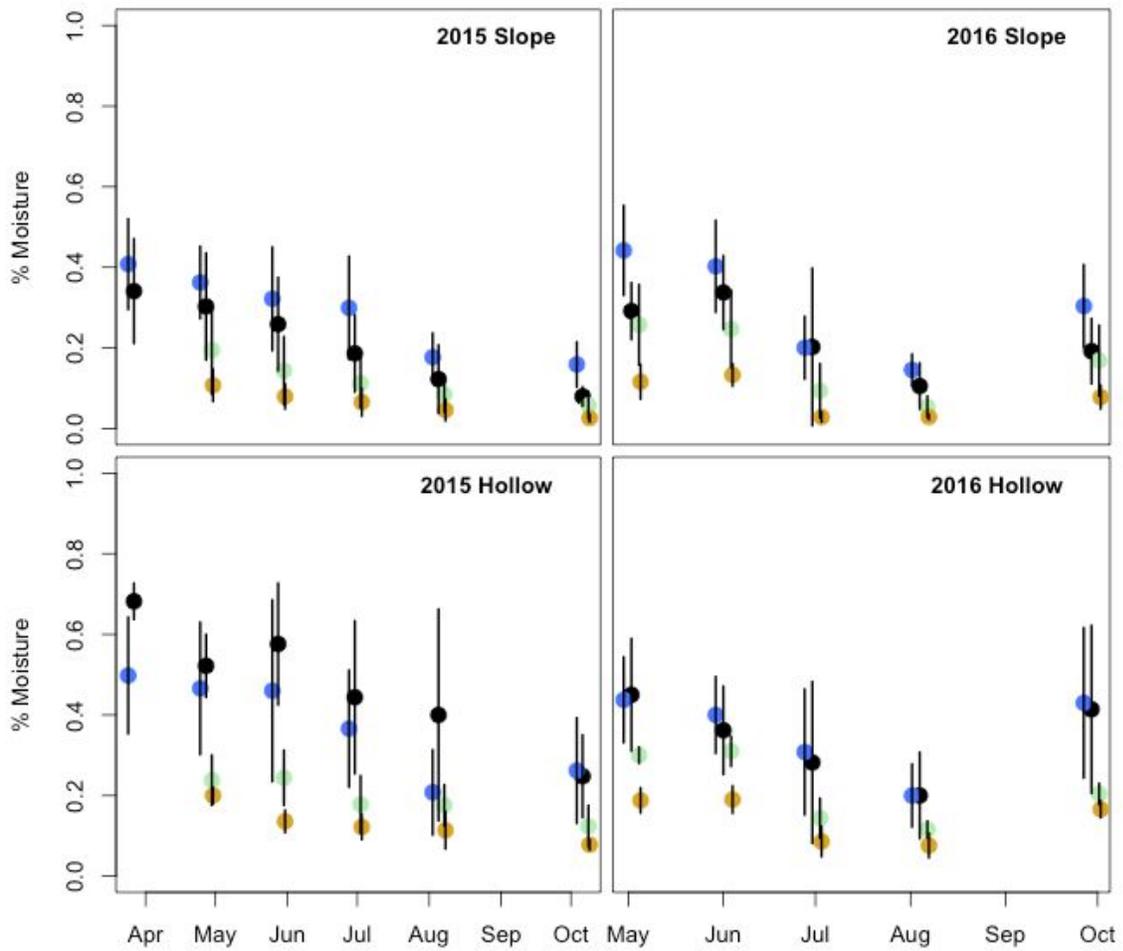


Fig 7. Seasonal patterns of % Soil Moisture are shown at each of the four sites sampled, where blue represents the high elevation, south facing site, black is the high elevation, north facing site, yellow is the low elevation, south facing site, and green is the low elevation, north facing site. Error bars display the standard deviation.

Student Fellowship: Removal of selenium by co-precipitation with microbially induced calcite precipitation

Basic Information

Title:	Student Fellowship: Removal of selenium by co-precipitation with microbially induced calcite precipitation
Project Number:	2016MT307B
Start Date:	3/1/2016
End Date:	2/28/2017
Funding Source:	104B
Congressional District:	1
Research Category:	Water Quality
Focus Category:	Treatment, Water Quality, Water Supply
Descriptors:	None
Principal Investigators:	Neerja Zambare

Publications

There are no publications.

Neerja Zambare

Montana Water Center Fellowship

Final Report 2016-2017

Removal of selenium by co-precipitation with microbially induced calcite precipitation

PROJECT BACKGROUND AND DESCRIPTION

Selenium (Se) is a contaminant that can leach out from coal mining waste when exposed to groundwater under aerobic conditions causing release into surrounding water streams. Selenium is known to bio-accumulate. As it moves up the food chain, it can cause deformities and reproductive abnormalities in fish, while in humans it is known to lead to gastrointestinal disturbances, nail and hair loss and dermatitis, and neurotoxicity.¹ Co-precipitation has been studied abiotically with selenium, where it was shown that selenite can incorporate in the CaCO_3 crystal lattice more readily compared to selenate.² However, biological co-precipitation has not been tested and the work presented here was based on biological precipitation of calcium carbonate. Ureolytic bacteria can bring about the hydrolysis of urea (ureolysis) which creates chemical conditions conducive to calcium carbonate precipitation when aqueous calcium is present. The most common forms of aqueous Se are selenite and selenate, which are oxyanions.³ Therefore, co-precipitation of Se with MICP would involve these oxyanions potentially replacing the carbonate anion.

The aim of this study was to investigate whether aqueous selenium can incorporate into the calcium carbonate that is formed via bacterial ureolysis by the ureolytic soil bacterium *Sporosarcina pasteurii*. This was done in two phases, the first phase of experiments looked at the effects of concentrations of calcium and selenium on the removal of aqueous selenium. The second phase investigated the removal behavior of selenite versus selenate, and looked at MICP with selenium co-precipitation in field wastewater samples from the coal-fired power plant in Colstrip, MT. This work did not establish the specific mechanism of removal but focused on investigating whether selenium removal alongside MICP is possible and feasible.

METHODS

Batch experiments were set up in artificially prepared groundwater (reference) with calcium and selenium added at various test concentrations. The AGW was also supplemented with urea to facilitate ureolysis. The batch reactors were inoculated with an overnight culture of *Sporosarcina pasteurii* centrifuged, washed and adjusted to an OD of 0.4. Over the 100-hour duration of each

experiment, temporal fluid samples were collected for chemical analyses including pH, dissolved urea, calcium and selenium concentrations.

