Montana Water Center
Annual Technical Report
FY 2015

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 researcher's and students' work.

Jamie McEvoy of Montana State University received an award of $14,886 to study "Assessing the capacity of natural infrastructure to increase water storage, reduce vulnerability to floods, and enhance resiliency to climate change". A report from this project is presented later in this annual report.

Ellen Lauchnor of Montana State University received an award of $15,000 to study "Nitrifying wastewater biofilms and the influence of emerging contaminants". A report from this project is presented later in this annual report.

Benjamin Poulter of Montana State University received an award of $5,832 to study "Designing scenarios for hydrologic resilience in the Upper Missouri Headwaters with integrated ecosystem models". A report from this project is presented later in this annual report.

Sarah Benjaram, at Montana State University received a $1,000 student fellowship to study "Climatic and geomorphologic influences on soil development and transport in the Bitterroot and Sapphire Mountains, Montana, USA". A report from this project is presented later in this annual report.

Michael Jahnke, at University of Montana received a $1,000 student fellowship to study "Sediment routing in steep mountain streams to understand hillslope-channel connectivity". A report from this project is presented later in this annual report.

Miranda Margetts, at Montana State University received a $1,000 student fellowship to study "Enhancing Tribal Environmental Health Literacy: Developing a toolkit to improve community understanding of rights and responsibilities regarding water quality". A report from this project is presented later in this annual report.

Taylor Wilcox, at University of Montana received a $909 student fellowship to study "Environmental DNA to evaluate individual variation in rainbow trout spawning date". A report from this project is presented later in this annual report.

The Montana Water Center selected three faculty seed grant projects and five graduate student fellowship projects to fund in 2016 with USGS 104(b) research program funds administered by the Montana Water Center. The selected faculty grants are:

Robert Payn of Montana State University will receive an award of $14,961 to study "Understanding how beaver mimicry restoration influences natural water storage in Missouri River headwater streams".

Lindsey Albertson of Montana State University will receive an award of $15,000 to study "Impacts of river flow and temperature on salmonfly productivity and terrestrial subsidy".

Alysia Cox of Montana Tech - University of Montana will receive an award of $15,000 to study "Characterizing Microbial Activity as Related to Water Quality in the Clark Fork Headwaters: A Baseline Study".

The selected student fellowships are:

Jordan Allen, at Montana State University will receive a $1,000 student fellowship to study "Impacts of glacial processes on nitrogen cycling in the Beartooth Mountains, Montana".

Keenan Brame, at Montana State University will receive a $1,000 student fellowship to study "Transportation, Sediment-Association, and the Future of Microbial Contaminants on the Little Bighorn River".

Rachel Powers, at University of Montana will receive a $1,000 student fellowship to study "Riparian Ecosystem Succession Following Fire Disturbance on the North Fork Flathead River, Montana".

Claire Qubain, at Montana State University will receive a $1,000 student fellowship to study "Snowpack controls on nitrogen availability and nitrogen uptake in a Rocky Mountain conifer forest".

Neerja Zambare, at Montana State University will receive a $1,000 student fellowship to study "Removal of selenium by co-precipitation with microbially induced calcite precipitation".

Improving accessibility to satellite soil moisture measurrements: Linking SMOS data retrievals to ground measurements in Montana

Basic Information

Title:	Improving accessibility to satellite soil moisture measurrements: Linking SMOS data retrievals to ground measurements in Montana
Project Number:	2014MT284B
Start Date:	3/1/2014
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	MT 1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Surface Water, None, None
Descriptors:	None
Principal Investigators:	Paul C Stoy

Publications

There are no publications.

Improving accessibility to satellite soil moisture measurements: Linking SMOS data retrievals to ground measurements in Montana

An interim report for the Montana Water Center

Paul C. Stoy

April 31, 2015

The aridity index of Montana has increased over the past 50 years due to an increased atmospheric demand for water rather than a decrease in precipitation (Sheffield et al. 2006; Stoy 2013). Improved access to state-of-the-art observations of Montana water resources will enable managers to make informed decisions about our increasingly scarce water supply, and lessons learned in Montana may have benefits for other semiarid regions across the globe (Wallace and Batchelor 1997).

Plant growth is more sensitive to soil moisture than any other variable in the hydrologic cycle (Rodriguez-Iturbe and Porporato 2004). Soil moisture is conventionally measured at scales on the order of centimeters manually or using time domain reflectometry (TDR), but COSMOS (Zreda et al. 2008) and satellite-based soil moisture measurements (see Table 1 in Ford, Harris, & Quiring, 2013) create new opportunities for studying soil moisture across larger scales in space. COSMOS measures soil moisture using neutron backscatter on spatial scales of hundreds of meters and at depths on the order of 5 – 30 cm from a ground-based platform, and SMOS is a satellite measures the top centimeters of soil in 50 km footprints. It is unclear if these differences in spatial scale and location lead to important discrepancies in soil moisture estimates in Montana.

The present project funded 2.3 months of graduate student summer support to: 1) Download and process data from the European Soil Moisture and Ocean Salinity (SMOS)

satellite; 2) Validate SMOS data for agricultural regions of Montana; 3) Provide public soil moisture data access. The proposed project is designed to align with Montana Water Center priority issues by fostering student involvement, assisting new faculty members, providing seed funding with potential for larger programs, and conducting research relevant to MT water challenges.

As noted, SMOS has partial spatial coverage of the terrestrial surface and provides soil moisture estimates over the first few centimeters of soil in 50 km swaths. As a consequence, there is often a spatial disconnection between the area of SMOS measurement and area of interest. We compared SMOS data against TDR measurements from a site in the Judith Basin near Moore, MT, and against COSMOS observations near Fort Peck, MT (Figure 1).

Observations reveal a substantial mismatch between SMOS and TDR measurements in the Judith Basin (Figure 1) with an average difference of 0.2 m^3 m^{-3} or more, and a close match between SMOS and COSMOS observations at Fort Peck, usually within 0.05 m^3 m^{-3} or less (Figure 2). The mechanisms that underlie these differences is unclear; the SMOS footprint encompasses both the Judith Basin TDR measurements (Figure 3) and Fort Peck COSMOS observations (Figure 4). The SMOS center point and COSMOS sensors are separated by only 3.8 km at Fort Peck on similar land cover (Figure 5). TDR measurements and SMOS center points are separated by 7.5 km in the Judith Basin and both are on agricultural land. The SMOS pixel in the Judith Basin overlaps with the Big Snowy Mountains, although one would expect springtime soil moisture measurements to be higher than the observed SMOS range of 0.05 to 0.35 during this period.

Observations suggest that SMOS observations may or may not intersect with TDR and COSMOS observations, albeit for reasons that are unclear. SMOS captures observations across a large 50 km pixel with a three day overpass, and the characteristic spatial and temporal scales of soil moisture variability may be much finer than its native measurement resolution (Katul et al. 2007). It is likewise unclear how to best communicate such observations outside of making data from the Judith Basin TDR observations publically available as COSMOS already is (http://cosmos.hwr.arizona.edu/Probes/StationDat/048). Further, the recently-launched Soil Moisture Active Passive (SMAP) mission reports data in smaller 10 km pixels every 2-3 days. Future efforts should use seek to validate publicly-available SMAP data rather than SMOS, which requires permissions and extensive processing, for an improved understanding of the variability of Montana's near-surface soil moisture resources for agricultural and water resource planning.

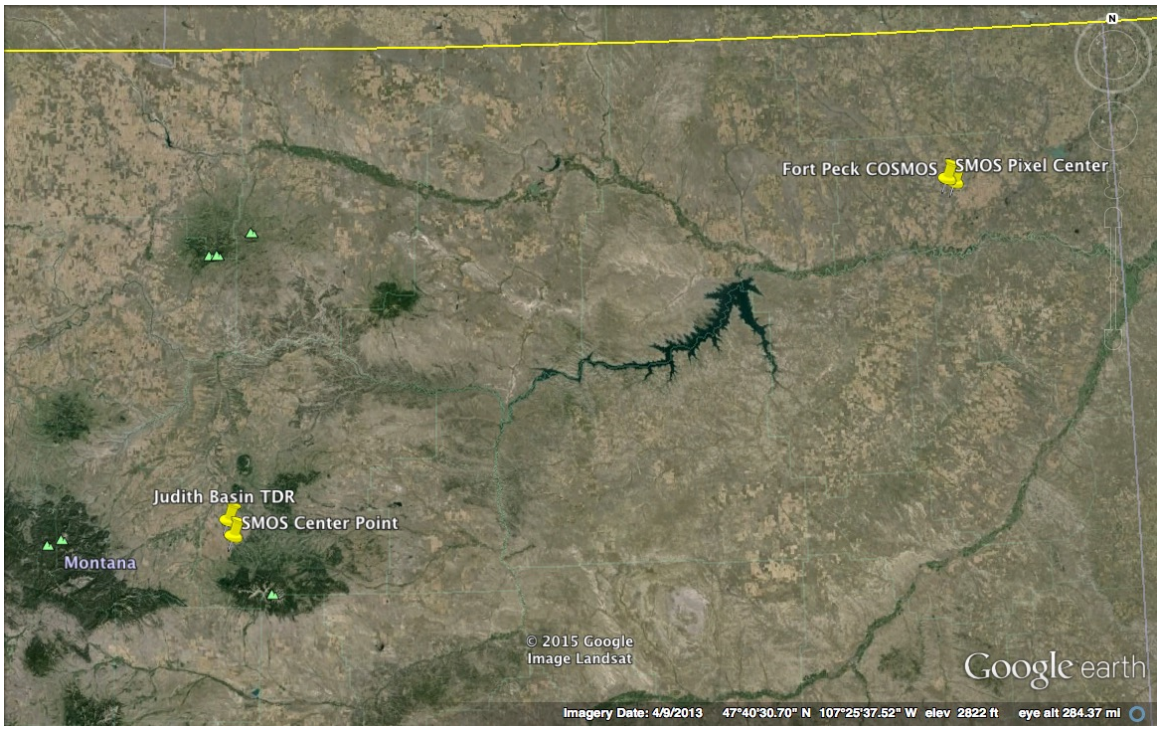

Figure 1: The location of Time Domain Reflectometry (TDR) and COSMOS observations in the Judith Basin and Fort Peck, MT compared against 50 km SMOS pixel center points. The vertical gray line is the Montana/North Dakota border and the yellow line is the US/Canada border.

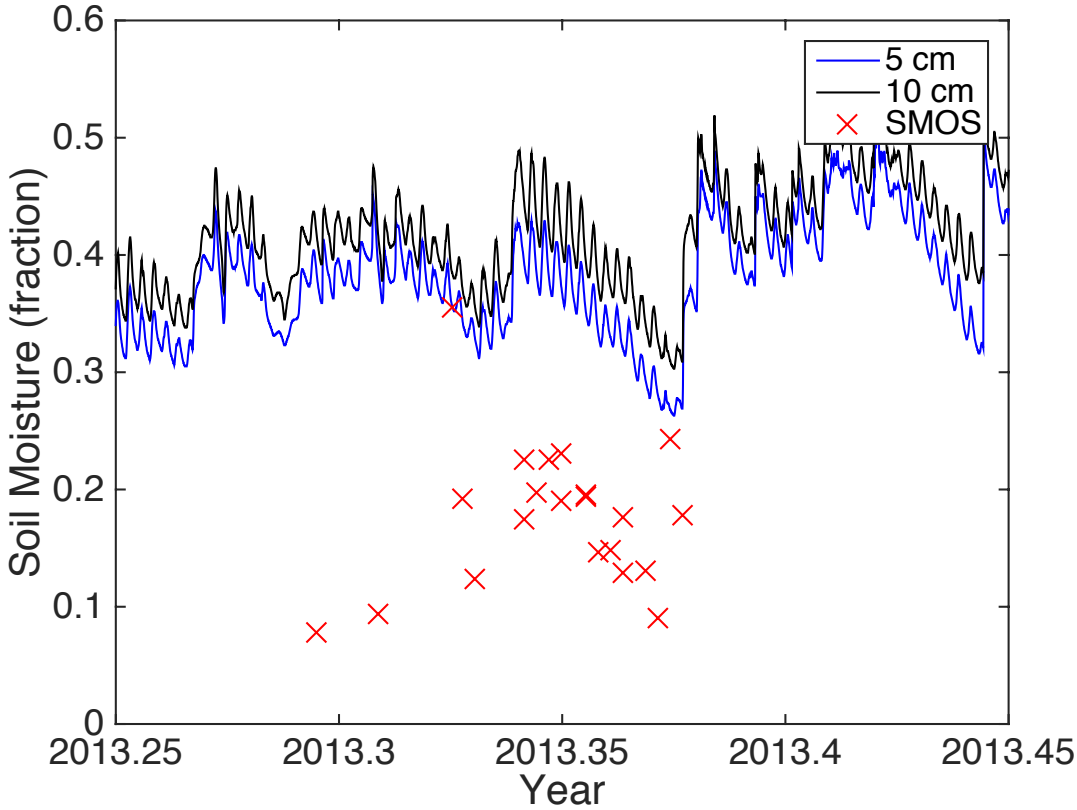

Figure 2: SMOS and time domain reflecometry (TDR) measurements in the Judith Basin near Moore, MT.

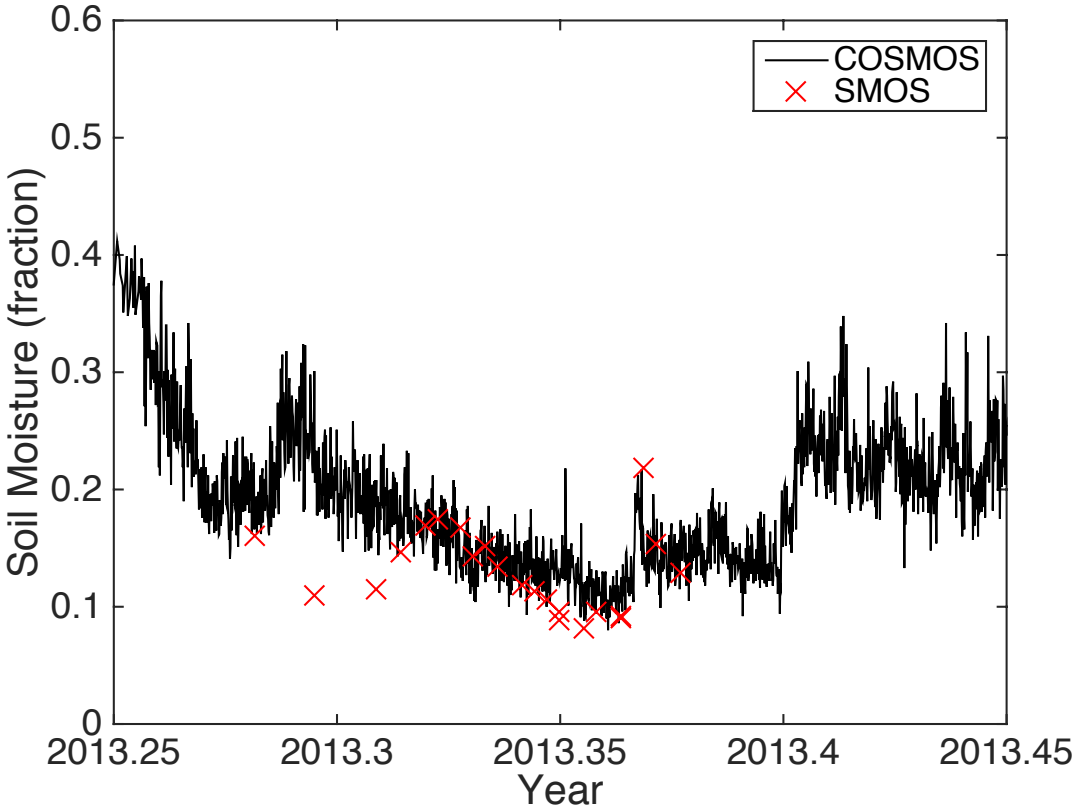

Figure 3: SMOS and COSMOS observations from sites near Fort Peck, MT.

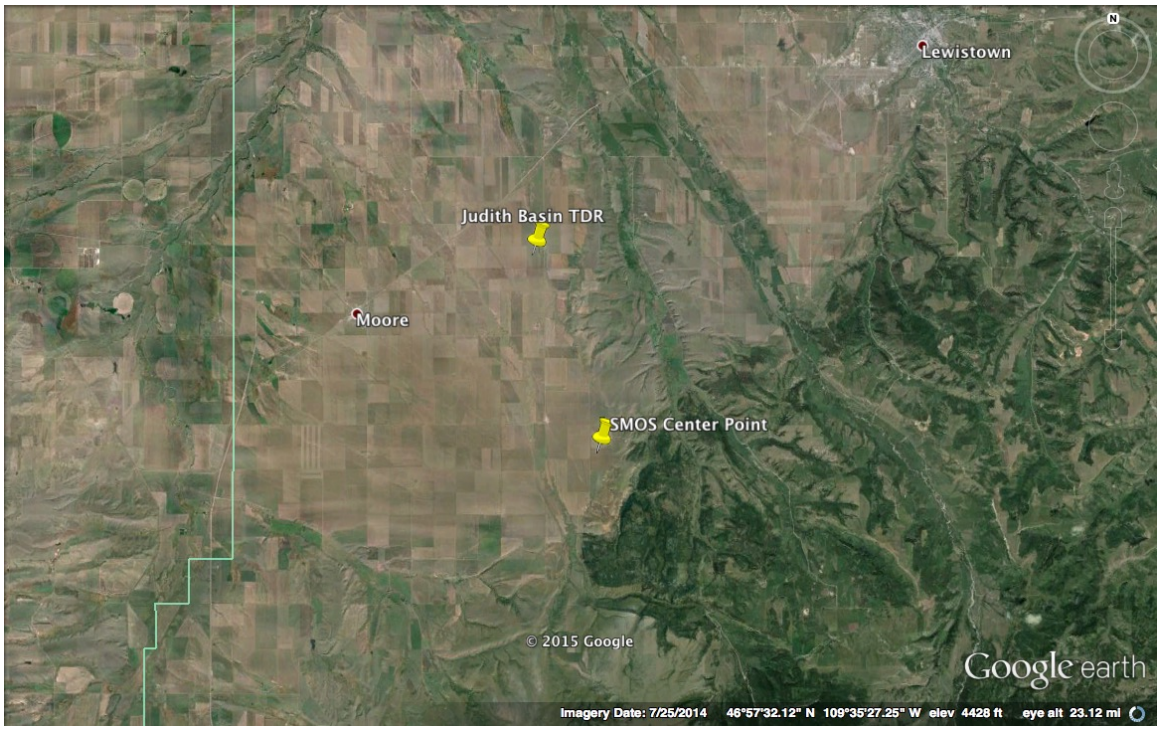

Figure 4: The locations of the Judith Basin time domain reflectometry (TDR) observations and Judith Basin SMOS Center point.

Figure 5: The locations of the Fort Peck COSMOS observations and the corresponding SMOS center point.