In the first phase of experiments, four combinations of two calcium concentrations (1.75 mM and 0.1 M) two selenium concentrations (2.5 ppm and 5 ppm) were tested to assess the effects of concentrations on selenium removal in addition to investigating the possibility of the process. In addition to these MICP experiments, several control experiments were also performed to quantify potential selenium volatilization or abiotic precipitation in the absence of MICP.

In phase 2, 10 other experiments were performed with field samples from the coal-fired power plant in Colstrip, MT. Samples were collected from the wastewater ponds at this power plant. In the original abiotic selenium co-precipitation study, there was evidence showing selenite being able to incorporate into calcite over selenate. This was incorporated in the field experiments with selenium added as selenite or selenate. Colstrip water was used instead of AGW in the rest of the experiments, which included a combination of filtered and unfiltered water, and selenium added as selenite and selenate. All conditions tested are given in Table 1.

Table 1. (a) Experimental design of MICP and selenium (as selenate) removal batch tests in phase 1.

	#	<i>S. pasteurii</i>	Calcium (mM)	Selenium (ppm)
MICP experiments	1	Yes	1.75	2.5
	2	Yes	1.75	5
	3	Yes	100	2.5
	4	Yes	100	5
Controls	5	No	No	2.5
	6	No	100	5
	7	Yes	No	No
	8	Yes	100	No
	9	Yes	1.75	No
	10	Yes	No	2.5
	11	Yes	No	5

Table 1. (b) Experimental design of batch tests in phase 2. This phase tested water from the Colstrip power plant.

#	Base water	Selenium form (ppm)	pH ₀
1	AGW	Selenate (2.5)	7.4
2	AGW	Selenate (5)	7.7
3	AGW	Selenite (2.5)	7.7
4	AGW	Selenite (5)	7.8
5	Colstrip	No	3.6
6	Colstrip	No	6.7
7	Colstrip	Selenate (2.5)	7.2
8	Colstrip	Selenite (2.5)	6.9
9	Colstrip filtered	No	7.3
10	Colstrip filtered	Selenate (2.5)	7.3

RESULTS

Phase 1:

Four combinations of calcium and selenium (as selenate) concentrations were tested under batch conditions in phase 1 (MICP experiment in Table 1.a) In all experiments inoculated with *S. pasteurii*, the pH increased to about 9.5 indicating the occurrence of ureolysis (Figure 1)

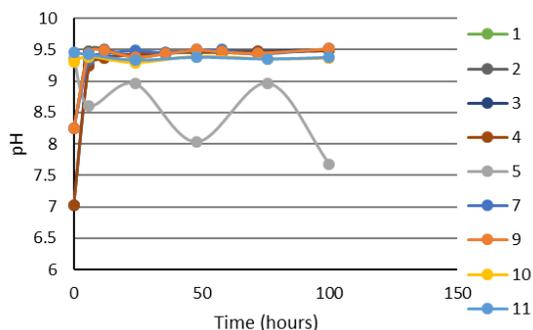


Figure 1: pH increase over time in all experiments where bacteria were present indicating ureolysis.

Preliminary results show that selenium removal depends on the initial concentrations of both selenium and calcium. Only 1% of aqueous selenium was removed at low calcium and selenium concentrations (#1 in Table 1.a). Increasing either calcium or selenium concentrations (within the design concentration limits) increased percent selenium removed comparably (2-5%). High concentrations of both selenium and calcium led to the highest selenium removal of 76%. The controls without bacteria and calcium showed no selenium removal indicating that MICP is indeed the mechanism responsible for aqueous selenium removal. However, the control without bacteria and calcium showed 1.3% selenium removal showing that selenium volatilization is a possibility in these systems. Energy Dispersive X-Ray results suggested that the precipitates (Figure 2) were calcium carbonate.

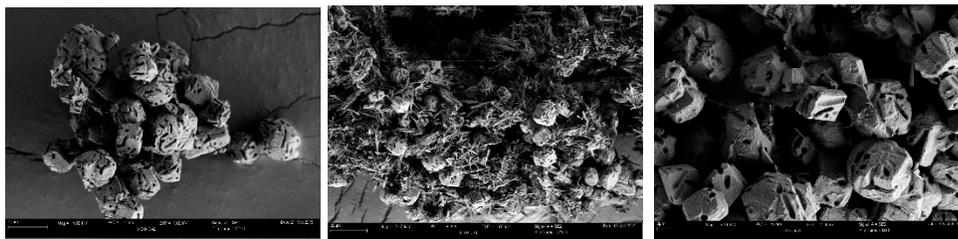


Figure 2: (Left to Right) Scanning Electron Micrographs of crystals formed in the no selenium control (#9), 2.5 ppm Se (#1) and 5 ppm Se (#2) respectively.

Phase 2:

In all AGW experiments inoculated with *S. pasteurii*, the pH increased to about 9.5 indicating the occurrence of ureolysis. In the experiment where Colstrip water was not adjusted to a pH of 7, there was no increase. This can be attributed to the cells not being able to survive in the low pH

conditions of the untreated waste water (around pH 4) (Figure 3). In the Colstrip field water reactors when the pH was adjusted to 7 prior to inoculation, the pH increase was comparatively lower and the pH plateaued at 8.

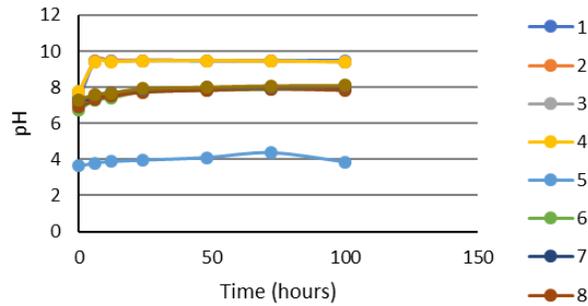


Figure 3: pH increase over time is higher for AGW experiments compared to Colstrip water experiments. No pH increase was observed in the unadjusted Colstrip water experiment.

Despite this pH increase, the urea concentrations did not decrease in the Colstrip water reactors (Figure 4) suggesting that the pH increase was not indicative of ureolysis in these experiments.

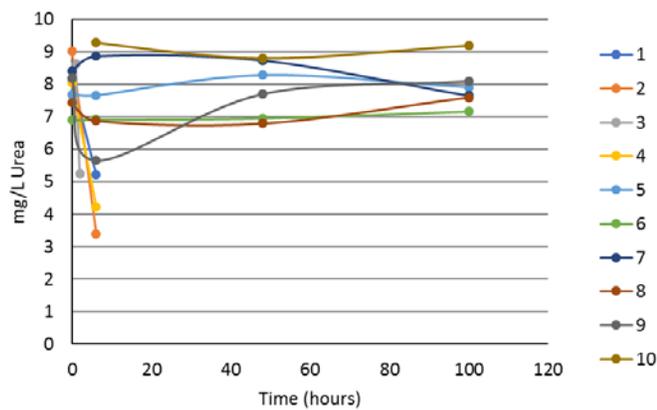


Figure 4: Urea was consumed rapidly in the AGW experiments whereas no urea decrease was measured in the Colstrip water experiments.

The results from phase 2 are preliminary and still undergoing investigation, but they indicate that all samples were acidified prior to analyzing on the ICPMS. Analysis for ICPMS requires internal standard calibration and in most of these experiments, the internal standard concentrations showed a high deviation. This means that the mass balances need to be reanalyzed and verified due to potential inaccuracies in liquid sample analyses. This was especially true with the experiments in phase 2. Moving forward, phase 2 samples will be re-analyzed on the ICPMS to increase confidence in the data. As the liquid samples are preserved in acid according to standard EPA approved methods, reanalysis at a later date within several months of preservation is not an issue. Regardless of this

potential analytical issue, the overall trends in the data can be utilized to make general conclusions on selenate remediation via MICP.

CONCLUSIONS

Despite the noise in the data, under certain conditions, selenium (as selenate) was removed from solution alongside the occurrence of MICP. However, the Colstrip data suggest that MICP might not be the most effective method for selenium removal. This is important from a potential application standpoint of this technology. More work is required to determine whether the selenate removed in phase 1 was indeed in the CaCO₃ precipitates formed by MICP or if other selenium removal mechanisms were responsible.

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Using weathering geochemistry to understand the sources of base flow water supply in rivers across mountain-basin transitions in the Upper Missouri Watershed

Basic Information

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Publications

There are no publications.

Using weathering geochemistry to understand the sources of base flow water supply in rivers across mountain-basin transitions in the Upper Missouri Watershed

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Introduction

A repeated landscape pattern in the inter-mountain west is relatively steep, actively eroding mountainous headwater streams draining onto more depositional sedimentary environments in intermountain basins. Little is understood about how hydrologic storage changes across this dramatic transition between hydro-

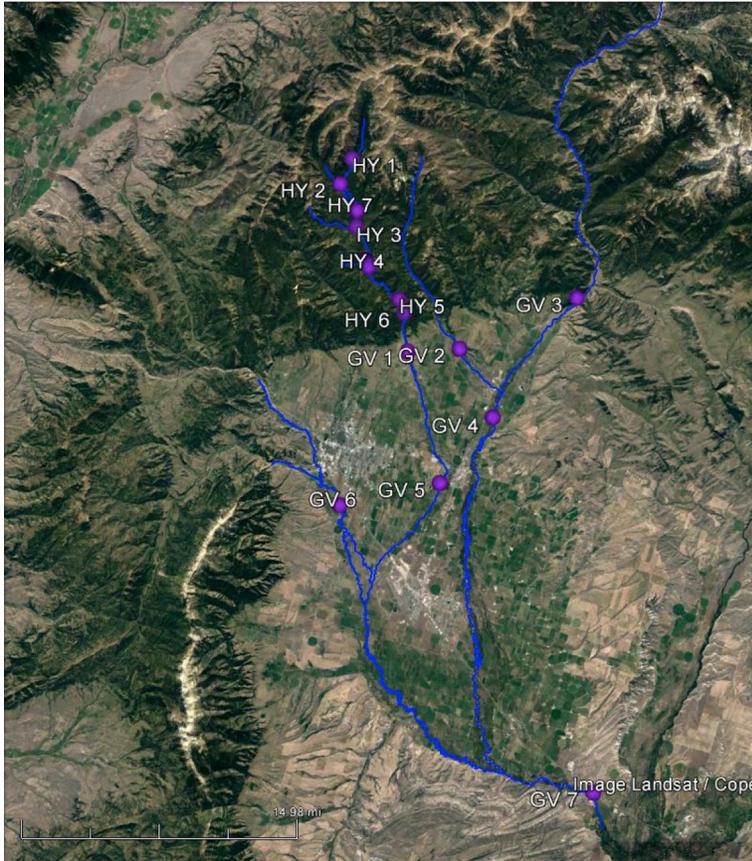


Figure 1. Sample locations in Hyalite Canyon (HY) and the Gallatin Valley (GV). Site HY8 is not shown but is adjacent to HY4 at Moser Creek.

geomorphological process domains. This limits our ability to make informed management decisions regarding baseflow water supply, because human infrastructure typically becomes more directly coupled to the hydrosystem within intermountain basins. In summer 2016, we were funded by USGS to evaluate the Gallatin River watershed as a case study in the continuum of watershed hydrologic storage and the coupling between human and natural systems that are typical for the region. Geochemical weathering imparts a chemical signal on water quality that is an underutilized source of information about the nature of base flow storage along the mountain-basin continuum.

Therefore, we are exploring spatial and temporal patterns of weathering products dissolved in base flow of the Gallatin River and its network, with the purpose of gaining new insight into the patterns of aquifer storage contributing to surface-water base flow across the mountain-basin continuum.

Our **goal** for this research is to apply emerging geochemical methods to improve understanding of hydrologic storage dynamics that are characteristic of the inter-mountain region, in order to improve the ability to detect and predict how climate and land use change influences water supply quantity and quality. By examining mountain-to-basin transitions, we seek to address a key gap in our understanding of inputs from the headwaters that drives river biogeochemistry and may influence observations downstream. A longer term goal is to link these Missouri Headwaters chemistries with downstream results, including a time series of Sr isotope data on the middle Missouri (Yankton Gage; Paces unpublished data), and dissolved inorganic and organic carbon loads (DIC and DOC loads) suggesting land use effects on productivity (Stets *et al* 2014, Stackpoole *et al* 2014).

Activities to date

Field sampling. Surface water samples were collected from Hyalite Canyon (six to eight sites) and Gallatin Valley (seven sites) on three dates in 2016 (February, May, July, August; three of these prior to award) and two dates in 2017 (February and May) (Table 1, Figure 1). These sites reflect the mountain-basin transition from the alpine catchment of Hyalite Creek (a tributary of the East Gallatin River to sites traversing the Gallatin Valley along the main stem and tributaries of the Gallatin River to its lowest elevation site at Logan, MT (HY7). To represent the endmember geochemistry of the oldest rocks in the lower canyon and at the mountain front, well samples were collected in Hodgeman Canyon just east of Hyalite Canyon on 18 May 2017.