References

Ford TW, Harris E, Quiring SM (2013) Estimating root zone soil moisture using near-surface observations from SMOS. Hydrol Earth Syst Sci Discuss 10:8325–8364. doi: 10.5194/hessd-10-8325-2013

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Wallace JS, Batchelor CH (1997) Managing water resources for crop production. Philos Trans R Soc London Ser B Biol Sci 352:937–947. doi: 10.1098/rstb.1997.0073

Zreda M, Desilets D, Ferré TPA, Scott RL (2008) Measuring soil moisture content non-invasively at intermediate spatial scale using cosmic-ray neutrons. Geophys Res Lett 35:L21402. doi: 10.1029/2008GL035655

Assessing the capacity of natural infrastructure to increase water storage, reduce vulnerability to floods, and enhance resiliency to climate change

Basic Information

Title:	Assessing the capacity of natural infrastructure to increase water storage, reduce vulnerability to floods, and enhance resiliency to climate change
Project Number:	2015MT292B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	MT 1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Drought, Water Quantity, Water Supply
Descriptors:	None
Principal Investigators:	Jamie McEvoy

Publications

There are no publications.

Assessing the capacity of natural infrastructure to increase water storage, reduce vulnerability to floods, and enhance resiliency to climate change

Progress Report for the Montana Water Center

Jamie McEvoy

May 1, 2016

Project Overview

Climate Change is projected to affect the quantity, quality, and timing of water availability in Montana. These projections have raised concerns about water storage capacity in many basins in the state. The *2015 Montana State Water Plan* identifies the need for increased water storage and retention as "an important tool for meeting future demands and responding to climate change" (p. 4). Recognizing the role that natural infrastructure (i.e., riparian areas, floodplains, and wetlands) plays in slowing runoff and promoting groundwater recharge (i.e., water storage), this plan calls for exploration of using natural infrastructure to store and retain water for the benefit of water supplies and ecosystems. However, research is needed to quantify the natural storage capacity of particular basins. This project used the Musselshell River basin, which experienced unprecedented flooding in 2011 and 2014, as an initial case study for assessing the potential for natural water storage.

The current project provided partial funding[1] to support Danika Holmes, a masters student in Earth Sciences. Holmes developed a geospatial model for identifying prospective natural storage implementation sites and estimated the water storage potential of an identified site located on a portion of the Musselshell River (MSR) floodplain in central Montana. In this study, storage potential was defined as the physical volume of space available for the storage of water between the land surface of the study site and the underlying groundwater table. Geographic Information System (GIS) techniques were used to develop a model for identifying areas with high potential for natural storage capacity. All data inputs for the model are open-source data. Geographic analysis was completed using ArcGIS 10.2.

Project Findings

Site Selection and Model Development

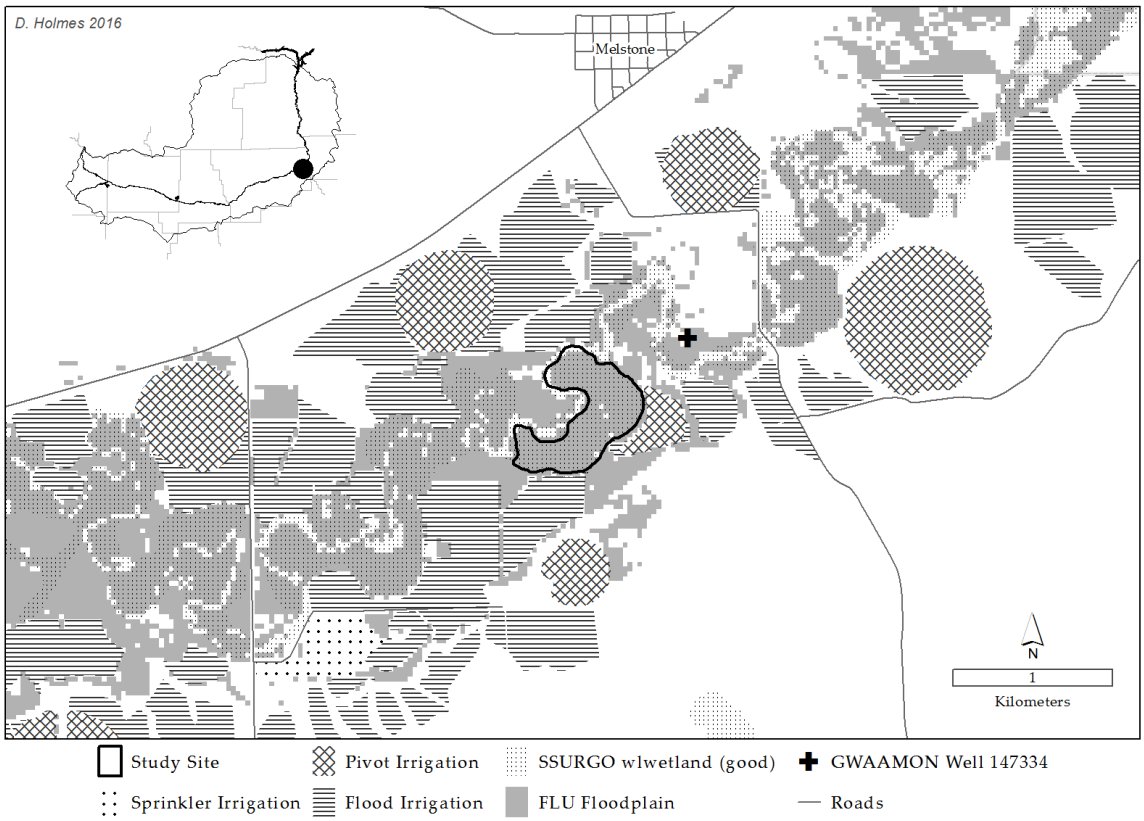
The first step in quantifying natural storage potential was to identify an appropriate site within the 450 km^2 surrounding Melstone, MT due to the notable impacts of the 2011 flood in the area. The specific study location was further refined according to a set of four selection criteria: 1) site classification as 'floodplain', 2) proximity to a long term monitoring well, 3) high suitability of soils to support wetland habitat, and 4) the absence of built infrastructures such as roads and railroads on the site. The development of a GIS-based model to select potential sites and quantify floodplain storage relies on the availability of data informing four key

[1] Additional funding was provided by a $5,000 matching grant from the Montana Department of Natural Resources and Conservation and funds from McEvoy's start-up index at Montana State University.

elements: surface elevation, physical soil characteristics, land cover and land use, and groundwater level.

A study site with an area of 33 ha was selected based on its classification as floodplain, its high suitability to support wetland habitat, the absence of on-site transportation infrastructures, and close proximity (422 m) to the study area's of long term ground water assessment and monitoring (GWAAMON) well (Figure 1). A 2 ha portion of the study site is classified by the U.S. Fish & Wildlife Service's National Wetlands Inventory as freshwater emergent palustrine wetland. The study site is surrounded by productive agricultural lands that are irrigated with flood, sprinkler, or center pivot methods, and is located 1.8 kilometers south of Melstone.

Figure 1. Location of study site south of Melstone, Montana, including classification characteristics of site and surrounding area.

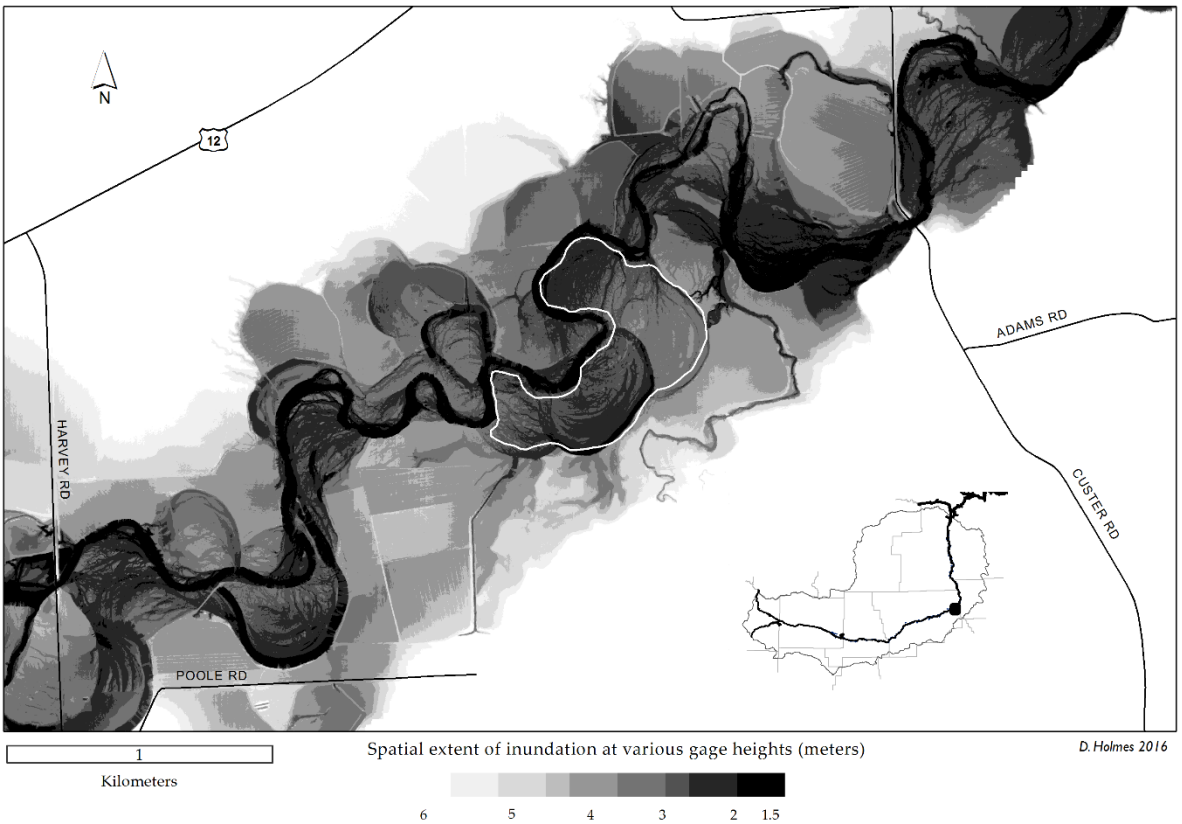


Quantifying Storage

The natural storage potential of the selected site (S_{site}) was quantified for both high and low static water level ($\varphi_{high}, \varphi_{low}$). S_{site} was defined as the combined total storage capacity of the volume of space in the soil between the study site's ground surface (g) and the underlying water table (φ) that can hold water (S_{ground}), and the potential pooled water volume above the surface (V_{pool}).

An inundation map of the study site was created using LiDAR elevation data and LiDAR-derived custom cross sections of the floodplain surrounding the study site. The inundation model simulates areal flood extents that correlate with certain stream gage (h_g) levels evident in the nearest MSR stretch (Figure 2). The inundation model was originally developed by DTM Consulting, Inc. for use in the Yellowstone River Basin, and was customized for application in this study. This part of the model first calculates the difference in vertical (z) distance between individual cells in the LiDAR imagery and the lowest z point of a cross section (i.e. the portion of stream surface intersected by a cross section) nearest to the cell. A given cell is considered to be inundated when the difference in z distance between the cell and the closest cross section's lowest z is surpassed by h_g. Inundation levels were calibrated to the h_g data, and mapped inundation extents were calculated for h_g values ranging from 1.5 m to 6 m. The study site was simulated to be entirely inundated when h_g was measured at 3.4 m, which is considered flood stage ($h_{g3.4}$) at the Musselshell gage.

Figure 2. Study site inundation map showing the extent of flooding associated with specific MSR gage heights. The site is entirely inundated when gage height is measured at or above 3.4 meters.



4. Results

Potential storage was calculated for the study site under six different conditions for a total of eight storage estimations ranging from 45,004 m^3 to 799,707 m^3 (Table 1). The model shows that the least water is stored when the water table is high, the site surface is vegetated, and the stream is at $h_{2.1}$. Alternatively, the study site was simulated to store the most water with a lower water table and a bare surface, and when the river is at flood stage.

Table 1. Study site storage potentials under six varying gage height conditions. All storage potentials are highlighted and shown in m^3, with the smallest and largest estimations shown in darker contrast.

	$h_{g2.1}$		$h_{g3.4}$	
Volume Conditions	ϕ_{high}	ϕ_{low}	ϕ_{high}	ϕ_{low}
V	144,317	171,454	1,247,048	1,446,872
V_{pool}	44,405	44,405	571,101	571,101
S_{site}	**67,207**	**71,495**	**768,135**	**799,707**
V_{veg}	22,202	22,202	284,934	284,934
S_{site}	**45,004**	**49,292**	**481,968**	**513,540**

Future Research

While the natural storage model developed in this study provides a method for quickly identifying sites with high potential to function as natural storage structures and a method for estimating floodplain water storage potential, there are several model limitations. In future studies, available water storage or porosity values should be determined using data collected in the field, and stream stage and discharge data should be collected as close to potential sites as possible. Further research should emphasize natural storage model input validation and calibration. Additionally, improving the accuracy of this natural storage model to better understand the contribution of natural storage sites to late-season return flows, for instance, requires the consideration of several other hydrologic variables, including (but not limited to):

- Rates of groundwater recharge
- Anthropogenic groundwater diversion trends
- Channel migration patterns
- Local hydraulic conductivity and hydraulic gradient
- Interflow speed and direction

- Precipitation (rain and snow)
- Surface roughness
- Local geology and lithology
- Stream discharge and stage data directly upstream and downstream of the study site
- A vegetation profile of the area, as well as local evapotranspiration rates
- An updated, high-resolution soil survey for more precise physical soil characterization

Lastly, given that successful natural storage projects will most likely require approval by and participation of landowners and local stakeholders, further research is needed on the human dimensions of natural storage projects. Specifically, policy research should be conducted in a multi-state comparative study to examine how different states manage rainwater harvesting and the potential implications of water storage projects. Additionally, interviews should be conduted with landowners to identify the barriers and opportunities for implementing natural storage projects on their property.

Project Outputs

The graduate student (Holmes) and her advisor (McEvoy) have presented this research at multiple conferences. Holmes has received several "best poster" awards for her work. Holmes defended her thesis in April 2016 and accepted a full-time job as a water specialist with the Montana Department of Natural Resources. Holmes and McEvoy will submit an article to the peer-reviewed, open-access journal of *Water* in June 2016. Below is a list of project outputs:

- 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). Awarded 2nd Place in AWRA Poster Competition

- Danika Holmes. MSU Earth Sciences Student Colloquium. Poster Presentation: "A Geospatial Model for Identifying and Quantifying Natural Storage Potential in the Musselshell River Basin." (May 2015). Awarded 2nd Place in best poster competition by Montana Association of Geographic Information Professionals.
- 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).
- Holmes, Danika. 2015. Montana State University Graduate Student Summit. Poster Presentation: "Natural Infrastructure, Water Storage, and Drought Resilience in the Musselshell River Basin." (October 2015). Awarded 1st Place in Poster Competition.
- Danika Holmes and Jamie McEvoy. 82nd Annual Fall Water School for Water & Wastewater Operators & Managers. Oral Presentation: "Musselshell River Natural Storage Project." (Sept. 4, 2015)
- Holmes, Danika. American Association of Geographers. Oral Presentation. "Drought Resilience, Natural Infrastructure, and Modeling Water Storage: A Geospatial Approach." (April 2, 2016).
- Holmes successfully defense of Masters Thesis, April 14, 2016
- Holmes accepted a full-time job with Montana DNRC – to begin May 2016.
- A journal article will be submitted to *Water* in June 2016

Nitrifying wastewater biofilms and the influence of emerging contaminants

Basic Information

Title:	Nitrifying wastewater biofilms and the influence of emerging contaminants
Project Number:	2015MT293B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	MT 1
Research Category:	Water Quality
Focus Category:	Wastewater, Water Quality, Treatment
Descriptors:	None
Principal Investigators:	Ellen Lauchnor, Ellen Lauchnor

Publications

There are no publications.

Nitrifying wastewater biofilms and the influence of emerging contaminants

An interim report to the Montana Water Center

Ellen Lauchnor, Assistant Professor of Civil Engineering

April 30, 2016

Across the U.S., organic contaminants originating from pharmaceuticals, personal care products and other commonly used household products have been detected in surface and groundwater resources, including those used as municipal water supplies and even in processed municipal water [1-4]. Many of these contaminants of emerging concern (CEC) are known to have endocrine disrupting effects on aquatic species at concentrations measured in the field [5] and may have adverse, largely unquantified effects on human health. The widespread occurrence of these CECs in natural water must be addressed due to their potential to impact ecosystems and human health at low levels of exposure [1]. While source reduction may reduce CEC concentrations it will not eliminate them. Therefore, the study of water treatment processes that promote removal of these contaminants and continue to provide treatment of traditional contaminants, such as organic carbon and nutrients, is of interest across the U.S. and worldwide.

One CEC, triclosan, is an antimicrobial commonly found in household products such as soaps, toothpaste and as coatings on children's toys. Triclosan is commonly used in personal care products such as antibacterial soaps and has been shown to inhibit treatment processes in wastewater, in addition to being toxic to environmental species when detected in natural receiving waters[4,6,7]. Triclosan prevalence in wastewater treatment plants (WWTP) can result in detrimental impact to WWTP treatment efficiency and nutrient removal.

Of particular concern are the nitrifying bacteria that participate in nitrogen removal, as they are prone to inhibition and toxicity during exposure to contaminants [8-10]. Nitrifying bacteria are composed of two groups that sequentially convert ammonia to nitrate, ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB). Both AOB and NOB are autotrophic and slower growing than heterotrophic organisms, thus they are sensitive to inhibition and wash-out leading to loss of nitrification in WWTP.

This project investigated the impact of triclosan (TCS) on nitrifying bacteria in activated sludge flocs and nitrifying biofilms inoculated from a local wastewater treatment plant. Activated sludge was obtained from the biological treatment train at the Bozeman Wastewater Reclamation Facility. The facility operates a 5-stage Bardenpho process to remove BOD, nitrogen and phosphorus via microbial treatment. The Bardenpho process consists of five stages: fermentation, first anoxic, nitrification, second anoxic, and reaeration. Samples for activated sludge experiments and biofilm inoculum were extracted from the nitrification zone of the treatment train.

Investigations of nitrification and TCS fate in the activated sludge cultures were performed via batch studies in artificial wastewater, within 48 hours after sampling from the Bozeman WRF. Cultures were washed via centrifugation and added to fresh artificial wastewater in one liter flasks, with or without TCS addition. Triclosan has a very low solubility in aqueous solution, thus to generate a stock solution for addition to the flasks, the TCS was dissolved in a solvent, dimethyl

sulfoxide (DMSO). Prior tests with pure cultures of the nitrifying bacteria, *Nitrosomonas europaea*, did not show evidence of inhibition or toxicity by DMSO exposure alone.

Ammonium, nitrite and nitrate were monitored in the activated sludge cultures for 3 days, with results shown in Figure 1. The DMSO controls did indicate inhibition by DMSO, though it is also clear that exposure to all concentrations of TCS tested reduced the total nitrification in the 3 day batch tests. Further investigation of the nitrite and nitrate concentrations over time show accumulation of nitrite in TCS exposed cultures, due to inhibition of nitrite oxidation. These preliminary results indicate that nitrite oxidation may be more inhibited than ammonia oxidation by TCS exposure.