During field sampling, water samples were filtered (0.45 μm) and analyzed at sample collection points for temperature, pH, electrical conductivity (EC), specific conductivity (SC), dissolved oxygen (DO), and alkalinity (colorimetric titration). When conditions allowed, discharge measurements were taken using the area velocity method with stream velocities measured using a Marsh McBirney flow meter (Hach). At sites located near a USGS gage, discharge measurements were compared to USGS values and generally taken from the USGS database for a given date.

Additional sampling during the coming year in Hyalite Creek and the Gallatin Valley will occur in August 2017, February 2018, and May 2018. Additional well sampling and soil sampling will occur during summer 2017 at sites selected to capture endmember values for soils and alluvium in the Gallatin Valley.

Table 1. Surface water sample locations and elevations

Site ID	Location	Latitude	Longitude	Elev. (ft)
HY1	Hyalite Creek above reservoir	45.4502	-110.959	6862
HY2	Emerald Creek at Hyalite Creek	45.4733	-110.954	6766
HY3	Lick Creek at Hyalite Creek	45.5035	-110.987	6405
HY4	Hyalite at Langhor's Campground	45.5329	-111.015	6090
HY5	Hyalite at Practice Rock	45.5521	-111.061	5822
HY6	Hyalite at USGS gage 06050000	45.5617	-111.071	5680
HY7	Hyalite below reservoir at old gage	45.5012	-110.986	6444
HY8	Moser Creek near Langhor's campground	45.5375	-110.016	6142
GV1	Hyalite at South 19th	45.4528	-110.958	5309
GV2	South Cottonwood at South 19th	45.5770	-111.145	5237
GV3	Gallatin River at Gallatin Gateway (USGS gage 06043500)	45.5100	-111.259	5183
GV4	Gallatin River at Axtell Bridge	45.6244	-111.211	4833
GV5	Hyalite/Middle Creek at 4Corners	45.6864	-111.169	4686
GV6	East Gallatin at Water Reclamation Facility (USGS gage 06048650)	45.7259	-111.066	4610
GV7	Gallatin River at Logan (USGS gage 06052500)	45.8864	-111.441	4089

Laboratory Analysis. Solute concentrations in water samples were determined at Montana State University Environmental Analytical Laboratory (MSU-EAL). Water samples are analyzed for total carbon (TC), inorganic carbon (IC), and total nitrogen (TN) using a Shimadzu combustion analyzer. Major anions (NO_3^- , SO_4^{2-} , and Cl^-) were determined by ion chromatography (Dionex 2100). Major ions and trace metals were analyzed by inductively coupled plasma mass spectroscopy (ICP-MS) or optical emission spectroscopy (ICP-OES) at MSU-EAL and at the Montana Bureau of Mines and Geology (MBMG) in Butte, MT. Based on U concentrations, 40 water samples collected during baseflow conditions in February 2016/2017 and August 2016

were prepared for U and Sr isotopic analysis in the MSU Soil Biogeochemistry laboratory as previously described (Ewing *et al* 2015, Paces and Wurster 2014): samples were spiked with ^{266}U , dried down on a hotplate in a total exhaust clean hood, subject to U and Sr purification using standard ion exchange, and carried to the USGS Southwest Isotope Research Lab (SWIRL) at the Denver Federal Center in Denver, CO. At SWIRL, purified samples were analyzed by thermal ionization mass spectrometry (ThermoFinnegan Triton) to determine the U and Sr isotopic composition and the precise U concentrations of the samples (Ewing *et al* 2015, Paces and Wurster 2014).

Student research. MS student Erika Sturn undertook sampling in 2016, along with sample handling and preparation for ICP and combustion analysis. Based on solute and flow data through fall 2016, she completed a professional paper and presented it to the MSU campus community for completion of her MS work through our online program. MS student Florence Miller has built upon this foundation with subsequent sampling, analysis, and data management, and plans to complete her thesis work with submission of one to two manuscripts for publication in spring-summer 2018. Undergraduate research assistant Sam Leuthold and MS student Ethan Wologo will continue to support sampling efforts and are exploring utility of water isotope measures for further elucidating system hydrology in 2017-2018.

Results to date

Complete solute data for samples collected has been obtained and compiled; our focus in this report is on interpretation of key isotopic measures obtained to date. Isotope composition data sheds light on geochemical sources of water, water movement and water flow path (e.g., Paces and Wurster 2014). The isotopic ratio $^{87}\text{Sr}/^{86}\text{Sr}$ provides a fingerprint the geologic source of water, while $^{234}\text{U}/^{238}\text{U}$ activity ratio (UAR) reflects water-rock contact time in the context of rock geochemistry, water-rock ratio, and surface area; and hence can be interpreted as flow path length within a given rock type and depositional setting, with a higher UAR generally representing a longer flow path for a given rock material and fracture pattern or texture.

Sr isotope values and concentrations. Figure 2 presents Sr concentrations, $^{87}\text{Sr}/^{86}\text{Sr}$ composition, and Ca/Sr ratios of samples taken during baseflow conditions (February 2016/2017 and August 2016) as a function of elevation. In Hyalite Creek, Sr concentrations increase with the inflow of streams derived from sedimentary rock units, and $^{87}\text{Sr}/^{86}\text{Sr}$ values increase down canyon due to increasing rock age and Rb/Sr content of the lower elevation Mississippian formation and Archean gneiss geologic units (Faure and Mensing 2004). At the mountain front transitioning to the Gallatin Valley, South Cottonwood Creek (GV3) produced the most radiogenic waters. With the exception of South Cottonwood Creek, water tends to become increasingly radiogenic as it flows through the valley. The Ca/Sr ratio shows a similar trend to the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio in Hyalite Canyon. However, the Ca/Sr ratio decreases moving downstream in the Gallatin Valley, drawn down by the low Ca/Sr ratio of the West Gallatin. Together, this informs us that lithology is controlling Sr concentration, $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratio, and Ca/Sr ratio in Hyalite Canyon. In the Gallatin Valley, surface water changes composition as it flows through the alluvial fans, and the Gallatin River at Logan represents a mixture of these tributaries.

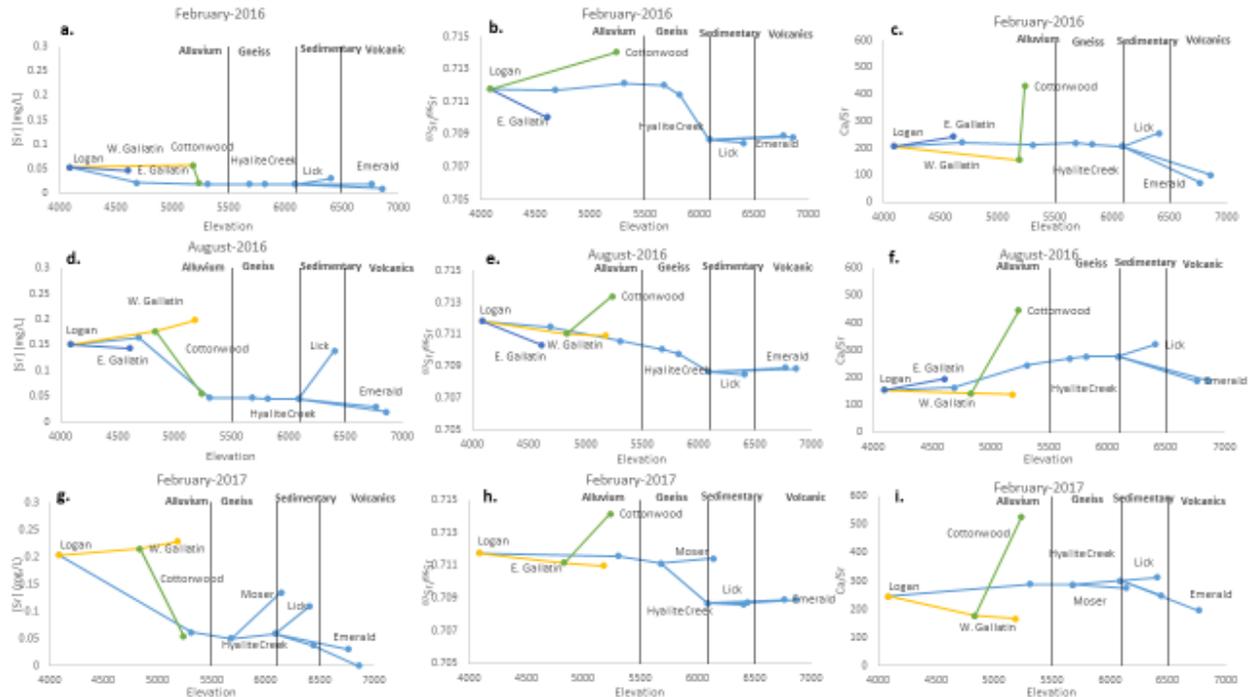


Figure 2. Elevation gradient comparing elevation to Sr concentration (a,d,g), $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratio (b,e,h), and Ca/Sr ratio (c,f,i) during February and August base flow conditions.

U isotope values and concentrations. Figure 3 presents U concentrations, UAR, and $1000 \cdot \text{U}/\text{Na}$ ratios of samples taken during baseflow conditions (February 2016/2017 and August 2016) as a function of elevation. U concentration increases downstream in Hyalite Canyon. In upper Hyalite Canyon UAR values are low (~ 1.5), suggesting relatively short flow path water, possibly soil derived. At Langohr Campground, the lower extent of glaciation, there is an increase in UAR values to ~ 3.0 , followed by a decrease downstream. We hypothesize that this increase reflects the input of longer flow path water, possibly moving slowly through glacial till or enhanced by expanded catchment area in the glaciated zone and outflow at the Archaean contact. The decrease in UAR values downstream in Hyalite Creek suggests the input of low UAR, shorter flow path water and the exchange of surface and groundwater through loss of groundwater to fractured bedrock as 'Tothian flow' (Tóth 1963). At the same time, the $1000 \cdot \text{U}/\text{Na}$ ratio increases downstream of Langohr Campground, suggesting the input of U rich water. There is little change in UAR values throughout the Gallatin Valley below the mountain front (GV3-7), and the UAR and Sr values in the Gallatin River at Logan suggest a mixture of all tributaries. The $1000 \cdot \text{U}/\text{Na}$ ratio increases moving down the Gallatin Valley, reflecting increasing U concentration.

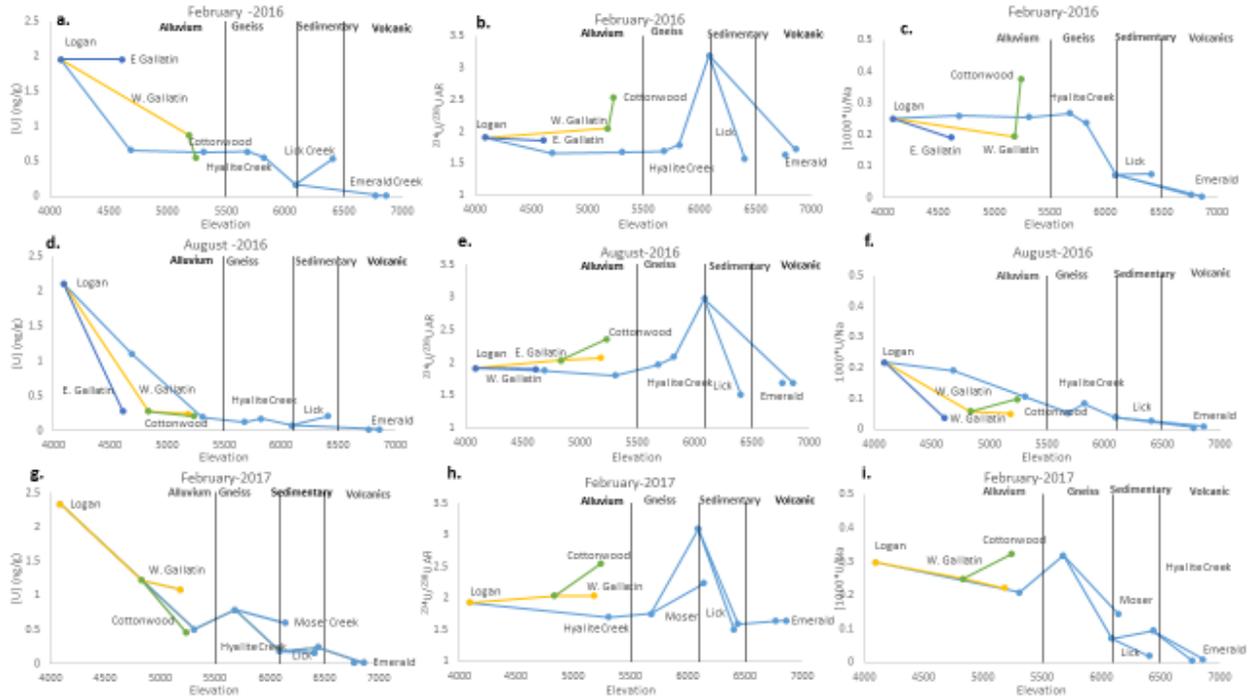


Figure 3. Elevation gradient comparing elevation to U concentration (a,d,g), $^{234}\text{U}/^{238}\text{U}$ activity ratio (b,e,h), and $1000 \cdot \text{U}/\text{Na}$ ratio (c,f,i) during February and August base flow conditions.