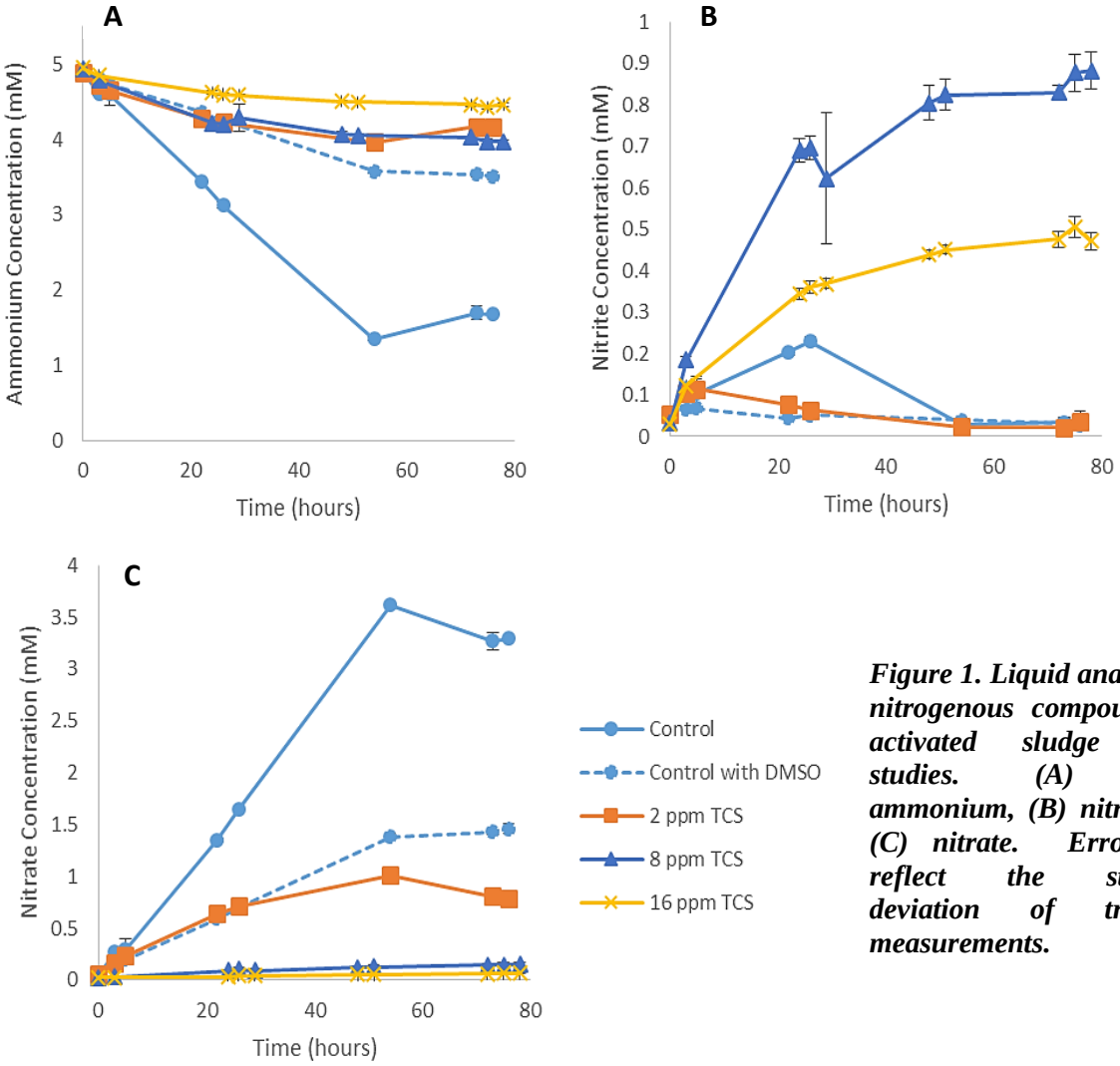


Figure 1. Liquid analyses of nitrogenous compounds in activated sludge batch studies. (A) Total ammonium, (B) nitrite and (C) nitrate. Error bars reflect the standard deviation of triplicate measurements.

Triclosan was detected by high performance liquid chromatography (HPLC). Initial TCS detection has been performed with an HPLC with UV detector and is being adapted to a new HPLC-MS/MS system, expected to achieve significantly lower detection limits. The concentrations of triclosan tested reflected the current limitations of the HPLC-UV system.

Initial decreases in triclosan concentration corresponded to sorption of the compound to the activated sludge biomass (Fig. 2). Batch tests with killed biomass show equivalent decreases, indicating initial loss is due to sorption. Previous studies on TCS have shown strong partitioning onto biomass in activated sludge[11]. However, during exposure to a lower TCS concentration of 2 ppm, sustained decrease in TCS was observed over time in activated sludge, indicating degradation was occurring. In further pure culture studies with nitrifying bacteria, no degradation of TCS was observed, thus heterotrophic organisms or other species in the activated sludge were likely responsible for triclosan degradation.

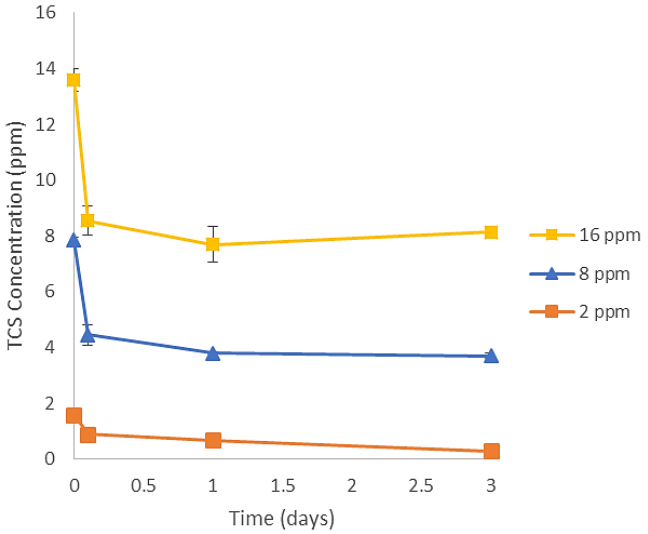


Figure 2. Triclosan loss in activated sludge batch studies. The initial drop in concentration after time zero corresponds with addition of the sludge and sorption of triclosan to the biomass.

A biofilm flow-cell was constructed for cultivation of nitrifying biofilms, using a previous design by BioSurface Technologies, Inc., Bozeman, MT (Fig. 3). The biofilm reactor consisted of three channels for replicate biofilm experiments and was constructed of polycarbonate. The flow cell was operated with a recirculating flow design (Fig. 3) to provide mixing and a hydraulic retention time of four hours. Several operational schemes were tested prior to settling on the configuration shown in Fig. 3. The biofilms were inoculated with activated sludge sampled from the Bozeman WRF, the same source culture used in the suspended cell batch studies. Biofilm systems were operated for over 200 days to achieve steady-state performance prior to conducting inhibition studies.

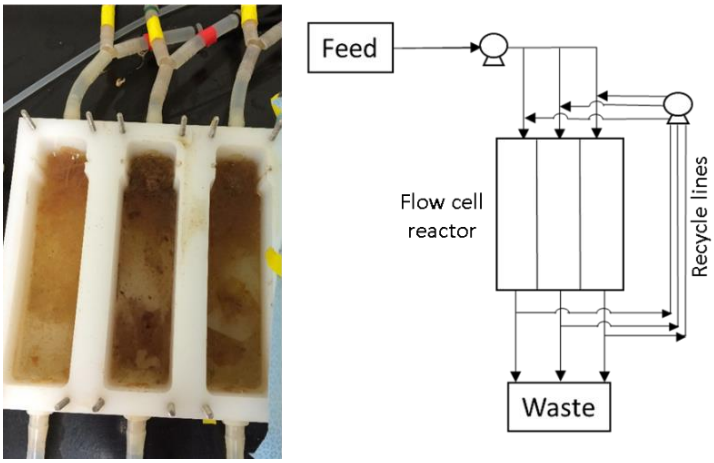


Figure 3. Left: Photo of the wastewater biofilm flow cells after several months of operation. Right: Final design of the biofilm flow cell system.

Biofilm inhibition experiments were conducted under batch conditions, due to strong sorption of TCS in the reactor system and tubing. Before and during triclosan exposure, liquid samples for nitrogen species analysis were taken and oxygen flux into the biofilms (respiration) was measured with a micro-scale oxygen sensor.

Oxygen flux, or respiration in the biofilm, was reduced with addition of TCS and greater inhibition corresponded to higher concentrations of TCS addition (Fig. 4). Respiration by nitrifying bacteria and heterotrophs both contributed to these measurements, so to compare with complete loss of nitrification, the nitrification inhibitor allylthiourea (ATU) was added. ATU blocks activity of AOB, thus additionally preventing subsequent NOB activity[10]. Nitrification loss due to ATU inhibition accounted for 25% of total respiration, similar to the loss incurred by 8 ppm TCS. Analyses of nitrogen species and nitrification rates in biofilms during and after TCS inhibition are ongoing.

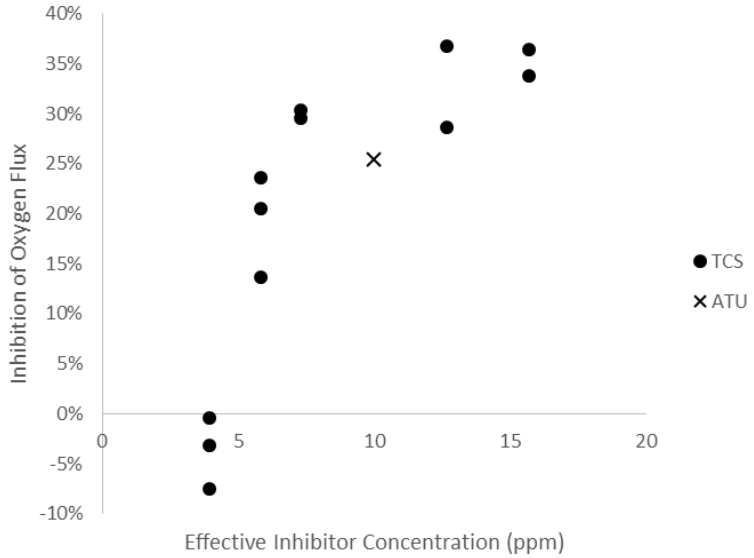


Figure 4. Percent inhibition of respiration in nitrifying wastewater biofilms during exposure to 4-16 ppm TCS. Respiration due to nitrification is eliminated under ATU exposure (x).

In biofilm experiments, TCS disappearance can be modeled by diffusion into the biofilm and sorption without degradation. Ongoing work includes further analysis of TCS transport in the biofilm and DNA based analyses of the bacterial populations in activated sludge and biofilms before and after TCS exposure.

This project is the dissertation research of current Environmental Engineering M.S. student, Kylie Bodle. Ms. Bodle's thesis defense is planned for Summer 2016 and a manuscript for peer-reviewed publication of the work is in preparation.

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Designing scenarios for hydrologic resilience in the Upper Missouri Headwaters with integrated ecosystem models

Basic Information

Title:	Designing scenarios for hydrologic resilience in the Upper Missouri Headwaters with integrated ecosystem models
Project Number:	2015MT294B
Start Date:	3/1/2015
End Date:	2/29/2016
Funding Source:	104B
Congressional District:	MT 1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Climatological Processes, Drought, Water Quantity
Descriptors:	None
Principal Investigators:	Benjamin Poulter, Benjamin Poulter, Benjamin Poulter

Publications

There are no publications.

Designing scenarios for hydrologic resilience in the Upper Missouri Headwaters with integrated ecosystem models

Progress Report to the Montana Water Center

Ben Poulter (PI)

April 29, 2016

Introduction

Water in the west remains a key ecological, social and political issue, with conflicts over use bound to increase with population growth and climate change. However, current tools are inadequate for assessing and monitoring water resources, where for example, declining stream flow trends in the Upper Missouri River Basin since the 1950s remain unexplained and attribution to climate change, land-use change, and management remain uncertain (Norton et al., 2014).

The goal of our Montana Water Center funding was to develop a stream flow model for the Greater Yellowstone Ecosystem (fig. 1) that could be coupled with an ecosystem model that accounts for land use and land cover change, including disturbance and vegetation-hydrology feedbacks due to climate change. We proposed that the stream flow model would also predict stream temperature and used to estimate fish metabolic processes as a way to extend our research to habitat suitability. The framework we proposed would be integrated with ongoing planning for building hydrologic resilience in the region through the use of beaver mimicry constructed.

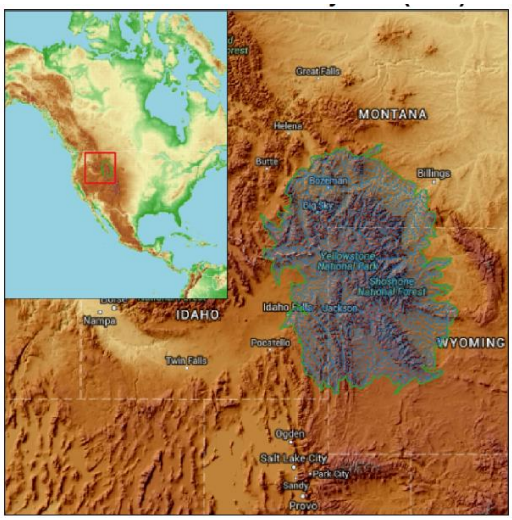

Figure 1: Outline of the Greater Yellowstone Ecosystem, approx. 200,000 km2.

Our partners included the Wildlife Conservation Society who is leading hydrologic resiliency projects in the region, the USGS who is conducting fish habitat suitability research, and University of Montana for expertise in ecohydrology modeling. An

Undergraduate researcher from Montana State University was recruited to help carry out the research, working with a PhD student funded by the Montana Institute on Ecosystems.

Work To Date

The project began in May 2015 when undergraduate Jerad Hoy at Montana State University joined the lab of Ben Poulter to begin the modeling research. Following a joint MSU and UM workshop and discussions on the general approach held in June 2015, the modeling took place in five phases, 1) development of the stream network, 2) development of the routing model, 3) development of the stream temperature model, 4) integration with the fish metabolic model, and 5) model benchmarking and calibration with observations.

1) The stream network (fig. 2) was developed using ArcHydro tools that used a digital elevation model from the HydroSheds archive to create a catchment and stream network dataset. Catchments were defined by 5 km^2 basins and stream reaches for each catchment given a unique code identifier.

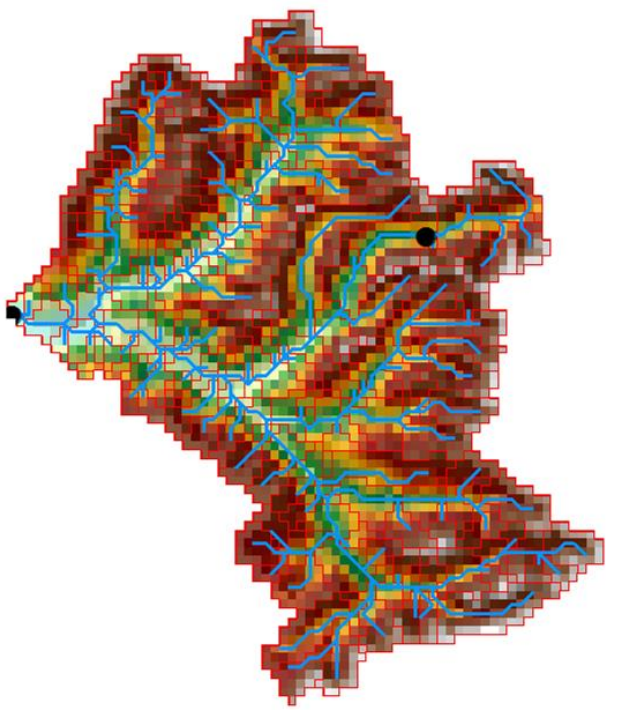

Figure 2: 1km digital elevation model for the Lamar Watershed showing the 5 km catchments and stream reaches.

2) Monthly surface and sub-surface runoff, and snowpack, were generated at 1km spatial resolution for the Greater Yellowstone Ecosystem (GYE) from 1980-2014 using the LPJ-GUESS ecosystem model using either DAYMET2 or TOPOWX climate forcing (Oyler et al., 2015). The files were stored as netcdf format and an R program was written to ingest the runoff files and route the

water to stream reaches using the 5 km catchments as the unit for aggregation (fig. 3).

$$\frac{\mathrm{d}S}{\mathrm{d}t} = R_s + Q_{gw} + Q_{in} - Q_{out} - Q_{loss}$$

Figure 3: Stream flow model incorporates inflow, outflow and storage.

3) A stream temperature model using air temperature and information on the amount of water entering each reach directly as snow melt was used to estimate stream temperature (fig. 4).

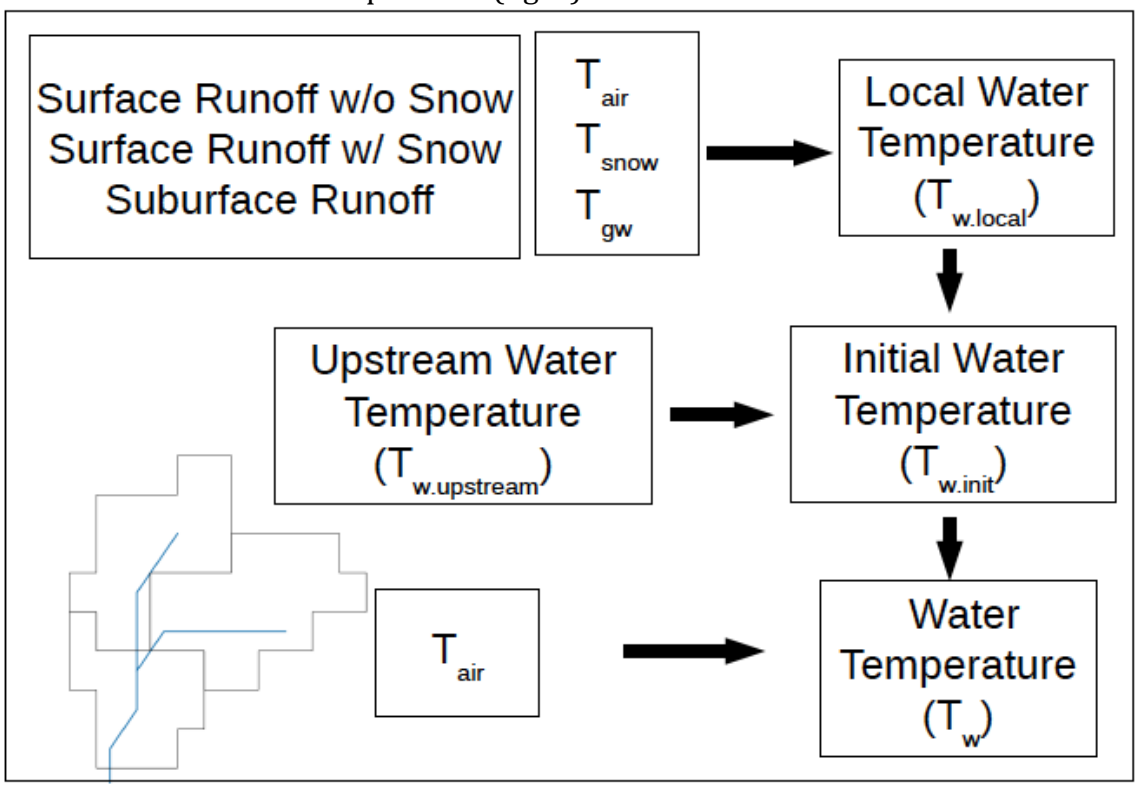

Figure 4: Stream temperature model is based on SWAT approach and uses runoff and snow and air temperature to calculate stream temperature.