Figure 4 plots the UAR values versus $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios. In Hyalite Canyon the Absoraka volcanics dominate the lithology for Upper Hyalite Creek and Emerald Creek (HY1 and HY2), these are reflected in surface waters with relatively low $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios and low UAR values suggesting short flow paths. The Jurassic sedimentary units at Lick Creek (HY3) remain less radiogenic with low UAR values. At Langohr Campground (HY4) low $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios suggest consistent source, but with higher UAR values suggesting longer flow path lengths. Downstream of Langohr higher $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios and lower UAR values at Practice Rock and the USGS Gauge (HY5 and HY6) suggest exchange of water, with loss to fractured Archean gneiss bedrock and gain from shallow flow through soils. A well completed in the Archean bedrock at Hodgeman's Canyon may provide key end member values for the Archean gneiss; samples from this well and adjacent stream were collected in May 2017, and will be processed this summer. In the Gallatin Valley, samples along the mountain front (GV1-Hyalite Creek at South 19th, GV2-South Cottonwood Creek, GV3-Gallatin at Four Corners) vary in ways suggestive of lithology, with the most radiogenic $^{87}\text{Sr}/^{86}\text{Sr}$ values at GV2 suggesting influence by a neighboring fault in the Archean gneiss (Vuke *et al* 2002). As water flows through the Gallatin Valley there is a large seasonal variation, likely due to changes in water flow with summer irrigation. Hyalite Creek (also known as Middle Creek in the valley) has changes in its isotopic composition as it moves through the alluvial fans between at South 19th (GV1) and Four Corners (GV5), indicating that convergent flow through the alluvial fans impacts stream geochemistry in the valley. Again, the Gallatin River at Logan (GV7) represents a mixture of mountain and valley end members.

Water isotope values will be used to evaluate seasonal, elevational and soil dynamics that influence streamflow character.

Hypothesis 2. *Across the mountain-basin transition, controls on geochemical mixing will exhibit a fundamental change from convergent flow through bedrock derived sources to divergent flow through alluvial/soil sources.*

Our results support our prediction of strong contrast in $^{87}\text{Sr}/^{86}\text{Sr}$ values but not $^{234}\text{U}/^{238}\text{U}$ activity ratios from crystalline basement sources compared to Mesozoic to Cambrian limestone sources, both by virtue of their geochemical character and their likely contrasting flow character (fracture flow vs. karst) (Horton *et al* 1999, Paces *et al* 2015). However, the variation in UAR values within Hyalite Canyon reveals flowpath length variation consistent with geomorphic character of the glaciated zone above Langhor's Campground (HY4), and the pinch point in the canyon at the sedimentary-crystalline boundary below HY4. We will test our understanding of the processes at play in this zone using longitudinal sampling in Hyalite Creek during summer 2017.

Within the Gallatin Valley depositional basin, we expected that divergent hydrologic pathways would become more important, as infiltration through carbonate-rich soils at lower elevations and flow through aquifers containing limestone alluvium influence shallow groundwater. We thought that geochemical indication of weathering effects would be enhanced in irrigation return-flow to adjacent rivers. We therefore expected the following trends with elevation in the Gallatin Valley: an increase in Ca/Sr ratios accompanied by more uniform, intermediate $^{87}\text{Sr}/^{86}\text{Sr}$ ratios reflecting this mixture of sources, and $^{234}\text{U}/^{238}\text{U}$ activity ratios that mix limestone dissolution values approaching unity (secular equilibrium) with soil infiltration values of ~ 1.5 as observed in similar semiarid soil environments (Sharp *et al* 2003). Instead, we observed (Figures 2 & 3) that Ca/Sr ratios and UAR values were steady through the valley, suggesting mixing of mountain front sources, while U concentrations and $^{87}\text{Sr}/^{86}\text{Sr}$ values rose, suggesting increased influence of U rich and radiogenic Sr sources such as mountain front recharge from Archean rocks or recharge from Tertiary sediments lower in the valley (Michalek & Custer, personal communication). We will use targeted sampling to evaluate candidate endmember waters through well sampling in the valley and longitudinal sampling in the Gallatin River and tributaries during 2017-2018.

Generally, we expected the combination of Sr and U isotope values to be an effective tool for parsing the relative influence of infiltration and storage in the basin hydrologic system on altering the original chemistry of recharge delivered from the mountain system. Increases in U concentration and $^{87}\text{Sr}/^{86}\text{Sr}$ values with flow through the valley (Figures 2 & 3) may support this prediction. This idea will be further tested through direct examination of U and Sr isotope values in soil carbonate from variable age fans and substrate (loess vs. alluvium) in the valley during summer 2017 and subsequently. Water isotope measures in soils reveal complexity of this interaction (Orlowski *et al* 2016, Oerter *et al* 2014) and will be used to evaluate seasonal water dynamics in soils that may be influenced by differential mobility with soil development (Brooks 2015, Brooks *et al* 2015, Evaristo *et al* 2015).

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Information Transfer Program Introduction

Supporting students to become water science professionals is a core mission of the Montana Water Center. The center continued to work closely with faculty researchers to engage students in water-related research including producing reports and publishing papers. Faculty researchers who received research funding from the Water Center are required to actively mentor students in the research projects.

The Center encouraged students from a wide array of disciplines that are water related to apply for student fellowships. The Water Center also encouraged students engaged in water resource studies to present at regional and national conferences. The presentations and publications of faculty and students reported in their annual reports attests to the support given to students to both take on research and also present it at local and national meetings as well as follow through to publication in scientific journals.