4) The fish metabolic model from the USGS (Al-Chokhachy et al., 2013) was coupled with the stream temperature model to estimate fish growth for each reach.
5) Lastly, the monthly stream flow and stream temperature simulations for each reach were compared with USGS gauges and other independent observations. Error statistics including Taylor Diagrams and Nash Sutcliff metrics were used to understand bias, difference in phase, and overall predictive strength of our model.

Key Results

The main result from our work is that throughout the Greater Yellowstone Ecosystem, increasing spring stream flows have been observed due to warmer temperatures causing faster snow melt (fig. 5).

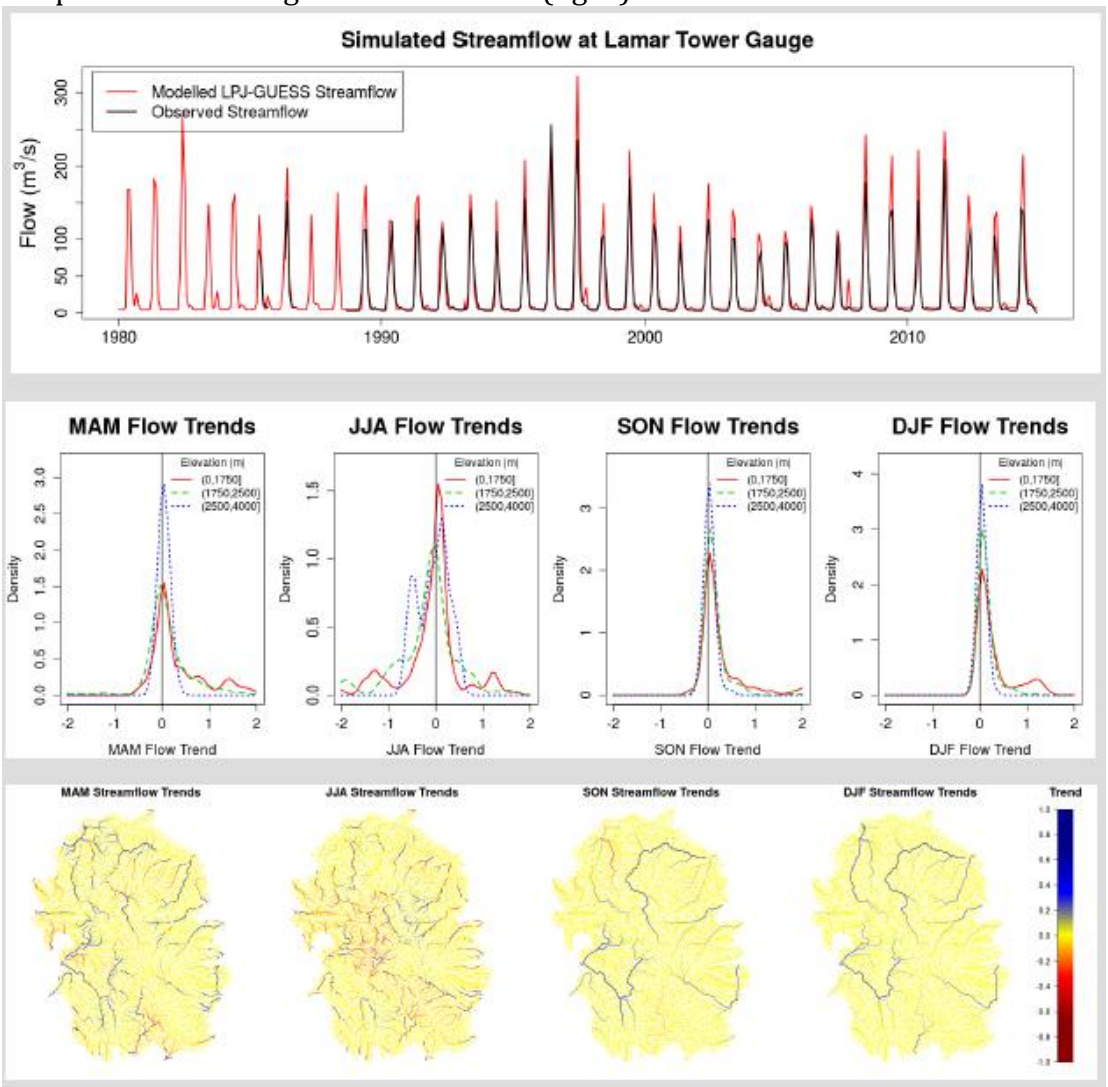

Figure 5: Top Panel: time series of stream flow for Lamar, Middle Panel: distribution of stream flow trends for four seasons and by elevation, Bottom Panel: spatial distribution of stream flow trends in the GYE.

This loss of spring snow pack has then led to decreased summer flows and increasing stream temperature. The results are fairly robust regardless of the climate dataset used to run the model, i.e., DAYMET2 or TOPOWX. In addition, the pattern in increasing spring and declining summer flows is found regardless of elevation in the GYE.

Outreach

- Research presented by Ben Poulter to the:
    - Montana Institute on Ecosystems Rough Cut Seminar Series (2015)

    - USGS North Central Climate Science Center (2016)
- Manuscript in preparation from *Ecosystems* journal led by undergraduate researcher Jerad Hoy (to be submitted summer 2016)
- Research presented at the European Geophysical Union by undergraduate Jerad Hoy "From terrestrial to aquatic fluxes: Integrating stream dynamics within a dynamic global vegetation modeling framework"
- Water Center support of Undergraduate Researcher Jerad Hoy led to:
    - Awarded the MSU Emerging Presidential Scholar Award (Spring 2016)
    - Received internship at NASA AMES (Summer 2016)
    - Awarded support from the MSU Honors College

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Student Fellowship: Climatic and geomorphologic influences on soil development and transport in the Bitterroot and Sapphire Mountains, Montana, USA

Basic Information

Title:	Student Fellowship: Climatic and geomorphologic influences on soil development and transport in the Bitterroot and Sapphire Mountains, Montana, USA
Project Number:	2015MT295B
Start Date:	5/1/2015
End Date:	8/1/2015
Funding Source:	104B
Congressional District:	MT 1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Geomorphological Processes, Sediments, None
Descriptors:	None
Principal Investigators:	Sarah Benjaram, Sarah Benjaram

Publications

There are no publications.

This report provides a summary of my research over the past year and my research goals for the next year.

RESEARCH GOALS AND SUMMARY

The overall goal of my research is to investigate the drivers of soil formation and erosion. Climate is broadly understood to influence soil weathering, as rainfall and temperature determine moisture availability and the rate of chemical reactions that weather rock into soil. However, landscape morphology and erosion can make this climate-weathering relationship more complex and difficult to observe (e.g., Norton et al., 2010; Dixon et al., 2012). By studying one landscape carved by now-extinct glaciers and one that was unglaciated, I aim to weigh the relative effect of past glaciation and its topographic legacy against that of modern water availability on the chemical and physical weathering of soil. My research quantifies topographic and climatic controls on soil formation and weathering by testing three hypotheses:

H1: Climate legacy controls *erosion rates* via its impact on slope morphology.

H2: Climate legacy controls *soil cover and extent of chemical weathering* via its impact on slope morphology.

H3: Modern climate acts as a secondary control on weathering rates and soil chemistry.

Toward this end, I have spent the past year analyzing topographic and remotely sensed data, conducting field surveys, preparing field samples for geochemical analysis, and putting the resulting geochemical data into context regarding topographic and climatic controls. Further research over the next year will focus on synthesizing and comparing disparate data sets, analyzing LiDAR data that will be newly acquired in Summer 2016, and publishing results.

STUDY SITE AND APPROACH

My research examines the ways soil formation and weathering are controlled by landscape morphology and climate, focusing on distinct mountain ranges along the Bitterroot River in Western Montana that offer important contrasts in morphology and climate history. The Bitterroot Mountains on the west side of the valley (Fig 1) are characterized by steep, rocky ridges separating a series of parallel U-shaped valleys carved by multiple Pleistocene glacial advances and retreats, with forested hillslopes and notable heterogeneity in soil cover. In contrast, the Sapphire Mountains to the east remained unglaciated and exhibit more gentle grassy and forested hillslopes with consistently greater soil cover, characteristic of diffusion-like geomorphic processes. The two ranges still experience different climates today, likely driving different rates of chemical and physical erosion. The Sapphires lie in the rain shadow of the Bitterroots and receive roughly half as much precipitation (maximum annual precipitation in the Bitterroots exceeds 250 cm y^{-1} at the ridge, while the Sapphires receive only 130 cm y^{-1}). I have selected a representative catchment from each range: Lost Horse Creek in the Bitterroot Mountains and Rye Creek in the Sapphire Mountains. These two catchments, both underlain by the same granodiorite unit, provide an ideal location to examine the interplay between landscape morphology, climate, and soil processes.

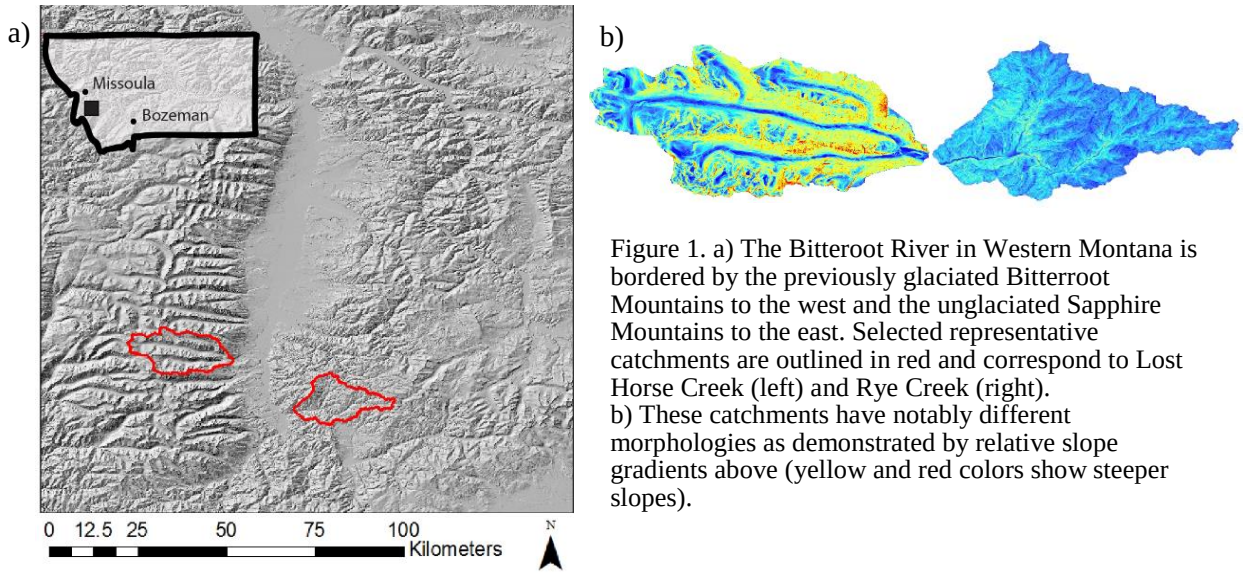

Figure 1. a) The Bitteroot River in Western Montana is bordered by the previously glaciated Bitterroot Mountains to the west and the unglaciated Sapphire Mountains to the east. Selected representative catchments are outlined in red and correspond to Lost Horse Creek (left) and Rye Creek (right).
b) These catchments have notably different morphologies as demonstrated by relative slope gradients above (yellow and red colors show steeper slopes).

My approach consists of four primary components:

1) Collection and cosmogenic analysis of ^{10}Be in river sands to assess erosion rates (H1)

^{10}Be is a cosmogenic radionuclide that is produced in situ within minerals at Earth's surface. The concentration of ^{10}Be within quartz grains in a sample of river sand can be used to derive an integrated millennial-timescale erosion rate for the upstream basin. By combining this measurement with x-ray fluorescence (XRF) measurements of soil and rock chemistry and applying geochemical mass balance, I will quantify the average physical and chemical components of hillslope erosion (e.g. Riebe et al., 2003, 2004).

2) Field surveys to determine persistence and thickness of soil cover (H2,H3)

The transition between soil-mantled to rock-dominated hillslopes represents an important local and landscape-scale threshold, but its underlying morphologic or geochemical controls remain debated. By measuring soil thickness and percent soil cover at numerous sample sites, I will quantify the soil cover across my two study catchments. To do this, I establish a 3x3 m grid at each sample site divided into 9 squares and estimate the percent soil cover in each square (Fig 2). I also measure depth to refusal by hand auger.

Figure 2. Field grid for collecting soil samples and assessing rock content of soil. The grid is outlined in red to make it more visible in the photo. Each square within the grid is 1m^2.

3) Collection and geochemical analyses of soils and rocks to determine weathered extent (H2,H3)

I am quantifying extent of chemical weathering across the study catchments by indexing soil chemistry to its parent material. Utilizing the 3x3m sample grid (Fig 2), I collect the top 10 cm of soil from each of the 9 squares. Approximately 10-20 rock samples are collected at the surface within 10m of my grid to represent an average parent material from which this soil was formed. Bulk elemental composition of the soil and rock samples is measured using XRF and corrected for loss on ignition.

I quantify weathering both with respect to a specific element as well as overall chemical weathering extent. Following the example of Riebe et al. (2001), I calculate a chemical depletion fraction (CDF), which compares the relative enrichment of an inert element (titanium is used here) in soils compared to their parent rock: CDF = 1 - $\left(\frac{[Ti]_{rock}}{[Ti]_{soil}}\right)$. I also calculate losses of major elements that are important in weathering and nutrient cycling, such as sodium, magnesium, potassium, and calcium. This index of mass loss is calculated as:

$\tau_i = \left(\frac{i_{soil} * Ti_{rock}}{i_{rock} * Ti_{soil}}\right) - 1$. Here $\tau > 0$ represents fractional mass gain in soil relative to its parent material and $\tau < 0$ represents fractional mass loss (Muir and Logan, 1982).

I target sample sites at a variety of topographic positions, including various points along a hillslope and in valley bottoms, and at a variety of slope gradients and aspects.

4) GIS analysis of field- and remotely-sensed data to understand topographic and climatic controls on soil cover and weathering (H1,H2,H3)

Lastly, I combine geochemical measurements, field data, remotely sensed data, and topographic metrics developed with digital topographic models to calculate how modern climate influences soil development via moisture control and how past climate influences soil development through its morphologic legacy.

RESEARCH UPDATE

Significant progress has been made during the past year towards the completion of this research on topographic and climatic controls on weathering and soil cover. In the past year I have:

- Collected 387 soil thickness measurements using a hand auger across two catchments;
- Collected over 200 surface samples of rock and soil for determination of weathering extent;
- Analyzed 118 samples for elemental and mineralogical composition using x-ray fluorescence;
- Begun laboratory cosmogenic analysis on six samples of river sands in order to assess erosion rates;
- Conducted GIS-based analysis to compare and correlate field- and remotely-sensed data on weathering, soil cover, vegetation cover, and topography.

Below, I summarize these activities in the context of my stated research goals and provide preliminary results. I also lay out a clear timeline for completing the proposed research project by the end of 2016.

H1: Comparison of physical erosion rates with Topography and Climate (H1)

Using cosmogenic ^{10}Be-derived erosion rates and analysis of catchment topography (relief, slope, roughness), I am testing the hypothesis that previously glaciated catchments erode more rapidly than non-glaciated ones due to the influence of post-glacial landscape morphology (i.e, erosion rates vary with catchment slope). I have sampled river sands from three catchments in the Bitterroot Mountains and three in the Sapphire Mountains. I am currently processing samples in the Cosmogenic Lab at Montana State University to isolate quartz and extract beryllium, and expect to have results by the end of summer 2016. Thorough topographic analysis has already been conducted in the two catchments of primary interest. These catchments (Rye Creek in the Sapphires and Lost Horse Creek in the Bitterroot Mountains) are underlain by uniform lithology, but show significant differences in terms of slope morphology associated with their respective glacial histories (Fig 3).

H2: Characterization of soil distribution and chemical weathering in the context of topographic controls

I hypothesize that soil cover and chemical weathering are negatively correlated with slope gradient, such that the steeper morphology of previously glaciated catchments results in thinner soils with significantly less spatial cover. In order to assess the topographic control on soil cover and extent, I have completed field sampling and geochemical analyses of soils and rocks via XRF, and am comparing GIS-derived topographic parameters to measurements of soil cover and weathering. Preliminary data show Lost Horse Creek has significantly steeper slopes than Rye Creek (Fig 3).

I use depth of refusal, the depth to which a hand auger can penetrate, as a proxy for regolith thickness. I predicted that slope gradient would correlate with decreasing soil cover. At a landscape scale, previously glaciated steep terrain generally has thinner soils (Lost Horse soil thickness = 19.3 cm ± 3.1; Rye Creek soil thickness = 35.2 ± 3.5). Even within hillslopes considered soil-mantled, we find significantly less soil cover as determined by soil cover estimates at sample sites (LH = 87 ± 2.6 %; RC = 97 ± 1.9 %).

Field-based data show a negative correlation between depth of refusal and local slope gradient in Rye Creek (Sapphire Mountains), indicating that soils generally become thinner as hillslopes steepen. However, soil thickness in Lost Horse (Bitterroot Mountains) shows no relationship with slope gradient (Fig 4). These data suggest that in Lost Horse Creek, soil thickness is highly variable but not explained directly by slope steepness. Further investigation is needed to understand what local controls can explain the heterogeneity in soil thickness.

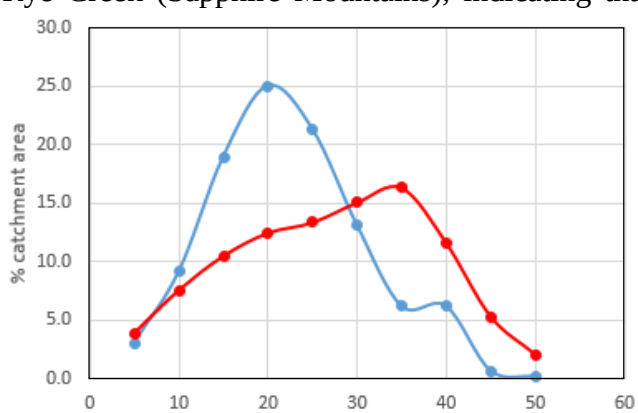

Figure 3. Slope distribution of Lost Horse Creek (blue) and Rye Creek (red) catchments.

Chemical weathering of soils is also expected to reflect topography, since at steep slope gradients, soil may be eroded downslope before weathering reactions have

had sufficient time to progress. Therefore I expect lower chemical depletion at higher slope gradients. While Rye Creek has more highly weathered soils (CDF ranges from 0.47-0.94, with a mean of 0.73) compared to Lost Horse (range = 0.17-0.84, mean = 0.54), there is no clear trend with local topographic metrics such as slope gradient. Interestingly, Lost Horse Creek shows greater variation in CDFs, whereas Rye Creek has high CDF throughout the catchment, suggesting that in the gentle slopes of Rye Creek, soil has time to weather in place whereas in Lost Horse Creek it is removed from hillslopes as debris before weathering completely.

Together, these data indicate that while catchment scale morphology (controlled by its climate legacy) controls physical and chemical weathering of soils, local morphologic controls on weathering remain somewhat elusive, especially in steep catchments with complex and heterogeneous soil cover.

H3: Modern climatic controls on soil distribution and chemical weathering

Glaciated catchments are expected to show less weathered soils if catchment weathering rates and local soil chemistry are primarily controlled by slope morphology (H1,H2). However, I hypothesize that soils will show greater weathering at higher precipitation given the same slope gradient and regardless of glacial history. To assess the influence of modern climate on soil cover and extent of weathering, I compare my field and XRF data with climatic data and proxies including mean annual rainfall, temperature and the topographic wetness index (TWI). Rye Creek receives less precipitation than Lost Horse Creek, as the Sapphires lie in the rain shadow of the Bitterroots. However preliminary data show that rainfall does not appear to control the amount of soil present or the extent of chemical weathering.

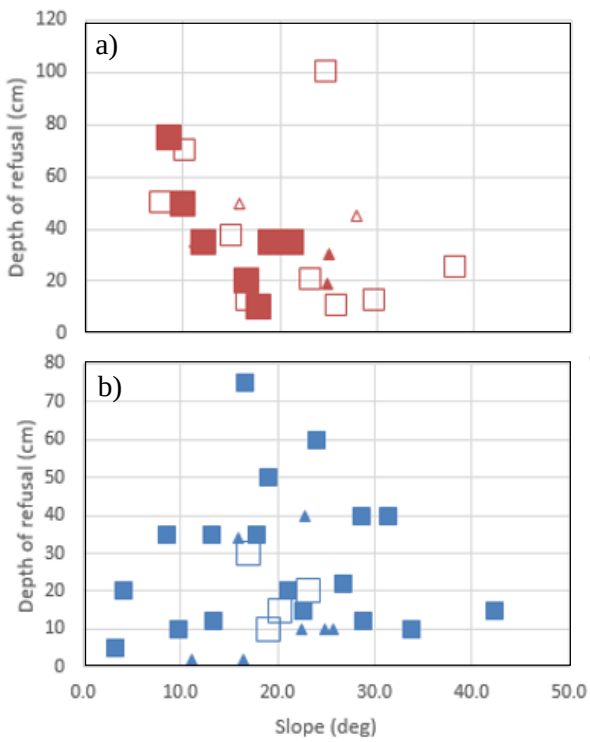

Figure 4. Regolith thickness (measured as depth of auger refusal) vs. slope gradient in a) Rye Creek and b) Lost Horse Creek. Filled squares represent south-facing slopes (within 45° of true south), open squares represent north-facing slopes (within 45° of true north). Triangles represent aspects not within 45° of N or S. Filled triangles are S-facing and open triangles N-facing.

I also compare north- and south-facing slopes, as north-facing slopes receive less sunlight, resulting in deeper snowpack and delayed summer snow melt, thus influencing the moisture available to soils throughout the year. No aspect control is apparent in either landscape in the relationships between slope and soil thickness (Fig 4) or chemical weathering extent (not shown).

These results suggest that moisture availability is not limiting to the conversion of rock into soil or the chemical weathering reactions of soil, and thus indicates that modern climate may not be important to soil evolution in these landscapes.

RESEARCH PLAN

My results so far are leading me to more questions about the relationship between modern climate, past climate, and soil evolution. For the remainder of the year I will focus on understanding variability and local topographic controls on both geochemical data and field-based measurements of soil cover. The National Center for Airborne Laser Mapping (NCALM) has selected my research for airborne laser swath mapping (ALSM) and aerial photography, which will be extremely beneficial for my project because meter-scale variations in topography and bedrock cover have significant implications for soil development. The ALSM survey will take place in the summer of 2016 when the ground is free of snow cover.

Previous work has demonstrated the value of measuring fine-scale surface characteristics in order to understand soil production and erosion in mountain landscapes. The difference between 30m and 1m resolution can yield major advances in geomorphic observations. High-resolution topographic data will allow me to quantify rock exposure through slope measurements (e.g., DiBiase et al., 2012) and surface roughness (Milodowski et al., 2015) and calibrate it using field surveys and aerial photography. These data provide insight into how slope thresholds and fine-scale surface characteristics control soil cover. One-meter resolution data is integral to these questions, and the ability to distinguish between soil and bedrock hillslopes is rapidly lost with coarser data resolution (e.g., DiBiase et al., 2012). Additionally, I will be able to explicitly link morphology and landscape heterogeneity to chemical weathering of soils, exploring how small changes in gradient and convexity and concavity of a hillslope influence soil weathering, and identify zones dominated by distinct geomorphic processes such as landsliding or diffusive transport.

Future analysis will continue to explore links between fine-scale topographic data, long-term land surface observations provided by existing remotely sensed data, and my new field and lab-based data on weathering and soil cover. An additional year of NASA funding will greatly strengthen my ability to provide critical insight into the relationship between climate and landscape evolution.

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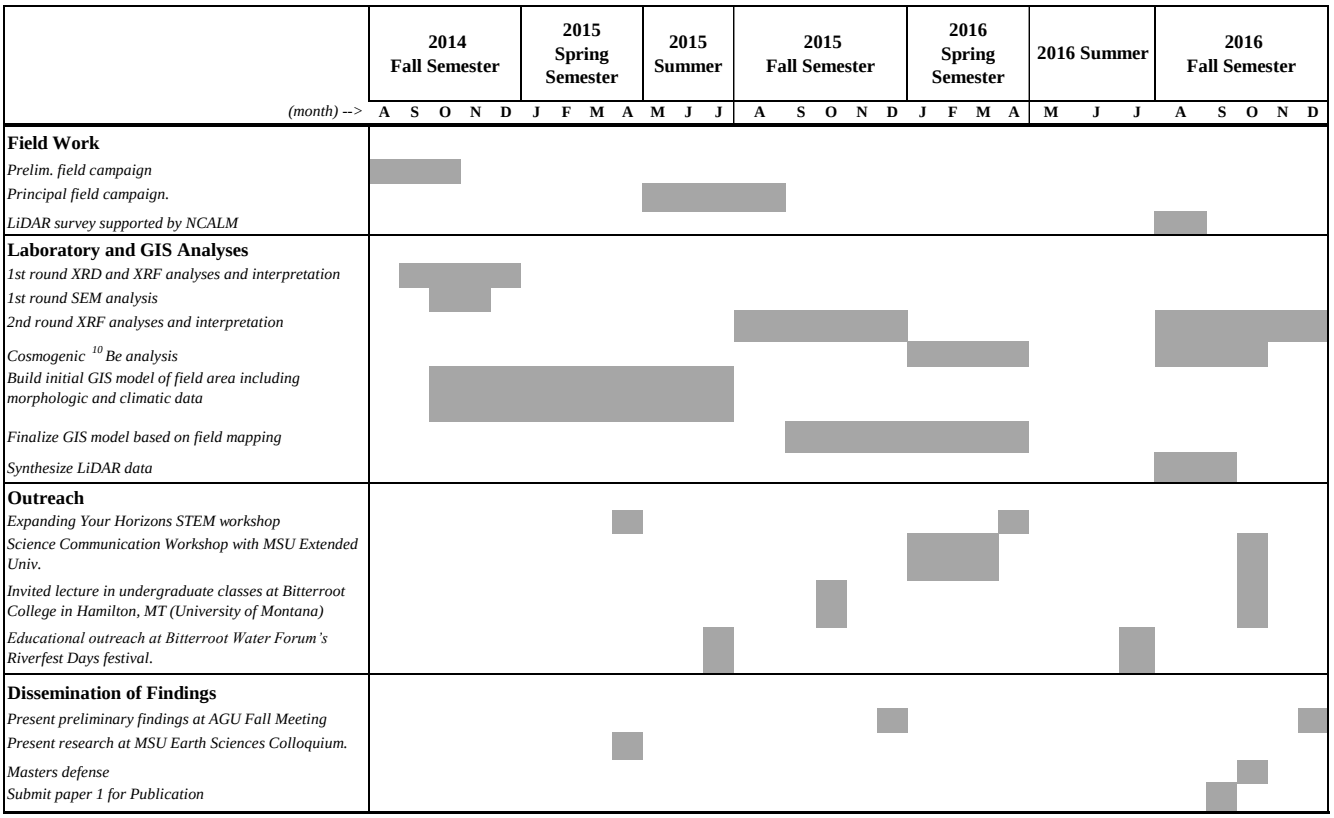
2014 Fall Semester
2015 Spring Semester
2015 Summer
2015 Fall Semester
2016 Spring Semester
2016 Summer
2016 Fall Semester
(month) -->
A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
Field Work
Prelim. field campaign
Principal field campaign.
LiDAR survey supported by NCALM
Laboratory and GIS Analyses
1st round XRD and XRF analyses and interpretation
1st round SEM analysis
2nd round XRF analyses and interpretation
Cosmogenic 10 Be analysis
Build initial GIS model of field area including morphologic and climatic data
Finalize GIS model based on field mapping
Synthesize LiDAR data
Outreach
Expanding Your Horizons STEM workshop
Science Communication Workshop with MSU Extended Univ.
Invited lecture in undergraduate classes at Bitterroot College in Hamilton, MT (University of Montana)
Educational outreach at Bitterroot Water Forum's Riverfest Days festival.
Dissemination of Findings
Present preliminary findings at AGU Fall Meeting
Present research at MSU Earth Sciences Colloquium.
Masters defense
Submit paper 1 for Publication

Student Fellowship: Sediment routing in steep mountain streams to understand hillslope-channel connectivity

Basic Information

Title:	Student Fellowship: Sediment routing in steep mountain streams to understand hillslope-channel connectivity
Project Number:	2015MT296B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	MT 1
Research Category:	Climate and Hydrologic Processes
Focus Category:	Geomorphological Processes, Sediments, Models
Descriptors:	None
Principal Investigators:	Michael Jahnke, Michael Jahnke

Publications

There are no publications.

Michael Jahnke Water Center Report

Michael Jahnke initiated a research project on "Sediment connectivity between post-fire debris flows and stream channels in a mountain watershed." Michael completed a full research proposal (attached) and began field work during summer 2015. These efforts included reconnaissance in the Rye Creek watershed, a tributary to the Bitterroot River in western Montana, deployment of pressure transducers for stage monitoring, identification of debris-flow fans for potential coring and grain-size analysis, and preliminary total-station surveys of channel morphology along select study reaches. Michael decided, however, that he did not wish to continue a research-based M.S. and left the Geosciences graduate program at the end of summer 2015. Although Michael did not complete his M.S., his preliminary work contributed to a National Science Foundation proposal submitted by Andrew Wilcox (Michael's M.S. advisor) and Jean Dixon (Montana State University) entitled "Sediment connectivity and its morphologic and vegetative controls: Linking soils and streams in mountain landscapes of the northern Rockies." The proposal was submitted to the Geomorphology and Land-use Dynamics program in May 2016.

M.S. Research Proposal:
Sediment connectivity between post-fire debris flows and stream channels in a mountain watershed

Michael C. Jahnke, M.S. Candidate, University of Montana, Department of Geosciences

ABSTRACT

Steep mountain streams with a snowmelt-dominated hydrology may be heavily influenced by wildfire-related erosion from hillslopes. This research will quantify sediment routing from hillslope to channel in one of these streams, and will examine the persistence of geomorphic impacts on channels by post-fire debris flows and the time needed for a stream to process these pulses of sediment. The end result of this work will be a better conception of hillslope-channel connectivity - which will grant a clearer understanding of how these systems could respond to changes in sediment input due to climate change or land use change. I will measure fallout radionuclides ^{7}Be, ^{137}Cs, and ^{210}Pb in Rye Creek, Montana to discover the ratio of recently contributed sediment to older sediment in the channel as well as to 'fingerprint' the source areas of the sediment inputs. I will also develop a predictive model of sediment routing and morphodynamic change in the channel by integrating field measurements of channel morphology and pebble counts with a numerical model. The Morphodynamic and Sediment Tracers in One-Dimension (MAST-1D) model will be used to evaluate and elaborate on the conceptual model introduced by Hoffman and Gabet (2007), and to predict in-stream morphology, ultimately improving our comprehension of hillslope-channel connectivity.

1 INTRODUCTION

Understanding hillslope-channel connectivity (i.e., the water-mediated transfer of sediment from hillslopes to channels in a catchment) is key to understanding sediment routing in mountain watersheds (Fryirs, 2013). Awareness of the sources and concentrations of sediment in the channel is important when considering ecosystem health and management practices. This research will quantify the movement of sediment from hillslope to a mountain river channel in western Montana. Several studies provide a qualitative, conceptual look at the interplay between hillslopes and channels (Benda et al., 2005; Fryirs, 2013), but a gap remains in testing the conceptual models (Hoffman and Gabet, 2007) with field measurements and numerical simulations (Viparelli et al., 2013) to predict sediment routing through these systems. I aim to combine tools in geomorphology, including surveys of channel geometry, pebble counts, and GIS analysis, that have been used in many similar studies along with the use of fallout radionuclides which can be used both to trace the source of river sediments and indicate the 'newness' of in-channel sediment (Bonniwell et al., 1999).

1.1 Sediment budgets

A sediment budget is an expression of the conservation of mass in a geomorphic system that provides a framework for accounting for sediment transfer and storage dynamics (Dietrich and Dunne, 1978). To create an accurate sediment budget each process that contributes to sediment flux must be quantified (Fryirs, 2013). In mountain watersheds, there is large spatial and temporal variability in erosion and deposition (Smith and Wilcock, 2011; Kirchner et al., 2001) which means events that contribute large amounts of sediment in a small area and over a short time period may not be captured (Benda and Dunne, 1997). Sediment budgets can be used

to determine the sediment delivery ratio (Blake et al., 2009; Fryirs, 2013) that quantifies the ratio of sediment produced on the hillslope (debris flows) to the sediment that is delivered to the channel (debris fans). This ratio takes into account storage on the land surface and is dependent on the time-scale chosen. Developing a sediment budget that accurately describes all of the processes at work on multiple timescales would allow for better prediction of sediment routing through these systems.

When considering hillslope-channel connectivity, the transport processes both on the hillslope and in the channel must be studied. This is a requirement to develop an accurate sediment budget and also to better understand how the connection differs depending on the border between hillslope and channel (Fryirs, 2013). Along the majority of the mountain channel reaches, the stream directly borders the hillslope and there is very little to no floodplain. Sediment is transported from hillslope to channel and infrequently is transported from channel to hillslope. Debris flows are seen as the dominant transport mechanism in field studies of mountain watersheds (Theule et al., 2012; Benda et al., 2005). In environments with steep slopes and snowmelt hydrology, wildfire has a large influence on sediment transport and erosion.

1.2 Post-fire debris flows

In semiarid mountain watersheds of the Northern Rockies, wildfires decrease slope stability by reducing vegetation cover and cohesion and altering soil characteristics (Shakesby and Doerr, 2006; Gabet, 2003), which, combined with high-intensity rainfall, can result in generation of overland flow and debris flows (Gabet and Bookter, 2008). The fate of debris flows, including whether they reach the hillslope-channel interface, how much of their sediment is deposited in the channel, and downstream routing of their sediments, is poorly understood.

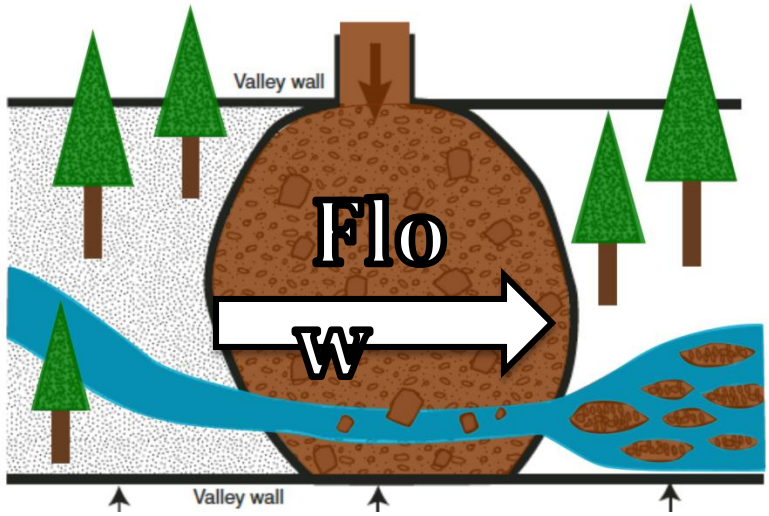

Figure 1. Conceptual model of post-fire debris flows (modified from Hoffman and Gabet 2007)

Studies of debris flows and channel effects in Sleeping Child Creek (Hoffman and Gabet, 2007), a small drainage in the Sapphire Mountains that is north of my study area, provide a conceptual model of post-fire debris flow and associated hillslope-channel connectivity (Figure 1). After wildfires occurred in the Sleeping Child Creek drainage in 2000, storms passed over this area in July 2001 triggering multiple debris flows that impacted the channel. At each location, the debris flow pins the channel against the valley wall and/or dams the flow of the stream. Next the flow built up against the blockage until it overtopped the fan and began to incise through the material (Madej, 2001). As other sediment is transported downstream as suspended load, coarse sand and fine gravel are deposited on the fan, lessening the gradient upstream of the debris flow deposit. Coarse gravel and small cobbles are transported downstream from the fan as bed load short distances and increase the slope downstream of the fan (Hoffman and Gabet, 2007). After

an undetermined amount of time, the channel will recover to some equilibrium state where it again reaches a balance between sediment deposition and transportation (Madej, 2001). The degree to which these processes persist in the landscape is yet unknown.

1.4 Sediment pulse transport

Post-fire debris flows introduce sediment to the channel as large pulses. The transport of these sediment pulses is dispersion-dominated (Lisle et al., 2001). Dispersion tends to be favored when the sediment pulse has a large range of grain sizes and the volume introduced to the channel is large compared to the channel dimensions (Sklar et al., 2009; Lisle et al., 2001). Translation, an alternative mechanism by which sediment pulses move downstream as a distinct unit (Sklar et al., 2009), is favored with a smaller grain size distribution and when the pulse sediment has a smaller grain size than the channel bed material (Madej, 2001; Lisle et al., 2001).