In addition to working with faculty and students, Water Center programs reached thousands of others interested in water issues in Montana, including water resource professionals, teachers, farmers, ranchers, engineers, drinking water and wastewater system operators.

Education and outreach on various water topics was delivered to Montana citizens through the Montana Watercourse (MTWC), which is part of the Montana Water Center. MTWC provides hands-on, dynamic, water education through a series of diverse programs that target all levels of water users, youth through adults. Using practical, unbiased, legal, and scientific information, MTWC educates Montanans on basic water facts, water problems, and their solutions (mtwatercourse.org).

Specific information transfer activities include the following:

The MTWC conducted research and writing on the Water Chapter of the Montana Climate Assessment throughout 2016. MTWC presented preliminary findings at two meetings in the fall of 2016: • Director Cross presented at the Governor's Drought Committee Meeting in October 2016 • Director Cross presented at the National Drought Resiliency Partnership Demonstration Project/Upper Missouri Basin Study meeting in November 2016

Responded to information requests on water topics ranging from water rights to water quality to effects of climate change on water supply.

Sponsored the 83rd Annual School for Water & Wastewater Operators & Managers held in October 2016 at Montana State University. This training was attended by staff members of water and wastewater utilities with the purpose of preparing new system operators to pass the certification exam, and familiarize participants with other resources they may find helpful in the future. Director Cross gave a welcome address and moderated discussions during the training

Two professional development courses were offered in FY2016. "River Restoration and Bank Stabilization" was offered March 29-30 in Billings, Montana; "Stream Restoration" was offered October 20-21 in Big Sky, Montana. Both were offered as two-day, in-person courses discussing bank stabilization and river/stream restoration techniques and applicable rules and permitting regulations specific to Montana. Resource managers, land owners, consultants and others involved in the restoration process joined the class.

Grant funded water education programs were delivered by MTWC that focused on the following areas: water quality monitoring training, Project WET curriculum training, lake ecology graduate course, careers in water, and the Montanan Water Supply Initiative material. Funding for these programs is provided through various grants including significant funding from the Environmental Protection Agency.

Information Transfer Program Introduction

Helped organize and execute a state water meeting with the Montana Section of the American Water Resources Association in Fairmont, MT on October 12-14, 2016. The conference theme was “Water Quality & Quantity in a Changing Climate.” Approximately 200 people attended the conference. Oral and poster presentations highlighted much of the current water research being conducted throughout Montana by university, federal, state, county and non-profit researchers and resource managers. Director Cross gave a welcome address and moderated discussions throughout the conference.

USGS Summer Intern Program

None.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	5	1	0	0	6
Masters	8	3	0	0	11
Ph.D.	4	0	0	0	4
Post-Doc.	0	0	0	0	0
Total	17	4	0	0	21

Notable Awards and Achievements

Related to the 104b grant to Jamie McEvoy (2015MT292B “Assessing the capacity of natural infrastructure to increase water storage, reduce vulnerability to floods, and enhance resiliency to climate change”), the following two posters received “Best Poster” at respective conferences:

Holmes, Danika and Jamie McEvoy. 2015. Montana Section of American Water Resources Association, Missoula, MT. Poster Presentation: “Natural Infrastructure, Water Storage, and Drought Resilience in the Musselshell River Basin.” (Oct 7-9, 2015).

McEvoy, Jamie and Danika Holmes. 2015. North Central Climate Science Center Open Science Conference: Integrating Research and Management of Change from the Mountains to the Plains, Colorado State University, Fort Collins, CO. Poster Presentation: “Assessing the capacity of natural infrastructure to increase water storage, reduce vulnerability to floods, and enhance resiliency to climate change” (May 20-22, 2015).

Additionally, Jamie McEvoy was invited to participate in an interdisciplinary SNAPP (Science for Nature and People Partnership) research synthesis project on Ecological Drought, supported through NCEAS (National Center for Ecological Analysis and Synthesis) and funded through USGS.

<http://snappartnership.net/groups/ecological-drought/>

Publications from Prior Years

1. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Articles in Refereed Scientific Journals - Bywater-Reyes, S. *, A.C. Wilcox, R.M. Diehl. 2017. "Multi-scale influence of riparian trees on fluvial topography quantified with ground-based and airborne LiDAR." *Journal of Geophysical Research-Earth Surface*. doi: 10.1002/2016JF004058.
2. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Book Chapters - Major, J.J., A.E. East, J.E. O'Connor, G.E. Grant, A.C. Wilcox, C.S. Magirl, M.J. Collins, and D.D. Tullis. 2017. "Geomorphic responses to U.S. dam removal—A two-decade perspective." In *Gravel-Bed Rivers 8: Rivers and Disasters*. J. Laronne and D. Tsutsumi, eds. Wiley and Sons, pp. 355-383.
3. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Articles in Refereed Scientific Journals - Bywater-Reyes, S. *, A.C. Wilcox, J.C. Stella, and A.F. Lightbody. 2015. "Flow and scour constraints on uprooting of pioneer woody seedlings." *Water Resources Research* 51, doi:10.1002/2014WR016641.
4. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Articles in Refereed Scientific Journals - Evans, E. and A. C. Wilcox. 2014. "Fine-sediment infiltration dynamics in a gravel-bed river following a sediment pulse." *River Research and Applications* 30(3): 372-384, doi: 10.1002/rra.2647.
5. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Articles in Refereed Scientific Journals - Bean, J.R., A.C. Wilcox, W. Woessner, and C. Muhlfeld. 2015. "Multi-scale hydrogeomorphic influences on bull trout spawning habitat in snowmelt-dominated headwater streams." *Canadian Journal of Fisheries and Aquatic Sciences* 72(4): 514-526, doi: 10.1139/cjfas-2013-0534.
6. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Dissertations - Sharon Bywater-Reyes, 2015. "The influence of pioneer riparian vegetation on river processes from the plant to reach scale," Ph.D Thesis, Geosciences, University of Montana
7. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Dissertations - April Sawyer, 2015. "Flood Duration and Chute Cutoff Formation in a Wandering Gravel-bed River," M.S. Thesis, Geosciences, University of Montana.
8. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Dissertations - Caelan Simeone, 2016. "Chute cutoff case study on an anabranching river: Investigating changes caused by avulsions," Senior honors thesis, Geosciences, University of Montana.
9. 2012MT272B ("Student Research Fellowship: Quantifying the Sensitivity of Spring Snowmelt Timing to the Diurnal Snowmelt Cycle") - Dissertations - Kellner, Frederick. 2013. Ensemble Modeling of SWE Distribution in the Bitterroot Mountains, Montana, USA. MS Thesis. Geosciences. University of Montana.
10. 2013MT281B ("Student Fellowship: Maintaining Migratory Pathways of Imperiled Large River and Small Stream Prairie Fishes in the Face of Climate Change") - Articles in Refereed Scientific Journals - Dockery, D. R., McMahon, T. E., Kappenman, K. M., & Blank, M. (2016). Evaluation of swimming performance for fish passage of longnose dace *Rhinichthys cataractae* using an experimental flume. *Journal of Fish Biology*.
11. 2013MT281B ("Student Fellowship: Maintaining Migratory Pathways of Imperiled Large River and Small Stream Prairie Fishes in the Face of Climate Change") - Articles in Refereed Scientific Journals - Dockery, D. R., McMahon, T. E., Kappenman, K. M., & Blank, M. (2017). Swimming performance of sauger (*Sander canadensis*) in relation to fish passage. *Canadian Journal of Fisheries and Aquatic Sciences*, (ja).
12. 2013MT281B ("Student Fellowship: Maintaining Migratory Pathways of Imperiled Large River and Small Stream Prairie Fishes in the Face of Climate Change") - Dissertations - Dockery, David

- Russell. 2015. Relationships among swimming performance, behavior, water velocity, temperature, and body size for sauger (*Sander canadensis*) and longnose dace (*Rhinichthys cataractae*). MS Thesis. Fish and Wildlife Management, Montana State University
13. 2014MT284B ("Improving accessibility to satellite soil moisture measurements: Linking SMOS data retrievals to ground measurements in Montana") - Articles in Refereed Scientific Journals - Vick, E. S., Stoy, P. C., Tang, A. C., & Gerken, T. (2016). The surface-atmosphere exchange of carbon dioxide, water, and sensible heat across a dryland wheat-fallow rotation. *Agriculture, Ecosystems & Environment*, 232, 129-140.
 14. 2014MT284B ("Improving accessibility to satellite soil moisture measurements: Linking SMOS data retrievals to ground measurements in Montana") - Articles in Refereed Scientific Journals - Welch, C. M., Stoy, P. C., Rains, F. A., Johnson, A. V., & McGlynn, B. L. (2016). The impacts of mountain pine beetle disturbance on the energy balance of snow during the melt period. *Hydrological Processes*, 30(4), 588-602.
 15. 2012MT265B ("Nutrient dynamics and ecosystem function in coupled aquatic-terrestrial ecosystems during a mountain pine beetle infestation of whitebark pine") - Dissertations - Hilary G. Eisen. 2013. Changes in litter inputs and decomposition in headwater streams during a mountain pine beetle infestation of whitebark pine. MS thesis. Wildlife Biology, University of Montana.
 16. 2014MT285B ("Contaminants monitoring and natal dispersal of ospreys along the Yellowstone River") - Other Publications - Warlick, Linnea and K. Ostovar. 2014. Baseline hematological values for osprey (*Pandion haliaetus*) nestlings on the Yellowstone River, MT. Report YRRC 2014-04. Submitted to RMC SEED Fund and the Yellowstone River Research Center, Rocky Mountain College, Billings, MT. Pp 1-10.
 17. 2014MT290B ("Student Fellowship: Precipitation and topographic controls over montane forest transpiration") - Articles in Refereed Scientific Journals - Martin, J, Looker, N, Hoylman, Z, Jencso, K, and Jia Hu. Hydrometeorology organizes intra-annual patterns of tree growth across time, space, and species in a montane watershed. *New Phytologist*, accepted - May, 2017.
 18. 2015MT292B ("Assessing the capacity of natural infrastructure to increase water storage, reduce vulnerability to floods, and enhance resiliency to climate change") - Articles in Refereed Scientific Journals - Holmes, Danika, Jamie McEvoy, Jean Dixon, Scott Payne. Under Review. "Using GIS Methods to Quantify Natural Water Storage Potential in the Musselshell River Basin, Montana." Submitted to *Water*
 19. 2015MT292B ("Assessing the capacity of natural infrastructure to increase water storage, reduce vulnerability to floods, and enhance resiliency to climate change") - Dissertations - Holmes, Danika Leah. 2016. Natural Water Storage and Climate Change Resiliency in Montana: A Geospatial Approach. MS Thesis. Earth Sciences. Montana State University.
 20. 2015MT293B ("Nitrifying wastewater biofilms and the influence of emerging contaminants") - Dissertations - Bodle, Kylie. 2016. Effects of Triclosan Exposure on Nitrification in Activated Sludge, Biofilms, and Pure Cultures of Nitrifying Bacteria. M.S. Thesis. Montana State University.
 21. 2016MT307B ("Student Fellowship: Removal of selenium by co-precipitation with microbially induced calcite precipitation") - Other Publications - Poster - Zambare, Neerja, Ellen Lauchnor, and Robin Gerlach. "Heavy metal contaminants from mine tailings – remediation by co-precipitation." National Association of Abandoned Mine Lands Programs Annual Conference September 25-28, 2016, Bozeman, MT.
 22. 2015MT298B ("Student Fellowship: Environmental DNA to evaluate individual variation in rainbow trout spawning date") - Articles in Refereed Scientific Journals - Wilcox, T. M., McKelvey, K. S., Young, M. K., Sepulveda, A. J., Shepard, B. B., Jane, S. F., ... & Schwartz, M. K. (2016). Understanding environmental DNA detection probabilities: A case study using a stream-dwelling char *Salvelinus fontinalis*. *Biological Conservation*, 194, 209-216.
 23. 2015MT294B ("Designing scenarios for hydrologic resilience in the Upper Missouri Headwaters with integrated ecosystem models") - Conference Proceedings - B Poulter, E Joetzjer, K Renwick, G Ogunkoya, K Emmett. 2016. Addressing spatial scales and new mechanisms in climate impact

- ecosystem modeling. In American Geological Union, Fall Meeting 2016. Abstract.
24. 2015MT294B ("Designing scenarios for hydrologic resilience in the Upper Missouri Headwaters with integrated ecosystem models") - Conference Proceedings - J Hoy, B Poulter, K Emmett, M Cross, R Al-Chokhachy, M Maneta. 2016. From terrestrial to aquatic fluxes: Integrating stream dynamics within a dynamic global vegetation modeling framework. European Geological Union, General Assembly Conference, Abstracts 18, 5073.