Pulses that originate from debris flows dominate sediment flux in mountain watersheds. In steep channels, sediment transported by the stream has a much more minor contribution to total sediment flux. Only about 20-30% of sediment contributed to a point in the channel can be attributed to fluvial sediment transport (Benda et al., 2005). Measuring suspended and bed load for a discharge answers the question of how much sediment the channel is carrying at varying flows, but not where the material originates. It is possible to collect suspended sediment samples for geochemical analysis of fallout radionuclides in order to determine the source area of sediment, which improves our understanding of sediment routing.

As sediment pulses move downstream they alter channel geometry, bedforms, and roughness, as documented in flume (Sklar et al., 2009), and field studies (Madej, 2001; Lisle et al., 2001), including by Hoffman and Gabet (2007) in Sleeping Child Creek. Madej (2001) proposes a conceptual model (Figure 2) for morphodynamic change in systems based on gradient and number of large discharge events. Observing and analyzing a mountain headwater system with hillslope-channel interaction will give more insight to both of these models and the processes at work.

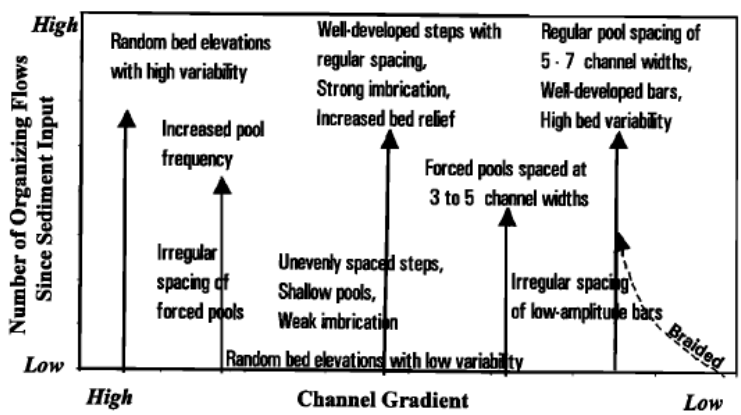

Figure 2. Conceptual model relating channel gradient to number of large discharge events (from Madej 2001)

1.5 Fallout radionuclides

Fallout radionuclides serve as a tool for tracing sediments, including measurement of particle transport distances and times, identification of source areas of in-channel sediment, and measurement of the age of erosion (Wallbrink and Murray, 1993; Bonniwell et al., 1999). These radionuclides are produced in the atmosphere, result from thermonuclear weapons testing in the 1950s and 60s, or result from radioactive decay of ^{226}Ra to ^{210}Pb (Figure 3) (Walling, 2003). The three fallout nuclides, ^{7}Be, ^{137}Cs, and ^{210}Pb, have varying half-lives, 53.4 days, 30.1 years, 20.4

years, respectively, making them suitable to answer different research questions (Walling, 2003). ^{7}Be can be used to tag 'new' sediment and determine the recent contribution to the channel from the hillslope. Concentrations of ^{7}Be decrease rapidly with decreasing discharge and increasing distance from the source (Bonniwell et al., 1999). This method is suitable for tracing current contributions of sediment to the channel, but to analyze the amount of sediment added to the reach due to debris flows that happened years ago, a nuclide with a longer half-life must be employed. ^{137}Cs or ^{210}Pb are widely used to 'fingerprint' the source of sediment contributed to the channel. The concentration of fallout radionuclides is measured in the channel sediment and compared to the concentrations measured for various areas of the landscape, i.e. debris fan, hillslope, channel banks (Walling, 2003). Fallout radionuclides accumulate uniformly across the landscape and areas with greater erosion accumulate lower concentrations than areas with less erosion (Wallbrink and Murray, 1993).

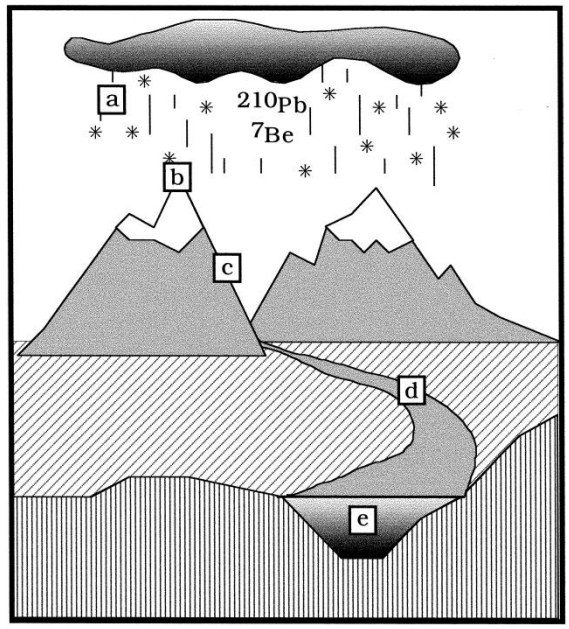

Figure 3. Radionuclides from creation in the atmosphere through the transport chain. (a) Radionuclides delivered to the atmosphere by fallout. (b) Radionuclides are released during snowmelt. (c) Radionuclides sorb to sediment and are transported to the channel (d). (e) In channel sediment is tagged 'new' or 'old' based on concentrations. (From Bonniwell, Matisoff, & Whiting, 1999)

2 OBJECTIVES

Steep mountain streams with a snowmelt-dominated hydrology may be heavily influenced by wildfire-related erosion from hillslopes. Hillslope-channel connectivity may therefore drive sediment input into streams. The result of my proposed research will be a better understanding of hillslope-channel connectivity by quantifying: **1**) persistence of geomorphic impacts on channels by post-fire debris flows – namely bed elevation and dominant grain size, and **2**) time needed both for processing of sediment pulses and movement downstream. My work will produce a predictive model, incorporating a nuclide mass balance and grain size distribution data, of sediment routing through mountain headwaters typical of the northern Rockies. The model will allow for better prediction of sediment routing through steep mountain streams. By examining and measuring stream morphology and comparing to model runs, I will test the conceptual model introduced by Hoffman and Gabet (2007).

3 RESEARCH PLAN

To accomplish my first objective requires using traditional field methods, fallout radionuclides, and applying measurements to a numerical model. To accomplish my second requires also the use of traditional field methods, a numerical model, and additionally the use of GIS methods and field observations. These measurements will be taken at debris fans of interest and channel reaches that extend 10 widths upstream and downstream of each location (Figure 6).

3.1 Study Site

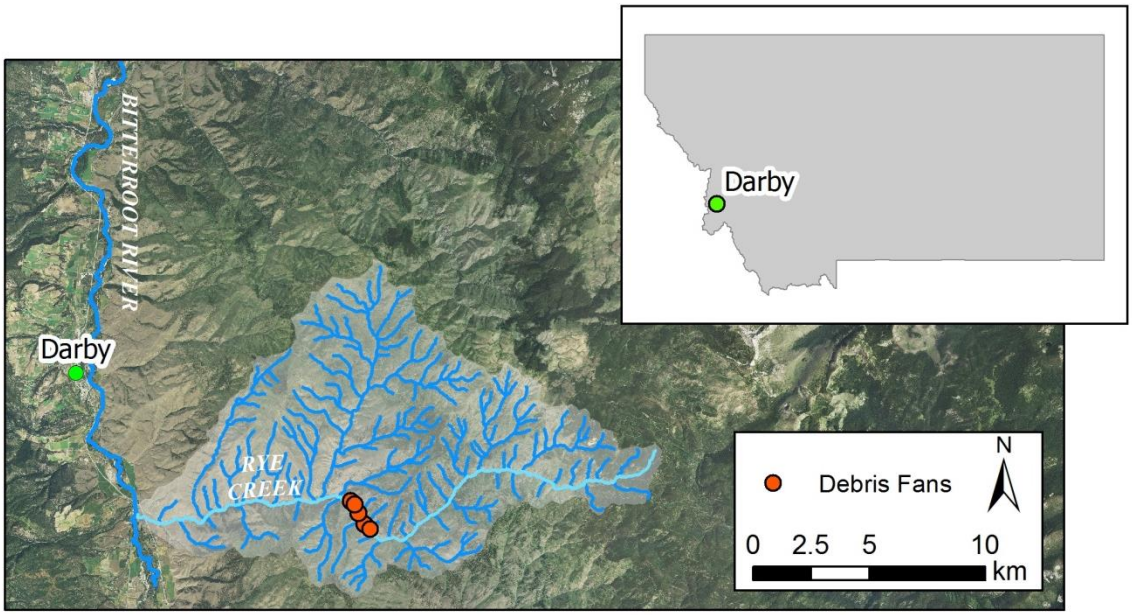

Figure 4. Study area showing proximity to Darby, MT and locations of debris fans of interest.

Rye Creek is a tributary of the Bitterroot River in the Sapphire Mountains of southwest Montana (Figure 4). The basin exhibits forested mountain slopes with terrain typical of the northern Rockies (District, 2014). The watershed comprises 163 km^2, and with only 39 km^2 privately owned lands, the majority of area falls within the Bitterroot National Forest (Forum, 2014). The area is comprised of Belt Series rocks and Idaho Batholith Granites that outcrop frequently and produce thin, highly erodible soils (Berg and Lonn, 1996).

The climate is a mix of Rocky Mountain interior and Pacific Northwest coastal influences (District, 2014). Precipitation falls predominantly as snow between November and April, though occasional summer thunderstorms are not uncommon (District, 2014). These sporadic storms occur from July to October during a warm, dry period that affects growth of vegetation and wildfire occurrence. There have been three significant fires in the drainage area since 1964, the most recent took place in 2000 (District, 2014). Burn severity of the 2000 fire was ranked high on the US Forest Service severity ranking. Burns of this magnitude consume all or almost all organic matter and destabilize the slope, allowing hillslope sediment transport to occur more easily (Parsons et al., 2010). There is a history of debris flows occurring along Rye Creek, relict fans are identifiable in the field. From field observations, it appears that the visible fans (Figure 6) are not a result of convective storms following the 2000 fire, but instead a legacy from a previous event. It is evident, however, that there have been multiple events in recent history.

3.2 GIS methods

LiDAR data for Ravalli County has been used to generate a slope map (Figure 5). Relict fan locations were pinpointed using ArcMap. The locations of the fans will be confirmed in the field to ensure their suitability for the project. I will import surveying data into ArcMap over a basemap of the area to understand the spatial distribution of channel shape and how slope changes moving downstream. I will gather points using a handheld GPS to mark the location of observed changes in bed elevation to compare to model data.

3.3 Traditional field methods and observations

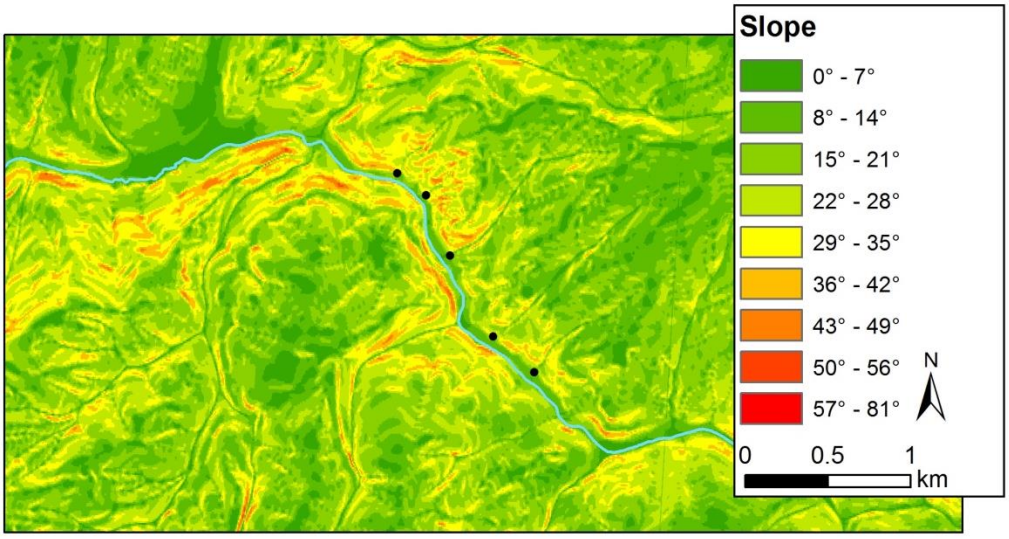

Figure 5. Slope map of the study area, relict fans show a gentler slope than the source gully.

In order to run a numerical model (described below), discharge data are needed, but Rye Creek is ungaged. Pressure transducers were installed March 2015 at two locations along Rye Creek upstream and downstream of the debris fans of interest in order to provide continuous measurements of stage (flow depth), including across the spring snowme lt hydrograph. HOBO U20 water level data loggers were installed in the stream inside drilled PVC piping for protection, attached via hose clamps to rebar in the streambed. I then measure discharge a FlowTracker ADV to establish a stage/discharge relationship. Discharge measurements will be completed every three weeks at cross sections near the debris fans. I will verify/supplement my discharge data by using the nearest USGS gage, 12344000, located downstream from where Rye Creek joins the Bitterroot River.

The grain size distribution of sediment on the streambed and on the relict debris fans will be determined through pebble counts (Wolman, 1954). At least 100 particles will be selected at random at each transect of the channel and at each debris fan. From these data, cumulative distribution curves will be constructed so that the D_{50} and D_{84} can be calculated (Madej, 2001). In addition to grain size distributions, channel geometry will be measured. I will use a Leica Total Station to measure a longitudinal profile and cross sections beginning at each debris fan and extending 15 channel widths upstream and downstream. Measured cross sections will be every 5 channel widths (approximately 2.5 m).

Figure 6. Typical relict debris fan at Rye Creek.

I plan to test the conceptual model put forth by Hoffman and Gabet (2007) both in the field and using a numerical model. In the field I will quantify the size distribution of channel material upstream and downstream from locations at which a debris flow impacted the channel. I will compare the up and downstream distributions with a reach of Rye Creek that was not affected by debris flows as a

control. This comparison will verify whether material with a smaller grain size gets entrained upstream of a fan and larger clasts deposit directly downstream of a debris fan.

Suspended sediment will be collected at each fan location using depth integrated sampling. Rye Creek is easily wadable at all flows, and is wide enough that I will collect 10 verticals at equal width increments across each cross-section as a representative sample (Guy and Norman, 1999). Samples collected will be weighed wet, then dried and weighed again. If suspended sediment discharge proves too little for isotopic analysis (1-6 g necessary (Bonniwell et al., 1999)), pump sampling (e.g., ISCO) will be used to collect larger masses of sediment for analysis. Depending on the suspended sediment concentration, between 70 and 900 l of water must be pumped for an adequate sample (Bonniwell et al., 1999; Wilson et al., 2007).

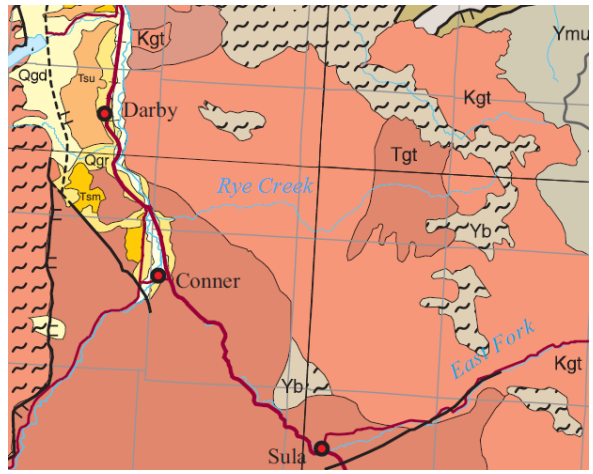

Figure 7. Geologic map of the Rye Creek drainage showing two main types of lithology.

3.4 Fallout radionuclides

In addition to suspended sediment samples, I will collect sediment samples from the channel bed, hillslope, and relict fans for isotopic analysis. At each fan, a sample of fine sediment will be collected from both the hillslope and channel bed portions of the fan. Geochemical tests for fallout radionuclides ^{7}Be, ^{137}Cs, and ^{210}Pb will be performed in the lab of Dr. Jean Dixon at Montana State University. Measuring the ratio of ^{7}Be/^{210}Pb provides an indicator of the 'newness' of sediment in the channel (Bonniwell et al., 1999). I will compare amounts of fallout radionuclides in channel sediment to those of hillslope/fan material to fingerprint the source of the sediment. Soils in the study area are formed from Belt Series metasedimentary (Yb) and Cretaceous or Tertiary granitic rocks (Kgt and Tgt) (Figure 7). The differences in bedrock material result in different erosion rates and therefore dissimilar sediment production rates. While no sources were found directly comparing the denudation rates of Belt Series metasedimentary rocks to granitic rocks in the northern Rockies, two studies measured the erosion rates in the Bolivian Andes (Aalto et al., 2006) and West Africa (Koita et al., 2013). Aalto et al. (2006) found that denudation rates of metasedimentary rocks are 1.9x greater than those of granitic rocks in the same climate and in basins with the same average hillslope, rock type accounts for 77% of the variation in sediment yield. Koita et al. (2013) discovered a similar trend, the total thickness of the weathering profile of metasedimentary rock is 4-10x thicker than that of granitic rock. Differences in bedrock are important in determining the sediment yield in a basin, but concentrations of fallout radionuclides are independent of soil type and geology (Walling, 2005). Fallout radionuclides are deposited uniformly across the Earth's surface and their concentration is dependent strictly on erosion rate, not the underlying geology. Rainfall deposits horizontal soil surfaces with fallout radionuclides and they accumulate according to the rate of erosion of the surface (Hancock et al., 2014). Higher concentrations of ^{7}Be and ^{137}Cs are a result of slower erosion rates and therefore lower rates of sediment transport from hillslope to channel. Lower concentrations of ^{7}Be and ^{137}Cs correlate with a faster erosion rate and greater rates of sediment transport to the channel (Blake et al., 2009). I will collect samples twice during

the summer field season at each cross section totaling 16 samples. Each time I collect sediment samples for geochemical testing I will collect one instream and one from the fan at each of the four relict fan locations. These fallout radionuclide data will be used to inform the amount of old versus new sediment in the channel and as input data to the numerical model (Viparelli et al., 2013).

3.5 Numerical model

The data gathered from field work will be used as input parameters into a numerical model. By running a numerical model, I will analyze change in bed elevation over time as it relates to the persistence of geomorphic impact of the debris flows. I will be implementing a one-dimensional sediment transport and morphodynamic evolution model, MAST-1D (Morphodynamic and Sediment Tracers in One Dimension) that couples the hillslope-channel system and allows for modeling over decadal and greater timescales (Lauer et al., 2014). Data gathered in the field, including channel geometry, gradient, channel and debris fan grain sizes, discharge, and sediment flux will be used at "input nodes" (red circles in Figure 8) at regularly spaced cross sections upstream and downstream of debris fan locations (Viparelli et al., 2013). This model is based on a conceptual river cross section that includes multiple sediment storage reservoirs that can be eroded if conditions allow (Lauer et al., 2014). As time passes in the model, sediment can move between substrate and active layer reservoirs by elevation change of the bed. Each node receives the sediment load specified by the upstream node, erosion or deposition occurs according to the embedded transport law, then a new sediment load is transported downstream to the next node. The change in bed elevation uses a simplified version of the Exner equation:

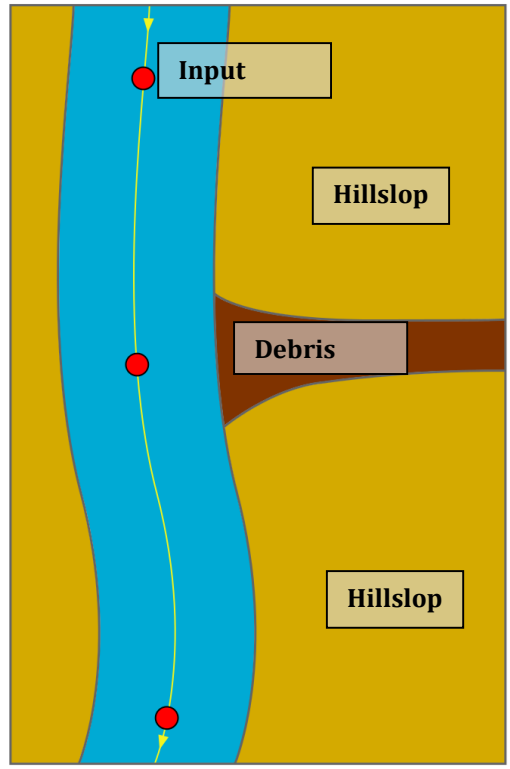

Figure 8. Plan view for MAST-1D numerical model; red circles are input nodes; channel geometry and grain size data required at each node

$$\frac{d\eta}{dt} = \frac{1}{1-\lambda}\frac{1}{dA}\sum_k (Q_{s,in,k} - Q_{s,out,k}) \qquad (1)$$

where η is the bed elevation, λ is the porosity of the bed, A is the bed area represented by the node and Q is the sediment flux into or out of the node of grain size k (Lauer et al., 2014). This equation functions to compute sediment flux for each grain size specified. Nodes that have a debris fan next to them will have a lateral sediment input with the same grain size as the fan material. Modeling debris fan inputs will grant a greater understanding of the time needed for a channel to process the material and route it downstream. The proposed research will implement MAST-1D in a novel way by studying a mountain headwater channel rather than a typical river-floodplain system.

4 OUTCOMES AND DELIVERABLES

The end result of my proposed research will be a better understanding of: **1**) hillslope-channel connectivity, **2**) persistence of geomorphic impacts on channels by post-fire debris flows, and **3**) time needed both for processing of sediment pulses and movement downstream. The main product of my work will be a predictive model in MAST-1D of sediment routing through mountain headwaters typical of the northern Rockies. Aspects of this model will address each facet of my proposed objectives.

- **1**) A better understanding of hillslope-channel connectivity will be developed by investigating rates of erosion across the debris fan-channel boundary and the relative contribution of sediment from the debris fans to the overall sediment budget of the site.
- **2**) Persistence of geomorphic impacts on channels by post-fire debris flows will be studied by running MAST-1D to analyze the change in bed elevation over time. The results will be compared to the conceptual model of processes (Hoffman and Gabet, 2007). Discharge will be varied in the model to identify the effects of increased or decreased flow on the dominant post-fire debris flow morphology in the channel.
- **3**) Using real-world grain size distributions will allow travel distances of each grain size to be measured after a pulse of sediment is delivered to the channel. The time needed for processing sediment pulses and movement downstream will also be determined using the MAST-1D model. It will also grant more insight into the transport of suspended load and bed load being transported from further upstream. This will further test the idea that pulse transport is dispersion dominated (Lisle et al., 2001; Sklar et al., 2009).

Developing a nuclide mass balance for Rye Creek will facilitate an understanding of the fate of sediment delivered to the channel in debris flows and how discharge affects processing time of the material. Knowledge of sediment routing and morphodynamic change will lead to better comprehension of hillslope-channel connectivity. A clearer understanding of hillslope-channel connectivity will give us a better idea of how these streams will respond to variance in sediment input and hydrology due to climate change or changes in land use, with implications for aquatic ecosystems and management. Integrating field methods with a numerical model, I will develop a predictive model of sediment routing and morphodynamic change in the channel that can be applied to other, similar mountain headwater channels.

5 TIME LINE

Time Period	Working On
Dec. – Feb. 2014/15	Finalize field site location/exact reach length
Jan. – Feb. 2015	Deploy pressure transducers to the field site
Jan. – Apr. 2015	Write departmental research proposal
Apr. – Jun. 2015	Prepare equipment for field season. Practice use of new/unfamiliar equipment.
Jun. – Sep. 2015	Complete field work during overnight (3-6 day) trips
Oct. – Dec. 2015	Input data into MAST-1D, complete runs for AGU poster
Jan. – Mar. 2016	Finish model runs (vary discharge, grain size distribution and volume of pulses)
Jan. – May 2016	Write thesis/journal paper
May – Summer 2016	Defend research/graduate

6 BUDGET

Budget Category	Total
Travel to/from field site	$700
Meals in the field	$450
Field assistant	$300
Geochemical testing for fallout radionuclides	$1280
Total estimated cost	$2730

Anticipating eight round-trip journeys for surveying the reach, collecting sediment load measurements, and gathering sediment samples for geochemical testing, totaling 1,248 miles at $0.56/mile (minimum allowable) is $698.88 and per diem meals for extended trips totaling 15 days at $15/day is $225. Most of the surveying work will require a second set of hands to complete, so there is $300 budgeted for a field assistant, plus another $225 for meals for this assistant. The field assistant will help with surveying the reach and collecting sediment load and geochemical samples. Geochemical testing will be conducted at Montana State University in the lab of Dr. Jean Dixon. Sediment samples will be tested for the fallout radionuclides at a cost of $80 per sample (estimate from Dr. Dixon as of 1/20/15). An estimated 16 samples will be tested for a cost of $1280.

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Student Fellowship: Enhancing Tribal Environmental Health Literacy: Developing a toolkit to improve community understanding of rights and responsibilities regarding water quality.

Basic Information

Title:	Student Fellowship: Enhancing Tribal Environmental Health Literacy: Developing a toolkit to improve community understanding of rights and responsibilities regarding water quality.
Project Number:	2015MT297B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	MT 1
Research Category:	Social Sciences
Focus Category:	Law, Institutions, and Policy, Water Quality, Education
Descriptors:	None
Principal Investigators:	Miranda Margetts, Miranda Margetts

Publications

There are no publications.

Montana Water Center - 2015 Fellowship
Final Report

Miranda Margetts, 1st May 2016.

Title:
Enhancing Tribal Environmental Health Literacy: Developing a toolkit to improve community understanding of rights and responsibilities regarding water quality.

Background:
The lack of environmental health literacy awareness in relation to water quality is resulting in devastating short and long-term impacts on Native American communities. Native American communities do not receive the same environmental protections that more affluent areas do and risk avoidance measures (e.g. fish advisories explaining fish toxicity levels) are often hard to understand and not language or culturally appropriate. Native American communities are at particular risk for exposure to environmental contaminants due to subsistence diets, and spiritual and cultural practices that increase their likelihood for contact with contaminated soil and water.

Making informed environmental health choices requires the development of skills to understand and take action towards environmental health risks. Various Federal, State and Tribal laws and policies regarding environmental health and water quality exist on tribal lands, creating a barrier to access to health information and a complex patchwork of information community members must face in order to understand their rights. Due to the legal and jurisdictional complexity on tribal lands, aspects of environmental health issues can be particularly difficult to navigate.

Research approach:
Based on the information outlined above, we undertook to identify and present the key knowledge 'gaps' in relation to community understanding of water quality laws in Native American communities. We aimed to obtain a set of key principles and ideas relevant to environmental health rights pertaining to water quality (from the existing patchwork of legislation) to ultimately inform broader community-development efforts in Native American communities.
The ultimate goal was to raise awareness and compile information that community members and educators can use to make informed environmental health decisions - through improving knowledge of rights, obligations and mechanisms available to influence environmental health.

Steps completed and Outcomes:
As part of our research methodology, we initially conducted a literature review (academic and legal databases, policies, legislation and commentary from tribal, state and federal environmental health departments and committees and existing

tools from environmental health law advocacy and water quality organizations) to identify the key areas to be addressed.

In addition to the literature review, we then reviewed and documented those existing resources that have been designed to increase community members' water quality knowledge (for example, guidance material, water quality curriculum, training and operational manuals).

Based on our literature review we compiled a list of initial themes. Examples of themes are included below:

- *Tribal recognition of strong link between environmental health and public health*
- *Tribal environmental health literacy requires attention and is complex due to jurisdictional legal layers*
- *Many tribal communities grappling with issues related to water quality – some similar, some different*
- *Tribal laws can be tailored and implemented to address Tribe-specific environmental health risks*
- *Emphasis on importance of raising awareness of relevant rights and community mechanisms to improve health outcomes*
- *Broader guidance as to 'how' a community obtains such information is lacking*
- *Lack of regulation of private well water use problematic*

Interviews were conducted with the following stakeholders and representatives of particular organizations:

- *Environmental Protection Agency*
- *National Congress of American Indians (Policy Research Center)*
- *Centers for Disease Control (Tribal Public Health Law branch)*
- *State water agencies*
- *Tribal law experts*
- *Water law and policy experts*
- *Tribal community members*
- *Montana State University Extension (Water Quality)*
- *Institute for Tribal Environmental Professionals, Northern Arizona University*
- *National Tribal Toxics Council*
- *University of California Cooperative Extension*
- *Indian Health Service, Office Environmental Health and Engineering, Indian Health Service*
- *EPA Tribal Program Office (Helena EPA – Region 8, Tribal EPA)*

The interviews were of an open-ended format. By design they enabled us to elicit information about the current legal and policy landscape across the various jurisdictions and tribal communities in relation to water quality.

The contents of our toolkit was informed by the literature review, stakeholder interviews and specific Tribal Water Law training modules. As our focus was on both youth and adult environmental health literacy, we decided to produce an adult-

focused document and a youth-focused document. While the legal issues of water quality on tribal lands are complex, through our research approach and consensus gathering efforts, we were able to distil the key principles and themes from the legislation and broader documentation. This information formed the basis for both of our documents, with the youth focused document taking an age-appropriate focus.

In addition to the guidance documentation we were able to produce, we also compiled a list of important themes we encountered in relation to environmental health literacy and community knowledge of legal/policy mechanisms to address environmental risks. Examples are listed below:

- *Environmental health literacy is closely tied to achieving environmental justice; community understanding of mechanisms to influence change (i.e. laws and policies, governance roles and responsibilities) is important*
- *Connection between health literacy and empowerment, unfair community structures, power relation imbalance*
- *The concept of 'Legal literacy' relates to environmental health concerns*
- *Tribes are developing and implementing their own laws to promote protection of clean water– source of community empowerment*
- *Current laws do not adequately reflect or protect the impacts and higher exposure rates to certain toxicants and pollutants on some tribal lands as a result of subsistence diets – water quality is a key factor*
- *Water contamination on reservations is significant; Tribes are at a higher risk of exposure to contaminants; penalties for polluters on reservations is not equitable*
- *Lack of funding to monitor and ensure compliance, enforcement etc. regarding water quality is exacerbating issue*
- *Collaborative community approach to address water quality concerns given multiple stakeholders and variety of roles and responsibilites at an operational level*

Use of funds:

As outlined in our initial Fellowship application, our funds were primarily used to support both research and dissemination efforts related to the project. We were invited to continue engagement with the National Congress of American Indians by presenting the work at their Tribal Leader/Scholar Forum during the Mid-Year National Conference in June 2015 in St. Paul, MN.

We presented our material at this event and also used the opportunity to meet with stakeholders in person, gather more evidence to inform our documentation, and discover valuable dissemination and future collaborative channels.

This forum was particularly useful given its ability to target the unique audience of Tribal Leaders. The presentation provided a means of raising awareness of the issues to our audience, and also highlighted efforts to address this issue through improving environmental health literacy. By presenting at the conference we believe we were able to:

- *Provide an insight into the existing injustices in relation to water quality;*
- *Highlight complexities in relation to water quality laws;*
- *Highlight commonalities and differences across tribes regarding water quality issues;*

- *Highlight principles and foundations in the laws that can be used to improve environmental health literacy and capacity building efforts;*
- *Showcase examples of tribal efforts and the use of laws and policies to impact water quality, and*
- *Provide an opportunity to start discussion and assist dissemination.*

Conclusion and next steps:
This particular project has also been able to inform a broader environmental health literacy project focused on water quality and Native American youth (led by Dr. Vanessa Simonds, Associate Professor, Montana State University). The focus in this discrete component on the legal and policy issues in relation to tribal water has fortunately been able to inform some aspects of the broader longer-term project. As described above, our focus on this specific issue has also elicited a range of issues for further consideration in relation to water quality and environmental health literacy. It has been particularly timely in light of the national attention to devastating health impacts from poor water quality in some US communities and the apparent lack of environmental health literacy as a contributing factor. It is our intention to continue this work and submit a paper to peer-reviewed journals for publication in order to highlight the importance of water quality and environmental health literacy on tribal lands.

Thank you for opportunity to complete the 2015 Montana Water Center Fellowship.

Student Fellowship: Environmental DNA to evaluate individual variation in rainbow trout spawning date

Basic Information

Title:	Student Fellowship: Environmental DNA to evaluate individual variation in rainbow trout spawning date
Project Number:	2015MT298B
Start Date:	3/1/2015
End Date:	2/28/2016
Funding Source:	104B
Congressional District:	MT 1
Research Category:	Biological Sciences
Focus Category:	Ecology, None, None
Descriptors:	None
Principal Investigators:	Taylor Wilcox

Publications

There are no publications.

Taylor Wilcox 2015 Montana Water Center Student Fellowship Project Summary

Please note that there was an approved shift in the focus of this project from the original proposal to another environmental DNA project in collaboration with researchers at the National Genomics Center for Wildlife and Fish Conservation and Montana Fish, Wildlife and Parks in Missoula, Montana including Kellie Carim, Ladd Knotek, Will Schreck, Kevin McKelvey, Mike Young, and Mike Schwartz. This work naturally builds on my first dissertation chapter (Wilcox et al. 2016 in Biological Conservation) and will be followed by additional experiments prior to submission as its own publication in a peer-reviewed journal.

ABSTRACT

Environmental DNA (eDNA) sampling is a rapidly-emerging approach to non-invasively detect the presence of rare and cryptic aquatic animals from their genetic material in the water. In stream systems the distance downstream that DNA is transported from living organisms is of particular interest because it influences how much sampling is needed to have a high detection probability when animals are rare. However, few studies have explored this experimentally. In this study we used caged fishes in natural streams to measure the transport dynamics of eDNA over 700 – 1,000 m. We found that eDNA could be detected at least 1 km downstream from just 3 – 5 individual animals and that eDNA transport dynamics were consistent with previous work in a related salmonid species. This work improves our understanding of the behavior of eDNA and will help inform sampling design in new systems.

INTRODUCTION

Environmental DNA (eDNA) sampling uses genetic material from the environment (e.g., water) to infer species presence (Jerde et al. 2011). There is increasing evidence that eDNA sampling is substantially more sensitive for rare species detection than traditional methods in many aquatic systems (e.g., Smart et al. 2015, Valentini et al. 2015, Wilcox et al. 2016). Many studies have now applied eDNA sampling successfully to stream and river systems (e.g., Laramie et al. 2014, Spear et al. 2014, McKelvey et al. 2016). Streams and rivers provide unique opportunities and challenges to eDNA sampling. Because of downstream flow, eDNA in these systems may be at lower concentrations than in lentic pond and lake systems, decreasing species detection probability (Thomsen et al. 2012). However, downstream flow also provides the opportunity for transport of eDNA making species potentially detectable distantly from their location. This may increase detection probability of rare species, particularly those with patchy distributions and those in difficult-to-access habitats. This downstream transport is further of interest because it disassociates the distribution of detected eDNA from the distribution of the species. This may allow researchers to more easily assess biodiversity at large scales (Deiner et al. 2015), but this also complicates inference when the precise location of species is of interest.

The transport dynamics of eDNA from aquatic animals is still poorly understood, particularly over long distances. In the only study to access eDNA transport distances over > 250 m, Deiner and Altermatt (2014)) had eDNA detections of a lake-obligate species up to 12 km downstream. In contrast, Pilliod et al. (2014) failed to detected caged tailed frogs in a stream just 50 m downstream from caged animals. Jane et al. (2015) explored eDNA transport dynamics in more detail by sampling at regular intervals downstream out to approximately 240 m downstream of caged brook trout (*Salvelinus fontinalis*). This study, and further analyses by Wilcox et al. (2016) suggests that DNA from fishes is transported greater distances downstream at higher stream flows. It is unclear from these studies over what distances our models of eDNA transport are applicable and how general the relationship is between stream discharge and eDNA transport distance.

The purpose of this study was to assess transport dynamics of eDNA from fishes in streams over approximately one kilometer. To do this, we used caged fish in two different streams which were known to not otherwise have these species present.

METHODS

Site descriptions

We conducted experiments in two streams in western Montana, U.S.A. The tributary to Deer Creek (N 47.2377 W -113.6587) is located above a natural fish passage barrier on Deer Creek. The streams upstream of this barrier do not contain any *Oncorhynchus spp.* fishes based on electrofishing sampling in 2014 and three eDNA samples taken shortly prior to this study. For this stream, westslope cutthroat trout (*Oncorhynchus clarkii lewisi*) were captured via backpack electrofishing from Deer Creek downstream of the fish passage barrier. We also conducted experiments on a segment of West fork Lolo Creek that is above another natural fish passage barrier (N 46.6635 W -114.5790). This section of stream does not contain any bull trout (*Salvelinus confluentus*) based on extensive eDNA sampling (McKelvey et al. 2016). Bull trout were captured via backpack electrofishing from another stream in the same basin. All animals were transported in an aerated cooler and returned as close as was practical to their place of capture at the end of the experiment. All sampling and experiments were done in accordance with an Environmental Assessment by Montana Fish, Wildlife and Parks (April 3, 2015). Mean wetted widths were 2.7 and 3.5 m for Deer Creek tributary and W.F. Lolo respectively. Over the course of the study the stream discharges ranged from approximately 19 – 34 L/sec (mean = 26) for the Deer Creek tributary and 60 – 70 L/sec (mean = 66) for W.F. Lolo.

Field experiments

Fish were held in cages placed in a shaded pool at each stream. Cages were approximately 0.5 X 0.5 X 1.0 m and made of steel, but lined with soft netting to prevent fish injury. The bottom of the cage was lined with large stones and logs were placed in the cages to provide shelter. For both streams, caged fish experiments were done in three replicate sessions the course of three weeks. Each week 3 – 5 fish were captured, weighed, measured, and placed in the cage on Monday and allowed to acclimate for 48 h. A new group of fish was used for each session with 168 – 193 and 69 – 84 g total biomass for the Deer Creek tributary and W.F. Lolo respectively.

We collected samples on Wednesday, Thursday, and Friday. Using a protocol described in Carim et al. (2014) we collected 5 L samples by filtering water through 1.5 micron pore glass filters immediately below the cage, 50 and 100 m downstream, and then every 100 m downstream to 700 m (Deer Creek tributary) or 1,000 m (W.F. Lolo). We collected samples moving from downstream to upstream to avoid contaminating downstream sampling locations. Samples were stored in silica descent and transferred to a – 20 C freezer within 24 h of collection. On Friday of each week the fish were released and the cage was left fishless for at least 72 h before beginning the next session. To confirm that 72 h was sufficient for all eDNA to be washed out of the system after all sessions had been completed we took samples again on the following Monday. On each Thursday we also used the mid-section depth method to measure stream discharge near the cage site. Experiments ran from June 22 to July 20, 2015 in the Deer Creek tributary and from July 20 to August 10, 2015 in W.F. Lolo.

Conservative tracer

To compare our eDNA results with the behavior of a biologically-inert solute and to test for dilution from groundwater inputs we used chloride as a conservative tracer in each stream. In each stream continuous chloride additions were done using a QBG fluid metering pump (Fluid Metering Inc.) to inject a sodium chloride solution at the cage site. On July 16 we injected approximately 5,955 g of sodium chloride into the Deer Creek tributary at a rate of 10.3 g NaCl/minute for 542 minutes. On July 23 we injected approximately 5,642 g of salt into W.F. Lolo at a rate of 16.8 g NaCl/minute for 224 minutes (23 July 2015). Prior to injection we measured specific conductivity (Pro 2030 unit from YSI) at each downstream

eDNA-sampling location, moving from downstream to upstream. We measured specific conductivity at the downstream-most site during the injection (700 m and 1,000 m for the Deer Creek tributary and West Fork Lolo, respectively), using a hand-held conductivity meter, recording specific conductivity every 1 – 5 minutes. We then measured specific conductivity at each eDNA-sampling site once specific conductivity at the most-downstream site had plateaued (542 and 178 minutes for the Deer Creek tributary and West Fork Lolo, respectively). Once these longitudinal samples had been collected, we confirmed that the pump rate had held constant, then ended the injection. In both streams conductivity declined back to baseline prior to eDNA sampling the following day.

Genetic analysis

We extracted DNA from one half of each filter using the DNEasy Blood and Tissue Kit and QIAShredder columns (QIAGEN) using a protocol adapted from Goldberg et al. (2011). Each samples was analyzed in triplicate using species-specific qPCR markers to quantify mitochondrial DNA (mtDNA) copies (Wilcox et al. 2013, 2015). Quantification was done by comparison with a standard curve prepared from a linearized synthetic plasmid containing the target amplicon. All PCRs were multiplexed with an internal positive control to test for PCR inhibition and each plate contained triplicate no template controls to test for contamination during PCR setup. All plates were run on a StepOne Plus instrument (Thermo-Fisher Scientific). See Wilcox et al. (2013, 2014) for methodological details.

Data analysis

We used the chloride injection data to estimate discharge at each eDNA sampling location for both streams using the methods described in Webster and Valett (2006). These estimates only allow for inflows that cause dilution and cannot detect outflows from the stream, but concentration is affect in the same as eDNA in the water column.

We used the spatially-replicated eDNA concentration data to estimate transport distance – the mean distance that a particle travels downstream before settling (Paul and Hall 2002) – for each session. To do this, we regressed log mean eDNA concentration + 1 for each downstream site against distance. The slope, k, is the particle settling velocity per meter and $1/-k$ is the transport distance (*Sp*; Paul and Hall 2002, Wilcox et al. 2016). In W.F. Lolo there was a split in the stream channel between 50 and 200 m downstream. There may have been incomplete mixing of eDNA at these sites, so the eDNA transport analysis only used data from > 200 m downstream from the cage in this stream.

RESULTS

eDNA results

We collected and analyzed 210 environmental samples for westslope cutthroat trout or bull trout DNA. We detected no evidence of PCR inhibition in any of the samples, and as expected, all samples collected 72 h after fish were removed from cages were negative for westslope cutthroat trout or bull trout DNA. Estimated target eDNA concentrations ranged from 0 – 1,696 and 0 – 138 mtDNA copies/L in the Deer Creek tributary and W.F. Lolo respectively. At least one sample was positive at each distance downstream in both study streams with detection rates ranging from 0.56 – 1.00 and 0.33 – 0.89 for the Deer Creek tributary and W.F. Lolo respectively. In general, eDNA concentration declined with distance downstream, but there was high variation between sites, replicate samples within a single session, and between sessions (Figure 1).

Conservative tracer results

The Deer Creek tributary had substantially greater transient storage than W.F. Lolo as evidence from a longer time to achieve plateau chloride concentrations (quantitative analysis in progress). There was

similar estimated discharge in the Deer Creek tributary over the entire 700 m study reach (approximately 15 – 21 L/sec), but discharge increased over the 1,000 m study reach in W.F. Lolo (approximately 56 – 112 L/sec).

Transport dynamics

Transport distance estimates for the Deer Creek tributary were similar across sessions (Range and median), but one session in W.F. Lolo was substantially greater than the other two sessions (range and median, some other metric). These estimates are approximately what would be predicted given stream discharges from previous work in Wilcox et al. (2016; Figure 2).

DISCUSSION

In this study we used controlled field experiments in two streams and found 1) that eDNA from two different salmonid species can be detected with a probability > 0.3 at least 700 – 1,000 m downstream in a high-gradient, wadeable stream and 2) that although there is large variation in eDNA concentrations between sessions and replicates, the downstream transport trend over these distances is related to stream discharge in a way that is consistent with previous work on fish-derived eDNA and other fine particulate organic matter in streams.

In traditional sampling the specific habitat containing the target species must be sampled in order to have a detection. Environmental DNA sampling is less sensitive to location, making it particularly efficient relative to traditional method when animals are rare and patchily-distributed (unpublished simulations). The results from this study show reasonable detection probabilities at least out to one kilometer downstream from several animals. This supports current recommendations from the National Genomics Center for Wildlife and Fish Conservation to sample at 1.5 km intervals for the detection of rare fish populations in streams.

Our research group has previously studied eDNA transport dynamics in closely-related brook trout (*Salvelinus fontinalis*; Jane et al. 2015, Wilcox et al. 2016). These studies have suggested that eDNA transport may increase with stream discharge. In this study we found that transport dynamics were similar to those in brook trout for both of our study streams and species, suggesting that this relationship between transport and stream discharge may be relatively robust to individual stream characteristics and salmonid species. We are currently looking for opportunities to further test the generality of this relationship.

Our estimates of transport distance in this study did not attempt to correct for groundwater inflows. It is interesting to note that transport distances observed in W.F. Lolo were equal or greater than expected, even though inflows almost doubled estimated discharge over the study reach in this stream. These results suggest that increased transport distances may largely offset dilution effects from increased stream flows for eDNA detection. This is an important area for future investigation because the relative sensitivity of eDNA in streams and rivers of varying size are largely unknown. The project described here is an important step in better predicting the behavior of eDNA in new systems, which will help to inform sampling design for previously unstudied taxa.

FIGURES

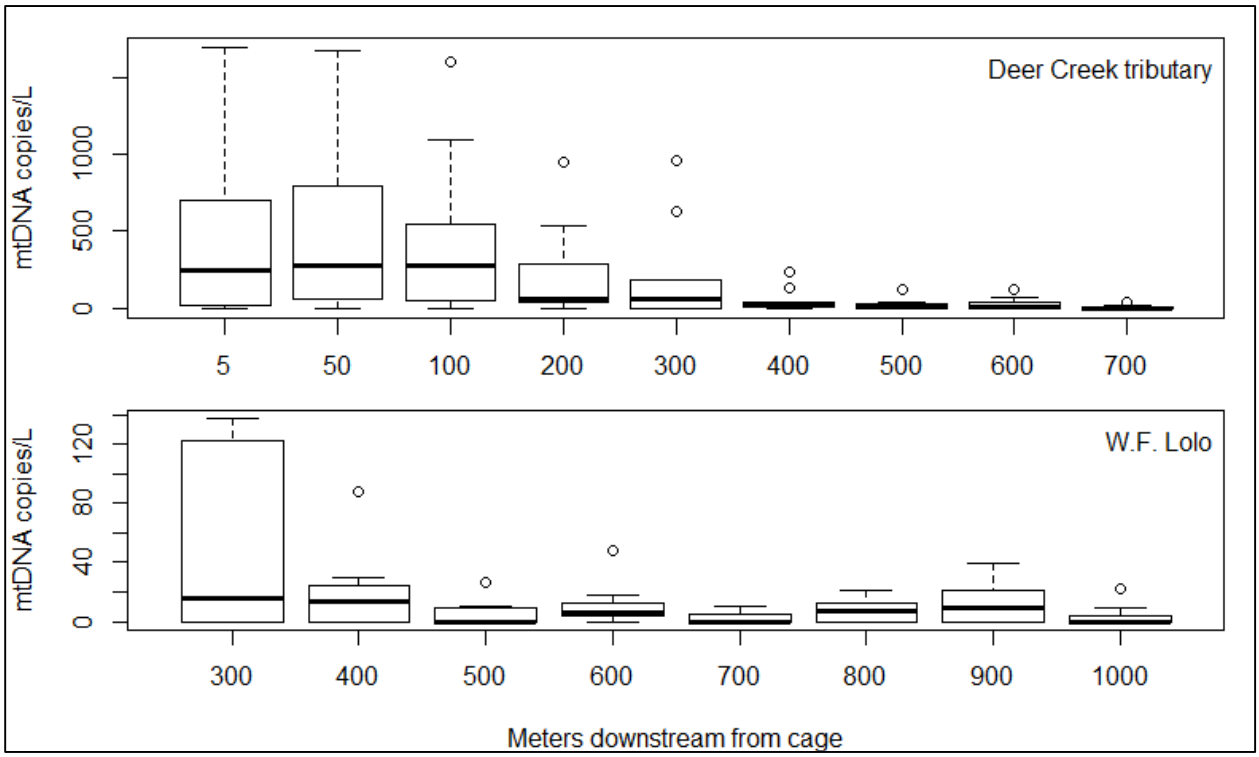

Figure 1. Estimated mitochondrial DNA copy concentration (mtDNA copies/L) from westslope cutthroat trout and bull trout for the Deer Creek tributary and W.F. Lolo, respectively. Data are pooled from across three sessions (n = 9 samples) per downstream location in each stream. We only considered W.F. Lolo data starting 300 m downstream from the cage because a channel split upstream appears may have caused incomplete mixing of eDNA.

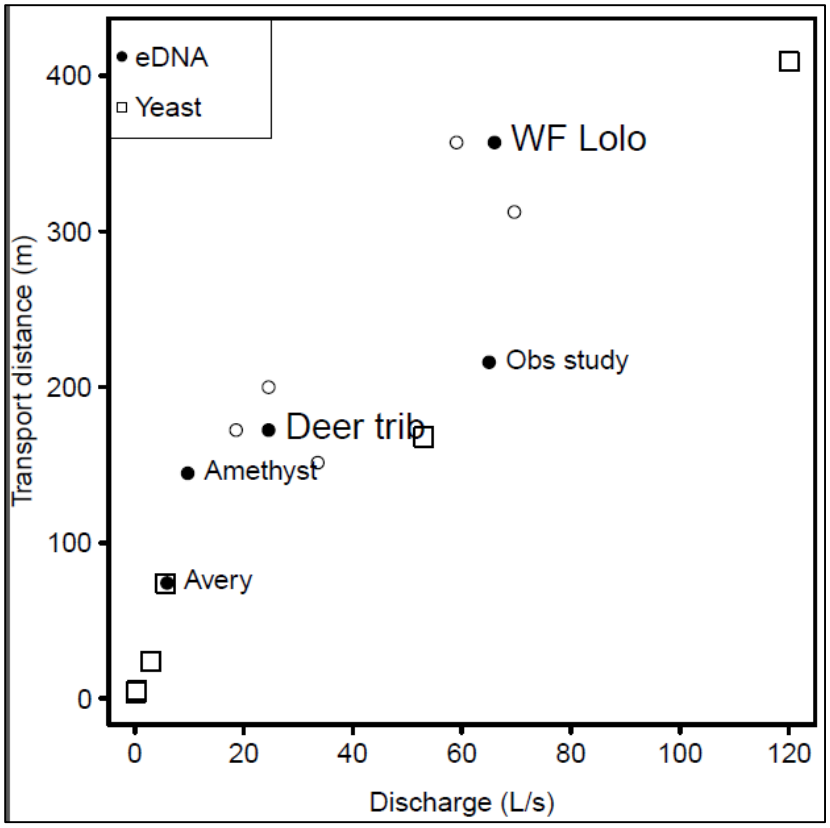

Figure 2. Adapted from Wilcox et al. (2016) this figure shows transport distance (mean distance that a particle is transported downstream; m) versus stream discharge (L/sec) from a previous study on caged brook trout (Amethyst and Avery; Jane et al. 2015), an observational brook trout study (Obs study), brewer's yeast experiments (white squares; Paul and Hall 2002), and this study (Deer trib and WF Lolo). Black dots show median estimates for eDNA and the open circles show the individual estimates for the Deer Creek tributary and W.F. Lolo (one W.F. Lolo point > 400 m transport distance). The results of this study are consistent with our prediction that eDNA transport increases with stream discharge.

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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 new website was created. It can be viewed at http://www.montanawatercenter.org. We have created a "news" page and also will soon be sending out a compilation of monthly blogs to our newsletter subscribers.

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

*Sponsored the 82nd Annual School for Water & Wastewater Operators & Managers held in October 2015 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 and Assistant Director McGinnis moderated talks given during the week.

*Offered a professional development course titled: “Ecological Stream Restoration in the Context of Montana Regulations”. This was offered as a two-day, in-person course discussing stream restoration technoques and applicable rules and permitting regulations specific to Montana. Resource managers, land owners, consultants and others involved in the restoration process joined the class. Topic selection and planning of the 2016 professional development course is already in progress.

* Grant funded water education programs were delivered by MTWC that focused on the following areas: water rights trainings, dam owner workshops, 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 Montana Department of Natural Resources and Conservation, and the Environmental Protection Agency.

*Helped organize and execute a state water meeting with the Montana Section of the American Water Resources Association in Missoula, MT on October 8-9, 2015. The conference theme was "Linking Water Research to Policy and Water Management". Approximately 204 people attended the conference with 43 speakers and 40 poster presentations. 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.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	3	0	0	0	3
Masters	5	0	0	0	5
Ph.D.	2	0	0	0	2
Post-Doc.	0	0	0	0	0
Total	10	0	0	0	10

Notable Awards and Achievements

Publications from Prior Years

1. 2010MT221B ("Student Fellowship: Potential Meltwater Contributions from the Glaciers in Glacier National Park, Montana") - Dissertations - Clark, Adam, 2012,Quantifying Glacier-Derived Summer Runoff in Northwest Montana, "MS Thesis", Geology, University of Montana, Missoula, Montana, 57 pages.
2. 2010MT229B ("Student Fellowship: Distinguishing anthropogenic influences on a changing flow regime of the Upper Smith River, Meagher County, Montana") - Dissertations - Stanley, Andrea, 2013, Hydrologic Conditions and Streamflow Change in an Evolving Semi-Arid Agricultural Watershed, Smith River, Montana,"MS Thesis", Geosciences, University of Montana, Missoula, Montana, 81 pages.
3. 2010MT228B ("Student Fellowship: Rapid detection of pathogens in water using a combination of molecular techniques") - Dissertations - Lim, Kien, 2013, DEVELOPMENT OF FLUORESCENT IN SITU HYBRIDIZATION FOR DETECTION OF L. PNEUMOPHILA USING SOLID PHASE LASER CYTOMETRY, "MS Thesis", Microbiology, Montana State University, Bozeman, Montana, 76 pages.
4. 2010MT225B ("Student Fellowship: Fisheries Restoration Potential of the Clark Fork River Superfund Site: Habitat Use and Movement in Relation to Environmental Factors") - Dissertations - Mayfield, Mariah, 2013, LIMITING FACTORS FOR TROUT POPULATIONS IN THE UPPER CLARK FORK RIVER SUPERFUND SITE, MONTANA, "MS Thesis", Fish and Wildlife Management, Montana State University, Bozeman, Montana, 101 pages.
5. 2011MT244B ("Student Fellowship: Population-scale effects of hypoxia on the distribution and abundance of fishes in Silver Bow Creek") - Dissertations - Naughton, Joe, 2013, SALMONID RESPONSE TO SUPERFUND REMEDIATION IN SILVER BOW CREEK, MONTANA, "MS Thesis", Fish and Wildlife Management, Montana State University, Bozeman, Montana, 151 pages.
6. 2011MT247B ("Student Fellowship: Effects of the mountain pine beetle on snow hydrology in Montana") - Dissertations - Welch, Chris, 2013, THE IMPACTS MOUNTAIN PINE BEETLE ON FORESTED SNOWPACKS: ACCUMULATION AND ABLATION, "MS Thesis", Land Resources and Environmental Sciences, Montana State University, Bozeman, Montana, 95 pages.
7. 2012MT264B ("Thresholds in fluvial systems: Flood-induced channel change on Montana rivers") - Articles in Refereed Scientific Journals - Wohl Ellen, Brian P. Bledsoe, Robert B. Jacobson, N. LeRoy Poff, Sara L. Rathburn, David M. Walters and Andrew C. Wilcox, 2015, The Natural Sediment Regime in Rivers: Broadening the Foundation for Ecosystem Management, Bioscience, 65 (4), 358-371.
8. 2012MT266B ("Student Fellowship Project: Evaluating hydrogeomorphic controls on bull trout spawning habitat in mountain streams, Northwestern Montana") - Dissertations - Bean, Jared, 2012, Multi-scale hydrogeomorphic influences on bull trout spawning habitat in snowmelt-dominated headwater streams, "MS Thesis", Geosciences, University of Montana, Missoula, Montana, 100.
9. 2012MT274B ("Student Research Fellowship: Food web effects of stream invasion by Potamopyrgus antipodarum and interactions with eutrophication") - Dissertations - Richins, Eric, 2015, COMMUNITY PERTURBATION ASSOCIATED WITH NEW ZEALAND MUDSNAIL (POTAMAPYRGUS ANTIPODARUM) INVASION: DISCREPANCIES IN TEMPORAL AND SPATIAL ASSESSMENT, "MS Thesis", Wildlife Biology, University of Montana, Missoula, Montana, 49 pages.
10. 2012MT277B ("Student Research Fellowship: Soil temperature and moisture controls on stream recharge from snowmelt events, Lost Horse Canyon, Bitterroot Mountains, MT") - Dissertations - Woelber, Brett, 2013, Energy controls on diurnal snowmelt events and stream recharge, Lost Horse Canyon, Bitterroot Mountains, MT, "MS Thesis", Geosciences, Missoula, Montana, 25 pages.